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WHITE STURGEON ABUNDANCE AND ASSOCIATED HABITAT IN LOWER GRANITE RESERVOIR, WASHINGTON

A Thesis
Presented in Partial Fulfillment of the Requirements for the
Degree of Master of Science
with a
Major in Fisheries
in the
College of Graduate Studies
University of Idaho

DRAFT

by
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August, 1994

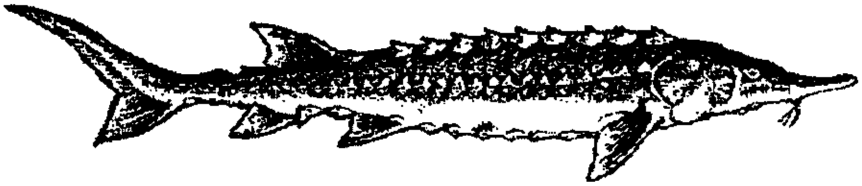
AUTHORIZATION TO SUBMIT

ABSTRACT

White sturgeon *Acipenser transmontanus* were sampled in Lower Granite Reservoir (LGR) from 1990-91 to describe population abundance and use of reservoir habitat. A total of 946 white sturgeon were sampled with 9,951 gill net and 6,755 setline hours of effort. Abundance of white sturgeon (>40 cm FL) was estimated at 1,372 (95% CI 578-2,166) with an average density of 0.38 fish/ha. Approximately 94% of white sturgeon sampled were <125 cm TL (112 cm FL) with the majority of aged fish between 0-8 indicating a primarily juvenile population residing in LGR. Mean relative weight (103) and comparison of length-weight relationships indicated fish condition in LGR has improved since previous studies conducted in the Lower Granite - Hells Canyon Reach (Coon et al. 1977; Lukens 1984). Mortality rates adjusted for gear selectivity were $Z = 0.70 \pm 0.10$; $A = 0.50$; $S = 0.50$ in 1990 and $Z = 0.73 \pm 0.16$; $A = 0.52$; $S = 0.48$ for 1991. White sturgeon were not distributed uniformly in LGR. Approximately 56% (446) of the fish were sampled at the upper end of the reservoir near the Port of Wilma (RKm 215.6). Catch rates and suitability indices indicated white sturgeon used habitat at the upper end of LGR with greater frequency than mid and lower reservoir transects. These upper areas coincided with higher velocity, larger substrate and shallower depths relative to transects sampled downstream. However, stepwise discrimant analysis of habitat variables explained only 26% of the variation between locations classified as present or absent suggesting other criteria were responsible for white sturgeon distribution in LGR.

ACKNOWLEDGMENTS

Special thanks are due to my major professor, Dr. David Bennett, who provided my first opportunity for involvement in the fisheries program at the University of Idaho. This opportunity, with guidance and inspiration from Dr. Bennett, focused my efforts into a career. I am also deeply indebted to Tom Dresser, Ken Tolotti and Mike Mosher who provided tireless field assistance during my graduate study. There were many other students who contributed their time, energy and skill that deserve recognition. They are: Randy Osborne, Tom Curet, Tim Curet, Steve Brink and John Bailey. I would also like to thank the U.S. Army Corps of Engineers, Walla Walla, Washington for providing the support for the white sturgeon project. And finally, the person who gave the most support and understanding, my wife Kelly.



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STATUS OF WHITE STURGEON

White sturgeon *Acipenser transmontanus* are members of the Family Acipenseridae which consists of 4 genera and 23 species of sturgeon (Scott and Crossman 1973). Seven species of sturgeon are found in North America, including white sturgeon , which are restricted to the Pacific shores and river systems. White sturgeon evolved approximately 250 million years ago during the Cretaceous Period and are known for their longevity and large size. White sturgeon commonly exceed 40 years of age and are the largest freshwater and/or anadromous fish in North America with the largest capture at 630 kg in the Frazer River near New Westminster, British Columbia in 1897 (Scott and Crossman 1973). White sturgeon are iteroparous with females spawning at intervals from 2 to 8 years.

White sturgeon are a valuable resource supporting recreational, commercial and tribal fisheries (Semakula and Larkin 1968; Kohlhorst 1980; Raymond 1988; Brannon et al. 1985; Galbreath 1985; Oregon Department of Fish and Wildlife 1988; Hanson et al. 1992). White sturgeon are presently the most popular recreational fish in the Columbia River with sturgeon anglers representing up to 49% of all recreational fishing effort in the lower Columbia River during February to October (Oregon Department of Fish and Wildlife and Washington Department of Fisheries 1991; Hess and King 1989; Hess and King 1990). In Idaho, value of the recreational fishery for white sturgeon has been estimated at $8.9 million in 1989 (IDFG, unpublished data).

Historically, white sturgeon were found in rivers with access to the Pacific Ocean from central California to the Aleutian Islands of Alaska. They reproduce in at least three large river systems; the Sacramento-San Joaquin, Columbia, and Fraser rivers. However, development of the major river systems and adjacent watersheds in the Pacific Northwest has severely reduced and degraded historical sturgeon habitat (Hanson et al. 1992). Mainstem dams have created landlocked subpopulations and restricted use of various habitats that may have enhanced sturgeon production historically (Devore et al. 1993). Factors associated with fragmented populations, reduction in flows, pollution, reduced prey abundance and sedimentation are presumed contributors to the decline of white sturgeon. White sturgeon are considered depressed throughout most of their native range (Hanson et al. 1992; Conte et al. 1988). Landlocked populations of white sturgeon in the Snake River in Idaho are classified as a species of special concern (Mosley and Groves 1990; 1992). The United States Fish & Wildlife Service (USFWS) recently proposed listing the Kootenai River white sturgeon in northern Idaho as endangered under the Endangered Species Act (PNUCC 1993).

Specific habitat requirements for each lifestage of white sturgeon are poorly understood. The purpose of this 2 year study (1990-1991) was to assess white sturgeon abundance, physical habitat use in Lower Granite Reservoir (LGR), and potential impacts between white sturgeon and disposal of dredge material in LGR, Washington.

STUDY AREA

Lower Granite Dam, the uppermost of four reservoirs in the Lower Snake reservoir chain, provides electrical power generation, flood control, navigation and recreation (Bennett and Shrier 1986). Lower Granite Reservoir was impounded on the Snake River in 1975 with the completion of Lower Granite Dam. The reservoir extends 48 river kilometers (RKm) from the confluence of the Snake and Clearwater Rivers (RKm 225.8) in central western Idaho downstream to Lower Granite Dam (RKm 173.3) in southeastern Washington. One major tributary, the Clearwater River enters the reservoir near Lewiston, Idaho (Figure 1).

Total surface area of the reservoir is 3602 ha with a maximum depth of 42.1 m and mean depth of 16.6 m. Lower Granite Reservoir is thermally layered and has a maximum surface temperature of 26.°C. Shoreline substrate varies from rip-rap, mud-sand beaches to steep basalt cliffs. Riparian vegetation is sparse due to water level fluctuations (1.52 m) from reservoir operations. The majority of vegetation, short grasses, and shrubs is found on alluvial fans which extend from the canyon walls.

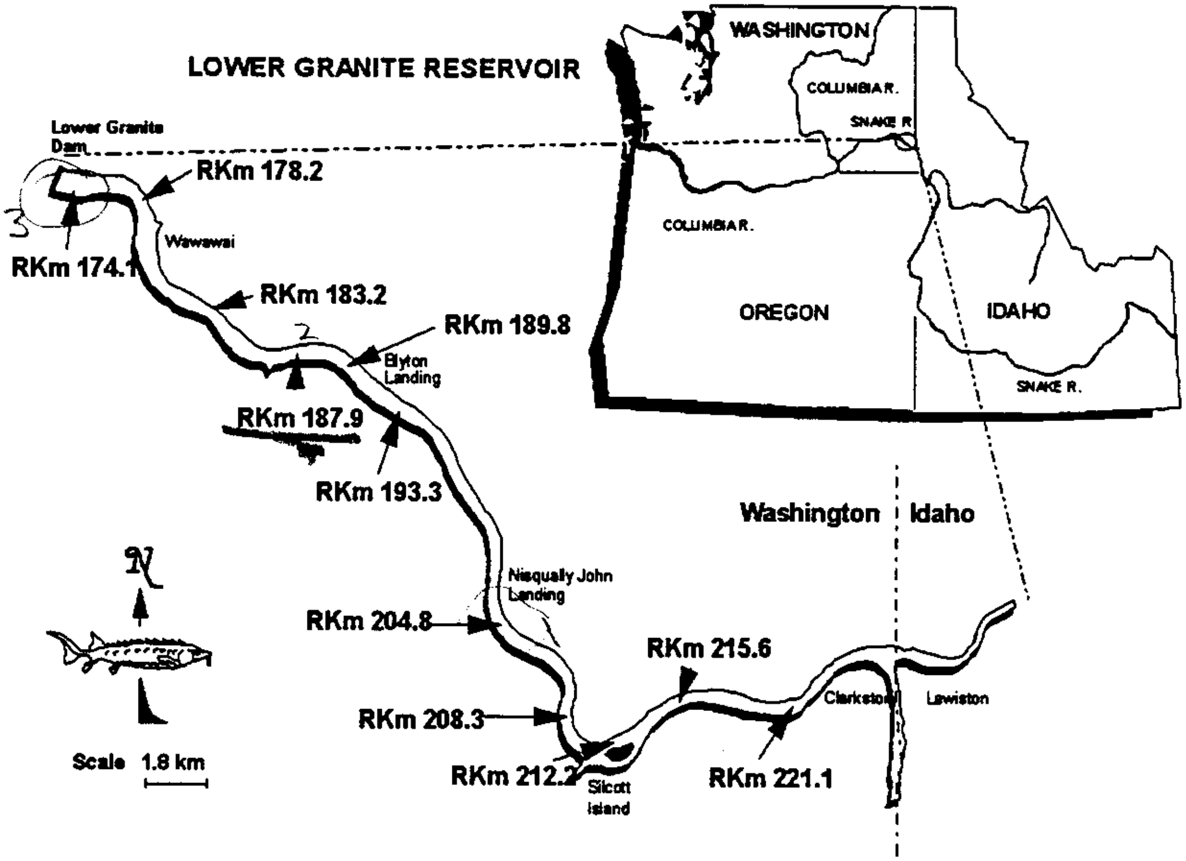


Figure 1. Map and location of transects sampled for white sturgeon in Lower Granite Reservoir (LGR), Washington 1990-91.

CHAPTER 1. Population Status of White Sturgeon in Lower Granite Reservoir

INTRODUCTION

White sturgeon remain relatively abundant in the Snake River between Lower Granite Dam (RKm 173.1) and Hells Canyon Dam (RKm 398) (Cochnauer 1983; Cochnauer et al. 1985; Lukens 1985). White sturgeon use both riverine and slack water habitats between Lower Granite and Hells Canyon dams although appear more abundant in the river than in the slack waters of LGR (Hanson et al. 1992). Anglers during 1988-1989 captured 50 fish in LGR (Zinicola and Hoines 1988; Washington Department of Fisheries , unpublished data 1989) while over 300 white sturgeon were hooked and released in the Snake River above LGR (IDFG, unpublished data). Lower Granite Reservoir currently maintains a consumptive sport fishery for white sturgeon between 121 and 152 cm TL while angling for white sturgeon in the Snake River above LGR has been catch and release since 1970.

