461

WINTER-RUN CHINOOK SALMON IN THE SACRAMENTO RIVER, CALIFORNIA WITH NOTES ON WATER TEMPERATURE REQUIREMENTS AT SPAWNING

SPECIAL SCIENTIFIC REPORT–FISHERIES No. 461

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

WINTER-RUN CHINOOK SALMON IN THE SACRAMENTO RIVER, CALIFORNIA WITH NOTES ON WATER TEMPERATURE REQUIREMENTS AT SPAWNING

by

Daniel W. Slater

Special Scientific Report--Fisheries No. 461
Washington, D.C. . November 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

Stewart L. Udall, *Secretary*

Frank P. Briggs, *Assistant Secretary for Fish and Wildlife*

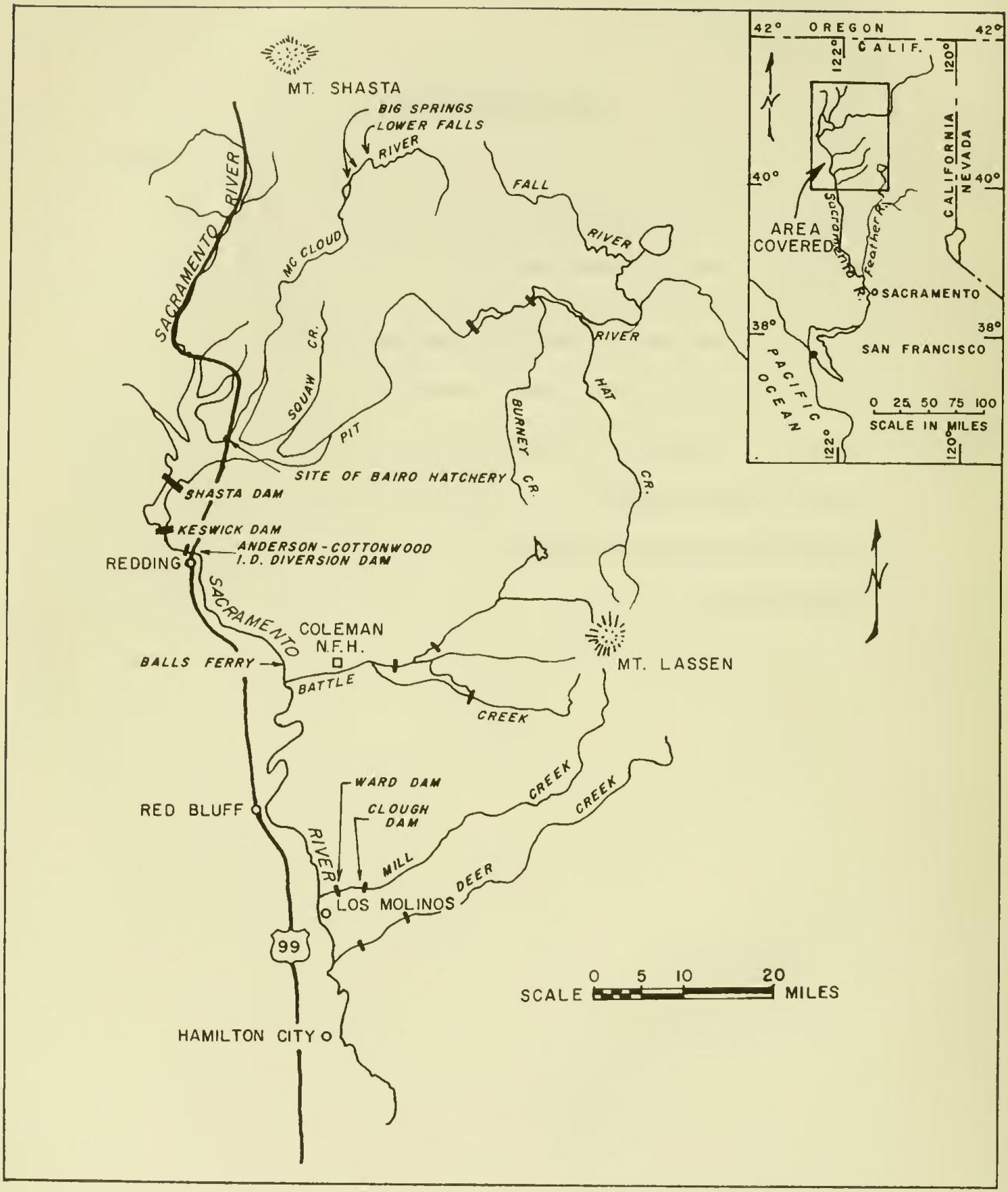
FISH AND WILDLIFE SERVICE

Clarence F. Pautzke, *Commissioner*

BUREAU OF SPORT FISHERIES AND WILDLIFE

Daniel H. Janzen, *Director*

CONTENTS



Frontispiece.--Upper Sacramento River and Tributaries

WINTER-RUN CHINOOK SALMON IN THE SACRAMENTO RIVER, CALIFORNIA, WITH NOTES ON WATER TEMPERATURE REQUIREMENTS AT SPAWNING

by Daniel W. Slater
Bureau of Sport Fisheries and Wildlife
Fish and Wildlife Service
U.S. Department of the Interior

ABSTRACT

Salmon specialists throughout the Pacific Coast indicate that the winter-run chinook salmon is restricted to California's Sacramento River system. The characteristics and habits of the race are unique in the following respects: Fresh-water holding period, December to April; spawning period, April into July. The up-migration is concurrent with the late segments of the fall run, but the adults are distinguishable by the green condition of the gonads. The down-migration is concurrent with that of the spring-run fry, but the migrants are 2-inch or larger fingerlings. Evidence is lacking to determine whether there is an earlier down-migration of fry. The race appears to hold great promise as a stock to be introduced into areas where May-August temperatures are 42.5° - 57.5° F., for it supports superb angling during the fresh-water holding period. Water temperatures in May through August are seen as the factor limiting the natural extension of the range of the race.

Fry (1961) states that winter-run fish are the least known and probably the least abundant of the Central Valley chinook (king) salmon runs. This paper is intended to shed a little light on the first point and discount the latter point.

