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Distribution and Movements of White Sturgeon in Three Lower Columbia River Reservoirs

Abstract

We determined the distribution and movement of white sturgeon (*Acipenser transmontanus*) in Bonneville, The Dalles, and John Day reservoirs on the Columbia River from April through August, 1987-1991. The study also evaluated effects of hydroelectric dams on white sturgeon populations. Differences in catch per setline-day indicated that white sturgeon densities were greatest in Bonneville Reservoir and least in John Day Reservoir. White sturgeon concentrated in tailraces of dams and density generally declined downstream through each reservoir. Distribution within each reservoir varied with sampling month and were related, in part, to temperature. Most fish were caught at depths from 10 to 30 m. Tagged fish were often recaptured in locations other than those where originally marked. Some fish were recaptured as far as 152 km from where released. Individual fish frequently traveled the length of a reservoir, but were seldom recaptured in another reservoir. Dams restrict white sturgeon movements, may limit populations in some reservoirs, and concentrate fish immediately downstream, potentially increasing their vulnerability to exploitation. To optimize these fisheries, resource managers must recognize differences among reservoirs and employ regulatory schemes specific to each.

Introduction

The white sturgeon (*Acipenser transmontanus*) is a unique and ancient species endemic to large, cool rivers along the Pacific coast of North America. White sturgeon are among the largest freshwater fish in North America, exceeding 6 m and 800 kg (Scott and Crossman 1973). In the Columbia River basin, white sturgeon historically ranged from the ocean as far as 1300 km upstream into Idaho, Montana, and Canada. Individual fish were thought to have moved freely throughout the area (Scott and Crossman 1973). Sturgeon regularly undertook long-distance movements, apparently to take advantage of seasonal changes in food and habitat in this dynamic river environment (Bajkov 1951).

Dams, constructed on the mainstem Columbia since 1933, limit the distribution and constrain movements of sturgeon which, unlike salmon, do not normally use fish ladders. Cochnauer *et al.* (1985) suggested that white sturgeon populations in some landlocked portions of the river were isolated with respect to reproduction. Productivity appeared to vary among populations as some supported fertile fisheries while others could sustain no exploitation (Cochnauer *et al.* 1985). Also, dams may have led to genetic divergence of impounded populations due to reproductive isolation (Brown *et al.* 1992).

Understanding the distribution and movement of white sturgeon in landlocked populations may help determine why some populations thrive while others appear to be in danger of extirpation. Size-specific seasonal movements have been observed for landlocked white sturgeon in the unimpounded Hanford Reach of the mid-Columbia River (Haynes *et al.* 1978, Haynes and Gray 1981), but no information exists for impounded populations. This paper investigates white sturgeon distribution and movement within and among the lower Columbia River reservoirs.

Study Area

The study area included the three lowest mainstem reservoirs of the Columbia River: Bonneville (Lake Bonneville), The Dalles (Lake Celilo), and John Day (Lake Umatilla). Bonneville Reservoir (74 km; 8400 ha) is relatively shallow (average depth 6.7 m) with mostly sand substrate supporting large beds of rooted aquatic macrophytes during the summer. The Dalles Reservoir is the smallest (38 km; 4500 ha; average depth 7.5 m), and the most riverine, with cobble, gravel, and sand substrates distributed throughout most of its length. John Day Reservoir is the largest (123 km; 21,000 ha; average depth 8.0 m) and the most diverse. The reservoir grades from a riverine upper section with gravel and cobble substrates to a shallow transition section with sand substrate, and finally to a lentic lower section with steep cliff and boulder banks. Average daily river discharge through the study area ranges seasonally from 3000 to over 12,000 m^3/s.

