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Evidence for Fluoride Effects on Salmon Passage at John Day Dam, Columbia River, 1982—1986

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Abstract.—There is evidence that fluoride from an aluminum plant near John Day Dam had a significant negative effect on passage time and survival of adult Pacific salmon *Oncorhynchus* spp. at the dam. In 1982, fluoride concentrations of 0.3-0.5 mg/L were recorded at the dam. These concentrations were probably representative of fluoride levels at the dam in earlier years as well, based on the aluminum plant's fluoride discharge records since 1971. From 1980 to 1982, the time (>150 h) required for upstream migrants to pass John Day Dam and the mortality (>50%) of migrants between Bonneville and McNary dams (below and above John Day Dam) were unacceptably high. Bioassay experiments on the behavior of upstream-migrating adult salmon suggested that fluoride concentrations of about 0.5 mg/L would adversely affect migration. Subsequent experiments suggested that 0.2 mg F/L was at or below the threshold for fluoride sensitivity of chinook salmon *O. tshawytscha* and below the threshold for fluoride sensitivity of coho salmon *O. kisutch*. Beginning in 1983 and continuing through 1986, fluoride discharges from the aluminum plant were greatly reduced and there was a corresponding drop in fluoride concentrations in the river. Concurrently, fish passage delays and interdam losses of adult salmon decreased to acceptable levels (28 h and <5%, respectively).

The upstream migration of adult spring chinook salmon *Oncorhynchus tshawytscha* in the Columbia River has been subject to unusually long delays at John Day Dam (river kilometer 348, measured from the river's mouth). Like most other hydroelectric projects on the Columbia River, John Day Dam has facilities for the passage of migratory adult salmonids. These facilities include a fish collection system along the downstream face of the powerhouse and a fishway with auxiliary water-supply systems on both sides of the river.

During the spring migration period, the average passage time for radio-tagged salmonids at John Day Dam was 158 and 156 h in 1979 and 1980, respectively (Johnson 1981). In contrast, average passage time at Bonneville Dam (km 234) was less than 48 h; at The Dalles Dam (km 310), it was less than 24 h. Liscom and Stuehrenberg (1983) also found inordinate delays at John Day Dam; passage times for radio-tagged salmonids were twice as long at John Day Dam in fall 1982 as they were at The Dalles and McNary (km 471) dams. Individual fish tracked below John Day Dam spent most of the time in the tailrace area, just below the dam. Although the fish apparently located the collection system entrances, they were reluctant to enter and remain in the system. The delay of nearly 1 week at John Day Dam appeared to contribute to increased mortality and may have affected the spawning success of migrating adult salmonids.

Migratory delays at John Day Dam were not decreased appreciably by changes in fishway entrance locations, water discharge volumes or configurations, or turbine operating conditions (Johnson et al. 1980). Also, fish usually preferred the south fishway over the north fishway, which was initially thought to be related to the cause of the general delay. From 1971 through 1985, 16-50% (mean, 33%) of the migrating adult salmonids used the north fishway.

The lack of response by migrating salmonids to flow alterations below the dam focused attention on the possibility that something in the water might be causing fish to avoid the north fishway and delay their passage. If behavior-altering pollutants were present at even very low concentrations, migrating adult salmonids might sense and respond to them. Brown et al. (1982), Cooper and Hirsch (1982), and Kleerekoper (1982) reviewed numerous laboratory studies demonstrating the acuity of olfactory perception in salmonids; threshold values for many chemicals are near 10^{-6} mg/L. Pollutants could cause avoidance or attraction, overwhelm biologically relevant odors, or damage chemoreceptive mechanisms. Unavoidable low-level pollutants might alter detection of predators or food as well as reproduction or migration.

In 1982, preliminary studies of the distributions of many pollutants near John Day Dam suggested that the fish-passage delays might be related to contaminants discharged at an aluminum smelter

outfall on the north shore of the Columbia River about 1.6 km upstream from John Day Dam (Damkaer 1983). High concentrations of fluoride in the vicinity of John Day Dam prompted us to focus sampling efforts on this contaminant. The purpose of this paper is to document changes in the migratory behavior of adult salmonids at John Day Dam in relation to fluoride concentrations and to present data from behavioral bioassays that demonstrate the effect of fluoride on migrating adult salmon.