Winter-run chinook salmon *(Oncorhynchus tshawytscha)* have been known to Upper Sacramento Valley residents and to students of California salmon for many years. They have been mentioned, usually in an offhand way, in the literature many times. Yet, one gathers from discussion and correspondence with salmon workers that these fish are little understood.

Basically, four reasons are indicated for this lack of understanding: (1) Concurrence of both the adult run and the fisheries dependent upon it with the latest segments of the fall run, (2) occurrence of the adult fresh-water stages during winter and spring when observation is difficult and seldom practiced, (3) isolation of winter-run spawners during the years prior to construction of Shasta Dam in inaccessible sections of the McCloud River, and (4) until recently, the numerically small size of the runs. Historically, no distinction of winter-run fish was made in either the sport or the commercial river fisheries. The "green" condition of the gonads would have distinguished them in the inland waters from the late fall run, but apparently few, if any, were taken there until 1949 following their displacement to holding and spawning areas of the mainstem Sacramento River downstream from Shasta Dam. Had their habits been understood, it seems likely that efforts would have been made

to transplant them to other areas from the McCloud River.

In preparation for this paper, about 20 salmon agencies and students (located widely throughout the known range of chinook salmon) were queried by mail to ascertain whether the winter run discussed here is known elsewhere than in the Sacramento River. All 18 responses were negative, but nearly all evidenced sincere interest in this race. The information and encouragement received from these responses has been most helpful and is greatly appreciated. Sincere thanks are extended to John Pelnar and Harry D. Baer of Coleman National Fish Hatchery for data provided from the hatchery records. I also thank Richard J. Hallock for original data supplied from his observations and files. Donald H. Fry, Eldon P. Hughes, and Richard J. Hallock, of the California Department of Fish and Game, reviewed the manuscript, and their suggestions have sparked material improvements in the presentation.

