DISTRIBUTION AND MOVEMENT OF JUVENILE SALMON IN BROWNLEE RESERVOIR, 1962–65

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ABSTRACT

Juvenile salmon—chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), and sockeye and kokanee (*O. nerka*)—were studied. Their rates and direction of movement, spatial distribution, and successful passage to the outlet varied in relation to surface currents, water temperature, and dissolved oxygen concentrations.

Some juvenile salmon stayed in Brownlee Reservoir through the summer, fall, and early winter; the percentage varied between years. The percentages were highest in years with high water level and retarded, disoriented flows during the spring migration. Salmon that held over eventually concentrated in rather restricted areas of the reservoir through the summer and early fall, owing to high epilimnion temperatures and to low concentrations of dissolved oxygen that extended into the epilimnion from the hypolimnion.

When the water level was low and reservoir currents were oriented downstream, loss of orientation by juvenile salmon was least and movement through the reservoir was most rapid. These reservoir conditions varied, but salmon populations that migrated early in the year were most likely to encounter them.

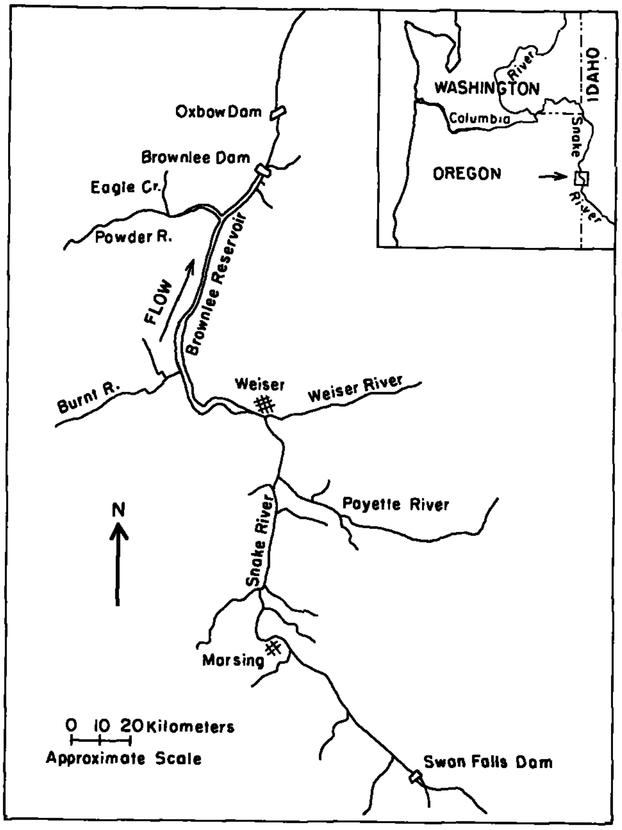

FIGURE 1.—Brownlee Reservoir, Snake River, and major tributaries.

Published April 1970.

The completion in 1958 of Brownlee Dam on the middle Snake River (Soule, Heikes, Mitchell, and Schaufelberger, 1959) created a long, narrow reservoir along the path of migrating Pacific salmon (genus *Oncorhynchus*) and anadromous rainbow trout (steelhead) *Salmo gairdneri* (fig. 1). At full pool the impoundment is 92 km. long, less than 0.8 km. wide, and nearly 92 m. deep. The upper 24-km. of the reservoir is relatively shallow, slow moving, and forms a river-run impoundment. The lower 68 km., which thermally stratifies, lies within an arid mountainous terrain. Powder River Arm, a prominent appendage on the Oregon side, joins the reservoir 17 km. above the dam and extends westward for 15 km. The upper 5 km. of the arm forms a wide, shallow, unstratified pond when the reservoir is full. Juvenile salmon enter the reservoir from the Snake and Powder Rivers en route to the sea.

When Brownlee Reservoir was completed, detailed knowledge was lacking on the passage of Pacific salmon and steelhead trout through large reservoirs; therefore, BCF (Bureau of Commercial Fisheries) conducted detailed research at Brownlee in 1962–65. These studies covered native stocks of steelhead trout, spring and fall chinook salmon (*O. tshawytscha*), and kokanee (landlocked sockeye salmon, *O. nerka*) in addition to hatchery-reared fall chinook, sockeye, and coho (*O. kisutch*) salmon. The research, which began in the spring of 1962, consisted of five studies: (1) limnology of the reservoir system (Ebel and Koski, 1968), (2) upstream migration of adult chinook salmon through the reservoir (Trefethen and Sutherland, 1968), (3) migration of juvenile salmon and trout into the reservoir (Krcma and Raleigh, 1970), (4) distribution and movement of juvenile salmon in the reservoir (this report), and (5) migration of juvenile salmon and trout from the reservoir (Sims, 1970).

Our report gives an account of movements and distributions of the juvenile salmon in relation to their environment. Data on the movements of juvenile steelhead trout were difficult to analyze and report, as we were unable to clearly distinguish them from the nonanadromous wild and hatchery-reared rainbow trout that were also in the reservoir.

EQUIPMENT AND PROCEDURES

To obtain the desired information, it was necessary to sample the juvenile fish in the lower 68 km. of the reservoir. This sampling involved both gear and marking efforts.

FISHING EQUIPMENT

Studies had indicated that four types of fishing equipment were needed to capture juvenile fish: floating traps, gill nets, purse seines, and two-boat trawls. These, together with the fingerling collection facility (skimmer net) of the Idaho Power Company 1.5 km. above the dam, provided basic data on the movement of juvenile salmon within the reservoir. The sampling equipment was deployed to intercept migrants in the upper, middle, and lower reservoir from early in the year until late fall (fig. 2).

Floating Traps

Floating traps were the most effective fishing gear for capturing age-group 0 salmon (fig. 3). The dimensions of the trap, mesh size, and fishing methods were similar to those described by Rothfus, Erho, Hamilton, and Remington.[1] From one to seven of these units were used. The traps were tended every other day early in the year and each day between mid-March and early July. Thereafter, as fish became less available, the traps were operated with diminishing frequency and in most years were removed by late July.

Gill Nets

The number of gill net stations fished depended on the water level and its effect on the length of the reservoir. At each site, two or three parallel sections of multifilament net, 30 m. long by 4.5 m. deep, were fished at predetermined depths in a manner similar to that described by Rees (1957). The mesh sizes were 1.9, 2.5, 3.1, 3.8, 5.1, and 6.3 cm. stretched mesh, of which the 2.5- to 3.8-cm. sizes were most effective. The nets were most efficient on salmon over 90 mm. fork length and at night.

Purse Seines

Two purse seines (Durkin and Park, 1967) were used as mobile sampling gear on fish concentrations throughout the limnetic environment of the reservoir. One of the seines was 180 m. long and 10.5 m. deep; the other was 210 m. long and 16.5 deep. Both were set from a barge. Purse seines were used in the main reservoir during spring and early summer and in the Powder River Arm during fall.

Two-Boat Trawls

Surface trawls (Johnson, 1956) were used to locate concentrations of salmon and to determine their relative abundance. The trawls were 3.0 m. high, 5.4 m. wide at the mouth, and 7.8 m. long.

MARKING

Various types of marks were placed on captured juvenile fish for identification at recapture. The type of mark depended on the size of fish. Fish less than 100 mm. long were marked with vinyl thread tags (developed by personnel of the Fish Commission of Oregon). A jaw tag clamped to the left mandible marked the fish (100 to 250 mm. long); fish over 250 mm. had a plastic dart tag. Color coded tattoos, used in 1962, were discontinued when the vinyl thread tag became available. Other groups of fish were marked by clipping fins before they entered the reservoir (Krcma and Raleigh, 1970).

[1] Lloyd O. Rothfus, Michael Erho, J. A. R. Hamilton, and Jack D. Remington. 1964. A study of reservoir rearing of coho salmon in Lake Merwin, Washington. State Wash. Dep. Fish., Res. Div., 18 pp. (Processed.)

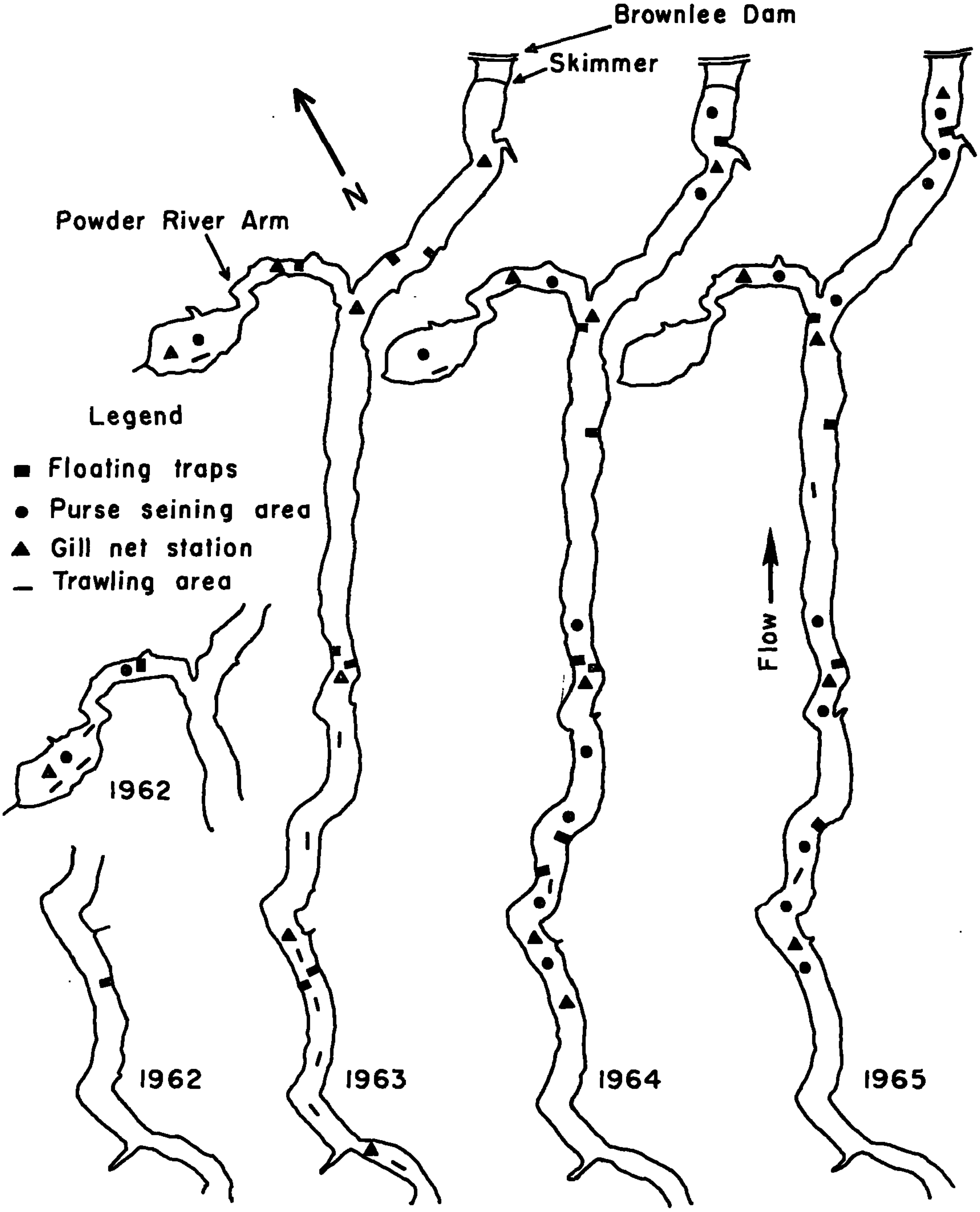

FIGURE 2.—Location of sampling areas and types of fishing gear used in Brownlee Reservoir, 1962–65.

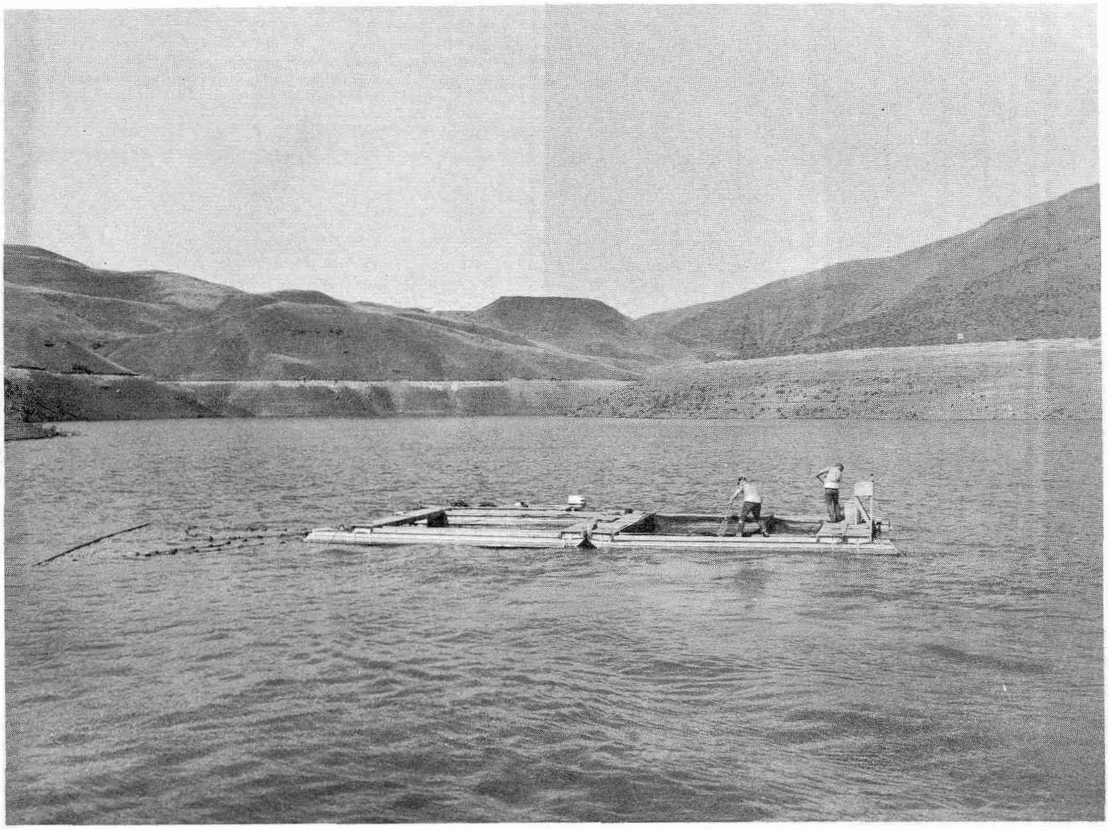

FIGURE 3.—Floating trap used to capture juvenile salmon moving near the shore. Salmon were diverted to the trap by a lead extending from the shoreline.