Methods

Sampling stations were established above and below John Day Dam in the Columbia River and in the mouth of the John Day River, which enters the Columbia River about 3.2 km above John Day Dam (Figure 1). One sampling site (station 10) was established at the aluminum plant outfall, and two additional stations were established in the lagoon on the Washington shore at the base of the hill upon which the aluminum plant is located. This lagoon is between the outfall and the dam and is directly connected to the Columbia River by a large culvert near the upstream end.

At stations 1–13 and in the lagoon, physical characteristics were recorded at 5-m intervals from the surface to the bottom, and water samples were collected at the surface, middepth, and near-bottom. Total depths at stations were about 30 m in the Columbia River and 15–25 m in the John Day River and the lagoon. Water samples were also collected from the surface at three downstream locations at both John Day Dam (stations 14–16) and The Dalles Dam (the Washington-shore fishway, the central powerhouse area, and the Oregon-shore fishway) and at four downstream locations at Bonneville Dam (both ends of the new powerhouse, south end of the spillway, and south end of the old powerhouse). Beginning in 1983, water samples for fluoride and turbidity analyses were collected daily from the north and south fishways at John Day Dam, April—October. Other locations from which surface water samples were regularly

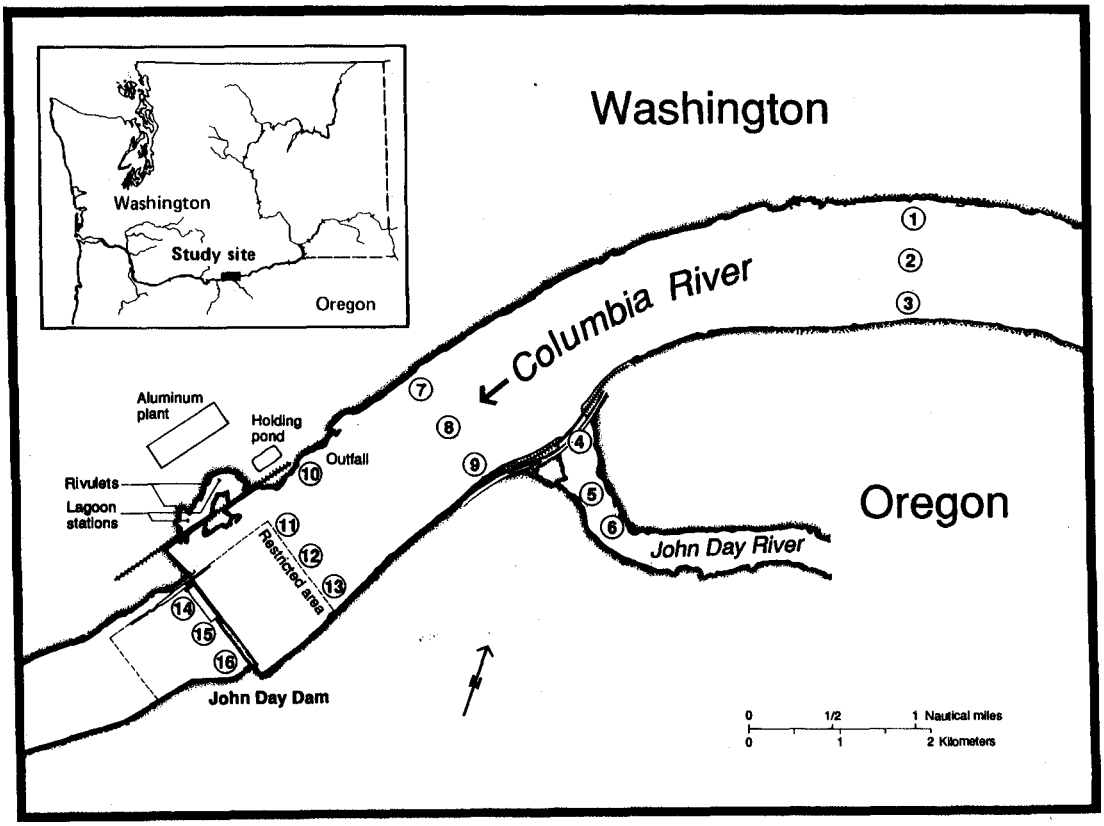

FIGURE 1.–Study area for the adult salmonid passage-delay program, John Day Dam region, Columbia River. Circled numbers indicate sampling sites.

collected included the holding pond uphill from the aluminum plant outfall and two rivulets freely flowing down the hill from the aluminum plant to the large lagoon described previously.