OBSERVATIONS BEFORE CONSTRUCTION OF SHASTA DAM

Livingston Stone may have observed winter-run salmon on the McCloud River during his early investigations of the 1870's. The McCloud River now enters Shasta Lake and is no longer accessible from the sea as it was then (see frontispiece). Certainly, fish of this run were known at least as early as 1902, for a pair of salmon were observed spawning on April 24 of that year in the McCloud River opposite Baird Hatchery, now covered by Shasta Lake. This observation was credited by Rutter (1904, p. 73) in the annual report of the Commissioner of Fisheries for 1902 to Superintendent Lambson of Baird Hatchery. No evidence has been turned up that this observation was considered more than interesting. If later students were intrigued by it, they were silent in print.

Hanson, Smith, and Needham (1940, pp. 42-43) reported that 25 salmon were seen on May 26, 1939, over nests in the upper McCloud River, at Big Springs and upstream to the Lower Falls. A spawned-out female was found June 12, 1939; eggs were taken from three nests on June 23 and 27; eyed eggs and alevins were obtained from two nests on August 5; and fingerlings were seined from the river at Big Springs on September 29, 1939. (These observations were made during the pre-Shasta-Dam surveys; salmon were blocked from these areas beginning in May 1942.) These authors suggested "a separate winter run." Needham, Smith, and Hanson (1941, p. 66) were more definite and cautioned that allowance must be made for winter-run salmon in any salvage plan (for Shasta Dam). Unfortunately, knowledge of the critical temperature requirements of salmon egg stages was inadequate to make any effective allowance.

OBSERVATIONS DURING SALVAGE OPERATIONS RELATED TO SHASTA DAM (1943-46)

It remained for Needham, Hanson, and Parker (1943, p. 23) to unequivocally commit the name "winter run" to these fish. (The unique spawning time of the run was, as noted above, established first by Lambson's observation in 1902.) These authors gave an account of the trapping and hauling work during 1943 on chinook salmon blocked by Keswick Dam. This was the first season that salmon were blocked. In June 1943, ripe, winter-run females with flowing eggs were found in the hauling trucks; later that month, spawned-out fish were found in Deer Creek where the trapped fish were released. Of 5,245 salmon transferred from Keswick Dam to Deer Creek during June 1943, 59 were reported by these authors to have been winter run; the rest were spring-run chinooks. Only seven (four females and three males) of the winter run survived to spawn. Presumably none of the eggs survived, for the water temperatures in Deer Creek downstream from the mouth of the canyon, where the fish were forced to spawn, were and are too high for incubating eggs in July and August. Yet these fish would have fared no better in the main river.

Moffett (1949) noted: "During the years 1943 and 1944, when Shasta and Keswick dams were blocks to upstream migration but stored little or no water, river temperatures in summer were so high that the spring-run salmon would have been eliminated or seriously impaired

had they been forced to remain below the dams over summer." Temperatures in the Sacramento River downstream from Shasta Dam were not recorded in 1943, but they no doubt were in the sixties and seventies in June and July as recorded in 1939 at Redding. Seymour (1956) and Hinze, Culver, and Rice (1956) have shown that very low survival of eggs is to be expected at temperatures above about 58° F.

Although 8,034 salmon were transferred to Deer Creek and 4,048 to Battle Creek from Keswick and Balls Ferry traps during 1944, no winter-run fish were noted. Temperatures of Shasta Reservoir releases into the Sacramento River were 61° F. when first recorded early in August 1944, possibly low enough to permit survival of eggs deposited before July. But oxygen deficiency, common to waters from new reservoirs, and heavy-metal pollution probably occurred in initial releases from the new reservoir. Heavy-metal pollution was seen to kill adult fish in November 1944.

In March 1945, about 200 chinook salmon, assumed to be winter run, were trapped at Keswick and hauled to Deer Creek. Additional winter-run fish may have been included among the 252 chinook salmon hauled from Keswick during April through June, but it is unlikely that any were among the 2,838 hauled from Balls Ferry during May through August of 1945. It is assumed that some, perhaps most, of the winter run escaped being taken in the Keswick traps in 1945. The temperature of the released water from Shasta Reservoir did not exceed 55° F. until mid-September in 1945. Thus, any winter run that escaped could have spawned in the Sacramento River successfully. In 1946, only 20 fish were trapped at Keswick Dam in May and none prior to that month. Apparently, the entire winter run of 1946 remained in the hospitable waters of Sacramento River.