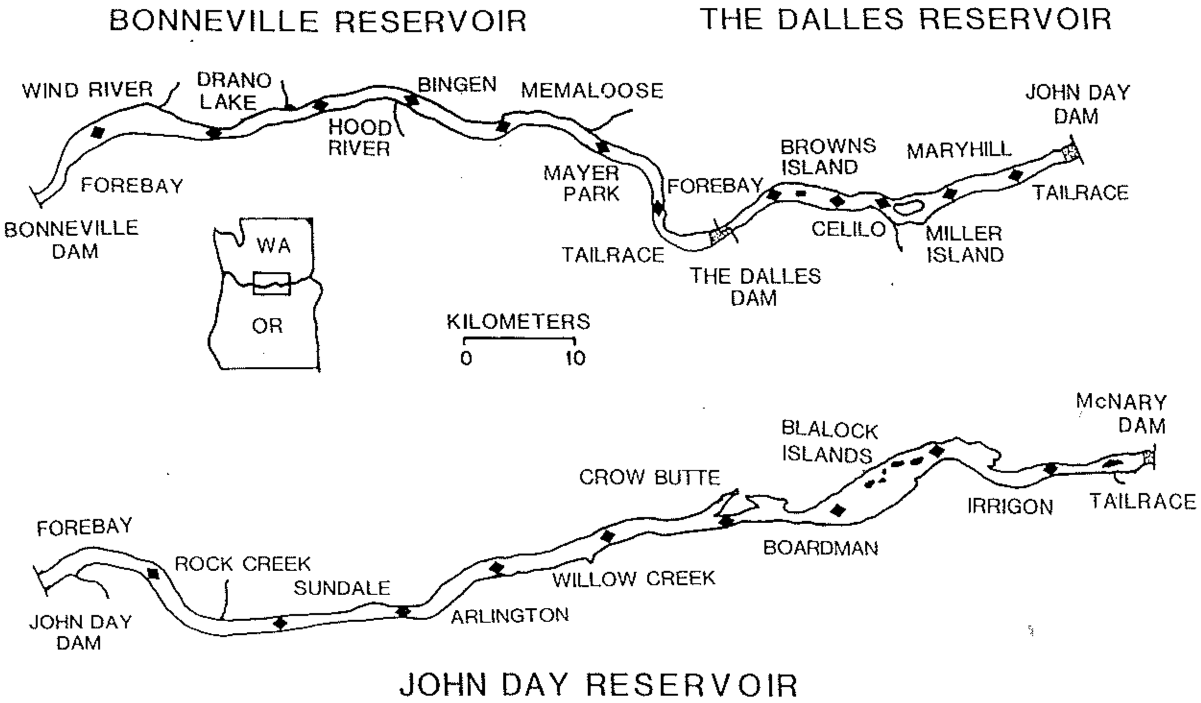

Figure 1. Columbia River from Bonneville to McNary Dams. Sampling area boundaries are indicated by ◆'s. Boat-restricted zones in dam tailraces are shaded.

Methods

To estimate population statistics, we collected white sturgeon during 1988-1989, and 1991 in Bonneville Reservoir; 1987-1989 and 1991 in The Dalles Reservoir; and 1990-1991 in John Day Reservoir. Stratified sampling was conducted from April through September in 1987 and 1990, May through August in 1988, April through August in 1989, and July through August in 1991. We divided Bonneville Reservoir into eight 10-km segments, The Dalles Reservoir into six 7-km segments, and John Day Reservoir into ten 12.5-km segments (Figure 1). We also sampled the boat-restricted zones (BRZ's) which are less than 0.3 km long, and immediately downstream from The Dalles, John Day, and McNary dams. The BRZ's are unlike the remainder of the reservoir because the adjacent dam concentrates and injures potential prey fishes and creates eddies and still water nearby for predators. Because BRZ's are unique habitats, their results are reported separately.

Sampling was distributed equally among segments and river kilometer sampling sites in each reservoir to obtain representative population samples. Each segment was normally sampled every 4 weeks in Bonneville Reservoir, every 3 weeks in The Dalles Reservoir, and every 5 weeks in John Day Reservoir. From April through June in 1991, we concentrated our sampling locations where we caught most sturgeon in previous years.

White sturgeon were collected using setlines which provide the greatest catch rate and are less size-selective than other types of gear (Elliott and Beamesderfer 1990). Each line had 40 hooks (sizes 12/0, 14/0, and 16/0) baited with pieces of Pacific lamprey (*Lampetra tridentata*). We fished lines for an average 24.8 hr per set. Sets were concentrated in main-channel habitats outside navigational lanes at depths from 3 to 51 m.

