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DIEL AND SEASONAL MOVEMENTS OF WHITE STURGEON, *ACIPENSER TRANSMONTANUS*, IN THE MID-COLUMBIA RIVER

The white sturgeon, *Acipenser transmontanus*, is a commercial and sport fish common to major river systems of the Pacific Coast from Monterey, Calif., to Alaska (Scott and Crossman 1973). However, there is considerable confusion concerning migration habits or seasonal movements of the species. Early workers (Jordan and Evermann 1908; Craig and Hacker 1940) considered white sturgeon anadromous. In free-flowing rivers, white sturgeon move upstream in spring prior to spawning (Carl et al. 1967; Bell 1973). Other investigators (Bajkov 1951) suggested seasonal movements in the lower Columbia River may be related to feeding.

Although some white sturgeon can be found in the ocean and may ascend rivers to spawn, the species is not truly anadromous. Many individuals remain in freshwater, and those found in the upper Columbia River and its tributaries are landlocked by a system of hydroelectric dams. However, permanent freshwater residents also show seasonal movements. Studies in 1975 and 1976, involving radio-tagged white sturgeon in the mid-Columbia River, indicated sturgeon movements >2 km occurred when river temperatures exceeded 13° C (Haynes et al. 1978). Furthermore, size and possibly sexual maturity influenced direction of movement in the river. Smaller white sturgeon moved downstream in summer, larger sturgeon moved upstream in summer and fall, and intermediate-sized sturgeon remained near release points. Although seasonal movements may be related to water temperature, no quantitative data exist on diel activity patterns of the species. To further evaluate seasonal movements in the free-flowing Hanford reach of the Columbia River, we fitted additional white sturgeon with radio transmitters in spring and early summer 1977 and continued monitoring fish which had been tagged in 1975 and 1976.

Methods

Radio-telemetry equipment was developed by the University of Minnesota, Bioelectronics Laboratory (Tester and Siniff[1]). Nineteen white sturgeon ranging from 98 to 236 cm total length were captured with trammel nets and angling gear at White Bluffs Pool (Figure 1), about 48 km upstream from Richland, Wash. Transmitters were selected so as not to exceed 2% of estimated sturgeon body weight and were attached dorsally (Haynes et al. 1978). Twelve transmitters had temperature sensors (precision ±0.2° C, Kuechle[2]). An automatic, channel-scanning receiver and recording station, capable of sequentially monitoring 16 channels, was established at White Bluffs Pool to record environmental temperatures and sturgeon movements in and out of the pool. Receivers operated on a carrier frequency of 53 MHz

[1]Tester, J. R., and D. B. Siniff. 1976. Vertebrate behavior and ecology progress report for period July 1, 1975-June 30, 1976. COO-1332-123. Prepared for U.S. Energy Research and Development Administration. Contract No. E(11-1)-1332 by Univ. Minn., Minneapolis, 63 p.
[2]V. B. Kuechle, Bioelectronics Laboratory at Cedar Creek, University of Minnesota, Minneapolis, pers. commun. 1977.

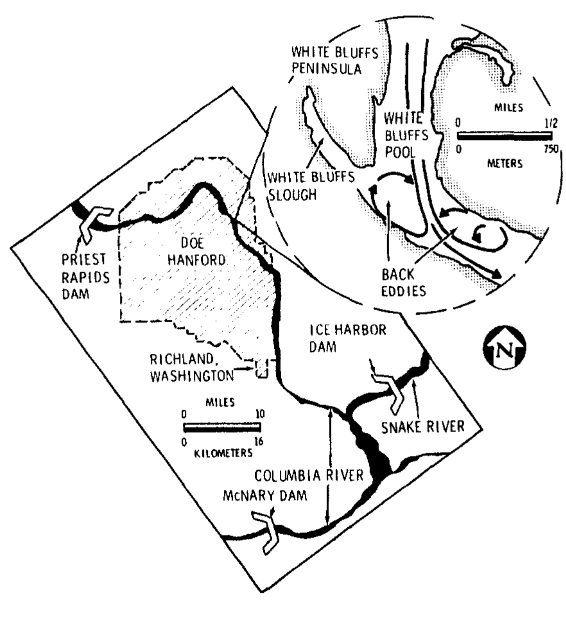

FIGURE 1.—White Bluffs monitoring area for white sturgeon movements in the Columbia River.