Current information on the status of white sturgeon inhabiting LGR is limited. Prior white sturgeon studies conducted between Lower Granite and Hells Canyon dams mainly described the population status above LGR with little data on fish residing in the reservoir. Coon et al. (1977) estimated 8,000 - 12,000 white sturgeon (>46 cm TL) in the Snake River between Hells Canyon and Lower Granite dams during 1972-1975 with 44 fish sampled in the reservoir near Blyton Landing. Lukens (1984) reported an estimate of 4,000 white sturgeon between the confluence of the Snake and Clearwater rivers and Hells Canyon Dam. Efforts at collecting white sturgeon in LGR were unsuccessful (Lukens 1984). Recent studies (1992-93) monitoring fish stocks in LGR sampled 320 white sturgeon from mainly upper reservoir locations (Tom Dresser, University of Idaho, personal communication).

OBJECTIVES

1. Assess population status of white sturgeon in Lower Granite Reservoir with regard to population abundance, structure and relative condition; and

2. Describe distribution and movement of white sturgeon in Lower Granite Reservoir.

METHODS

Sampling Design

Hydroacoustic transects used by Thorne et al. (1992) to assess community abundance of fishes in LGR were systematically surveyed to locate overall distribution of white sturgeon. Preliminary survey data from 20 transects identified varying concentrations of white sturgeon in thalweg and bench areas adjacent to the thalweg. The reservoir was divided into three segments comprising of lower, mid and upper reaches. Transects were randomly selected from each reach and sampled with effort distributed evenly between thalweg and adjacent thalweg areas. Two 4-month sample intervals were conducted per year beginning in early spring and ending in late fall-winter seasons. A total of 18 random transects from lower, mid and upper reservoir segments were sampled for white sturgeon through 1990-91 (Table 1).

Table 1. Descriptive locations of transects sampled for white sturgeon in Lower Granite Reservoir, Washington during 1990-1991.

River Kilometer	Year Sampled	Location
174.1	1990	transect 0.8 kilometers upstream of Lower Granite Dam
178.2	1990/1991	transect 0.8 kilometers downstream of Wawawai Landing
183.2	1990	transect 3.7 kilometers upstream of Wawawai Landing
187.9	1990/1991	transect 2.25 kilometers upstream of Knoxway Bay
189.9	1990/1991	transect 4.0 kilometers upstream of Knoxway Bay
193.3	1990/1991	transect 0.8 kilometers upstream of Blyton Landing
204.8	1990/1991	transect 2.4 kilometers upstream of Nisqually John Landing
208.3	1991	transect 5.9 kilometers upstream of Nisqually John Landing
212.2	1991	transect located at upstream end of Silcott Island
215.6	1990/1991	transect 0.4 kilometers downstream from Port of Wilma
221.1	1990/1991	transect 0.3 kilometers downstream from Red Wolf Crossing Bridge

Collection Gear

Gill nets were the primary collecting gear used to assess relative and absolute white sturgeon abundance. Eight experimental gill nets (1.8 x 61.2 m) were set on the reservoir bottom perpendicular to the shoreline at each of the nine transects sampled. Four nets with bar mesh ranging from 2.54 to 15 cm were fished at the deepest cross section of the main channel with the remaining four nets fished adjacent to the main channel, typically on bench areas. Gill nets were fished a total of 6 hours and checked at 2-3 hour intervals. Five gill net passes per 4-month sample interval were conducted with each gill net pass requiring approximately 11 to 14 days to complete. A total of 20 sample passes were completed during 1990-91.

Setline sampling was conducted at each transect to supplement gill net effort. Setline sampling consisted of a 122 m mainline (1/4" cord rope) weighted on the bottom with tuna circle hooks attached every 3 m for a total of 24 hooks. Setline rigging was adopted from methods described by Apperson and Anders (1990) in the Kootenai River sturgeon investigations. Gangen lines were constructed with a stainless steel halibut snap and 4/0 ball bearing swivel attached to 100 to 250 kg test gangen twine. A stainless steel hog ring crimped onto a cadmium-tin coated circle tuna hook was tied to each gangen twine with hooks ranging in size from 16/0, 14/0 and 12/0. Each gangen line measured approximately 60 cm long from mainline to the hook and were rigged onto the mainline in random order. Hooks were primarily baited with Pacific lamprey *Lampetra tridentata*, rainbow trout *Oncorhynchus mykiss* and largescale suckers *Catostomus macrocheilus*. An ultrasonic transmitter and 61 m foam-filled rope (float-line) was attached and submerged with the setline to prevent navigational hazard and vandalism. Setlines were retrieved by locating the sonic transmitter and intercepting the submerged float-line with a grapple hook.

Corrections for gear size selectivity (vulnerability) were made using mark-recapture data. Vulnerability was estimated using the ratio of recaptures to marks-at-large by 20 cm FL intervals. The vulnerability curve describing the relationship between recapture rate and fork length was fitted with a power regression (Table Curve, Jandel Scientific 1993). The observed length frequency distribution was then corrected by dividing the observed frequency in each size class by the predicted vulnerability (Beamesderfer and Rieman 1988).

Capture and Tagging

Captured sturgeon <100 cm TL were placed in a circular well to permit fish to respire throughout handling time. Larger sturgeon (>100 cm TL) were examined in a 2.2 m x 1 m vinyl stretcher filled with water. Fish were measured, weighed, marked and promptly released. White sturgeon in 1990 initially received a numbered Floy tag below the posterior insertion of the dorsal fin. An external numbered aluminum lap seal tag was also crimped around the leading right pectoral fin ray of fish >40 cm TL as a secondary mark. Floy tagging was discontinued in 1991 and replaced with a passive integrated transponder (P.I.T.). This tag was injected into the dorsal musculature midway between the leading edge of the dorsal fin and right lateral row of scutes.

Population Abundance

Abundance of white sturgeon was estimated by using a Jolly-Seber open population model (Ricker 1975) :

$$N_i=\frac{(M_i*n_i)}{m_i}$$

where:

N_i = population estimate at ith interval

$M_i = (Z_i*R_i + m_i)/r_i$
Z_i = individuals marked prior to ith interval but not caught in ith interval
R_i = number released with marks
r_i = number of ni observed after time i
m_i = number recaptured at time i

Jolly-Seber model performed the matrix calculation and 95% confidence intervals. Mark-recapture samples were grouped by 2 week sample intervals for a total of 20 intervals completed during 1990-1991. Fish recovered in the same interval in which they were marked were not treated as recaptures in the population estimate. Population abundance was also calculated using a Schnabel closed population estimator modified by Chapman with >10% recapture rate for comparison (Ricker 1975) :

$$\frac{1}{\hat{N}} = \frac{(m_t*r_t)}{(c_t*m_t^2)}$$

where:

m_t = total number of marked fish in population on start of day t
c_t = total sample taken on t day
r_t = number of recaptures in c_t sample

Confidence intervals (95%) were calculated by:

$$N = \frac{\sum (C_t*m_t)}{r'}$$

Variance was determined by the equation:

$$r' = \sum r_t + 1.92 \pm 1.96\sqrt{\sum r_t + 1}$$

Population Structure

Size Distribution - Corrected length frequency distribution of white sturgeon was used for evaluation of the population structure.

Age and Growth - Procedures used to collect, prepare and read leading pectoral fin rays were adopted from methods described in Nigro (1989). A 10 mm section of the left pectoral fin ray was removed for age determination. Ray sections were removed 1 cm distal to the articulation of the fin with a fillet knife and fine-toothed hacksaw. Fin samples were air dried and transversely sectioned with a Buehler Isomet low speed saw and series 15 HC diamond wafering blade. A minimum of 3-5 transverse sections were cut ranging from 0.3 to 0.6 mm thick and mounted on a glass microscope slide with clear nail polish.

Fin ray sections were viewed with a micro-fiche screen. White sturgeon were aged by counting periodic translucent rings on cross sections of the anterior pectoral fin ray (Rien and Beamesderfer 1992; Tracy and Wall 1992). Each continuous ring was counted as an annulus. Length at age relationships were quantified by fitting fork length (cm FL) and age (years) to a polynomial function.

Fork length and weight (kg) data were fitted to a standard allometric function: $W = a\ L^{b}$. Condition factor of white sturgeon in LGR was compared among other white sturgeon in the Pacific Northwest with estimates of mean relative weight (W_r) based on the standard weight equation (W_s): $W_s = 1.952\ \mathrm{E}\text{-}06\ \ TL^{3.232}$ (Beamesderfer 1992). Relative weight values were obtained by dividing the actual weight of a fish (>60 cm) by the standard weight (W_s) for fish of that length and then multiplying by 100 (Wege and

Anderson 1978). Beamesderfer (1992) indicated that restricting analyses of lengths to 60 cm would minimize efforts of error in weighing small fish.

Mortality - Instantaneous total mortality (Z) was calculated from the slope of the descending limb of a log transformed catch curve (Ricker 1975). Catch curves were constructed for 1990-91 corrected length frequency distributions by calculating the proportion of age classes by length from aged fish. Percentages computed from the various age classes were applied to the corrected length frequency distribution. Natural log of catch was fitted with a linear regression on > 5 observations to determine the absolute value of Z. Approximate 95% confidence limits about Z are estimated from the regression as ± 2 SE. Total annual mortality (A) was derived as A = 1-S where survival rate (S) = e^{-z}.

Distribution and Movement

White sturgeon distribution was determined by comparing catch rates among sample transects. Mean catch rate of sturgeon collected by gill nets were calculated for each transect by computing catch vs. effort

$$CR=\frac{\sum (c_i * f_i)}{N_i}$$

where:

CR = mean catch rate
c_i = number of fish capture
f_i = amount of t sampling effort
N_i = number of t sample intervals

Statistical differences ($P<0.05$) in catch rates among transects are evaluated by using a multiple comparison test (SAS Institute 1988). Recovery of marked white sturgeon also provided information on distance and direction traveled within LGR. Seasonal changes in distribution within LGR was evaluated using an index (I): I = S - L/T where S = river mile where fish were captured, L = river mile of the lower reservoir boundary, and T = reservoir length (North et al. 1992). A high kilometer index indicates upstream movement and conversely a low index indicates downstream movement.

RESULTS

Population Abundance

Approximately 9,951 gill net and 6,755 setline hours of effort were expended from May 1990 through November 1991. A total of 946 white sturgeon were sampled with 147 (14.9%) recaptures. Gill nets collected 918 (0.97%) sturgeon and setlines 28 (0.03%). Abundance of white sturgeon (>40 cm FL) in LGR was estimated by Jolly-Seber at 1,372 (95% CI 578 - 2,166) which provided an average density of 0.38 fish/ha. A modified Schnabel estimator yielded similar results of 1,524 (95% CI 1,155 - 2,240).