We measured sturgeon fork length (FL) to the nearest cm and examined each fish for tags. Untagged sturgeon longer than 64 cm were spaghetti tagged at the anterior base of the dorsal fin. Sturgeon longer than 84 cm were tagged with a second spaghetti or Petersen disc dangler tag at the base of the posterior end of the dorsal fin (Smith 1978). A total of 7351 fish were tagged with individually numbered spaghetti and disc tags. The Washington Department of Fisheries (WDF) also provided tag recoveries from the recreational and commercial fisheries in the three reservoirs and in the free-flowing river between Bonneville Dam and the ocean.

We examined white sturgeon distribution by comparing setline catch rate among areas. Statistical differences ($p < 0.05$) in catch rates were evaluated on transformed catch per set data [ln(catch+1)] with programs of the Statistical Analysis System (SAS 1988a, SAS 1988b). To examine seasonal changes in distribution within each reservoir, we used an index (I) where:

$$I = \frac{S - L}{T}$$

and S is river km where fish were captured, L is river km of the lower reservoir boundary, and T is reservoir length in km. The values were averaged for all fish captured during a sampling cycle. A high river kilometer index indicates upstream distribution; a low index indicates downstream distribution. We assumed that seasonal changes in average catch rates implied changes in movement rates. The relationship between catch and water temperature was evaluated using linear regression.

We compared numbers of fish released and recaptured at each site to estimate the extent of movement within each reservoir and to determine whether individuals moved among reservoirs. Recaptures included all fish caught with setlines, and sport and commercial fisheries, where the kilometer of capture could be determined.

Results

Distribution

White sturgeon were not evenly distributed among study reservoirs. Average setline catch per day in Bonneville Reservoir 4.10 fish/set in 942 sets) was 1.5 times greater than in The Dalles Reservoir (2.70 fish/set in 978 sets), and 7.5 times greater than in John Day Reservoir (0.55 fish/set in 1194 sets). Catch rate differences among reservoirs were statistically significant (Table 1).

Densities (catch per day, 1987-1990) of white sturgeon were greater in the BRZ downstream of each dam than in the rest of the reservoir by 3 times in Bonneville Reservoir, 6 times in The Dalles Reservoir, and over 20 times in John Day Reservoir. Densities outside BRZ's generally decreased with distance from the dam (Figure 2). Catch rates outside BRZ's approached those near dams only at the mouth of the Klickitat River (Memaloose segment) in Bonneville Reservoir. Catch rate differences among segments were significant in all three reservoirs (Table 1).

TABLE 1. Statistical comparisons of log-transformed catch [ln(catch+1)] of white sturgeon per setline day in Bonneville, The Dalles, and John Day reservoirs, 1987-1990. The Analyses of Variance (ANOVA) are one-way comparisons except Catch vs. depth*size which evaluates interaction in a two-way ANOVA.

Comparison	Reservoir	df_1*	df_2*	F*	p*
Catch vs. reservoir	–	2	3,111	774.60	0.0001
Catch vs. area	Bonneville	8	933	12.00	0.0001
	The Dalles	6	971	43.62	0.0001
	John Day	10	1,183	75.06	0.0001
Catch vs. month	Bonneville	4	922	39.48	0.0001
	The Dalles	4	930	12.40	0.0001
	John Day	5	1,144	6.78	0.0001
Catch vs. depth	Bonneville	6	916	2.89	0.0086
	The Dalles	6	927	2.37	0.0282
	John Day	6	1,142	1.49	0.1783
Catch vs. depth*size	Bonneville	12	2,748	1.38	0.1676
	The Dalles	12	2,781	2.08	0.0153
	John Day	12	3,426	1.48	0.1237

*Degrees of freedom (df), test statistic (F), and observed probability level (p) in ANOVA.

