Activities and Organization

April 1994

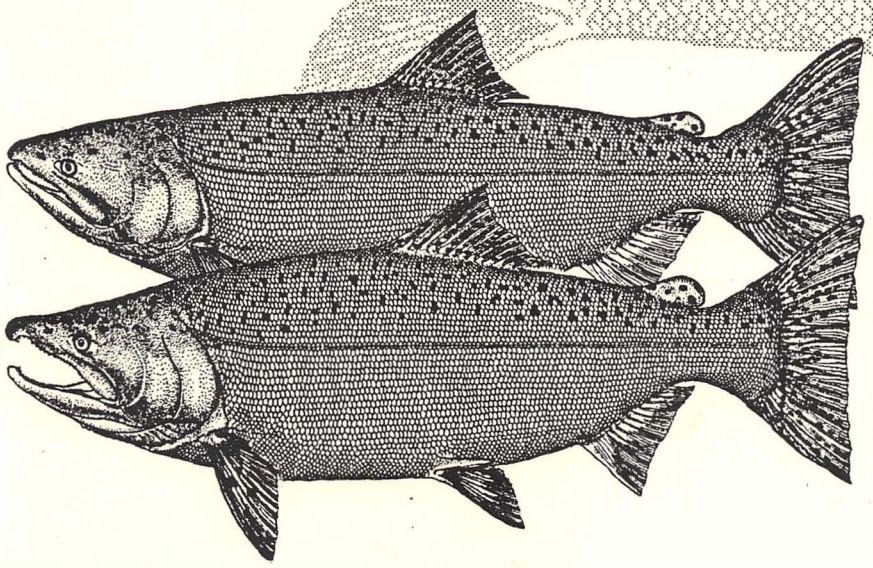
CZES

Coastal Zone and Estuarine Studies Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington



COASTAL ZONE AND ESTUARINE STUDIES DIVISION

ORGANIZATION AND ACTIVITIES

Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112

April 1994

NORTHWEST FISHERIES SCIENCE CENTER
RESEARCH MISSION STATEMENT

Under the National Marine Fisheries Service mission of "Achieve a continued optimum utilization of living resources for the benefit of the Nation," it is the responsibility of the regional research center to support planning, developing, and managing of multidisciplinary programs of basic and applied research designed to:

1) better understand the living marine resources (including marine mammals) of the northeast Pacific Ocean and the environmental quality essential for their existence and continued productivity;

2) describe and provide to management, industry, and the public options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs and international commitments.

To fulfill this mission we shall: 1) develop the scientific basis to determine and provide information on the status of stocks/populations of living marine resources, the status of fisheries for exploited species, the effects of pollution and human alterations on the habitats of these resources, the effects of environmental variability, the quality and safety of fishery products, and the enhancement of anadromous fishery resources; 2) collect, document, and interpret scientific and economic data as technical support for management plans, international negotiations, and fishery development programs; 3) provide technical advice on, review, and monitor fishery plans and grant programs; 4) pursue fundamental research on specified topics; and 5) maintain strong relations with the academic community and industry (through grants, contracts, and cooperative programs as appropriate) and with users and the general public. We cooperate with the other Fisheries Regions of the National Marine Fisheries Service in the sharing of expertise and in multi-regional programs consistent with national goals and needs and international commitments.

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DIVISION OVERVIEW

Objective and Role

The scientific mission of the Coastal Zone and Estuarine Studies (CZES) Division is to develop information leading to the conservation, enhancement, and balanced use of the marine and anadromous resources of the Pacific Northwest. A fishery represents a complex of interactions among organisms, environment, habitat use, and social values underlying harvesting and processing systems. The CZES Division conducts research to understand these interactions and to identify and solve problems within this complex.

Problem Setting

Research of the CZES Division focuses on the Columbia River Basin and Puget Sound, and the salmonid resources these watersheds support. The Division conducts its research within the framework of four research programs: *Ecological Effects of Dams, Habitat Investigations, Fisheries Enhancement,* and *Conservation Biology*.

Ecological Effects of Dams

The **Ecological Effects of Dams Program** focuses investigations on the Columbia River watershed, which covers 259,000 square miles in Idaho, Montana, Nevada, Oregon, Washington, Wyoming, and Canada (Fig. 1). More than 100 dams were built or authorized in the basin to provide power, irrigation, navigation, and water storage. These structures severely changed ecological conditions in the watershed and caused the loss of over 50% of the spawning and nursery habitats of important fishery resources, namely those of salmon and steelhead. Division research is part of a coordinated, comprehensive plan, which is intended to double the fishery within the next 10 to 15 years despite this loss of habitat.

The Ecological Effects of Dams Program undertakes applied research relating to migration of anadromous fish between spawning areas and the sea. Studies are carried out on the effects of water-resource development on river ecosystems, fish passage, survival of various stocks of anadromous fish, and the development of systems for alleviating adverse effects. For example, the rapid acceleration of powerhouse construction in the Columbia Basin in response to the energy crisis created a river situation in which a greater percentage of juvenile migrants passed through turbines. As a result, the time available to develop and refine solutions to fish passage problems was severely shortened.

Fortunately, our research has already pointed the way to several important practical steps to reduce salmon and steelhead

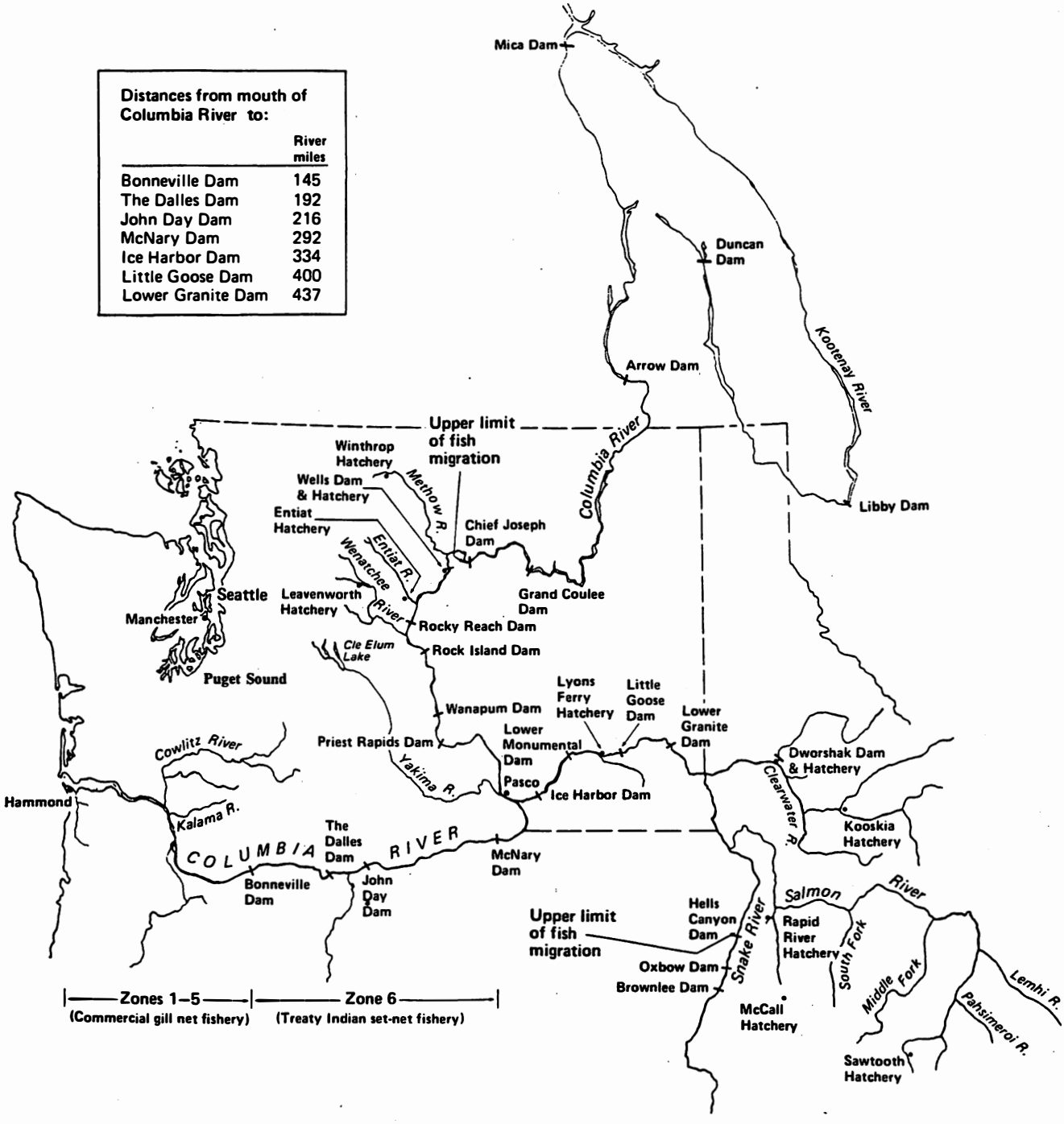

Figure 1.--The Columbia River Basin, showing the location of major mainstem dams on the Columbia and Snake Rivers. Important field sites, field stations, and Puget Sound are also shown.

losses due to dams. Passage of the Pacific Northwest Electric Power Planning and Conservation Act of 1980 and its accompanying Fish and Wildlife Program further accelerated the goal of enhancing Columbia River salmonid production. Information obtained from the study of the Columbia Basin problem also has application to anadromous fish resources in Alaska, California, the Great Lakes, and on the east coast.

Habitat Investigations

The focal point for research activities of the **Habitat Investigations Program** is the Columbia River estuary. This unique body of water covers about 400 square km and extends from the Pacific Ocean to about River Kilometer 75. The estuary is an extremely important and complex area involving a variety of biological and physical interactions. It is an important link in the life cycle of some of the most important food and sport fishes in the Northwest (e.g., salmon and steelhead). It is also an area subject to both subtle and drastic changes brought about by human activities.

The activities of the Habitat Investigations Program fall under four broad fisheries-resources research areas: 1) environmental background studies, 2) studies on the impacts of dredging and dredge-disposal, 3) studies on the impacts of discharged materials or heat, and 4) lower river and estuarine salmonid studies. Recent Program projects include several surveys in the Columbia River estuary and in other biologically strategic areas on the Oregon and Washington coast, a study of white sturgeon below Bonneville Dam, and a survival study of

juvenile salmon after using various fish passageways at Bonneville Dam.

Program research emphasizes salmonids, sturgeon, and other important fish and benthic species, particularly Dungeness crabs. This program is also compiling a database on living marine resources in selected estuaries on the Pacific coast. These data are compiled in cooperation with the Ocean Assessment Division of the NOAA National Ocean Service.

Through the Habitat Investigations Program, the Division monitors the biological effects of natural and man-made environmental changes, and predicts the consequences of contemplated actions through evaluation of pilot programs. Research information from this Program is used by many federal, state, and private agencies having major activities or responsibilities in the estuary and along the adjacent coasts. These agencies include the NMFS Northwest Region, Bonneville Power Administration (BPA), U.S. Army Corps of Engineers (COE), Environmental Protection Agency (EPA), U.S. Fish and Wildlife Service (USFWS), and the Columbia Basin Fish and Wildlife Authority (CBFWA). Habitat Investigations research is also used by state fish, game, and environmental departments, and by local port authorities and utility systems.

Fisheries Enhancement

The **Fisheries Enhancement Program** provides regional leadership in research directed toward enhanced production of aquatic organisms for commercial and recreational uses, and the conservation of endangered populations. Operating primarily from

the Manchester Field Station on Puget Sound (Fig. 1), the Program conducts a mix of basic and applied research in the areas of fish physiology (reproductive and developmental biology, endocrinology) fish health, and fish husbandry. Puget Sound, an inland sea with over 3,700 km of shoreline and numerous deep and sheltered waters, has considerable potential for producing fish, shellfish, and aquatic plants, and is an ideal focal point for this research.

Current research emphasizes development of technology to improve the quality and production of juvenile salmonids at public hatcheries. The NATURES project focuses on behavior and habitat interactions of hatchery-reared fish with the goal of improving the survival of both hatchery and wild juveniles. Fisheries Enhancement Program scientists are also studying physiological processes in juveniles to determine optimal timing for release of juveniles from hatcheries and to identify biochemical/physiological indices that can be used to predict adult salmon returns. Results of these studies have been applied by Washington Department of Fisheries in the design and implementation of their Puget Sound delayed release and extended rearing programs. As a result, an improved fishery now exists that not only benefits the recreational harvest, but eases the problem of allocation of fish between Tribal and non-Tribal fishers.

Better techniques for maintenance of brood stocks of Pacific and Atlantic salmon and cutthroat trout have also been developed by scientists in the Fisheries Enhancement Program. Current

efforts are centered on improvement of techniques for maintenance of endangered stocks of sockeye salmon and threatened stocks of spring and fall chinook salmon. Two areas of special emphasis are research on control of infectious diseases, and research to better understand endocrine control of sexual maturation and reproduction. A major accomplishment in the latter area has been the isolation and identification of hormones in coho salmon that are important in initiating and controlling spawning in adult fish, and that will have important applications in managing captive broodstocks.

The development of the Passive Integrated Transponder (PIT) tag by scientists in the Fisheries Enhancement Program has opened many new avenues of research. The PIT-tag is a revolutionary marking device that can be used to individually identify up to 35 billion fish. Fisheries Enhancement Program scientists have been at the forefront of research on this technology for over a decade, designing and testing highly specialized equipment for use at dams to monitor passage of PIT-tagged fish and in studying effects of the tags on survival, growth, and reproduction of salmon. New and innovative uses for PIT-tag technology have been emerging rapidly in recent years, helping fish culturists and fisheries managers deal with increasingly complex information needs.

Finally, the technology for salmon rearing and enhancement developed by the Fisheries Enhancement Program has had many applications in commercial salmon farming in Washington state; annual production in recent years has been more than 5.5 million

pounds of salmon with a wholesale value of $15.3 million. Farmed fish now constitute 15% of the total Washington salmon harvest. The information obtained by this program on development and improvement of freshwater and seawater rearing systems and on detection and prevention of fish diseases enables public and private growers to substantially increase production at reduced cost.

Conservation Biology Program

The **Conservation Biology Program** was established in 1993 in response to increasing demand for conservation of wild populations of anadromous Pacific salmonids. As these species are highly migratory, program research is concerned with U.S. waters from California to Alaska, as well as with international issues related to salmon from British Columbia and Asia that are encountered on the high seas.

A major responsibility of the Conservation Biology Program is providing the scientific basis for decisions on listing anadromous Pacific salmonids under the U.S. Endangered Species Act (ESA). NMFS has statutory responsibility under the ESA for anadromous as well as marine species, and scientific information developed by Conservation Biology Program staff is used by NMFS in making listing determinations, developing recovery plans, and reviewing actions that may adversely affect listed species. Program scientists have also helped formulate NMFS policy with respect to two important issues: identification of distinct salmon populations that qualify as "species" under the ESA, and delineation of appropriate uses of artificial propagation for

conservation and recovery of salmon populations listed under the ESA.

Conservation Biology scientists also conduct basic and applied genetic research related to the conservation of Pacific salmon. This involves the study of salmon that are captured in common-property fisheries as they migrate across international, federal, and state-managed jurisdictions. Wild salmon stocks are of particular concern in mixed-stock fisheries because they generally cannot support high harvest rates that target more abundant hatchery fish. The genetic stock identification (GSI) method developed by Conservation Biology Program scientists is being used to estimate the stock composition of mixed-stock fisheries, based on genetic characteristics assayed in samples from the fishery and in spawning populations that may be contributing to the fishery. Furthermore, in contrast to large-scale marking programs that generally focus on hatchery populations, the GSI method provides information for the conservation of wild populations.

Other basic research conducted by Conservation Biology Program scientists includes analyzing temporal genetic variation, monitoring the genetic consequences of hatchery supplements to natural populations, and developing methods to estimate the effective size of hatchery and wild populations. These fundamental parameters are a key to developing biologically sound conservation strategies. In these analyses, as well as in application of the GSI method, a factor that often limits the power of resolution is the quantity and quality of genetic

markers. Therefore, basic research into developing more and better genetic markers through application of molecular genetic technology remains an important component of future research by the Conservation Biology Program.

Organization, Facilities, and Funds

The Coastal Zone and Estuarine Studies Division has a professional staff of fishery scientists, engineers, electronic specialists, and various support personnel. Requests for their expertise and sharing of their techniques are national and international in scope. The CZES Division organization chart is presented in Figure 2.

Support staff bring capabilities of management, bioengineering, budgeting, and statistical analysis to bear on the operations of the Division. Core technology of the Division consists of the four programs, which are staffed by scientists and technicians who carry out basic and applied research.

Projects are organized with consideration of the need to understand and solve problems in three major areas: 1) the effects of water and water-related land resource development on ecosystems, habitats, and fish passage and survival; 2) development of means for improving management of fishery resources through physiological control and enhancement; 3) use of genetic research to determine status of mixed stocked fisheries and endangered or depleted stocks. Staff directly related to each of the four programs are identified in Figure 2.

The largest field stations for research on the Columbia River are located at Pasco, Washington, and Hammond, Oregon.

Coastal Zone and Estuarine Studies Division

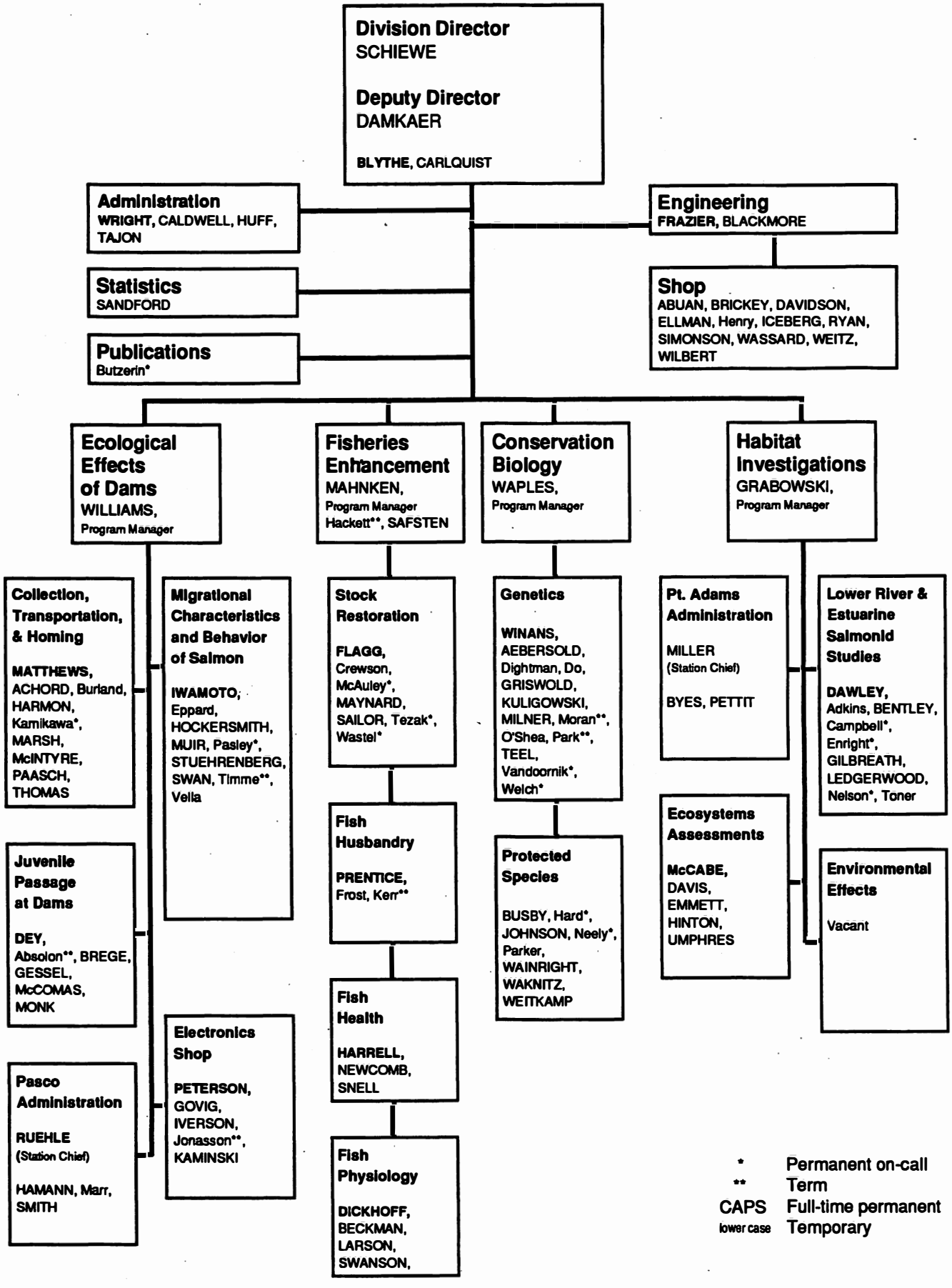

Figure 2.--Coastal Zone and Estuarine Studies Division organization chart.

