PACIFIC SALMON

Hatchery Propagation and Its Role In Fishery Management

CIRCULAR 24

FISH AND WILDLIFE SERVICE
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Abstract

Population growth and industrial increase have intensified the problems of salmon-fishery maintenance. Natural propagation has been interfered with by pollution and by dams that cut off the salmon from their natural spawning grounds. Hatchery propagation helps maintain the fishery by offsetting the loss in natural spawning. This review of salmon-hatchery operations describes the life history of the Pacific salmon and explains the equipment used and the methods followed in hatchery propagation.

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By William Hagen, Jr.

Circular 24

United States Department of the Interior, Douglas McKay, *Secretary*
Fish and Wildlife Service, John L. Farley, *Director*

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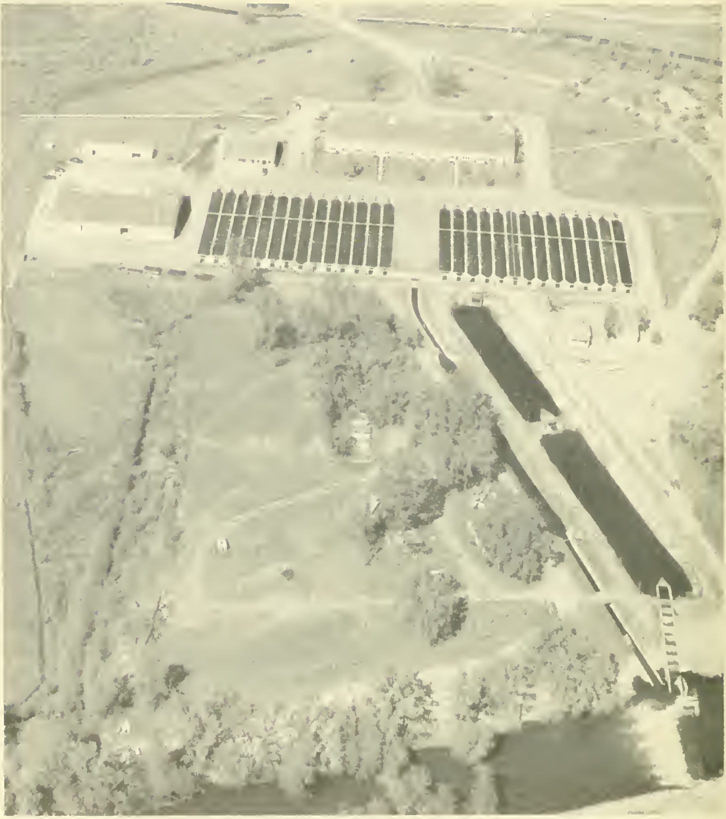

FIGURE 1.—Coleman (Calif.) Salmon Hatchery of the Fish and Wildlife Service. In foreground, diversion dam in stream, fish ladder to adult-salmon ripening ponds, fingerling rearing ponds. Buildings from left to right: equipment and shop, cold storage and food preparation, and the hatching building. The waste-water channel back to the stream serves also for passage of young fish released from the rearing ponds.

PACIFIC SALMON

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The salmon of the Pacific coast have always been an important food source for man. Craig and Hacker (1940) give an excellent account of the dependence of the Indians upon the salmon of the Columbia River, and estimate that before the arrival of the white man the catch was about 18 million pounds annually. Rostlund (1952) also indicates the importance of the salmon to all the Indian tribes of the western shores of North America. The early settlers relied upon the resource for food, and later exploiters took the salmon in great numbers for commerce.

Throughout the development of the Pacific Northwest and Alaska, salmon have played an important part. Today, the salmon fisheries are essential in the economy of these two regions. The resource contributes a substantial bulk of protein food.

Population growth and industrial increase have intensified the problems of salmon-fishery maintenance. Streams required for the natural reproduction of the species have been polluted and dammed for irrigation and the production of electric power; watersheds have been denuded of forest cover resulting in floods; and the rivers generally have been so utilized as to deny the original users—the salmon—adequate spawning area for self-perpetuation. Overexploitation, too, has depleted the stocks.

Man's inevitable progress has had a damaging impact upon the salmon resource. There have been relatively minor attempts to counteract or mitigate the damage.

Artificial or hatchery propagation of salmon on the Pacific coast was first undertaken in the 1870's, when efforts were made to establish runs of various species in other areas of the United States and in foreign countries. In later years, salmon-hatchery operations have had as their objective the maintenance of salmon runs in streams where overfishing, pollution, dams, and other factors have decimated populations. The operation of a present-day hatchery is considered successful only if its output of young fish contributes to the management of a fishery and results, either directly or indirectly, in the maintenance or increase of catch by sport or commercial interests.

On the Pacific coast, industrial advancement and its demands upon water for power has discouraged and will further discourage the natural reproduction of salmon. The need for the hatchery-reared salmon to overcome, at least in part, the manmade deterrents to natural reproduction is becoming ever more apparent.

The conservation of the salmon resource is a public responsibility and, as such, is of concern to the agencies of the State and Federal governments. In the Territory of Alaska, the United States Fish and Wildlife Service is charged with jurisdiction over the fishery; in the coastal States, the salmon fisheries are regulated by the States and conservation activities are undertaken by both the Service and the States. It is not possible for a private individual or a group to control the catch of salmon resulting from natural or artificial reproduction in a given stream. This is true because the catch is from public waters, either the open ocean or the mouth of the stream. However, in years past some packers of salmon have undertaken to improve salmon runs by assistance to natural reproduction and through artificial propagation. Probably the earliest such effort was by Hume (1893).

This publication describes briefly the species of Pacific salmon and their characteristics, reviews present-day methods of the artificial propagation of the Pacific salmon, outlines the human factors endangering the maintenance of the fishery, and explains the role of the hatchery in the attempt to maintain the fisheries at their highest possible level.

FIGURE 2.—Indians at Celilo Falls on the Columbia River fishing for salmon. The Dalles Dam Reservoir will eliminate this ancestral fishing site.

Five species of salmon are native to both North Pacific Ocean coasts, from Monterey Bay in California and from northern Japan on the Asiatic coast, northward to and somewhat beyond Bering Strait between Alaska and the Soviet Union. One additional species that is not native to the North American coast is found in northern Japan.

Attempts have been made to introduce various species of Pacific salmon into waters of the eastern coast of the United States, as well as into waters of many foreign countries and the Hawaiian Islands. Chinook and red (sockeye) salmon have been planted in waters of 17 Gulf and Atlantic Coast States. Introductions of the species have been successful only in southern Chile and in southern New Zealand, although temporary success has attended the efforts to establish chinook, sockeye, and silver salmon in the coastal streams of eastern Canada and northeastern United States. These efforts and successes, as well as the factors apparently limiting the habitat of Pacific salmon, are reported by Davidson and Hutchinson (1938). No substantial and successful efforts to transfer species have been undertaken since their report.

Many lakes in Canada and in northern United States contain landlocked red or sockeye salmon. Within the natural range of sockeye salmon, many individuals remain in the lakes by choice; whereas elsewhere the species has been stocked in lakes not accessible from the ocean. These lake-dwelling forms generally have the same life cycle as their ocean-reared brothers but usually attain not more than half their size.

Life History

All the species of Pacific salmon are anadromous, that is, they spend a portion of their lives in the ocean and at maturity ascend fresh-water streams to spawn. All have the same general pattern of life. Early life is in fresh water; growth to maturity is in the ocean; and maturity is followed by the return to the original stream to spawn and die. There is no authenticated record of a Pacific salmon surviving the first spawning and returning to the ocean. There are variations among species and within species with regard to the length of time spent in fresh-water and in salt-water habitats. Man-made conditions have resulted in considerable deviation from the natural schedules of salmon, often with disastrous consequences to the population of salmon.

When salmon enter fresh water on their spawning migrations, they cease feeding. Pink and chum salmon, being "short-run" species, may stop taking food while still in salt water and some distance from their home streams. Chinook and silver salmon, the principal sport species, strike at lures probably in annoyance rather than as possible food after entering the brackish and fresh waters of their streams. Sustenance for the fish during the journeys up the river is provided by the body fats and tissues, which also provide materials for the development of reproductive products—the eggs or ova of the female and the spermatozoa of the male. The latter, however, are usually fully developed when the fish enters fresh water, whereas the eggs of the female become "ripe" or mature at about the time the fish arrives at the spawning area. The flesh of the adult salmon deteriorates rapidly after the fish enters fresh water, as the body is being drained of its sustaining materials for the survival of the fish and the development of reproductive products, while there is no intake of food for conversion to energy. Thus, the salmon taken at the mouths of the rivers, or offshore in the ocean, are much more desirable for human consumption than are those taken upstream in the rivers. Fish taken offshore or at the mouths of rivers have firm flesh of good color but the fish taken upstream have flesh that is soft and off color. There is variation among and within the species in this respect.

During the spawning migration in fresh water, the adult salmon will proceed quite rapidly upstream. The rate of progress usually is from 3 to 10 miles or more a day. Chinook and red salmon in the larger streams of Alaska may spawn at the extreme headwaters 1,500 or more miles from the ocean, and the same was true in the Columbia River before the construction of dams. Chum and pink salmon usually spawn within a few miles of the ocean and often just above the reach of the tides. Here, too, there is considerable variation among and within species.

Despite the much-publicized ability of adult salmon to leap vertical

Figure 3.—Salmon leaping at falls.

distances of 10 or more feet, it has been established that waterfalls of this height will quite effectively block the upstream migration of most salmon. Even a waterfall of 5 or 6 feet will stop the majority of salmon unless water-flow conditions are ideal. Fish ladders for salmon at dams rarely require the fish to leap a vertical distance of more than 2 feet, and most ladders are so adjusted as to permit the fish to swim, rather than jump, a rise of about 1 foot.

Upon arrival at the spawning area the female deposits her eggs in a nest, or redd, which she digs in the gravel of the stream or, in some instances, in shallow lake-shore waters. Burner (1951) describes the characteristics of the redds, as well as their preparation and the activities of the fish:

> During the prespawning state, the female salmon is green, that is, the eggs are neither ripe nor loose in the ovaries. Males are seldom in attendance, and are frightened away by the female, who repels all intruders of either sex. The female digs the redd as she turns on either side, at an angle of about 45° to the current, head upstream, body arched, and makes a series of violent flexions with body and tail. The tail strikes gravel occasionally and the strong-boiling current created carries gravel and silt a short distance downstream. This material spreads out in a flat semicircle at first; then, as the digging upstream proceeds, it collects into a loose pile called the tailspill. With more digging, the redd assumes a long oval shape about twice the length of the salmon and several inches deep. The prespawning digging of the redd may go on for as many as 5 days.
>
> At the beginning of the spawning stage, the nest is ready for the eggs. All loose gravel and fine material have been removed from the pot, or center of the redd, the shape of which is such that any current in the bottom flows upstream then upward and outward. Usually there remain in the pot large stones too heavy for the fish to move far, and the crevices between these rocks provide excellent lodgement for the eggs. Males are constantly present now. The female alternately digs at the redd and settles back into the depression to release eggs. A male then moves quickly alongside the resting female, curves his body against hers, and releases sperm in a small milky cloud that settles briefly in the bottom of the redd where the eggs are lodged. The newly deposited eggs are thus surrounded by sperm and eventually fertilized. Excess sperm is carried slightly upstream along the bottom of the redd and gradually carried away by the current. During the spawning stage the redd increases considerably in length and depth, and appears to move upstream as a result of the continued digging at the upstream wall and the filling in of the tailspill area.
>
> The postspawning stage begins after the female finishes depositing her eggs. Males are no longer attentive. The female is gaunt and spent, but she continues to dig at the gravel with ever-weakening efforts until she dies. This postspawning digging, which may continue for 10 days, becomes shallow, off center, and ineffective. The area of the nest is increased without (after the first day at least) adding to the protection of the eggs.

Each salmon female produces from 2,000 to 5,000 eggs, the number depending upon the species and size of the fish. The time required for the eggs to hatch is regulated by the temperature of the water. One measure that was devised by Seth Green for brook trout was 50 days at 50° F., and plus or minus 5 days for each degree less or greater than this average. This formula can be applied only as a general guide for salmon. Newly hatched fish, called alevins or fry, live in the gravel of the redd, where they are somewhat protected from their larger enemies. They gradually absorb the food in the attached abdominal yolk or umbilical sac. Upon almost complete absorption of the yolk sac, the young fish emerge from the gravel, usually in late winter or early spring, and seek food. The young of some species almost immediately start downstream toward the ocean, but others remain in fresh water for a year or more. The young of pink and chum salmon usually enter salt water soon after emerging from the gravel. The young of the fall chinook salmon may also start down very soon after emergence. The fingerlings of spring chinook, red, and especially silver salmon may remain in fresh water a year or longer.

Why some species of salmon enter salt water soon after emergence from the gravel and why other species remain in fresh water for extended periods, is imperfectly known. Clemens (1952) believes that the behavior of the fish at all ages is the result of a series of interactions between the fish and the environment. Seaward migration of red (sockeye) salmon fingerlings from the Fraser River (British Columbia) is described from this viewpoint. Then, too, there must be some physiological changes in the organism. According to Black (1951), "Young salmon entering the sea must have adequately developed chloride-secreting cells in the gills to survive."

Studies indicate the heavy mortality among young salmon during their periods in stream and ocean. Neave (1953) shows that, of young pink salmon spawned, 13.1 to 1.6 percent enter the ocean, and of those entering the ocean about 2 percent survive to return as adults to their home stream. The mortality of other species seems to be about the same. Under completely balanced conditions, two fish of each brood, a male and a female, would have to survive to spawn—representing 100-percent effective maintenance of the species.