A combination of length-frequency ranges and the above marks identified specific populations and individual fish and, thus, yielded data on direction and rate of movement, spatial distribution, growth, and survival of the populations of salmon that entered the reservoir.

Upon capture, the fish were anesthetized, measured (fork length) to the nearest millimeter, examined for marks, and tagged if not previously marked. Scales for age determination were taken each month from a sample of up to 10 fish in each 5-mm. length group in the catches. All fish were released near the capture site.

THE ENVIRONMENT OF THE RESERVOIR

Apparently, the conditions exerting the greatest effect on the environment of Brownlee Reservoir were the size and timing of the annual reservoir drawdown and fillup and the volume of flow through the impoundment. Water level of the reservoir, filling, spillway discharge, and flow varied considerably during the 4-year study (fig. 4). The drawdown was least (6.4 m.) in 1963 and greatest (28.3 m.) in 1965. Drawdown typically began in December or January. Filling began each year in early April except in 1965 when it was delayed until mid-May. Filling was nearly complete by late June 1962, mid-April 1963, mid-June 1964, and mid-June 1965. The extent of drawdown or fill determined the length of the reservoir, and the time of filling determined the quality of the water through which the fish migrated.

SURFACE CURRENTS

The volume of inflow and outflow, together with the water level of the reservoir, determined the orientation and stability of currents and the velocity of flow. Figure 5 shows typical currents under different reservoir conditions.

The stability, velocity, and orientation of the reservoir surface currents varied considerably over the study years (1962–65). Surface currents near

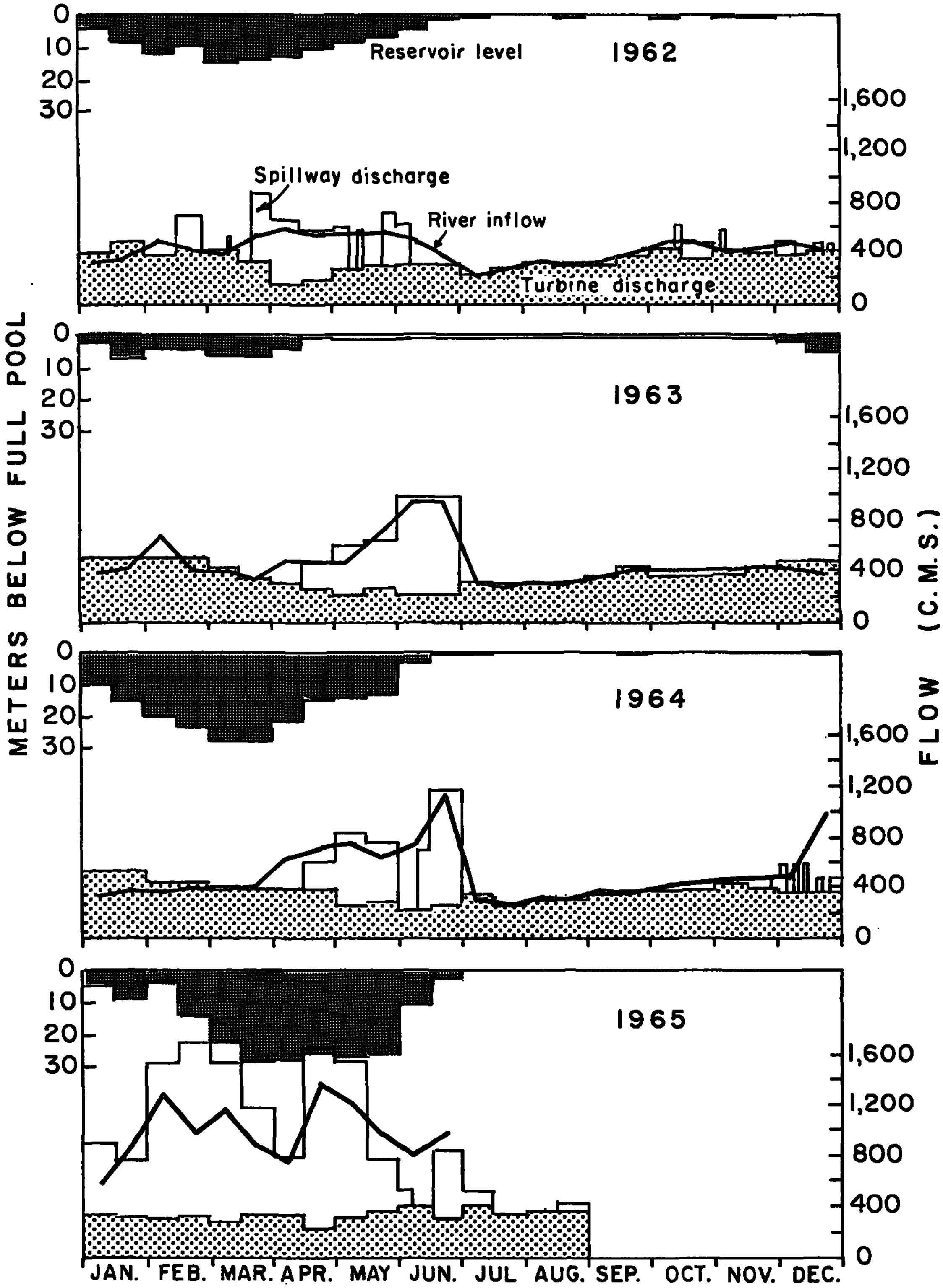

FIGURE 4.—Semimonthly averages of reservoir water level, turbine and spillway discharges, and Snake River flow into Brownlee Reservoir, 1962–65. Flow is in cubic meters per second.

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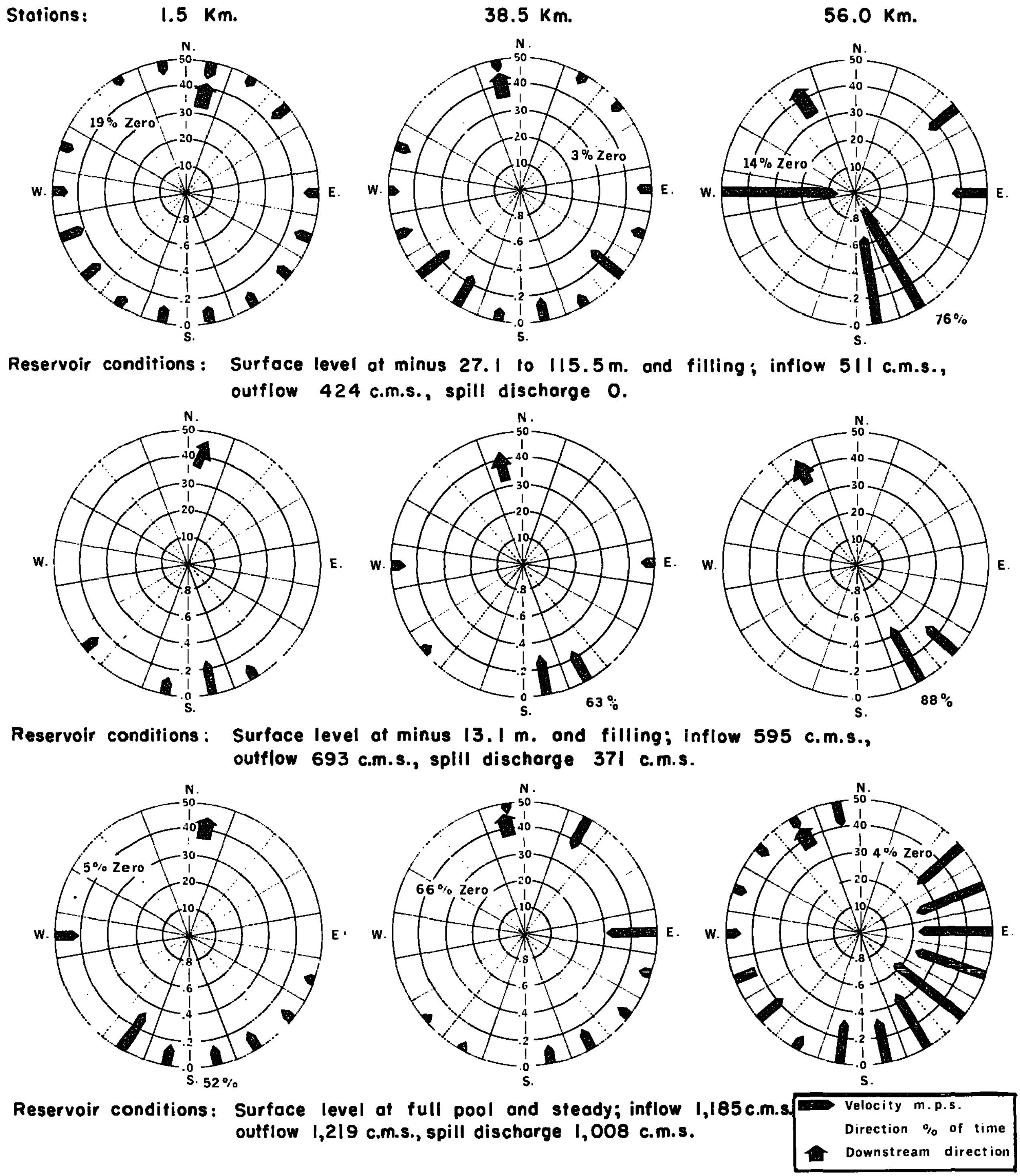

FIGURE 5.—Direction (percentage of time, indicated by scale between center and upper margin of each figure) and average velocity (m.p.s. scale between center and lower margin) of currents recorded at 3-m. depth in Brownlee Reservoir. Direction of current reads toward point of wedge. Percentages of time (if any) during which no flow was detectable are given within each circle; when flow was in a particular direction more than 50 percent of the time the percentage is given outside of the circle. Adapted from Ebel and Koski (1968).

the dam were affected mainly by the presence or absence of spillway discharges even when the reservoir level was down 27.1 to 15.5 m. (fig. 5). Surface currents in the middle and upper sections of the reservoir, however, appear to be little affected by spillway discharges. Reservoir level and volumes of flow had the greatest effect on the orientation and stability of the surface currents in these areas (fig. 5).

TEMPERATURE CYCLE

The volume of flow and water level of the reservoir also influenced the characteristics of temperature and oxygen in the impoundment. Figure 6 shows a generalized annual thermal cycle in the reservoir. From January to mid-March, isotherms of 1° to 6° C. were vertically aligned. Horizontal alignment of isotherms began in late March, and thermal stratification developed by early June. A sharp convergence line (not shown in fig. 6) was formed in the upper reservoir in late spring of 1963 when cold, dense river water sank below the warmer surface water (Ebel and Koski, 1968). In late June, the temperatures of the river water and surface water were similar and the line disappeared. By mid-July the entire reservoir was usually stratified with well-defined epilimnion, thermocline, and hypolimnion. In late summer, water temperatures ranged from 5° C. in the hypolimnion to as high as 24° C. at the surface. In mid-October a convergence line was again formed by rapidly cooling water from the Snake River and the thermocline was gradually eroded. Vertical alignment of isotherms began again in early December.

DISSOLVED OXYGEN CYCLE

The dissolved oxygen content of the reservoir followed a similar cycle each year (fig. 7). The reservoir was near saturation and relatively stable from January to mid-March, at which time oxygen concentrations began to decline in the deeper parts. Depletion of oxygen continued through the summer until August when all water below 30 m. had less than 3 p.p.m. In September, the cooler, oxygenated water from Snake River began to sink below the surface of the upper reservoir. By November, most of the water had 7 to 9 p.p.m. of oxygen.