Distribution of white sturgeon lengths among gill net mesh sizes indicated recruitment to the smallest mesh (2.54 cm) occurred near 40 cm FL. White sturgeon did not appear to fully recruit to the entire gear until >80 cm FL (Figure 2).

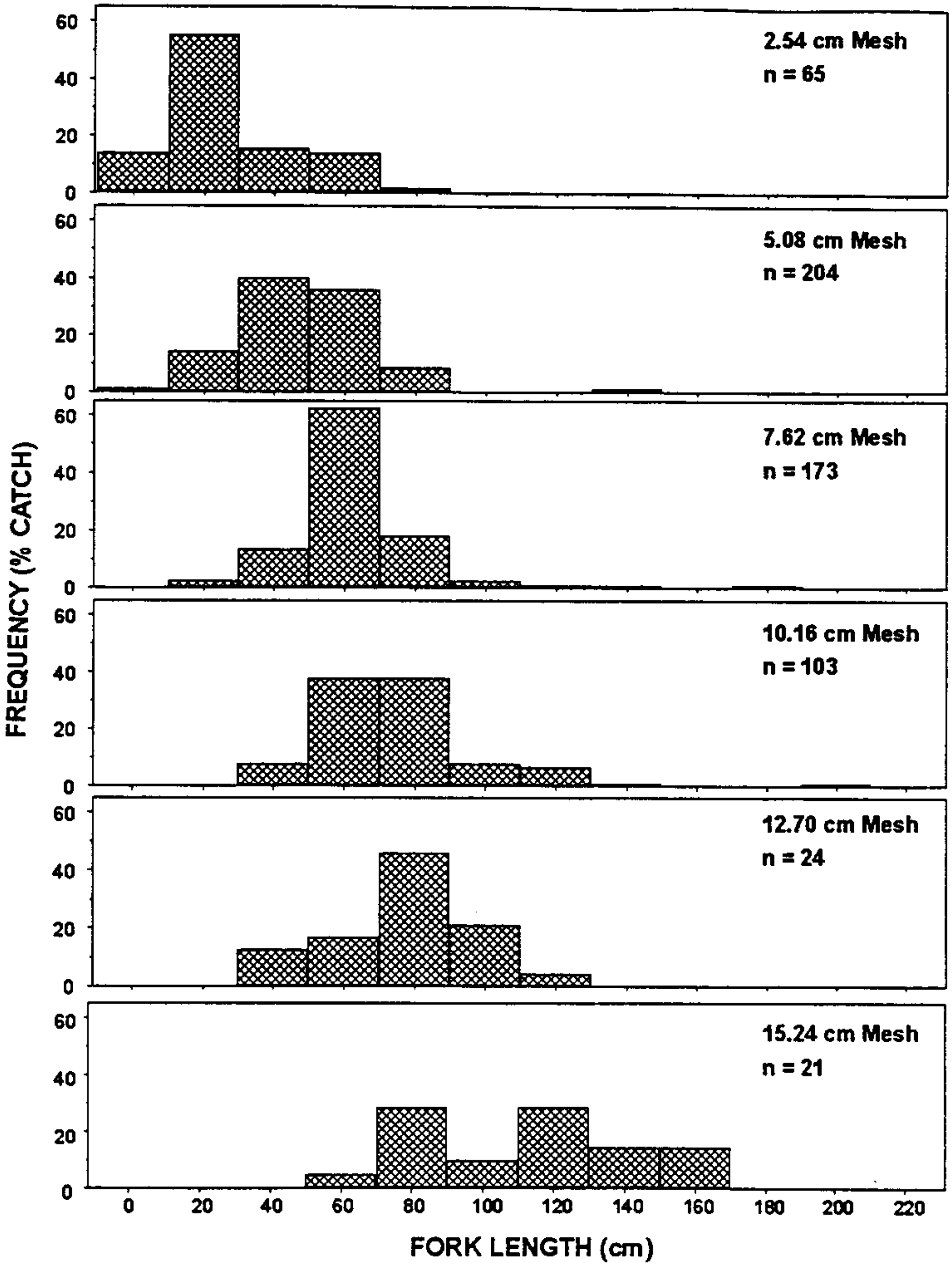


Figure 2. Size distributions of white sturgeon collected by gill net mesh size in Lower Granite Reservoir, Washington 1990-91.

Population Structure

Size distributions - Observed length frequencies of white sturgeon sampled with gill nets and setlines were significantly different ($\chi^2 = 248$; df = 11; $P<0.001$). White sturgeon collected with gill nets ranged in length from 10.3 to 203 cm FL with a mean of 62.3 cm FL. White sturgeon collected with setlines ranged from 69 to 236 cm FL with a mean of 127.3 cm FL (Figure 3). Vulnerability of white sturgeon to capture with gill net sampling increased with fish size ($r^2 = 0.75$; Figure 4a). Recapture rates determined white sturgeon measuring 140 cm FL were most vulnerable (0.40) to capture by gill nets (Table 2). The corrected length frequency distribution indicated juvenile white sturgeon measuring <112 cm FL (125 cm TL) comprised 94% of the length distribution sampled with gill nets (Figure 4b). Fish lengths corrected for gill net selectivity also indicated a significant difference between observed and corrected length frequencies ($\chi^2 = 36.2$; df = 8; $P< 0.001$). Length data for setlines were not corrected for gear selectivity due to small sample size (n = 21).

Age and Growth - A sample of 504 white sturgeon were aged from 0 to 29 years. Lengths of fish aged approximated the length distribution of all white sturgeon (779) captured during the study ($\chi^2 = 12.25$; df's = 11; $P> 0.05$). Juvenile white sturgeon from ages 0-8 (1991-61) comprised 84% of the entire sample with 1986-87 aged fish indicating weak year-classes (Figure 5). The relationship that best described the length-at-age data was the following polynomial function: $L_t = 25.54 + 9.02 + (-0.181)\, t^2 + 0.002\, t^3$ (Figure 6a). A plot of length at age data indicated growth was relatively consistent up to age ≥ 8 with increasing variation in lengths occurring ≥ 8 (Figure 6b).

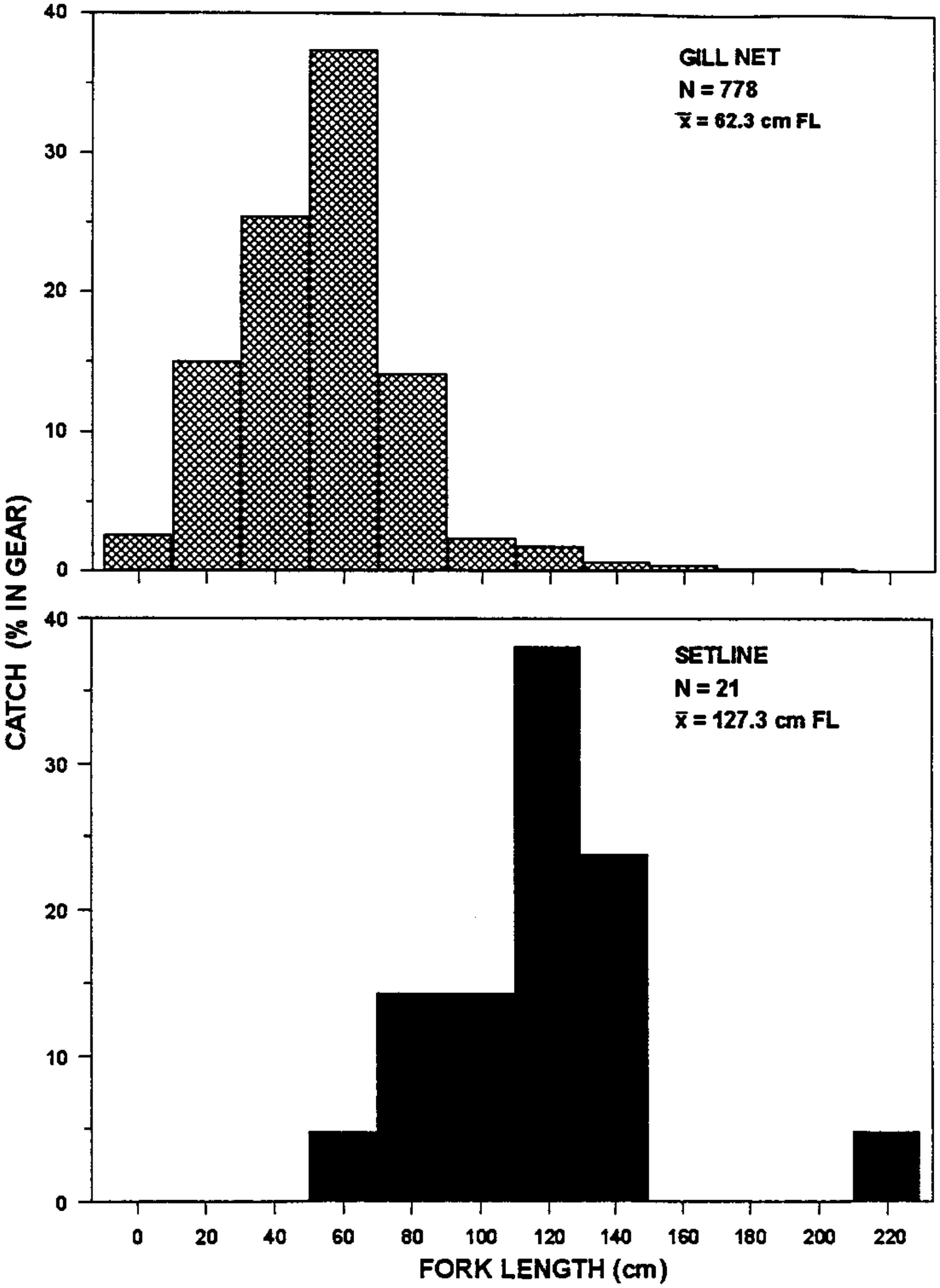


Figure 3. Observed length frequencies of white sturgeon collected with gill net and setline gears in Lower Granite Reservoir, Washington 1990-91.

