Emigration of age-0 chinook salmon (*Oncorhynchus tshawytscha*) smolts from the upper South Umpqua River basin, Oregon, U.S.A.

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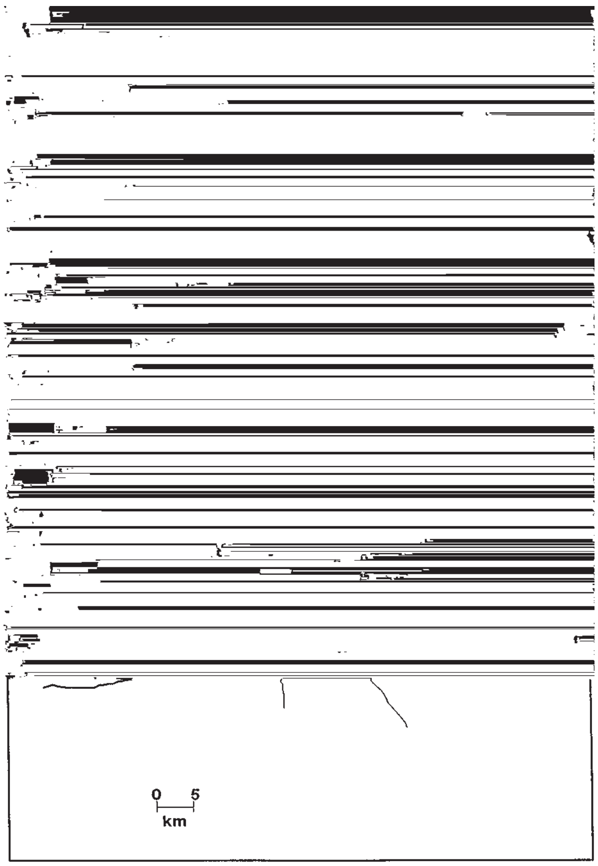
Abstract: Two rotating smolt traps were used through 4 consecutive years to monitor emigrations of age-0 chinook salmon (*Oncorhynchus tshawytscha*) from two watersheds of the upper South Umpqua River basin, Oregon, U.S.A. The number of wild smolts moving past the mainstem South Umpqua River trap ranged from 26 455 in 1991 to less than 5000 in 1993. The number of wild smolts passing the Jackson Creek trap ranged from 13 345 in 1991 to 0 in 1993. Higher numbers of wild smolts were significantly ($P = 0.003$) correlated with higher numbers of prespawning adults counted in index reaches the preceding year. Timing of emigration of smolts was found to be significantly related to stream temperature ($P < 0.05$) and phase of the lunar cycle ($P < 0.05$) but not related to changes in discharge (*P*

Fig. 1. Location of the two smolt traps within the South Umpqua River basin.



watershed where smolts are enumerated (Irvine and Ward 1989).

Understanding factors affecting the magnitude and timing of smolt emigrations is important for stock restoration and management. The objectives of this paper were to (*i*) characterize the magnitude and timing of age-0 chinook salmon emigrations from two adjacent basins in a southwestern Oregon, U.S.A., river system and (*ii*) relate the timing of these emigrations to adult escapement and four environmental factors: stream temperature, changes in stream discharge, lunar cycle, and photoperiod. For adult escapement, our null hypothesis was that the magnitude of smolt emigrations was unrelated to the number of adult fish returning to spawn the previous year. For environmental factors, our null hypotheses were that percentages of the total smolt emigrations would occur in proportion to the frequencies of occurrence, during the emigration period, of specific stream temperatures, daily changes in discharge, phases of the lunar cycle, and photoperiod.

Materials and methods

Study site

The study was conducted in two large drainages of the upper South Umpqua River basin, Oregon, U.S.A. (Fig. 1): the mainstem South Umpqua River drainage basin (area 78 567 ha) and the Jackson Creek drainage basin (area 37 297 ha). Stream width at the study sites during low flows was 20 m in the mainstem and 15 m at Jackson Creek. Discharge, riparian zone vegetation, and land use practices are described in Roper (1995).

Table 1. Percentage of age-0 chinook salmon populations emigrating between 15 April and 31 August estimated to have been missed due to trap malfunctions or traps not being deployed.

		Run missed due to trap malfunction, %	
Year	Rearing history	South Umpqua River	Jackson Creek
1991	Wild	2.9 (26 455)	4.2 (13 345)
	Hatchery	—	0.5 (47 453)
1992	Wild	14.8 (14 689)	0.0 (1635)
	Hatchery	0.0 (82 031)	—
1993	Wild	16.1 (4978)	0.0 (0)
	Hatchery	12.7 (85 537)	—
1994	Wild	0.1 (15 665)	0.0 (7394)
	Hatchery	—	—

Note: Run strength when traps were not operating was estimated using regression methods. Numbers in parentheses are the estimated total run size. Dashed indicate no hatchery fish released.

The stock of chinook salmon is small, averaging less than 300 returning adults annually (Oregon Department of Fish and Wildlife, Roseburg, Oreg.) and has a low probability of remaining viable through the next 100 years (Ratner et al. 1999). Surveys conducted for adult chinook salmon indicated that spawning occurred upstream from the confluence of the mainstem and Jackson Creek. For the entire distance between the ocean and the confluence of these rivers (314 km), no dams impede salmon migration.