Other important on-site field facilities are located at major dams on the Columbia and Snake Rivers or at dams on tributary streams. This extensive network of research sites includes facilities at Lower Monumental, Little Goose, Lower Granite, McNary, John Day, The Dalles, and Bonneville Dams, as well as field stations at Clatskanie, Oregon and Cook, Washington. The principal station for Fisheries Enhancement Program research is located on Puget Sound at Manchester, Washington. Finally, the Division has office, shop, and laboratory space and hatchery and holding facilities at the NMFS Northwest Fisheries Science Center in Seattle.

For the past several years, about three-fourths of the operational funds required for Division research activities has come from reimbursable contracts. In 1993, about $9.7 M were provided via reimbursable contracts with other agencies and about $2.7 M were provided via NMFS appropriated funds (Fig. 3). The main sources of reimbursable funds are the COE and BPA because of their responsibility and desire to restore fish runs lost through hydroelectric development in the Columbia Basin.

However, this degree of reliance on contracts from other agencies to carry out high priority research creates serious problems within the Division, particularly in the areas of long-range planning, organization, and staffing. Fluctuations from year to year in amounts and types of research contracts have resulted in large shifts in research emphasis and reassignments of many field research staff. Fortunately, we have developed a talented and flexible staff to accommodate these fluctuations.

Coastal Zone and Estuarine Studies Division

FY93 FUNDING

(in thousands)

Program	*Base*	*Reimbursable*
Ecological Effects of Dams	658.3	4,862.3
Habitat Investigations	704.8	987.5
Fisheries Enhancement	530.4	3,507.2
Conservation Biology	844.9	401.5
TOTAL	2,738.4	9,758.5
Total FY93 Funding	12,496.9	

Figure 3.--Coastal Zone and Estuarine Studies Division, 1993 funding summary by program.

Funding summaries for FYs 1984-1993 are presented in Table 1.

Operations and Goals

Generally, CZES Division research goals are to obtain information on the status of populations, patterns of fish behavior, environmental factors, and enhancement systems, and to develop alternative protection or enhancement systems related to specific endangered or threatened species problems. The application of this information by management agencies results in capital savings in fish passage facilities, increased production in fisheries and aquaculture, and maintenance of environmental quality.

Our research applications also promote optimum multiple uses of resources. Various types and degrees of cooperation with other organizations are required for the implementation of research findings by resource and policy managers. These organizations include federal and state agencies, private industry, and various conservation and interest groups. Consideration of these organizations is also necessary in problem identification and definition, planning, programming, budgeting, evaluation, and applications of new information and technology.

The CZES Division activities are coordinated with those of other NMFS Divisions within the Region primarily by the Deputy and Division Directors; however, scientist-to-scientist interaction is also encouraged. One important area where planning and coordinated research will continue to be emphasized relates to the goals of the Environmental and Technical Services

Table 1.--Coastal Zone and Estuarine Studies Division, 1984-1993 funding summary.

FY	Reg. funds $K	US/Can. Salmon Treaty	Hi-seas drift-net	Endgr. species	Squaw-fish	REIMBURSABLES To CZES	To Center	To NOAA/NMFS	To DOC	Total contract	Total FY $K
84	1713.1					2449.8	448.5	701.4	18.0	3617.7	5330.8
85	1728.8					2976.5	243.1	366.4	18.0	3604.0	5332.8
86	1698.3	272.4				3392.5	256.6	369.3	19.1	4037.5	6008.2
87	1697.0	284.5				3123.7	231.6	394.4	18.1	3767.8	5749.3
88	1690.7	306.8				4012.3	225.5	383.9	23.3	4645.0	6537.5
89	1698.7	260.1				5416.9	472.0	553.1	32.5	6474.5	8433.3
90	1740.9	260.1	256.9			3260.3	451.5	608.6	33.7	6743.8	9001.7
91	1883.0	260.1	274.5	96.0	92.0	4164.1	288.3	508.0	24.8	4985.2	7590.8
92	1732.0	305.2	305.0	377.6	110.0	9314.1	982.8	1454.5	58.8	11810.2	14640.0
93	1794.7	290.6	198.0	356.3	98.8	8122.5	659.8	927.2	49.0	9758.5	12496.9

Division (ETSD) of the Northwest Region, and CBFWA. Cooperative evaluation and feedback processes are an inherent part of this operation.

In summary, CZES Division research goals are to obtain information on fishery ecology and production, behavioral patterns in fish, environmental factors, and husbandry systems as related to specific fish (e.g., salmon) and companion resources such as shellfish. Information produced by the Division are intended to help growers, management agencies, and the food industry achieve increased seafood production, enhancement of recreational fisheries, and maintenance of environmental quality.

ECOLOGICAL EFFECTS OF DAMS PROGRAM

Background

The construction of dams and other water resource developments brought about dramatic environmental changes in the Columbia River system. Dams altered flow patterns, temperature regimes, and competitor-predator relationships; they flooded spawning areas and created physical barriers to migrating anadromous fish. These were major factors in the decline of salmonids, from a peak run of 10 to 16 million fish historically to about 2.5 million now. With continuing development of the Columbia River system in the United States and Canada, river flows are now better controlled, and the volume of spill at dams is substantially reduced. Turbine capacity at dams has more than doubled since 1974, which has further reduced the volume of water spilled; even with implementation of a water budget under the Pacific Northwest Electric Power Planning and Conservation Act of 1980.

Large investments were made to build fishways that provide upstream migrants access to spawning areas and propagation facilities that increase production of salmonids. Nevertheless, many adult fish migrating upstream are lost each year, and a high percentage of native and hatchery-reared juveniles die from a variety of causes during their seaward migration. If past investments are to result in the most efficient production of salmonids, responsible agencies must be aware of the impact of existing environmental conditions on the fishery resources and be

cognizant of the consequences of projected changes so that appropriate corrective or mitigative actions can be taken.

Research conducted by NMFS and its predecessor organization, the Bureau of Commercial Fisheries, has provided a broad base of information on the effects of in-river changes on salmonids. Management agencies use this information to develop techniques that improve survival rates of salmonids migrating between spawning areas and the sea. Problems in the fishery resources created by continuing development in the Columbia River system are under observation by the Ecological Effects of Dams Program, and field research is conducted with the following objectives:

1) Determine the effects of dams and other resource developments on fish migration and survival.
2) Assess detrimental effects of changes on fishery resources.
3) Develop systems for protection of fish from hazardous conditions such as turbines at hydropower dams (Fig. 4).
4) Evaluate the effectiveness of protective actions.
5) Provide information to improve enhancement, rehabilitation, and redistribution of salmonid stocks in currently depleted areas.
6) Provide information on species survival and behavior for stocks of juvenile migrants passing dams where various bypass methods are used.

Specific research projects of the Ecological Effects of Dams Program are developed by program personnel on the basis of critical needs, and are often a direct response to requests from outside agencies (e.g., state agencies, COE, BPA, etc.) who are

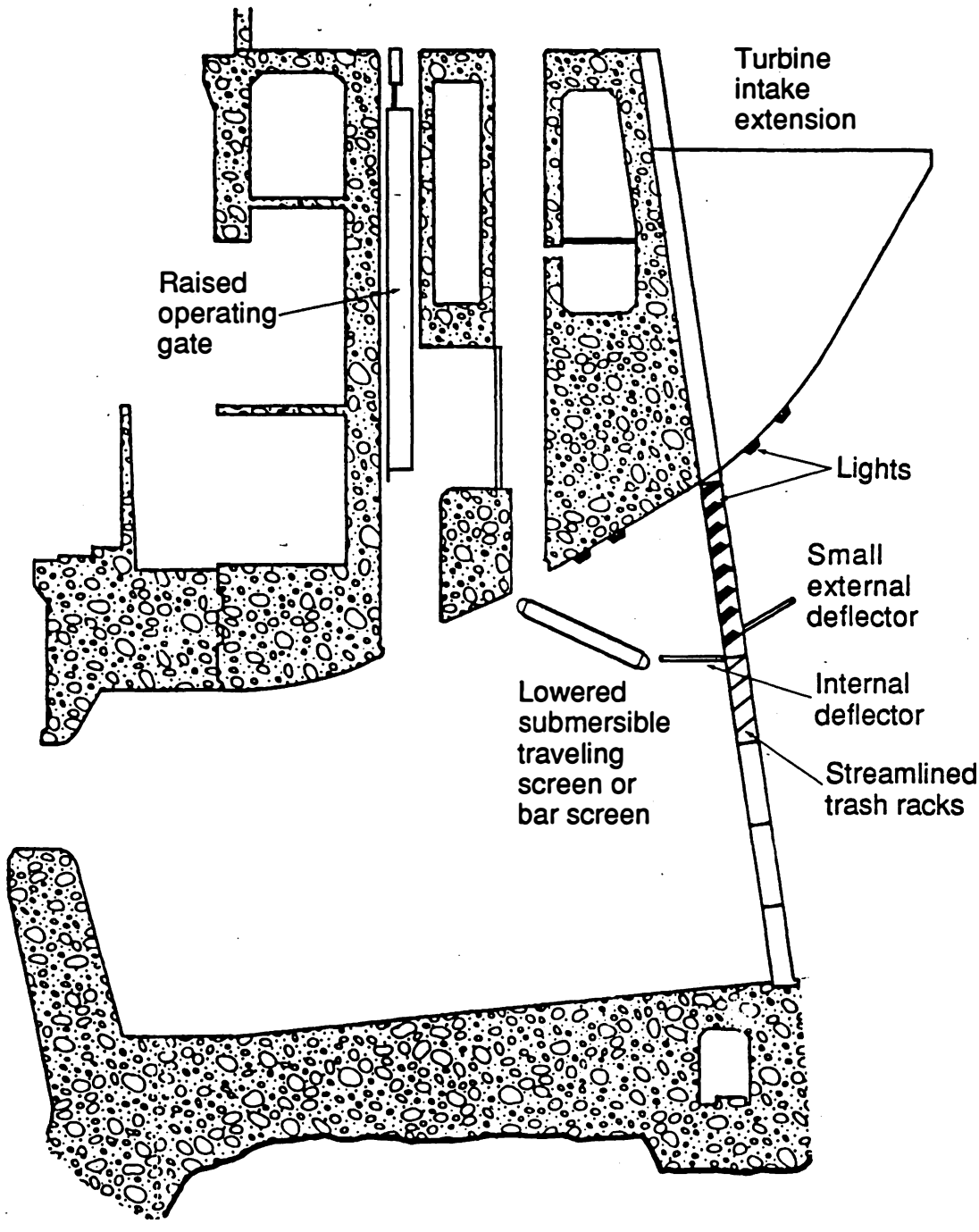

Figure 4.--Schematic cross-section through Bonneville Dam Second Powerhouse showing modifications tested to improve juvenile salmonid guidance at hydroelectric projects on the Columbia and Snake Rivers.

responsible for providing safe and effective fish passage facilities, but lack the technical capability to develop and evaluate fish-protection devices. Research proposals are coordinated with and reviewed by the member agencies of CBFWA through a number of advisory and technical committees.

Research consists of cooperative efforts between four ongoing project teams:

1) Migrational Characteristics and Behavior of Juvenile Salmon.
2) Collection, Transportation, and Homing.
3) Juvenile Passage at Dams.
4) Electronic Surveillance.

Within this framework, studies are aimed at obtaining information in major research areas which include the following:

1) Adaptability of juvenile salmonids to changing environments created by dams.
2) Collection and transportation of juvenile salmonids.
3) Migrant passage (juveniles and adults) at dams.
4) Enhancement and redistribution of stocks.

The relationships between program organization and major areas of research are shown in Figure 5. Most of the work is done at field sites extending from the upper reaches of the Salmon River (tributary of the Snake River) downstream about 700 miles through the Snake and Columbia Rivers; however, some research is conducted at the NMFS laboratory in Seattle or at other locations. Although the program provides the expertise for a vigorous field effort, the majority of funds for field

Migrational characteristics & behavior of juvenile salmon	Collection, transportation, and homing	Juvenile passage at dams	Electronic surveillance
Describe dam passage patterns and impacts, including survival between dams Assess the integrity of mark-recovery data Identify behavioral changes associated with smolt development Assess the feasibility of manipulating smolt development and its associated behavior relative to migration and passage Determine the migrational timing of wild smolts marked in spawning and rearing areas of tributaries to the Snake River	Continue evaluating benefits of transporting smolts from Snake River dams using CWT technology Determine feasibility of alternate release sites for transported fish	Measure fish guidance at Lower Granite, Little Goose, Lower Monumental, McNary, The Dalles, and Bonneville Dams Develop techniques for improving guidance of subyearling chinook salmon Continue evaluating fingerling bypass at dams: Lower Granite Little Goose Lower Monumental McNary John Day The Dalles Bonneville Investigate use of extended screening devices to improve fish guidance	Develop improved techniques for monitoring behavior of juvenile & adult salmon Monitor fish behavior and provide measures of survival Provide measures of fallback at dams Evaluate fish passage facilities at dams on the Columbia River and its major tributaries

Figure 5.--Relation of organizational phases to major areas of research in the Ecological Effects of Dams Program.

operations are obtained through contracts with federal agencies such as BPA, COE, and EPA or with Public Utility Districts (PUD).

Data on juvenile salmonid migrations have been obtained from release and recovery of marked fish. Initial population estimates of native and hatchery-reared fish were made in the upper Snake River, and additional estimates were made as migrants were subsequently recovered in gatewells of dams or in traps and seines along the migration route. In 1983, this annual routine monitoring of migrational behavior, including daily population estimates of juveniles arriving at key locations, was turned over to the Fish Passage Center. This organization was formed as a result of the Pacific Northwest Electric Power Planning and Conservation Act. Routine annual estimates of migration timing for various populations of juvenile migrants are now computed by the Fish Passage Center, which uses techniques developed by CZES. However, in 1993, CZES began using new techniques for population estimates, utilizing the passive integrated transponder (PIT) tag, which more precisely measures inriver survivals for migrating juvenile salmonids.

Other research on juvenile migrants measures stress and injury in experimental groups subjected to newly developed or improved bypass systems, such as those recently completed at Little Goose and Lower Monumental Dams.

Fish diverted from turbine intakes into gatewells are collected and marked at Lower Granite or McNary Dams; some of these fish are transported about 200 to 350 miles downstream (treatment groups) and others are released at the dam (controls). The recovery of marked fish at different points downstream

provides data on survival, timing, and migration rates. Evaluation of the collection and transportation system is based on the recovery of marked adults captured in the ocean or detected at Little Goose, Lower Granite, or McNary Dams during their spawning migration. Recoveries in the river fisheries and on the spawning grounds provide further information on the return of marked fish and the effects of transport on homing ability.

Radio-tracking techniques are used to observe movements of adult and juvenile salmonids in relation to physical and operational features at dams and in impoundments. Adults and juveniles tagged with radio tags are observed with radio direction finders from shore and boat stations, and locations of fish are plotted on a chart of the area by triangulation. Fish movement is compared with flow conditions and various operating techniques at adult and juvenile passage facilities.

For the Ecological Effects of Dams Program, most field activities peak during the downstream migrations of juvenile salmonids in the spring and summer, when fish are collected, marked, and released for future recovery. Juvenile recovery efforts extend into the summer, and efforts to recover marked returning adults extend into the fall. Between these major periods of field activity, personnel analyze data, prepare reports, and modify equipment and procedures to improve operations in the next field season. A review of program research progress is held in the winter--usually in late December or early January. When it is apparent that additional studies should be initiated, proposals are prepared and submitted for consideration.

Recent Accomplishments

Collection, Transportation, and Homing

Since 1990, the Collection, Transport, and Homing Project has focused on studies to evaluate collection and transportation of fish marked as juveniles. Studies were conducted in 1986, 1989, and 1992-93 at Lower Granite Dam, and from 1986 to 1988 at McNary Dam (Fig. 6). Research in the 1980s assessed the benefits of transporting fish by barge past the hydropower system to a release site below Bonneville Dam.

Adult returns these releases, begun in 1992, will determine if there are additional benefits in transporting fish another 125 miles downriver to a release site in the Columbia River estuary. The first returns from steelhead barged to the estuary began in summer 1993. Insufficient recoveries have been made to date to determine additional benefits from this extended transportation.

Analyses of adult return data for yearling chinook salmon and steelhead from 1986 and 1989 transportation experiments at Lower Granite Dam were recently completed. These data show a transport/control ratio of 1.6:1 and 2.4:1 for fish collected at the dam and transported to a release site below Bonneville Dam. Too few returns were observed from the 1986 work at McNary Dam to provide a meaningful analysis. However, returns from the 1987 and 1988 research showed a transport/control ratio of 1.7:1 and 1.4:1, respectively. Results from the McNary Dam research on transported fall (subyearling) chinook salmon were especially strong in their indication of transport benefits.