The records of the salmon salvage work conducted during the construction of Shasta and Keswick Dams thus indicated that the winter-run populations were small and were harshly dealt with by construction conditions, particularly high water temperatures, and by the salvage activities which placed emphasis on saving the spring-run fish (table 1.).

Table 1.--Winter-run chinook salmon stocks blocked by Keswick Dam and water temperatures of Sacramento River during June-July spawning periods of years 1943 through 1946

Year	Indicated winter-run salmon stock	June-July water temperatures at Redding
		°F.
1943...	About 100 fish observed, probably no reproduction.	[1] 62-73
1944...	Unknown number, possibly reproduction in main river.	[2] 52-61
1945...	About 200 fish observed, probably with no reproduction; unknown number assumed to have reproduced successfully in main river. (McLean, 1945, reported observing a ripe female on May 5, 1945, on a riffle downstream from Redding.)	46-50
1946...	Unknown number assumed to have reproduced successfully in the Sacramento River.	46-50

[1] Assumed from data of 1939 at Redding.
[2] Extrapolated from record of Shasta Dam release temperatures beginning August 2, 1944.

RESTORATION OF THE RUNS AFTER THE 1943-46 SALVAGE OPERATIONS

From the low point of 1943-46, the winter run quickly recovered. Smith (1950), in studying the upper Sacramento River sport Fishery during 1947-48 and 1949-50, noted increased catches of winter-run chinook salmon in January and February 1949. He concluded that a "sizable" run was present. This was only 4 years after the apparent destruction of all the fish of this race (about 200) that could be trapped at Keswick Dam. But some of the 1945 brood stock escaped capture, perhaps a far greater number than indicated by the trapping record. Also, the 1949 stock might well have been considerably augmented by 3-year-old fish of the 1946 brood. In any case, this initial recovery seems to have been both substantial and rapid.

The winter-run fishery and the spawning escapement have continued to increase. Azevedo and Parkhurst [1] noted that increased numbers winter-run fish were encountered in the fall-run spawn-taking operations at Coleman National Fish Hatchery during 1949 through 1956.

Since water of Battle Creek, on which Coleman Hatchery is located, is too warm for winter-run fish, those trapped at Keswick Dam (table 2) are now hauled to spawning areas in the main Sacramento River downstream from Redding; no other suitable water is available for them.

Richard J. Hallock reports (personal communication) that an estimated 11,000 winter-run salmon were caught by anglers in the 101-mile reach of the Sacramento River between Hamilton City and Keswick Dam during the winter season 1961-62. He observes that the total winter-run population now bears little relation to the counts at Keswick. I inject the word "now" on the assumption that the present ideal temperature regime of the Sacramento River probably leads to spreading the fish over a much greater length of river than was the case during 1943, the first year of salvage operations, when the fish piled up below Keswick Dam. For example, his observations of the sport fishery and activity of fish in the river indicate that the largest populations occurred in 1957-58 and 1961-62 whereas the seasons 1958-59 and 1960-61 were indicated to be largest by counts at Keswick. On June 15, 1963, I observed that numbers of spawning salmon on the riffles near Redding were nearly as great as I have observed during the fall-run spawning peak which occurs commonly in November at this site.

Hallock states further that several pairs of winter-run salmon were observed in Mill Creek below Ward Dam in June 1958. On May 22, 1962, he counted 47 live salmon active over redds and 5 dead salmon in Mill Creek between Clough and Ward Dams, and considered that spawning had just begun. He reports also that on May 22, 1962, a co-worker, John Riggs, counted 457 winter-run salmon and estimated a total population of 2,687 fish in Battle Creek in the 2 miles between Coleman Hatchery and the county bridge.

In summary, although no carcass-count nor other careful population estimates have been made, spawning-ground and fishery observations of the years 1948-49 through 1962-63 indicate that the winter run has become much more abundant than the spring run in the mainstem Sacramento River and appears to be approaching the full fun in abudance.