Basic physical characteristics (temperature, dissolved oxygen, pH, and conductivity) were measured in situ with a Montedoro-Whitney Mark V(A) Water Quality Analyzer ®.' Water samples for fluoride analysis and turbidity measurements were collected in Niskin® closing water bottles, constructed of teflon-lined polyvinyl chloride. Fluoride was determined by an ion-specific electrode with an apprgpriate buffer to prevent interference by cations (APHA et al. 1981). Turbidity measurements were made with an HF Instruments® portable turbidimeter (model DRT-15). The instrument was field-calibrated daily against a factory-supplied standard.

Bioassay tests were conducted at Big Beef Creek Fish Research Station on Hood Canal, Washington. From September through December 1983, over 400 tests were conducted with returning chinook salmon, coho salmon O. *kisutch,* and chum salmon O. *keta.* From September through December 1984, 178 tests were conducted on returning chinook and coho salmon. All test fish were captured in a weir trap that blocked the upstream movement of fish into Big Beef Creek.

A concrete walled spawning channel was furnished with a two-choice flume (Figure 2). An 8-m partition divided this flume into two longitudinal sections of equivalent size and water flow. Upstream migrants could choose to proceed into the left or right arm; each arm had a funnel trap that prevented fish from returning downstream. At the head of this two-choice flume, about 15 m from the starting point (acclimating area), a 55-L carboy emptied into the flowing creek water in each arm of the flume. The flow-rates were identical from each carboy, adjusted to empty the carboys in about 1 h. Control tests were conducted with no fluoride in either carboy. All other tests were conducted with sodium fluoride in only one carboy (randomly chosen each day). In 1983, the fluoride concentration was maintained at approximately 0.5 mg F/L in the treatment arm of the flume. This concentration was equivalent to the highest fluoride level we observed in the Columbia River at John Day Dam in 1982. In 1984, the fluoride concentration was reduced to 0.2 mg/L, which was similar to fluoride levels observed in the Columbia River in 1983–1985.

Reference to trade names does not imply endorsement by the National Marine Fisheries Service.

Fish were tested one at a time and were allowed to acclimate about 10 min in the holding area downstream from the two-choice flume. A gate was then carefully raised from behind a concealed observation area, and each fish was allowed 60 min (1983) or 20 min (1984) to move upstream before the test was scored. The observation period was shortened in the interest of running more tests when it became evident that many of the test fish were making their choices well before 20 min had elapsed. When a fish moved upstream beyond the funnel trap in either side of the flume within the allowed time, the test was terminated and the choice was recorded (fluoride or nonfluoride side); if a fish did not move upstream into either side of the flume within the allowed time the test was scored "no choice." Chi-square analysis ($P < 0.05$) was used to test for significant differences between treatments.

Results

Physical Characteristics

Because the Columbia River was mixed by frequent strong winds and river flow and spill rate at John Day Dam varied through the year, very few consistent patterns of monitored physical characteristics were observed in the study area (Table 1). Measurements of pH indicated only small temporal or spatial differences in this region of the river, and there were no clear horizontal or vertical patterns in conductivity of the river water, reflecting a uniform distribution of major ionic materials. Of considerable interest, however, were indications that the generally warmer (and, therefore, less oxygen-rich) and more turbid John Day River influenced the Columbia River near John Day Dam. Physical data corroborated photographic evidence that the John Day River could influence returning salmonids as they approach John Day Dam. Dates, times, locations, depths of measurement, and corresponding physical characteristics of river water in the John Day Dam region for 1982–1985 are available in tabulated form in Damkaer (1983) and Damkaer and Dey (1984, 1985, 1986).