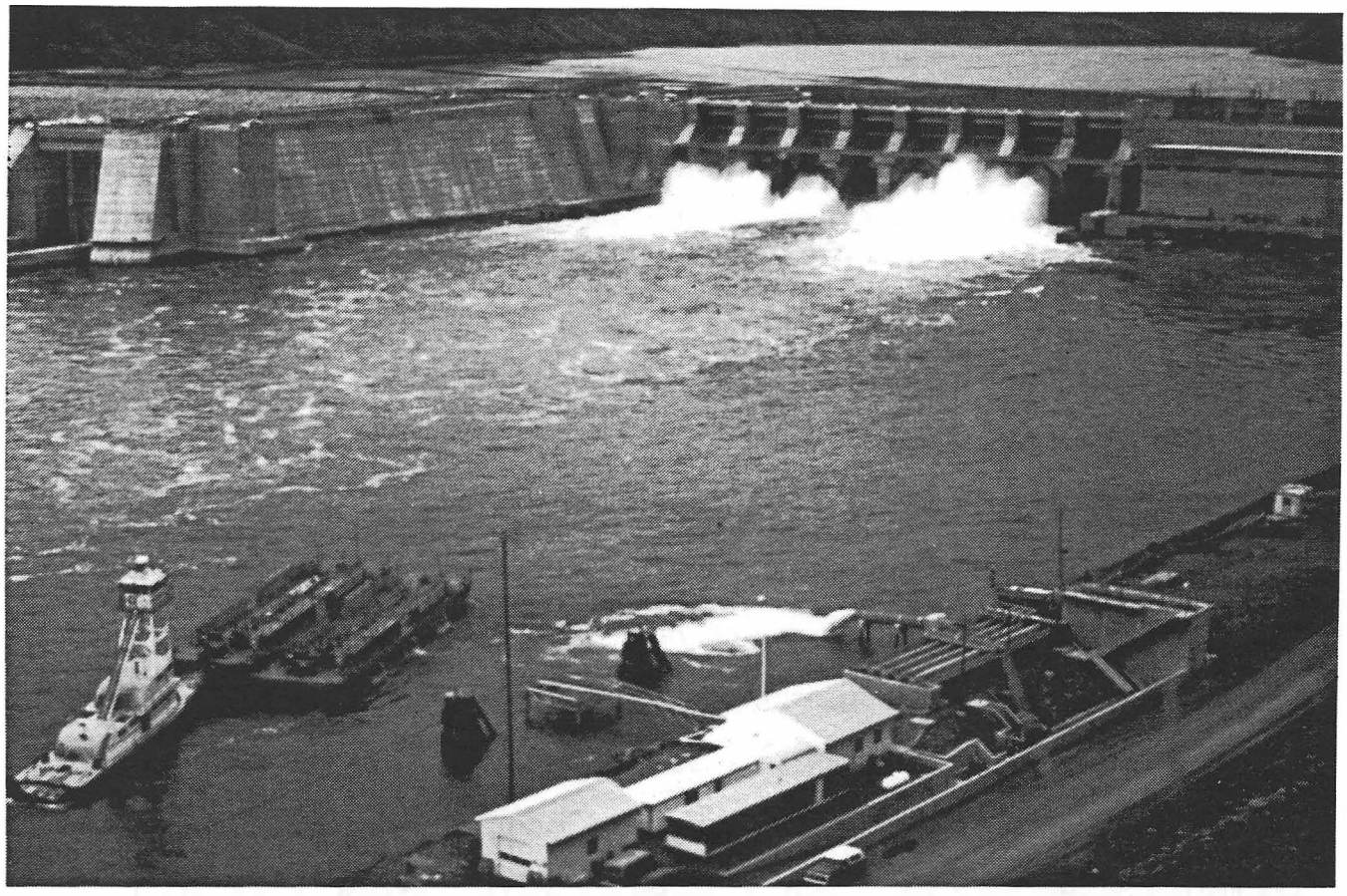

Figure 6.--Transportation barge at Lower Granite Dam.

Transported/control ratios ranged from 2.8:1 to 3.3:1 in this study. This was a result of very poor survival to inriver migrants during that summer: flows were lower, while river temperatures and predator activity and consumption rates were higher.

Migrational Characteristics and Behavior of Juvenile Salmonids

The primary activities of this project are to describe migrational characteristics and estimate survival of juvenile downstream migrants in the Columbia-Snake River system.

Since 1988, research staff have annually PIT tagged between 7,500 and 20,000 wild spring/summer chinook salmon parr in the upper Snake River Basin. Data from these studies are used to determine the timing and estimate the magnitude of wild juvenile outmigrations. In each year following parr tagging, detection rates of wild and hatchery spring/summer chinook salmon smolts were monitored at Snake and Columbia River dams.

These studies demonstrated that the outmigrations of wild fish are protracted while the outmigrations of hatchery fish are compressed. In addition, wild summer and spring chinook salmon smolts began their outmigration either earlier or later than their hatchery counterparts. A second important finding of these studies was that the timing of smolt passage at Lower Granite Dam appeared to be independent of river flow levels: cumulative passage rates past the dam were nearly identical in all years under conditions of substantially different flows.

In 1993, a study was initiated to field test and evaluate a new survival estimation methodology for juvenile salmonid

migrants (the modified Single-Release-Model). First-year results will identify operational and logistic constraints and determine the model's ability to predict survival through hydroelectric projects and other specific reaches of river with known precision. A total of 34,900 hatchery-reared yearling chinook salmon were collected, PIT tagged, and released from Lower Granite reservoir and Lower Granite and Little Goose Dam turbines, bypasses, and spillways (Fig. 7). These fish were interrogated, captured, and re-released from Lower Granite, Little Goose, Lower Monumental, and McNary Dams. Project staff are presently analyzing the first year's results.

Juvenile Passage at Dams

Research to evaluate and improve juvenile collection/bypass systems has been conducted at Lower Granite, Little Goose, Lower Monumental, The Dalles, and Bonneville Dams. Efficacy of bypass systems at dams is measured in terms of fish guidance efficiency (FGE), or the percentage of juvenile migrants that are diverted from turbines and into the bypass system. The CBFWA has set an interim goal of 50 and 70% and a long-term goal of 70 and 80% FGE for subyearling and yearling migrants, respectively.

None of the bypass systems currently meet these long-term goals: FGEs at most dams range from 25 to 45% for subyearlings and from 60 to 75% for yearlings. Research efforts are directed toward developing the means to achieve the CBFWA long-term goals. These efforts include attempts to improve the submersible traveling screen, which physically diverts fish from the turbine intakes (Fig. 4).

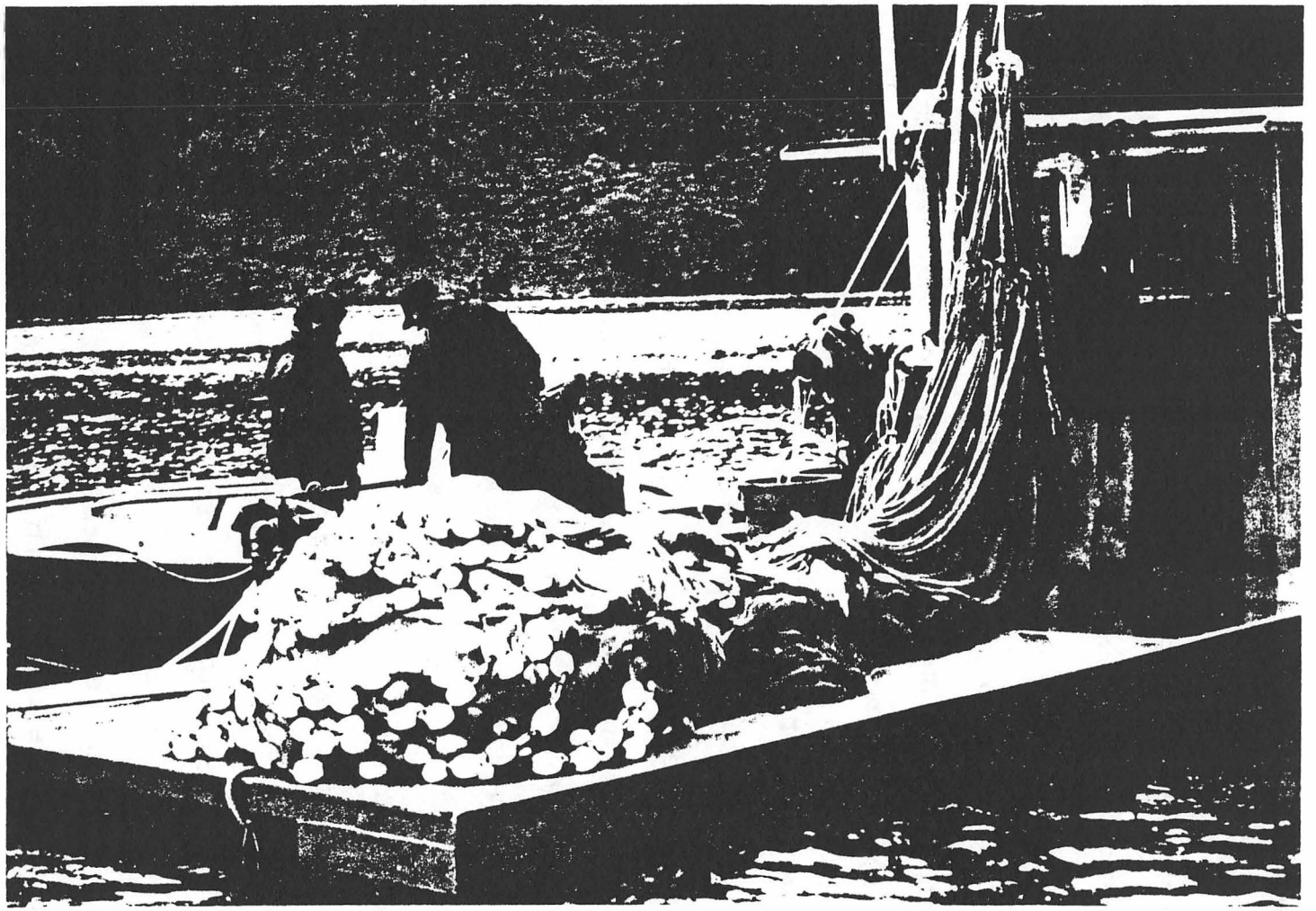

Figure 7.--Purse-seine barge used to collect juvenile chinook salmon for survival studies.

Although an actual prototype traveling screen was not tested, research completed at Lower Granite Dam in 1989 indicated the feasibility of increasing guidance if the screen length was doubled. As a result, the COE began the design of screens for testing in prototype conditions.

In 1991, research began at McNary Dam to test selected configurations of extended length screens that are twice as long as screens now installed. Two types of surface material on the extended screens were tested. The first was a traveling mesh used on standard length screens. The second was a fixed bar-screen material with a movable brush to keep the surface free of debris.

Guidance efficiency with the traveling mesh and fixed screen configurations was greater than 80% for the yearling chinook salmon and ranged from approximately 60 to 85% for subyearling chinook salmon. For subyearling chinook salmon, this was substantially higher than guidance levels measured in previous years with a standard screen. There was, however, a higher level of descaling with the traveling mesh configuration.

Additional research was conducted in 1992-93 with attempts to modify the screens to decrease fish injury and descaling while maintaining high guidance. After adjustments, both of the extended-length screens tested outperformed the standard-length screen, with 88 and 81% FGE for yearling chinook salmon in spring and 67 and 59% FGE for subyearling chinook salmon in summer. Descaling levels with the modified screens were reduced so that they were similar to levels observed with the standard screens

now in use. Additional research will be required to determine which screen configuration will provide the greatest improvement in fish survival at McNary Dam.

Based upon preliminary results with extended screens at McNary Dam in 1991, we planned to construct and test prototype screens for Lower Granite and Little Goose Dams. In spring 1993, we tested modified extended-length screens at Little Goose Dam to determine their potential to improve FGE. Fish guidance efficiency was high (85-90%) and was not significantly different between screen types. Additional research is required to determine which screen type and configuration will provide the greatest improvement in fish survival at Little Goose Dam.

The Dalles Dam lacks a fish bypass system, but in 1993, we began to test extended traveling-screen configurations to determine the potential for fish guidance. The extended-length submersible traveling screen and the extended-length bar screen outperformed the standard-length screen, with spring FGEs of 73 and 60% vs. 44% and summer FGEs of 59 and 51% vs. 23%. Additional research is needed to determine which screen type and configuration will provide the greatest improvement in fish survival at The Dalles Dam.

At Lower Monumental Dam, a juvenile bypass system was completed in 1992. We conducted a post-construction evaluation of FGE with the newly installed submersible (standard length) screens. More than 65 and 85% of yearling chinook salmon and steelhead, respectively, were diverted from the turbine intakes and into the bypass system.

A similar post-construction evaluation of standard screens was conducted after completion of a new juvenile bypass system at Bonneville First Powerhouse. Results indicated that FGE was much lower than expected based on prototype research. From 1990 to 1992, we attempted to improve guidance into the new bypass system by raising the operating gate (Fig. 4), changing the porosity of the screens, and lowering the screens farther into the gatewells. Although improvements were made, overall guidance levels remained far below the minimum 70% FGE considered necessary for improving overall survival of Columbia River Basin salmon stocks.

After completion of Bonneville Second Powerhouse in 1982, research determined that FGEs were far below the levels expected based on their design. We tested a number of different options for improving FGE over the next 6 years. Based on these test results, we recommended several improvements to the bypass system components and powerhouse structure, which were carried out over the next few years. These improvements included extending turbines intakes; lowering submersible traveling screens; and streamlining trashracks in the south, middle, and north turbine units under full and partial powerhouse operation.

In 1993, research was conducted during spring and summer to evaluate FGE with the completed improvements. Results of spring tests indicated that slots without turbine intake extensions attracted more fish and had higher FGE than slots with extensions during 4- or 6-unit operation. Mean FGE ranged from 35 to 60% with 4- or 6-unit operation and from 45 to 55% with 8-unit operation. In summer, FGE for subyearling chinook was

significantly higher with 6-unit operation than with 4-unit operation, and higher in the north test unit (34%) than in the south test unit (25%). However, although results were improved over initial measurements in 1983, they were much below the minimum 70% considered necessary for improved survival.

The Juvenile Passage at Dams Project has also undertaken studies to explain the varying FGE at different dams. At the NMFS Pasco Field Station, we initiated a study to evaluate fish behavior in relation to water velocity as a potential explanation of these varying FGEs. Under subdued light conditions within a 1 x 2-m flume, fish were released at a set distance, upstream from barriers of different porosities, and their was behavior noted. Detailed water-velocity measurements within the flume were also taken with a Laser-Doppler system. Results indicated that fish avoided areas where water velocities decreased from approximately 77 cm^2/s to 67 cm^2/s over a distance of 10 cm. We concluded that the installation of screens that cause these velocities may decrease the ability of screens to divert fish away from turbines.

A review of FGE research over the past 20 years was also conducted to determine if there were correlations to any obvious physical factors in the environment. Only water temperature and Julian date of testing were found as significant factors within years. However, between-year variability was so large that these correlations are fairly meaningless. Fish guidance research at all projects showed that each project is unique, and solutions that might be viable at one bypass system may not be appropriate

at another. Furthermore, fish behavior and physiology apparently play a large role in successful fish guidance, to that even the most up-to-date bypass systems may not be successful for all fish at all times.

In addition to evaluations of FGE after installing new screens, post-construction evaluations of new and upgraded bypass facilities were completed. In 1991, we evaluated the updated juvenile fish collection and bypass facility at Little Goose Dam, and in 1993, the newly constructed facilities at Lower Monumental Dam. To determine if there were areas in the new facilities that caused injury or descaling to juvenile yearling chinook salmon or steelhead, marked groups of hatchery fish were released from various points along each bypass system. They were then recaptured and examined for descaling and injury. Some problems were noted at both facilities and relatively minor modifications were made. These modifications alleviated problems in the interim, and extensive permanent modifications were made prior to the next outmigration.

Evaluations of stress and fatigue were also measured by sampling migrant yearling chinook salmon and steelhead from different locations. Blood was collected from the sampled fish and analyzed for plasma, cortisol, and lactic acid. Plasma evaluations at Little Goose Dam indicated that concentrations of these three factors significantly increased as the fish passed through the first part of the facility, but decreased to baseline levels within 2 to 6 hours after passage. However, these increases appeared to be within normal limits for both species.

Plasma analysis is in progress on samples from Lower Monumental Dam.

Finally, the reliability and efficiency of sampling systems were evaluated. The number of PIT-tagged fish detected at bypass systems was compared to the number that should have been detected according to the total number of fish released and the attempted sample rate. A t-test analysis detected no significant differences were found between projected and actual sample rates.

Studies were also conducted at Lower Granite Dam in 1990-92 and at Little Goose Dam in 1993 to evaluate, modify, and improve the new slide-gate systems, which work in conjunction with PIT-tag detectors to intercept PIT-tagged fish as they enter the bypass systems. After many modifications and tests, the systems were proven to reliably detect, intercept, and bypass PIT-tagged fish back to the river at the sampling sites. System-wide survival studies initiated in 1993 were made possible by the operation of these slide-gates.

Between 1989 and 1992, we evaluated the efficiency and affect on fish quality of the Chandler Canal Juvenile Fish Collection Facility on the Yakima River. We also began studies with fish collected at the facility to determine differences in survival between fish released at various locations in and around the facility. After modifications, the samplers at the facility did not decrease fish quality; however, it appeared that fish exiting the facility survived at lower rates than those not diverted into the Chandler irrigation canal.

Electronic Surveillance

Adult chinook salmon and steelhead were radio tagged in the lower Yakima River between 1988 and 1992. Stock distribution and timing of upstream movements were examined and passage facilities at irrigation projects within the basin were evaluated. Information on stock timing and composition will be used by the Yakima Production Program to determine when hatcheries will take brood stock from the wild runs. Travel time data from the radio-tagged fish indicated good adult salmonid passage conditions at all of the irrigation diversion projects in the basin. Five steelhead spawning populations and four spring chinook salmon spawning populations have been identified, and locations of segregated spawning populations were identified for taking brood stock.

Studies were begun in 1992 to evaluate adult fish passage facilities at PUD dams on the mid-Columbia River. Adult sockeye salmon were radio tagged and monitored as they passed Wells Dam and were tracked to the spawning grounds in the Okanogon River to determine spawning success. Sockeye salmon passed Wells Dam without any problems, but only approximately 50% arrived at the spawning grounds as a result of a temperature block at the mouth of the Okanogon River. In 1993, 700 spring/summer chinook salmon were tagged to evaluate the adult fish passage facilities at remaining dams. Work is ongoing and fish are still passing the projects.

Field Facilities

Ecological Effects of Dams program staff are based at field stations in Pasco and North Bonneville, Washington. The Pasco Field Station (Fig. 8) includes a complete machine shop equipped to overhaul vehicles, cranes, outboard motors, or boats. Metal-shop facilities allow for fabrication, construction, or modification of a variety of research gear, from small, portable fish tanks to large, submersible traveling screens used in turbine intakes at dams. There are also riverside facilities for behavior and performance tests of adult or juvenile salmon. These include permanent experimental raceways capable of holding more than 100,000 smolts.

