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IMPACT OF ARTIFICIAL PROPAGATION OF SALMON ON THE PACIFIC COAST OF THE UNITED STATES AND CANADA 1872 - 1979

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RÉSUMÉ

—Avant les années 1960, les repeuplements n'ont pratiquement pas permis d'augmenter la production des pêcheries de saumon du Pacifique. Par la suite, grâce à des programmes de recherches effectués plus particulièrement pour le développement des pêches de la rivière Columbia, la production artificielle a joué un rôle important dans le maintien des pêcheries de saumon en mer et en rivière.
A l'heure actuelle, environ 50 % des prises de saumons chinook (Oncorhynchus tshawytscha) *et coho* (Oncorhynchus kisutch), *ainsi que de truites de mer (Salmo gairdneri) effectuées sur la côte pacifique sont issues de la production de smolts de pisciculture. Les recherches actuellement en cours doivent permettre d'augmenter cette contribution.—*

The first hatchery in North America that reared Pacific salmon *Oncorhynchus spp.* was operated by the United States Fish Commission in 1872 on the McCloud River in northern California, United States of America. At conception this hatchery was intended to provide Pacific salmon to supplement the declining Atlantic salmon, *Salmo salar,* fishery on the east coast of the United States. Hatcheries were later established at Harrison Lake, British Columbia, Canada, in 1884 and on the the Clackamas River in Oregon, U.S.A., in 1877. By this time the main reason for artificial propagation of Pacific salmon was to maintain the west coast fishery at a high level instead of supplementing the declining Atlantic salmon fishery on the east coast. This policy produced a network of hatchery stations from California northward to Alaska with annual ova production in the hundreds of millions by 1900.

The period from 1900 to 1960 could be characterized by a long plateau of slow learning, when many problems concerning Pacific salmon propagation became obvious, but very few solutions were discovered. During the early part of the period, 1900-1930, serious problems such as thoses associated with disease and nutrition were uncorrected, mainly because, despite annual rises and declines in numbers of salmon, the overall salmon catch of the Pacific Coast remained fairly constant. Beginning about 1930, the loss of freshwater spawning and rearing habitat became a serious problem, especially in the Columbia River, the most important producer of chinook salmon on the Pacific Coast. About the same time it also occured in the Sacramento River in California. The primary cause of the loss of fish was irrigation diversions with few fish passage facilities, followed by hydroelectric projects with their upstream and downstream fish passage problems, and finally a degradation of the freshwater environment from pollution.

In 1949 the Columbia River Fishery Development Program was initiated to counteract the severe loss of salmon and steelhead trout, *Salmo gairdneri,* resulting from the expansion of water-use projects in the Columbia River system (Fig. 1). The Program is a cooperative effort of fish management agencies of the States of Oregon, Washington, and Idaho and the Federal Government and is administered by the Environmental and Technical Services Division, National Marine Fisheries Service, NOAA, Portland, Oregon. The Program has included two major functions : 1) the protection and improvement of stream environment which has included improvement of natural habitat, such as clearing obstructions from nearly 2,000 miles of tributary streams, building 87 fishways past natural barriers, and installation of 570 screens in diversion ditches and canals, and 2) the production of fish in hatcheries which has been accomplished by the construction or modernization of 21 salmon and steelhead hatcheries on the lower Columbia River and tributaries.

A supplementary function of the Program is to fund operational improvement research studies to complement the hatchery system. Major achievements of the studies have been : 1) determination of the physiological factors controlling downstream salmonid smolt migration through understanding the development of osmotic and ionic regulation in coho salmon (CONTE et al. 1966), chinook salmon (WAGNER et al. 1969) and steelhead trout (CONTE and WAGNER 1965), thus improving hatchery release timing ; 2) improved fish diets through development of the Oregon Moist Pellet (HUBLOU 1963) ; 3) reduction of natural competition and predation through the development of Squaxin, a selective toxin for squawfish (MACPHEE and RUELLE 1969) ; 4) improved marking techniques through developement of the implanted coded wire fish tag (BERGMAN et al. 1968) ; and 5) increased wild production through rehabilitation of chinook salmon runs in the Clearwater River system in Idaho, and Wind River in Washington, and the Willamette River system in Oregon. A major focus of the Program has been to improve the effectiveness of artificial propagation. There were two reasons for concentrating on hatchery produced salmon and steelhead trout : 1) their life histories allow successful hatchery propagation and 2) these species are of great historic, economic and social importance to the U.S.A. Over the past decades Pacific salmon have ranked first or second in landed value of commercial finfishes to U.S. fishermen. In addition, the net economic value of marine and freshwater sport fishing for salmon in the U.S.A. in 1970 was estimated at $ 77.7 million (WAHLE et al. 1974).