SUCCESS OF SPAWNING LIMITED BY WATER TEMPERATURES

Spawning of winter-run salmon in Mill Creek, Battle Creek, or Deer Creek could not normally be successful because water temperatures in July exceed 70° F. Since temperatures in the midsixties are lethal to salmon eggs, the unsuitable nature of these streams is apparent. During the spring of 1958, a total of 420 winter-run fish were hauled from Keswick to Coleman National Fish Hatchery and 309 more of this race were trapped from Battle Creek. From 236 females among these fish, only 381,065 eggs were obtained during the period April 30-June 13, 1958. Losses of the developing eggs and fry were heavy (table 3). Only

[1] R.L. Azevedo and Z.E. Parkhurst: The Upper Sacramento River Salmon and Steelhead Maintenance Program, 1949-1956. Manuscript report in files of the U.S. Fish and Wildlife Service. 96 pp.

Table 2.--Keswick Dam trapping operations 1957-58 through 1962-63

[Data for this table was supplied by John Pelnar, Manager, Coleman National Fish Hatchery, and Harry D. Baer, superintendent of trapping and hauling operations at the hatchery, including Keswick trap]

Season	Trapping period	Number of chinook salmon trapped and hauled from Keswick Dam	
		Total	Winter-run
1957-58	Nov. 15 - Jan. 27	9,229	1,540
1958-59	Nov. 17 - Feb. 13	13,517	4,657
1959-60	Nov. 16 - Jan. 29	7,566	376
1960-61	Nov. 16 - Jan. 23	9,859	919
	May 2-4	2,110	2,110
1961-62	Nov. 16 - Jan. 15	5,647	166
1962-63	Nov. 13 - Feb. 27	15,662	[1] 852
	May 23 - Jul. 12	586	586

[1]Of 270 salmon collected while emptying the trap on February 27, the majority were winter run. They were released unsorted into Sacramento River near Redding. This 270 is not included in the winter-run column, only in the total column.

Table 3.--Mortality of winter-run chinook salmon eggs and young fish with related water temperatures at Coleman National Fish Hatchery, 1958-59

[Compiled by Harry D. Baer from records of Coleman National Fish Hatchery]

Month	Monthly mortality rate	Accumulated mortality	Average water temperature
	Percent	*Percent*	°F.
May	[1] 11.5	[2] 6.4	56.5
June	49.1	51.5	59.7
July	97.6	98.8	63.3
August	13.6	99.0	59.4
September	11.1	99.1	57.1
October	4.3	99.1	53.9
November	1.1	99.2	48.5
December	3.2	99.2	47.3
January	2.8	99.2	45.7

[1]Approximate, based on derived number on hand at beginning of month comprised of actual number on hand, 47,227, plus half of those added during month, 328,362, or a total of 211,408.

[2]Referred to total of 381,065 eggs ultimately collected during the period April 30-June 13, 1958.

4,436 fingerlings remained at the end of July, and only 3,036 fish, weighing 114 pounds, were liberated on January 29, 1959. This was the most sucessful attempt to raise winter-run salmon in Battle Creek water; almost complete failure was had in 1955 and a complete failure in 1959.[2] It is obvious that these survivals would not maintain a run in Battle Creek, and it may be concluded that the fish straying into Mill Creek and Battle Creek are essentially wasted.

TIMING OF UP-MIGRATION AND SPAWNING

Hallock's observations on the timing of the runs indicate that winter-run fish first passed the mouth of Feather River (near Sacramento and about 225 miles downstream from Keswick Dam) during the first week of November in 1957 and 1958. Experience at Keswick traps indicates arrival there during the last half of December, but migration to this point is delayed near Redding by closure of the fishway on Anderson-Cottonwood Irrigation District's diversion dam until about November 15 each year. On July 14, 1961, I observed about 100 winter-run chinook salmon on the redds beneath the Highway 99 bridge at Redding. Most of these fish appeared to be in postspawning condition. One female was apparently in the process of building a nest. On July 3, 1962, salmon in postspawning condition were numerous at this site. On August 9, 1963, one tired, worn female was near a redd beneath the bridge, two spawned-out females had been landed by a fisherman, and other stragglers were noted on downstream riffles. The experience of personnel at Coleman Hatchery indicates the spawning range is from the latter part of April to the latter part of July.