Fluoride Concentrations

1982.–According to monthly discharge records submitted by the aluminum plant to the Washington State Department of Ecology, the average daily fluoride discharge by the plant was 384 kg in 1982, which was typical of the reported average discharges in previous years. From April to June 1982, fluoride concentrations in the John Day Dam

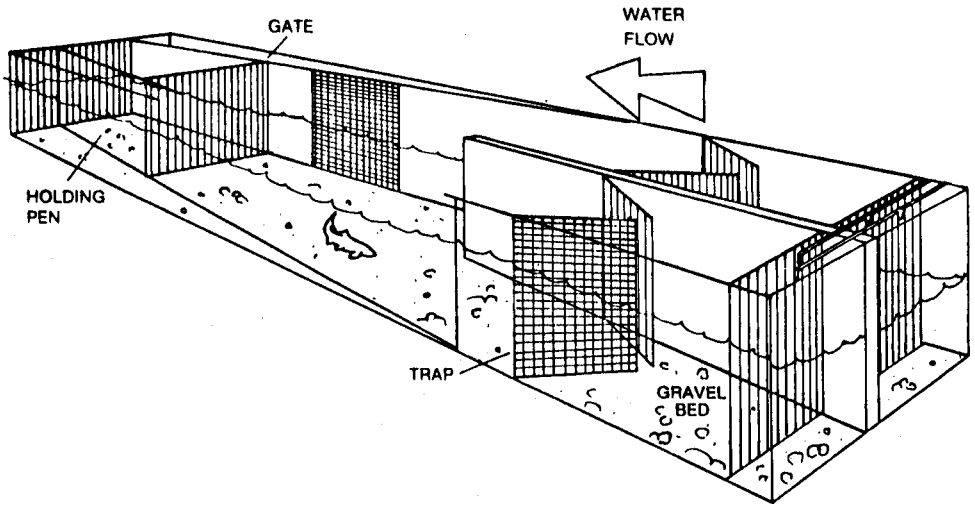

FIGURE 2.-Two-choice flume for fluoride-gradient salmon behavior tests, diagrammatic view.

forebay, particularly along the north shore, were generally above 0.2 mg/L, against a likely Columbia River background (McNary Dam) of about 0.1 mg/L (Table 2). The highest fluoride concentrations were usually along the forebay's north shore, close to the aluminum plant outfall, where they ranged between 0.3 and 0.5 mg/L. Fluoride concentrations in this range were measured here as far back as 1971 by staff of the aluminum plant and in 1971 and 1972 by National Marine Fisheries Service personnel. During periods of strong westerly winds, high fluoride concentrations were more evenly distributed throughout the study area, including the upstream sampling stations.

Mean fluoride concentrations downstream at The Dalles and Bonneville dams were less than 0.2 mg/L.

1983.-The aluminum plant was required to modify its pollution discharge system and began using a landfill to store pollutants in January 1983. As a result, the 1983 fluoride discharges into the Columbia River were about one-fourth those of previous years. Except in September and October, when the new treatment system malfunctioned,

TABLE 1.-Physical characteristics (water-column ranges) of the Columbia River at sampling stations near John Day Dam, May 1982. See Figure 1 for station locations.

Station	Total depth (m)	Temperature (°C)	pH	Conductivity (mS)	Dissolved oxygen (mg/L)	Turbidity (NTU[a])
1	32.9	11.5-12.0	7.8-7.9	0.14	12.9-13.3	9.0-11.0
2	31.1	11.4-11:7	7.7-7.9	0.14	12.9-13.3	9.0-11.0
3	32.9	11.4-11.8	7.8-7.9	0.14	12.8-13.3	9.0-12.0
4	18.0	12.0-15.7	7.5-7.7	0.13-0.14	10.6-12.6	15.0-18.0
5	25.4	11.7-16.0	7.5-7.8	0:13-0.14	10.6-12.9	14.0-18.0
6	25.6	11.9-16.0	7.6-7.8	0.13-0.14	10.7-12.7	14.0-19.0
7	35.0	11.4-11.5	7.6-7.7	0.14	13.1-13.7	9.0-12.0
8	27.4	11.4-11.6	7.5-7.6	0.14	12.9-13.3	10.0-12.0
9	31.1	11.3-11.6	7.6-7.7	0.14	12.9-13.3	10.0-12.0
10	31.0	11.6-12.0	7.6-8.0	0.14	12.8-13.4	9.0-10.0
11	32.9	11.5-11.6	7.6-7.7	0.14	13.0-13.4	9.0-10.0
12	31.1	11.4-11.6	7.6-7.7	0.14	12.9-13.4	10.0-11.0
13	32.9	11.4-11.9	7.6-7.8	0.14	12.3-13.4	11.0-12.0
14 (North fishway)		12.1	8.1	0.14		11.0
15 (Powerhouse)		12.0	8.0	0.14		12.0
16 (South fishway)		12.1	8.0	0.14		13.0
Lagoon						
East	15.0	11.5-15.1	8.0-8.1	0.15-0.16	10.8-11.8	4.0-5.0
West	25.6	10.5-15.0	8.0-8.2	0.15-0.18	9.9-11.5	3.0-5.0

[a] Nephelometric turbidity units.