There are years of too few fish and years of too many fish for the spawning areas available, but without outside influence, the runs would tend to stabilize themselves. As in the maintenance of all living things, one species lives upon, and is controlled by, other species to provide a balance throughout the natural environment.

It is well that in nature's scheme of survival the salmon produces so many eggs and resulting offspring, for through the stages of its life the salmon is preyed upon by insects, birds, reptiles, mammals, and fishes. The eggs in the nest provide food for bottom organisms such as crayfish and the water forms of some insects. The fry are taken by birds, other fishes, crayfish, flies, and even by snakes. The young fingerling on its way to the ocean runs a gantlet of larger fish and birds. In the ocean, other fishes and mammals such as seals and sea lions prey upon the salmon. When returning to the river, the adult fish is subjected to attacks by birds and bears in the shallow rapids and on the

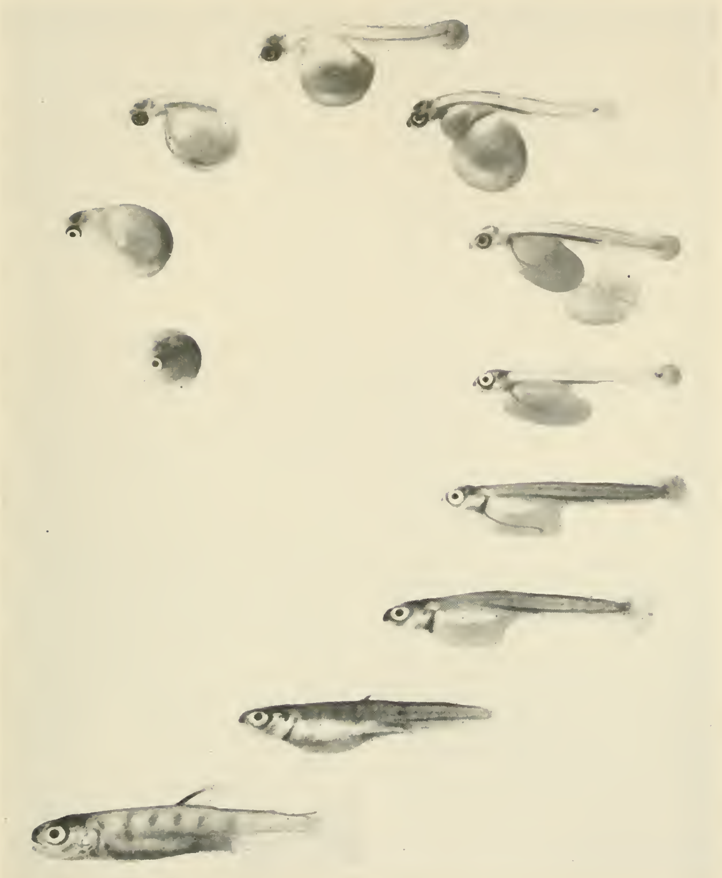

Figure 4.—Stages of development of silver salmon (*Oncorhynchus kisutch*) from eyed egg to feeding fingerling. Approximately twice normal size.

spawning beds. In addition, death from other natural causes, including disease, reduces the brood. Topping all of these hazards are man's nets and hooks, and his dams and pollution, which take a large toll of the remnant of the original brood. Fortunately, nature was so very generous in the stock of fish surviving to enter the rivers to spawn that in most instances a spawning stock was left even after man's take and destruction, although man has been thorough in his harvesting or destruction of entire runs in some rivers.

In general the order in which the species are discussed here is the sequence of their time of entering the streams to spawn, as well as the distance they ascend the streams. Those which run first go farthest. The economic value of the individual fish of each species rates in the order given, but the magnitude and the overall value of the species differ from the order of listing.

The identifying characteristics for the systematic classification of the adults of the various species of salmon are reported by Jordan (1925), Schultz (1936), Clemens and Wilby (1946), and many others; characteristics for the identification of young salmon, by Forester and Pritchard (1944), Schultz and Hanson (1935), and others. The identifying characteristics are not repeated here.

Oncorhynchus tshawytscha: Chinook (Columbia River and south), spring (British Columbia), king (Alaska), quinnat, tyee, Columbia or Sacramento salmon.

Range: Bering Sea to Monterey Bay, but predominant in the Columbia and Sacramento Rivers. Of the 1951 United States and Alaska pack of canned chinook salmon, 61 percent was from the Columbia River, though many of the fish originating in this river were taken at sea or landed elsewhere.

Weight: Average at maturity, from 12 to 40 pounds. Fish of greater average weight are found in Alaska, and fish of progressively smaller weights are taken farther south. The average for the Columbia River is 20 to 22 pounds; and for the Sacramento River, about 16 pounds. The maximum weight of chinook salmon is about 120 pounds, but 50- to 80-pound fish are quite common in Alaskan waters.

The species is the first of the salmon to enter the rivers in the early spring, but the spawning migrations are distinctly separated into spring and fall runs, and often a summer run is considered to exist. The spring run consists of the most desirable fish, entering the rivers in the spring of the year and ascending farthest upstream. The fall run enters the rivers in August and September. The fall fish are somewhat heavier than the spring fish and are more nearly mature upon entering the rivers; the flesh of the fall fish is soft and pale when in the river, and the exterior has the discoloration typical of salmon approaching the time of spawning. The fall chinook do not seek the upper reaches of the streams to spawn. On the Columbia River the bulk of the fall chinooks spawn within 200 miles of the ocean, mostly within a few miles of salt water.

Spawning of spring-run chinooks may occur as early as mid-July; that of the fall run in August and September, and often into October. In some streams south of Sacramento, spawning may take place in midwinter. In one small stream tributary to the Columbia River, fall chinooks of large size have been observed spawning in December, considerably later than is usual in the watershed.

Chinooks usually are 4 years of age at the time of spawning, but a few may be younger and substantial numbers may be 5 years old, while some are several years older.

Young of the spring chinook may remain in fresh water for a year or more after emerging from the gravel, or they may enter the ocean within weeks of hatching. The latter is generally true of the fall chinooks. Studies indicate that the fish that migrate to the sea at the earliest time attain the greatest mature size (Van Hyning 1951), but it is probable that the smaller the fish upon entrance into the ocean, the less the chance of survival.

Chinook salmon are most abundant in the Columbia River, and the spring run used to migrate hundreds of miles to the headwaters. The power and irrigation dams erected in the upper river, therefore, have been particularly harmful to this species. The blocking of the spring chinooks from major spawning areas, together with pollution and overfishing, has resulted in a major reduction of spring-chinook populations in the Columbia River, as well as in other streams. The fall chinook has, in most watersheds, been able to reproduce satisfactorily in the lower tributaries, but water-use projects also threaten these fish.

Of interest to this discussion is the appearance of "grilse," "jacks," or precocious chinook males in the spawning migrations. These males usually are 3 years old, whereas the average age of chinooks is 4 years. These smaller fish are fully mature but are not utilized in hatchery spawning operations and are at a disadvantage in natural spawning. It is reported that the numbers of "jacks" or red salmon entering the Fraser River are indicative of the size of the run to be expected the following year (Gilbert 1931-34, Rounsefell and Kelez 1938). The writer was unsuccessful in attempts to correlate the returns of "jack" fall chinooks to specific streams in the Columbia River Basin with the returns of average-age fish the following year.

Oncorhynchus nerka: Red (Alaska), sockeye (British Columbia and Puget Sound), blueback (Columbia River), Fraser River salmon. Landlocked forms are known as kokanee, silver trout, yank, or little redfish.

Range: Bering Sea to the Columbia River, predominating in suitable streams north of Puget Sound; rarely found south of the Columbia River, although in 1953 five "strays" entered the traps at the Coleman Hatchery (California) of the Fish and Wildlife Service in Battle Creek, tributary to the upper Sacramento River.

Weight: Columbia River average, 3 pounds; British Columbia and Alaskan waters, up to 7 pounds, with maximum about 16 pounds.

The red salmon, like the spring chinook, often ascends the rivers for great distances. It spawns only in streams having lakes in their headwaters. (Rare exceptions to this rule have been reported.) The adult red salmon remains in the headwater lake until the reproductive products are almost fully developed and then ascends the smaller streams tributary to the lake to spawn. A few fish may spawn in gravel in shallower lake areas where springs issue from the bottom, or in the gravel of the outlet from the lake. Red salmon generally are 4 years of age at spawning; a few may be younger and many may be 5 or more years old.

The young red salmon, after their emergence from the gravel, descend to the lake and remain there for a year or more before following the river to the ocean. As red salmon feed upon plankton (minute organisms in the water), the length of residence in the lake may be determined by the abundance of plankton. Some of the young fish may remain in the lake throughout their lives, spawning and dying at 4 years of age like their sea-grown brothers but usually attaining only about one-half their size. The progeny of these lake-dwelling forms may descend to the ocean and return as normal sea-run specimens.

The run of red salmon into the rivers begins in June and continues throughout August. Spawning may start as early as July in northern streams and be concluded in September, but in the upper Columbia spawning is complete early in October.

Oncorhynchus kisutch: Silver, coho, silversides.

Range: Sacramento River to Bering Strait, but most abundant in Puget Sound and British Columbia waters. Present in most streams of the Pacific coast.

Weight: In Alaskan waters the species attains an average weight of about 14 pounds, but in the streams to the south the weight is considerably less. Maximum weight is about 30 pounds.

Most mature silver salmon enter fresh water from late September to early November, although some may appear earlier or much later. Of the five species of salmon, the silver is best adapted to diverse conditions. It spawns in the very headwaters of streams as well as very close to salt water. The wide variations in time and place of spawning result in differences in time of hatching and in development of the fry and fingerlings.

Silver eggs usually hatch during the early spring, and a few of the young fish migrate soon after to the ocean. Most of the young fish remain in fresh water throughout the summer and the following winter, usually migrating to the ocean early in their second year. Because of this tendency to remain in fresh water for a year or more, the silver, like the red salmon young, must depend upon the food supply of a limited fresh-water area, and survival probably is jeopardized during years of heavy spawning and subsequent overutilization of available food.

Investigations have indicated that young silver salmon in the ocean may remain relatively close to their home stream, often remaining in estuaries and inside passages while making remarkable growth. The majority return to their respective streams to spawn during the fall of their third year.

The silver salmon is taken, along with the chinook, in the offshore commercial troll fishery and is caught by sportsmen throughout the year in some bays and estuaries.

Oncorhynchus gorbuscha: Pink or humpback.

Range: Washington State to northwest Alaska, but most abundant northward from Puget Sound. Rare appearances in California (Smedley 1952).

Weight: Smallest of the Pacific salmon, averaging only about 5 pounds and rarely attaining a weight of 9 pounds.

The pink salmon usually reproduces in the smaller streams a short distance from the sea and often just above tidewater. With the approach of the spawning season in August and early September, the fish develop a prominent hump on the back (from which is derived one of the common names of the species) and a distortion of the jaw. Each female deposits about 2,000 eggs. The fry, upon emergence from the gravel, migrate at once to the sea.

The pink salmon invariably have a life cycle of 2 years. In some areas there is a large run every second year.

Oncorhynchus keta: Chum or dog.

Range: Columbia River northward, especially abundant in Alaska. Occasionally taken in the Sacramento River.

Weight: Average about 10 pounds; maximum, 30 pounds.

Chum are the latest of the salmon to run, usually reaching the streams and spawning from October through December. The majority of the migrating adults are 4 years old, but a large proportion of the run are 3-year fish. Spawning is in the lower tributaries of the main rivers and in a great many of the smaller streams. The species does not ascend the streams for any

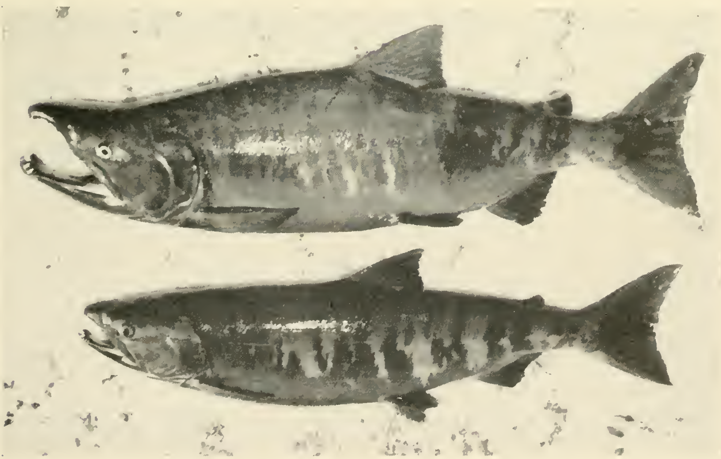

FIGURE 5.—Chum salmon (*Oncorhynchus keta*) at spawning time. Male upper, female lower.

great distance, usually spawning very close to salt water. Upon emergence from the gravel, the fry migrate to salt water.

The chum is the least valuable of the Pacific salmon. The flesh deteriorates rapidly after the fish enter fresh water.

Salmo gairdneri: Steelhead trout.

Range: Southern California to western Alaska.

Weight: Average is about 12 pounds, but individuals may exceed 35 pounds.

Steelhead are included in this account because of their close association to salmon in habits, their entrance into commercial and sport fisheries, and their inclusion in hatchery operations along with the salmon.

The steelhead trout is a rainbow trout that has spent part of its life in the ocean and ascends the coastal streams to spawn. It does not stop feeding upon entrance into fresh water, nor does it necessarily die after the first spawning.