From the above observations and those reported previously, we may establish tentative limits to the timing of the run. These winter-run chinook salmon apparently arrive in the vicinity of Redding from late November through February, and probably later, and spawn from late April nearly through July, with most activity in May and June. Incubation of the eggs extends at least through August.

The adults arrive on the spawning area in beautiful condition. Sleek, fat, silvery, and full of fight, winter-run chinooks are much sought by sport fishermen. They are generally reported to be an excellent food fish with a pale pink flesh. Hallock confirmed the latter generalization by interviews of experienced fishermen during the fall of 1962. All fishermen reported the flesh to be light pink or pink. Their unique occurrence fills a valued place in the all-year Sacramento River salmon fishery.

The principal fishing period for winter-run fish in the Redding-Red Bluff area, as reported by Hallock, is mid-December through March with a peak during January-February. However, he also reports that ripe fish are landed in significant numbers during May and June as far downstream as Los Molinos, about 70 miles below Keswick Dam.

In their appearance and habits the winter-run fish seem to be more closely allied to the spring run than to the fall run. Like the spring-run fish, they ascend the river in firm "green" condition, ripening slowly in fresh water. However, unlike the spring run, their spawning period does not overlap that of any other run. This may account for their increasing population in contrast to the spring run. The young winter-run fish are out of the gravel and growing before the spring run commences spawning. The spring run, on the other hand, is only well-started spawning before the early fall-run spawners move in to compete for nest sites. This competition, plus the indicated hybridizing of the spring and fall races, appears to have held down the spring run, perhaps even to have eliminated it as a distinct race in the mainstem Sacramento River. Such hybridizing could not readily be detected through routine field observation, for the hybrids would continue to enter the river in

---

[2] By contrast, Harry D. Baer reports (personal communication) that an experimental hatching of winter-run eggs in 50° F. Sacramento River water at Keswick during 1963 has been highly successful. From 52 ripe females trapped between May 22 and July 12, 235,700 eggs were obtained, fertilized, and carried through the eyed stage with only about 5 percent mortality. Fifty thousand eyed eggs of this group were shipped to the Fish and Game Department at Melbourne, Victoria, Australia, and received in good shape. Rearing, to be attempted at Coleman Hatchery, is yet unproved.

both spring and fall and to spawn throughout the overlapping spawning periods. The status of the spring run in the mainstem is thus speculative. Suffice it to state that spring-run chinook salmon have not been noted to have been abundant in mainstem Sacramento River during the summer holding period of recent years. Small runs of spring-run fish still ascend such tributaries as Mill and Deer Creeks, however.

TIMING OF DOWN-MIGRATION

The downstream migration of young winter-run chinook salmon has not been intentionally studied. Netting operations conducted under the author's direction on the Sacramento River at Balls Ferry in November and December 1951 provided suggestive evidence. Among 3,048 young chinook salmon taken during about 45 nights of fyke-net fishing, 25 fish ranged in fork length from 58 to 90 mm., averaging 68.1 mm. Of the other 3,023 young chinooks, 3,011 were 41 mm. or shorter (table 4) and are considered to have been spring-run and fall-run fry.

The 58-90-mm. group fits expectations for winter-run fish based on growth of the other races. At the time of capture, these 25 fish