These seasonal changes occurred each year, but with certain differences. In 1965, a drawdown of 28.3 m. and a late filling period caused: (1) late formation of a thermocline, (2) higher average temperatures from top to bottom, (3) lower oxygen concentrations during August and September, and (4) currents that were consistently oriented downreservoir through May. Drawdown was significant in 1964 (26.7 m.), but the filling began earlier and volumes of inflow and outflow were smaller. Temperatures were lower and concentrations of dissolved oxygen were higher in 1964 than in 1965, but conditions were less favorable for fish than in 1962 or 1963. A reservoir drawdown sufficient to allow sustained downreservoir current velocities can prevent a sharply defined convergence line from forming. For this reason, no convergence line formed in the upper reservoir in the spring of 1962, 1964, or 1965.

Generally, the temperatures and dissolved oxygen in the reservoir were within acceptable limits for survival of salmon during their spring migration (March-June). These conditions, however, began to deteriorate by late June and were marginal to restrictive until late September. A more detailed report of the environment was presented by Ebel and Koski (1968).

DISTRIBUTION AND MOVEMENT OF NATIVE STOCKS OF SALMON

Juvenile salmon from four populations were indigenous to Brownlee Reservoir: Two were progeny of spring chinook salmon, one of fall chinook salmon, and one of kokanee. The account of movement and behavior of juvenile salmon while passing through the reservoir environment is presented by species and population.

SPRING CHINOOK SALMON

Offspring of spring chinook salmon enter the reservoir from two areas: the Weiser River, a tributary of the Snake River, and Eagle Creek, a tributary of the Powder River (fig. 1). Migrants from Weiser River must traverse the entire reservoir on their seaward migration, whereas Eagle Creek migrants have less than one-half of the reservoir to negotiate. The two populations also differ in average age, size, and season of entry. Table 1 gives yearly estimates of the numbers of young fish that entered the reservoir in 1962–65.

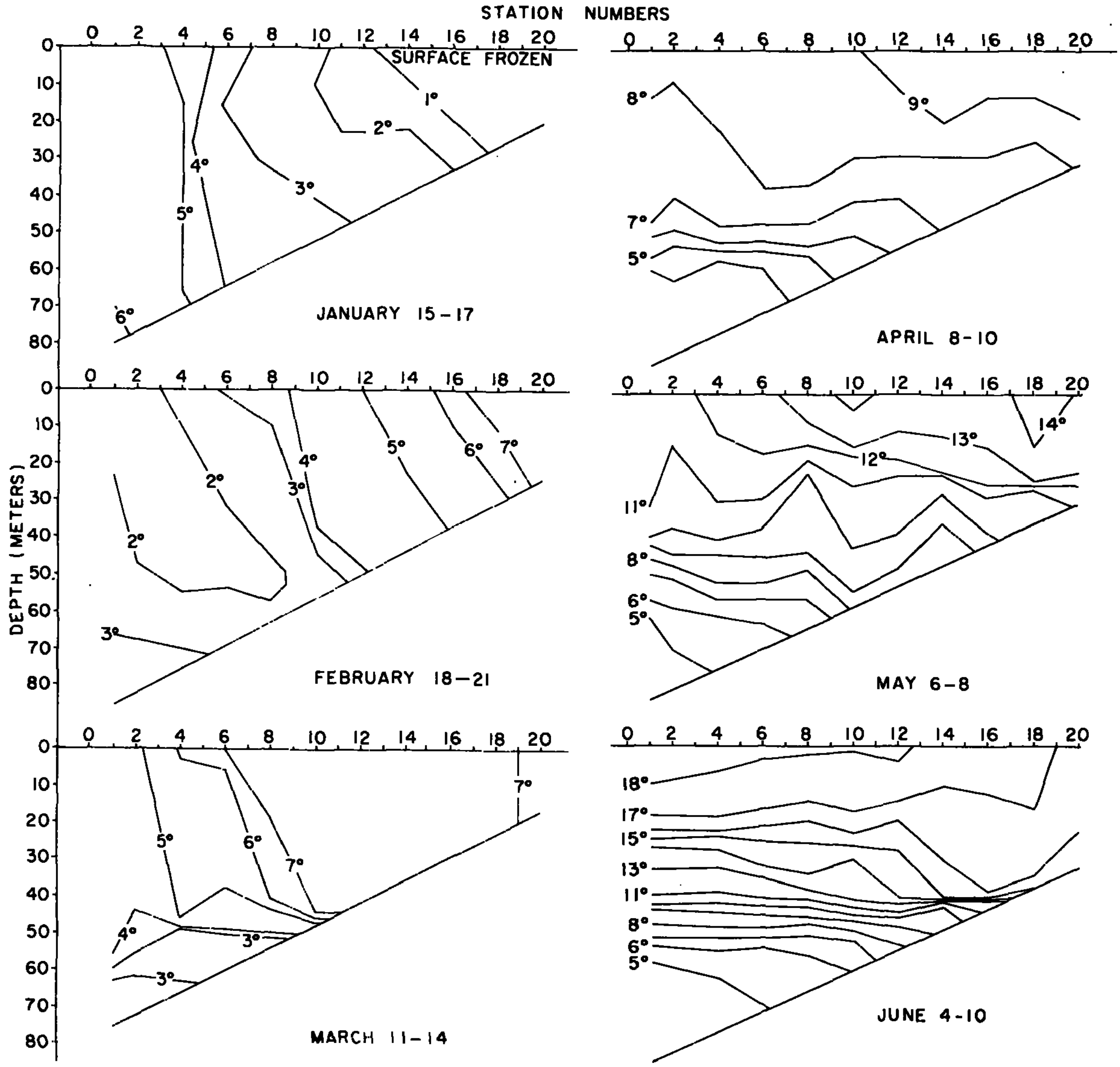

Figure 6.—Water temperature profile and stratification cycle at Brownlee Reservoir, 1963, modified from Ebel and Koski (1968).

Table 1.—*Estimated numbers of juvenile spring chinook salmon that entered Brownlee Reservoir, 1962–65 (from Krcma and Raleigh, 1970)*

	Weiser River origin	Eagle Creek origin				
Year	Age-group I	Spring migrants Age-group 0	Spring migrants Age-group I	Spring migrants Age-group II	Fall migrants Age-group 0	Fall migrants Age-group I
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
1962	122,500	(1)	(1)	(1)	116,000	1,200
1963	15,000	600	13,500	(2)	7,500	(2)
1964	6,800	(2)	6,700	(2)	(2)	(1)
1965	3,200	(2)	(2)	(2)	(1)	(1)

[1] Not estimated.
[2] Negligible numbers.

Weiser River Population

Spring chinook salmon from the Weiser River, 106 to 176 mm. long, entered the reservoir as yearlings from early April until late June. The migration peaked from late April to early May each year.

Through late May, spring chinook salmon from the Weiser River that were in the reservoir could be distinguished from fall chinook salmon of age-groups O and I on the basis of length; they were longer than age-group O but shorter than age-group I of the fall stock. After late May, as length

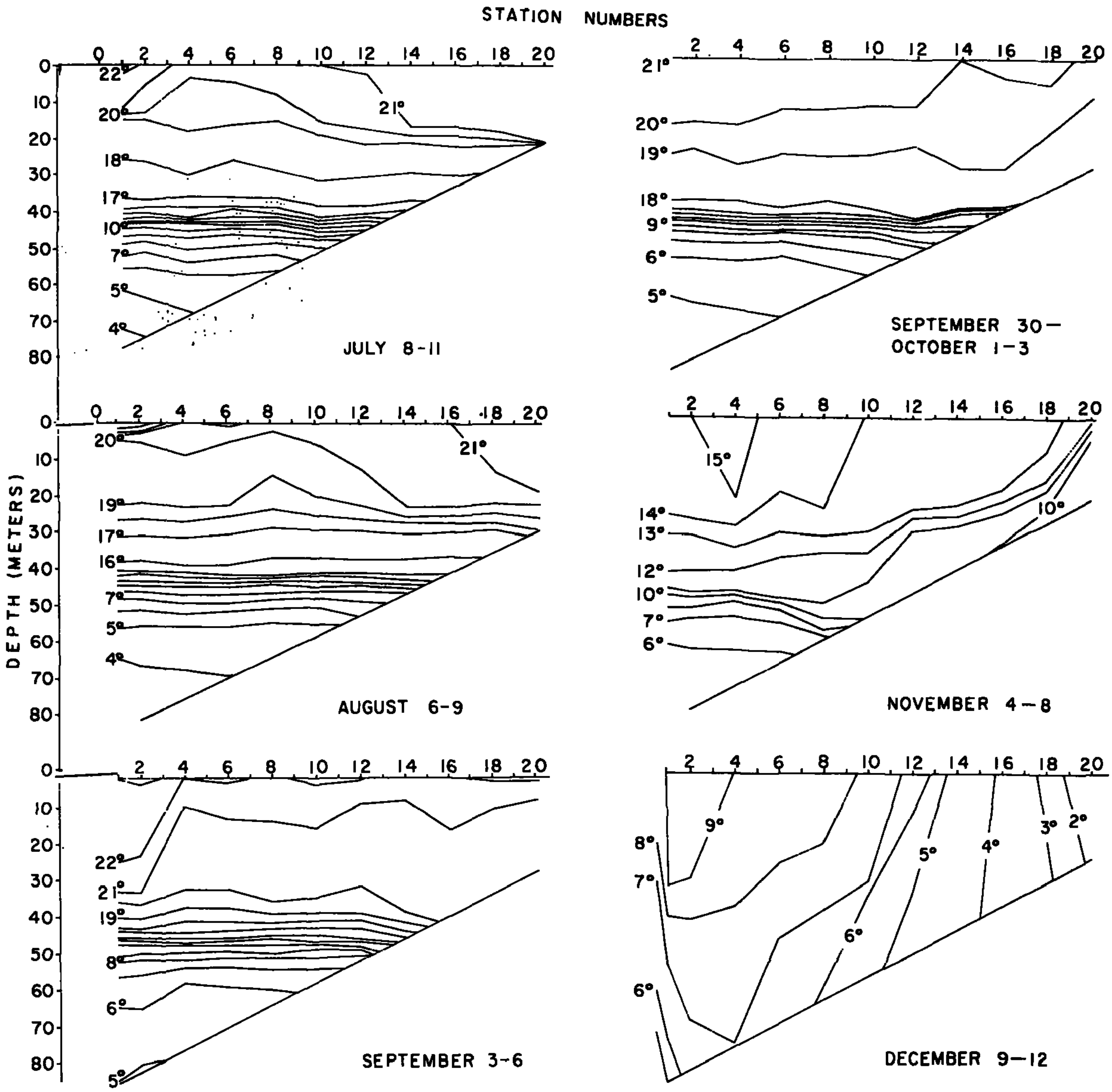

FIGURE 6.—Continued

measurements overlapped, the populations were separated on the basis of marked fish in the catch. By late May, however, the peak of migration from the Weiser River had usually passed through the reservoir.

A comparison of the timing of peak catches in the Snake River above the reservoir and at Brownlee Dam provided rough estimates of the time required for passage through the reservoir—about 2 weeks in 1962 and 3 weeks in 1963 (fig. 8). Differences in flow and length of reservoir between the 2 years appear to account for the more rapid movement in 1962. From early May through early June 1962 the reservoir was drawn down 9 m. and was about 75 km. long. Over the same period in 1963 it was nearly full and 92 km. long (fig. 4). Because of decreased depth and length in 1962, the average movement of the water mass through the reservoir was more rapid and conducive to passage of fish.