Steelhead trout apparently range widely in the ocean along the coasts, and it is believed that they return to their native streams to spawn. The steelhead may enter fresh water in almost any month, although they do not spawn until late winter or spring

Steelhead adults may enter practically all streams. They may ascend to the extreme headwaters or spawn very close to salt water. In this respect they are similar to silver salmon.

The young steelhead trout spend 1 or 2 years in fresh water and 2 or more summers in salt water. Adults may enter the rivers in their third, fourth, or fifth years. Like the Atlantic salmon, they may spawn more than once, returning to the sea after each spawning, but it is reported that less than 15 percent survive to spawn a second time.

Steelhead enter into the commercial fishery for salmon to a considerable extent and are much sought after by sport fishermen.

The Homing Instinct

Jordan (1925), discussing the theory that Pacific salmon return to their home streams to spawn, reiterated his 1880 statement that "we fail to find any evidence of this [homing] in the case of the Pacific-coast salmon, and we do not believe it to be true. It seems more probable that the young salmon hatched in any river mostly remain in the ocean within a radius of 20, 30 or 40 miles of its mouth." He believed that the salmon return to their home stream by chance rather than through instinct. Nevertheless, there is little doubt that salmon do possess an instinct that leads them from the ocean to their home stream and hundreds of miles upstream to the particular tributary of their birth.

An interesting experiment was undertaken at the Spring Creek hatchery of the Fish and Wildlife Service at Underwood, Wash., some 200 miles upstream from the mouth of the Columbia River. At this hatchery a run of 10,000 to 18,000 fall chinook salmon has been established: the adults return to the small stream where they were released as fingerlings, where no adult salmon had appeared before the establishment of the hatchery in 1899. In 1951, 43 of these returning adults were marked, loaded into a tank truck, and released 18 miles farther up the Columbia River. Of these, five returned downstream, past the mouth of the Big White Salmon River (where thousands of salmon spawn) to the fish ladder at the hatchery, and ascended again to the hatchery spawning ponds. Others were caught in the fishery, and a few were taken elsewhere. Although the results of this experiment are not conclusive, they indicate that salmon do return to their own particular streams whenever possible. Rich (1939) states:

> The evidence also shows clearly that the Pacific salmon return from their life in the sea predominately to their home streams thus justifying acceptance of what is known as the "home stream theory."

In recent years a number of studies of the ocean movements of salmon, particularly chinook and silver, have been reported (Van Hyning 1951, Kauffman 1951, Neave 1951, Fry and Hughes 1951.) These studies indicate the extensive coastwise movements of some of the salmon species. British Columbia investigators (Pritchard 1934, Mottley 1929) found that when young chinook salmon leave their natal streams along the coasts of Washington, Oregon, and California, and particularly the Columbia River, they disperse northwesterly along the United States and British Columbia coasts. Some apparently go southward. It has been shown that many of the adult Pacific salmon that have been captured in the ocean, tagged and released, then travel hundreds of miles in the ocean before entering streams to spawn. Adult chinook salmon were tagged in 1928 by the Bureau of Fisheries (now the Fish and Wildlife Service) off Baranof Island, Alaska. Of the recoveries 60 percent were taken in the Columbia River, indicating the great distance traveled by these salmon.

It may be concluded that young salmon of some species do migrate great distances in the ocean and upon reaching maturity almost invariably return to their home stream to spawn.

The impulses or guides that direct the fish from the ocean to the natal stream and to the proper tributary of that stream are unknown. When the young salmon enters the ocean, the search for food causes him to travel many hundreds of miles and often go great distances from his home stream. At maturity, when he is 1 year to more than 3 years old, he starts for his particular stream, proceeding rapidly and in a direct route. This is indicated by the investigations of Pritchard (1934), Mottley (1929), Rich (1939), and others. The salmon, hundreds of miles from his native stream, possibly depends upon currents, varying salinities of the ocean, geographical features, or the sun or moon to direct him. Perhaps when the salmon feels or tastes or smells the flow of his particular stream in the ocean, he recognizes it by senses more accurate than the finest analytical equipment man has devised. The delicate perceptiveness of the salmon not only enables him to enter the proper main stream but also leads him upstream to the exact tributary from which he emerged as a small fish. In reaching this stream, he probably will have passed and ignored many other streams flowing from watersheds similar to the one for which he is bound. Many such streams are identical so far as man can determine, but the salmon senses a difference. Hoar (1951) and Black (1951) are of the opinion that the thyroid hormone indirectly influences the migration of fish.

It is believed that the entrance of salmon into their natal stream to begin the upstream journey to their species' spawning areas is determined neither by chance nor by degree of maturation of sexual products. Lloyd Royal (1951) of the International Pacific Salmon Fisheries Commission presented interesting facts and theories on this point. Years of investigation of the Fraser River (Canada) stocks of red (sockeye) salmon have revealed that there are distinct races entering the river and bound for spawning areas at greatly varying distances from the ocean. After "loitering" in the general area at the mouth of the Fraser for a time, each race will quite suddenly move upstream toward its tributary-stream spawning area. It appears that the red salmon of the various races time their departure so as to arrive at the spawning area, "whether 30 or 730 miles from the sea," at the period of appropriate water temperatures at that point. Too-early arrival results in ineffectual spawning during high water temperatures. Late arrival results in nonproductive spawning because of low temperatures. Studies in other places have not been so intensive as those on the Fraser, and consequently neither corroborative nor contradictory evidence is available; but the Fraser River study suggests the effect that manmade obstructions have on the races by delaying individuals on their upstream migration.

Economic Value

The most recent complete records compiled by the United States Fish and Wildlife Service and by the Department of Fisheries of Canada reveal the magnitude and importance of the commercial salmon fishery to the economy of the Pacific coast.

In 1951 the commercial fishermen operating in Alaskan waters landed 277 million pounds of salmon, for which they received 32.4 million dollars. Pink, red, and chum salmon made up the bulk of the catch. The salmon prepared for market, including 165 million pounds of canned salmon valued at 79 million dollars, totaled 189 million pounds valued at 86 million dollars.

The catch in the waters of Oregon, Washington, and California for 1951 totaled 98 million pounds valued at 20 million dollars to the commercial fishermen and at about three times that value for the final market product. Chinook, silver, and chum made up the bulk of the catch. The landings in Washington, Oregon, and California were 77, 14, and 7 millions of pounds, respectively.

FIGURE 6.—Brailing salmon from a floating trap in Alaska.

Statistics for the 1951 British Columbia commercial catch are 202 million pounds landed with a value of 28 million dollars. Sixty percent of the poundage resulted from chum and pink catches. Of the total poundage, 44 percent was taken by seine and 41 percent by gill net.

The 1951 total of the commercial salmon fishery of the Pacific coast of North America is 577 million pounds with a value of 80 million dollars *to the fishermen.*

In addition to the commercial fishery, there is a tremendous sport fishery from southeastern Alaska to the Sacramento River. It is almost impossible to estimate the catch and value of this fishery with any degree of accuracy. An attempt has been made to determine the sport catch from the Columbia River. The figure arrived at is a catch of 2 million pounds annually. If all of a sport fisherman's expenditures in connection with his seeking of salmon were charged against his catch, the flesh would certainly be valued at several dollars a pound. In one of the best studies of its type, Wallace (1952) determined that in Washington State the 400,000 fish-and-game license holders spent 36.7 million dollars in 1950 for sport fishing. The license holders who participated in the survey reported an average expenditure of $125 per capita for fishing.

The exceptional nutritive value of salmon flesh is well known. This flesh is quite as valuable as beef and other meat products and even exceeds beef in desirable components such as iodine, phosphorus, and fluorine.

Early History and Objectives

The modern program of artificial or hatchery propagation of Pacific salmon had its beginning at the Baird Station (California), on a tributary of the upper Sacramento River (Stone 1878). This egg-taking station was established by the United States Commission of Fish and Fisheries (now the Fish and Wildlife Service) for the purpose of collecting eggs of the chinook or quinnat salmon for shipment to foreign waters. Additional egg-taking stations were later established in Oregon and Washington.

As the salmon fishery expanded and became more efficient, exploitation reduced the runs of salmon to dangerous lows. In many places fishing became unprofitable, although the production potential of the spawning areas of the streams remained constant. Attempts were made to maintain the runs of salmon or to restore them to former levels of abundance through hatchery propagation. Salmon hatcheries were established for the purpose of taking and incubating eggs and releasing the resulting small fish or fry.

Salmon hatcheries are now recognized as tools to assist in the management of fisheries. The product of the hatchery, regardless of size of the fingerlings, is not considered an end in itself. There is a definite need for the hatchery output of young salmon to counteract the increase of human population, the resulting industrial development, and the intensified fishing.

In the early years of commercial fishing for salmon, the fish had free access to their original spawning areas in the hundreds of coastal rivers. The advance of civilization gradually limited the areas available for spawning. The modern salmon hatchery is in existence to counteract so far as possible the harmful influences of man. Major dependence for maintenance of the salmon runs must remain with natural reproduction. The primary purpose of the hatcheries is to provide stock with which to restore or develop runs, although the hatchery-reared salmon contribute to a considerable degree directly to the catch. The maintenance of a fishery, however, must depend largely upon regulations and the removal of blocks to migration, including pollution, in order that salmon may ascend to spawning areas. Stream and lake areas must be available for the early rearing of the salmon.

In the 1930's it was realized that, in order to assure adequate return for the fishery and for spawning, some species of salmon must be reared to large size before their release. This continues to be the general hatchery practice.

Circumstances Requiring Hatchery Propagation

Probably the best example of the harmful effects of man's progress upon anadromous fish is in the Columbia River Basin. It has been established that at least half of the original spawning and rearing area of the Columbia River watershed has been made unsuitable or inaccessible to salmon and steelhead trout. Dams have been responsible for this reduction of area available for natural reproduction. The hundreds of small dams erected many years ago in the Columbia Basin in connection with logging operations and for irrigation purposes deprived salmon of headwater spawning areas, as did Grand Coulee and other large dams. Many additional large dams are planned for construction in the Columbia River and these will further limit salmon migrations or make the remaining spawning areas more difficult to reach. Even if the adult fish surmount the dams and reach the spawning ground, the seaward-migrating fingerlings will suffer heavy mortality in passage over the dams and through the power turbines.

Another factor that has impaired the salmon resources is pollution from industrial sources. In the Willamette River, tributary to the Columbia, a pollution block destroyed the substantial chinook runs not only by blocking the upstream migrations but also by causing the death of any fingerlings migrating downstream during the summer and fall. Fortunately, very few streams of the Pacific coast are so polluted as to destroy runs entirely. Pollution was one of the causes for the almost complete loss of Atlantic salmon in the New England States. Modern regulations and laws have tended to reduce this threat to salmon during the relatively recent industrial development of the West. In areas like the Willamette River, where pollution has actually blocked salmon migration, substantial improvement has been effected through

FIGURE 7.—Fishways in foreground and on far shore at Bonneville Dam on the Columbia River.

the efforts of State and Federal agencies. It is anticipated that the Willamette block will be eliminated by 1954. However, sawmill and mining wastes, as well as warm waters from atomic-energy plants on many streams have tended to decrease the suitability of the waters for salmon, as well as for humans.

Early logging operations were detrimental to salmon. All cover was removed from the hills, logging debris was dumped into streams, and logging dams were constructed wherever convenient. The net result was extremely harmful to anadromous fish. Rapid runoff waters from the bare hills silted streams and spawning beds, high- and low-water periods were accentuated, waters often became too warm for salmon survival, and dams blocked upstream migration. Only in recent years have our forests been managed on the basis of sustained yield. Many of the heavily logged watersheds have now developed good second-growth cover, and present-day logging practices and laws are more conducive to preservation of salmon habitat.

A large-scale salmon-salvage program was undertaken on the upper Columbia River in 1939, when construction of Grand Coulee Dam blocked salmon from hundreds of miles of spawning area. This program transferred the runs of salmon that formerly ascended to the areas above Grand Coulee to tributaries below the dam. As part of the salvage program, several salmon hatcheries were constructed. The chinook and silver salmon ascending the river to Grand Coulee Dam have been maintained in predam numbers, and the populations of red salmon have shown tremendous increases (Fish 1948). The hatchery production and release of fingerling red salmon can definitely be correlated with the return of the adult fish to the fishery 3 years later.

On the Sacramento River in California, the construction of Shasta Dam stopped salmon from ascending to the major spawning areas of the watershed. A hatchery (fig. 1) was constructed on Battle Creek, a tributary below the dam, and adult salmon ascending to Keswick Dam immediately below Shasta were trapped and transferred to Battle Creek. This operation has resulted in maintenance of the salmon in the Sacramento River—hatchery operations have provided necessary stock, and cooler waters issuing from the reservoir have made the river below the dam more suitable for salmon spawning. The hatchery operation has resulted in definite and substantial contributions to the fishery in the San Francisco Bay area, as well as in the coastal waters as far north as Vancouver Island. The improvement of conditions for spawning of salmon below Shasta Dam has not been duplicated in connection with the construction of any other major dam.