Smolt trapping and population estimation

Traps

Age-0 chinook salmon were sampled and enumerated in the spring and summer, from 1991 to 1994, with two rotating smolt traps. The larger trap (2.44-m orifice) was located in the mainstem South Umpqua River 2 km upstream from its confluence with Jackson Creek; the smaller trap (1.52-m orifice) was located in Jackson Creek 1 km upstream from its mouth (Fig. 1). Cabling systems on both traps permitted operation in the area of greatest water velocity. Thedinga et al. (1994) described operation of traps of this design.

Traps were deployed in April or early May and removed in mid-October. Both traps were fished continuously, barring malfunctions, until the end of July. From August until mid-October, they were operated intermittently, typically 5 days out of 7. This April–October time period encompassed the period during which most of the age-0 smolts emigrated from the South Umpqua River watershed (Table 1). All captured fish were measured for fork length or randomly sampled for lengths if catches were large.

Population estimation

Trap efficiencies were determined by marking captured fish with one of four caudal fin marks and then transporting the marked fish 400 m above the trap site and releasing them into the stream so that they were available for recapture as they moved past the trap a second time. Four unique caudal marks were used because 99% of the recaptures from bimonthly releases at the Jackson Creek trap site in 1990 were subsequently recaptured within 4 days. The percentage of the marked fish recaptured was used to estimate trap efficiency (Seelbach et al. 1985). Trap efficiencies were determined independently at each trap site. Confidence intervals (CI) for trap efficiencies were calculated directly from the binomial distribution (Seber 1973; Dowdy and Wearden 1983). Trap efficiency averaged about 15% at both traps throughout the study.

Population estimates were determined by multiplying the number of unmarked fish captured in the trap by the inverse of the trap

were large and significant ($P < 0.01$) in both rivers and for all years.

Changes in discharge

For more than 60% of the days when traps were in operation, discharges were slowly decreasing, i.e., from >0 to 10% less below the previous day's flow. Nearly 70% of the smolts emigrated during these days. Deviations from the null hypothesis that emigration was proportional to the number of days in each of the five discharge categories were small and nonsignificant ($P > 0.05$). Wild smolts were evidently not relying on changes in discharge as an emigration cue.

Lunar cycle

Although smolts emigrated during all four lunar phases, in five of the seven monitored emigrations (mainstem, 1991, 1992, and 1994; Jackson Creek, 1991 and 1992), smolts were significantly ($P < 0.05$) more likely to have moved during the waning and new moon phases rather than during the waxing and full moon phases. On average, for all seven smolt runs, 66% of the smolts emigrated during the waxing and new moon phases, even though these phases constituted only half the emigration period.

Photoperiod

Significantly more fish than expected ($P < 0.05$) emigrated past both traps when day length was increasing. In six of the monitored emigrations (mainstem, 1991–1994; Jackson Creek, 1992 and 1994), at least 75% of the total spring emigration was completed prior to the summer solstice, whereas slightly less than 50% of the capture season occurred prior to this day. In only one case (Jackson Creek, 1991) did a majority of fish leave when day length was de-

Of these three environmental factors, stream temperature explained the most variation in timing. An earlier median emigration date was consistently associated with higher average spring stream temperatures, and smolts emigrated within a narrow temperature range of 12.5–15°C. Timing of age-0 chinook salmon migrations was also related to temperature in a stream in British Columbia (Holtby et al. 1989). These authors and Rombough (1985) have suggested that the timing of emigration in age-0 smolts is influenced by stream temperature through controls on the rate of juvenile development. Cooler stream temperatures during winter and spring slow growth so that fish emerge and migrate later. In contrast, warmer stream temperatures accelerate juvenile development and hasten emigration in the spring. The idea that warmer water temperatures in spring could increase growth rates is supported by our data. Higher stream temperature were positively related to fish length within the South Umpqua River basin ($r^2 = 0.54$, $P \leq 0.001$; Roper 1995).

Although the positive relationship between stream temperature, fish size, and photoperiod (prior to 21 June) makes it difficult to distinguish their roles in controlling the emigration timing of wild smolts, water temperature rather than fish size or photoperiod evidently cued hatchery-reared fish. In 1992 and 1993 in the mainstem, when sizes of released hatchery fish were similar (85.1 and 83.3 mm) and releases occurred at nearly the same day length (30 May versus 26 May), the number of days after release when median emigration occurred was substantially different (3 versus 20 days). In 1992, when average spring water temperatures were 15.3°C, the median emigration occurred 17 days sooner than in 1993, when average stream temperatures were 9.9°C. This difference suggests that even large fish may emigrate later when water temperatures are low (Ewing et al. 1984).

The greater tendency for smolts to emigrate during the new and waning moon phases in this study is consistent with other research relating moon phase to smolt emigrations (Grau et al. 1981). Because wild smolts in the South Umpqua River basin emigrate primarily at night (Roper and Scarnecchia 1996), movements during dark moon phases may be an adaptation to minimize predation risk.

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tory characteristics (Lichatowich et al. 1995) as well as affect the ultimate survival of smolts (Bilton et al. 1982). Because land management activities have already simplified many of the streams within the upper South Umpqua River basin (Dose and Roper 1994), future land use within this basin must be undertaken with regard to potential effects on smolt emigration and survival.

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