and were capable of distinguishing 100 discrete crystal-tuned transmitters. Sturgeon, including those radio-tagged in 1975 and 1976 (Haynes et al. 1978), were located once or twice per week with boat- and truck-mounted receiver gear. On several occasions, sturgeon locations were monitored manually over a 24-h period.

During the summer we measured Columbia River temperatures at numerous midchannel locations from Priest Rapids Dam to Richland, 95 km downstream (Figure 1). On these occasions river temperatures only varied about 1° C. Therefore, mean river temperatures (standard deviation = 0.5° C/d) during the study were calculated from 12 temperature readings taken daily at Priest Rapids Dam. Daily mean river temperatures were averaged weekly. Main current temperatures in White Bluffs Pool were monitored by a reference temperature transmitter in the pool and were also measured while tracking fish.

Analysis of variance was used to compare mean sturgeon environmental temperatures in six time periods (0200-0600, 0600-1000, 1000-1400, 1400-1800, 1800-2200, and 2200-0200 h) with the weekly mean river temperature from 19 June to 20 August 1977. Differences between sturgeon environmental temperatures and weekly average river temperatures were experimental units within each time period. Honest significant difference (HSD) tests (Snedecor and Cochran 1972) were used to establish which periods differed.

White Bluffs Pool is 1.5 km long and has three distinct habitats (Figure 1). Most of the pool is part of the deep, swiftly flowing main current of the Columbia River and has a rock bottom. A deep, slow-moving back eddy with a sandy bottom lies off the tip of White Bluffs Peninsula. White Bluffs Slough has a mud and rock bottom and extends 1 km upstream along the peninsula. The pool ranges in depth from 1 m in the slough to 20 m in midpool, and the main current is well mixed (Gray et al.[3]; Page et al.[4]). However, underground spring seepage areas, common in the region, are 1°-5° C lower, and slough areas are 2°-5° C higher, than mixed main currents in summer (Haynes 1978).

[3]Gray, R. H., T. L. Page, and E. G. Wolf. 1976. Report on aquatic ecological studies near WNP-1, 2, 4, Sept. 1974-Sept. 1975. WPPSS Columbia River ecology studies, Vol. 2, 115 p. Battelle, Pac. Northwest Lab., Richland, Wash.

[4]Page, T. L., R. H. Gray, E. G. Wolf, and M. J. Schneider. 1976. Final report on aquatic ecological studies conducted at the Hanford Generating Project 1973-74. WPPSS Columbia River ecology studies, Vol. 1, 206 p. Battelle, Pac. Northwest Lab., Richland, Wash.

Results and Discussion

Main current temperatures in White Bluffs Pool averaged within 0.5° C of Priest Rapids Dam temperatures and weekly standard deviations averaged 0.3° C throughout 1977. Therefore, deviations in daily and weekly midriver temperatures were small relative to temperature differences in spring seepage and slough areas in summer. Throughout the summer of 1977, individual sturgeon with temperature transmitters engaged in movements that often resulted in a 2°-4° C daily change in recorded temperature. The analysis of sturgeon environmental temperatures versus weekly average river temperatures during certain periods of the day (Table 1) indicated significant differences ($P<0.001$). Because deviations in main river temperatures were 8-25% less within and between days than changes in sturgeon environmental temperatures, recorded temperature changes indicated sturgeon moved into areas of differing environmental temperatures. Position determinations confirmed these movements and indicated sturgeon generally occupied midchannel areas from early morning until midafternoon. Movements into nearshore and slough areas were observed in late afternoon and evening.