On the basis of the comparison of peak catches, the movement through the reservoir of yearling chinook salmon from the Weiser River averaged 6.4 km. per day in 1962 and 4.8 km. per day in 1963. Recapture of 334 marked individuals in 1962 and 1963 indicated that these fish moved through

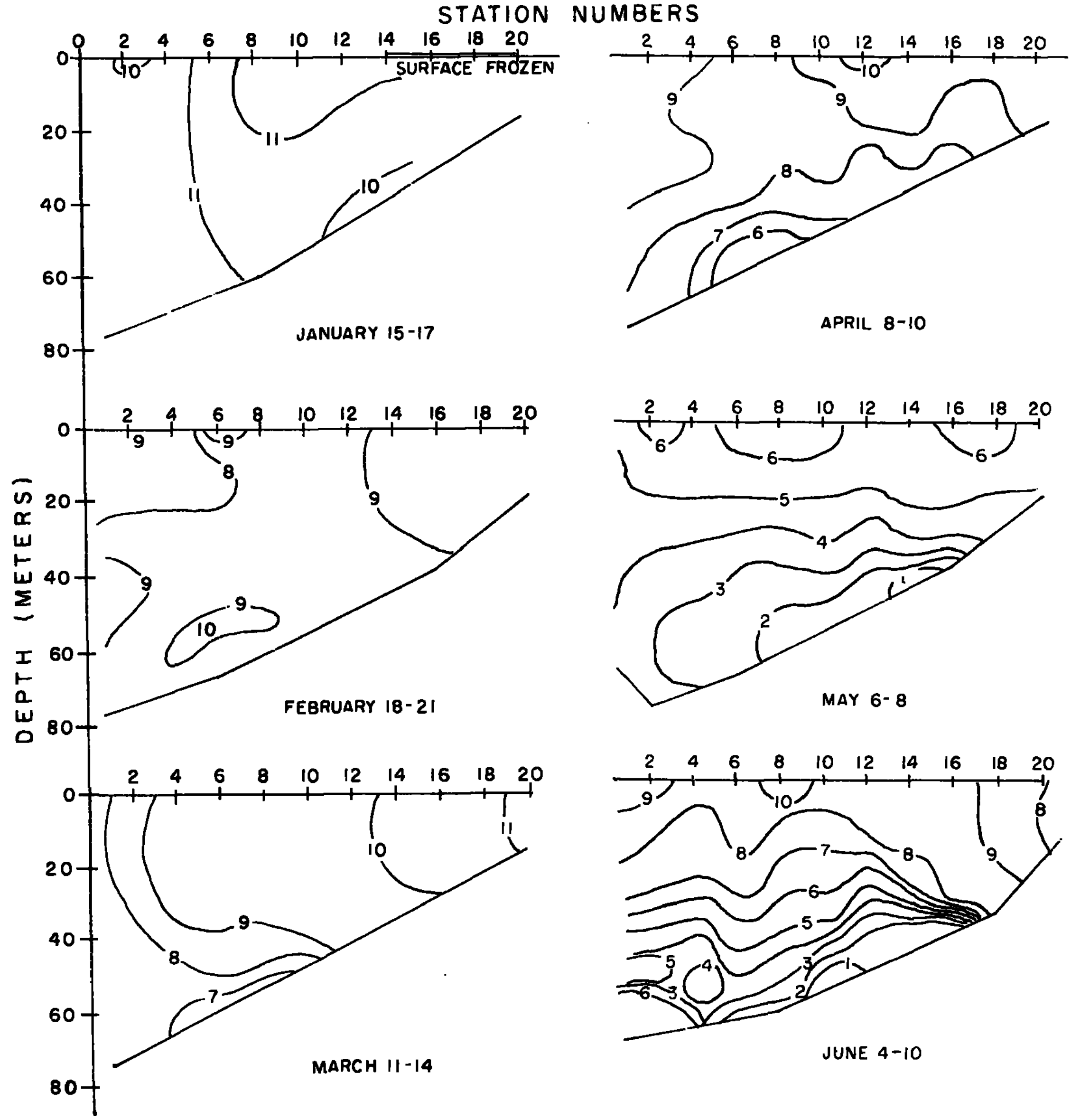

FIGURE 7.—Dissolved oxygen (p.p.m.) profiles from Brownlee Reservoir, 1963, modified from Ebel and Koski (1968).

the reservoir with little wandering and corroborated the estimated rates of movement.

In 1962, about 3,200 fish from the Weiser River population were marked as they were entering the reservoir. Six were recaptured the following spring (1963) in the reservoir. In 1963, about 1,900 fish were marked during their migration into the reservoir; in late June and July, 23 were recaptured in the Snake River. A study of growth patterns on their scales showed that they had returned upstream from the reservoir. These recaptures indicate that some fish of the Weiser River population become disoriented and hold over in the reservoir, but this behavior did not appear to be a major factor in the general movement of this early migrating population of large yearling fish.

In general, the Weiser River chinook salmon passed through a more benign environment in the reservoir than did populations migrating later in the season (figs. 6 and 7).

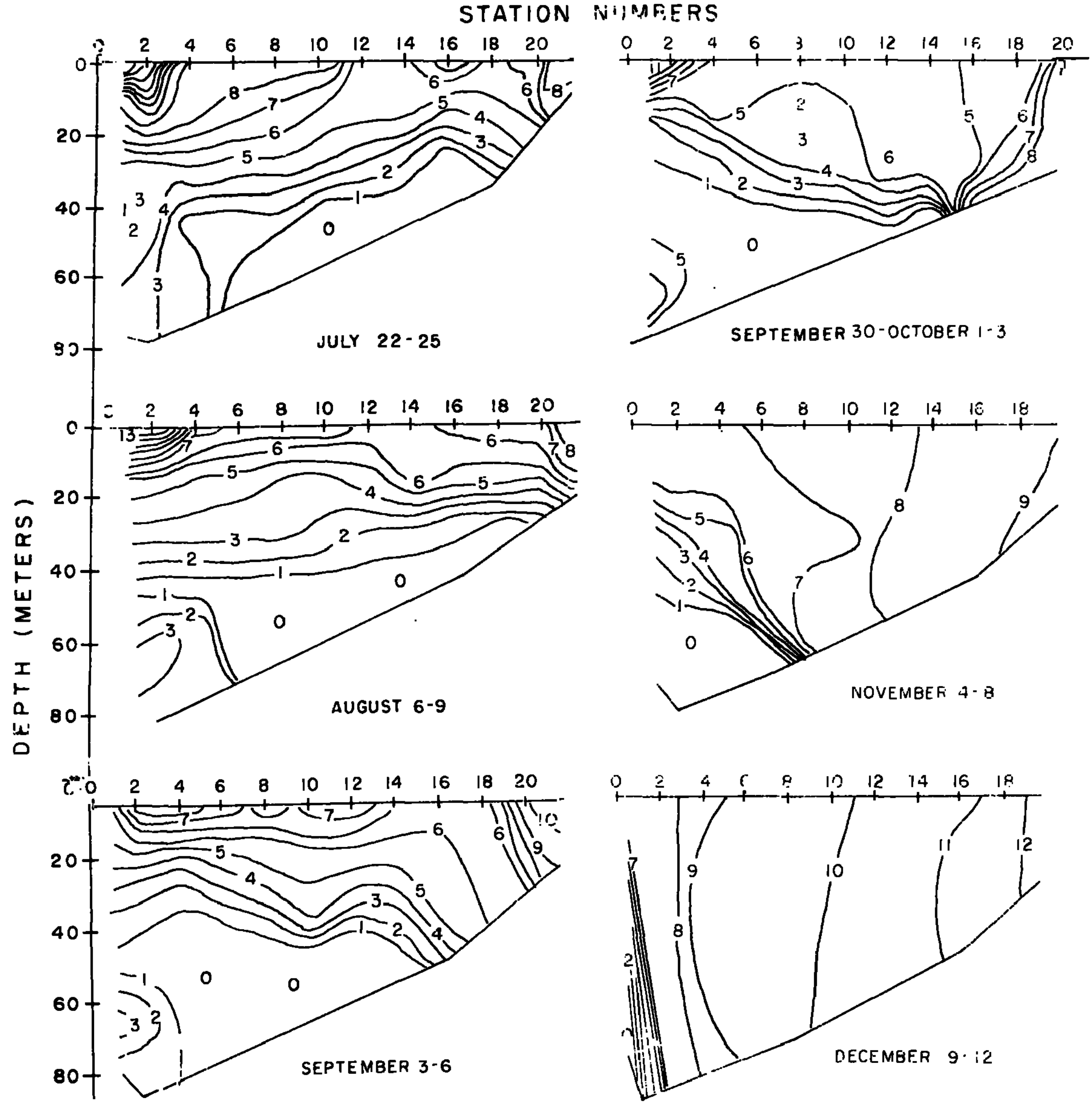

FIGURE 7.—Continued

Eagle Creek Population

The principal migration of spring chinook salmon from Eagle Creek into the reservoir was in the fall and consisted of age-group O fish, 53 to 125 mm. long. This movement was followed by a second lesser migration of age-group I fish, 65 to 138 mm. long, from February to May (Krcma and Raleigh, 1970). Only chinook salmon that had held over from the spring migrations were found in significant numbers in the reservoir at that time of year. These populations were separable by size (fig. 9).

Continuous recovery from the upper Powder River Arm and the main reservoir of marked age-group O fish from the fall migration from Eagle Creek indicated that not all these fingerlings continued to move through the reservoir. Further evidence was obtained by comparing mean lengths of fish caught leaving Eagle Creek with those of fish from the reservoir. Fish that remained in the stream grew little through the fall and winter, whereas those in the reservoir continued to grow.

Incidental movement of Eagle Creek fish from the reservoir began in November, but a sustained

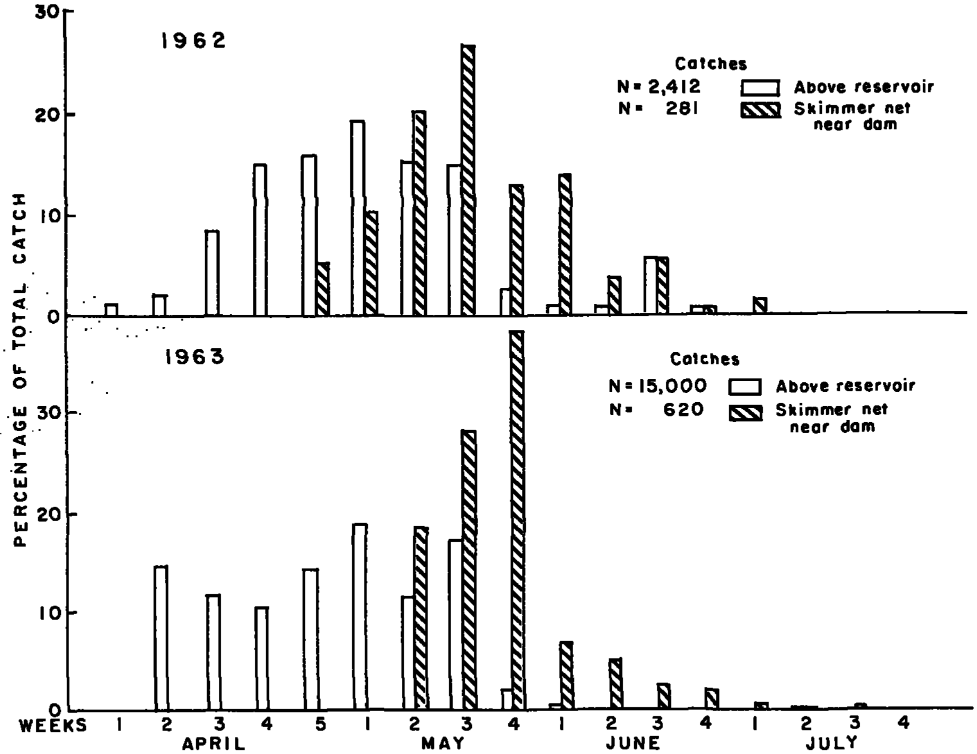

FIGURE 8.—Percentages of the total catch of juvenile spring chinook salmon from Weiser River, taken during different weeks at the upper and lower ends of Brownlee Reservoir, 1962–63.

outmigration did not occur until after the first of the year (Sims, 1970). There were two major migrations of Eagle Creek fish from the reservoir each year; the first consisted of fish that entered the reservoir in the fall and overwintered, and the second consisted of spring migrants that moved directly from the stream to the dam (fig. 10). The first group migrated from the reservoir primarily from late January to April and the second group from late March to June (fig. 11).

We investigated the possibility that the reservoir might be delaying the seaward migration of the fall migrants. Tagging data showed that most fall migrants spent about 3 months in the reservoir, whereas most spring migrants moved through the reservoir in a much shorter time. In 1964 and 1965, groups of Eagle Creek fall migrants were marked, transported around Brownlee and Oxbow Dams, and released in the Snake River. Sampling at Ice Harbor Dam (442 km. downstream from Brownlee) showed that fish released in the river below the dams overwintered in the Snake River and arrived at Ice Harbor Dam at about the same time as the group that passed through the reservoir.[3] It appears, therefore, that Brownlee Reservoir did not unduly delay the fall migration from Eagle Creek and that these fish normally overwinter before going to sea.

Although Brownlee Reservoir did not appear to cause an appreciable delay in the seaward migration of the fall migrants, some fish from Eagle Creek became disoriented in the reservoir under certain conditions. In 1962 and 1964, fish from Eagle Creek moved consistently downstream toward the dam. In 1963, however, a segment of the population moved upreservoir. This movement was proven by capture of 12 marked individuals in the Snake River 4 km. above the reservoir in late June and July 1963. Drawdown of the reservoir exceeded 14 m. in 1962 and 1964 but was only 6.4 m. in 1963. Figures 4 and 5 indicate that these conditions would provide weak downstream currents in 1962 and 1964 but disoriented currents in

[3] Personal communication, Howard Raymond, Fishery Biologist, BCF Biological Laboratory, Seattle, Wash., June 1965.