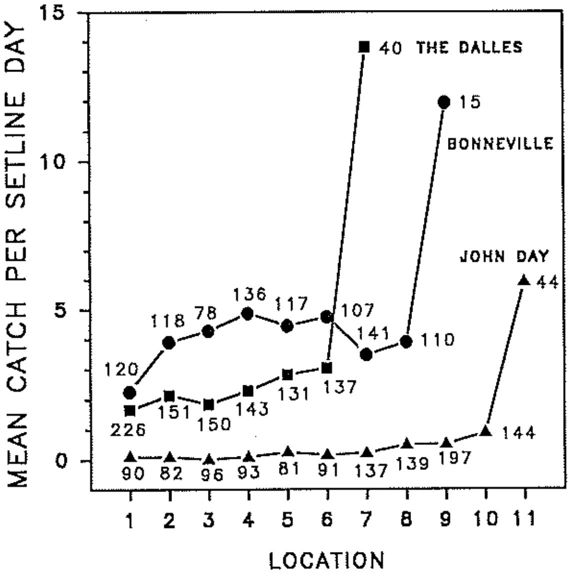

Figure 2. Mean catch per setline day of white sturgeon in Bonneville, The Dalles, and John Day reservoirs, 1987-1990. Number of sets indicated for each reservoir segment. Locations are: Bonneville Reservoir; 1=Forebay, 2=Wind River, 3=Drano Lake, 4=Hood River, 5=Bingen, 6=Memaloose, 7=Mayer Park, 8=Tailrace, 9=The Dalles Dam boat-restricted zone (BRZ). The Dalles Reservoir; 1=Forebay, 2=Browns Island, 3=Celilo, 4=Miller Island, 5=Maryhill, 6=Tailrace, 7=John Day Dam BRZ. John Day Reservoir; 1=Forebay, 2=Rock Creek, 3=Sundale, 4=Arlington, 5=Willow Creek, 6=Crow Butte, 7=Boardman, 8=Blalock Islands, 9=Irrigon, 10=Tailrace, 11=McNary Dam BRZ.

Seasonal changes in distribution were noted in The Dalles and John Day reservoirs. Relative numbers of white sturgeon collected in midreservoir increased from April through June and declined by August and September, implying downstream and then upstream redistribution of fish (Figure 3). Differences in catch proportions in lower, middle, and upper thirds of each reservoir were related to month (Bonneville: $X^2 = 186.75$; df = 8; $p < 0.001$; The Dalles: $X^2 = 1{,}197.19$; df = 10; $p < 0.001$; John Day: $X^2 = 334.78$; df = 10; $p < 0.001$).

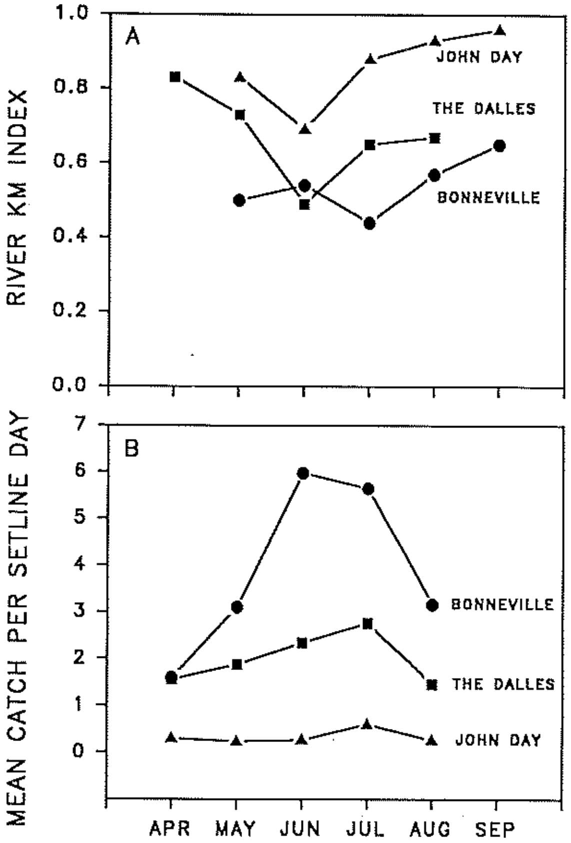

Figure 3. Index of white sturgeon distribution (A) and mean catch per setline day (B) in Bonneville, The Dalles, and John Day reservoirs, 1987-1990. The index is the mean kilometer of capture of all white sturgeon caught during a month. The index is standardized for reservoir size by subtracting the lower reservoir bound and dividing by reservoir size. Sturgeon collected in tailrace boat-restricted zones are excluded.

Catch rates in all three reservoirs peaked in June or July. Monthly differences in catch rates were significant (Table 1). Mean monthly catch rate generally increased with increasing temperature up to about 18°C and declined at greater temperatures (Figure 4). Linear regressions show that about 10-30% of the catch rate variation is related to water temperature (Bonneville: df = 3, $r^2 = 0.32$, $p = 0.32$; The Dalles: df = 3, $r^2 = 0.09$, $p = 0.62$; John Day: df = 4, $r^2 = 0.17$, $p = 0.41$).