To mitigate the losses of salmon expected to result from the construction of additional dams in the Columbia Basin, the Fish and Wildlife Service, together with the fishery agencies of Idaho, Oregon, and Washington, evolved in 1947 a plan known as the lower Columbia River fisheries development pro-

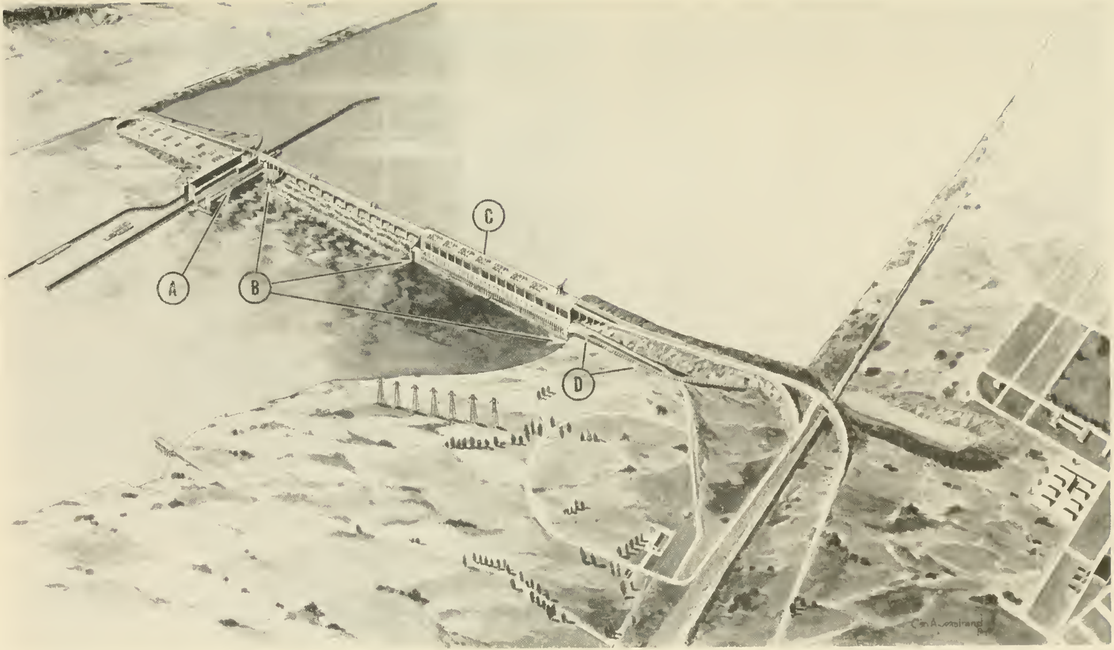

Figure 8.—Sketch of McNary Dam on the Columbia River showing fishways for the passage of salmon: A, Washington fish ladder; B, entrances; C, powerhouse; D, Oregon fish ladder.

gram. This had as its objective the maximum development of populations of salmon in the streams tributary to the lower Columbia River. Under this program, log dams and debris were removed from streams, and natural waterfalls were blasted or laddered to permit free access for salmon to all possible spawning areas. A large number of hatcheries are producing fingerling salmon that are stocked into barren streams or used to develop as rapidly as possible the maximum populations of salmon in all suitable streams. Most of the dams to be constructed will include fish-passage facilities to permit the maintenance of at least a part of the upper-river runs of salmon. As a result of these activities, it is anticipated that a substantial portion of the average (1940–49) sport-commercial-Indian catch of 31 million pounds of salmon a year attributable to production from the Columbia River Basin can be maintained.

Irrigation developments have most consistently been destroyers of young salmon. On their migration toward the ocean, large numbers of the young fish using any major downstream flow enter irrigation ditches and merely provide fertilizer for the farm fields. During the past 20 years, primarily in the Columbia River watershed but also in other streams of the Pacific coast, the Fish and Wildlife Service and the fishery agencies of Washington,

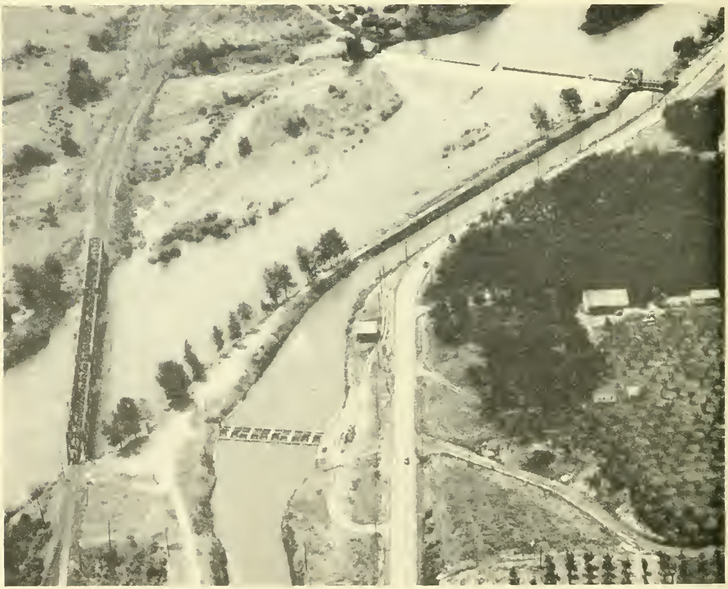

FIGURE 9.—Fish screens located in irrigation canal to stop young salmon and return them to the Yakima River.

FIGURE 10.—Revolving fish screens in irrigation canal. Waterflow from right to left.

Oregon, and California have installed or have required the installation of hundreds of screens to prevent entrance of the young fish into the irrigation ditches. On some of the very large Federal irrigation developments such as the Delta-Mendota diversion, at Tracy, Calif., complicated fish-screen installations are required. Such screens save many thousands of young fish annually. In many streams, however, the diversion of water for irrigation has resulted in the complete loss of spawning areas, as the water remaining has been insufficient to support fish life. Often artificial propagation must be relied upon to replace these losses.

Probably the greatest threat to the resource is in the contemplated construction of power dams in the streams of Alaska and British Columbia, where tremendous hydropower potentials exist. Piecemeal reduction of available spawning areas has been most harmful. The construction of a dam on a relatively small stream usually is not considered particularly harmful to the overall salmon production, but in the aggregate these projects destroy major portions of the resource. It is anticipated that large segments of the remaining salmon populations will be destroyed by the construction of dams, and that the salmon hatchery will be necessary for partial preservation of some of the affected populations.

A comprehensive research program is expected to determine means by which adult salmon may be passed over dams without delay and means by which the young salmon may proceed downstream without suffering substantial mortalities in passage through turbines or over spillways. A popular belief is that if fish ladders or fishways are provided in a structure for the upstream passage of adult salmon, the problem is solved. *This is far from the truth.* A salmon, as previously stated, has stored energy which is sufficient only to maintain himself and develop reproductive products during the diffcult journey from the ocean to the spawning area. Furthermore, he follows a time schedule and must arrive at the spawning area during the brief period when water temperatures are suitable for successful spawning. His time schedule does not take into consideration one or more dams at each of which he may be delayed several days before finding and ascending the fish-passage facility.

Losses of young salmon when passing a dam while on their way to the ocean are substantial. Studies at 62-foot Bonneville Dam on the Columbia River indicate substantial loss among young salmon, and current investigations of the Washington Department of Fisheries and of the International Pacific Salmon Fisheries Commission at 3 dams over 100 feet high reveal losses of 35 percent or more among downstream migrant salmon.

It is apparent from the foregoing that fish ladders alone will not preserve salmon runs. The adults must quickly find and easily ascend the ladders, and the young salmon must be led to safe passageways by some as-yet-undeveloped device.

There are still other undesirable features that develop upon the construction of many dams. Species of fish that prey upon young salmon and are not themselves desirable for sport or food find reservoirs behind some dams conducive to their existence and increase. In a single reservoir, and particularly in a series of impoundments such as is planned for the Columbia River, predatory species will cause major losses among young salmon. Also, reservoirs often inundate spawning areas, making them unattractive to spawning salmon because of water depth and absence of quite rapid flow over and through the gravel.

Hatchery propagation is not expected to be able to compensate for or to mitigate satisfactorily the losses caused by dams and pollution, but hatchery-reared salmon can help maintain populations at the highest possible level of abundance by supplementing natural reproduction.

Methods

The salmon hatcheries operated by the fishery agencies of California, Oregon, and Washington, and by the United States Fish and Wildlife Service in the three States, propagate, collectively, chinook, red, silver, chum, and pink salmon, and steelhead trout. There are differences in techniques and procedures employed by different hatcheries, usually because of the species propagated and the physical characteristics of the watershed and the fish-cultural station, but generally the methods of salmon propagation at hatcheries on the Pacific coast are quite similar.

The species of salmon differ considerably in characteristics, and these differences complicate hatchery propagation. The adults of one species may be difficult to trap and hold to spawning, and the young of another species may be difficult to rear. Differences in these and other respects are found within species in the same watershed, although the hatchery water supply or physical characteristics may determine the extent of deviation within species.

Although more detailed descriptions of procedures and equipment will be given, it is well to outline briefly the essential steps taken to propagate salmon at a hatchery. The methods are quite similar to those employed at trout hatcheries.

The first requirement is adult salmon from which eggs and sperm may be secured. These brood fish are trapped by placing a rack or racks across a stream up which the mature fish are migrating. "Ripe" females are selected and killed, and the eggs are removed from the body cavity. The milt or sperm of males is expressed onto and mixed with the eggs. After a few minutes the surplus sperm is washed from the eggs and the latter are taken into the hatchery, where they are placed in baskets or on stacked trays so arranged in the hatchery troughs as to permit circulation of water among the eggs. At the end of the incubation period, which varies according to the water temperature (50 days at 50° F.), the small fish or fry emerges from the egg shell with an attached umbilical or yolk sac that supplies sustenance until the fish is capable of taking food by mouth, approximately 3 weeks later.

When the young fish are free-swimming, they are fed in the hatchery troughs for a time and then transferred to outside rearing ponds. There the fish continue to receive food and grow to the appropriate size for release. In the early years of salmon culture, practically all young fish were released as unfed fry. In recent years, as many have been held for pond rearing as facilities will permit. Exceptions to this are the chum and pink fry, which, under natural conditions, immediately seek salt water and so are released from the hatchery. Many of the fall chinook salmon also are released as fry or after a few weeks of rearing, principally because of a lack of rearing space. On the other hand, where it is possible to do so, red, silver, spring chinook, and steelhead trout are held in rearing ponds for a year or more.

Some comments regarding the individual species of salmon and of steelhead trout are of interest and pertinent to a discussion of salmon culture but need not be included in the detailed descriptions that follow.

As has been mentioned, the chinook-salmon runs into the rivers are quite arbitrarily divided into two groups. The spring chinook adults enter the rivers in the spring and early summer and usually ascend the rivers farthest, spawning from midsummer to about October. The fall chinooks enter the rivers from midsummer to September, spawning from August to October in relatively lower reaches of the rivers and often close to tidewater. The spring chinook is in prime condition when it enters the rivers, having stored fats for sustenance on a long journey inland; and usually the female contains immature or green eggs that will not be developed for spawning for many weeks or perhaps several months. The fall chinook, on the other hand, usually is not in prime condition when it enters the river; the flesh deteriorates rapidly, as the spawning time is often a matter of only days or possibly 2 or 3 weeks.

It is evident that to trap the spring chinooks for spawning at the mouth of a long river would require that these fish be held for many weeks or several months before the sexual products would be "ripe" and suitable for artificial spawning. Successful holding of adult spring chinook, even in carefully constructed "natural" ponds or streams sections, has proved very difficult. Experience at several hatcheries has revealed the difficulties to be encountered in such holding. At a few points spring chinook adults have been retained successfully until mature; the success appeared to be due to the water supply. There may be also a psychological as well as a physiological effect upon the fish because they are in foreign waters and not en route to their home streams. Theoretically, it would be possible to trap these spring-run fish immediately below their spawning areas, but the cost in relation to the relatively few fish that would be taken in the small tributaries would be excessive. Even here, too, many quite green fish would be taken.

The fall chinook adults are quite readily trapped and spawned in the tributaries of the lower reaches of the various watersheds. There the fish are almost ripe and usually need be held for only a few days before spawning. The fall fish do not "resent" being held in ponds or between racks as do the springs. The fall fish are much more docile and are quite readily "herded" or led where most convenient for accomplishment of spawning.

After the eggs of spring or fall fish are taken and placed in the hatchery, there is no appreciable difference in the incubation. Maximum returns to the fishery are secured by rearing the young spring chinooks for about 1 year before releasing them into the streams. Such rearing should be with as nearly natural water temperatures as possible. Experience has shown that when the spring chinook fingerlings attain a size of 3 to 5 inches they exhibit a decided desire to migrate downstream. In hatcheries where warm spring water is available, the tendency is to provide warmer than natural waters for rearing, resulting in unnaturally great food intake and growth of the fish. Thus, the migration urge may come upon the young fish, requiring their release during periods of severe cold when there is anchor ice in the streams or other factors unfavorable for stream survival. The fall chinook fingerlings do not generally exhibit such migration urges.

The adults of silver and red salmon trapped long before their spawning period also are difficult to hold in ponds or streams without mortality, but experience with these species has not been so extensive as with the chinooks. Generally artificial spawning of silver salmon takes place near the spawning areas, and the red salmon are trapped and spawned as they ascend streams from lakes to spawn. Steelhead trout adults, too, when trapped along with salmon in the fall, are difficult to hold over the winter for spring spawning.

Studies by the Washington Department of Fisheries have shown that silver-salmon young should be reared in the hatchery ponds until their second spring and then released. The same appears true of steelhead-trout young. Yearling red-salmon fingerlings have produced excellent returns when released into their "home" lake in the fall of the year.

Chum salmon usually are almost mature sexually when they enter fresh water, and the adults can be readily trapped and spawned. Under natural conditions the young fish proceed to salt water immediately after emergence from the gravel, and the usual hatchery practice is to release the young fish at that time.