Future Projects

Program research leading to increased protection for downstream migrant salmonids at dams is planned. The following activities will play a significant part in attaining the Northwest Power Planning Council (NWPPC) goal of doubling Columbia River fish runs:

1) Continue evaluation of adult return data from previous and new experiments.
2) Initiate new transport evaluations from Lower Monumental Dam utilizing state-of-the-art techniques with coded-wire tags and brands.
3) Participate in the development and execution of drawdown proposals for Snake River reservoirs.
4) Continue research on the extended-screen concept at Lower Granite, Little Goose, McNary, and The Dalles Dams.

Figure 8.--CZES Pasco Field Station (Pasco, Washington).

5) Evaluate extended-screen prototypes at John Day Dam.
6) Continue research with PIT tags to estimate salmonid survival within the Columbia River hydroelectric system.
7) Develop a juvenile acoustic PIT-tag.
8) Continue evaluation of adult passage facilities at mid-Columbia Dams.
9) Re-evaluate adult passage facilities at lower Columbia River Dams.
10) Continue to PIT-tag wild parr in the Snake River Basin and monitor their timing and survival through the Snake River.
11) Evaluate collection and bypass systems as they are completed or when refurbished.

HABITAT INVESTIGATIONS PROGRAM

Background

Habitat Investigations Program goals are to provide information for the protection and enhancement of fisheries habitat and to predict the effects of alterations and contaminants in the lower Columbia River, Columbia River estuary, and Oregon and Washington coasts, including Puget Sound. This program studies the relationships between organisms in freshwater and marine environments and conducts research on which to base management and regulatory decisions.

Habitat Investigations Program findings are used by many federal, state, and private agencies with major activities or responsibilities in the lower Columbia River and along the adjacent coast. These include the COE, EPA, BPA, NMFS/ETSD, NWPPC, Columbia River Inter-Tribal Fish Commission (CRITFC), USFWS, CBFWA, and Columbia River Estuary Study Taskforce (CREST); as well as state fish, game, and environmental departments, port authorities, and local utility systems.

Data products and services produced by this program are used for the following purposes: to assess research results, management proposals, and permit requests; to prepare environmental impact statements; to determine optimum methods and times of maintenance dredging; to determine optimum dredged-material disposal methods and localities; to provide information on the survival and timing of juvenile salmonids to the estuary (which relates to the management of water and power at hydroelectric dams); and to provide environmental information

leading to the protection, restoration, and enhancement of habitat and fisheries resources.

Present field work and research is conducted in the Columbia River and estuary and adjacent coastal waters, and in Puget Sound. These are largely contract-supported studies funded by the COE, BPA, and U.S. Navy. Most are related to the survival of juvenile salmonids through the Columbia River to the estuary and ocean: others are assessments of habitat, dredging, and dredged-material disposal. Natural impacts, such as seawater intrusions, dilutions, in-river suspended matter, and sedimentation are also studied.

Assessments of habitats and ecosystems are made through observations of diversity, abundance, ecosystem relationships, and bioassay studies. While these studies are important in evaluating effects of various human activities, they often do not provide for sufficient effort on many high priority research goals or on regional environmental issues. Some limited ecosystem information (e.g., on finfish, shellfish, and benthos) for a number of separate sites has been obtained through outside agency support.

Recent Accomplishments

Recent Habitat Investigations Program activities are refinements or extensions of the first CZES Division projects in the lower Columbia River and estuary, which began in the mid-1960s. These projects fall under four broad research areas: 1) background studies of the environment, 2) studies on the impacts of dredging and dredged-material disposal on benthic

invertebrates and fishes, and 3) studies on the impacts of atmospheric gas-supersaturated water on aquatic biota, and 4) lower river, estuarine, and nearshore ocean salmonid studies.

General Habitat/Environmental Studies

Columbia River white sturgeon--Research began in 1987 to determine the impact of hydropower system development and operation on white sturgeon (*Acipenser transmontanus*) in the Columbia River Basin (Fig. 9). This research corresponds to the study objectives of the "White Sturgeon Research Program Implementation Plan," which was developed by BPA and approved by NWPPC in 1985. In response to this plan, the Habitat Investigations Program, the Oregon Department of Fish and Wildlife (ODFW), the Washington Department of Fisheries (WDF), and USFWS cooperatively developed two 5-year research proposals.

The proposals address two reaches of the Columbia River: from the estuary to Bonneville Dam and from Bonneville Dam to McNary Dam. The following four high-priority work elements were elucidated in these proposals:

1) Describe the reproduction and early life-history characteristics of white sturgeon populations.
2) Describe the life history and population dynamics of subadult and adult white sturgeon.
3) Define habitat requirements for all life stages of white sturgeon and quantify the extent of available habitat.
4) Evaluate the need and identify potential methods for protecting, mitigating for losses, and enhancing white sturgeon populations.

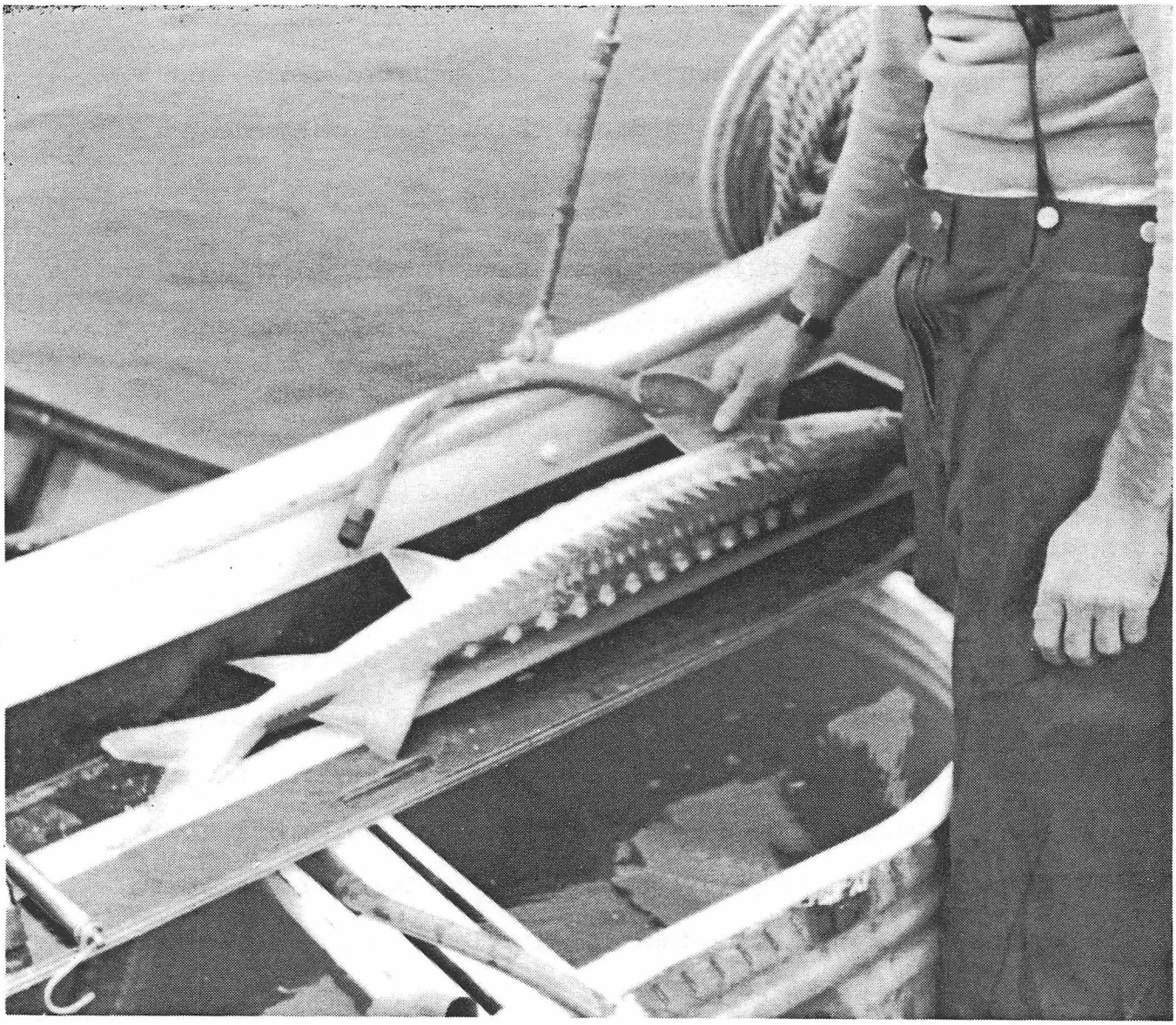

Figure 9.--White sturgeon collected for marking and release during sturgeon-habitat evaluations in the lower Columbia River.

This proposal was reviewed and approved by the Regional Steering Committee for White Sturgeon Research; the research is funded by BPA.

The Habitat Investigations Program was responsible for parts of Work Elements 1 and 3 downstream from Bonneville Dam. This is the only reach in the Columbia River system known to support all developmental stages of white sturgeon and to do so in sufficient numbers to provide a baseline for comparison of habitat availability and utilization upstream from Bonneville Dam.

Sturgeon downstream from Bonneville Dam have unrestricted access to the ocean and therefore may exhibit characteristics of sturgeon stocks prior to dam construction. This lower reach now supports relatively large sport and commercial white sturgeon fisheries. A second 5-year segment of the white sturgeon study was initiated in 1993, and Habitat Investigations Program staff will again investigate reproduction and early life-history characteristics and habitat requirements.

During the first 5-year segment, initial research activities included a literature review and the testing and modification of sampling gear. Field work that began in 1987 has accomplished the following objectives: 1) determined the most suitable method for collecting white sturgeon eggs, larvae, and juveniles (Fig. 10); 2) made a preliminary determination of the downstream distribution of white sturgeon larvae; and 3) established appropriate sampling sites to index habitat preferences or requirements of juvenile white sturgeon.

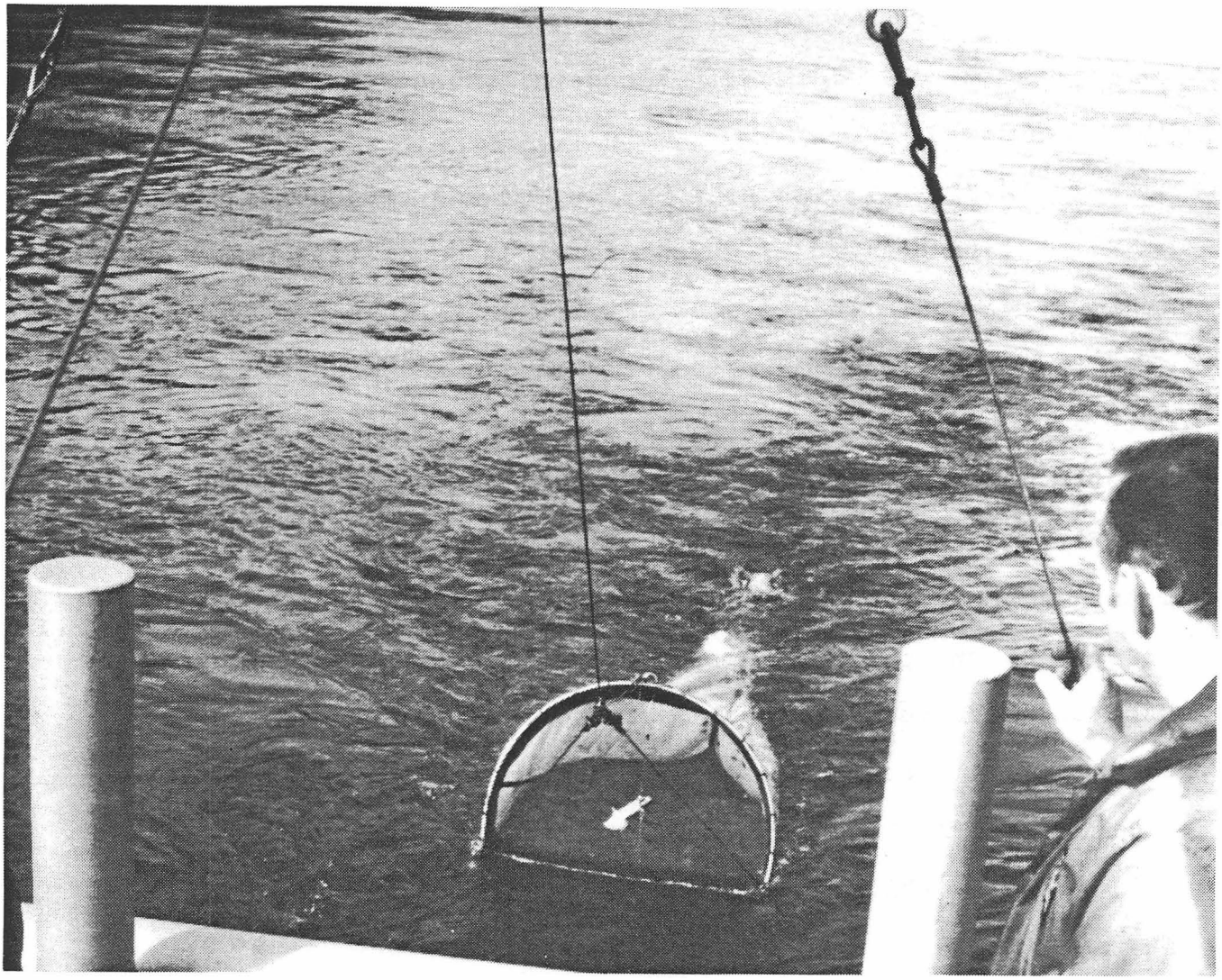

Figure 10.--Plankton net used in collecting white sturgeon eggs and larvae in the lower Columbia River.

The study was completed in 1992, and researchers arrived at the following conclusions:

1) White sturgeon spawning occurs in a limited reach of river downstream from Bonneville Dam, and larvae are dispersed throughout the lower Columbia River at least to River Kilometer (Rkm) 45 (Fig. 11).
2) Dams limit the movement of white sturgeon and have functionally isolated the populations in mainstem Columbia River reservoirs.
3) The status and dynamics of both impounded and unimpounded white sturgeon population are unique.
4) Productivity of white sturgeon populations is less in reservoirs than in the unimpounded area downstream from Bonneville Dam.
5) Recruitment and subsequent population size are limited by the effects of river discharge on spawning habitat, which is restricted to high-velocity areas immediately downstream from each dam.
6) Reservoirs provide large areas of suitable habitat for juvenile and adult white sturgeon, but compensatory population responses may reduce productivity if carrying capacity is exceeded (Fig. 12).
7) Fisheries for white sturgeon have recently declined in The Dalles and John Day impoundments; however, population collapse is likely if present exploitation rates continue.

The following recommendations were made, based on the first segment of the study: intensify management of white sturgeon in

Figure 11.--White sturgeon larva from the lower Columbia River, the river's only reach where all life stages are commonly found.

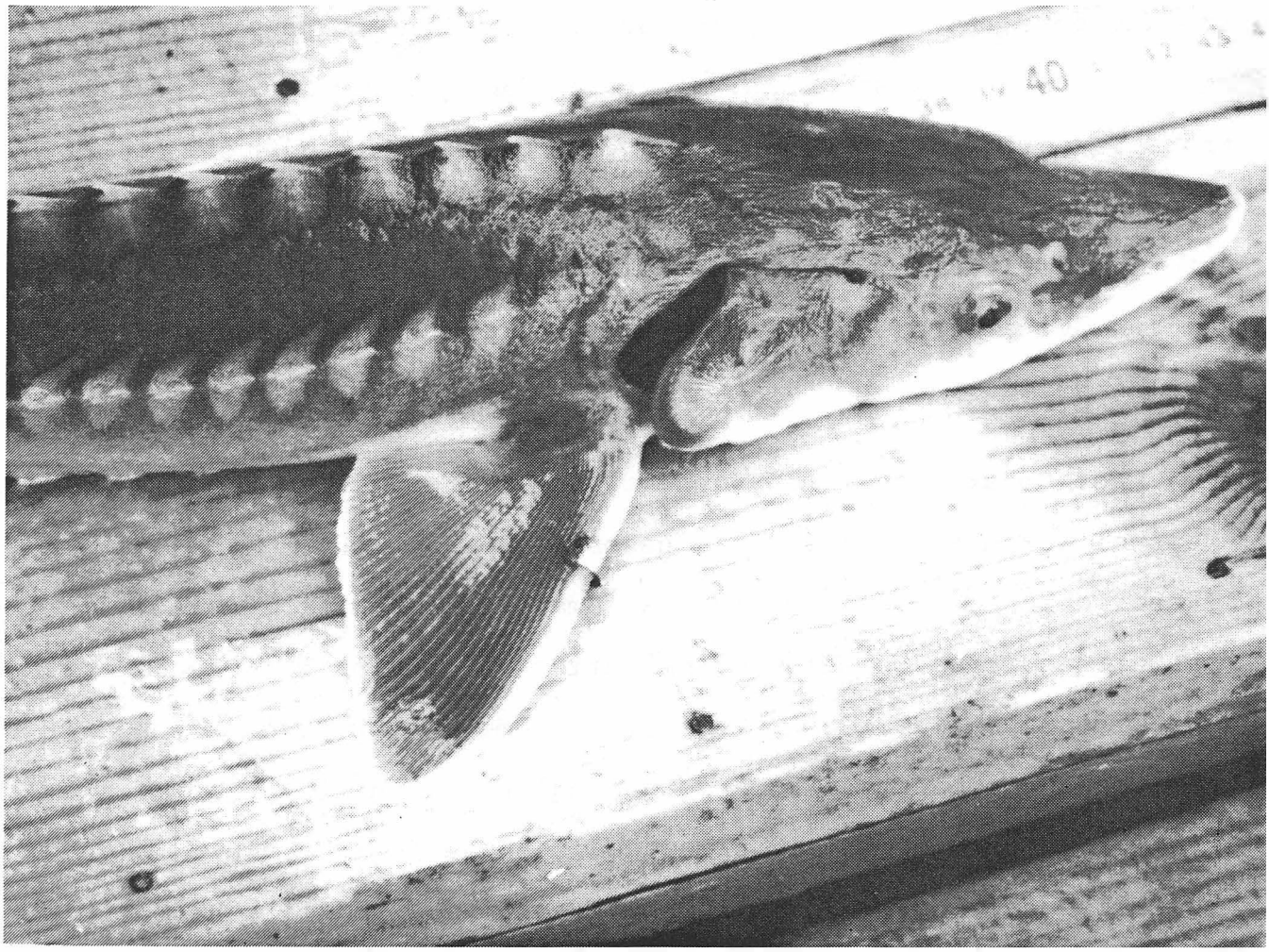

Figure 12.--A juvenile white sturgeon tagged with a bird-band tag placed around the anterior ray of the right pectoral fin.

impoundments; evaluate spawning and recruitment with augmented river flows in May and June; evaluate the feasibility of transplanting juvenile white sturgeon upstream to enhance impounded populations; identify habitat requirements and the extent of suitable habitat for subadult and adult white sturgeon; and investigate the need and methods to protect and enhance populations.