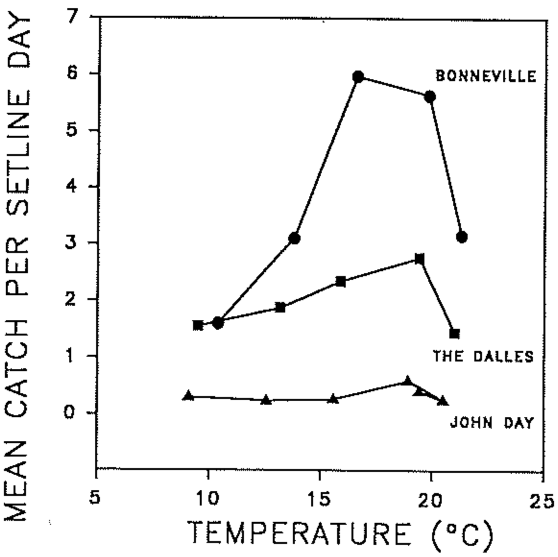

Figure 4. Mean catch of white sturgeon per setline day versus mean monthly temperature for Bonneville, The Dalles, and John Day reservoirs, 1987-1990. Sturgeon collected in the tailrace boat-restricted zones are excluded.

Catch rates at different depths were significantly different, except in John Day Reservoir where sampling success was poor (Table 1). Few white sturgeon were captured at depths less than 10 m (Figure 5). No meaningful size-depth relationship was evident (Figure 6), although a statistically significant size-depth interaction was noted for The Dalles Reservoir (Table 1).

Movements

Movements up to 152 km were observed among tagged sturgeon. Of 635 tagged individuals, 59% moved at least 1 km and many moved 10-30 km (Figure 7). Average distance traveled between release and recapture was 8.1 km. Of sturgeon that moved between tagging and recapture, 49.9% moved upriver and 50.1% moved downriver. Differences in fish size did not appear to affect distance or direction of fish travel.

Most movement was restricted to the collection reservoir and the extent of movement was related to reservoir length (Figure 7). Only 4% of 635 recaptured white sturgeon moved past a dam in the study area (Table 2). Of these, 26 moved downstream, and 1 moved upstream.

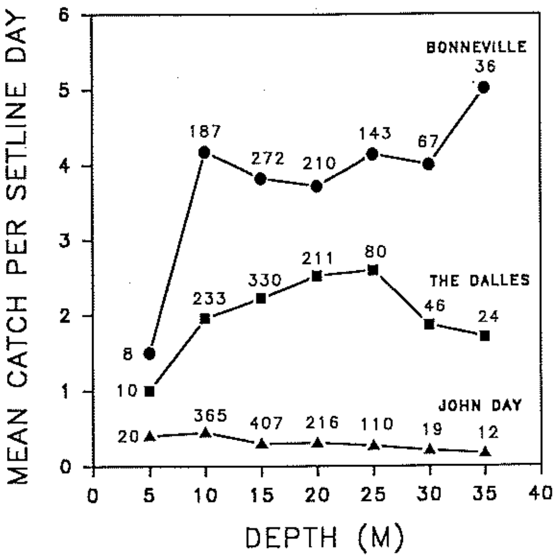

Figure 5. Mean catch of white sturgeon per setline day by 5-m depth intervals for Bonneville, The Dalles, and John Day reservoirs, 1987-1990. Number of sets is indicated for each depth interval. Sturgeon collected in the tailrace boat-restricted zones are excluded.