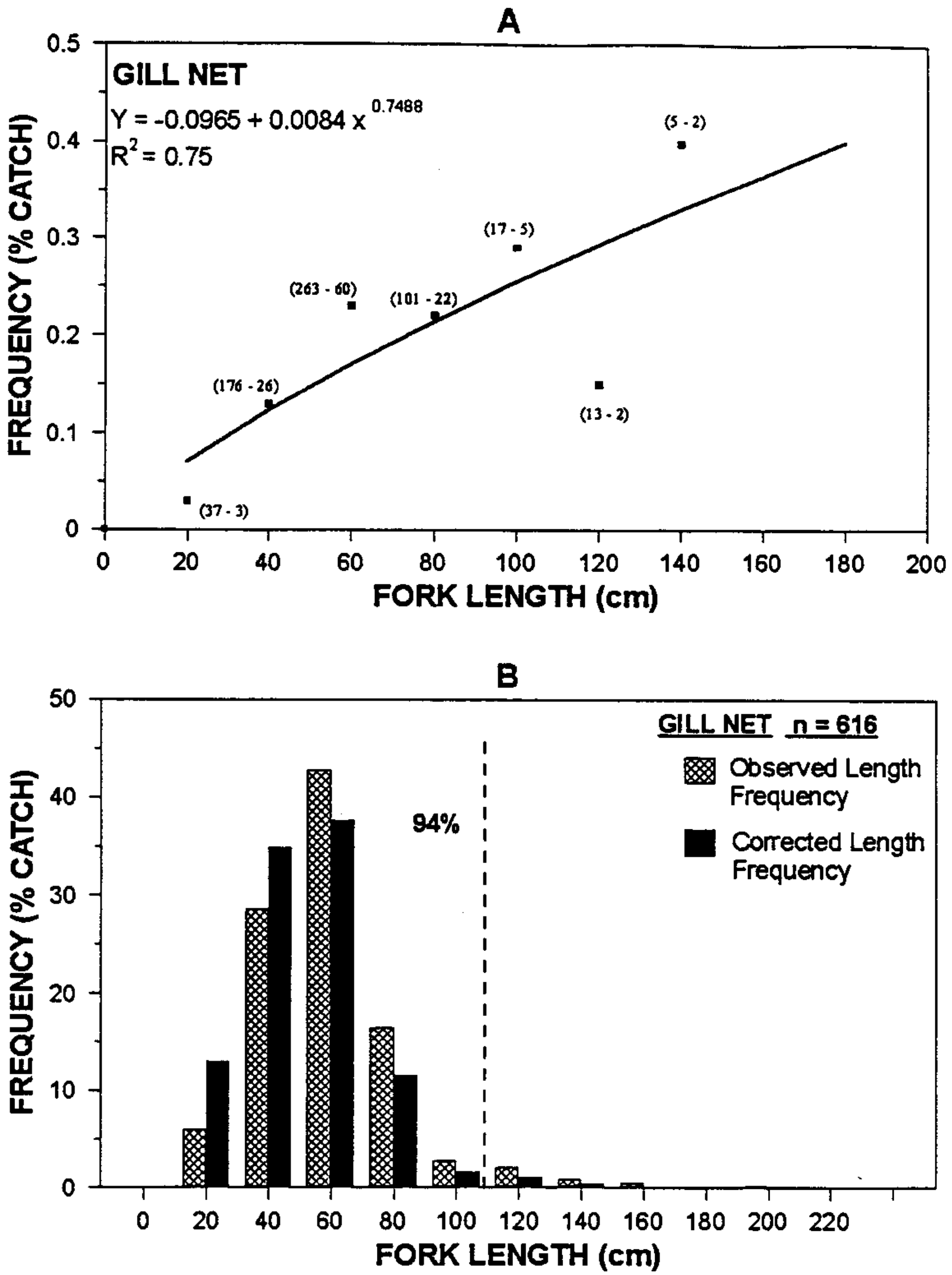


Figure 4. Recapture rate a) and corrected length frequency b) for white sturgeon captured with gill nets in Lower Granite Reservoir, Washington 1990-91.

Table 2. Gill net recapture rate of white sturgeon sampled by length interval in Lower Granite Reservoir, Washington 1990-1991.

Fork Length (cm)	Marks at Large	Recaptured Marks	Recapture Rate
20	37	1	0.03
40	176	22	0.13
60	263	60	0.23
80	101	22	0.22
100	17	5	0.29
120	13	2	0.15
140	5	2	0.40
160	12	0	0.00
180	0	0	0.00
200	1	0	0.00

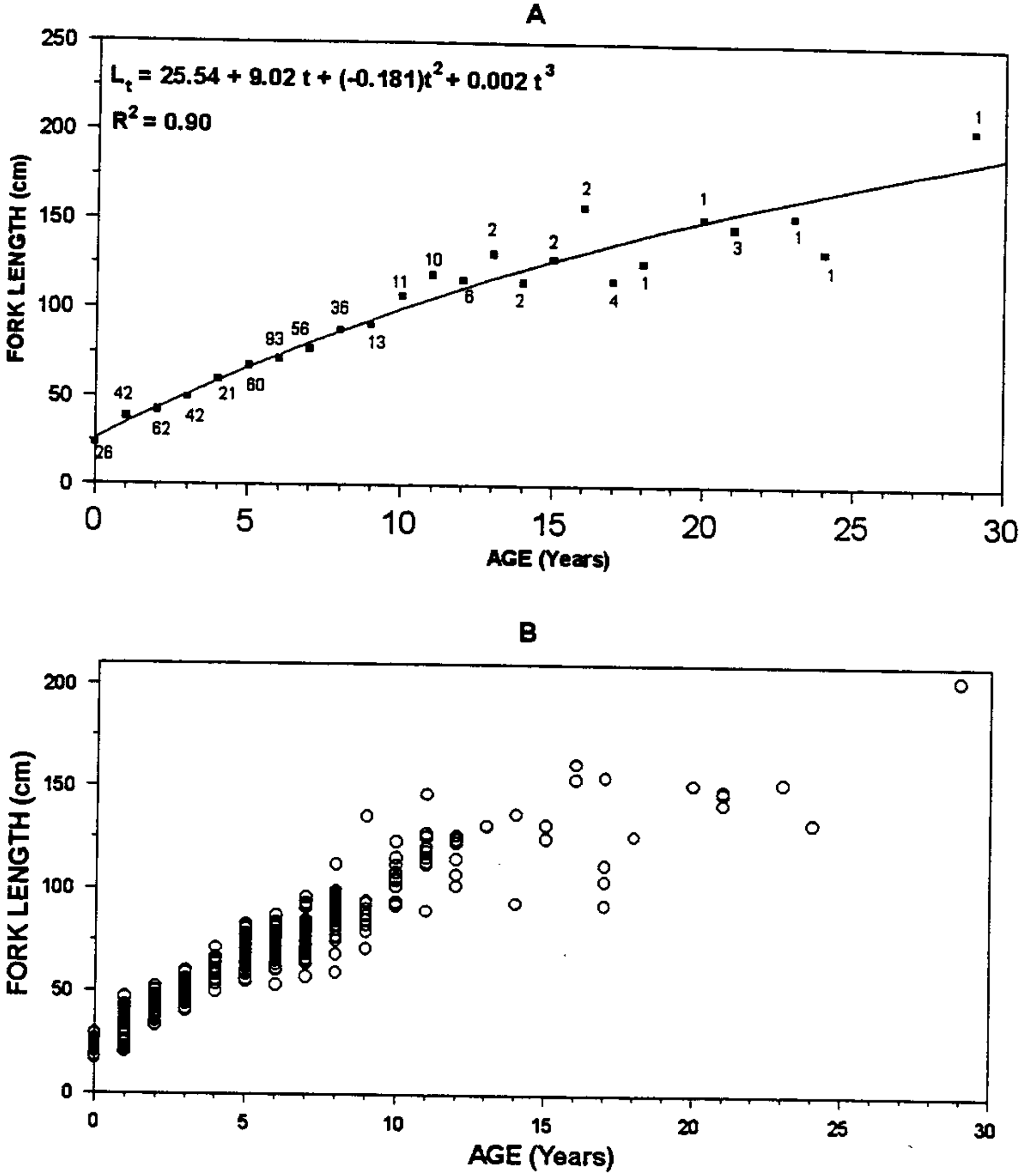


Figure 6. Mean fork length at age data and polynomial growth function a) and length at age data b) for white sturgeon sampled in Lower Granite Reservoir, Washington 1990-91.

The maximum length for fish between ages 8 and 9 increased 23.2 cm FL while the mean increased only 3.2 cm FL indicating increased growth for some individuals beginning at age 8. The difference in mean length at age was greatest between 16 and 17 years (41.4 cm FL).

Paired length and weight measurements were obtained from 733 white sturgeon with lengths ranging from 12 to 161 cm FL and weights from 0.005 to 37 kg. The length-weight relationship was fitted to the allometric function: ($r^2 = 0.97$; $W = 5.3\ E\text{-}06 * L^{3.0838}$ (Figure 7a). Mean relative weight (W_r) of white sturgeon >60 cm FL was 103 (Figure 7b).

Mortality - Total instantaneous mortality (Z) rates varied widely from 0.65 ± 0.12 (ages 6-9) during 1990 and 0.41 ± 0.20 (ages 7-11) for 1991 (Figure 8). Rate estimates adjusted for gear selectivity were Z = 0.70 ± 0.10; A = 0.50; S = 0.50 in 1990 and Z = 0.73 ± 0.16; A = 0.52; S = 0.48 for 1991 (Figure 8). Estimates of mortality and survival rates were not computed for larger size sturgeon due to small sample sizes.

Distribution and Movement

White sturgeon abundance was not distributed uniformly throughout LGR. Approximately 56% (446) of white sturgeon sampled with gill nets were captured near the Port of Wilma and Red Wolf Crossing Bridge (RKm 215.6-221.1) coinciding with locations of highest catch-per-unit-effort CPUE (0.32 fish/hr; Figure 9a). Catch rates for white sturgeon decreased considerably with downstream sampling from RKm 215.6