The fall chinook salmon is the species most extensively propagated at most of the salmon hatcheries. It is probably the easiest to secure and handle in the hatchery. Furthermore, the fall chinook is native to the lower reaches of the watersheds, and therefore usually below major dams, and can be maintained and developed most readily. There is economic justification, too, for concentration upon the propagation of fall chinook in those areas where manmade conditions require the assistance of the hatchery for the maintenance of the salmon resource. All of the species require about the same capital and annual investment for hatchery production to secure like returns in numbers of adult fish, but the fall chinook, attains the greatest adult size and thus contributes more pounds of fish per dollar invested.

The following descriptions of methods, procedures, and equipment are of those generally employed in the propagation of fall chinook salmon. The few deviations from this pattern to propagate other species will be noted if pertinent.

Spawn taking

When a group of adults is available in the racked stream area or in the holding pond, and the majority are mature, the fish are brought together in a small area for sorting and spawning. The usual spawning run consists of both sexes in about a 50–50 ratio.

Experienced men sort the salmon, placing males and ripe females in separate enclosures. Jacks or precocious males, as well as surplus males, are killed. Green females are returned to the pond for further maturation.

The indication of ripeness in the female is the separation of the eggs in the ovaries, but it is not usually possible to determine this by an exterior examination. Experienced spawntakers rely mainly upon the general appearance of the female and upon the looseness and position of the eggs as determined by gently passing the hand over the abdomen. Picking the fish up and gently pressing on the abdomen will result in the extrusion of eggs from the vent, but this method is not always indicative of the maturity of all eggs, as those near the vent may be ready for spawning while others further forward may not have separated. Under natural conditions, spawning by each female is under way for several days, the eggs being released as they become mature. It is impractical in artificial spawning operations to extend the spawning of each fish over several days, so quite often the spawning of apparently ripe females is delayed for an additional day in order to be certain that all eggs are separated, which results in improved fertilization of eggs. However, where large numbers of adults are handled, as at some of the lower Columbia River stations, space does not permit this practice.

Usually all males attending the females are ripe and will produce adequate sperm. Only 1 male is considered necessary for the fertilization of the eggs of 3 or 4 females when artificially spawned. As the sexes appear in approximately equal numbers the surplus males usually are removed, particularly when large numbers of fish must be handled and space is at a premium. In the event that there is a shortage of males, those present are utilized several times, as they create new sperm to replace that taken.

When the sorting of fish is completed and all ripe females and a

FIGURE 11.—Fall chinook salmon being prepared for spawning.

sufficient number of males are corralled, workers kill the fish by sharp blows on the top of the head. The salmon are laid in a row, three females and a male, and so on. The tail of each fish is cut to drain blood from the body so that the blood will not later become mixed with the eggs and interfere with fertilization.

The spawntake holds a female salmon vertically by inserting one hand in the gills, with the back of the fish hanging between his knees. The vent is held just above a 10- to 14-quart pail or bucket. A knife, usually one specially made for this operation is inserted in the vent and drawn upward toward the head, the body wall being cut to one side of the ventral fins and to the top of the body cavity (fig. 12). If the eggs are fully separated, they will pour into the bucket.

After the eggs have been stripped from about three females, which is done rapidly, the sperm of a male is extruded into the pail and thoroughly hand-mixed with the eggs. Often a small amount of sperm will be placed in the bottom of the bucket before eggs are placed therein, and sperm may be introduced after eggs have been taken from each female.

The foregoing process may be repeated until the bucket is about two-

FIGURE 12.—Spawning chinook salmon at the Coleman (Calif.), Hatchery of the Fish and Wildlife Service: Left—eggs being removed from female; right—extruding spermatozoa from male onto eggs.

thirds full of eggs. Within 2 minutes, if the eggs and sperm have been thoroughly mixed, all eggs should be fertilized, each egg having been entered by one sperm only. The bucket of eggs is then gently immersed in clear water to permit the flow of water into and around the eggs so that they harden. Excess sperm which may adhere to the eggs and encourage the growth of fungus is washed from the eggs. Recently a device for better washing of eggs has been developed by the Fish and Wildlife Service. This device consists of a perforated inner bucket or pail which may be removed and set in running water to wash all the surplus sperm from the eggs. (See fig. 12.)

Each pail of washed eggs is carried into the hatchery building, where the eggs are deposited in trays or baskets for the incubation period.

Incubation of eggs

When the freshly fertilized and washed eggs are taken into the hatchery, they are placed on trays or in baskets in troughs through which water is circulated at all times.

The temperature of the water determines the rate of development of the salmonoid eggs and therefore the number of days required for hatching. The highest sustained temperatures should be less than 60° F. Slightly warmer waters may result in excessive mortalities. On the other hand, prolonged periods of water temperatures below approximately 34° F. result in a very long incubation period and often in the production of abnormal fry in which the yolk material is not absorbed. In waters having an average temperature of 50° F., it can be expected that the salmon (or trout) eggs will hatch in about 50 days, and that the fry will have absorbed the yolk sac in about 3 weeks and will then start taking food by mouth. The rate of development of the eggs and fry is important to the routine fish-cultural operations.

Throughout the various stages of development the salmon egg is subject to mechanical injury. There are some stages in which the egg is much more susceptible than in others, a condition that influences hatchery procedures. Two principal phases of development of the salmonoid egg are commonly recognized by the fish culturist. The "green" state is that period of development from the fertilization and water hardening of the egg to the closing of the blastopore. During the first 24 to 48 hours of this phase the eggs are quite resistant to mechanical injury, and it is during this period that the eggs must be placed on the trays or in baskets to remain undisturbed until the green stage is complete. Usually the eggs are so placed within a few hours of spawning. The remainder of the period of egg development to hatching is called the "eyed" stage and is characterized by the appearance of the eyes of the embryo through the shell of the egg. After all eggs are eyed, they can be handled gently. It is common practice in salmon and trout hatcheries to shock the eggs at this time to rupture the vitelline membrane of undeveloped eggs. This is done by dropping the

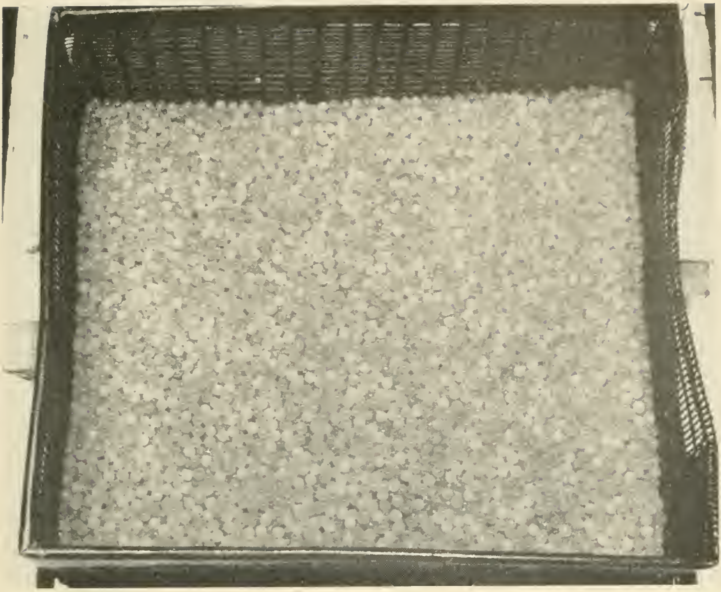

FIGURE 13.—Salmon eggs in basket raised from water.

eggs several inches into water, with the result that infertile or undeveloped eggs turn white. These eggs, which would eventually become dead tissue and encourage fungus growth, are removed.

Shocked eggs are replaced on the stacked trays in the water or, if they were in baskets, they may now (or later) be placed on trays, to remain there until hatching is complete and the fry have absorbed most of the yolk sac. The young fish are then placed directly in the troughs, where they are fed finely ground meats. In some salmon hatcheries the eggs are permitted to hatch in the baskets, and the fry drop through the wire mesh to the trough bottom.

Dead eggs provide the tissue for the growth of fungus that, if not controlled or removed, will spread over and smother surrounding eggs. In view of the delicacy of the eggs during the green stage, it is not desirable to attempt to remove the dead eggs because adjacent eggs might be injured. It is possible to prevent or inhibit growth of fungus by routine chemical treatments of the eggs, and during the green stage such treatments are a weekly routine at many hatcheries. Burrows (1949) describes this treatment.

Silt carried in the water supply can also coat and smother eggs. For this reason and others a clean water supply for the hatchery is desirable. Silt can be removed by passing the water through a filter

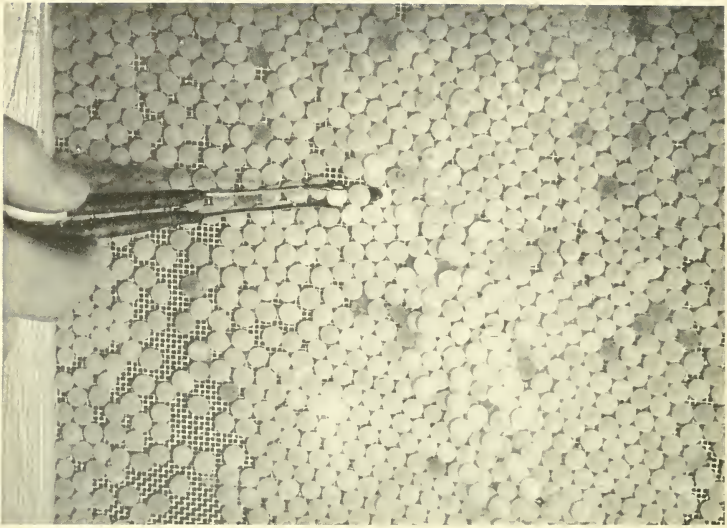

FIGURE 14.—Picking dead (white) eggs from tray. A few newly hatched fry can be seen and the darker colored eggs are about to hatch.

before the water enters the hatchery. Silt also may be drawn from the stacks of eggs by raising dam boards between stacks and drawing the water down the entire trough. This should not be done during the critical development stages when the eggs are green.

Rearing

Most hatcheries have a number of ponds in which the young salmon are reared to larger sizes. It is a generally accepted principle that the larger the fish are when released, the better the chance of survival to maturity. Chum and pink salmon fry normally migrate to salt water immediately upon emerging from the gravel of the stream bed, so these species are released from the hatchery as fry. Fall chinook salmon fry usually are reared in hatchery ponds for a few weeks to several months, the time depending upon the capacity of rearing facilities. For the best results with spring chinook, red, and silver salmon, and steelhead trout, the young fish must be reared for a year or more. Silver and spring chinook fingerlings released in the second spring about 1½ years after spawning have produced good returns, whereas the release of silvers at small sizes has given unsatisfactory returns.

It is apparent that the rearing of some species of salmon for varying periods is necessary for adequate returns. It is equally true that such rearing can be justified on a basis of economics, the hatchery costs being calculated against the returns of adult fish to the commercial and sport fishermen. This subject is discussed in a following section.

Upon absorption of the yolk sac (see fig. 4), fry usually are fed in the troughs for a week or more before being placed in the rearing ponds. To secure maximum production, the ponds are stocked to a safe carrying capacity and some of the growing fish are removed at intervals and stocked into native waters. By this practice the quantities of salmon being reared may be near the safe carrying capacity at all times. If adequate rearing space is available, or if all of the fish must be reared to a specific size or for a definite period before releasing, the initial stocking of the ponds is limited to the numbers of salmon young that can safely be held in the ponds until released.

It is the practice at all Fish and Wildlife Service salmon hatcheries to use pounds as the measure for calculating the carrying capacities of ponds, troughs, or fish-distribution tanks, and the quantities of food to be presented to the fish. Attempting to determine carrying capacities and quanities of food to be fed when only numbers of fish are known is inconvenient and inaccurate.

The objective of Fish and Wildlife Service hatcheries is to produce annually 1 pound of salmon for each cubic foot of water available in troughs and ponds for rearing. Occasionally, at some hatcheries, this goal is exceeded, but the average is still below the objective. When attempting to achieve an annual production of 1 pound per cubic foot of water, it is necessary to carry near the maximum poundage in all rearing facilities throughout the year.

One important factor that may limit the efficient utilization of rearing equipment is the incidence of disease. Some hatcheries may experience persistent disease among the stocks of fish held, usually attributable to the water supply. Although the usual diseases at the modern hatchery need not cause excessive mortalities if prophylactic measures are routine procedure, the methods of applying treatments often require that the rearing facilities be stocked with fish at levels considerably below capacities. Such routine control measures also require labor. Diseases and their control will be discussed in a following section.

Obviously the foods presented to young salmon in ponds are of extreme importance, not only for adequate growth but also to maintain the fish in a healthy condition. This subject is discussed separately.

Cleanliness in the troughs and ponds in which salmon or trout are being reared is desirable. Although some hatcheries appear to be able to produce fish successfully and efficiently with but a minimum of labor expended on the cleaning of ponds, experience has shown the advantages of cleanliness. Only the concrete ponds in general use for the rearing of salmon can be cleaned satisfactorily. At some hatcheries the growth of algae on pond walls and floors is removed by weekly brushing. Another procedure is to apply special paint or a solution of copper sulfate and salt

FIGURE 15.—Cleaning a raceway pond containing chinook salmon fingerlings.

to the dry pond, and then flush the pond thoroughly before the introduction of fish. This inhibits or prevents growth of algae during the rearing season.

Algae are not harmful to salmon in ponds and usually (as in the wild) harbor small animal organisms upon which the fish can feed, but the large numbers of fish held in a rearing pond minimize the contribution of this food source. Also, the algae growth is a lodging place for fish excrement, unconsumed food, and disease organisms.