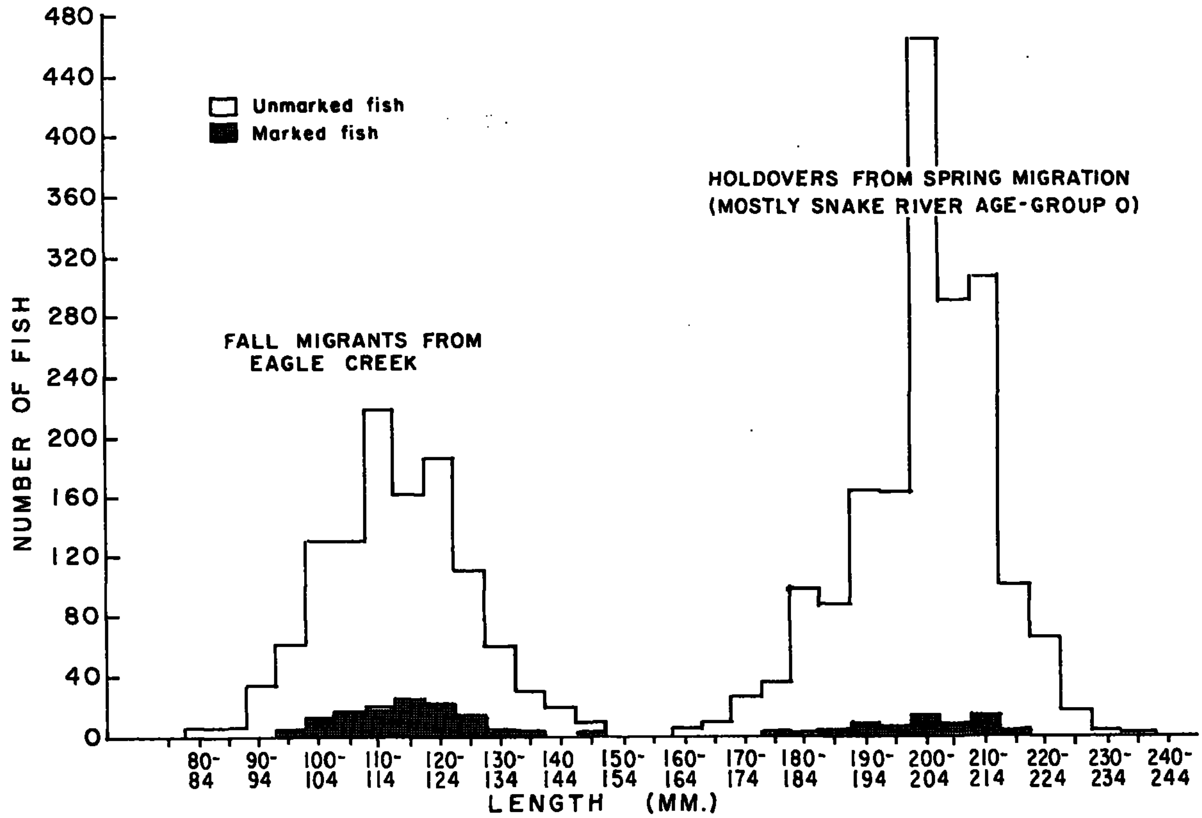

FIGURE 9.—Lengths of juvenile spring chinook salmon from Eagle Creek that entered Brownlee Reservoir in the fall and lengths of holdover chinook salmon from populations that entered in the spring, in samples collected September through December 1962.

1963. We presume that some Eagle Creek fish moved upreservoir in 1963 because of frequent upreservoir currents. The fish that arrived at the upper end of the reservoir in late June and July as the "smolting" condition (Hoar, 1963; Conte, Wagner, Fessler, and Gnose, 1966) was attenuating and reservoir temperature and oxygen conditions were deteriorating (figs. 6–7) may have been attracted upstream by the relatively cooler, oxygenated water of the Snake River.

FALL CHINOOK SALMON OF AGE-GROUP O

Juvenile fall chinook salmon entered the reservoir as age-group O and at a smaller length (33–105 mm.) than other populations. They began their migration from spawning grounds in the Snake River about 120 km. above the reservoir. Table 2 gives estimates of fall chinook juvenile salmon that entered the reservoir.

We studied the offspring of native populations in 1962 and 1963; hatchery-reared juvenile fish from other sources were released in the spawning area for study as they passed through the reservoir in 1964 and 1965.

TABLE 2.—*Estimated numbers of fall chinook salmon that entered Brownlee Reservoir, 1962–65 (from Krcma and Raleigh, 1970)*

Year	Native	Hatchery-reared
	Number of fish	
1962	529,000	(1)
1963	374,000	(1)
1964	(2)	111,500
1965	(2)	162,800

1 None released.
2 Negligible numbers.

Juvenile native fall chinook salmon entered the reservoir from late April through June in 1962 and from late April through mid-June in 1963. Mean lengths of age-group O fish in the reservoir were 56 to 85 mm. through the 1962 season and 75 to 195 mm. in 1963.

Peak catches above the reservoir and at the fingerling collection facility near Brownlee Dam

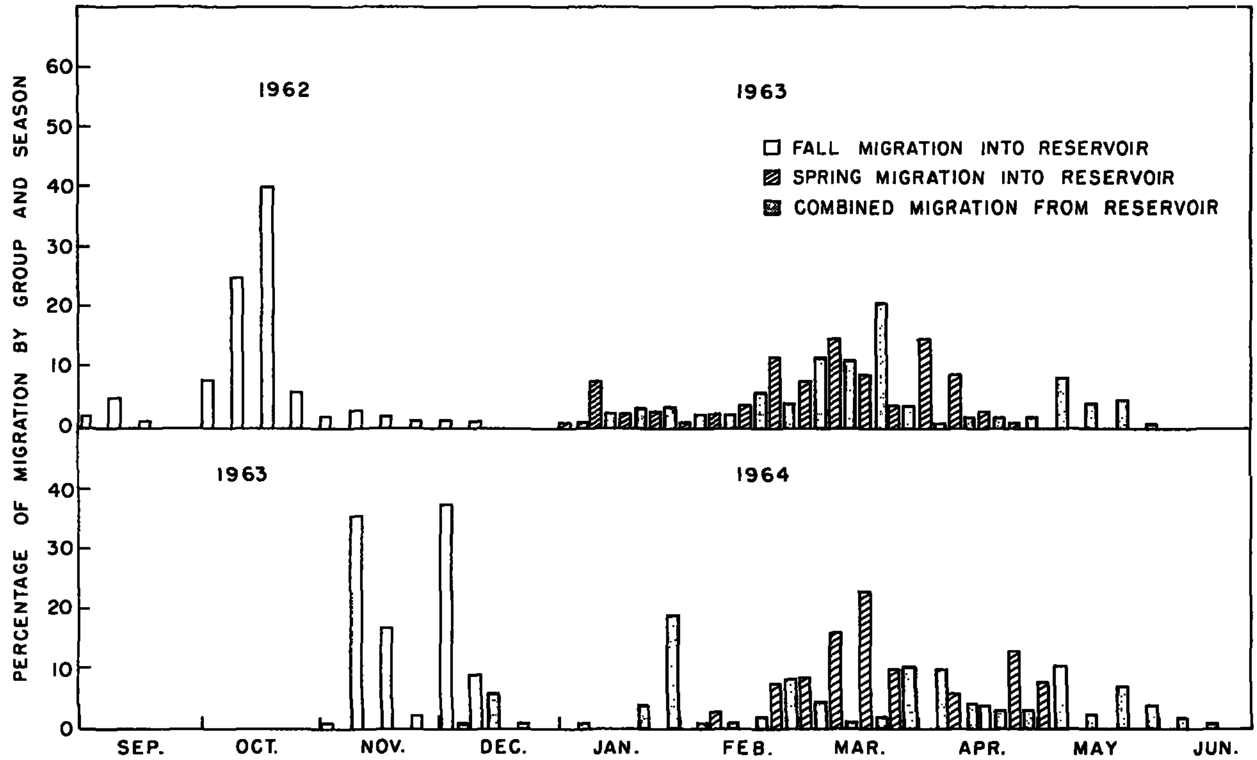

FIGURE 10.—Percentage of total catches of juvenile spring chinook salmon from Eagle Creek that entered and that left Brownlee Reservoir in different months, 1962–64. Fish entering the reservoir were caught in a louver trap at Eagle Creek (Krcma and Raleigh, 1970); fish leaving the reservoir were caught in skimmer net traps in the forebay (1963) or in scoop traps below the dam (1964).

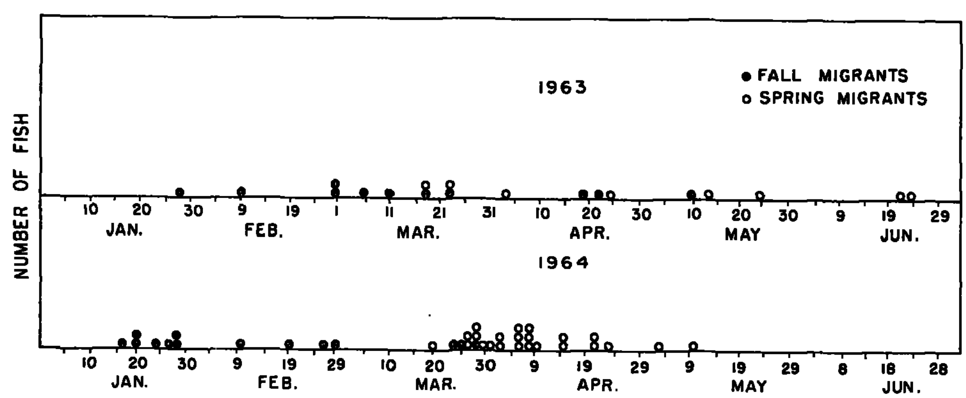

FIGURE 11.—Date of arrival at Brownlee Dam of juvenile spring chinook salmon tagged at Eagle Creek during the fall and spring migrations of 1962–64. Each circle represents one recovery.

showed that juvenile fall chinook salmon passed through the reservoir in about 2 weeks in 1962 and in about 7 weeks in 1963 (fig. 12). Figures 4 and 5 indicate that the currents would have been of low velocity but moderately well oriented downstream during the 1962 migration. In 1963, the migrant fall chinook salmon entered the reservoir a week later than in 1962 (fig. 12). At that time the reservoir was drawn down only 3 m. and was being filled. Although volumes of inflow and outflow were moderate to high, the currents were disoriented (figs. 4 and 5).

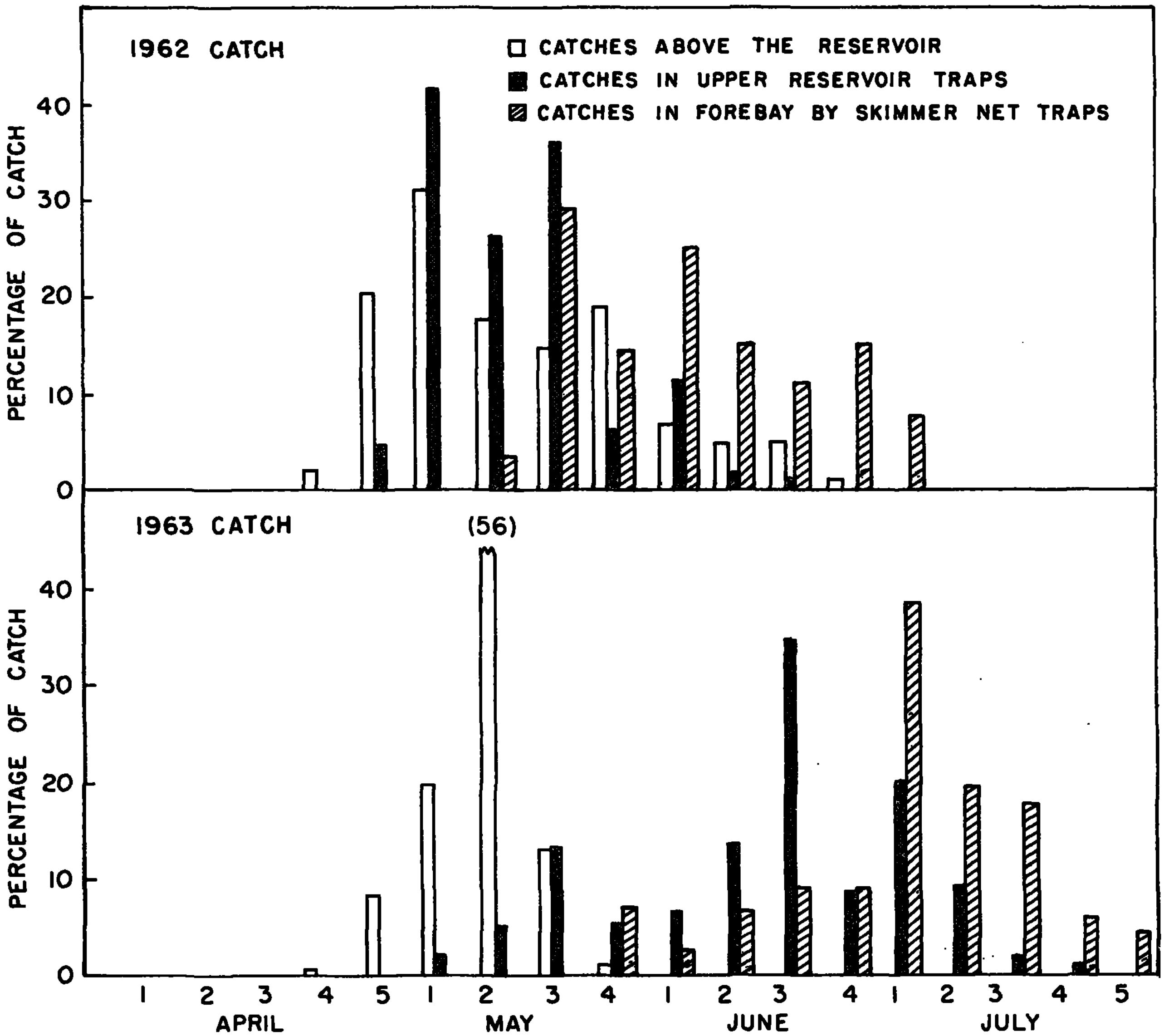

FIGURE 12.—Catches of native juvenile fall chinook salmon in the upper reservoir and at Brownlee Dam, 1962–63.