West Coast Estuarine Inventory--In cooperation with NOAA's National Ocean Service's Ocean Assessment Division, the Habitat Investigations Program compiled a summary database on living marine resources for selected estuaries of Washington, Oregon, and California (Table 2). This two-volume summary became the west coast component of NOAA's National Estuarine Inventory. The final inventory, which is presented in atlas form, reviews available data on the distribution, abundance, and life-history of 47 economically and ecologically important species from 32 west coast estuaries. The complete, computerized database will enable comparisons between species, groups of species, or specific life-stages, as well as comparisons between estuaries and geographic regions.

This inventory was a necessary step in providing documentation that will allow coordinated regional management. It provides a ready reference to key organisms and their distributions, and should direct researchers and managers toward areas where new data are required. Much more information is needed, even on temporal abundances, for many organisms included in the inventory. After completion of distribution data, details

Table 2.--Estuaries in the West Coast Living Marine Resources Inventory.

Washington	Oregon	California
Puget Sound	Columbia River	Klamath River
Hood Canal	Nehalem River	Humboldt Bay
Skagit Bay	Tillamook Bay	Eel River
Grays Harbor	Netarts River	Tomales Bay
Willapa Bay	Siletz River	Central San Francisco/
	Yaquina Bay	San Pablo/Suisun Bay
	Alsea River	South San Francisco Bay
	Siuslaw River	Elkhorn Slough
	Umpqua River	Morro Bay
	Coos Bay	Santa Monica Bay
	Rogue River	San Pedro Bay
		Alamitos Bay
		Anaheim Bay
		Newport Bay
		Mission Bay
		San Diego Bay
		Tijuana River

on physiology, ecology, and response to environmental stresses are the next most important considerations.

The inventory reflects much effort and thought in gathering vital unpublished data and "gray literature" from a variety of groups and individuals. This is especially true for the life-history stages that are dependent on estuaries. The ongoing research cited in this inventory will also be useful for clarifying and updating inventory information.

Impacts of Dredging and Dredged-Material Disposal

Columbia River Estuary Long-Term Management Strategy--Long-Term Management Strategy (LTMS) is a recent policy initiative of the COE. To meet their future needs, the Portland District COE will develop a 2-year LTMS program for maintaining the deep-draft channel in the Columbia River estuary. The program goal is to develop a 50-year operation and maintenance plan for dredging and dredged-material disposal in the estuary.

The Columbia River estuary is to serve as one of two national demonstration projects for the COE. The study area encompasses the 40-ft deep-draft navigation channel from RKm 7 to 45. At present, there are four estuarine disposal sites: Miller Sands, Rice Island, Pillar Rock Island, and Area D (an in-water disposal site). These sites receive approximately 2.2 million cubic yards of relatively clean sand from this reach annually (1983-1987 average). At the current rate of dredging, it is estimated that an additional island will be created from this material every 25 to 30 years.

Miller Sands is a 234-acre, horseshoe-shaped island located between Columbia RKm 34 and 40. It was first formed from dredged materials in 1932 (Fig. 13). Since then, dredged material has been deposited on the island about every 2.5 years. However, it is estimated that Miller Sands has a remaining disposal capacity of only 6-8 years.

In 1974, Miller Sands was one of six sites selected by the COE Waterways Experimental Station for testing the feasibility of developing marsh and upland habitats on dredged-material disposal sites. Habitat Investigations Program staff from the former Prescott Field Station inventoried and assessed pre- and postdisposal aquatic habitat development at Miller Sands from March 1975 to July 1977. This study found little influence by the created habitat on the predisposal aquatic biological community.

The staff conducted four field surveys of fish and benthic invertebrate communities at five locations in the Columbia River estuary (Miller Sands, Jim Crow Sands, Taylor Sands, Desdemona Sands, and Rice Island). The five areas surveyed in 1988-1989 were all productive estuarine habitats. Habitat Investigations researchers recommended a long-term (3-5 years) study to describe the natural fluctuations in population abundances in a given area prior to the initiation of further habitat modifications.

The results of such a study would provide a solid foundation of data from which to evaluate the environmental impacts of habitat modification. In 1991, the COE contracted with the Habitat Investigations Program to assess the aquatic biological

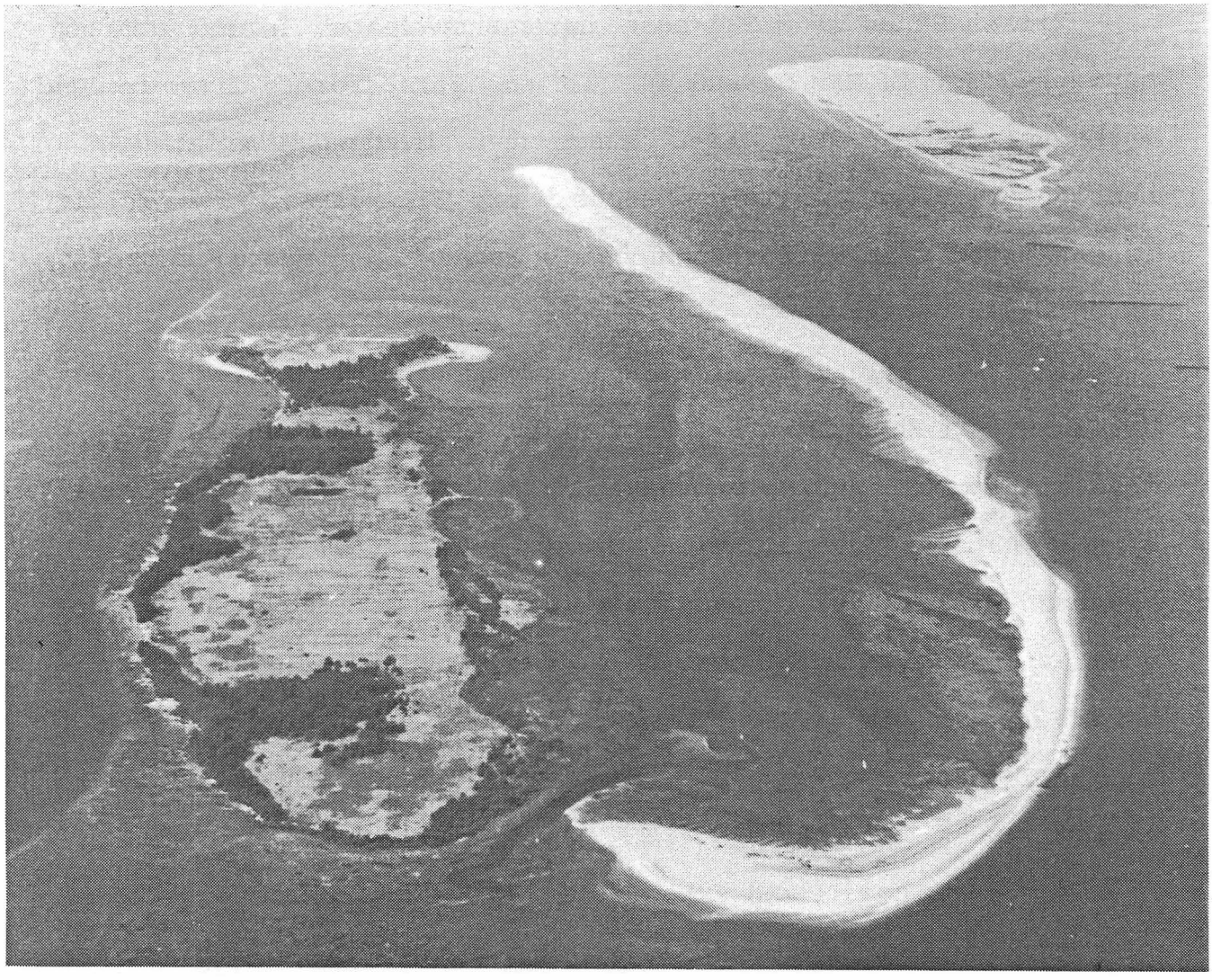

Figure 13.--Miller Sands, a 234-acre island in the Columbia River estuary, formed since 1932 from material dredged from the navigation channel.

communities just north of Rice Island and to continue monitoring the biological communities at Miller Sands. Results of the studies will be added to the long-term database for this area.

Dungeness crab--In September 1988, Habitat Investigations Program staff completed a 5-year study of Dungeness crab (*Cancer magister*) in or near frequently dredged areas of the Columbia River estuary. The study, in cooperation with the COE, was initiated primarily to investigate the impact of the 1984 deepening of the Columbia River entrance channel. Information was obtained about the estuarine and nearshore distribution, relative abundance, and size-class structure of Dungeness crabs (Fig. 14). The estuary is an important nursery area for juvenile crabs. Juvenile crabs are particularly vulnerable to hopper and pipeline dredging. Based on these studies, recommendations regarding optimum dredging seasons were made to minimize these harmful effects. Because of annual population fluctuations and the commercial and recreational values of Dungeness crab, NMFS is continuing this study with monthly surveys to develop a long-term database.

Tillamook Bay ocean dredged material disposal site--The Habitat Investigations Program staff and the Portland District COE cooperated in a study of the demersal fish and benthic invertebrate communities at four interim disposal sites along the Oregon coast, with one site offshore from Tillamook Bay, Oregon (Fig. 15). Two surveys (September 1984 and January 1985) showed that the demersal fish and benthic invertebrate population was

Figure 14.--Dungeness crabs are valuable commercial and recreational shellfish in the Columbia River estuary and on the adjacent coast.

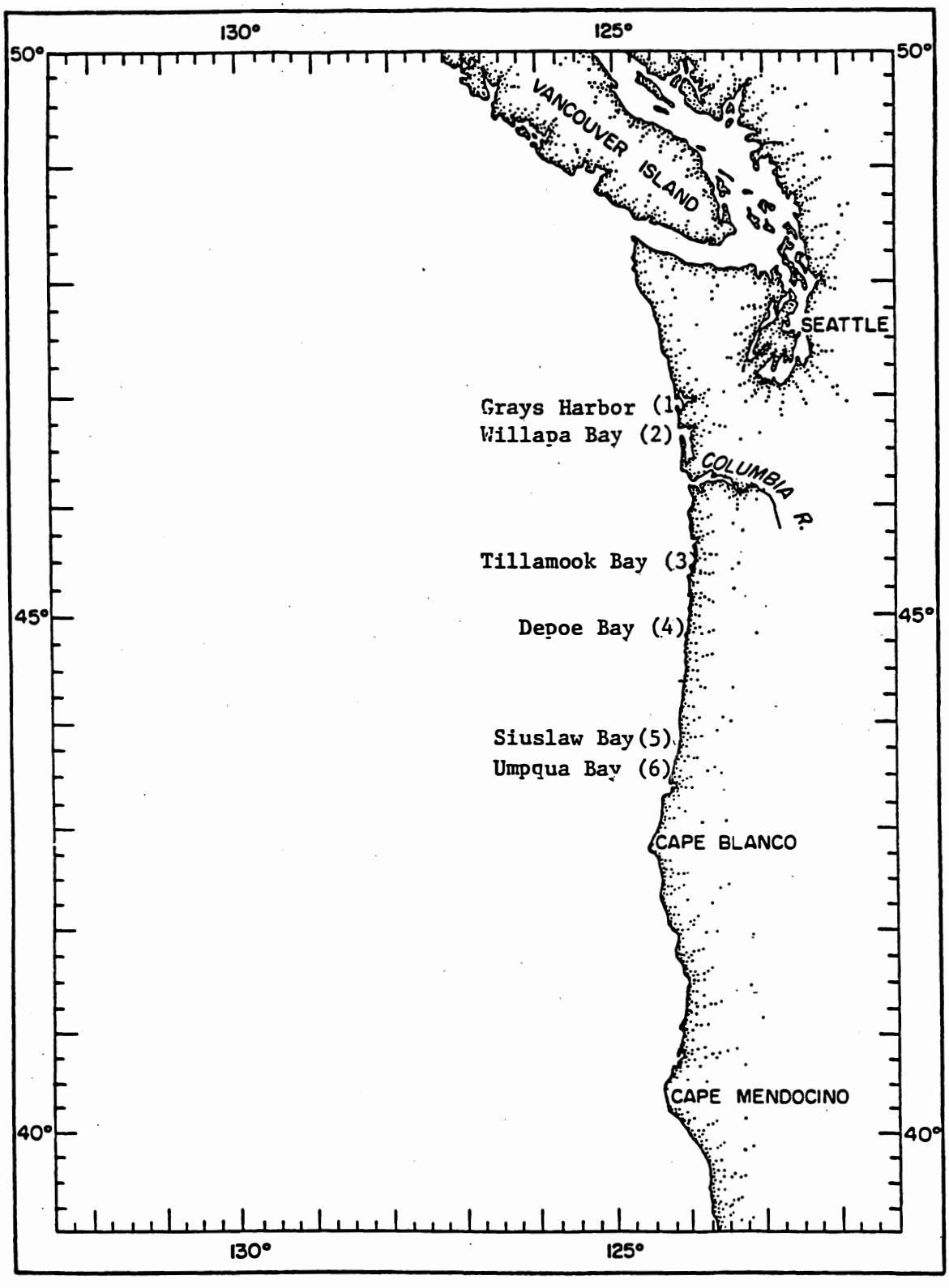

Figure 15.--Washington and Oregon coastal survey sites for interim dredge-disposal (1-4) and dredge-effects (5-6) areas.

greater at Tillamook Bay than at the other three sites, and this led to a third survey in July 1985. All three surveys suggested that very high densities of fishes, crabs, and benthic invertebrates occur annually at the Tillamook site.

The Tillamook offshore site has not received dredge spoils since 1977. It has recently been suggested that this site be used for the disposal of fine-grain material dredged from the federal portion of the bay entrance navigation channel. This proposal causes concern because of the presently high numbers of benthic invertebrates, and these concerns are magnified when disposal of suffocating, fine-grain material is considered.

The Portland District COE, accompanied by our program staff, conducted a sediment survey in May 1988. Sediments were collected along a transect extending offshore from the existing disposal site. Preliminary examination of the sediment samples indicated a reduction in benthic invertebrates 2.4 miles offshore at an approximate depth of 61 m. A fourth survey, conducted at the Tillamook offshore disposal site in September 1988, found lower benthic invertebrate densities at the deeper stations than at the interim site. However, densities may have been underestimated because of sampling problems associated with poor weather conditions.

To verify benthic invertebrate densities off Tillamook Bay, Habitat Investigations staff conducted a fifth survey during September 1990. This survey sampled all 34 benthic invertebrate stations and all 10 trawling stations.

The area off Tillamook Bay again had higher benthic invertebrate densities and species diversity than any area surveyed off the Oregon coast. Benthic invertebrate densities were highest at two stations within the interim disposal site, but densities farther offshore in deeper water were also high.

Few nearshore areas off the Oregon coast have been intensively sampled by bottom trawl. Therefore, it is somewhat difficult to assess the relative value of the area off Tillamook Bay with regard to the life histories of fish and large epibenthic invertebrate species. However, it is clear that this area supports high densities of a variety of fish and decapod species.

When survey data is better established, it would be useful to identify the physical and biological mechanisms that allowed development of such an unusually dense and diverse benthic invertebrate community, and to link those mechanisms to the high numbers of fish in the area. Primary production from Tillamook Bay may contribute significantly to the food chain of this nearshore ocean area, and the abundant food chain may serve as the support for this large and diverse biological community.

Coos Bay, Oregon navigation channel, and ocean dredged-material disposal site--In 1989 Habitat Investigations Program staff conducted a preliminary biological survey in a cooperative agreement with the coe. The COE initiated this work to determine the need for a comprehensive biological assessment of the area impacted by the deepening of the Coos Bay navigation channel. A comprehensive survey for a minimum of four seasons

was recommended. This survey is to be conducted before dredging begins, with follow-up surveys after dredging.

In April and October 1992, Habitat Investigations staff conducted biological surveys at the present disposal site and two possible expansion sites. Their final report is pending.

Columbia River ocean dredged material disposal Site F--In 1989, the COE agreed to assist in deepening navigational channels to the Tongue Point finger piers (Astoria, Oregon) and to a nearby turning basin for commercial vessels. The COE estimated that about 2.0-2.8 million yd^3 of material would be removed from the area with a clamshell dredge. The material was to be removed from July to October 1989 and dumped at Site F, which is located offshore from the mouth of the Columbia River.

Because of concerns about the potential impacts of dredged material on Dungeness crabs and demersal fishes, both of which support important local fisheries, COE and Habitat Investigations staff agreed to cooperate in environmental studies of the disposal site and its adjacent areas. A predisposal survey (June 1989) and three postdisposal surveys (June 1990, 1991, and 1992) were done to evaluate the effects of dredged material on the biological community; specifically, benthic and large epibenthic invertebrates and demersal fishes.

Passage Survival of Juvenile Salmonids at Bonneville Dam

In 1987, the Habitat Investigations staff and the Portland District COE began a multiyear study to evaluate survival of 0-age chinook salmon passing through the Second Powerhouse

turbines, juvenile bypass system, and spillway at Bonneville Dam. In 1992, a related study began, which included evaluations of the First Powerhouse bypass and turbines, as well as the Second Powerhouse turbines. Nearly two million fish in groups of 20,000 or 30,000 were coded-wire tagged (CWT) and freeze branded, and released at various sites above and below the dam during June and July. Unfortunately, flows were not high enough in 1987-1988 to provide for assessment of spillway passage survival, but survival tests were repeated in 1989.

Results were assessed by comparing percentages of treatment-group brands recovered at Jones Beach (Columbia River estuary, RKm 47) in the year of release. Long-term survival is assessed by similar comparisons of CWTs from returning adults recovered by on-going state and federal fishery programs.

At the Second Powerhouse, during the first 3 years of this study, the highest recovery percentages were those observed from the spillway and downstream release groups, with 0.93 and 0.89% estimated survival to Jones Beach. By comparison, recovery percentages for upper and lower turbine, bypass, and frontroll release groups were 0.81, 0.81, 0.78, and 0.84% respectively. Surprisingly, the recovery of bypassed fish was statistically lower than that of fish released into the turbines. Mortality in marked fish released at a shore site downstream from the dam was also greater than expected. This was cause for concern, since this site has been used frequently for several years to release transported fish collected from upstream Columbia and Snake River collection facilities.

In 1992, investigations at Bonneville Dam First Powerhouse indicated that relative survival of subyearling juvenile chinook salmon was significantly lower for fish passing through the bypass system than for those passing through turbines. Fish passing through a Second Powerhouse turbine and tailrace had slightly greater survival than those passing through the First Powerhouse bypass system and tailrace, but this difference was not statistically significant.

Tagged recoveries of returning adults will be the final assessment criterion, but preliminary recovery data from Jones Beach indicated two potentially serious problems in fish passage through and near Bonneville Dam.

Evaluation of the bypass system at Bonneville Dam--Results of passage survival tests at Bonneville Dam from 1987 to 1992 suggested little or no benefit for outmigrating juvenile salmonids diverted to the bypassed systems. This unexpected finding prompted a change in research direction to assess the detrimental impacts for fish using the bypass system.

An examination of the physical features of the bypass system by NMFS and the COE did not reveal any obvious problems. Therefore, we examined other potential causes of mortality. Water velocities adjacent to the bypass terminus varied from 1 to 1.6 m/second, and these velocities were thought to be too fast to allow predation by northern squawfish. Purse seining at the bypass outlet produced little evidence of injury or mortality to salmonids, although insufficient fish were recovered to allow accurate assessment. In 1990, research was begun using a

trap-net recovery system to assess the physical condition of outmigrants following passage through the bypass system.