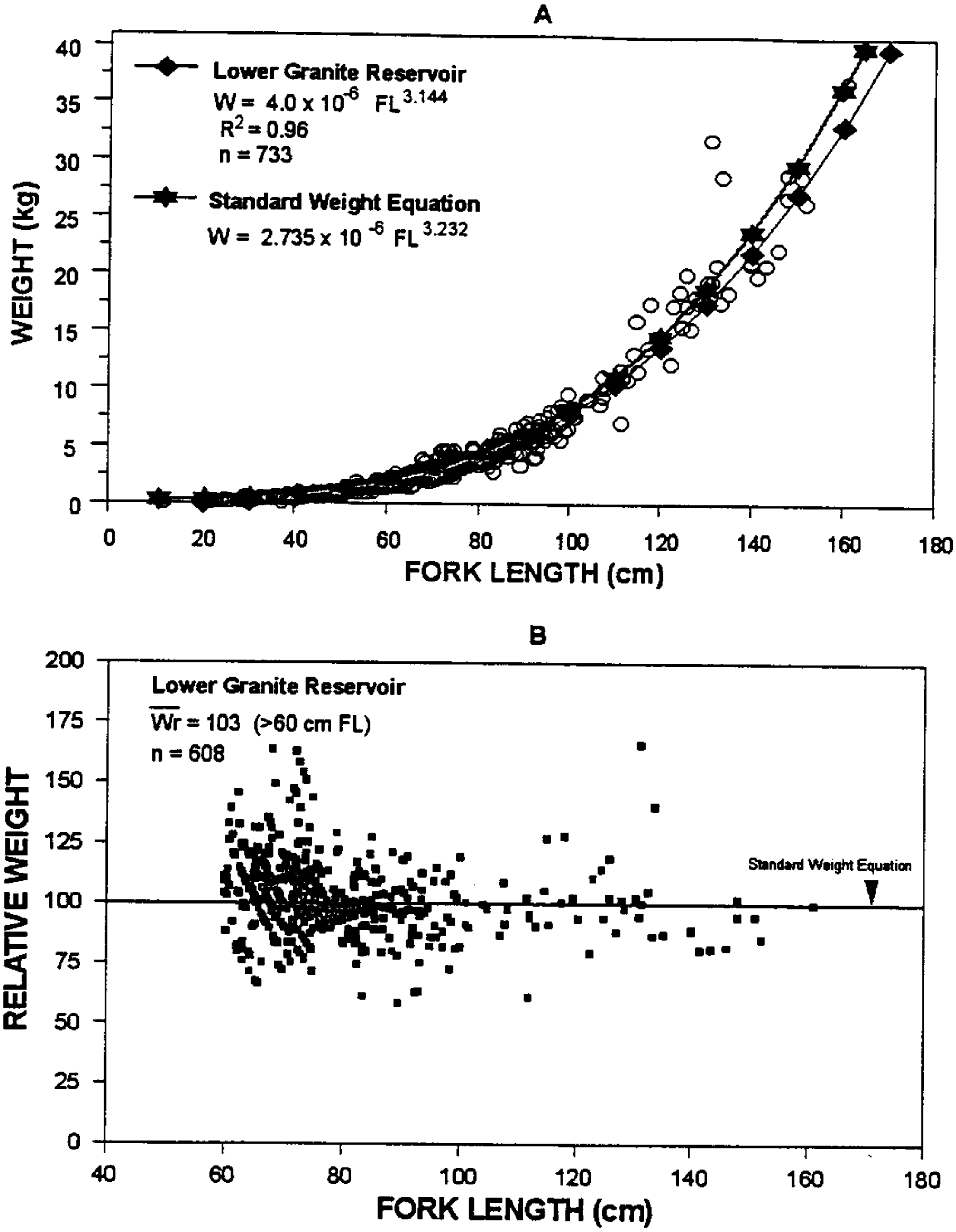


Figure 7. Length-weight relationships a) and mean relative weight b) of white sturgeon (>60 cm FL) sampled in Lower Granite Reservoir (LGR), Washington 1990-91. Length-weight regression for LGR based on white sturgeon >45 cm FL.

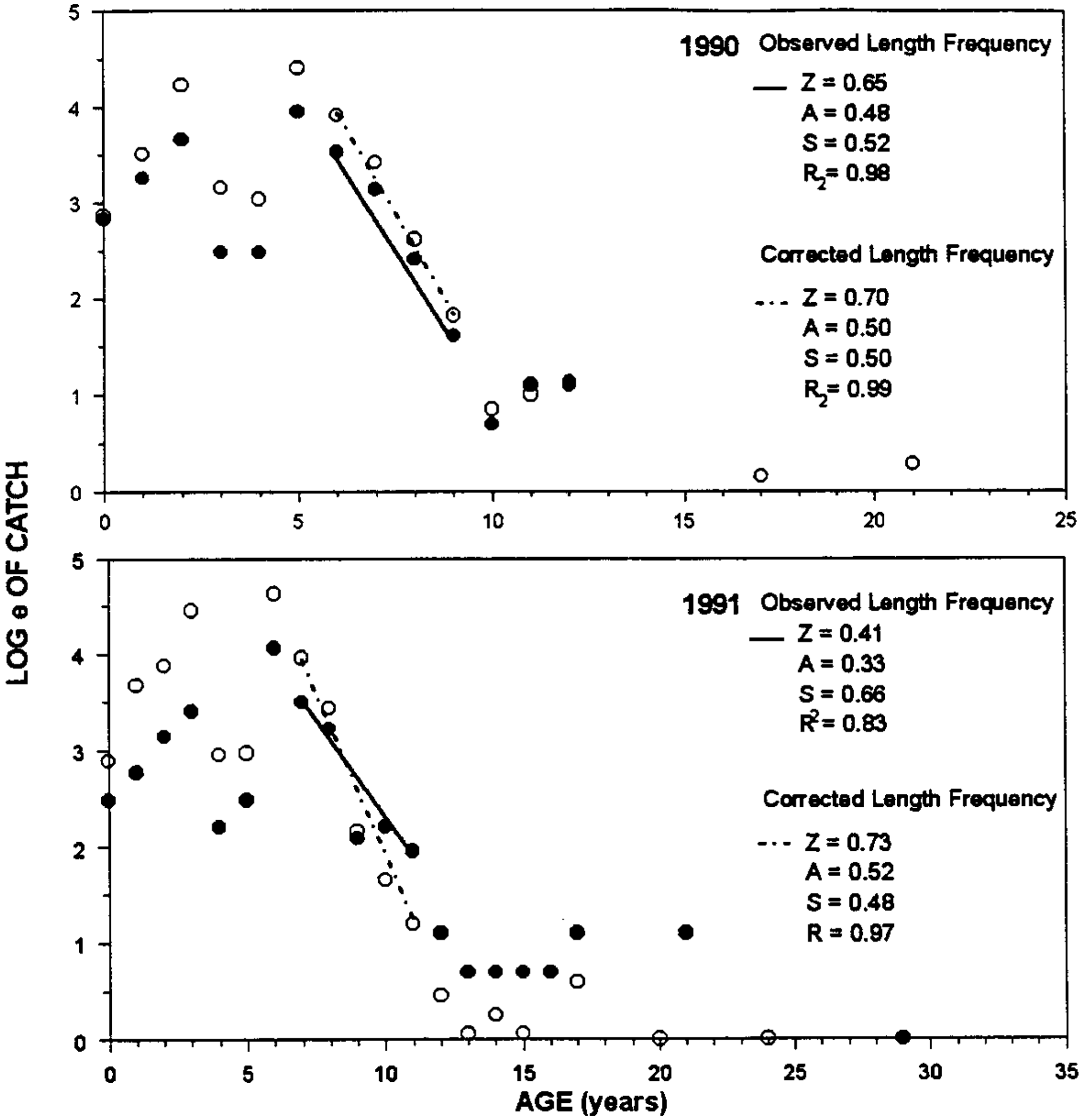


Figure 8. Catch curves for white sturgeon sampled with gill nets in Lower Granite Reservoir, Wa. Rate estimators (Z, A, S) for ages 6 - 9 (1990) and 7-11 (1991) are indicated for each regression.

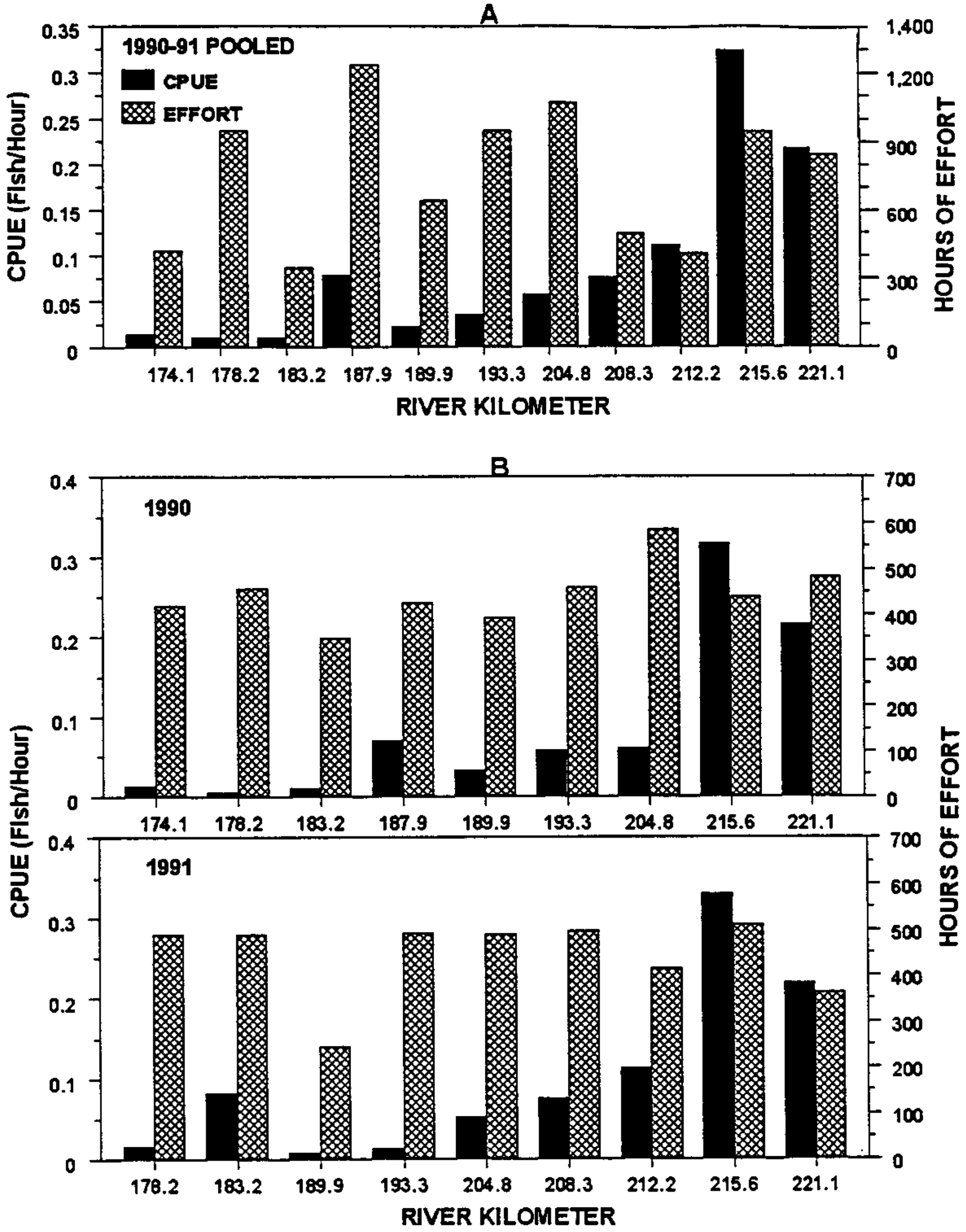


Figure 9. White sturgeon catch rates for 1990-91 a) and by year b) with gill net sampling in Lower Granite Reservoir, Washington.

Mistually Join/
Centennial Island

during both sample years (Figure 9b). Comparison of CPUE among transects determined catch rates at transects above RKm 204.8 statistically higher (P<0.001) than transects below RKm 204.8 with exception of RKm 187.9 (Figure 10). White sturgeon <35 cm FL were sampled primarily at transects upstream of RKm 212 ~~while fish~~ >35 cm FL fish were collected throughout LGR (Figure 11).

2,5 km upriver [illegible]

Seasonal changes in distribution occurred in LGR. Relative numbers of white sturgeon in the upper section of the reservoir increased from May through November implying upstream redistribution as the season progressed (Figure 12a). However, multiple comparison tests indicated seasonal use of mid and lower reservoir transects was not significant with exception to RKm 187.9. Number of white sturgeon sampled at RKm 187.9 was highest (0.31fish/hr) only during April-July 1991 and declined sharply as summer progressed (Figure 13a and 13b). Catch rates at RKm 187.9 in 1990 were low (Figure 13a) and are also similar in 1992 (David Bennett, University of Idaho, personal communication). Catch rates at remaining mid and lower reservoir locations were low regardless of season.