During summer 1977 from 0200 to 1000 h, sturgeon environmental temperatures (Figure 2) were somewhat, but not significantly, lower (−0.35° C) than weekly average river temperatures, suggesting presence in deeper, and possibly spring-fed areas. During 1400-2200 h, sturgeon environmental temperatures were significantly ($P<0.05$ by HSD) higher (0.85° C) than the weekly average river temperature, indicating presence in warmer, shallow slough areas. During 1000-1400 h and 2200-0200 h, sturgeon environmental temperatures were somewhat higher (0.32° C) than the weekly average, suggesting transition periods when sturgeon moved between inshore and midchannel areas.

Although changes in sturgeon environmental temperatures documented movements among

TABLE 1.—Analysis of variance on differences in mean sturgeon environmental temperatures in six daily time periods (0200-0600, 0600-1000, 1000-1400, 1400-1800, 1800-2200, and 2200-0200 h).

Source	df	SS	MS	*F*
Among time periods (diel)	5	164.67	32.93	47.7**
Within time periods	701	485.28	0.69	
Total	706	649.95		

**$P<0.001$.

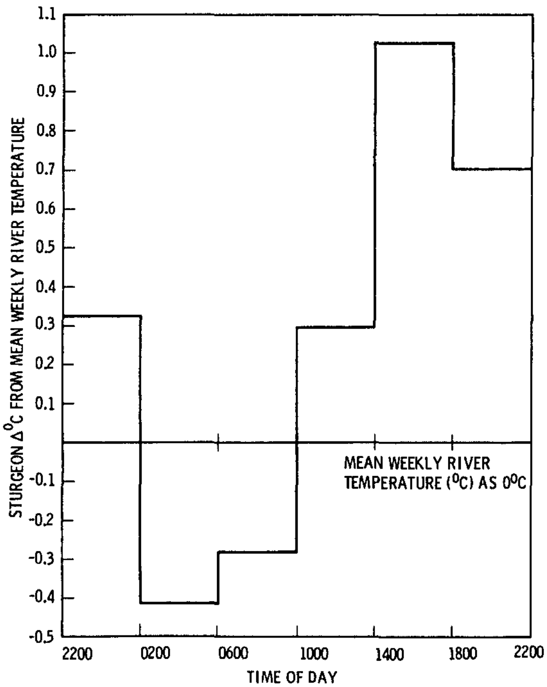

FIGURE 2.—Mean sturgeon environmental temperature deviation (Δ° C) from mean weekly Columbia River temperatures averaged over 4-h periods within the diel cycle, from 19 June through 20 August 1977.

habitats, we do not believe temperature differences in White Bluffs Pool caused diel sturgeon movements. Rather, diel movements are probably influenced by light. Movement to cool, deep areas occurred prior to sunrise and movement to warm, shallow areas peaked after sunset. Sturgeon were sensitive to light when captured for tagging and remained active until a towel was placed over their eyes. Bait angling for sturgeon was most successful during sunset and sunrise, and netting near shore was most productive at night. Evening movements to back eddy and slough areas of White Bluffs Pool, where benthic organisms and smaller fish are more abundant, may be related to feeding.

Sturgeon are bottom feeders and in freshwater reportedly eat crustaceans (*Daphnia* and copepods), molluscs (clams and snails), insect larvae (chironomids, stone flies, and ephemeropterans), and fish (Bajkov 1949; Semakula and Larkin 1968). Sturgeon in the mid-Columbia River at Hanford ingest crayfish, fish (including whitefish, suckers, and sculpins), midge and caddis fly larvae, snails, and periphyton (Gray et al. footenote 3; Page et al. footnote 4).

Daily environmental temperature records indicated sturgeon did not consistently engage in a diel movement pattern. Sturgeon sometimes spent one or more days in cooler, midchannel areas. Occasionally, sturgeon remained near inshore areas through midday, although variability within and among fish was common.