At the Second Powerhouse bypass system, hatchery fish showed no evidence of injury from passage, but run-of-the-river fish showed high blood levels of cortisol, indicating stress and possible fatigue related to passage through the bypass system. Other researchers found high densities of northern squawfish near the outlets of the bypass systems and evidence of heavy predation.

We speculate that the apparent stress and fatigue of passage through the bypass system diminished the predator avoidance capabilities of juvenile salmonids. This likely results in higher predation rates than for fish using other passage routes. Evaluation of physical effects of bypass passage is expected to be completed soon. The COE, assisted by the regional fisheries agencies, is planning to alter the outlet locations of the bypass systems to provide a more predator-free environment for juvenile salmonids.

Effectiveness of predator removal--Habitat Investigations staff completed a 3-year study to evaluate the effectiveness of predator removal and use of alternate release sites for protecting juvenile chinook salmon released from Bonneville Hatchery. The northern squawfish is a voracious predator on outmigrating juvenile salmonids, and numerous efforts by various agencies are underway to reduce or control northern squawfish populations.

Pairs of marked groups of juvenile chinook salmon were released from the hatchery, either into Tanner Creek (the normal release site) or into the midstream Columbia River. Releases were made before and after 4 days of intense electrofishing to remove northern squawfish from the confluence of Tanner Creek and the Columbia River. Recovery percentages from collections made downstream at Jones Beach were higher for midstream-released fish than for releases into Tanner Creek in all cases. The difference in recovery percentages for the second pair of marked groups (following northern squawfish removal) was smaller than that observed for the first pair of groups. This indicated some benefit from localized northern squawfish removal.

Northern squawfish in lower Columbia River tributaries--Program staff surveyed numerous lower Columbia River tributaries to determine the abundance and distribution of northern squawfish. The goal was to determine whether northern squawfish from the mainstem Columbia River move into tributaries to spawn, and if they prey on hatchery-released salmon smolts.

Northern squawfish were found congregating in tributaries above brackish water, principally for spawning. In tributaries with salmonid hatcheries, northern squawfish fed opportunistically on hatchery-released salmonids. In other tributaries, they fed on crayfish. Limited mark-recapture information indicated that northern squawfish migrate into tributaries from the mainstem Columbia River, and return after spawning.

Nitrogen studies--Beginning in 1993, the Habitat Investigations Program began an evaluation of the effects of dissolved gas supersaturation on migrating juvenile salmonids and aquatic biota in the Columbia River downstream from Bonneville Dam. Approximately 50% of the sampling for this study was conducted concurrently with a juvenile salmonid stranding study. The remainder was conducted independently to evaluate effects of dissolved gas supersaturation on juvenile salmonids, resident fish species, and resident invertebrates. Dissolved gas measurements for each sampling location were collected using a tensiometer.

The results indicated that, within the limits of the study area, sampling gear, and sampling locations, low incidence of gas bubble disease symptoms occurred in 6 of the 19 species examined. Mild gas bubble disease symptoms were observed in less than 1% of juvenile chinook salmon and peamouth, in 3% of juvenile coho salmon, and in 2% of juvenile steelhead collected. Moderate-to-severe gas bubble disease symptoms were observed in less than 1% of sticklebacks and prickly sculpins collected. Additional studies are required to establish baseline data, and future efforts will evaluate effects of gas supersaturation throughout the lower Snake and Columbia Rivers.

Field Facilities and Vessels

Hammond, Oregon (RKm 14)

CZES Division's field staff were stationed at Hammond, OR, just west of Astoria, in response to increased responsibilities resulting from government-mandated environmental research. The

Point Adams Biological Field Station (Fig. 16) is a former Coast Guard Rescue station, located on the waterfront and ideally suited for estuarine and coastal studies. The main building is sound and solidly built, and although it dates from the 1930s and was not designed as a research facility, the building provides excellent service. Together with the main building, there is a garage/shop, a storage building, and a fourth building, which will eventually be converted into a bioassay laboratory with flow-through fresh water/seawater. We are presently using this fourth building as a wet lab, which required a minimum amount of refurbishing and cost.

There are no onsite structures for vessel moorage, so the station's smaller vessels are kept at the Hammond boat basin, about 1 km to the west, where the main shop and warehouse are also located. The largest vessel, the *Sea Otter*, is moored at the Warrenton boat basin, approximately 6 km to the east.

Clatskanie, Oregon (RKm 75)

The Clatskanie Field Station consists of several portable buildings on leased property at Jones Beach. After extensive exploratory sampling on both Oregon and Washington shores, Jones Beach was chosen in 1968 as the principal location for capturing downstream migrant salmonids entering the estuary. The constricted site permits effective and optimal sampling by beach- and purse-seines of an estimated 0.1-0.6% of all salmonids migrating from the upriver basin. Operations began at Jones Beach in 1966 and, except for the periods from 1973 to 1976 and 1984 to 1986, sampling has been continuous during all spring

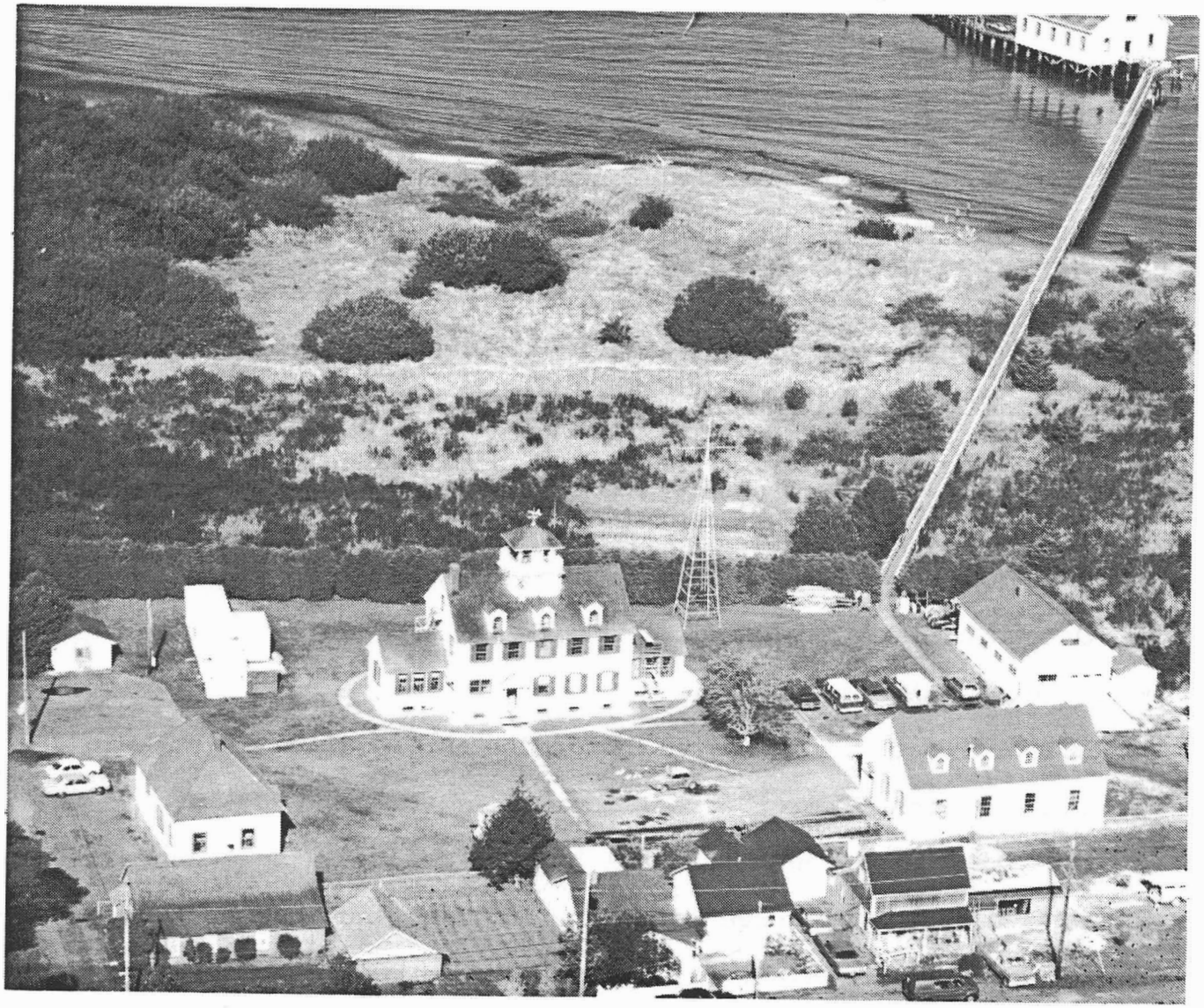

Figure 16.--CZES Point Adams Biological Station (Hammond, Oregon), former Point Adams U.S. Coast Guard Rescue Station.

outmigrations. The Clatskanie facilities are also used shared with other agencies during cooperative studies.

Research Vessels

Our principal vessel is the 57-ft *Sea Otter* (Fig. 17). Built in 1975, her present capabilities are trawling (8-m shrimp trawl), benthic sampling (box corer, epibenthic sled, etc.), plankton towing, and water sampling. Two large hydraulic winches will soon replace her single small winch to increase trawling capabilities to the commercial-sized nets (two 8-m trawls). Electronic equipment includes VHF and single side-band radios, 24-mile radar, Loran-C, RDF, and depth sounders. Cruising range is 1,000 miles, and a minimum sampling crew of four is required. *Sea Otter* is primarily used for studies on the Columbia River mouth and ocean/coastal studies.

Other vessels include the *Columbia* (Fig. 18), a 36-ft twin gasoline-powered fiberglass hull built in 1977; and *Nerka*, a 40-ft, twin diesel-powered, steel hull. The *Nerka* is a converted Coast Guard utility/rescue boat, and is fast, but due to her narrow beam she is relatively unsuitable for nearshore ocean studies. Therefore, she is used for Columbia inriver and estuarine studies. *Columbia* has a more stable work platform and has been used for purse-seine studies in the nearshore surf zone, but she is generally too small for offshore work.

Capabilities of the *Nerka* and *Columbia* are trawling, purse seining, pot fishing, and benthic/epibenthic sampling. Electronic equipment includes VHF radios, depth sounders, and radars. Crew requirements are two to four depending upon

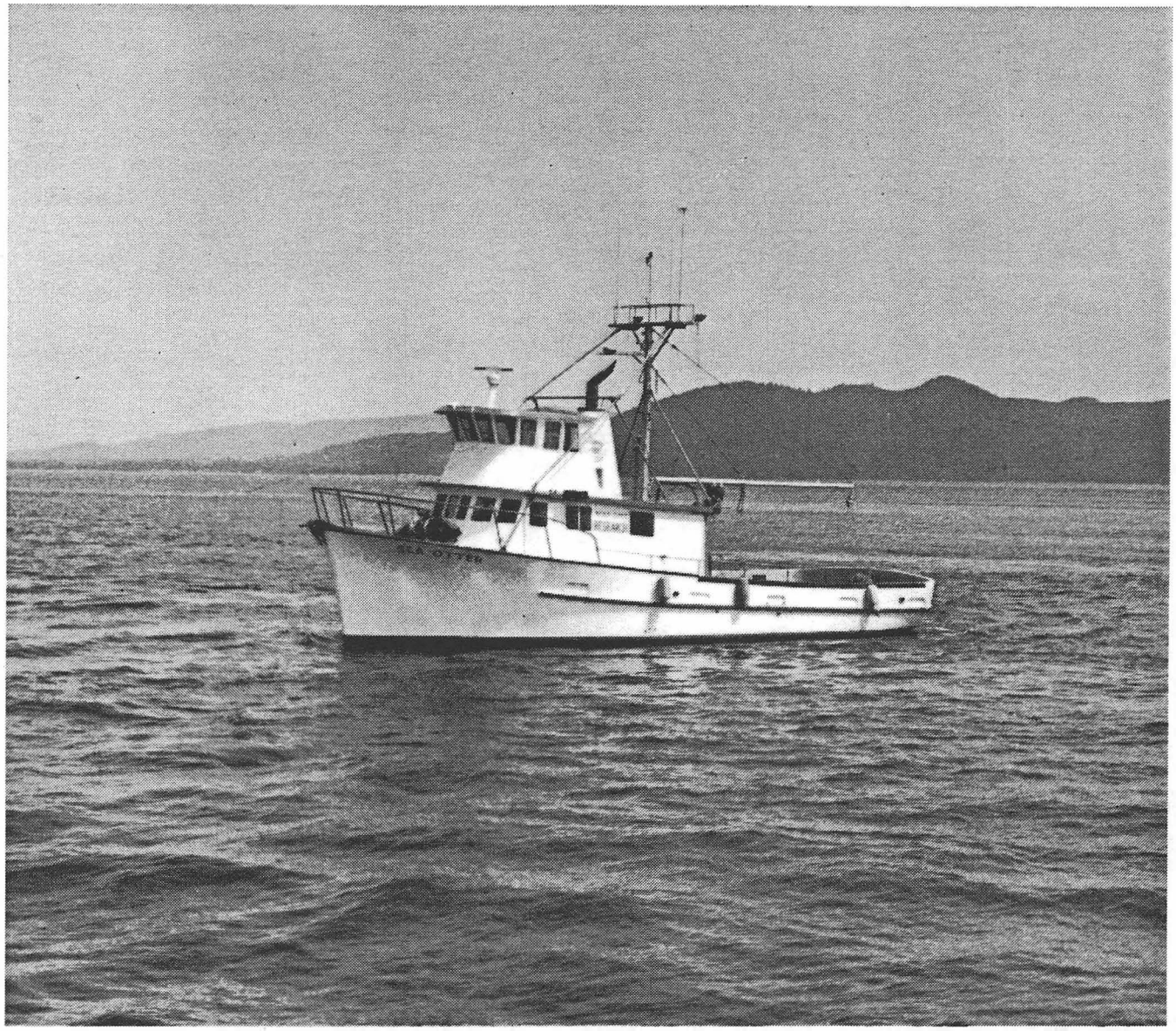

Figure 17.--Habitat Investigations Task's 57-foot Sea Otter, used primarily for fisheries-resource impact studies along the Washington and Oregon coasts.

Figure 18.--The 36-foot Columbia, used mainly for purse-seining in the Columbia River estuary.

project. The Clatskanie Field Station also has two 26-ft, inboard-outboard, purse-seine barges and four outboard-powered dories from 18 to 22 ft. The Point Adams Biological Field Station has two 17-ft Boston Whalers and a 23-ft inboard-outboard dory.

Future Projects

There are several research areas that may logically and fruitfully be expanded or intensified. Most potential projects are tied to outside funding and therefore the likelihood of developing any particular project is uncertain. Program efforts in the next 2-3 years will focus on projects that apply directly or indirectly to high-priority regional issues, such as the following:

1) The ecology and survival of juvenile salmonids in the critical transition from fresh water to the marine environment.
2) Seasonal ecosystem studies within the Columbia River estuary.
3) Effects of specific dredging activities in the Columbia River.
4) Seasonal ecosystem studies at coastal dredged-material disposal sites.
5) The survival of juvenile salmon using known passage routes at hydroelectric dams.

The Habitat Investigations Program will also encourage development of, and solicit funding for, the following research projects:

1) Study of juvenile salmonids in the Columbia River estuary to provide early evaluations and more precise interpretations of experimental hatchery releases and to monitor smolt quality and incidence of disease.
2) Establish a long-term habitat database for the lower Columbia River, the Columbia River estuary, and the marine waters adjacent to the Columbia River.
3) Investigate the effects of dredging and commercial trawling on coastal Dungeness crab populations.
4) Study the anchovy population off the Columbia River and its relationship to salmonid survival and growth.
5) Study the lingcod population off Grays Harbor.
6) Evaluate the extent of industrially polluted sediments in the Columbia River.
7) Investigate the effects on production of trace inorganic and organic pollutants in salmonid hatchery water.
8) Conduct limnological investigations of selected reservoirs on the lower Columbia and Snake Rivers.

FISHERIES ENHANCEMENT PROGRAM

Background

The goals of the Fisheries Enhancement Program are to develop and test methods for restoring and enhancing depressed salmon runs, including those of species listed by the NMFS as threatened or endangered. These depressed salmon runs migrate across a complex of international, federal, and state-managed jurisdictions. This interjurisdictional migration necessitates a strong federal role, and several federal legislative acts and treaties mandate NMFS participation in fisheries enhancement activities. These mandates were also expressed by the congressional authority that established the Columbia River Development Program (CRDP). The CRDP is mandated by the Endangered Species Act (ESA) and by the Mitchell Act, which funds the majority of hatcheries on the Columbia River system. These federally funded hatcheries currently release about 110 million chinook and coho salmon and steelhead smolts per year.

Our research programs are aimed at developing new information to enhance anadromous salmon runs. One strategy toward this goal is to improve operational efficiency and adult contribution of federally funded public hatcheries. A second strategy is to develop husbandry techniques for maintenance and restoration of severely depleted wild runs.

Recent Accomplishments

Physiology

Research conducted by Fisheries Enhancement physiologists is applied toward improved productivity in mitigation hatcheries and improved techniques for rearing adults in captive broodstock programs. Fundamental research focuses on the endocrine physiology of juvenile development, and the growth physiological and morphological indicators of reproduction.

Improved productivity of mitigation hatcheries--Hatchery enhancement of salmon and steelhead is a major part of regional salmonid management strategy: hatcheries produce more than one-half of the salmon caught in Washington, Oregon, and California. However, a 20-year decline in survival of Columbia River chinook and coho salmon has generated many questions about changes in ocean productivity, quality of riverine and estuarine habitat, and hatchery smolt quality.

Increased hatchery releases in recent years have not resulted in increased harvest. Improved efficiency in these public-sector hatcheries is considered by many to be the most economical means of improving the contribution of returning adults to ocean and river fisheries. Release of juveniles better fitted for marine survival can produce the same or better results than increasing production through new hatchery construction, and at lower cost.

The Fisheries Enhancement Program is developing methods for production of quality smolts that will migrate more rapidly downriver, adjust quickly to the ocean environment, and survive

better at sea. Research is based on the premise that fishery enhancement should not be accomplished at the cost of lower contribution of wild or naturally-reared fish in streams and rivers in the area of enhancement. Accordingly, a recently established research goal is to determine the interaction between hatchery and wild salmon.

Specific objectives are to develop accurate physiological measures of smolt development in hatchery and wild fish. These physiological measures can be used to determine environmental/husbandry factors affecting smoltification and to develop low-cost methods to control the smoltification timing of hatchery fish. These and other new rearing/release strategies will improve the contribution of adults to the fisheries.

When fully developed, these new methods will allow federal and state managers to optimize the release time of hatchery fish and minimize the inheritable adverse effects of hatchery fish on wild fish. Techniques for altering and optimizing the release of smolts will allow management agencies to program releases that coincide with or avoid environmental events in the river, estuary, and ocean. For example, releases could be scheduled to avoid periods of low flow at Columbia River hydroelectric dams, to coincide with periods of high ocean productivity or to avoid overloading the river with a massive single pulse of outmigrants from hatcheries.