With water adequate in temperature, quality, and quantity, with disease control, proper diets, and experienced care, the maximum production of healthy salmon may be expected.

Diseases

Throughout their lives all fishes are subject to attack by a great variety of disease organisms. In the wild, diseases rarely become epidemic, because of the wide dispersion of the fishes, which greatly decreases the probability of direct or indirect transmission of disease organisms.

In the hatchery pond or trough, the fish usually are exposed to the same diseases as are fish in the wild, particularly if—common in the propagation of salmon—the hatchery water supply is taken from a stream. Disease organisms among hatchery fish have an ideal opportunity to spread because crowded conditions permit easy transmission between fish. To combat disease epidemics or even relatively minor losses of fish, the fish-culturist eliminates the possibility of disease breeding or being retained in the algae and excrement in ponds and troughs. He has as a tool an adequate flow of water that washes organisms from the pond as rapidly as possible. Further, and most important, he uses proper diets to keep his fish in healthy condition and thus less susceptible to disease. He has, too, the recommendations of researchers who have identified disease organisms and methods of control. If unable to cope with a disease problem, the hatcheryman usually can call upon a pathologist for assistance.

In some salmon and trout hatcheries the control of organisms that may destroy eggs or fish is a continuous routine, and at all stations constant vigilance is required to recognize and control diseases at first appearance.

The most serious losses among eggs are occasioned by fungus growths. Other diseases of eggs, such as white spot and soft egg, are less well known, although white spot is believed to be caused by mechanical injury to the egg.

One group of plant organisms and four groups of animals comprise the principal organisms causing the diseases of salmon and trout. The bacteria, considered in the plant group, are the most important in connection with fish diseases, although the protozoans, trematodes, cestodes, and crustaceans—all animals—are represented in the fish-disease groups. Recently a virus infection has caused excessive mortalities among red-salmon fingerlings, and a similar infection may have been responsible for losses among other species in hatcheries throughout the country.

Parasitic infections may appear on the external surface of the fish, or they may be internal. Those on the exterior surfaces usually can be controlled or eliminated by chemical treatment. Internal parasites are much more difficult to recognize and control. The incorporation of appropriate chemical disinfectants in the food is effective with some internal parasites. Davis (1947) gives detailed descriptions of various disease organisms and their control, and includes an excellent list of references. Since the publication of Davis' work, many other researchers have provided additional information and references including Rucker and associates (1952) on gill disease, and on kidney disease (1951).

Too much stress cannot be placed upon the necessity for adequate diets for the production of disease-resistant fish. Nutritional deficiencies open the door to infection. When fish become weak from infection, they usually stop feeding and thus become weaker and less able to resist disease.

Foods for Hatchery Salmon

Until comparatively recent years the requirements of salmon and trout for the diet components necessary to life—carbohydrates, proteins, fats, minerals, and vitamins—were practically unknown. Research has not provided much specific information regarding the needs of fish, but the work of researchers on other animals, a limited amount of fisheries work, and trial-and-error methods, have improved tremendously the information available to the fish culturist. A review of recent publications will show the information available on fish nutrition. Although such a review is not included here, it is suggested that interested persons consult the issues of *The Progressive Fish Culturist* (Fish and Wildlife Service publication available in many libraries) for the past few years. This periodical contains much information of value to the salmon and trout culturist.

Experience and research indicate that the various species of salmon, and of trout, do not thrive upon the same diet. In fact, a diet of apparently the same components fed to a species of fish at one hatchery may not be adequate for the same species at another hatchery. Basic diets have been developed, but these usually must be altered to meet the requirements at different hatcheries.

In past years it was possible for each hatchery to secure its fish food locally. Beef, hog, and sheep livers, spleen, lungs, tripe, and other products not commonly used by humans were readily and cheaply available. In recent years the increased consumption of liver by humans and the marketing of dog and cat foods utilizing the other products have greatly reduced the supply and increased the costs. During this same period the requirements for salmon and trout fingerlings to maintain fisheries increased tremendously. The result has been a search for substitute foods readily available in quantity and at low cost. Many waste products have been tried, but only salmon viscera—eggs, testes, and ovaries—are available in large quantities, especially in Alaska. Salmon viscera, when combined with some fresh meats, have proved nutritionally equivalent to foods previously fed. It is probable that salmon viscera from Pacific Northwest canneries as well as large quantities from Alaska must be utilized, as the annual fish-food requirement of Pacific-coast salmon hatcheries alone is expected to exceed 10 million pounds within a few years.

A practical hatchery diet must be made up of components available in quantity at low cost and providing the nutrients necessary to produce desired growth with minimum mortalities. Whether raw or frozen, the food must be fresh when received and must be retained unspoiled until fed to the fish. Meat or fish products that have been frozen should not be permitted to thaw until required for the fish, and thawed products or diets should not be refrozen. The materials to be incorporated in the diet should be such as will combine to be presented to the fish in the most desirable consistency and form.

Dry animal meals have been used extensively in both trout and salmon diets. Unfortunate results have attended some of these efforts, but satisfactory results may be secured by preparing the meal at low temperatures and considering the percentages to be included in the diet, the water temperatures, and the species to be fed. Good results have been achieved at the Grand Coulee stations of the Fish and Wildlife Service, where Burrows (1949) determined that—

the Leavenworth production diet more closely fulfills the various requirements of a practical diet for the blueback [red] salmon than any other developed to date. This diet at temperatures above 50° F. consists of 20 percent each of beef liver, hog liver, and hog spleen, 30 percent salmon viscera, and 10 percent flame-dried salmon-offal meal. At temperatures below 50° the meal is deleted from the diet and the other ingredients increased proportionally.

At all salmon and trout hatcheries the objective is to produce healthy fish at the minimum cost. One general measure of success is the pounds of food required to produce a pound of salmon or trout. A few years ago 4 to 5 or more pounds of food were required to produce a pound of fish. This ratio has been considerably reduced through research; now it is not uncommon to average about 3 pounds of food to 1 pound of fish. In general, costs, too, have been reduced, but this does not necessarily follow, as the foods in the low-ratio diet may be more expensive than those in other diets.

At salmon hatcheries of the Fish and Wildlife Service, it is considered most desirable for the fish to be presented suitably prepared food that floats on the surface of the water for a time. This is accomplished by preparing food that does not easily separate in the water. There is less leaching of the food, and consequently almost all of the food is available to the fish. Certain ingredients tend to bind foods together. Salt in combination with hog, beef, or horse liver will form a rubberlike mass that is resistant to water. Dry meals in a food will absorb the nutritive juices of the meats, and the binding action will hold the food together so fish will receive the full benefit.

Recommended hatchery practice is to prepare and feed a food in the same day or within 24 hours at the most. Prepared foods should not be refrozen but should be held at low temperatures.

The preparation of food involves grinding the components to a fineness required for the fish size, mixing, and presenting the prepared food to the fish at regular intervals—several times each day to newly feeding fish and once or twice daily to larger fish. For the small fish the consistency of a diet may be changed so that the food will break up more readily in the water to provide particles fine enough for the fish.

The quantity of food to be presented to the fish is governed by size, species, and the temperatures of the water. The water temperature determines the activity of the fish and of the digestive processes. The intake of food to meet nutritive requirements increases as the water temperature rises, and vice versa. Growth of salmon in hatcheries is extremely rapid during the first year of life, when the body weight increases many fold. The food requirements of the various species of salmon and trout are definitely different. As a general guide to the feeding of salmonoids, charts have been prepared by which the quantities of food to be fed to a pond of fish may be determined if the total weight of the fish in the pond is known. The first charts were by Tunison (1936) and by Deuel, Haskell, and Tunison (1937, 1942).

FIGURE 16.—Weighing a sample of a known number of salmon fingerlings to determine weight of all fish in th epond to ascertain quantities of food to be fed daily.

Modified feeding charts have been prepared for the various species of salmon.

To use feeding charts it is necessary to know the weight of the fish in each pond. By weighing representative samples of fish at intervals and knowing the numbers of fish in the pond, the weight of all fish can be calculated. At large hatcheries, where it would be impractical to weigh numbers of fish in each pond at semiweekly intervals to determine amounts of foods to be fed, the Fish and Wildlife Service has developed the use of pilot lots of fish. These lots are held in small tanks and are weighed to indicate, with the application of factors to compensate for differing conditions, the weights of the fish in the many large ponds (Palmer et al., 1952). The daily offering of food to the fish is from 10 percent to 3 percent of the total weight of the fish—the smaller fish receiving the greater percentages.

A variety of methods have been employed to distribute the food to fish. The problem is one of presenting a desirable food in proper form and of distributing it so as to eliminate waste and assure an adequate daily ration for each fish. A converted potato ricer with holes of appropriate size has been used successfully when feeding small fish in troughs. Food for the fish is placed in the ricer and pressure is applied by hand to squeeze the food through small holes in the bottom of the ricer, which is moved back and forth in the water, breaking off the "worms" of food. An extension of this principle has been developed at the Leavenworth station of the Fish and Wildlife Service, where a large hand-operated pond ricer is used to feed ponds. At the Coleman station of the Service the same principle is applied, but compressed air is used to drive worms of food through the ricer perforations. The salmon hatcheries now being constructed for the Service include permanent air lines to ponds for pressure feeding. These methods have resulted in significant savings in funds and manpower and at the same time have produced healthy fish of uniform size.

FIGURE 17.—Placing food in a salmon pond with air-pressure ricer at the Coleman (Calif.) Hatchery of the Fish and Wildlife Service.

THE HATCHERY AND FISHERY MANAGEMENT

The fingerling salmon produced in the modern hatchery are utilized to the best advantage in the maintenance and development of populations of fish decimated or threatened with extinction. A number of hatcheries contribute to sport and commercial fisheries by making possible the capture of substantial numbers of adult salmon that were released as hatchery-reared fingerlings.

Under natural conditions, that is, in the absence of man-made deterrents to natural reproduction, the tremendous salmon populations were able to maintain themselves by entering the many coastal streams to reproduce. The early efforts of Indians in capturing salmon were relatively insignificant, for more-than-adequate numbers of fish usually reached the spawning areas. The fishing methods of the white man were much more intensive and efficient, but even then the tremendous catch need not have been particularly harmful to the runs. Scientific regulation of the fisheries would have permitted the escape of the necessary numbers of salmon during the *peak* of the run, for these were the fish having the greatest successful spawning potential. However, biological data were not available to indicate the desirability of such escapement, and extreme decimations of some stocks of salmon resulted. Basically, then, all that is necessary for the maintenance of a fishery is regulation to permit adequate escapement of the best spawning stock.

Unnatural conditions exist today in most of the salmon-spawning streams of the Pacific Coast States and in many of the streams of British Columbia and Alaska. These conditions have been discussed: dams and pollution, denudation of watersheds, irrigation diversions. These and other conditions have created blocks to upstream and downstream migrations of salmon, have destroyed or made unsuitable and inaccessible hundreds of miles of spawning area. These projects have interrupted the finely balanced timing of the salmon on their spawning migrations, and, regardless of man's ingenuity in mitigating the harmful effects of a dam (for instance, by the inclusion of fish-passage facilities), the salmon may still be delayed too long to arrive at the spawning area during the period of desirable water temperatures.

The salmon hatchery often, but not always, can substitute in part for natural reproduction lost by reason of man's activities. The program on the Columbia River, for example, includes salmon-salvage projects of unprecedented scope involving the transfer of very large runs of salmon to other than their natal tributaries; it also includes the further development of salmon populations in the lower-river tributaries to compensate in part for the anticipated loss of major portions of up-river races by reason of middle-river dams constructed and planned.

In the first instance, occasioned by the construction of Grand Coulee Dam, dependence was placed upon the instinct of salmon to return to the stream in which they were born or in which they spent their early months before migrating to the ocean. This program, dependent upon hatchery operations to a great extent, has been particularly successful. Hatchery production and stocking of red (blueback) salmon can be directly correlated with the tremendously increased runs of this species returning as adults.

The lower Columbia River program has not yet proved successful, but there is every indication that the clearance of streams (to permit greater utilization of spawning and rearing areas) and hatchery stocking will result in maximum production in the lower river tributaries that will largely replace loss of upstream production.

Studies of the results of hatchery production on the Sacramento River in California have revealed the major contribution of the hatchery product directly to the fishermen. O. B. Cope and D. W. Slater (unpublished report) state that hatchery fish released from the Coleman station of the Fish and Wildlife Service contribute an average of 14.5 percent of the catch of the net fishery alone. Preliminary data indicate the importance of the salmon from this hatchery in the offshore troll fishery northward from the Sacramento River to Vancouver Island, Canada.

These and other hatchery operations have been successful in partially compensating for the salmon losses caused by water-use projects. At many localities the direct and economical contributions of hatcheries to the salmon fisheries can be demonstrated. It is not inconceivable that hatchery propagation alone can maintain a salmon fishery of some magnitude in the event that conditions preclude natural reproduction and if the requirements for successful hatchery operations are available.

THE SALMON HATCHERY

Hatchery propagation of salmon is not recommended as a substitute for natural propagation but may be necessary to maintain salmon population under certain circumstances. The construction of a salmon hatchery is justifiable where there is a particular need.

A successful installation requires an appropriate site and adequate water of suitable quality and temperature. Plans for a hatchery must take into consideration the numbers and species of salmon to be produced, and the sizes of fish to be released. These factors will determine the rearing space required, the number of troughs or other facilities needed to incubate the eggs, and the quantity of fish food to be stored, prepared, and fed.