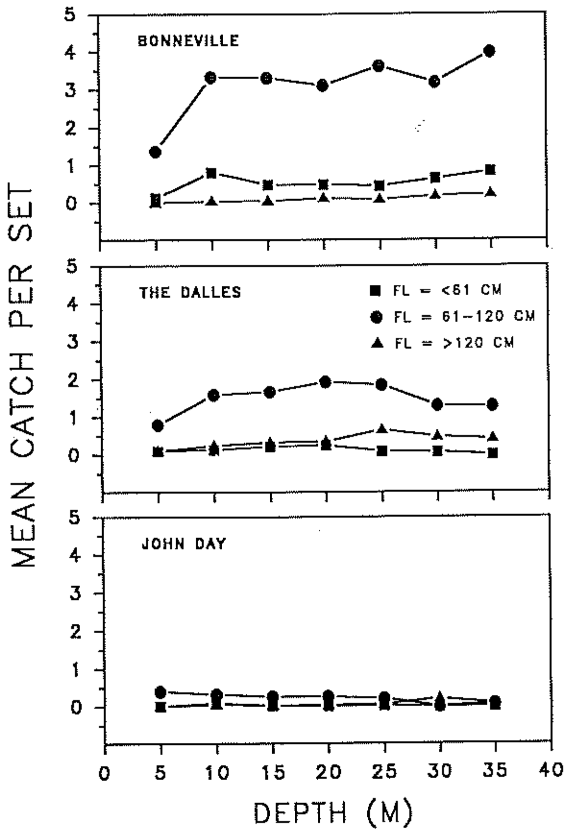

Figure 6. Mean catch of three size-classes of white sturgeon per setline day by 5-m depth intervals for Bonneville, The Dalles, and John Day reservoirs, 1987-1990. Number of sets is indicated for each depth interval. Samples collected in the tailrace boat-restricted zones are excluded.

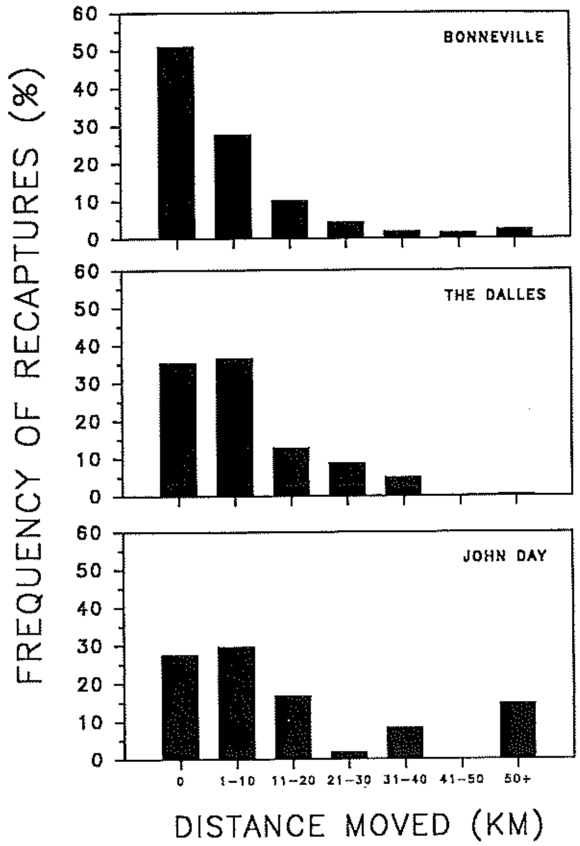

Figure 7. Frequency of white sturgeon recaptures by distance traveled between release and recapture in Bonneville, The Dalles, and John Day reservoirs, 1987-1991.

Discussion

The large differences observed in white sturgeon densities in the three study reservoirs may reflect differences in reproductive success, exploitation rate, and habitat availability. Regular year-class failures in John Day Reservoir, and to a lesser degree in The Dalles Reservoir (Anders and Beckman 1992) may have reduced white sturgeon numbers in these reservoirs. Recently, commercial fisheries have increased their exploitation of white sturgeon. John Day and The Dalles reservoirs were fished more than Bonneville Reservoir from 1980 to 1990 (personal communication, S. King, Oregon Department of Fish and Wildlife, Clackamas, Oregon). Finally, each reservoir has different physical conditions that may furnish critical resources in varying amounts. Although past fishery management has treated the three reservoirs as a homogeneous unit, our data imply that unique size or catch limits may be necessary to optimize the fishery in each.

TABLE 2. Number of tagged white sturgeon released in Bonneville, The Dalles, or John Day reservoirs and recaptured in another reservoir or outside the study area, 1987-1991.