Table 4.--Downstream migrant chinook salmon caught at Balls Ferry, 1951-1952

Period	Number of downstream migrants by fork-length groups						Average fork length of those over 57 millimeters
	30-35 mm.	36-41 mm.	42-47 mm.	48-56 mm.	57-90 mm.	91-120 mm.	
Nov 1-10	27	72	--	--	--	--	--
11-20	61	98	--	--	--	--	60.5
21-30	80	117	3	--	15	--	69.1
Dec 1-10	107	152	2	1	5	--	65.7
11-20	240	603	1	1	2	--	65.5
21-30	304	1,152	1	1	1	--	85
Dec 31-Jan 9	67	631	2	--	--	--	--
Jan 10-19	52	797	--	--	--	1	110
20-29	201	2,532	--	--	--	--	--
Jan 30-Feb 8	184	1,601	11	--	--	--	--
Feb 9-18	215	1,895	3	--	--	--	--
19-28	163	3,234	30	--	--	--	--
Feb 29-Mar 9[1]	161	2,562	5	--	--	--	--
Mar 10-19[1]	40	1,110	22	--	--	--	--
20-29[1]	92	1,824	29	1	--	1	112
Mar 30-Apr 8	--	[2] 912	--	([3])	([3])	([3])	--
Apr 9-18	--	[2] 300	--	--	--	--	--
19-28	--	[2] 241	--	--	--	--	--
Apr 29-May 27	--	--	--	[4] 325	--	--	--

[1] The numbers of fish in these rows include measured fish only; total numbers including unmeasured fish were as follows: Feb 29-Mar 9, 3,654; Mar 10-19, 2,517; Mar 20-29, 2,315.

[2] Distribution by sizes not available; the numbers shown by 10-day periods are total numbers. The total for the March 30-April 8 period includes the 73 fish described in footnote 3.

[3] Record shows 73 fish in the range 49 to 120 mm. were taken; detailed distribution is not available.

[4] Distribution by sizes not available; the average size for the 30-day period was 52.4 mm. which may be contrasted with the 40.9-mm. average size of the 30-day period preceeding it.

may have been as young as 4 months and as old as $7\frac{1}{2}$ months from known possible dates of winter-run egg deposition. This may be compared with the catch of 73 young chinook salmon taken in the same way at the same site during April 1952. These 73 fish are assumed to be a mixture of spring-run and fall-run migrants. They may have been as young as about 4 months or as old as almost 7 months from probable dates of egg deposition. The two groups have similar size ranges, but the average size of the 73-fish group is not available. It appears that both groups were likely to have been about 6 months old, on average. Since the 25-fish group had experienced somewhat higher average water temperatures, they should have been of larger size, as seems the case. Sampling during August through November is needed to place limits on the downstream migration of the winter run. It may be that their migration, fitted to pre-Shasta Dam conditions, does not begin until November, or it may begin earlier in agreement with other chinook races in California. We have no sampling earlier than November; hence we cannot make a choice between these possibilities.

DISCUSSION OF ENVIRONMENTAL CONTROLS

Although the winter run recovered quickly from near extinction to a notable abundance 4 years later, it is only now reaching an abundance comparable to the fall run, after more than 15 years. It is possible that the observed buildup is as rapid as can be expected with any introduction. Since these fish, prior to Shasta Dam construction, were probably abundant only in the McCloud River, they were, in effect, transplanted or introduced into an entirely new habitat many miles downstream and many feet lower in elevation. The new habitat has cold water temperatures simulating the original home stream. However, mine-waste pollution, which was not present in their McCloud River habitat, may have been harmful to the adults. If downstream migration of the young of this race is delayed until fall rains, the competition with trout and other competitors and predators may have more effect on this race. On the other hand, losses of migrants into irrigation pumps and diversions might be higher in other races, if the great proportion of the winter-run migrants descend in November.

Finally, in the holding areas below Keswick Dam, the adult fish are much more vulnerable to sport fishermen and poachers than they were in their ancestral home. They bite well and are much sought after, so that it is not surprising that the sport-fishing take in the rivers is proportionately higher with this race than with the fall or spring run. The sport and commercial take in the ocean may be smaller, however, because of the lateness of the run.

The habits of this run obviously adapt it to situations below large reservoirs as well as to spring-fed streams where suitable temperatures of 50° to 57° F. can be maintained during the May through August spawning and incubation period. These fish also should be ideally adapted to water temperature regimes of the southern hemisphere. However, the maturation of the eggs of winter-run fish under conditions of increasing daylight and increasing water temperatures, in opposition to conditions experienced by all other chinook salmon runs, is a fact to be carefully considered.

