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# Depth Distribution of Adult Chinook Salmon (Oncorhynchus tshawytscha) in Relation to Season and Gas-Supersaturated Water

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ABSTRACT

Pressure-sensitive radio transmitters were used to determine swimming depths of adult chinook salmon (*Oncorhynchus tshawytscha*) in relation to season and gas-supersaturated water in the lower Snake River, southeastern Washington. Thirty radio-tagged fish, 15 with external and 15 with internal transmitters, were monitored in supersaturated water in spring 1976. Nine fish with internal and 30 with external transmitters were monitored in the absence of supersaturation in fall 1976 and spring 1977 respectively.

Spring chinook salmon spent about 89% of their time below the critical supersaturation zone in 1976. Swimming depths of fall 1976 and spring 1977 chinook, migrating in normally saturated water, were shallower and differed significantly from those of fish migrating in supersaturated water in spring 1976.

Supersaturation of the Columbia and Snake rivers in the Pacific Northwest routinely occurs during spring runoff when water spilling over hydroelectric dams entrains large volumes of air (Ebel 1969, 1971; Beiningen and Ebel 1970, 1971; Meekin and Allen 1974a; Ebel et al. 1975). Body tissues and fluids of fish exposed to supersaturated water may also become supersaturated. Gas bubble disease develops when excess dissolved gases leave solution and form bubbles in fish tissues. The disease can be lethal, usually from vascular or cardiac blockage or hemorrhaging caused by emboli (Woodbury 1941; Renfro 1963), and has been responsible for severe fish losses (Beiningen and Ebel 1970; Raymond 1970; Meekin and Allen 1974b; Collins et al. 1975; Ebel et al. 1975).

Swimming depth is critical to fish survival in supersaturated water. Due to hydrostatic pressure, each meter of depth affords about 10% reduction in gas saturation. We used pressure-sensitive radio transmitters to determine in situ swimming depth of adult chinook salmon (*Oncorhynchus tshawytscha*) in supersaturated water in the lower Snake River during spring 1976 and in the absence of supersaturation during fall 1976 and spring 1977.

## METHODS

Depth telemetering radio transmitters and receivers were developed at the Bioelectronics Laboratory, University of Minnesota (Tester and Siniff 1976) and calibrated at our laboratory and on a metered line in the field prior to use. The individually identifiable transmitters operated on a carrier frequency of 53 MHz, and were accurate to ±0.5 m in 1976 and ±0.2 m in 1977. Tag pulse rate increased with depth and standard curves relating these variables were prepared for each tag. Tag accuracy was evaluated from the standard deviation among several readings at each depth. Receivers were capable of distinguishing 100 discrete crystal-tuned transmitters. Transmitter range varied with depth and transmitter orientation to a receiving antenna and averaged 1.6 km. We observed no difference in range between external and internal transmitter attachments. Transmitter life was 2–3 wk.

In 1976 and 1977, chinook salmon were trapped, anesthetized (MS-222), and tagged with metal core anchor tags (Floy Tag Co.)[1] and radio transmitters, in cooperation with the National Marine Fisheries Service at Little Goose Dam on the lower Snake River, southeastern Washington. In spring 1976 (late April to early June), 15 fish ranging in length from 73 to 97 cm and weighing 4.3 to 9.6 kg carried external transmitters and 15 ranging in length from 74 to 100 cm and weighing 3.6 to 12.7 kg had internal trans-

[1] Mention of trade names does not imply endorsement by Battelle.

mitters. During fall (late September to mid-October) 1976, 9 fish ranging in length from 72 to 102 cm and weighing 3.6 to 10.4 kg carried internal transmitters. In spring 1977 (late April to early June) 30 fish ranging in length from 66 to 101 cm and weighing 3.4 to 11.4 kg had external transmitters. Transmitters used in spring 1976 weighed 68 g in water and were 11.5 cm long and 2.7 cm in diameter. Transmitters used in the fall 1976 and spring 1977 were about half weight and two-thirds the volume of those used initially and weighed 34 g in air, and were 7.9 cm long and 1.9 cm in diameter.

External transmitters with a 20-cm whip antenna were attached beside the dorsal fin by a Teflon-coated wire anchored at one end in the tag. A sterilized 12.7-cm surgical cutting needle was used to pass the wire through the dorsal muscles and a plastic plate on the other side of the fish. The wire was knotted against the plate, passed through the opposite end of the plate, back through the fish and transmitter, and knotted against the transmitter. Internal tags were coated with glycerin and pushed through the esophagus to the gut with a smooth plastic inserter. The antennae of the internal tag was 50 cm long and trailed from the fish's mouth.

Fish were measured, weighed, transported 6.4 km downriver, and released after tagging. Fish movements after release were monitored during the day, and less frequently at night, with truck and boat-mounted receiver gear. Fish depths in the Little Goose Dam spill were continuously monitored by an automatic multichannel scanning receiver and stripchart recorder (Rustrack Model 288) mounted on the dam.

Tagged fish passing through the fish ladder at Little Goose dam were automatically diverted into a fish trap by a magnetometer-triggered device (Durkin et al. 1969). This allowed fish recapture, retrieval, and recalibration of some radio tags. The metal core anchor tags allowed detection of any fish that dropped the radio transmitter.

Gas-saturation levels were measured with a saturometer and compared to similar data collected by other agencies. Saturometer readings were converted to percent saturation (total gas pressure) according to the formula: percent saturation = (barometric pressure + saturometer pressure − vapor pressure) ×100/barometric pressure.