Trap and surface trawl catches in 1963 indicated that most of the migrants were remaining in the upper reservoir. They were in the Snake River water mass upstream from the point where the colder river water sank below the reservoir surface (Ebel and Koski, 1968; Raleigh and Ebel, 1967). Gill net sampling showed the fish were near the surface of the reservoir through mid-June. By late June, however, they were captured at all depths. At this time the river water began to warm and mix with the reservoir water mass; the convergence line disintegrated, and the juvenile fish began to move through the reservoir. Peak catches by traps in the upper reservoir and at Brownlee Dam showed that after the initial 5-week delay the fish migrated through the reservoir in about 2 weeks (fig. 12).

In 1963, the capture of a number of large fingerlings in the Snake River above the impoundment indicated a pronounced upreservoir movement of young fall chinook salmon (Krcma and Raleigh, 1970). Growth patterns on the scales showed that these fish had lived in the reservoir. The identification of marked fish indicated that most of the fish that moved upstream had migrated from Eagle Creek and the Snake River in the spring of 1963.

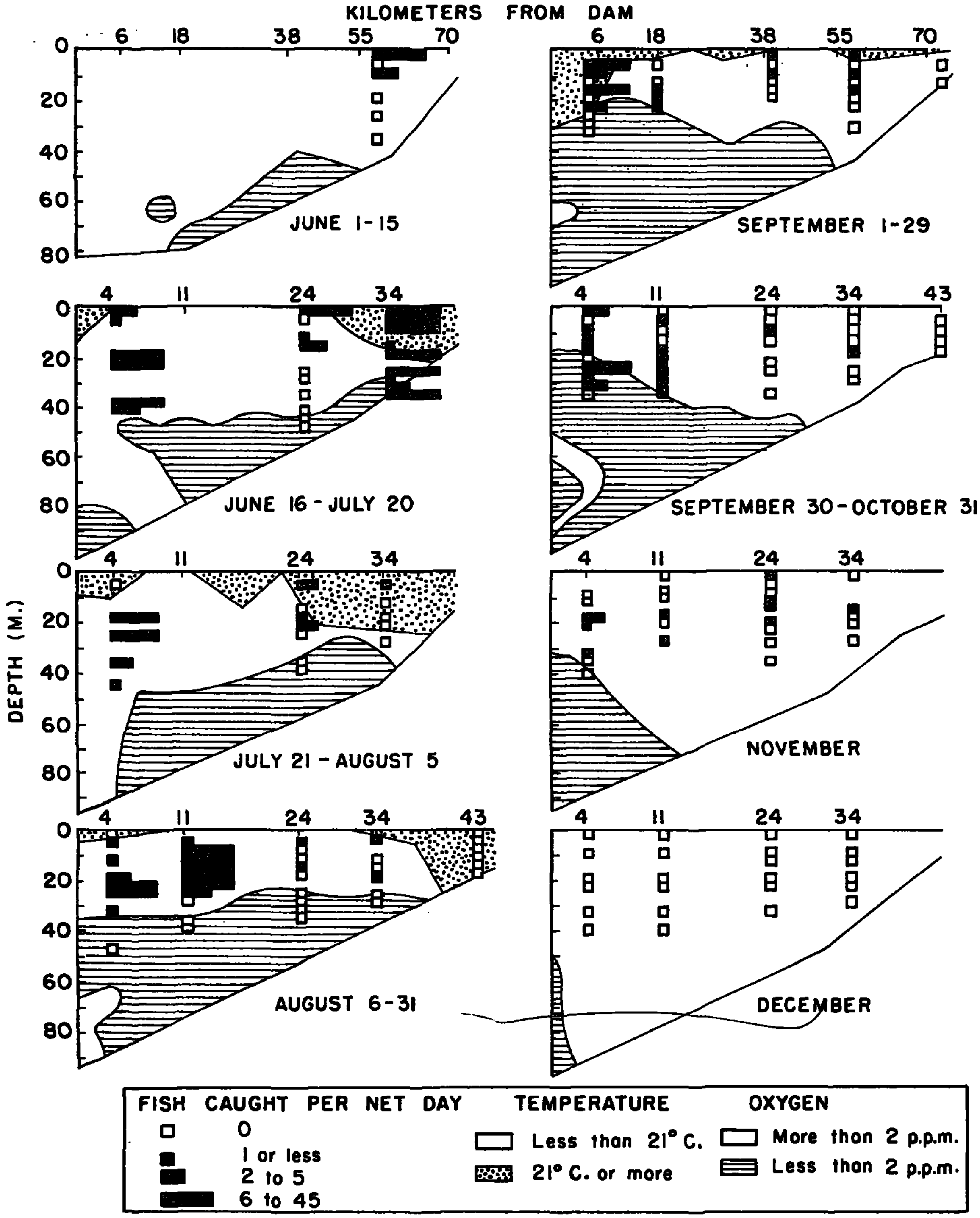

FIGURE 13.—Distribution of juvenile fall chinook salmon in Brownlee Reservoir in relation to critical oxygen and temperature regimes. Fish caught in gill nets in 1963.

We presume that these fish were attracted upstream by the cooler water of the Snake River (14–22° C.), which averaged 2 to 3° C. less than the reservoir. The subsequent downstream migration coincided with an increase in river temperatures to over 18° C. and the breakdown of the convergence line.

In most years, after the migration of smolts ended in late June or July, some chinook salmon remained in the reservoir as holdovers. In 1963, most of the migrants did not leave the reservoir even though the outmigration continued into August (Sims, 1970). The holdover fish were from all salmon populations but were mainly progeny of fall chinook salmon. They were easily distinguished from more recent arrivals by their large size; in addition, some had identifying fin clips or tags.

Gill net catches showed that the holdover salmon had a restricted spatial distribution through the summer and early fall. By late June or early July, surface temperatures exceeded 20° C. and oxygen depletion progressed upward from the bottom. These conditions were especially prevalent in the upper end of the reservoir (figs. 6 and 7). Increasing epilimnion temperatures and decreasing hypolimnion levels of dissolved oxygen eventually confined the holdovers into restricted areas unfavorable for juvenile salmon (fig. 13). By late September and October, conditions began to improve and the surviving juvenile salmon dispersed throughout the reservoir.

This same sequence of events occurred each year, but with modification. According to Raleigh and Ebel (1967), the amount of reservoir drawdown and the time and duration of the subsequent filling period appeared to be most significant in creating large differences in temperature and oxygen from year to year. In 1965, the large drawdown (28 m.) and prolonged filling (fig. 4) caused late formation of a thermocline, high temperatures, and low oxygen concentrations during late summer. In 1964, drawdown was significant (27 m.) but the filling period was shorter. Water temperatures and oxygen concentrations through the summer were more favorable than in 1965 but less favorable than in 1963, when the drawdown was small (3 m.) and the filling period was early and short.

Estimates of movement of juvenile fall chinook salmon into Brownlee Reservoir (Krcma and Raleigh, 1970) and later escapement (Sims, 1970) verified that the survival of holdover salmon was extremely poor. Fortunately, the conditions that brought about the harshest summer environment (large drawdown and delayed fill) were also the conditions that facilitated rapid passage of fingerlings through the impoundment (Ebel and Koski, 1968; Sims, 1970).

Holdovers of salmon were encountered in the Powder River Arm in October 1962 when 75 chinook salmon were caught. Two of these fish bore fin clips that identified them as progeny of fall chinook salmon from the Snake River that had entered the reservoir in the spring. One fish of this group was also recaptured at the upper end of the main reservoir in the spring of 1963.

In early summer of 1963, fall chinook salmon were captured in gill nets in the lower Powder River Arm. As the environment improved in the fall, many fish moved into the upper arm. From mid-September to mid-December, 561 chinook salmon were captured; of these 444 were tagged and released. The subsequent capture of 28 marked fish in the area of release provided evidence that some fall chinook salmon remained in the upper arm until drawndown in December. On the basis of captures of tagged and untagged fish in the Powder River Arm, a population estimate (made by the technique of Schnabel, 1938) of chinook salmon in the arm ranged from 2,631 to 6,521; the average of 22 estimates was 3,883.

The movement of holdovers from Brownlee Reservoir in 1963 began in January and peaked in February. A total of 5,396 fish were caught in the skimmer net and in scoop traps below the dam. The exodus in 1964 started in November, peaked in January, and was completed by mid-May (Sims, 1970). The total catch of the skimmer net (partially deactivated in February) and the scoop traps was 1,275 fish. This early outmigration appeared to be a displacement because of the approach of a cold water mass through the reservoir (fig. 14).

The recapture of marked holdover fall chinook salmon within the reservoir in 1963 provided information on movements of these fingerlings. Early in the year (before April) most of the fish moved toward the dam, but many moved upstream and a few were recaptured in the area of release. The recapture of fish in all areas of the reservoir and the relatively slow rates of movement indi-

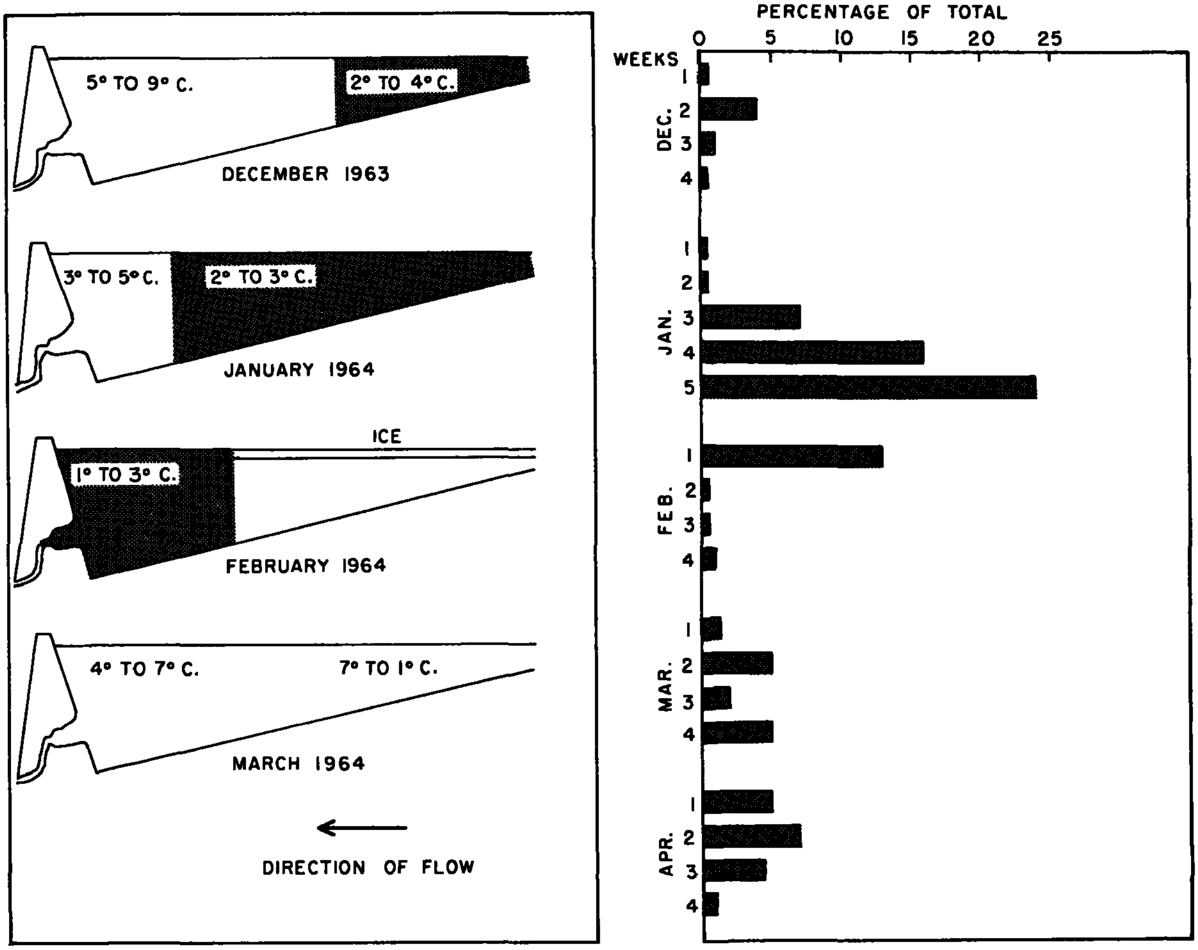

Figure 14.—Movement of holdover fall chinook salmon from Brownlee Reservoir in relation to water temperature. (The early outmigration coincided with the approach of a mass of cold water.)

cated that these fish were wandering. As the season progressed, however, the increases in the proportion and rate of movement downreservoir suggest the onset of a directed migration (fig. 15).

The holdover of fingerling salmon in Brownlee Reservoir was evident during each year of study, but the percentage of the total involved, as indicated from reservoir recruitment and escapement estimates (Krcma and Raleigh, 1970; Sims, 1970), fluctuated significantly. The percentage of holdovers seemed to be smallest in 1965, intermediate in 1964, and highest in 1963. The yearly percentage of holdovers varied inversely with reservoir conditions conducive to good passage of fish (figs. 4 and 5).