Hatchery Water Supply

Most important for the success of a salmon hatchery is the water supply in which the eggs are incubated and the young fish reared. The supply must be adequate in volume. Each hatchery trough may require 5 g. p. m. (gallons per minute) or more; a rearing pond should receive from 50 to 400 g. p. m., the amount depending upon pond size and the numbers of fish, as well as water temperature and oxygen content. A typical hatchery of 150 troughs and 20 raceways, using water only once through each trough or pond, should have available not less than 7,000 g. p. m. or about 14 cubic feet per second. If there are adult holding ponds, these can receive the water from the ponds. Under crowded conditions, when the numbers of adults approach the maximum capacity of the ponds, an additional supply of fresh, well-aerated water should be introduced.

The water to be used for salmon, and trout, propagation must be of a temperature within a definite range, should be relatively free of silt and debris, must be unpolluted, and should not contain excessive quantities of dissolved gases such as nitrogen or of minerals such as copper and iron. Within the range of the Pacific salmon, hard water rarely is encountered; most of the coastal streams in which salmon are found, and where hatcheries are located, are relatively soft water. The water should have a dissolved oxygen content of not less than 5 parts per million when introduced into the trough or pond, but greater oxygen content may be required if ponds or troughs are heavily stocked, depending upon water temperatures.

The numbers and size of fish in a pond or trough, and the water temperature, will determine the quantity of water required to be introduced. There is no rule by which the number of fish to be stocked may be determined, although a pond may be expected to carry up to 1 pound of fish per cubic foot of water. Generally a greater weight of larger fish than of small salmon can safely be carried in a pond or trough, but capacities vary with the species. The maximum carrying capacity of a trough or pond should be determined by trial at each hatchery. The total poundage should be determined with appropriate consideration for prolonged treatments for disease and for water drawdown when cleaning ponds or removing fish.

Generally the water supply for the hatchery is drawn from a stream draining an established watershed within which are few if any farms and livestock. Such a watershed usually provides unpolluted and relatively silt-free water. At some hatcheries it is necessary to provide a sand-gravel filter to remove objectionable silt.

The availability of spring water with a temperature range of 40° to 60° F. is desirable to warm winter stream waters used in the hatchery. Often warmer waters are needed to promote more rapid growth in order to meet certain planting requirements. Present knowledge indicates, however, that the rearing of some species, particularly spring chinook, should not permit too rapid growth. The young salmon, if they are reared rapidly to large size (6 to 8 inches) may exhibit a desire to migrate to the ocean in midwinter, when stream conditions are most unfavorable in some localities.

For the most efficient hatchery production of salmon, the water temperature should range from about 45° to 60° F. Incubation temperatures should be 45° to 55° F., and rearing temperatures of 50° to 60° F. are desirable. Higher temperatures are not to be sought because of disease development, and lower temperatures retard growth.

The supply of water for the hatchery may be carried from the source in a pipe or flume; an earthen ditch is not recommended because of the algae growth and the possibility that disease-carrying fish may find the ditch a suitable habitat. Flumes should be covered if leaves and wind-borne debris are present. The intake structure on a stream usually includes a barred grill or grissly to exclude logs and large debris, and a revolving or other type screen to remove smaller debris and to divert fish back to the stream. Also at the intake is a valve or stoplog arrangement for control of the water.

Water may be introduced into troughs or ponds directly from a

FIGURE 18.—Revolving screen in water supply flume diverts fish and debris back to stream at Little White Salmon Hatchery of the Fish and Wildlife Service.

pipe or from a head trough or flume. In the latter case, adjustable openings or spigots control the flow of water into each pond or trough. The manner of introduction of the water determines the extent of increase of bound oxygen.

If circular ponds or other types of ponds in which the water is recirculated are in use, it is necessary to have enough force or head behind the entering water to circulate the pond water properly. Here, for best results, the water is introduced from a pipe.

Water may be used more than once, that is, it may be passed from one pond or trough into a second pond or trough and thence into others. There should be sufficient fall of the water from the foot of one pond into the upper end of the next pond to assure adequate dissolved oxygen. One serious difficulty when passing the same water through a series of ponds or troughs is the possible spread of disease throughout the series, whereas ponds supplied with individual water would limit the disease to the single pond except where the source of water for the entire hatchery is affected, or tools and equipment are contaminated. There apparently are no advantages to reusing water when an adequate quantity is available.

Experience has shown the necessity of selecting a water supply suitable for the propagation of salmon and locating the hatchery at that point. The disadvantages of many such locations as to isolation are tolerable, but an inadequate or unsuitable water supply will prevent successful production of fish.

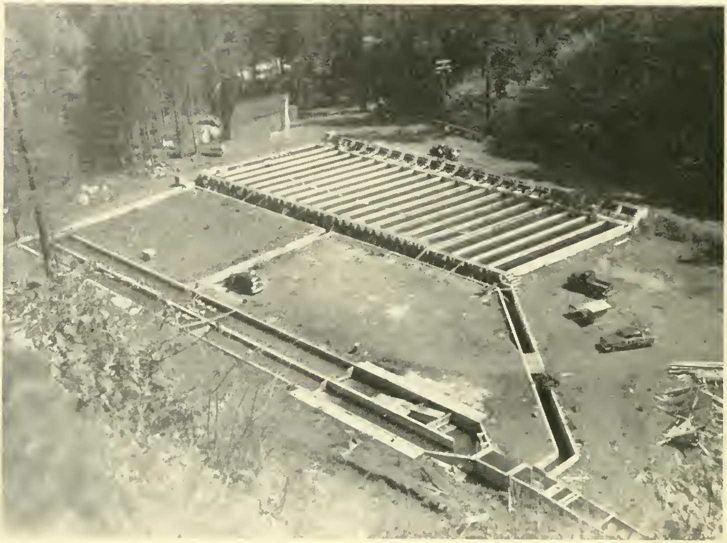

FIGURE 19.—Battery of salmon rearing ponds, large spawning ponds and fishway from stream to ponds at the Little White Salmon Hatchery of the Fish and Wildlife Service.

The Hatchery Building

It has become quite common for modern hatcheries to include in the hatchery building not only the troughs for the incubation of eggs and the rearing of very small fish but also the service facilities needed in connection with artificial propagation: the food-preparation room, cold-storage facilities, garage, shop, office, and often a small laboratory. When the establishment is quite large, it may be more economical to erect a separate garage building. To have all of the facilities under one roof is convenient, usually requires smaller initial cost, and reduces annual maintenance costs.

Troughs.—Hatchery troughs in the early days of salmon culture were commonly constructed of redwood or cedar with inside dimensions of about 14 feet long by 16 inches wide by 8 inches deep. Although some fish-culturists continue to prefer the shallow troughs, most salmon hatcheries constructed in recent years have been equipped with deep-type troughs, of the same dimensions except that the depth is usually 16 inches. A more modern innovation is a trough 3 feet deep by about 8 feet long which has the same egg capacity as the deep-type trough but requires only about one-half the floorspace. Troughs often have been constructed of more modern materials, such as concrete, aluminum, and enameled sheet steel. Plastic or plastic-covered troughs

FIGURE 20.—Interior view of Quilcene, Wash., Hatchery of the Fish and Wildlife Service. Double-deep-type troughs contain baskets of salmon eggs.

have been tried, but the wood troughs continue predominant, principally for economy.

Trays for the incubation of salmon eggs are of various sizes (for the deep troughs, 14 inches by 16 inches); most have a wood frame ($1\frac{1}{2}$ inches by $\frac{3}{4}$ inch) on the bottom of which is fastened a screen of suitable mesh. The eggs are placed on the trays in a single or double layer, and the trays are stacked and placed in the troughs. An arrangement of metal dam boards directs the flow of water up through a stack of trays, back to the bottom of the trough, and up through the next stack of trays. The trays stacked in a deep-type trough have a capacity of about 200,000 chinook-salmon eggs, running 50 to 80 eggs per fluid ounce.

When the young fish are free swimming and capable of taking food, they are taken from the trays and placed directly in the troughs (from which the dam boards have been removed). A wire-mesh screen or a perforated plate at the lower end of the trough prevents the escape of fish. The water level of the trough usually is maintained by a standpipe inserted between the screen and the lower end of the trough. The pipe can be removed readily to facilitate cleaning of the trough.

Water for the trough is introduced either from a head trough or by pipe, and the water may be passed from one to another of a series of troughs to conserve water, but with the disadvantages mentioned previously. Troughs usu-

FIGURE 21.—Stack of trays containing salmon eggs being lowered into a deep-type trough for the period of incubation.

ally are mounted on horses or pedestals about waist high. Occasionally troughs may be placed on or in concrete tanks which later are used for rearing.

In some hatcheries the waste water from the troughs may be utilized in outside ponds. At the Spring Creek (Wash.) Hatchery of the Fish and Wildlife Service, it is possible to drain the fish from the troughs into the waste-water trough in the floor and to divert known numbers of these very small fish into the various ponds for further rearing, or directly to the fish ladder down which they will descend to the Columbia River and thence to the ocean.

Food preparation room.—At salmon hatcheries the young fish are fed for different lengths of time before release. The diet received by these fish is of major importance. To prepare the foods properly for presentation to the fish, a special room and items of equipment are required. The size of the room and the size and variety of equipment depend upon the quantities of food to be prepared and the period of time over which such quantities will be required. A typical salmon-hatchery feeding program starts with the preparation of only a few pounds of food for very small fish. As the salmon grow, the quantities of food required gradually increase until a ton or more of prepared food may be needed each day.

A feeding operation of this magnitude is accomplished in a food-

Figure 22.—Typical food preparation room at the Quilcene, Wash., Hatchery of the Fish and Wildlife Service. Bandsaw, grinder and vertical mixer are standard equipment. Note chutes from dry meal storage bins.

preparation room with equipment such as a large meat grinder, a heavy-duty bandsaw, a dough mixer and/or a large vertical mixer, and a bone-and-gristle chopper, all power driven, and scales and sink. Construction of the room is such as to provide adequate light, good drainage, easily cleaned walls, and production-line arrangement of equipment.

Food storage.—Cold-storage space is essential, as most of the food for salmon is meat or fish waste. A reasonable measure of the space needed is enough room to freeze and store one-half of the total perishable food requirement for a year. If all of the foods received are meats, either fresh or frozen, the temperature of the cold room should be maintained at about 0° F., with the ability to freeze rapidly large quantities of fresh meats received in one shipment. If fish products are to be held in cold storage, the temperature should be maintained near −10° F. or below, with a capacity of at least −15° F. to freeze quickly fresh-fish products such as salmon carcasses.

At most salmon hatcheries a cool room is constructed as a first entrance into the cold room. In the cool room are stored those prepared foods that are to be kept cold for the next day's feeding but that should not be refrozen. The cool room is entered directly from the food-preparation room. The temperature of the cool room may be maintained by the effect of the adjoining cold room, but more often a separate refrigeration unit is necessary to maintain the cool-room temperature just above freezing.

Animal and fish meals often are used in fish hatcheries. These products are stored in rodentproof rooms or bins, usually in the loft over the food-preparation room. Downspouts from the bins, with controls, make the meals easily available in the feed room. (See fig. 22.)

Rearing Ponds

Rearing ponds specifically designed for the most convenient and efficient operation are required at salmon hatcheries. These ponds are of a variety of sizes and shapes, but certain designs have proved most successful.

The early ponds used for rearing of young salmon, particularly chinook and silver, were earthen, usually very long and narrow, and had the water flowing from one pond through a second and often through several ponds. The ponds at the modern salmon hatcheries are of concrete, and the tendency is to provide a good flow of water and use it only once when an adequate water supply is available. This practice permits easier cleaning of the ponds. In certain types of ponds the flow of water over the concrete bottom, as well as the movements of the fish, tends to concentrate debris at the outlet of the pond. Probably the greatest advantage of the concrete pond is in this cleanliness, there being minimum lodgement of disease organisms; whereas the opposite is true of the earthen ponds. When disease must be treated with chemicals, the concrete pond lends itself to such treatment. In general, despite the greater construction cost, the concrete pond is preferable to earthen ponds.

Probably the most common type of rearing pond at salmon hatcheries is the raceway, in which a substantial and uniformly dispersed flow is maintained from the water-intake end to the lower or screened end. (See fig. 19.) Ponds of this type are preferred at Fish and Wildlife Service hatcheries. The ponds are usually 8 feet wide and 80 feet long and have an average water depth of 2.5 feet. From the upper to the lower end, the bottom has a slope of 1 inch in each 10 feet of length. The inflow of water is 200 to 400 g. p. m., and spills from a head trough into the pond in a sheet as wide as the pond. This manner of introducing water provides as nearly as possible a uniform movement of water down the pond without dead-water areas. The screen and dam boards also extend the full width of the pond. The removable screen (of appropriate mesh, galvanized after weaving) or a perforated plate, placed in slots or grooves in the concrete at the lower end of the pond, prevents the escape of fish. The dam boards, also removable, are located downstream from the screen and maintain the desired pond level. At some hatcheries the lower end of the pond is sealed by a concrete wall and the overflow goes down a standpipe of appropriate height located between the end wall and the screen.

The raceway-type rearing pond has some disadvantages. A very substantial supply of water is required, although this could be reused in other ponds in a series. Young fish show a tendency to accumulate at the inflow end of the pond, thus apparently not utilizing efficiently the space provided. However, most efficient utilization of the pond space by stocking the pond to near capacity will result in better dispersion of the fish. It is believed that the foregoing, if a disadvantage, is minor as compared to the advantages of this type of pond in disease inhibition, ease of feeding, treatment for disease, and handling of fish.