Haynes et al. (1978) suggested long-distance sturgeon movements in the mid-Columbia River were related to temperature. Data collected in 1977 confirm these observations. Sturgeon movements >2 km up- or downriver began in early summer when river temperature rose to 13° C and ended in fall when temperature dropped below 13° C (Figure 3).

The possibility that photoperiod plays a role in initiation of long-distance movement and termination of movement appears unlikely. Pacific Northwest drought conditions in 1977 resulted in extremely low Columbia River flows and higher-than-normal water temperatures. River temperatures in 1977 did not drop below 13° C until early November, and sturgeon movements continued throughout. In previous years, river temperatures

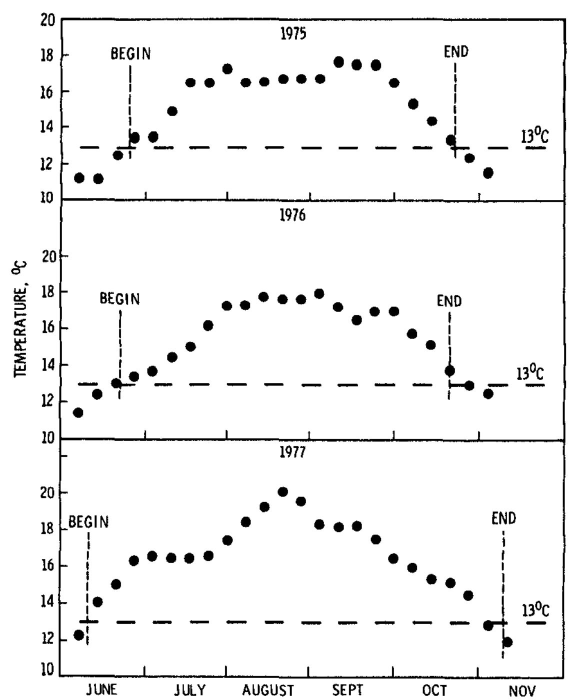

FIGURE 3.—Beginning and end of sturgeon movement (>2 km up- or downstream from release site) versus weekly average Columbia River temperatures in 1975 and 1976 (derived from Haynes et al. 1978) and 1977.

declined below 13° C and sturgeon movements ceased by mid-October. If photoperiod were involved, sturgeon movements in 1977 should have stopped at about the same time as they did in 1975 and 1976. Complete cessation of movement >0.5 km in autumn may be related to cold-induced inactivity.

Linear regression analyses comparing distances moved by sturgeon with river flows at Priest Rapids Dam produced scatter diagrams with regression coefficients approaching zero. In contrast to results of studies in the Snake River, Idaho (Coon et al.[5]), river flow apparently had no influence on long-distance sturgeon movements in the Columbia River at Hanford.

The complex interaction of water temperature, light cycle, feeding, urge to spawn, and other factors undoubtedly influence sturgeon movements in the mid-Columbia River. Although temperature is a major influence stimulating seasonal movements, light cycle and feeding probably influence diel movements.

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FEEDING PERIODICITY AND DIEL VARIATION IN DIET COMPOSITION OF SUBYEARLING COHO SALMON, *ONCORHYNCHUS KISUTCH*, AND STEELHEAD, *SALMO GAIRDNERI*, IN A SMALL STREAM DURING SUMMER

Throughout their native range in northwestern North America, juvenile coho salmon, *Oncorhynchus kisutch*, and steelhead, *Salmo gairdneri*, occur sympatrically in streams (Milne 1948). In these instances, social interaction between the two species leads to spatial segregation during the spring and summer, with coho salmon generally occupying pools and steelhead riffles (Hartman 1965; Allee 1974). A recent investigation of naturalized populations in the Great Lakes region has observed similar patterns of spatial segregation (Johnson and Ringler 1980).

It is generally accepted that social interaction among closely related fish species may lead to interactive segregation, with each species segre-