Movements from 0 to 25 river kilometers were observed from recaptured white sturgeon with the majority of fish travelling 1-5 river kilometers (Figure 12b). Differences in fish size did not appear to affect distance travelled in the reservoir (Figure 14). Sixty-five (44.2%) of the 147 recaptured white sturgeon moved upstream from their original release site while 29 (19.7%) travelled downstream. Seven fish were multi-directional in movement. The fastest movement recorded was 9.6 river kilometers in 3 days (Table 3). Approximately 65% of the fish recovered were collected within the

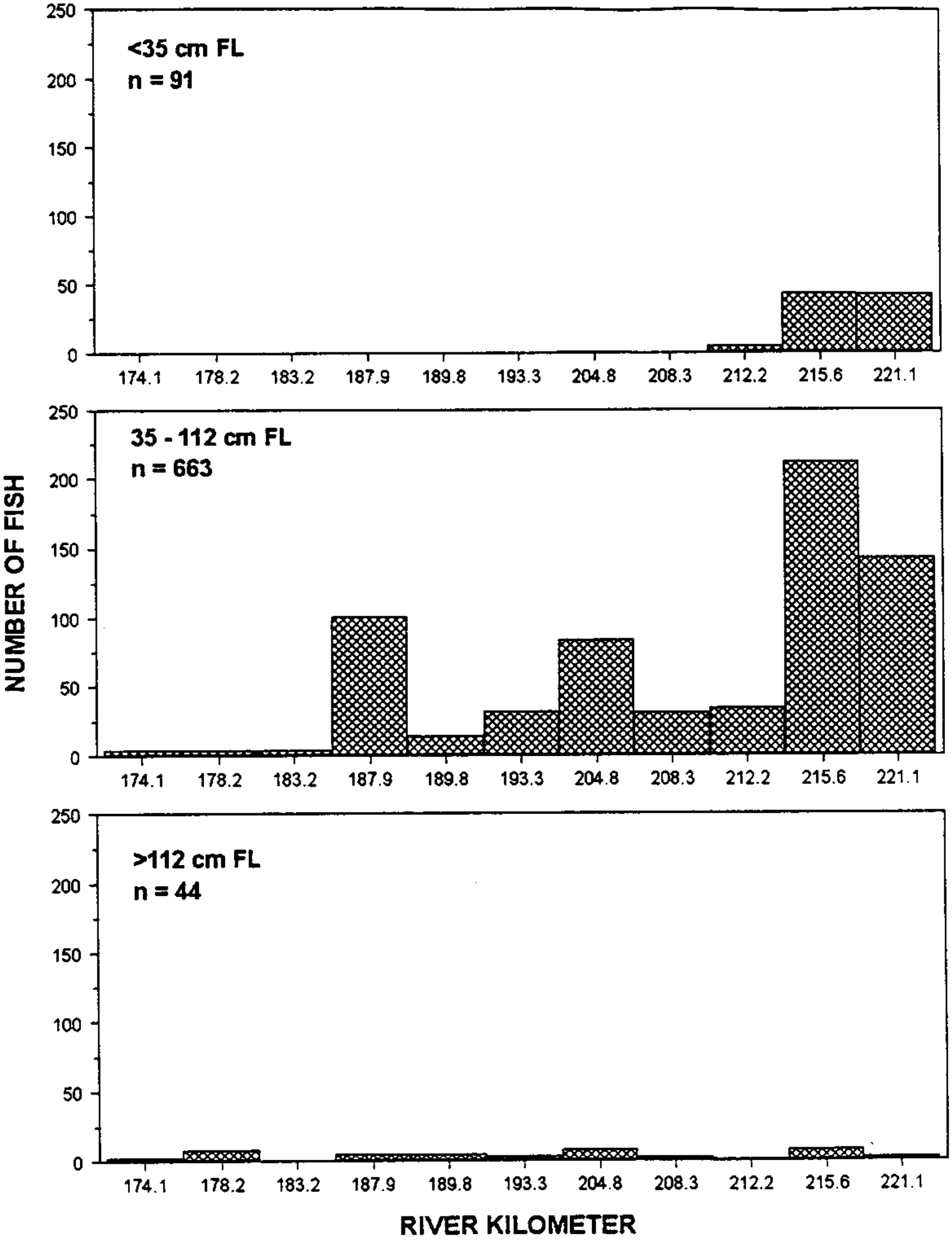


Figure 11. Location (RKm) and size of white sturgeon captured with gill net and setline data pooled in Lower Granite Reservoir, Washington 1990-91.

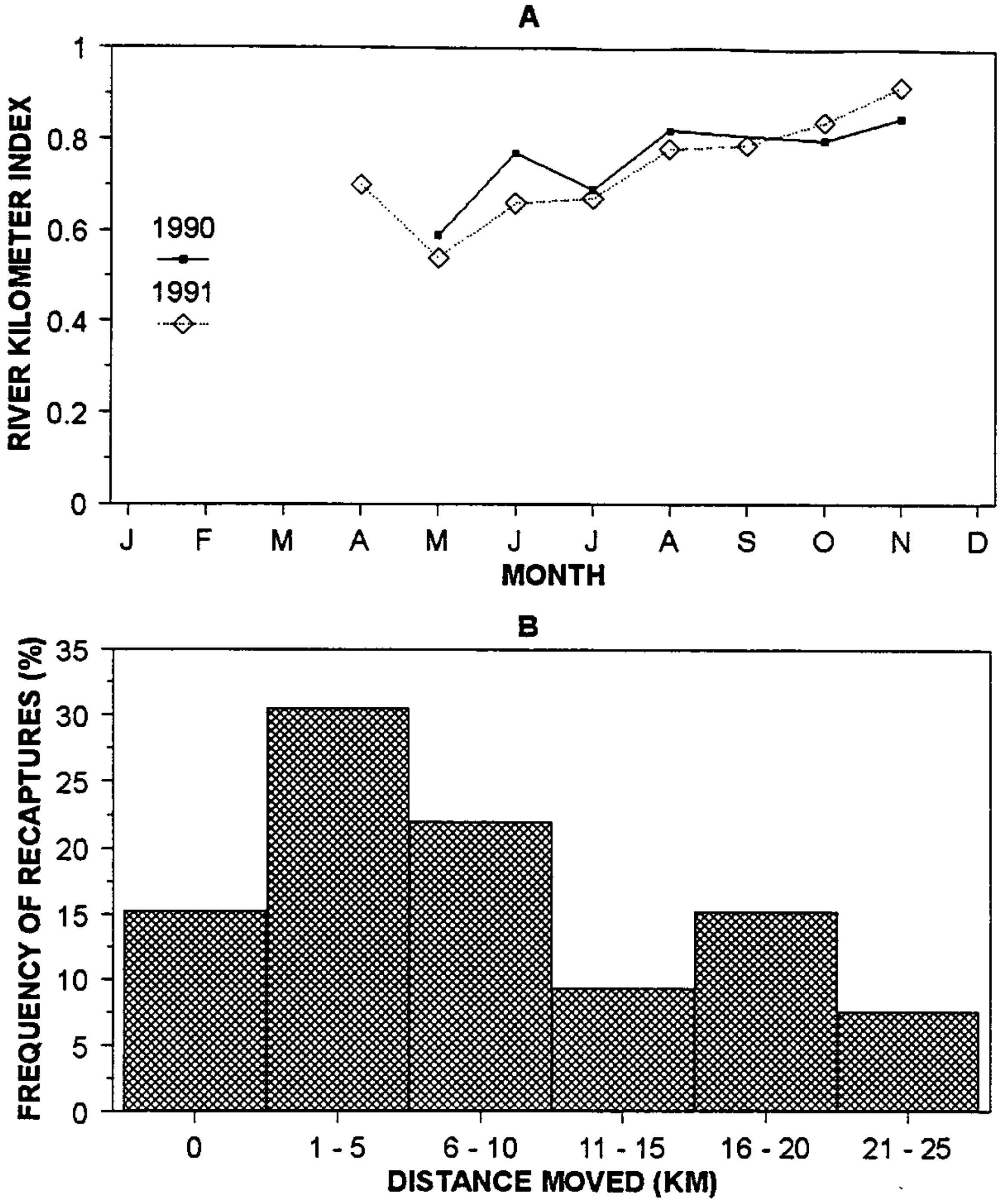
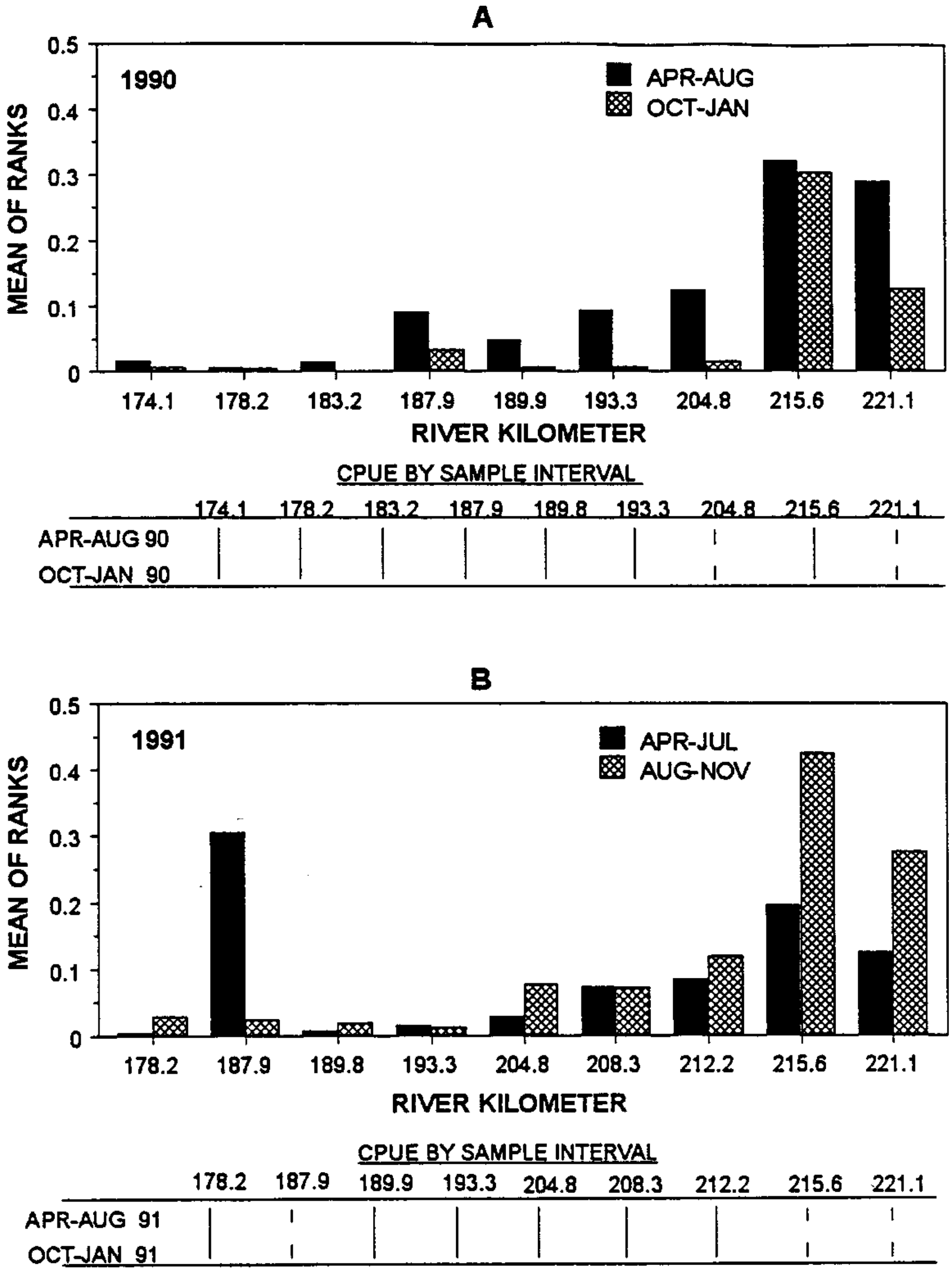


Figure 12. Index of white sturgeon distribution a) and distance travelled by recaptured white sturgeon b) in Lower Granite Reservoir, Washington 1990-91.