Reproductive physiology of salmonids--Reproductive physiology studies investigate the endocrine mechanisms involved in controlling reproduction in salmon. Controlled reproduction

is essential to the artificial manipulation of sexual maturation in captive broodstocks. With present captive rearing efforts, there are substantial problems associated with the timing of puberty and sexual maturation, prespawning mortality, and reliable production of high quality gametes. Methods to regulate sexual maturation in captive salmon could make culture of a variety of fish species more cost-effective by substantially increasing the yield of offspring from broodstock. These methods could simplify broodstock management programs and prevent prespawning mortalities due to precocious sexual maturation.

These techniques require a basic understanding of the physiological mechanisms involved in regulating the onset of sexual maturation (puberty), including the maintenance of gametogenesis and the initiation of final gamete maturation in fish. Therefore, we are currently conducting both basic and applied studies on endocrine control of salmon reproduction.

Our basic research in regulating reproduction focuses on pituitary gonadotropins because of their key role in regulating gametogenesis. Our applied research focuses on preventing precocious male maturation and developing methods for controlling reproduction in captive broodstocks. We are also trying to develop nondestructive techniques for evaluating sexual maturation in captive salmon. These techniques will help find early indicators of reproductive maturation so that maturation rates can be determined eight to nine months before the spawning season. This biotechnology will be applied to both aquaculture and captive broodstock programs.

Smolt indices and patterns of smolt development--One of our primary objectives is to relate measurements of smolt development (indices) in hatchery fish to fish husbandry techniques and ultimately to post-release performance. We have observed patterns in physiological indices, such as blood levels of developmental hormones, gill enzyme activity levels, and body morphology, that suggest a relationship between smolt quality and growth rate in spring chinook salmon. Faster-growing fish repeatedly show greater changes in smolt development indices while slower-growing fish reflect less movement in these same indices. These correlations are being tested in the laboratory to establish causality.

We have also found relatively consistent differences in smolt development indices among chinook salmon from five different hatcheries in the Columbia River Basin. This implies that the developmental characteristics of fish at these hatcheries may duffer due to husbandry practices. These practices should be experimentally altered to influence the timing and quality of smolts produced.

In addition to comparisons of smolts from different hatcheries, we have begun baseline work for investigating the interaction between hatchery and wild smolts. Sampling sites and methods have been established for a study of wild spring chinook salmon in the Yakima River Basin of Washington.

Developmental physiology and endocrinology of smoltification--We have observed springtime increases in messenger RNA (mRNA), which is used for biosynthesis of the

insulin-like growth factor (IGF-I), in adult coho salmon. These increases in IGF-I were higher in rapidly growing fish and were inversely proportional to changes in blood concentrations of pituitary growth hormone. This implies that IGF-I plays a major role in growth regulation and seasonal changes in growth rate. Furthermore, slow or abnormal growth of coho salmon may be due to growth hormone resistance.

To analyze these observations, we first determined the sequence of complementary DNA (cDNA) for IGF-I in salmon. Salmon cDNA was then cloned and inserted into bacteria, which produced biologically active recombinant salmon IGF-I.

To measure IDF-I messenger RNA (mRNA) in salmon tissues, we developed a solution-hybridization/RNAse protection assay. To measure. To measure levels of IGF-I in salmon blood. We found that liver production of mRNA for IGF-I increases during smoltification in coho salmon in fresh water. This suggests that IGF-I plays a role in the accelerated growth coincident with smoltification.

We also developed a radioimmunoassay for salmon thyroid stimulating hormone (TSH) of the pituitary gland. This assay will be used to study the role of pituitary stimulation of the thyroid during smoltification of juvenile salmon. Change in blood levels of the thyroid hormone, thyroxine, is already an established index of smoltification. Therefore, accurate measurement of TSH in blood during smoltification may yield a more precise index.

In related observations, we found that during their first summer Atlantic salmon in seawater have reduced capacity for storage of liver glycogen, but not muscle glycogen. Reduced levels of liver glycogen make fish more susceptible to stress-induced mortality. Depressed liver glycogen may be a contributing factor to the summer kill" phenomenon in Atlantic salmon.

Regulation of synthesis and secretion of gonadotropin hormones (GTH)--To develop methods for regulating reproduction in salmon, it is necessary to understand the factors regulating synthesis and secretion of the gonadotropins. Gonadotropins are regulated primarily by brain peptides and feedback of gonadal steroids.

Using both whole animal and cell culture experiments, we found that gonadotropin-releasing hormones stimulates secretion of both GTH I and GTH II. However, these secretions vary according to the stage of reproduction. We also found that testosterone stimulates synthesis of GTH II but inhibits secretion of GTH I. We are now investigating other neuropeptides that are involved in regulating GTH I and GTH II secretion.

One of our most important objectives is to determine what regulates synthesis of GTH I, since it is a key hormone in the initiation of gonadal growth and maturation. In a collaborative study with Dr. Niall Bromage at the University of Sterling, we found that secretion of GTH I in rainbow trout can be altered by photoperiod. In addition, we are initiating studies on the genetic regulation of GTH I and GTH II.

Physiological functions of salmon gonadotropins--We have purified coho salmon gonadotropin hormones I and II (GTH I and GTH II) and developed radioimmunoassays to quantify levels of these hormones in the blood. Application of these assays showed that during the phase of ovarian and testicular growth, plasma levels of GTH I increase, while GTH II is not detectable. However, prior to ovulation and spermiation, GTH II levels increase while GTH I levels decline.

Since plasma GTH I levels increase only in maturing fish 9 months in advance of spawning, we now have a marker for determining which fish are maturing in a given population.

We found that GTH I stimulates production of ovarian estradiol, testosterone, and testicular androgen throughout gametogenesis. However, during late phases of gametogenesis, GTH II regulates production of maturation-inducing steroids. In a collaborative study with Dr. Charles Tyler at Brunel University, we found that GTH I also functions to stimulate incorporation of yolk proteins into the oocyte during vitellogenesis. These results have been key to our applied work on the regulation of reproduction, since we now know that to manipulate early phases of maturation, we must be able to regulate synthesis and secretion of GTH I. In addition, GTH II must be regulated to control ovulation and spermiation.

Hormonal induction of spawning by gonadotropin-releasing hormone--Although pituitary extracts or gonadotropin-releasing hormone analogues (GnRHa) have been widely used to induce ovulation or spermiation in salmonids, a number of problems

persist with these techniques. These problems range from inappropriate timing of hormone administration to poor quality of hormone preparations.

In a collaborative study with Dr. Yonathan Zohar of the University of Maryland Center of Marine Biotechnology, we tested experimental devices that release controlled amounts of GnRHa for induction of ovulation and spermiation. A variety of species were tested, including sockeye salmon, coho salmon, Atlantic salmon, and rainbow trout. We characterized both biodegradable microspheres and non-biodegradable implants for their effects on the timing of ovulation/spermiation and quality of the gametes. Our techniques are now being utilized to synchronize spawning in male and female fish and to advance spawning in captive broodstock. We have been able to advance spawning by 45 days in coho salmon.

One important use of this technology will be to obtain gametes from endangered fish species. During 1992, only one male Redfish Lake sockeye salmon returned, and problems were encountered with inadequate milt production. We were very concerned the fish would die in captivity before sperm could be collected for cyropreservation. A GnRH implant was successfully used to induce spermiation and increase milt production.

We are now prepared to utilize this technology when necessary to overcome future problems with recovering gametes from endangered fish or other captive broodstock fish. Our present and future efforts are directed toward inhibiting

precocious reproductive maturation using antagonists of GnRH that could be administered with the biodegradable microspheres.

Somatolactin--We have developed assays to measure blood levels of a newly discovered pituitary hormone, somatolactin (SL). We found that blood levels of this hormone also increase during reproductive maturation. In vitro tests show that SL may stimulate production of reproductive steroids, although SL is much less potent than pituitary gonadotropins.

Stock Restoration

Restoration research for Pacific salmon centers around the development of fish husbandry techniques that aid in recovery of depleted stocks. The need for this research was heightened with the recent listing by NMFS of Snake River salmon for protection under the ESA. Stock Restoration activities include development of captive broodstock technology, development of fish culture techniques to produce "wild-like" fish from hatcheries, and supplementation research.

Captive broodstock studies--Since 1979, the Stock Restoration Program has worked with broodstock egg production for restoration of runs of Atlantic and Pacific salmon. One of the major barriers to restoration of depleted stocks of Pacific salmon is the availability of sufficient numbers of juveniles for supplementation (outplanting). Because of the moderately high fecundity of salmon, full life-cycle captive rearing affords the opportunity to produce a large number of juveniles in a single generation. However, broodstock technology for recovery of

endangered species of Pacific salmon is essentially in its infancy.

In most cases, only a portion of the remaining population can be reared in captivity. Therefore, we need to develop fish culture methods that ensure that offspring of a captive broodstock are indistinguishable from their wild cohorts in appearance, physiology, behavior, and genetic diversity. The Fisheries Enhancement Program has undertaken a BPA-funded assessment of captive broodstock technology to provide managers with guidelines to develop these research priorities and implement captive broodstocks.

The Fisheries Enhancement Program also has a long-term stock restoration project to determine optimal rearing strategies for captive broodstocks. Experiments are being conducted to compare the effects of freshwater vs. seawater rearing and to document the smolt physiology of progeny reared under the two scenarios.

Evidence suggests little difference in survival or offspring quality between fish reared in fresh water and seawater. However, our experience suggests that elaborate precautions, including filter and sterilization of rearing water, may be required to safeguard endangered species of Pacific salmon reared in seawater.

This research will allow fish culture strategies to be evaluated prior to incorporating the technology in species recovery plans, thus providing maximum safeguards for protection of depressed and endangered gene pools.

Endangered Redfish Lake sockeye salmon captive broodstock-- The Fisheries Enhancement Program is rearing endangered Snake River sockeye salmon in a multiagency captive broodstock project funded by the BPA. The NMFS listed Snake River sockeye salmon under ESA by the NMFS in December 1991 after a single adult female and three adult male sockeye salmon returned to spawn in Redfish Lake. Approximately one-half of the progeny of these fish are being reared by NMFS, with the remainder being reared by Idaho Department of Fish and Game.

Genetic strategies of captive broodstock sourcing were not a concern for the Redfish Lake sockeye salmon captive broodstock project because all returning adults from the anadromous gene pool were captured. Maintaining geographically separate captive brood populations was considered necessary to reduce the risk of catastrophic loss due to mechanical failure, human error, or disease.

Over 725 endangered Redfish Lake sockeye salmon juveniles are in protective culture at a NWFSC facility. This represents about 75% survival during the first 20 months of rearing and assures that sufficient juveniles will be available to aid recovery of the species.

Finally, Fisheries Enhancement Program scientists are members of the multiagency Oversight Committee that is coordinating recovery efforts for Snake River sockeye salmon. They are providing expertise regarding optimal supplementation strategies for release of these fish to their natal areas.

NATURES studies--In 1991, the Fisheries Enhancement Program began a BPA-funded study to develop a Natural Rearing Enhancement System (NATURES). The system is intended to produce "wild-type" Pacific salmon from hatcheries. This research was initiated in response to growing concern in the fisheries community that poor-quality hatchery smolts are not only less likely to survive than their wild counterparts, but they may also have a negative impact on the survival of wild fish. The underlying paradigm is that rearing fish in a naturalistic environment will increase post-release survival by decreasing stress, reducing domestication, and better acclimating fish to their post-release environment.

During the pilot phase of the NATURES study, we examined the concept that rearing fish in semi-natural habitats may make them more wild-like. Fall chinook salmon were reared in four barren conventional and eight naturalistic raceways with overhead cover, instream structures (aquatic plants), and natural substrates (sand or gravel). Naturalistically reared fish were more cryptically colored and had 50% higher post-release survival than their conventionally reared counterparts.

The NATURES program also investigated the use of live-food supplementation to increase the post-release foraging efficiency of hatchery-reared fall chinook salmon. Fry were reared on either a standard commercial pellet diet or a pellet diet supplemented with live prey, such as mosquito larvae, chironomids, and daphnia. In foraging trials, fish trained with live food ate twice as many familiar prey (chironomids) and novel prey (mayfly larvae) as untrained fish. This suggested that

live-food supplementation can be effective in increasing the post-release foraging ability of hatchery-reared salmon.

Information from individual NATURES research projects and literature reviews is being incorporated into a biospecification document that will guide state, tribal, and federal fish-supplementation research.

Yakima River Basin sockeye salmon restoration studies--Construction of irrigation dams without fish passage facilities resulted in the extirpation of sockeye salmon from the Yakima River Basin in the early 1900s. In 1987, the Fisheries Enhancement Program began a BPA-funded study of the feasibility of restoring sockeye salmon to Cle Elum Lake, the largest reservoir in the Yakima River Basin. The initial phases of this study have just been completed.

At the onset of this study, sockeye salmon were considered by many investigators to be difficult to culture. High prespawning mortality, low egg-viability, inability to mature in captivity, and low fry-to-smolt survival due to a viral pathogen (infectious hematopoietic necrosis) were viewed as acute limitations. Thus, sockeye salmon culture had been terminated in Washington State in the 1960s. Our study demonstrated that net-pen holding of prespawning adults in a lacustrine environment with isolated incubation and rearing of progeny can produce healthy juveniles. These results helped reestablish sockeye salmon culture in Washington State.

Results of the feasibility study showed that if mechanical traps and fishways are constructed at Cle Elum Dam, sockeye

salmon can be restored to Cle Elum Lake. They also suggested that fall releases of presmolts into the reservoir may be the most beneficial supplementation strategy.

Although the primary focus of research was to define lake and river conditions under which sockeye salmon can survive and outmigrate, the potential for success was demonstrated with the return of implanted adult fish. Four and seven adults returned from pilot-scale smolt releases in 1991 and 1992, respectively, and in 1993, over 20 adults returned. These first returns of sockeye salmon to the Yakima River Basin in over 60 years are extremely encouraging to supplementation studies toward the recolonization of blocked habitat.

Fish Health

Since 1991, as part of a BPA-funded program to establish supplementation hatcheries in the Yakima River Basin, Fisheries Enhancement biologists have conducted research to determine the extent of infectious disease and parasitism in wild salmonid populations. Preliminary results suggested that the same pathogenic organisms that cause morbidity and mortality in hatcheries and other fish-holding facilities in the Pacific Northwest also exist in wild salmonid stocks in the Yakima River.

Bacterial kidney disease (BKD) has long been identified as a common cause of mortality in salmonids. Therefore, Fisheries Enhancement biologists have also been involved with studies to gain approval for new antibiotic treatments of BKD. In addition, in 1993 these biologists initiated research on the efficacy of

non-antibiotic substances as feed additives to control BKD in artificially reared chinook salmon.

Grays Harbor coho salmon survival study--The Fisheries Enhancement Program participated in a cooperative research with WDF in the Grays Harbor area of western Washington from 1987 to 1990. Two major rivers, the Chehalis River and the smaller Humptulips River, flow into Grays Harbor. However, coho salmon from the Chehalis River had significantly lower survival and contributed fewer adults to the fishery than salmon from the Humptulips River.

As part of an investigation to determine the cause of this differential survival, wild and hatchery fish from both rivers were sampled biweekly from early March to June 1987 and 1988. Program biologists conducted intensive investigations of smoltification and general health in Grays Harbor coho salmon.

Their observations suggested that effluent from industrial and agricultural activities, combined with parasitism by the digenetic fluke *Nanophyetus salmincola*, was contributing to the decreased survival of coho salmon in the Chehalis River. NMFS also developed an experimental method for infesting salmon with this parasite.

Passive-Integrated-Transponder Tag Studies

In 1983, Fisheries Enhancement staff began to evaluate the technical and biological feasibility of adapting a new miniature identification system, known as a Passive-Integrated-Transponder (PIT) tag, for use in salmonids. The PIT tag has broad

application in fisheries science for monitoring movement and behavior of aquatic organisms. The project has been funded primarily by BPA.

The tag is a cylinder measuring 12 mm long by 2.1 mm in diameter, and consists of an antenna and a computer chip. Each tag is uniquely coded with 1 of 34 billion available codes. The tag is passive, having no power of its own, and must rely upon an external source of energy to operate. A 400-kHz signal is sent from an exciter, received by the tag antenna, and converted to power, which operates the tag electronics. A signal is then transmitted from the tag antenna to the monitor system, where the signal is decoded.

In recent years, task research has focused on: 1) comparing the biological effects of the tag to those of traditional marking methods, 2) developing new tag interrogation systems, and 3) installing new PIT-tag interrogation and separation systems at dams within the Columbia River Basin.

Comparative studies suggested that PIT tags and coded-wire tags reduced survival slightly, but at comparable levels. In the laboratory, trout preyed on PIT-tagged fish at the same rate as coded-wire-tagged, freeze-branded, and fingerling-tagged fish. In field studies, post-release, overwinter survival of PIT-tagged fish in two small Puget Sound streams was similar to that of their coded-wire-tagged cohorts. Post-release survival of ocean-ranched PIT-tagged coho salmon released from a north Puget Sound hatchery was also comparable to their coded-wire-tagged cohorts. However, in these studies the survival of all marked fish was

less than that of unmarked fish. In addition, PIT-tagged fish usually grew slightly less than their coded-wire-tagged and untagged cohorts in both laboratory and field studies.

Fisheries Enhancement staff have made significant advances in methods of interrogating PIT-tagged fish. Project investigators have developed and evaluated interrogation systems to expand the range of these detectors without harming the fish or interfering with their volitional movement. These systems have been used successfully in a test stream and at a hatchery. Migratory behavior in juvenile and adult salmon was not affected by the 400-kHz electromagnetic field generated by PIT-tag monitors.

An automatic system for separating PIT-tagged fish from non-PIT-tagged fish was developed and evaluated. These separation systems are now installed at Lower Granite, Little Goose, and Lower Monumental Dams and will also be installed at the new PIT-tag interrogation facilities at McNary and Bonneville Dams. Recent work has focused on developing software that would automatically separate fish based on their individual tag codes. The preliminary evaluation of this new software has been successful. In the future, the capability of interrogating returning adult PIT-tagged fish in fish ladders will be developed.