TABLE 2.-Mean fluoride concentrations at water sampling stations near John Day Dam, Columbia River, 1982 and 1983. See Figure 1 for station locations.

	Mean fluoride concentration (mg/L)					
	1982			1983		
Station	Surface	Mid-depth	Bottom	Surface	Mid-depth	Bottom
	0.18	0.17	0.16	0.12	0.13	0.13
2	0.17	0.17	0.19	0.13	0.13	0.13
3	0.18	0.16	0.17	0.13	0.12	0.14
4	0.13	0.12	0.12	0.13	0.14	0.12
5	0.13	0.15	0.14	0.11	0.11	0.12
6	0.12	0.13	0.14	0.11	0.08	0.12
7	0.23	0.24	0.23	0.14	0.13	0.13
8	0.25	0.25	0.22	0.13	0.12	0.13
9	0.27	0.26	0.26	0.13	0.12	0.11
10	0.38	0.30	0.31	0.14	0.13	0.14
II	0.23	0.22	0.24	0.13	0.12	0.13
12	0.21	0.20	0.23	0.13	0.12	0.13
13	0.19	0.22	0.22	0.13	0.12	0.13
14	0.26			0.14		
15	0.21			0.14		
16	0.22			0.13		
Lagoon						
East	0.29	0.25	0.26	0.18	0.18	0.17
West	0.31	0.28	0.29	0.18	0.18	0.20

the average daily fluoride discharge in 1983 was 107 kg.

Probably as a consequence of reduced fluoride discharge by the aluminum plant, the 1983 fluoride concentrations in the John Day Dam region were well below those of 1982 (Table 2). The general fluoride levels in the forebay were 0.10-0.15 mg/L; even near the aluminum plant outfall, they did not exceed 0.17 mg/L.

Fluoride concentrations below The Dalles and Bonneville dams were less than 0.15 mg/L.

1984 and 1985.-The average daily fluoride discharge from the aluminum plant was 128 kg in 1984 and 49 kg in 1985. These low fluoride discharges were reflected in continued low fluoride concentrations in the Columbia River; surface fluoride concentrations rarely approached 0.3 mg/L, and were generally 0.1-0.2 mg/L, even near the aluminum plant outfall. The highest fluoride concentration measured in the fishways was about 0.3 mg/L, but most measurements there were within a range of 0.1-0.2 mg F/L. On nearly all days, there was no detectable difference in fluoride concentrations between fishways.

The fluoride content of the two rivulets entering the large lagoon on the north shore upstream from the dam, however, was extraordinarily high (up to 10 mg/L). This unreported fluoride appeared to be leaking from the aluminum plant on the slope above. These concentrations were higher than generally noted in the holding pond for the outfall discharge (1.5-6.0 mg/L).

1986. -In March 1986, the aluminum plant reported a problem with its pollutant storage system. This resulted in discharges of up to 590 kg fluoride daily into the Columbia River during April. A mid-April fluoride concentration of 1.21 mg/L in a sample taken from shore near the aluminum plant outfall (station 10) was the highest recorded for Columbia River water during this study. Fluoride in the outfall holding pond was close to 8 mg/L, the highest measured during this study at this site. Fluoride concentrations were all above 0.20 mg/L along the Washington shore near the aluminum plant and John Day Dam. By October, however, fluoride concentrations were 0.16-0.17 mg/L in the outfall area of the river. Thus, there were clear indications that the greatly increased fluoride discharges from the aluminum plant in April temporarily raised the fluoride concentration in the Columbia River near John Day Dam just as the early, upstream-migrating spring chinook salmon and steelhead (anadromous rainbow trout O. *mykiss,* formerly *Salmo gairdneri)* were moving into the area.