KOKANEE OF AGE-GROUP I

A few kokanee were caught in the reservoir in 1963 and 1964, and large numbers entered the reservoir in 1965 (table 3). The fish were probably from the Payette River system (Payette Lakes and Cascade and Deadwood Reservoirs). The migration appeared each year in early June, peaked in mid- to late June, and continued into July. Too few fish were present in 1963 or 1964 to determine movement within the reservoir. In 1965, however, it was evident from gill net catches and the recapture of tagged fish that through June the migrants consistently moved downreservoir. By mid-July, when the reservoir was full and the outflow was greatly diminished, fish were moving upreservoir and downreservoir in about equal numbers.

Kokanee were captured near the surface early in the migration, but as the season progressed and the environment deteriorated, the population was concentrated near the dam at depths of 18 to 47 m., as were other salmon species that held over (fig. 13).

TABLE 3.—*Estimated length and numbers of kokanee that entered Brownlee Reservoir, 1963–65 (from Krcma and Raleigh, 1970)*

Year	Fish	Length	
		Mean	Range
	Number	*Mm.*	*Mm.*
1963	500		
1964	5,500	120	104-146
1965	506,800	108	70-155

Kokanee populations that passed through Brownlee Reservoir did not do well. The fish that we observed did not leave their nursery area until late spring. They arrived at Brownlee Reservoir when the impoundment was filling or full, the temperatures were rising, and spillway flow was reduced. If they did not move through the reservoir, the harsh environment in late summer probably caused almost total mortality. Emigration estimates made by Sims (1970) suggested that losses were large in 1964 and 1965. These fish apparently were unable to survive through the summer—a few holdovers of the 1962 migration were captured in 1963, but none were observed in later years.

DISTRIBUTION AND MOVEMENT OF HATCHERY-REARED SALMON

To bolster the dwindling numbers of native salmon and to observe the effect of the reservoir on the passage of other salmon species, we placed hatchery-reared fall chinook and coho salmon juveniles in the Snake River about 120 km. above the reservoir in 1964 and introduced hatchery-reared sockeye and fall-chinook juvenile salmon about 88 km. above the reservoir in 1965 (Krcma and Raleigh, 1970).

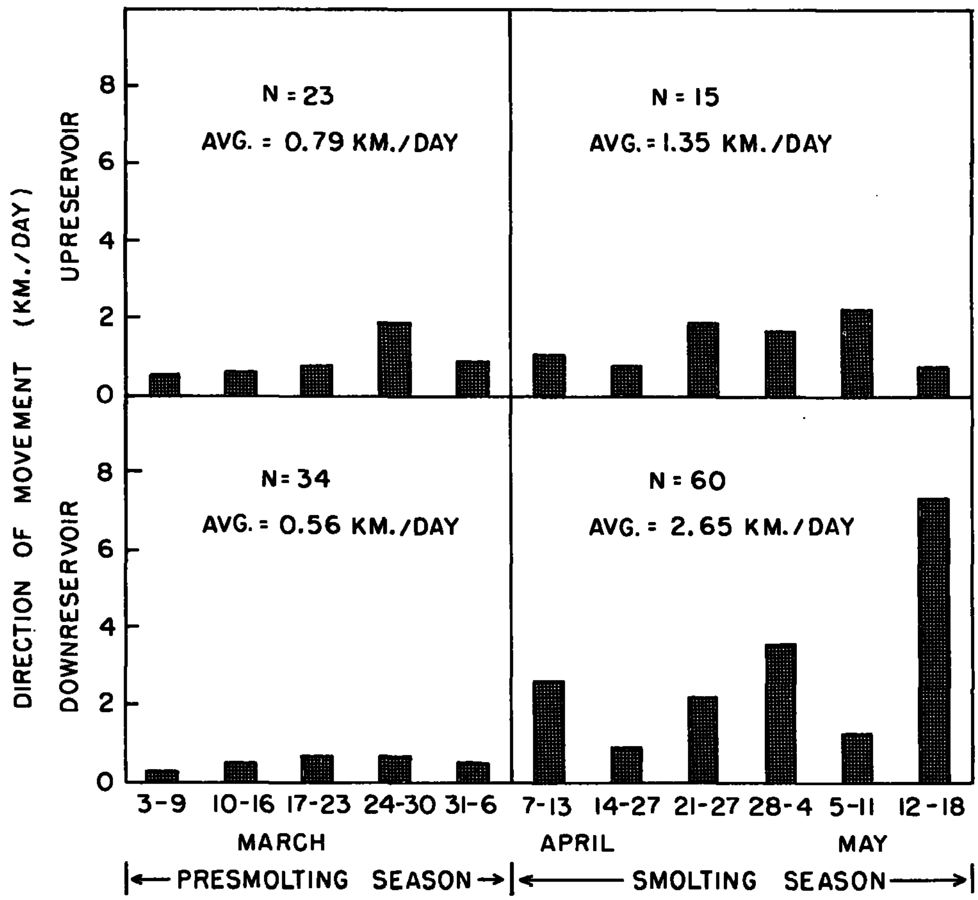

FIGURE 15.—Numbers of tagged juvenile chinook salmon holdovers recovered in Brownlee Reservoir, March 3 to May 18, 1963, showing direction and rate of movement.

FALL CHINOOK SALMON OF AGE-GROUP 0

Hatchery-reared fall chinook salmon were released in the Snake River about 120 km. above Brownlee Reservoir in March 1964 and 1965. Although released over a period of only 10 days, their movement into the reservoir extended over 3 months. Early and late migrants were 46 mm. and 130 mm. long in 1964 and 67 mm. and 135 mm. in 1965.

In 1964 and 1965, tagged hatchery chinook salmon moved primarily toward the dam until mid-May. After mid-May in 1964, some tagged fish were recaptured moving upreservoir; four tagged fish were recaptured in traps in the Snake River about 4 km. upstream from the head of the reservoir (Krcma and Raleigh, 1970). This upstream movement involved fewer fish in 1965. According to Sims (1970), 50 percent of the estimated migration of hatchery-reared chinook salmon into Brownlee Reservoir had left by the end of June 1964 and over 97 percent in 1965.

The movement upstream into the Snake River in 1964 might have been related to temperature, as noted previously for populations of native juvenile chinook salmon.

The ability of these fish to move through the reservoir to the river below Brownlee Dam (50 percent in 1964 and 97 percent in 1965) appeared to vary with volume of flow, direction of current, and length of reservoir. The drawdown lasted 6 weeks longer in 1965 than in 1964 and was accompanied by spillway discharges of large volume and duration and high volumes of inflow from the Snake River (fig. 4). During the 1965 migration this condition produced not only a smaller impoundment (45–50 km. long) but currents of higher velocity that were more consistently toward the dam than in 1964.

The rate of movement of tagged chinook salmon in the reservoir was similar in 1964 and 1965 even though the environments were different. The rate for all chinook salmon that moved toward the outlet averaged 3.0 and 2.9 km./day, respectively (table 4). Fish tagged through the first half of May generally moved faster than those tagged later. Upreservoir movement for nine chinook salmon averaged 0.89 km./day in 1964 and 2.0 km./day in 1965.

Chinook salmon recaptured downriver at Ice Harbor Dam averaged 19.9 km./day in 1964 and 18.8 km./day in 1965 through the reservoir and river.

Fish captured early in the season in midreservoir and along both banks indicated that fall chinook salmon of age-group O were distributed throughout the surface area. Gill net catches showed that juvenile chinook salmon moved both up and down the reservoir during darkness. This observation implies that most directed movement may have occurred during daylight and that fish milled or were carried by currents during darkness.

The distribution of hatchery-reared fall chinook salmon through the summer was similar to that of native fall chinook salmon (fig. 16). In the spring the fish were generally distributed throughout the epilimnion of the reservoir. As the surface temperature increased the fish moved into deeper water and downreservoir. Temperatures above 21° C. at the surface and low oxygen concentrations (less than 3 p.p.m.) at depths where the water was cooler forced the fish to move into restricted areas. The increased catches of fish in gill nets in the upper reservoir in June and July were probably the result of fish returning from a temporary upstream movement into the Snake River.

Some hatchery-reared chinook salmon from the 1964 release remained in Brownlee Reservoir during the winter. Sims (1970) estimated that only about 85 percent of the hatchery-reared fall chinook salmon that entered the reservoir in 1964 migrated out that year. Also 17 fish from this group were captured in the reservoir in February and March 1965.

TABLE 4.—*Summary of direction and rate of movement of tagged age-group O hatchery-reared fall chinook salmon in Brownlee Reservoir, 1964–65*

	Direction of movement				Rate of movement					
Year	Recaptured	Upreservoir	Down-reservoir	No movement	Upreservoir	Range	Down-reservoir	Range	Brownlee Reservoir to Ice Harbor	Range
	Number	*Number*	*Number*	*Number*	*Km./day*		*Km./day*		*Km./day*	
1964	60	9	37	14	0.89	0.06–1.85	3.0	0.31–9.7	19.9	12.6–33.8
1965	277	14	237	46	2.0	.08–9.76	2.9	.06–8.7	18.8	8.0–42.0

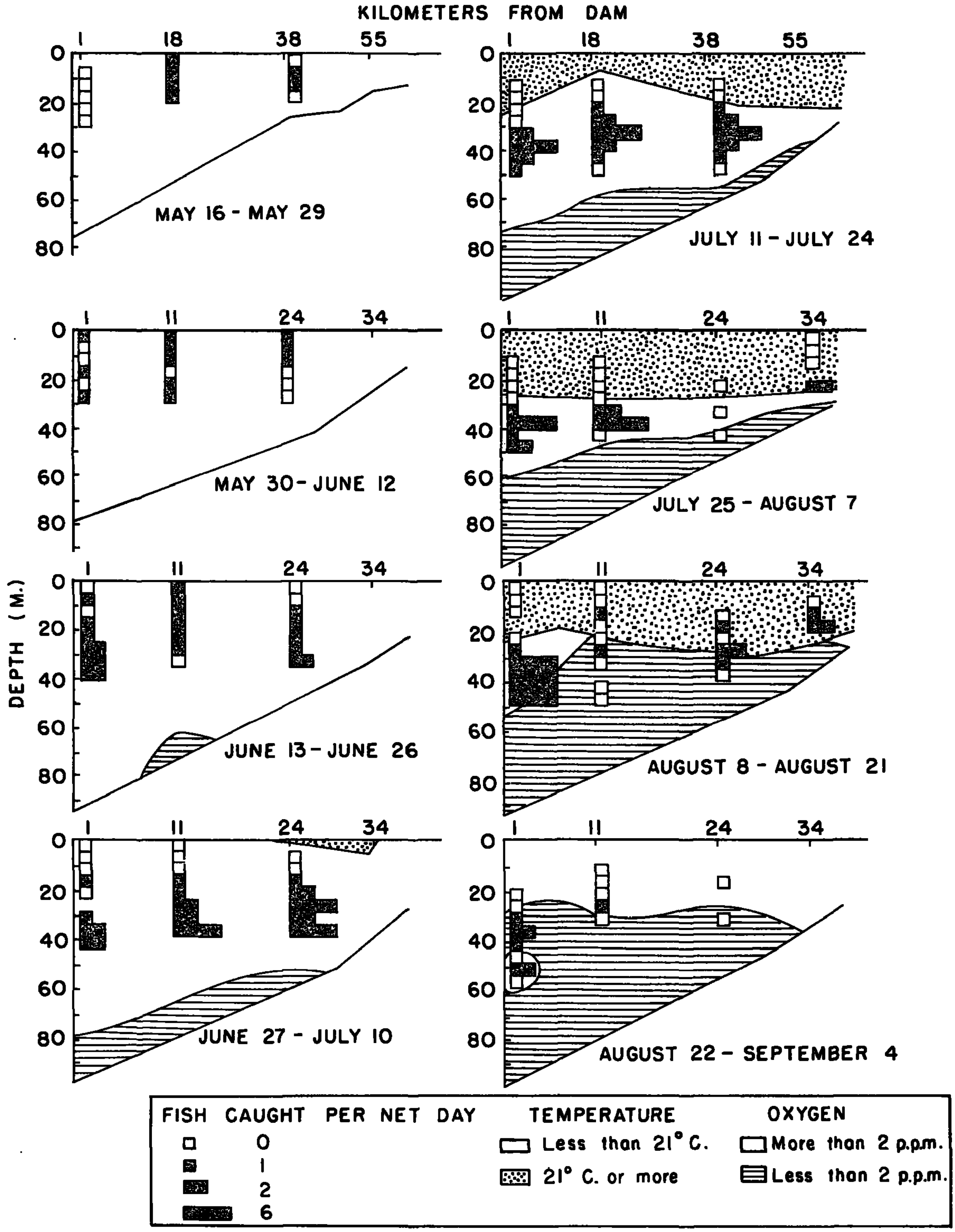

FIGURE 16.—Distribution of hatchery-reared fall chinook salmon in Brownlee Reservoir in relation to critical oxygen and temperature regimes as determined from gill net catches, 1965.

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COHO SALMON OF AGE-GROUP I

Of 375,000 juvenile coho salmon released in the Snake River 120 km. above the reservoir from March 15 to 30, 1964, an estimated 69,000 entered the reservoir (Krcma and Raleigh, 1970). Early in the migration these fish averaged 112 mm. long; by the end they averaged 131 mm.

On the basis of peak catches at the Snake River trapping site above the reservoir and at the dam, passage time through the reservoir was 2 weeks (fig. 17). The reservoir was only 64 km. long at the beginning of the migration as a result of a 13.5-m. drawdown; the distance between the reservoir and the trapping site in the river was about 35 km.