The Washington State Department of Game has used most successfully a circular concrete pond, usually 40 feet in diameter, about 24 inches in water depth, and having a very slight bottom slope toward the center stand-pipe outlet, which is surrounded by a square screen. Exceptional weights of trout have been produced from these ponds.

The circular pond requires a minimum of water, and its use is advantageous where water supplies are limited. Because of the continuous circular flow of water, however, disease organisms have greater opportunity to attack the fish and disease treatments are more difficult.

The Washington State Department of Fisheries and the Oregon Fish Commission favor a rectangular pond with a center partition that stops short of the end walls to permit circulation of the water. (See fig. 23.) In some of these ponds the inflow and outflow are at the same end of the pond. In later

FIGURE 23.—Salmon rearing ponds at the Green River Hatchery of the Washington Department of Fisheries.

years, the inflow and outflow have been placed at opposite ends of the pond, eliminating dead-water areas to some extent.

Of the many types of rearing ponds in use, the raceway pond is believed best suited to mass production of salmon fingerlings. Its capacity, measured in production per cubic foot of water, or per gallon per minute, probably is not so great as the circular pond; but its disease-inhibiting characteristics, as well as ease of cleaning, feeding, and handling the fish make it desirable where ample water supplies are available.

Trapping Adult Salmon

The location of traps for the taking of adult salmon for spawning will depend upon the species of fish sought. The most desirable trapping locality is immediately below the natural spawning area, where the fish can be taken when fully mature, but this usually is not feasible. The trapping for spawning of spring chinook, silver salmon, and steelhead trout offers the greatest difficulties, for many adults of these species may need to be held for weeks or months before spawning.

Until recent years it had been the general practice to place racks or weirs across a stream at a suitable point to enclose an area within which the adult salmon were trapped for spawning. The lower rack was so constructed as to permit the upstream passage of fish through one or more V-openings which could not easily be found again for escape. The upper rack permitted no passage. The mature fish were seined from the area and spawned. Several variations of this type of rack are sketched and described by O'Malley (1920).

Although the trapping and spawning of some species of salmon in the stream continue to be necessary where circumstances permit, a general practice is to install a diversion rack or dam in the stream and thus to divert the adult fish into a side channel or up a fish ladder and thence into concrete or earthen holding and spawning ponds.

A rack placed across a stream consists of weighted wood or steel tripods between which stringers are extended. Sections of suitably interspaced strips laid vertically are placed or leaned against the stringers on the upstream side of the tripods. The interspaces in the rack are of such width and number as to permit the free flow of water through the rack but are sufficiently small or narrow to deny passage of the salmon. The rack must be fish-tight along the stream bottom. O'Malley (1920) gives a detailed description of rack construction.

The streamflow characteristics, as well as the size and quantity of debris, such as logs, brush, and leaves, must be considered when determining the size and strength of the rack. The largest salmon rack ever attempted was laid across the main Sacramento River. The steel tripods were 12 feet high, and each of these weighed many tons when loaded with rock (on a platform within the three legs) to hold position in the current. The racks were of steel or strap iron. Flash floods in the river frequently shifted or

FIGURE 24.—Dam constructed across creek to divert adult salmon up fishway and into holding ponds. (See also fig. 1.)

carried away sections of the installation. Identical tripods have been utilized in the Big White Salmon River, tributary to the lower Columbia River.

Smaller rack installations are the rule and usually can be held in the stream with constant attention and effort through the few weeks of the spawning season. Under favorable circumstances it is possible to rack only a portion of a stream and thus divert part of the run of salmon into holding ponds. At other places, such as Walcott Slough on Hood Canal off Puget Sound, Wash., a permanent trap is installed in a small spring outlet within the reach of tidal rise. Here chum salmon are spawned with utmost convenience, as the adults entering the traps are fully mature. This run, incidentally, is hatchery-created and hatchery-maintained.

In certain streams where the bottom and channel are stabilized, concrete aprons about 15 to 20 feet wide often are placed across the bed of the stream, with appropriate means of anchoring tripods to the apron. Often, too, concrete blocks have been poured at intervals across the apron to replace the tripods. The racks are then laid against the sloping upstream face of the blocks. Where floods and logs are encountered, such permanent installations are undesirable because they form a solid foundation for a debris dam and resultant flooding of surrounding areas. On the Klickitat River, under the Federally financed fisheries program, the Washington Department of Fisheries has installed a new kind of tripod that is most convenient and successful in this type of stream with no heavy debris. This installation consists of a con-

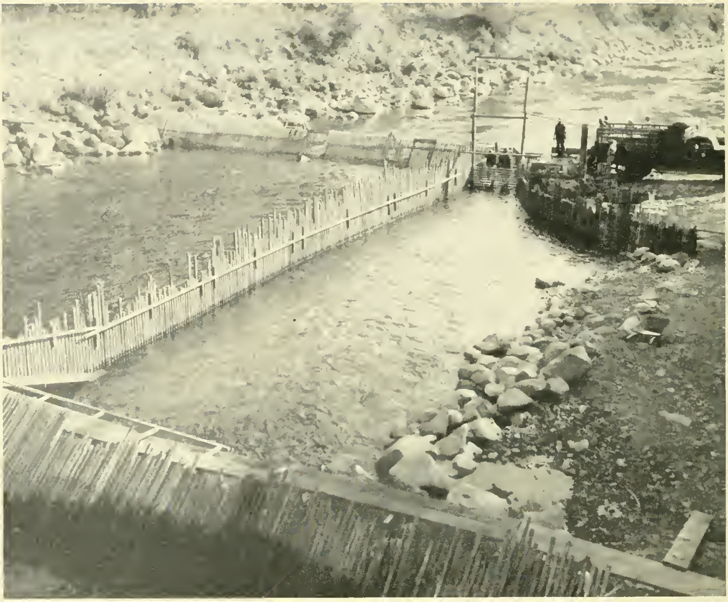

FIGURE 25.—Salmon trapping and spawning installation by the Fish and Wildlife Service on Wind River, Wash. Adult salmon enter the enclosure through a small opening in the far rack and are seined from the area.

crete apron with permanently fixed pipe-rack supports to replace the tripods. At the conclusion of the spawning period, the racks and the plank walkway across the top are removed and the individual pipe supports, attached by swivel joints at each end, are lowered to the apron surface. For the next spawning period these are caught with a hook and raised to a vertical position, and the walkway and rack sections are placed. This is purely a rack to stop salmon from further ascent of the river and to divert them into prepared holding ponds.

Another type of diversion structure is that placed permanently in Battle Creek, tributary to the Sacramento River, to divert adult salmon into the holding ponds of the Coleman station of the Fish and Wildlife Service. (See fig. 24.) This structure is a low concrete dam with a downstream sloping surface and apron over which the water pours in a sheet and in which salmon cannot secure a "foothold" to attempt a jump. During the salmon runs the fish are diverted to a fish ladder leading to large holding ponds. Throughout the rest of the year, a fish ladder in the dam itself is open to permit ascent of trout and some salmon to the stream above.

The type of rack installation for

FIGURE 26.—Seining chum salmon from the holding area at the Walcott Slough, Wash., spawning station of the Fish and Wildlife Service. Entrance V at lower right.

either trapping or diverting the salmon to holding ponds will depend upon the character of the stream and upon the species of fish to be spawned. Also dependent upon these factors will be the determination whether fish will be trapped in the stream or diverted to holding and spawning ponds. The latter is most convenient and successful for spawning operations at a hatchery where water supplies are readily available for the ponds. In isolated areas or at points removed from the hatchery, a temporary installation for trapping and spawning directly in the stream is most economical.

Adult Holding Ponds

Holding or retaining ponds for adult salmon differ greatly in size, depth, and general features. The principal differences are found in ponds designed for receiving and holding fall chinook salmon and those for spring chinooks. The spring chinook is more vigorous and aggressive in attempting to leave the pond and move further upstream. He also must be held much longer before maturing than the fall fish.

The retaining ponds for spring chinook salmon are quite complicated and are carefully designed and constructed to avoid death of adults as a result of injury and disease. At the Grand Coulee stations of the Fish and Wildlife Service, much attention has been given to the development of satisfactory ponds. The most successful pond yet devised, and one in which spring chinooks have been held very satisfactorily, is described by Roger Burrows (unpublished) of the Fish and Wildlife Service.

The retention of the fish until sexual maturity must meet two main requirements for successful operations. First, it must prevent mechanical injury to the adult stock, and second, it must inhibit the development of disease.

(1) It is characteristic of adult salmon when barred from further upstream progress to circle the area of impoundment. attempt to move upstream, and finally return to the upstream barrier and attempt to surmount it by jumping. Fish thus trapped will circle and mill around restlessly for 10 days to 2 weeks but eventually will settle down in the deeper portions of the area to await maturity. By that time, however, the damage has been done as far as mechanical injury is concerned. Fish have jumped out on the banks and died or returned to the pond severely abraded, injured themselves by hitting obstructions, or worn their nose fighting the upstream barrier. Any traumatic condition resulting from mechanical injury no matter how minute opens an avenue for infection and the death of the fish may result.

It is a relatively simple matter to prevent fish from jumping in a retaining area. Fish jump at the point of water inflow but they also jump at vertical banks. To prevent the latter all banks in an artificial pond should have at least a 45° slope. Salmon before making a jump nose along at the surface of the water. If the water surface is covered the fish will not jump. Taking advantage of this characteristic the water surface in the area immediately below the obstruction is completely covered by floating strips of canvas.

By the use of a submerged culvert the water may be introduced into the center of the upper section of the pond so that the fish can jump but still do themselves no harm by striking the banks. As far as is known jumping by salmon produces no ill effects as long as mechanical injury is not incurred. This type of barrier to the upstream migration has two advantages over the usual weir, first, the fish do not fight the upwelling water sufficiently to cause abrasions and, second, if properly placed or covered, jumping will either do no harm or can be prevented.

(2) The type of holding area and the water temperature are the two major factors concerned with the development or inhibition of disease.

A holding area to be satisfactory must have a continuing and fairly rapid interchange of water throughout the entire impoundment. Natural pools fulfill this requirement otherwise they would silt up and no longer be pools. Salmon prefer deep water in which to lie between migrations but this preference should not be satisfied at the sacrifice of water interchange. If relatively stagnant water is present in the deeper portions of the area, disease organisms which are waterborne have an opportunity to concentrate in these portions. As these areas are the parts preferred by the fish the infections become dominant and the natural resistance of the fish is not sufficient to cope with the disease. A good holding area, therefore, should have a bottom contour such as to avoid the development of areas of semistagnant water.

The temperature of the water is, also, an important factor which controls the development of disease. Both fungus (*Saprolegnia parasitica*) and columnaris (*Chondrococcus columnaris*), the principal causes of mortality in adult fish, do not reach their point of optimum development at temperatures below 60° F. For this reason holding areas in which the water temperature does not rise above 60° may be operated with a smaller water inflow and, consequently, a slower rate of interchange than areas which have

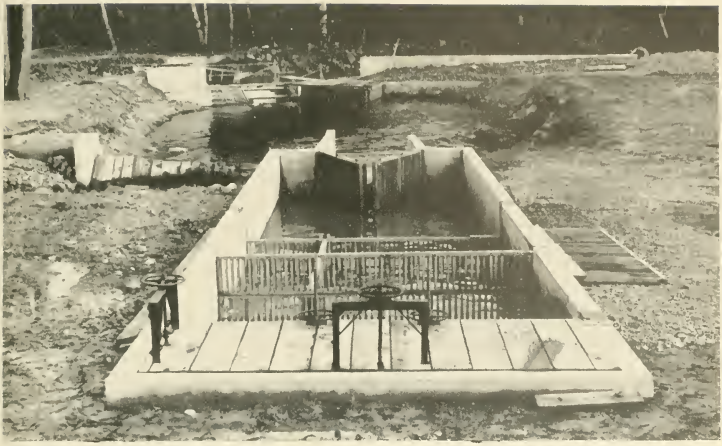

FIGURE 27.—Adult ripening and spawning (foreground) ponds to which adult salmon are diverted from the river in background.

temperatures in excess of 60° for extended periods. It is believed that an increase in the rate of interchange of the water in a holding area can be substituted for low water temperatures to inhibit disease development."

The retention of adult fall chinook salmon until ripe for spawning is not so difficult as the retention of springs. The former fish usually are almost ready for spawning when trapped and need to be held in the ponds for only a few days. These fish, also, are not so aggressive and can be retained more easily in the ponds. For these reasons it is not necessary to prepare such elaborate holding ponds. This is true of chum salmon, also. An adequate supply of aerated water is the principal requirement.

Personnel, Equipment, and Facilities

The number of persons required to staff a hatchery during the entire year depends upon the type of operation, including species propagated, climatic conditions, and the location of the unit. In general, the normal hatchery may be permanently staffed with 1 man for each 10,000 pounds of salmon produced. This rule has been applied to Fish and Wildlife Service units on the Columbia River. The production figure per man is higher than is usually attained at present. Additional help required can be recruited locally when needed.

The salmon hatchery is equipped with sufficient trucks to facilitate operations and with a shop in which repairs can be made to such equipment as trays, nets, and racks. Major vehicle repairs are most frequently made in a commercial shop unless a number of hatcheries in an area can profitably maintain a central repair shop with a mechanic in charge.

Accurate records of hatchery operations are maintained to facilitate activities and to provide a fund of basic information to evaluate, in the future, the results of the stocking of salmon. Routinely, the poundage of fish on hand must be known in order to calculate the quantities of food to be presented to the fingerlings in the ponds. Efficient operation of each hatchery requires tabulation of expenditures for labor, food, and other items, as well as the production of fish.

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