Fish Passage

Radio-tagging and tracking studies from 1980 to 1982 determined that fish passage times were unacceptably long at John Day Dam (there were no passage studies in 1983). Analysis of fish counts at the dams revealed an average "unaccountable loss" of 55% of the fall chinook salmon passing Bonneville Dam and expected to reach McNary Dam during 1980-1982 (J. DeVore, Washington Department of Fisheries, personal communication). In 1983, coincident with the fluoride discharge reduction, this loss was only 11%, the lowest since 1972. In addition, substantially fewer salmonid carcasses were observed below John Day Dam in 1983 than in 1982.

In 1984, the proportion of salmon reaching McNary Dam was comparable to the high value of 1983. Moreover, radio tracking was resumed at John Day Dam, and the median passage time for spring chinook salmon was slightly less than 48 h (Shew et al. 1985). In 1985, median passage time for spring chinook salmon at John Day Dam was 28 h (Peters et al. 1985) and the unaccountable loss of fall chinook salmon was near 5% (G. Norman, Washington Department of Fisheries, personal communication). Adult fish passage times were not determined at John Day Dam in 1986,

but only about 1% of fall chinook salmon were lost.

Returning salmonids generally preferred the south fishway at John Day Dam (Figure 3), a preference that remained stable from 1982 to 1985. In each of these years, an early short-term fluctuation in preference between the two fishways was followed by a strong and steady preference for the south fishway in spring and summer. In early fall, the fishway preference again began to fluctuate. The daily pattern of fishway preference, while at times suggesting that the migrating salmon were responding to short-term (several-day) events, did not appear to be related either to total Columbia River flow, to total spill at John Day Dam, or to the spill-to-flow ratio. Also, fluoride, turbidity, and water temperature measurements in the fishways did not indicate a relationship with passage preference. Whether or not the various factors monitored at the dam actually influence the salmonids' choice of fishway is only a part of the question; passage delay, not the choice of fishway, has been the problem at John Day Dam.

Behavior Experiments

To ensure that subsequent observations reflected behavior due to fluoride alone, control tests were conducted during 1983 and 1984 in which no fluoride was added to the flume and adult salmonids were allowed to choose between sides. In 43 tests with chinook salmon, 42 tests with coho salmon, and 34 tests with chum salmon in 1983, there were no significant channel preferences ($P > 0.30$). Only one of these test fish failed to move upstream out of the holding area and make a choice.

In 112 tests with returning male chinook salmon, 54 (48%) of the fish failed to choose between the flume arms with and without fluoride at a concentration of 0.5 mg/L (Table 3). Their activity was subdued and different from that of fish not exposed to fluoride. Significantly more of the chinook salmon exposed to fluoride failed to make a choice compared to the chinook salmon in the control tests ($P < 0.001$). Of the chinook salmon moving upstream and making a choice, 72% chose the nonfluoride side.

In 97 tests with returning adult coho salmon, 35 (36%) did not move upstream; of those that did, 66% chose the nonfluoride side (Table 3). The coho salmon generally appeared to be in better physical condition at this point in their migration, and were more active and decisive, than the chinook salmon. The proportion of coho salmon not making a choice when exposed to fluoride (0.5 mg/L) was not significantly greater than in the control group ($P > 0.10$). However, coho salmon avoided fluoride at nearly the same frequency as chinook salmon.

During December 1983, 77 fluoride tests were conducted with returning adult chum salmon. As in the earlier chinook salmon tests, significantly more chum salmon did not make a choice when fluoride (0.5 mg/L) was present than in control tests ($P < 0.01$). Of the 60 (78%) fish entering the two-choice flume, 58% chose the nonfluoride side (Table 3). This did not indicate a significant avoidance response, but the colder and more variable water temperatures in December may have influenced the sensitivity and activity of the chum salmon.

In fall 1984, control tests again indicated no preference for one side of the flume or the other among either the returning chinook or coho salmon ($P > 0.30$). Of the 97 chinook salmon exposed to 0.2 mg F/L, 52 (54%) failed to make a choice (Table 3), significantly more than control fish ($P < 0.001$). However, of the 45 (46%) chinook salmon that moved upstream, there was no significant difference between their choice of flume arms ($P > 0.30$).

The observations on 51 coho salmon exposed to 0.2 mg F/L did not indicate an avoidance response or a greater reluctance to make a choice than control fish (Table 3). Therefore, it is believed that 0.2 mg/L may be below the threshold fluoride concentration for returning coho salmon at Big Beef Creek.