Knoxway

Figure 13. Comparison of seasonal catch rates in 1990 a) and 1991b) white sturgeon sample locations in Lower Granite Reservoir, Wa. Sample locations joined with a solid vertical line indicate no significant difference (P>0.05).

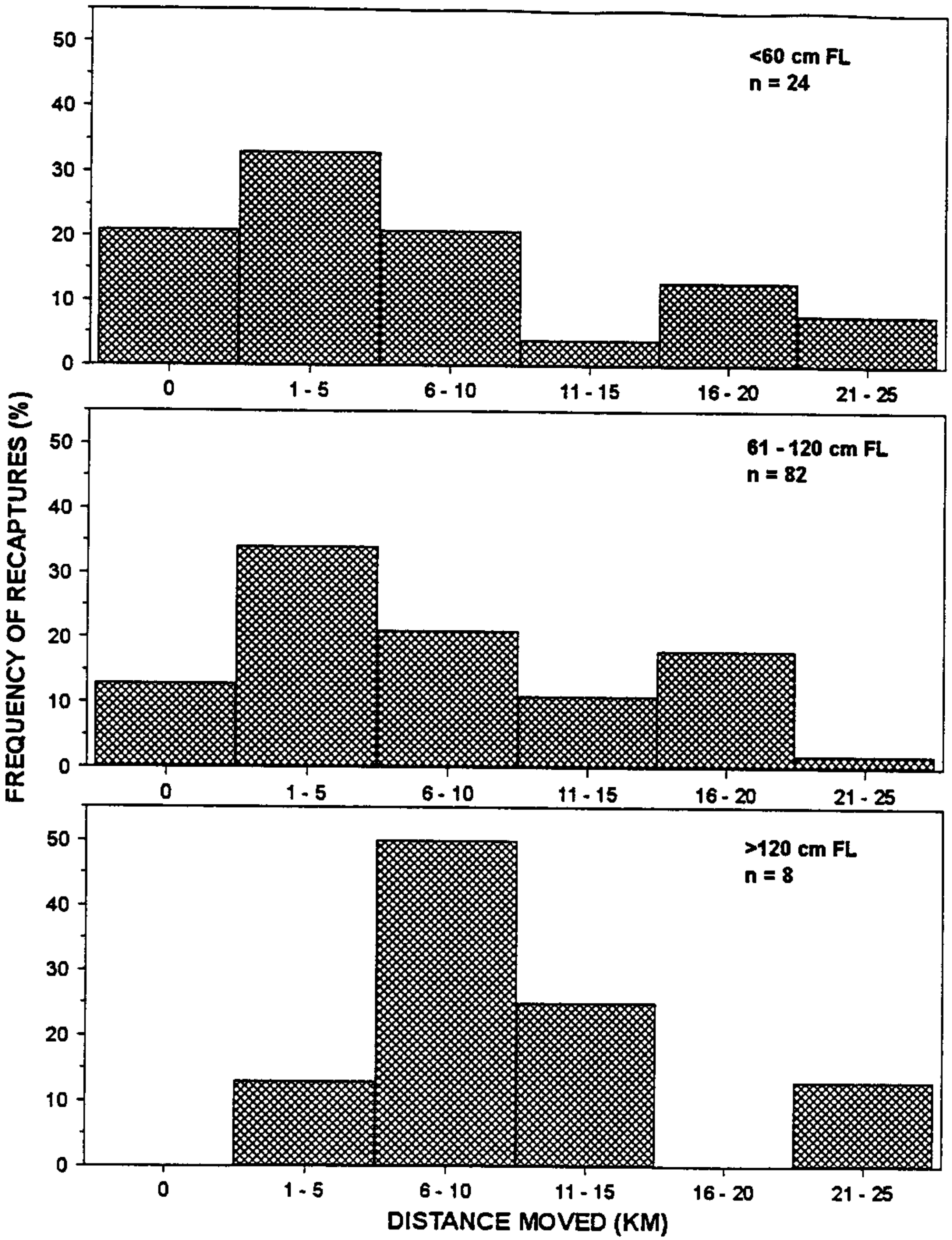


Figure 14. Frequency of white sturgeon recaptures by size and distance travelled in Lower Granite Reservoir, Washington 1990-91.

Table 3. Movement summary of recaptured white sturgeon in Lower Granite Reservoir, Washington 1990-91.

		DISTANCE (KM)		DAYS AT LARGE		
Movement	**Number**	**Mean**	**Range**	**Mean**	**Range**	**Mean Fork Length (cm)**
Downstream	29	12.1	0.9-33.2	210	3-494	81.7
Upstream	65	15.4	1.3-34.0	215	7-479	61.9
Multi-directional	7	25.6	6.7-38.5	301	127-439	7.45
None recorded	18	-	-	204	8-493	63.2

upper 10 river kilometers of LGR where densities of white sturgeon were highest.

DISCUSSION

Population Abundance

No prior estimates of white sturgeon abundance in LGR were available for comparison regarding long term changes in the reservoir's population. Recent (1992-93) monitoring of fish stocks in LGR by University of Idaho sampled 320 white sturgeon yielding an estimate of 1,804 (95% CI 816 - 7,219; Bennett et al. 1994). This estimate (1,804) is similar to mine (1,372) indicating abundance of white sturgeon in LGR has remained similar following my survey (1990-91).

Density of white sturgeon in LGR is also similar to densities reported above LGR from past surveys. Although direct comparisons were not possible, density of white sturgeon in LGR (28 fish/Rkm) was similar to 24 fish/RKm reported above LGR by Lukens (1985) but lower than estimates by Coon et al. (1977). Coon et al. (1977)

estimated white sturgeon densities ranged from 35 - 53 fish/RKm between Lower Granite and Hells Canyon dams while my estimate for LGR was 12 - 45 fish/Rkm (Table 4).

White sturgeon are generally considered less abundant in each upstream impoundment in the Columbia and Snake river system. Comparison of fish density in LGR with Columbia River impoundments concluded density of white sturgeon in LGR (0.38 fish/ha) was lower than reported in Bonneville (6.12 fish/ha) and The Dalles (2.51 fish/ha) reservoirs but slightly higher than John Day Reservoir (0.30 fish/ha; Beamesderfer and Rien 1992). The lower Columbia River below Bonneville Dam supported the highest density (14.6 fish/ha) of white sturgeon in the Pacific Northwest which was attributed to abundant food resources (DeVore et al. 1992; Table 4).

Population Structure

Size Distribution - Approximately 94% of the white sturgeon sampled in LGR were mainly of juvenile and young-of-the-year (YOY) fish indicating that mature adult white sturgeon (>125 cm TL) were not utilizing LGR with the same frequency as juveniles. Cochnauer (1983) determined white sturgeon >125 cm TL as mature. Recapture rates indicated vulnerability of white sturgeon to gill net sampling increased with size. Similarly, gill net sampling conducted in the Bliss-C.J. Strike Reach of the middle Snake River with similar mesh sizes (2.54-10.1 cm) were able to recruit large sturgeon (Lepla and Chandler, unpublished data). Gear selectivity evaluated by Elliott and Beamesderfer (1990) determined white sturgeon >90 cm FL fully recruited to setline gear. However, number of white sturgeon >90 cm FL sampled with setline or gill net

Table 4. Comparison of density estimates for white sturgeon sampled in Snake and Columbia river impoundments.

Year	Citation	Location	No. collected	FL (cm)	$\hat{N}$	Density
Snake River						
1972-75	Coon et al. (1977)	Lower Granite to Hells Canyon dams	881	>46[a]	- 8,000 - 12,000	- 35 fish/RKm
1979-81	Cochnauer (1983)	Bliss to C.J. Strike dams	905	>60	2,192 (1479 - 4276)	- 21 fish/RKm
1982-83	Lukens (1984)	Hells Canyon Dam to Lewiston, ID	331	>45	4,275 (-)	- 24 fish/RKm
1990-91	Author	Lower Granite Reservoir	946	>40	1,372 (578 - 2166)	0.38 fish/ha 28 fish/RKm
Columbia River						
1990	Beamesderfer and Rien 1993	John Day Reservoir	51,400	70-166	3,900 (2,300-6,100)	0.30 fish/ha
1988	Beamesderfer and Rien 1993	The Dalles Reservoir	11,300	70-166	9,000 (7,300-11,000)	2.51 fish/ha
1989	Beamesderfer and Rien 1993	Bonneville Reservoir	6,300	70-166	35,400 (27,000-45,400)	6.12 fish/ha

[a] cm TL

gear in LGR were few.

Presence of YOY and high abundance of juvenile white sturgeon in LGR indicated recruitment has been occurring in the Lower Granite-Hells Canyon population. The high abundance of juvenile and YOY fish near the upper end of LGR also suggests that the reservoir primarily serves as rearing habitat. Lukens (1985) speculated the upper pool of LGR served as rearing areas for juvenile white sturgeon which my data corroborates. Presence of YOY during 1990-91 fall sampling in LGR not only indicated recent spawning but suggested some downstream drift to the reservoir. Frequency of spawning above the reservoir and distance larvae disperse from these areas remains unknown. McCabe and Tracy (1993) suggested wide dispersal of white sturgeon larvae allowed more use of feeding and rearing habitats while minimizing competition. I have assumed no spawning occurred in LGR since velocities measured in the reservoir (0.0-0.60 m/sec) are below threshold levels perceived to elicit spawning (1.0 m/sec; Anders and Beckman 1993).