Initially Columbia River Program hatcheries were constructed for rearing of fall chinook salmon (scientists have separated chinook salmon into seasonal races based on time of entry into freshwater on their spawning migration) because of a serious decline of this run in the early 1950's (VAN HYNING 1973). Releases of migrant-size fall chinook salmon have ranged from 10 million fish from 6 hatcheries in 1949 to 99 million from 22 hatcheries in 1976 (WAHLE and SMITH 1979). However, prior to 1969 little was known about the quantitative contribution of these releases to the commercial and sport fisheries.

About 1960 the U.S.A. Office of Management and Budget declared a moratorium on further hatchery construction until there was proof that any expansion would be economically justified. Accordingly, the Columbia Fisheries Program Office initiated a marking study in 1962 which was designed to estimate the contribution of Columbia River hatchery-reared fall chinook salmon to the various fisheries. During the marking phase (1962-1965) identifying fin marks were applied to 21.3 million of the 213 million fingerling fish released (1961-1964). The study was confined to 12 hatcheries and 1 rearing pond that during this period propagated nearly 90 % of the fall chinook salmon artificially reared in the Columbia River system. Locations of the hatcheries are shown in Figure 2.

The mark recovery phase of the study began in 1963 and was completed in 1969. Major marine sport and commercial fisheries from southeastern Alaska to central California (and Columbia River) fisheries were sampled for marked fish (Fig. 3). Although some Columbia River hatchery fall chinook were captured in all marine fisheries from Alaska to California, most recoveries came from offshore areas of British Columbia and Washington. During the 7 years of sampling 65,620 marked fish were estimated to have been caught. The potential contribution of the four broods from the 13 study facilities, after adjustment for the effects of marking, was 1,433,300 fish. The value of the contribution was estimated at $ 12,027,000. Costs applicable to rearing were $ 2,859,700, yielding an average benefit to cost ratio of 4.2 to 1 (WAHLE and VREELAND 1978).

In 1965 the hatchery-produced fall chinook study was expanded to include coho salmon. Accordingly, representative samples from all Columbia River hatcheries rearing 1965 - and 1966 - brood coho salmon were marked. During the 2-year marking phase 4.1 million of the 40.1 million total coho production from 20 hatcheries were marked. Location of hatcheries is shown in Figure 4. As in the fall chinook study, commercial and sport fisheries in marine waters from Pelican, Alaska to Avila Beach, California, and including the Columbia River, were sampled for marks during 1967-69. A total of 179,096 marked coho was estimated to have been caught by the fisheries. An additional 33,910 marked fish returned to the study hatcheries to spawn. The potential contribution for the two broods from the 20 hatcheries after adjustments for the effects of marking was 2,188,172 coho. The value of the contribution was estimated to be $ 17,690,177. Costs of rearing the 2 broods were $ 2, 518,900 yielding and average benefit to cost ratio fo 7.0 to 1 (WAHLE et al. 1974).

The ocean distribution of the hatchery reared coho salmon catch differed markedly from that of the fall chinook. The fall chinook were taken mainly in the marine waters north of the Columbia River in British Columbia and Washington. Only 5 % of the catch was taken off Oregon and California. In contrast, few coho were caught off British Columbia, with 55 % of the catch taken south of the Columbia River off Oregon and California.