		Recapture year					
Release location	Recapture location	1987	1988	1989	1990	1991	Total
Bonneville	Below Bonneville	–	–	3	4	1	8
The Dalles	Bonneville	–	–	3	3	10	16
John Day	Bonneville	–	–	–	–	1	1
John Day	The Dalles	–	–	–	–	1	1
The Dalles	John Day	1	–	–	–	–	1

The small, unique areas in the tailraces immediately downstream of each dam (BRZ's) yielded high catch rates throughout the study. Beamesderfer and Rieman (1991) reported similar concentrations near dams for another resident predator, the northern squawfish (*Ptychocheilus oregonensis*). Increased food availability may explain these concentrations as these predators eat migrating salmonids (*Oncorhynchus* spp.), shad (*Alosa sapidissima*), and Pacific lamprey that have been injured and also concentrated during dam passage. Merrell (1961) observed a white sturgeon eating steelhead (*O. mykiss*) and chinook salmon (*O. tschawytscha*) which, he thought, were injured as they passed through an industrial plant on the Willamette River in Oregon. Concentrations of white sturgeon in dam tailraces increase their vulnerability to exploitation by bank anglers. Existing sanctuaries in dam tailraces provide significant conservation benefits to white sturgeon populations by restricting access by boat anglers to concentrations of sturgeon which are vulnerable to harvest.

Downstream from each dam, white sturgeon densities generally decreased as conditions became less riverine. The pattern in which white sturgeon moved downstream in summer and upstream in fall was reported by Haynes *et al.* (1978) in a study on the unimpounded Columbia River upstream of the McNary Dam Reservoir (Lake Wallula), and by Bajkov (1951) downstream of study reservoirs.

We caught white sturgeon at all depths, but observed little difference in catch rates at depths greater than 10 m. Although the low catch rates at depths less than 10 m in all reservoirs imply that white sturgeon prefer deep water, we took too few shallow water samples to confirm this preference. Fishers report good seasonal catches from shallow water flats with mussel beds. Additional work is needed to evaluate depth preferences and their interactions with current velocity and substrate preferences.

White sturgeon moved long distances over relatively short time periods in each reservoir. Frequent movements of marked fish indicate they were well mixed in each reservoir, minimizing the chance for biases due to marking and recapture (Ricker 1975). Dams constrain movements of most white sturgeon, although a few passed a dam. Most dam passage was downstream rather than upstream. Although distribution of our sampling efforts made observations of downstream movements more likely than upstream movements, we saw virtually no upstream passage of dams by white sturgeon we tagged or of any of the thousands of fish tagged annually by fishery managers monitoring the sturgeon population downstream of Bonneville Dam. Avenues for downstream passage include fishladders, spillways, turbines, or navigation locks. Opportunities for upstream movements are limited to navigation locks or fish ladders which were designed for salmonids and rarely permit sturgeon to pass.

The minimal downstream movement from one reservoir to another is likely to have little effect on population size or productivity, either up- or downstream of the dam passed. However, this movement may prevent genetically different populations from developing in each pool. Even minimal immigration is sufficient to prevent genetic differentiation unless there is strong differential selection in different areas (Nei 1987). Divergence depends on the number of migrants entering a population, not their proportion (Allendorf and Phelps 1981). Relatively few migrants are needed to counteract the effects of genetic drift in large populations. The white sturgeon movements we observed are inconsistent with observations of genetic diversity among white sturgeon populations in Bonneville, The Dalles, and John Day reservoirs based on differences in mitochondrial DNA (Brown *et al.* 1992). Larger sample sizes than used by Brown *et al.* (1992) may be required to accurately characterize differences.

White sturgeon evolved in a river environment characterized by diverse habitats corresponding to the surrounding topography and dynamic seasonal changes in prey abundance. The species appears to have adopted a nomadic life history strategy, in response to these conditions. This behavior persists in white sturgeon populations in the free-flowing section of the river downstream of Bonneville Dam (Bajkov 1951).

Dams are barriers to sturgeon movements and have created a series of populations which are functionally, if not genetically, discrete. Fish restricted to a reservoir cannot range among widely scattered habitats nor take advantage of seasonal concentrations of prey. Each population must depend on conditions within a specific reservoir to sustain production. Dams appear to provide optimal conditions only in small areas (BRZ's) and result in a net reduction in habitat quality. Impoundment has reduced habitat diversity by creating a homogenous slackwater habitat which may not furnish optimal conditions for the white sturgeon life cycle in all years. The combination of reduced habitat diversity and constraints on movement may reduce white sturgeon productivity in the impounded portions of the river.

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