Discussion

It is not easy to describe waterborne pollutant gradients in the John Day Dam region or to relate pollutants to the behavior of salmonids. If the Columbia River were free-flowing in this area, the temporal and spatial distributions of pollutants would be much less complex. Because of the dam and its reservoir, the pollution field is modified greatly by wind and the vacillating trajectory of the John Day River plume.

There is empirical and theoretical evidence, however, that fluoride from the aluminum plant at John Day Dam had a negative effect on adult salmon passage time and survival at the dam. Fluorides are toxic to trout and other fish. The fluoride concentration that kills 50% of test trout (LC50) is between 2.3 and 7.5 mg/L (Neuhold and Sigler 1960; Angelovic et al. 1961), or only about an order of magnitude higher than concentrations in the study area during 1982. There is little in-

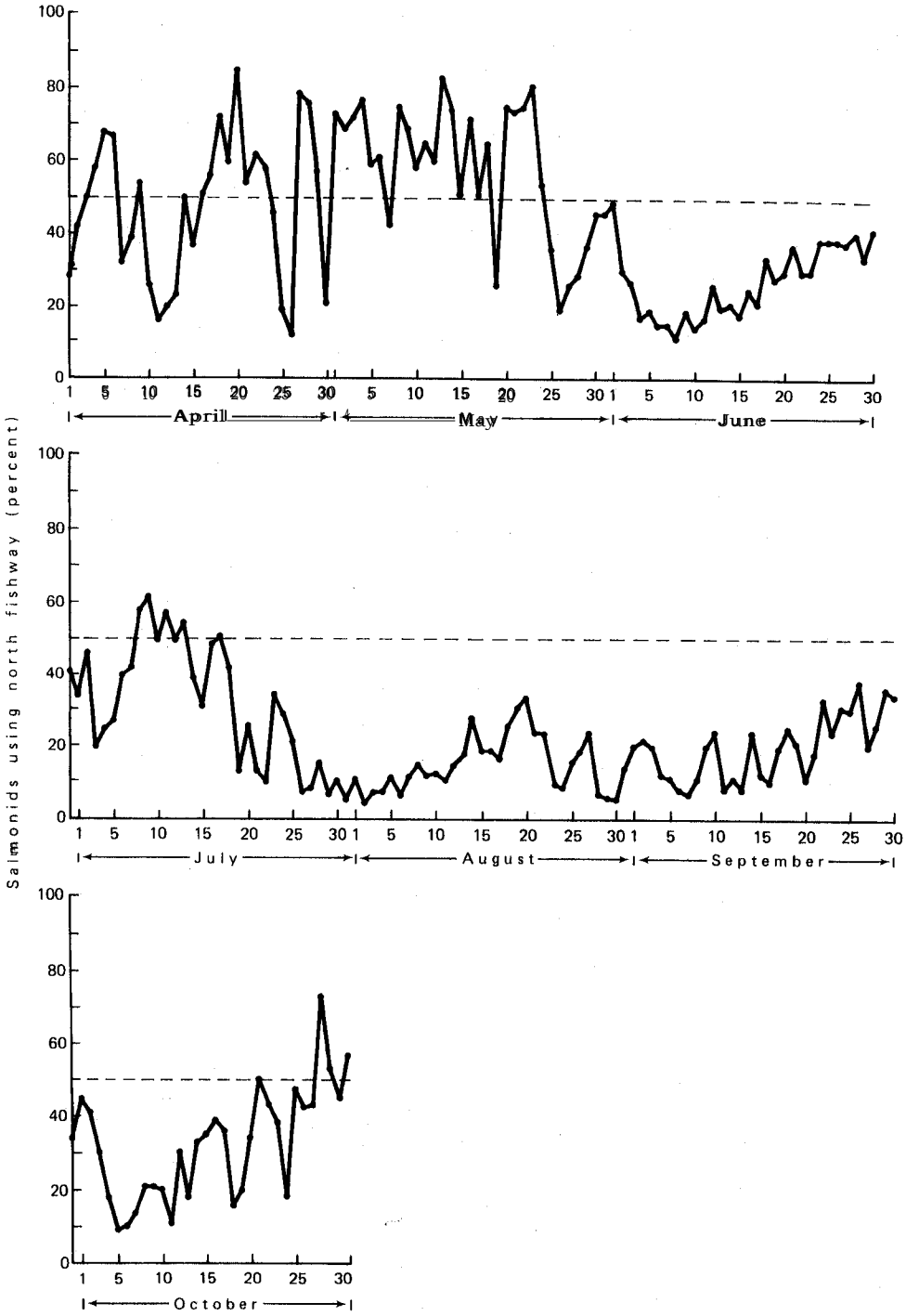

FIGURE 3.-Percentages of returning adult salmonids that used the north fishway at John Day Dam, Columbia River, 1982; through 31 October, 33% of returning fish had passed the north fishway and 67% had passed the south fishway (from U.S. Army Corps of Engineers fish counts).