The excellent benefit-cost ratio for the Columbia River coho salmon hatcheries of 7 to 1 was not possible before 1960. Most juvenile coho being reared in hatcheries being released before this time could be typified by their short rearing period, poor health due to nutritional deficiencies, and low survival. However, having benefited from advances in fish culture, especially nutrition, in the early 1960's these salmon were characteristically large and healthy with a high survival potential. The Oregon Moist Pellet Diet, which was developed by scientists of the Fish Commission of Oregon (now Oregon Department of Fish and Wildlife) and Oregon State University, should be given credit for most of the increased success of hatcheries. The new diet besides having high nutritive value has several other desirable qualities. First, because it is pasteurized, severe diseases which had been transmitted through food were controlled. Second, soluble food elements were not lost into the water by leaching because they are bound together in pellets. Third, sanitation in the rearing pond was improved because there is little food wasted that can harbor unwanted organismes (CLEAVER 1969).

As a result of all the foregoing and related efforts, artificial propagation now plays a critical role in maintaining productive marine and freshwater salmon fisheries.

In the 1950's 70 artificial rearing facilities released about 1.5 million pounds of chinook and coho salmon and steelhead trout annually which had a very low survival potential. Currently 150 rearing facilities located from southeast Alaska to central California release approximately 11 million pounds of the same species annually having a high survival potential. These hatcheries are estimated to contribute near one-half of the total catch of over 40 thousand metric tons in the Eastern Pacific Ocean marine and freshwater commercial and sport fisheries.

We are now entering a new era that promises to yield substantial improvement in the effectiveness of artificial propagation of Pacific salmon. An example of the most promising areas of research is what we call a study to assess "The Status of Smoltification and Fitness For Ocean Survival of Chinook and Steelhead". The study is designed to achieve three goals which follow : 1) develop the best time, sizes and methods of releasing fish, considering variations between hatcheries, 2) reduce competition between hatchery and wild fish in freshwater, 3) release hatchery fish which are ready to adapt to salt-water, thus dramatically increasing survival of both hatchery and wild fish.

The Pilot study, during 1977, conducted by National Marine Fisheries Service personnel at Manchester, Washington and funded by the Columbia River Fishery Development Program applied a series of sequential tests to determine the status of smoltification and fitness for ocean survival of nine stocks of chinook and coho salmon. Samples of each stock were : 1) examined for gill-ATPase enzyme activites up to time of release, 2) taken to Manchester for introduction into seawater net pens to determine long term (6 to 9 months) saltwater adaptability, growth, reversion to parr, and susceptibility to bacterial diseases. We concluded from the study that : 1) high gill ATPase activity at the hatcheries was directly related to survival in seawater in chinook salmon stocks, 2) in coho salmon stocks low ATPase activity at the hatchery did not result in high initial mortability upon saltwater entry but might be related to parr reversal in the late summer and fall months, 3) all nine stocks incurred losses due to *Vibrio anguillarum.*

In addition, research conducted in the 1970's has indicated that coho and chinook salmon can be manipulated by a number of techniques to : 1) alter migration routes ; 2) increase survival ; and 3) imprint to new homing areas. These techniques include delayed releases from both fresh and saltwater areas ; releasing salmon from floating net-pen culture systems ; culturing and releasing salmon from diked-tidal lagoons ; and the utilization of pumped saltwater raceways (NOVOTNY 1979).

A major research emphasis at this time is an attempt to assess the migratory instinct and seawater adaptation of coho and chinook salmon and steelhead trout cultured in the Columbia River hatcheries. This approach is expected to increase survival by closely aligning the time of releases of the fish from each hatchery with true physiological migratory function.

However, this is only another small step in a continuing process. To become complacent and accept the status quo would mean no future increases in salmon populations. If we can assume that some of the major problems of degradation of the runs in the Columbia River can be associated with a degradation in the environment ; if we can assume that the environment has now been stabilized ; then the next big effort must be in expanding our knowledge of genetics, disease and nutrition to provide fish that can readily survive these conditions.