TABLE 1.—*Depth distribution of chinook salmon tagged externally or internally with pressure-sensitive radio-transmitters in the Snake River.*

| | Percent time at depth | | | |
|---|---|---|---|---|
| | Spring 1976 | | Fall 1976 | Spring 1977 |
| Depth (m) | External tags | Internal tags | Internal tags | External tags |
| 0–1 | 2.9 | 2.4 | 22.5 | 10.9 |
| 1–2 | 7.4 | 9.4 | 13.2 | 19.8 |
| 2–3 | 12.0 | 17.1 | 21.2 | 18.3 |
| 3–4 | 7.1 | 12.3 | 9.9 | 13.4 |
| 4–5 | 21.2 | 10.8 | 13.9 | 9.8 |
| 5–6 | 10.2 | 11.3 | 7.9 | 8.3 |
| 6–7 | 6.5 | 4.3 | 4.0 | 6.0 |
| 7–8 | 4.9 | 4.2 | 4.6 | 4.0 |
| 8–9 | 9.5 | 7.6 | 2.0 | 3.0 |
| 9–10 | 7.1 | 2.3 | 0.7 | 2.8 |
| 10–11 | 5.1 | 2.8 | 0.0 | 1.3 |
| 11–12 | 4.3 | 4.6 | 0.0 | 0.8 |
| 12–13 | 0.6 | 8.9 | 0.0 | 0.8 |
| >13 | 1.1 | 1.9 | 0.0 | 0.9 |
| Number of fish | 12 | 14 | 9 | 30 |
| Number of depth recordings | 1,444 | 1,246 | 151 | 2,761 |
| Mean depth | 5.7 | 5.8 | 3.1 | 3.8 |

## RESULTS AND DISCUSSION

Depth distributions of spring 1976 chinook salmon were similar ($P > 0.05$) for externally and internally tagged fish (Table 1). Spring 1976 chinook salmon were recorded at least 2 m below the surface about 89% of the time. Previous studies (Trefethen 1963; Monan et al. 1970) indicated that salmonids swam close to shore in water less than 10–13 m deep. Based on gas-saturation levels (<130%) in the Snake River below Little Goose Dam during spring 1976 (Table 2), fish deeper than 1.5–2 m were below the critical zone (Leman 1973) where supersaturation did not exceed the tolerance of the species. Fall 1976 and spring 1977 chinook salmon were recorded closer to the surface (Table 1) than spring 1976 fish, and the differences were significant ($P < 0.05$).

Saturation levels above 110% generally produce gas bubble disease in juvenile and adult salmonids (Rucker and Tuttle 1948; Coutant and Genoway 1968; Rucker 1970)

TABLE 2.—*Atmospheric gas saturation of the Snake River below Little Goose Dam during spring and summer 1976 and spring 1977.*

| Date | | | Percent saturation |
|---|---|---|---|
| 1976 | April | 12 | 124 |
| | April | 26 | 122 |
| | May | 10 | 128 |
| | June | 7 | 126 |
| | June | 10 | 129 |
| | June | 11 | 128 |
| | June | 21 | 127 |
| | July | 5 | 118 |
| | July | 19 | 107 |
| | August | 2 | 101 |
| 1977 | May | 10 | 107 |
| | May | 20 | 106 |
| | May | 26 | 107 |

when dissolved gas tension in fish exceeds partial pressure. However, as hydrostatic pressure increases with depth, gas-phase partial pressure increases and maintains gases in solution. As long as fish remain below, or spend minimal time in, the critical zone, gas bubble disease will not occur. Although swimming depth of migrating spring chinook salmon may preclude gas bubble disease, delays in passage through shallow fish ladders may result in maximum exposure and could precipitate air embolism in fish with a high dissolved gas content.

Data on travel times of radio-tagged fish in the lower Snake River in spring 1975 (Gray and Haynes 1976) indicated that although fish moved rapidly between dams, about 48 km in 1–3 days, there were delays of up to 5 weeks in passage through fish ladders. Liscom and Monan (1976) found delays of up to 2 weeks at Lower Granite Dam. In both studies, some fish never negotiated the dams although they may have entered ladders, exited and reentered several times.

Falter and Ringe (1974) showed water temperatures ranging from 3–23.5 C were positively correlated with migration rates of rainbow trout (*Salmo gairdneri*). River temperatures during our study were relatively stable, increasing from 12.2 to 14.4 C and 11.1 to 14.4 C in spring 1976 and 1977 and decreasing from 18.3 to 15 C in fall. Therefore, effects of temperature on migration rates of chinook salmon were not evaluated.

Some fish successfully negotiating fish ladders may fall back over the dams. Monan and Liscom (1975) found 23 and 39% fallback of spring- and summer-run chinook salmon at Bonneville Dam on the Columbia River. Liscom and Monan (1976) found about 15% fallback at Lower Granite Dam on the Snake River, which is consistent with our findings at Little Goose Dam. Apparently, major Columbia and Snake River dams, several constructed during the last few years, seriously impede upstream migration.

Juvenile chinook salmon (Meekin and Turner 1974; Dawley et al. 1975; Blahm et al. 1976), northern squawfish (Bentley et al. 1976), herring (Stickney 1968), and golden shiners (Meldrim et al. 1973) apparently avoid lethal gas-saturation levels. However, avoidance studies with yellow perch (Meldrim et al. 1973) and juvenile coho salmon were inconclusive (Meekin and Turner 1974), and those with steelhead trout were conflicting (Blahm et al. 1976; Dawley et al. 1975). Our in situ studies showed adult chinook salmon swam deeper in supersaturated water than in normally saturated water and thus avoided potentially lethal conditions. In all cases, mean depth of travel was below the critical zone.

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