TABLE 3.—Summary of choices made by chinook, coho, and chum salmon when exposed to 0.5- or 0.2-mg/L concentrations of fluoride in a two-choice flume, Big Beef Creek, Washington, 1983 and 1984.

Species and side of flume chosen	Number of choices	
	0.5 mg F/L	0.2 mg F/L
Chinook salmon		
Fluoride side	16	25
Nonfluoride side	42[a]	20
No choice	54	52
Total	112	97
Coho salmon		
Fluoride side	21	19
Nonfluoride side	41[b]	15
No choice	35	17
Total	97	51
Chum salmon		
Fluoride side	25	
Nonfluoride side	35	
No choice	17	
Total	77	

[a] Significantly more than the number of chinook salmon that chose the fluoride side (chi-square test, $P < 0.001$).

[b] Significantly more than the number of coho salmon that chose the fluoride side (chi-square test, $P < 0.05$).

formation available regarding the sublethal effects of fluorides on salmon, or on fish behavior in general. However, fluorides are enzyme inhibitors (Neuhold and Sigler 1960; Birnbaumer 1977; Tepperman 1980) and could reduce the activity of fish at sublethal concentrations. Neuhold and Sigler (1960) reported that lethargy was among the early symptoms of fluoride intoxication in common carp *Cyprinus carpio* and rainbow trout. Atlantic salmon *Salmo salar* exposed to aluminum smelter waste (including fluoride) experienced an increase in oxygen consumption and ventilation rates and a decrease in heart rate (Johnstone et al. 1982).

The results of our behavioral experiments suggest that fluoride concentrations of about 0.5 mg/L adversely affect the migration of adult salmon and that 0.2 mg F/L may be near or below the threshold for fluoride sensitivity in Chinook and coho salmon. It was apparent that the chinook and chum salmon in the fluoride tests were much more reluctant to move upstream and make a choice of flume arms than fish in control tests. Thus, fluoride could affect the migratory behavior of adult salmon at John Day Dam not only by influencing their choice of fishway but, more importantly, by delaying their entry into either fishway.

Subsequent to the 1983 reduction in the aluminum plant's fluoride discharge, fluoride concentrations in the main river were reduced nearly 50%, fish passage times at John Day Dam were reduced and became similar to passage times at nearby dams, and interdam losses of fish were lower than they had been in over a decade. This circumstantial evidence and the results of our behavioral tests support the hypothesis that fluoride from the aluminum plant influenced fishway passage times of adult salmonids at John Day Dam. Although direct fluoride discharges have generally decreased, fluoride concentrations in the Columbia River near John Day Dam probably will continue to fluctuate periodically due to irregular discharges (as in 1986) and variable water flows.

The possible effects of other pollutants, including heavy metals and hydrocarbons, are also a concern. For example, the aromatic hydrocarbons (sums of concentrations of selected 1- through 5-ring aromatic compounds) in sediments near John Day Dam (average, 8,300 ug/L) approach concentrations found in the Duwamish Waterway (Seattle, Washington: range, 4,100—22,000 µg/L) and the Hylebos Waterway (Tacoma, Washington: 5,000—39,000 µg/L), which are considered among the most polluted areas in the USA (Malins et al. 1980, 1982). The effect of sediments polluted with aromatic hydrocarbons and heavy metals on salmon behavior is unknown, and the fraction of salmonid passage delay, if any, due to these materials has yet to be determined.

In view of the apparent negative effects of fluoride on salmonid passage and survival, the occurrence of fluoride in the entire Columbia River system requires continued attention. Natural sources of fluoride should be differentiated from industrial sources, of which there are several, generally located close to hydroelectric projects. Further work, therefore, should be directed toward determining the effects of industrial sources of fluoride and other pollutants on the passage of salmonids at Columbia River dams.

Acknowledgments

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