Field Facilities

The Fisheries Enhancement Program maintains two facilities: the Manchester Marine Experimental Station (Fig. 19) near Manchester, Washington; and a freshwater station at the

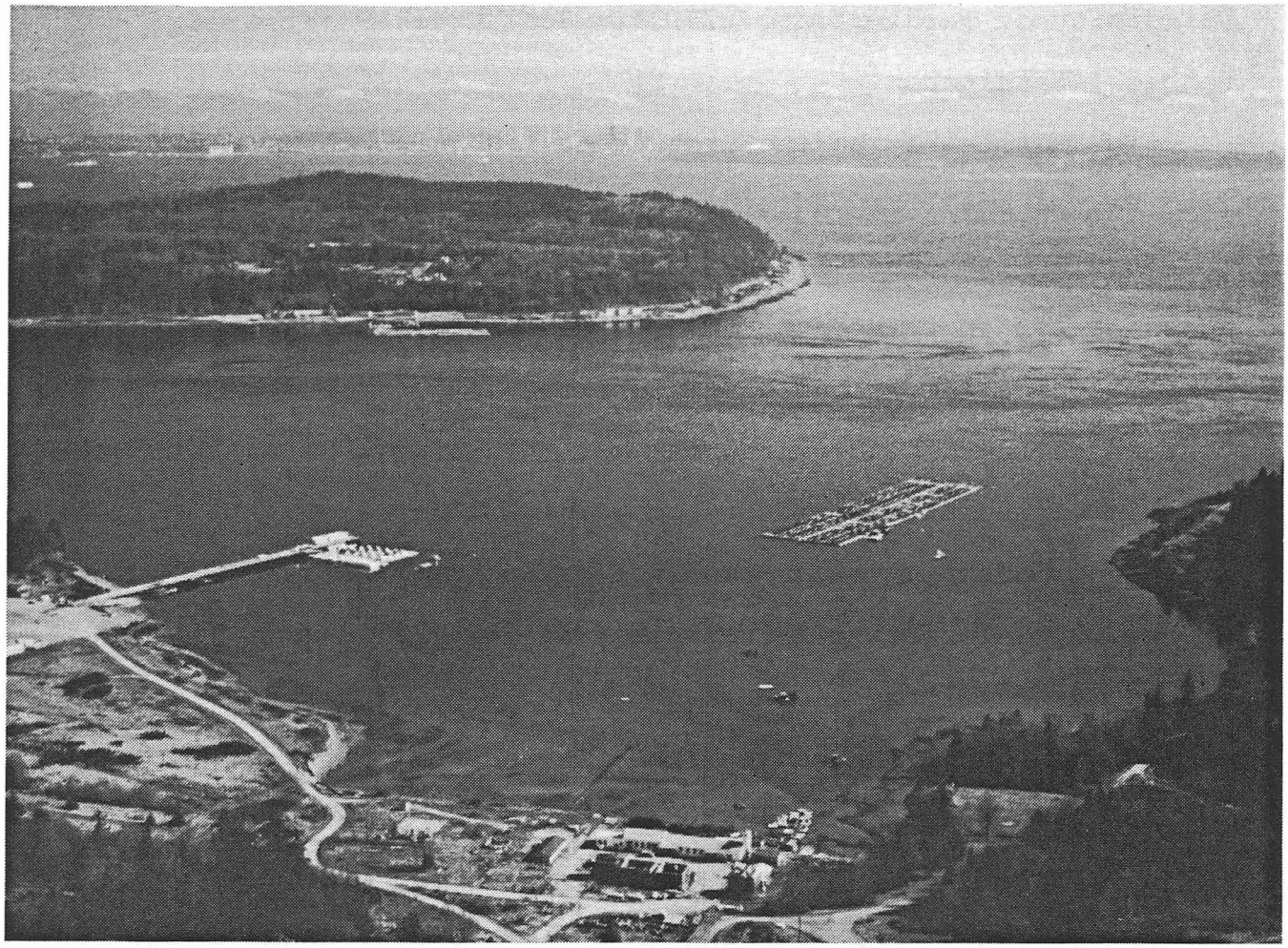

Figure 19.--CZES Manchester Marine Experimental Station (Manchester, Washington), on Clam Bay, western shore of Puget Sound; Seattle in background.

University of Washington's (UW) Big Beef Creek Station near Seabeck, Washington.

The Manchester Marine Experimental Station is situated on Clam Bay, a small bay adjoining the central basin of Puget Sound. The station is housed in a refurbished naval fire school on 22 acres of land surplused to NOAA in the late 1960s. The building contains five laboratories, six offices, and computer and conference rooms. Adjoining the main building is a smaller disease diagnostic laboratory containing a pathology lab, two offices, a darkroom, and a small experimental freshwater hatchery. An experimental seawater hatchery at the Manchester Station is in the final stages of completion. This facility will be used for captive broodstock and marine fish research.

A major advantage of the site is the excellent seawater quality. Clam Bay is a major tidal mixing zone between Sinclair and Dyes Inlets to the west and waters of central Puget Sound to the east. This environment, combined with an 800-ft pier made available to us by our next door neighbor, the EPA Region X Laboratory, make Manchester an excellent site for experimentation/culture of a variety of finfish and shellfish. At the end of the pier is an experimental salmon-farm (Fig. 20) consisting of a staging float and 35 net-pens of various sizes forming a combined rearing space of 4,100 m^3.

The Fisheries Enhancement Program also maintains an experimental hatchery at the UW Big Beef Creek (BBC) Station near Seabeck on Hood Canal. Both surface (creek) water and high-quality, 10°C artesian water are supplied to the facility.

Facility design includes flexible arrays of 0.2-12 m^3 rearing containers required for enhancement research (e.g., NATURES, captive broodstock, etc.). In addition, recently completed construction of an isolation rearing facility for endangered Redfish Lake sockeye salmon at BBC. The high quality artesian water ensures a quality rearing environment for protective culture of endangered species.

Future Projects

Future research in the Fisheries Enhancement Program will depend in part on the development of research proposals in cooperation with funding agencies. Research projects that deserve attention and effort are as follows:

1) Investigate the influence of growth rate and release size on smolt development and downstream migration of spring chinook salmon.
2) Analyze the relationship between smolt indices and adult survival of spring chinook salmon released from Columbia River hatcheries.
3) Investigate endocrine control of salmon smoltification.
4) Establish baseline data on physiological smolt development of wild chinook salmon prior to implementation of a supplementation program in the Yakima River Basin.
5) Characterize factors that control release of pituitary gonadotropins, and hence control puberty in fish.

6) Improve methods for artificial induction of spawning using controlled-release devices for the administration of gonadotropin releasing hormone (GRH).
7) Investigate the endocrine mechanisms controlling the development of maturation in Pacific salmon.
8) Develop a PIT-tag monitor with increased reading range so that tagged adult salmonids can be passively monitored in fishways.
9) Develop fish culture methods to aid recovery of depleted stocks of marine fish.
10) Refine fish culture techniques that produce "wild-type" juveniles from hatcheries to aid recovery of endangered stocks of Pacific salmon.
11) Develop captive broodstock technology to produce salmon that are indistinguishable from their wild cohorts with respect to appearance, physiology, behavior, and genetic diversity.

CONSERVATION BIOLOGY PROGRAM

Background

Concern began over reductions in runs of anadromous salmonids in the Pacific Northwest over a century ago. For most of that time, efforts have focussed on means to produce fish through artificial propagation to mitigate declines in wild populations. In the last decade, there has been an increasing recognition of the importance of conserving the genetic resources of wild populations upon which salmon production ultimately depends. The primary goal of the Conservation Biology Program is to provide scientific information that can be used to conserve these wild salmon populations in perpetuity.

The Conservation Biology Program started in 1992 as a project integrating Fisheries Enhancement Program staff working on genetics and protected species issues. It developed into a full program with two ongoing research projects in 1993. The first of these is the Protected Species Project, whose activities focus on issues related to the Endangered Species Act (ESA). NMFS is using the information developed by Protected Species Project scientists in ESA listing determinations, species recovery planning, and in permitting the process under the ESA. The second area of ongoing study falls under the Genetics Project, which combines basic and applied research on genetic issues related to the conservation of salmon populations.

Recent Accomplishments

Protected Species Project--Project staff are responsible for scientific research regarding the conservation, listing, and recovery of anadromous fishes. Primary focus is on the seven *Oncorhynchus* species indigenous to the eastern Pacific rim. Since 1990, NMFS Northwest Region has received eleven petitions to list selected populations of Pacific salmonids as threatened or endangered "species" under the ESA.

As amended in 1978, the ESA allows listing of "distinct population segments" of vertebrate species (including Pacific salmon) but provides no explicit guidance on how to determine when a population is "distinct" enough to qualify for protection. The unique life cycles of most species of Pacific salmon do not conform well to traditional models of population structure and life history. To provide a framework for evaluating petitions to list populations of Pacific salmon as threatened or endangered, the Protected Species Project has taken a lead role in developing NMFS policy to determine what constitutes a "species" of Pacific salmon under the ESA.

According to the policy (published in 1991), to be considered "distinct," a salmon population must 1) be substantially reproductively isolated and 2) represent an important component in the evolutionary legacy of the biological species. The policy defines such a distinct population as an Evolutionarily Significant Unit (ESU). The Protected Species Project is also conducting research on patterns of abundance in salmon populations. This information is used to help determine

whether listing as a threatened or endangered species under the ESA is warranted.

Petitions to list the following five populations of Pacific salmon were received by NMFS Northwest Region in 1990: Snake River sockeye salmon; Snake River spring, summer, and fall chinook salmon; and lower Columbia River coho salmon. Biological status reviews, which entailed population sampling and genetic analyses, were conducted for each petitioned species. In 1991, Snake River sockeye salmon were listed as endangered under the ESA, and Snake River spring/summer chinook salmon and fall chinook salmon were listed as threatened in 1992. Lower Columbia River coho salmon were not listed because of an inability to identify a wild component that retains the genetic legacy of indigenous populations.

Since 1991, petitions have been received by NMFS Northwest Region for six additional populations or groups of populations: Illinois River (Oregon) winter steelhead, Umpqua River (Oregon) anadromous cutthroat trout, mid-Columbia River summer chinook salmon, Stillaguamish River steelhead, coastal Oregon coho salmon, and coastwide coho salmon. The Illinois River winter steelhead petition was denied because that population alone does not constitute an ESU. However, NMFS initiated a comprehensive status review of coastal steelhead to define the broader ESU encompassing this population, and to determine whether listing is warranted. Biological status reviews are also underway for each of the other petitioned species, with determinations for all due between April and October, 1994.

Artificial propagation must be considered carefully in the conservation of Pacific salmon, because it can be a cause of decline as well as a means of recovery. Concerns regarding genetic and ecological effects of hatchery fish on natural populations have prompted NMFS to reevaluate the use of artificial propagation for Pacific salmon. The Protected Species Project has assumed a prominent role in developing NMFS policy to guide artificial propagation of salmon for enhancement, supplementation, and conservation under the Endangered Species Act.

An interim policy, published in 1993, establishes NMFS criteria to determine the status of artificially propagated salmon at the time of listing. This policy outlines considerations preceding the use of artificial propagation in the recovery of listed species, and provides guidance to minimize its possibly deleterious genetic and ecological effects.

The interim policy also provides a working foundation for the operation of existing and future artificial propagation facilities and maintains their compatibility with increasing conservation activities. Significant obstacles to the conservation of Pacific salmon remain, but the research conducted and the policies developed by Protected Species Project scientists provide the safeguards needed until these obstacles are overcome.

Protected Species Project scientists are currently conducting work in population dynamics to provide reliable assessments of the status of natural salmonid stocks in the

Pacific Northwest and California. All aspects of this research are also related to ESA activities, such as assessing the level of extinction risk faced by Pacific salmonid populations. Substantial effort in this area has gone into developing more reliable methods to assess such risk. The mathematical models commonly used for extinction risk assessment do not include important aspects of salmonid biology and management. We are developing new models that incorporate realistic age structure and that reflect the multiple-stock nature of salmon populations. Additionally, ESA assessments focus on natural production, so we are developing models to estimate production of the natural component of mixed hatchery/natural populations.

A great deal of modelling effort by other agencies has already gone into management decisions for listed Snake River salmon populations. Protected Species Project staff are currently evaluating the scientific basis for these models and their application to ESA issues. In addition, project staff are conducting a joint study with the University of Washington Fisheries Research Institute to apply statistical decision theory to management decisions for at-risk salmon stocks. This study will provide the analytic tools for evaluating extinction risk associated with differing management alternatives. These tools will be used in recovery plans for Pacific salmon stocks listed or proposed for listing under the ESA. The study will include a review of uncertainties (such as sampling error, information gaps, environmental fluctuations, etc.) in the ESA process for Pacific salmon.

Genetics--A primary objective of the Genetics Project is to identify naturally occurring genetic "marks" for characterizing salmon populations or stocks. These marks are identified using protein electrophoresis and various DNA techniques. They provide baseline data sets for forensic purposes and to determine the proportions of each stock in a mixed-stock fishery. Genetic stock identification (GSI) of chinook salmon has been the focus of research funded by the Pacific Salmon Treaty (PST) since 1985.

Since 1989, baseline genetic research has been conducted along the north coast of British Columbia and in the Snake River drainage. Genetic data on over 45 stocks of chinook salmon have been added to the coastwide baseline during this period, bringing the total to 196 stocks (with up to 41 loci each). Computer simulations for British Columbian mixed-stock fisheries indicated that a high degree of accuracy in detecting stocks could be achieved with the addition of this new data. In 1992, the summer troll fishery in Oregon was studied using the new baseline, and the results from a GSI analysis of 840 fish were provided to the Pacific Fisheries Management Council.

A growing concern in international fisheries management has been the allocation of coho salmon between U.S. and Canadian fisheries. In 1991, Genetic Project scientists began a genetic baseline for coho salmon, primarily for GSI analyses in Puget Sound and eastern Vancouver Island fisheries. To date, data on 75 loci have been collected from 35 populations from the Oregon coast to Puget Sound.

In addition, project scientists developed an assay for a new stock-discriminating locus (the transferrin locus), and data on this locus have been collected from 90 populations along the Pacific Coast from California to British Columbia. These studies demonstrate that coho salmon exhibit substantial levels of genetic variation and are amenable to GSI analysis.

Growing concern about the salmon harvest in driftnet fisheries on the high seas during the 1980s prompted a genetic study of Asian salmon in 1989. Genetics Project scientists participated in this study in cooperation with the Fishery Agency of Japan and the Pacific Research Institute of Fisheries and Oceanography in Kamchatka, Russia. The goal of the study was to complete a genetic baseline of chum salmon in Asia. Chum salmon is a significant species in all North Pacific high-seas fisheries, and the Asian data complement the available North American data for use in GSI analyses of high-seas fisheries. Data have been collected at 75 loci from each of 38 Japanese and Russian baseline samples for population genetic analysis.

These baseline studies have shown that clear regional differences exist among Asian chum salmon populations. Fisheries agencies now have access to a standardized, North Pacific baseline for chum salmon that includes data for 24 gene loci from 63 populations. In a demonstration of the efficacy of this baseline, five genetically distinct regional groups of fish from Asia and North America were identified from seven high-seas samples (totaling 1,029 fish) with a high degree of certainty.

Further high-seas sampling is being pursued jointly with Canadian and Japanese biologists.

A parallel study was also conducted to investigate the nature of DNA-level genetic variation in chum salmon populations. Because of separate evolutionary and genetic processes, DNA-level markers may reveal greater differences between stocks than do markers from allozymes. A baseline dataset, which includes 800 fish from 42 Asian and North American populations, has been completed for a polymorphic mitochondrial DNA mark in chum salmon. This marker shows large frequency differences between Japanese and Washington stocks and is the most discriminatory genetic marker yet described in chum salmon.

In spring 1993, the NWFSC hosted an international DNA workshop to review DNA technology and research in the fishery community. Specific objectives of the workshop were as follows: 1) Provide a forum for discussing the applications of DNA and other genetic techniques in addressing key salmon management issues; 2) Provide a coherent overview of various DNA projects with Pacific salmon currently underway in the region; and 3) Facilitate inter-laboratory communication to ensure the most efficient use of time and the most effective use of resources. Conservation Biology Program scientists are editing the proceedings of the workshop, which will appear in 1994 as a NOAA Technical Memorandum.

Another ongoing study conducted by the Conservation Biology Program is to evaluate the genetic effects of hatchery-reared fish used to supplement natural populations of chinook salmon and

steelhead in the Snake River Basin. This study is now in its fifth year and has contributed to both listing determinations and recovery plans for spring- and summer-run chinook salmon.

The study plan involves yearly monitoring of protein electrophoretic and meristic characteristics in hatchery, natural (supplemented), and wild (unsupplemented) populations in four different drainages for each species. Major results obtained to date include the following:

1) Genetic variability for both chinook salmon and steelhead is higher than previously reported for Snake River populations. However, no substantial differences in levels of genetic variability were observed between years or between hatchery and natural/wild populations in either species.
2) In both species, temporal differences within populations were generally smaller than differences between populations.
3) Differences between chinook salmon populations classified as spring- and summer-run accounted for little of the overall genetic diversity. In contrast, substantial genetic differences were observed between "B" run steelhead from Dworshak Hatchery and "A" run steelhead from other study sites.
4) Estimates of the effective number of breeders per year (N_b) derived from genetic data suggested that N_b in natural and wild Snake River spring/summer chinook salmon

populations is generally about one-quarter to three-quarters of the estimated number of adult spawners.

5) Examination of seven indices of bilateral asymmetry of meristic characters in chinook salmon revealed no correlation between the level of asymmetry and the level of genetic variability within individual fish.

In 1992, Genetics Project staff initiated the DNA phase of the genetic monitoring program for Snake River chinook salmon and steelhead. We hope that DNA methods will provide fine-scale resolution for situations in which protein electrophoresis does not have adequate power to discriminate between populations. This DNA research is directed toward the development of two classes of genetic markers: single base pair changes and copy-number variation in microsatellite loci.

DNA has been isolated from approximately 1500 steelhead and chinook salmon, representing over 100 collections. Preliminary screening of representative samples has identified several new genetic markers in both mitochondrial and nuclear DNA sequences. We have even found significant frequency differences among closely related populations. Efforts in the near future will focus on the construction of more extensive baseline data for our new markers. Of particular interest are restriction variants that have been identified in nuclear DNA of both species. Unlike earlier data from mitochondrial DNA, this type of variation is analogous to existing allozyme data and thus can be readily integrated into the existing baseline, providing additional power to traditional analyses.

We currently have three sets of primers for microsatellite sequences. To generate additional primers, we are moving forward with characterization of new clones we isolated from a genomic DNA library. Microsatellite sequences are highly variable and, although more difficult to develop and work with than structural genes, hold considerable potential for discrimination between closely related populations.

Future Projects

In the near future, likely topics for new and continued research by Conservation Biology Program staff include the following:

1) Extinction risk/management decision analyses for Pacific salmon.
2) Risk analysis models that incorporate the unusual age structure of Pacific salmon.
3) Modeling and analytical techniques for studying genetic changes over time in salmon populations.
4) Genetic monitoring programs for natural salmon populations supplemented with hatchery-reared fish.
5) Biologically-based guidelines for the use of artificial propagation that are consistent with the conservation of natural salmon populations under the ESA.
6) Modifications to the existing GSI algorithm that relax some of the assumptions limiting the method's usefulness in certain situations.

7) Refinement of protein electrophoretic techniques to allow a comprehensive analysis of population structure in coho salmon.
8) Inheritance studies to verify the genetic basis for observed protein electrophoretic variation in coho salmon.
9) Continued research and development of DNA markers in Pacific salmon, including examination of repetitive microsatellite sequences.
10) Quantitative genetic analysis of the genetic basis for life history diversity in Pacific salmon.

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