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COLUMBIA RIVER BASIN

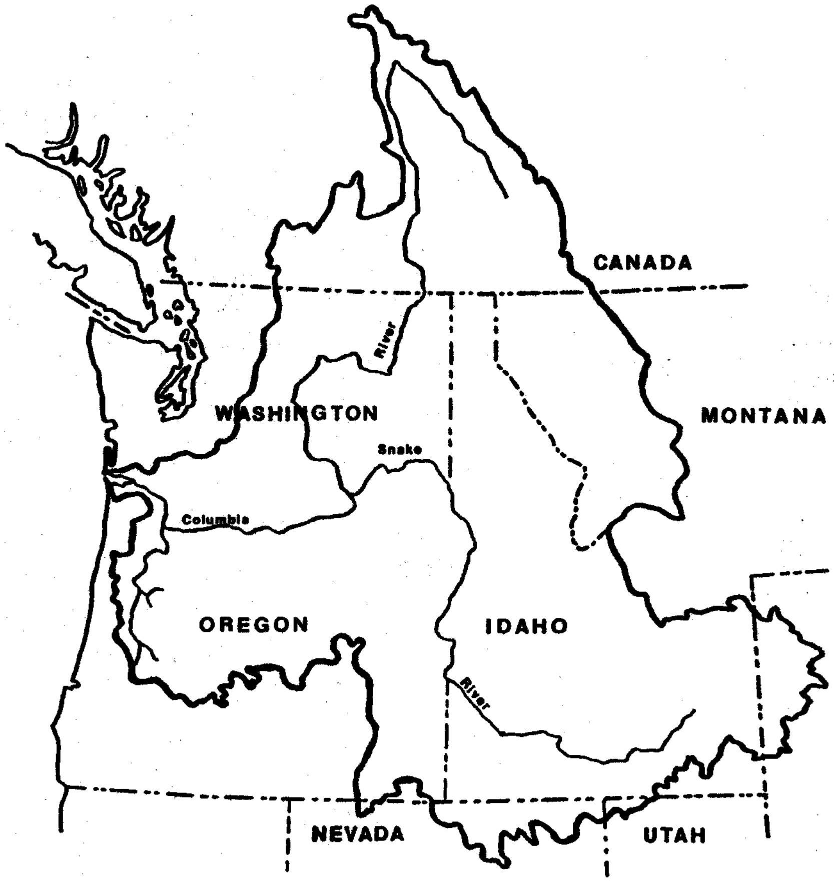
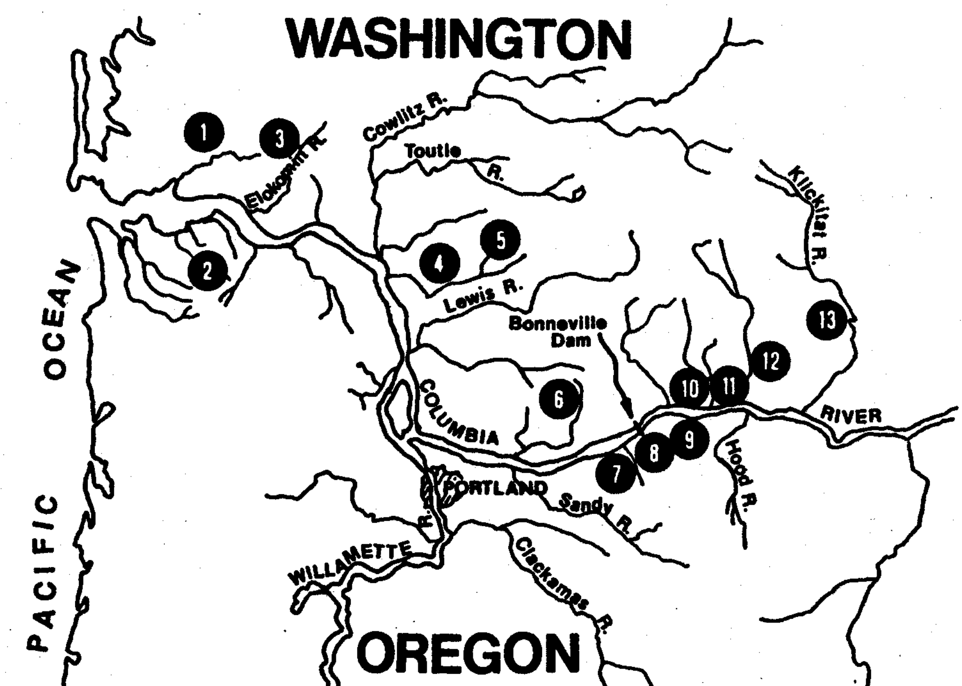