These fish, historically, were apparently adapted to streams fed largely by the flow of constant-temperature springs arising from the lavas around Mount Shasta and Mount Lassen. The McCloud River, their known home is renowned for its spring-fed flow, damped fluctuations, and stable, low temperatures (46° F. at Big Springs). Other streams in the vicinity such as Fall River and Hat Creek, both tributary to Pit River, and Battle Creek, tributary to mainstem Sacramento River, derive part of their flow from springs. Many other streams have cool flows in their headwaters. Since the range of suitable hatching temperatures is limited on the low side as well as the high (42.5°-57.5° F.--Combs and Burrows, 1957; Brett, 1959), it may be questioned whether any but a predominantly spring-fed stream could provide suitable temperatures for sustained production of winter-run fish. Cold, fluctuating, snow-melt streams would be little better than flashy, warm, rain-flooded streams. In any case, little evidence is extant that this run was distributed widely or that it ever was composed of large populations prior to Shasta Dam.

LITERATURE CITED

BRETT, J. R.
1959. Thermal Requirements of Fish--Three Decades of Study, 1940-1970. Trans. Second Seminar on Biol. Problems in Water Pollution, April 20-24, 1959, U.S. Public Health Service.

COMBS, B. D., and R. E. BURROWS.
1957. Threshold Temperatures for the Normal Development of Chinook Salmon Eggs. Progressive Fish Culturist, vol. 19, No. 1, pp. 3-6.

FRY, D. H., Jr.
1961. King Salmon Spawning Stocks of the California Central Valley, 1940-1959. California Fish and Game, vol. 47, No. 1, pp. 55-71.

HANSON, H. A., O. R. SMITH, and P. R. NEEDHAM.
1940. An Investigation of Fish-Salvage Problems in Relation to Shasta Dam. U.S. Fish and Wildlife Service, Special Scientific Report No. 10. 200 pp.

HINZE, JAMES A., A. NELSON CULVER, and G. V. RICE.
1956. Annual Report, Nimbus Salmon and Steelhead Hatchery, Fiscal Year of 1955-56. California Department of Fish and Game, Inland Fisheries Administrative Report No. 56-25. 50 pp. (mimeo.)

McLEAN, DONALD D.
1945. Late Spring Spawning of Chinook Salmon (Oncorhynchus Tschawytscha). California Fish and Game, vol. 31, No. 4, p. 211.

MOFFETT, J. W.
1949. The First Four Years of King Salmon Maintenance Below Shasta Dam, Sacramento River, California. California Fish and Game, vol. 35, No. 2, pp. 77-102.

NEEDHAM, P. R., H. A. HANSON, and L. P. PARKER.
1943. Supplementary Report on Investigations of Fish-Salvage Problems in Relation to Shasta Dam. U.S. Fish and Wildlife Service, Special Scientific Report No. 26. 50 pp.

NEEDHAM, P. R., O. R. SMITH, and H. A. HANSON.
1941. Salmon Salvage Problems in Relation to Shasta Dam, California, and notes on the Biology of the Sacramento River Salmon. Trans. American Fisheries Society, vol. 70 (1940), pp. 55-69.

RUTTER, C.
1904. Natural History of the Quinnat Salmon; A Report on Investigations in the Sacramento River 1896-1901. U.S. Fish Commission Bulletin, vol. 22 (1902), pp. 65-141.

SEYMOUR, A. H.
1956. Effects of Temperature Upon Young Chinook Salmon. University of Washington, Doctoral Thesis. 127 pp.

SMITH, S. H.
1950. Upper Sacramento River Sport Fishery. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 34. 44 pp.

GPO 868-004

The Department of the Interior, created in 1849, is our Nation's Department of Natural Resources, concerned with management, conservation, and development of water, wildlife, fish, mineral, forest, and park and recreational resources. It also has major responsibilities for Indian and Territorial affairs.

As America's principal conservation agency, the Department works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States, now and in the future.

UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L. Udall, *Secretary*
Frank P. Briggs, *Assistant Secretary for Fish and Wildlife*
FISH AND WILDLIFE SERVICE
Clarence F. Pautzke, *Commissioner*
BUREAU OF SPORT FISHERIES AND WILDLIFE
Daniel H. Janzen, *Director*