Recapture data from 26 tagged fish indicated that the rate of movement changed during the migration (fig. 18). Before May 20 when the reservoir was drawn down about 13 m. and the outflow volume was large (about 850 c.m.s.), 17 tagged migrants averaged 1.8 km./day. As the outflow was curtailed and the reservoir began to fill, the migration rate of nine tagged fish then dropped to 0.9 km./day. At this time the proportion of fish moving upreservoir also appeared to increase.

In early May most coho salmon were near the surface in the upper reservoir, but by the end of the month most had shifted to the vicinity of the dam at greater depths. As the migration rate slowed in late May and recruitment from the Snake River continued, catches were again good in the upper reservoir. In July the greatest concentration appeared to be in midreservoir at depths of 18 to 31 m. Catches declined through July, and only a few fish were captured thereafter.

SOCKEYE SALMON OF AGE-GROUP I

In 1965, 473,000 yearling sockeye salmon were released in the Snake River, 88 km. above Brownlee Reservoir. Krcma and Raleigh (1970) estimated that 360,000 had entered the reservoir. The salmon were from Babine Lake, British Columbia and reared to yearling stage at the Leavenworth National Hatchery, Wash. The left ventral fin was clipped on all fish. Migrants in March averaged 121 mm.; later migrants averaged 130 mm. by mid-May.

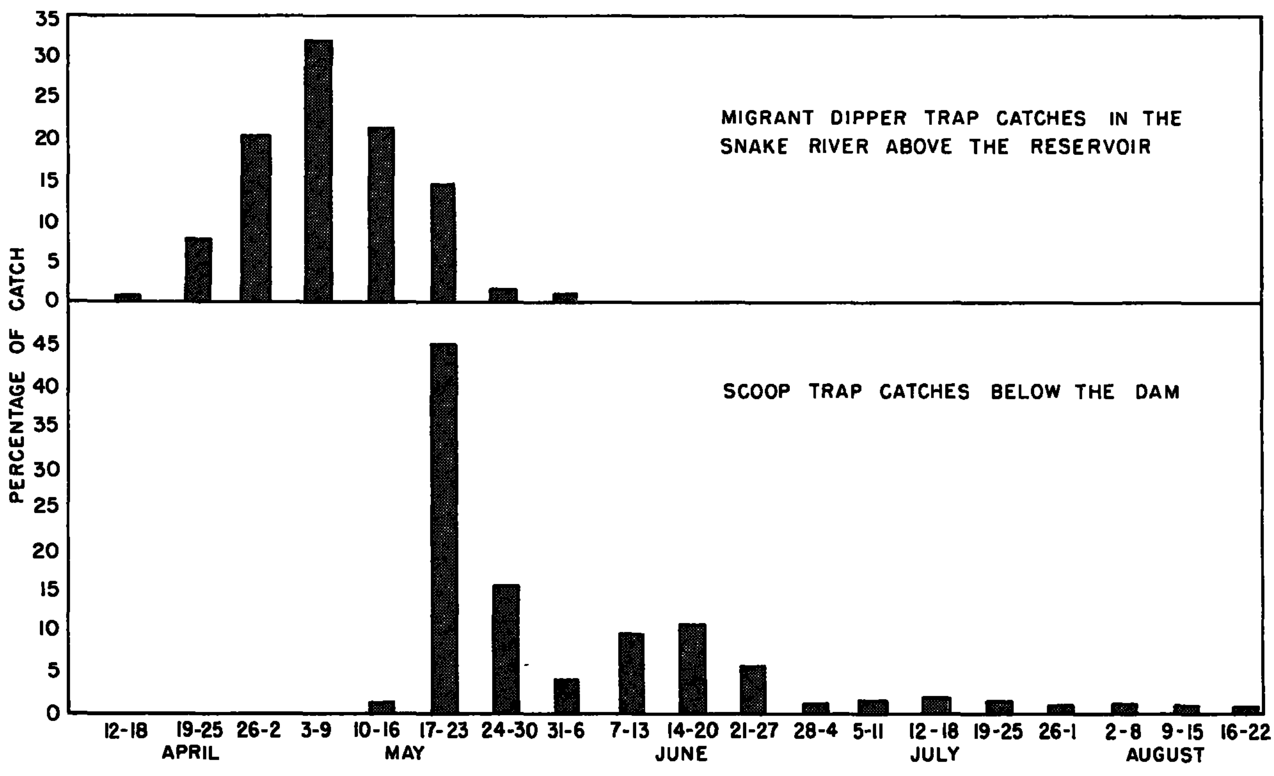

FIGURE 17.—Weekly catches of juvenile hatchery-reared coho salmon above Brownlee Reservoir and below Brownlee Dam, 1964.

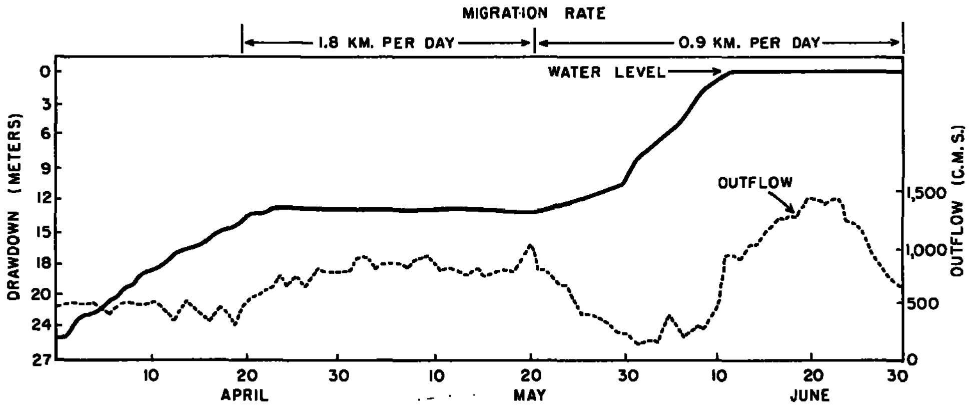

Figure 18.—Rate of downstream movement of tagged hatchery-reared coho salmon in relation to water level and outflow in Brownlee Reservoir, April 1 to June 30, 1964.

These fish moved rapidly downstream after release. The first sockeye salmon were captured in the reservoir on March 17—2 days after the initial release. Catches above the reservoir reached a peak during the first week of April and below the reservoir the following week. During the ensuing 2 months, 44 sockeye salmon were recaptured at Ice Harbor Dam and two at Bonneville Dam. The capture of fish in gill nets in the reservoir indicated that the fish moved consistently downreservoir. No sockeye salmon were observed in the Powder River Arm, and no delay within the reservoir was evident.

The average daily rate of movement for 117 tagged sockeye salmon that moved toward the outlet was 5.2 km./day. On the basis of this rate and the length of the reservoir (45–50 km.) in late March and early April, sockeye salmon required an average of about 8 or 9 days to move through the reservoir.

Most sockeye salmon were captured within 4.5 m. of the surface, some were between 4.5 and 13.5 m., and a few were taken as deep as 22.5 m. (table 5). Data on catch per unit of effort at three gill net stations indicated that the vertical distribution was similar throughout the reservoir.

Sockeye salmon were captured near shore and offshore in the upper reservoir. In the lower reservoir they were captured almost exclusively offshore. The recovery of tagged sockeye salmon indicated that fish tagged near the shore eventually moved to the open water, whereas those tagged offshore remained offshore.

During the migration period from March through mid-May 1965, the environment was favorable for fish passage. Dissolved oxygen concentrations were 6 to 11 p.p.m. until early May, and temperatures ranged from about 5° C. in late March to 15° C. in late April. The reservoir level was 24 to 30 m. below full pool through mid-May, and its length was reduced to about 45 km. Spill discharge at Brownlee Dam was continuous, ranging from a weekly average of 424.5 to 1,440.3 c.m.s. Current monitors, operated by personnel studying the limnology of the reservoir, revealed that surface currents were oriented toward the outlet. Ac-

Table 5.—*Depth distribution of sockeye salmon yearlings as indicated by the catch per gill net day at different depths in Brownlee Reservoir, March 17 to April 26, 1965* [1]

Depth	Mile 1			Mile 12			Mile 24		
	Sets	Sockeye	Catch per unit effort	Sets	Sockeye	Catch per unit effort	Sets	Sockeye	Catch per unit effort
M	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
<1.4	7	247	35.3	4	312	78.0	6	205	34.2
1.5–4.1	2	3	1.5	3	8	2.7	3	10	3.3
4.2–13.7	5	4	0.8	4	3	0.8	6	10	1.7
13.8–18.3	2	0	0.0	3	3	1.0	4	3	0.8
18.4–22.9	5	3	0.6	1	4	4.0	4	3	0.8
23.0–27.5	2	0	0.0						

[1] Mesh sizes used were 1.9, 2.5, 3.1, and 3.8 cm. stretched mesh.

cording to Sims (1970), nearly 100 percent of the sockeye salmon migration had passed through Brownlee Reservoir.

SUMMARY

The distribution and movement of juvenile salmon that migrate through Brownlee Reservoir, a large impoundment on the Snake River, was studied from 1962 to 1965. The study included native spring and fall chinook salmon and kokanee and hatchery-reared fall chinook, coho, and sockeye salmon.

Each native salmon population had a characteristic age, size, and time of entry into the reservoir. Most spring chinook salmon from Eagle Creek entered the reservoir in the late fall as age-group O, 53 to 125 mm. long. These fish overwintered in the reservoir, primarily in the Powder River Arm. They resumed their seaward migration in the spring just before the peak of a second outmigration from Eagle Creek in March and April of age-group I fish, 65 to 138 mm. long. The migration of juvenile spring chinook salmon from the Weiser River entered the reservoir in peak numbers in late April or early May; it consisted of age-group I fish, 106 to 176 mm. long. This movement was closely followed by that of age-group O fall chinook salmon from the Snake River, 33 to 105 mm. long, which entered the reservoir in peak numbers in mid-May. Kokanee migrants entered the reservoir latest in the season; age-group I fish, 70 to 155 mm. long, arrived in mid-June.

Hatchery-reared groups of salmon migrated into the reservoir as follows: fall chinook salmon of age-group O (46–135 mm.) in mid-May of 1964 and 1965; coho salmon of age-group I (71–166 mm.) in mid-May 1964; and sockeye salmon of age-group I (86–175 mm.) in early April 1965.

Migrants from all populations were near the surface as they entered. As the season progressed and the juvenile fish moved downreservoir, they tended to move into deeper water.

Migration peaks from the reservoir varied from year to year, depending on reservoir conditions, but were sequential by stock. Fish (mainly fall chinook salmon) that remained in the reservoir from the previous year's migration left the reservoir early (late January or February) at the approach of a cold water mass that moved through the reservoir. This migration was followed in late February and early March by fish (mainly fall chinook salmon) that had overwintered in the Powder River Arm. Spring migrants from Eagle Creek and Weiser River arrived at the dam in large numbers in April and May. Fall chinook salmon from the Snake River arrived in late May to early July and kokanee, in July or August. Hatchery-reared fall chinook salmon left in May 1964 and in April 1965, coho salmon in late May 1964, and sockeye salmon in April 1965.

Juvenile fish that did not leave the reservoir by late June or July were confined to restricted areas of the reservoir by high epilimnion temperatures and low concentrations of dissolved oxygen, which extended into the epilimnion from the hypolimnion. When this process began, juvenile salmon in the upper end of the reservoir usually reentered the slightly cooler waters of the Snake River. They returned to the reservoir when temperatures in the river began to approach 20° C. The survival of holdover salmon through the summer and early fall was extremely poor.

The differences in success of passage through the reservoir were more closely related to the physical conditions of the reservoir than to behavioral differences between species of salmon stocks. Success of passage for all populations was poorest in 1963 when the reservoir was nearly full throughout the migration. Under this condition, the reservoir was 92 km. long and surface currents were either weak or nonexistent and often moved upreservoir. Passage through the reservoir was intermediate in 1962 and 1964 when drawdown was 6 to 14 m. through May and the reservoir averaged 70 km. long. The most successful passage was in 1965 when the drawdown was large (26–28 m. through May), the reservoir was relatively small (45–50 km. long), and currents were consistently oriented downstream. Loss of orientation and upreservoir movement of the juvenile salmon were correlated with conditions in the reservoir most prevalent in 1963 and least prevalent in 1965.

Early entrance into the reservoir appeared to improve the chances of successful passage. In general, early fish encountered the best combination of reservoir length, current conditions, and environment. Late migrants, such as the kokanee, entered a rapidly deteriorating environment, and their success of passage was extremely poor.

ACKNOWLEDGMENTS

Many individuals contributed to this study, particularly the late Joe Dunatov, master fisherman, and crew chiefs Lawrence Davis, Maurice Laird, Lawrence Logan, Nathan Roe, and Philip Weitz. Employees of fishery agencies of Idaho, Oregon, and Washington and of the Idaho Power Company provided assistance and background information. We are also indebted to James Graban and the late Wayne Klaveno of the Idaho Fish and Game Department, Robert Gunsolus and Lawrence Korn of the Fish Commission of Oregon, Lloyd Rothfus of the Washington Department of Fisheries, and Wendell Smith, biologist of the Idaho Power Company.

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