Fig. 1



FALL CHINOOK STUDY HATCHERIES

1. Grays River
2. Big Creek
3. Elokomin
4. Lower Kalama
5. Kalama Falls
6. Washougal
7. Bonneville
8. Cascade
9. OxBow
10. Little White
11. Spring Creek
12. Big White
13. Klickitat

Fig. 2

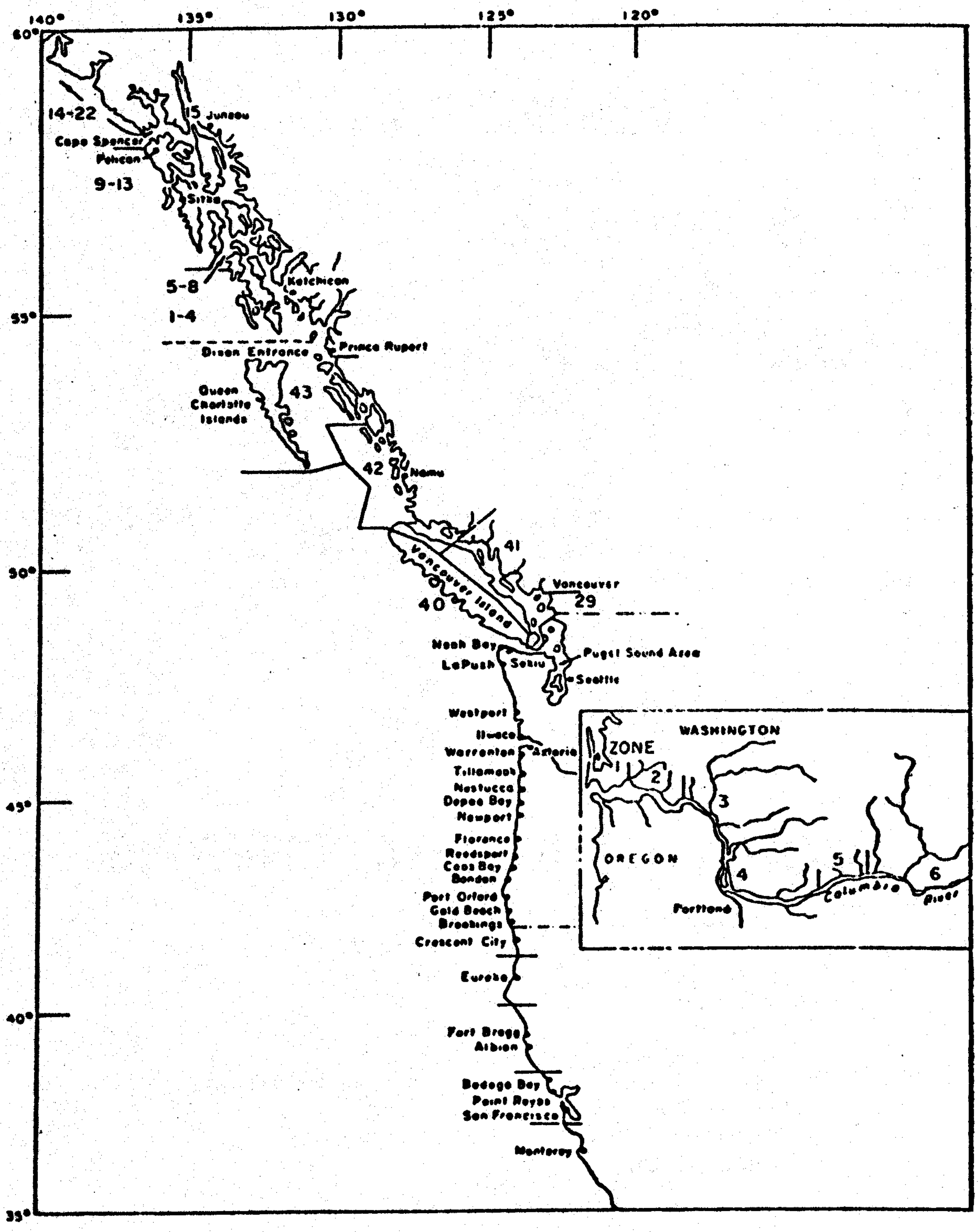
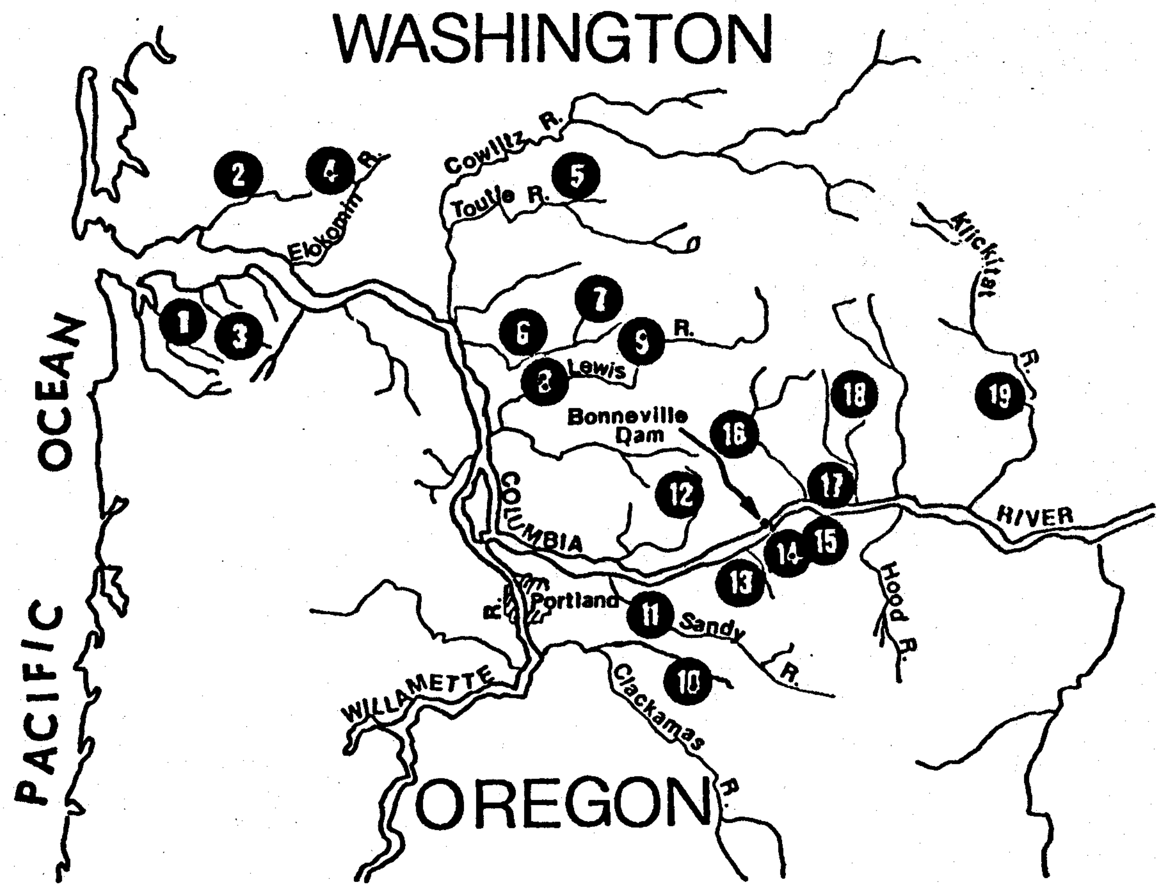


Fig. 3. — Ports and zones sampled for marked salmon of Columbia River origin.



COHO STUDY HATCHERIES

1	Klaskanine	11	Sandy
2	Grays River	12	Washougal
3	Big Creek	13	Bonneville
4	Elokomin	14	Cascade
5	Toutle	15	OxBow
6	Lower Kalama	16	Carson
7	Kalama Falls	17	Little White Salmon
8	Lewis River	18	Willard
9	Speelyai	19	Klickitat
10	Eagle Creek		

(Not shown - Leavenworth)

Fig. 4