Age and Growth - Mean length at age has increased significantly for white sturgeon since previous surveys in the Lower Granite - Hells Canyon Reach. Mean lengths of white sturgeon for ages 5-18 in LGR were longer than lengths of similarly aged fish during 1972-75 (Coon et al. 1977) and 1982-83 data (Lukens 1984). Mean lengths from fish aged during the earlier studies were outside confidence limits (95%) encompassing length at age data for 1990-91 (Figure 15a). This increase in growth over past surveys in the Lower Granite-Hells Canyon Reach may in part be related to sampling a juvenile population from an impoundment. White sturgeon from 1972-75 and 1982-83

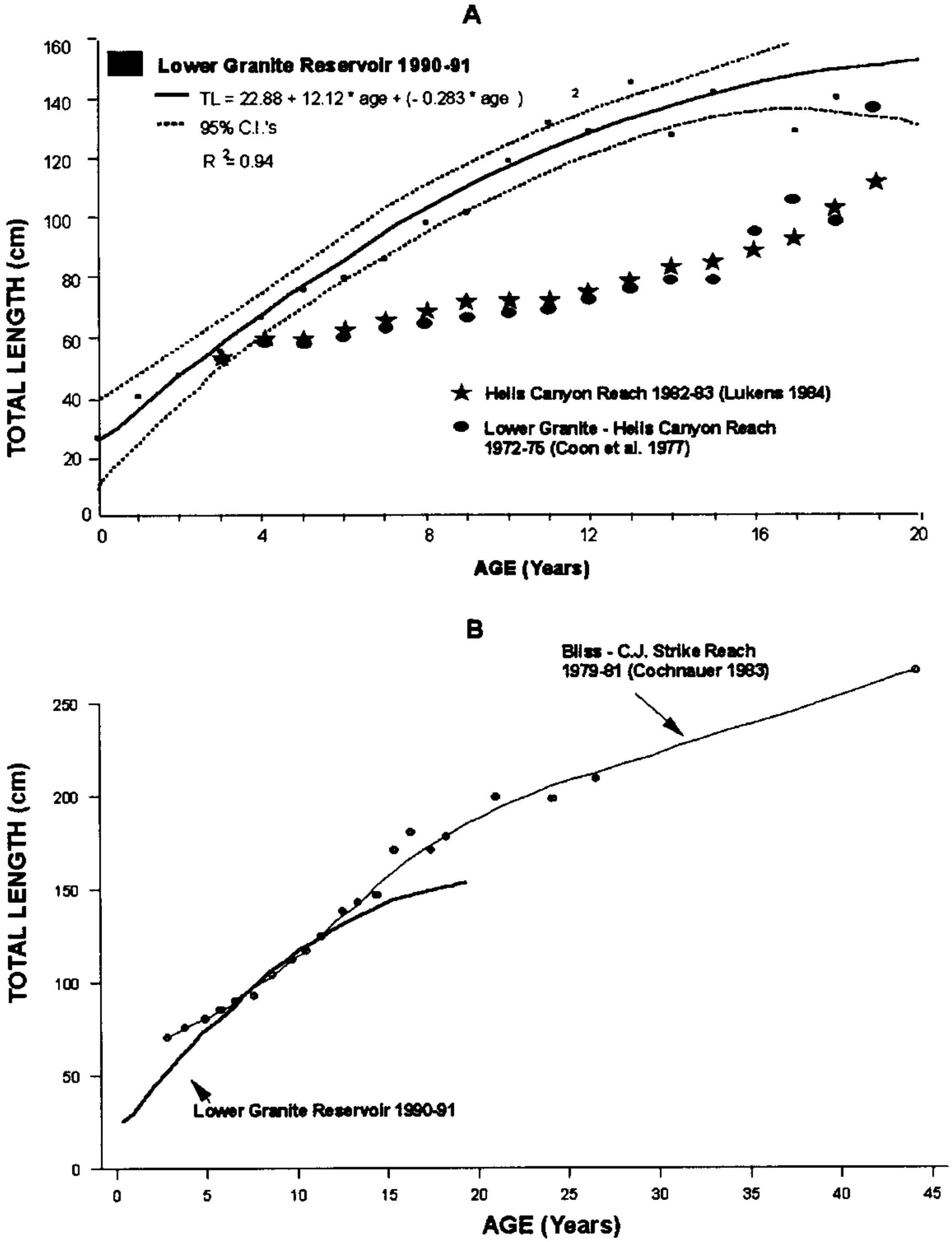


Figure 15. Comparison of mean total length at age for white sturgeon in a) Lower Granite Reservoir (LGR) 1990-91, 1972-75 (Coon et al. 1977), 1982-83 (Lukens 1984) and b) Bliss-C.J. Strike Reach 1979-81 (Cochnauer 1983).

surveys were primarily sampled in riverine sections above LGR which may have accounted for the slower growth rates. Miller and Beckman (1992) reported faster growth of juvenile white sturgeon in the Columbia River occurred in impoundments rather than the lower Columbia River, suggesting this faster growth was related to increased food availability. less prey diversity → only 2 3 spp, but sign. higher abundance of those preferred/catchable incr w/↑ reservoir ageing

Comparison of length at age data with white sturgeon in the Bliss-C.J. Strike Reach of the middle Snake River indicated growth was similar for ages 4-14 (Figure 15b). Growth rates in the C.J. Strike Reach appeared higher than in LGR for ages <3 and >14. Cochnauer (1983) reported white sturgeon in the middle Snake River exhibited higher growth rates due to warmer waters. w/ Dworsh + HC augm. LSR cooler w/ lower # suitable degree days for growth [illegible]

Comparison of mean lengths of juvenile white sturgeon from LGR and Columbia [illegible] River impoundments (Miller and Beckman 1992) indicated mean lengths were longer in LGR (Figure 16). Higher growth rates for Snake River white sturgeon relative to Columbia River populations may result from warmer waters, lower densities and less competition for food resources. Similar studies comparing Columbia River impoundments and the lower Columbia River determined juvenile white sturgeon from Columbia River impoundments had greater length-at-age and condition than fish from the lower Columbia River citing increased food availability and lower densities (Miller and Beckman 1992).

In addition, length-at-age data estimated from pectoral fin-rays must be interpreted with caution. Rien and Beamesderfer (1993) concluded estimating ages of adult white sturgeon from pectoral fin-rays is neither precise nor accurate and often underestimate the true age of adult fish. Age interpretations can be biased when annuli fail to form which

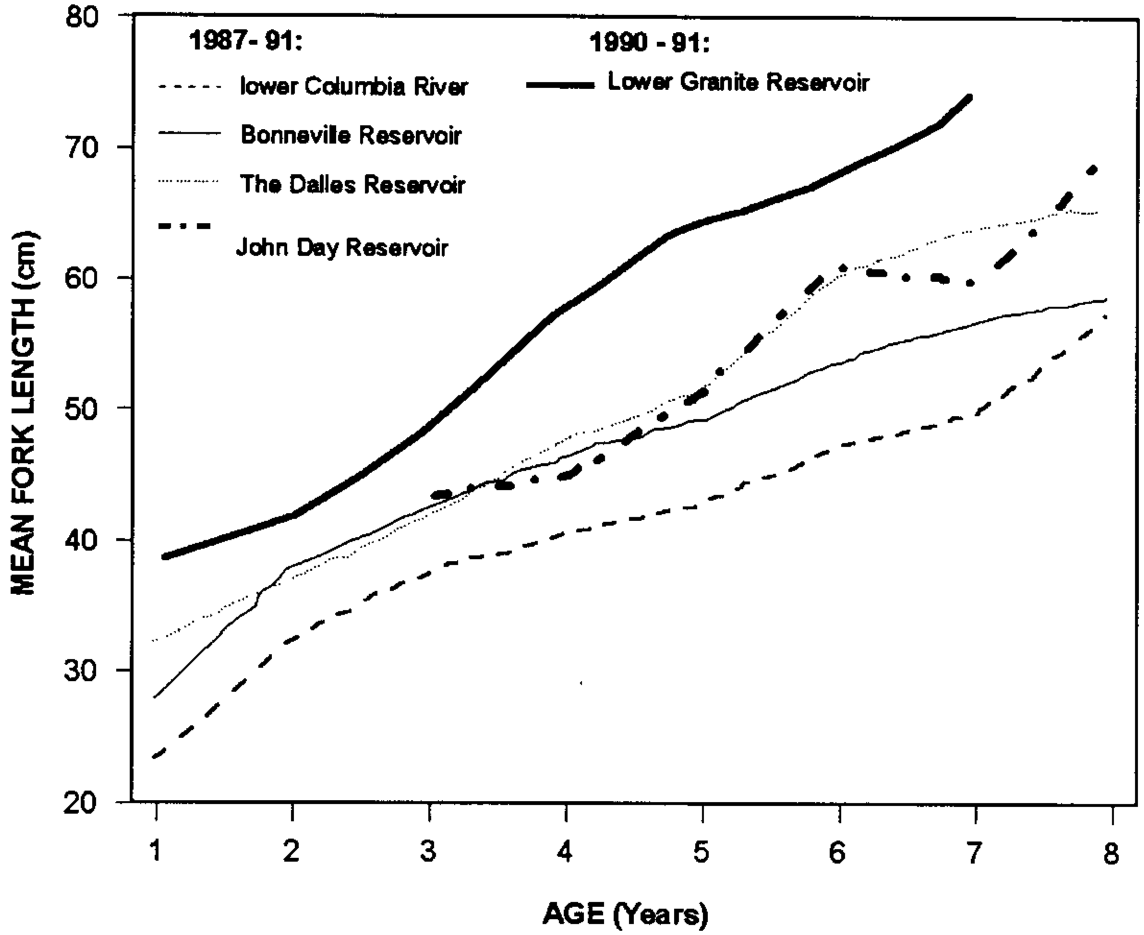


Figure 16. Mean fork length of 1-8 year old white sturgeon in Columbia River, 1987-91 (Miller and Beckman 1992). Mean fork length of similar aged white sturgeon (1-8) in Lower Granite Reservoir computed for comparison.

potentially occurs more often in impounded populations. Annulus formation appears more consistent in sturgeon populations with access to marine environments than impounded populations (Devore et al. 1992). This supports Coon et al. (1997) who found that visible annuli were not deposited each year for Snake River white sturgeon. However, it appears that aging juveniles white sturgeon may be easier and more accurate than for adults. Miller and Beckman (1992) reported higher agreement (64%) for aging juvenile white sturgeon, similar to fish aged in LGR, than aging of other white sturgeon studies with older fish (17-37%; Rien and Beamesderfer 1992, Brennan and Cailliet 1989, and Kohlhorst et al. 1980).

Low frequency of white sturgeon from the 1986-87 year-classes suggested potential low recruitment to the population during those years. Year-class failures have been observed in white sturgeon populations (Miller and Beckman 1992) with implications that the environment affects white sturgeon reproduction more than stock-recruitment relations during some years and in some areas (Parsley et al. 1992) which lends support to environmental perturbations influencing white sturgeon recruitment in the Snake River, Idaho since harvest was prohibited following 1970. Numerous environmental conditions can potentially impact white sturgeon recruitment over several years and life stages with water flows receiving recent attention. Spring flows in the Hells Canyon Reach associated with 1986-87 year-classes were relatively high compared to the following lower water years associated with the onset of the drought in the middle Snake River Basin (Figure 17). Suction dredging conducted near the Port of Wilma during 1987 may have also contributed to mortality of y-o-y and juvenile white sturgeon

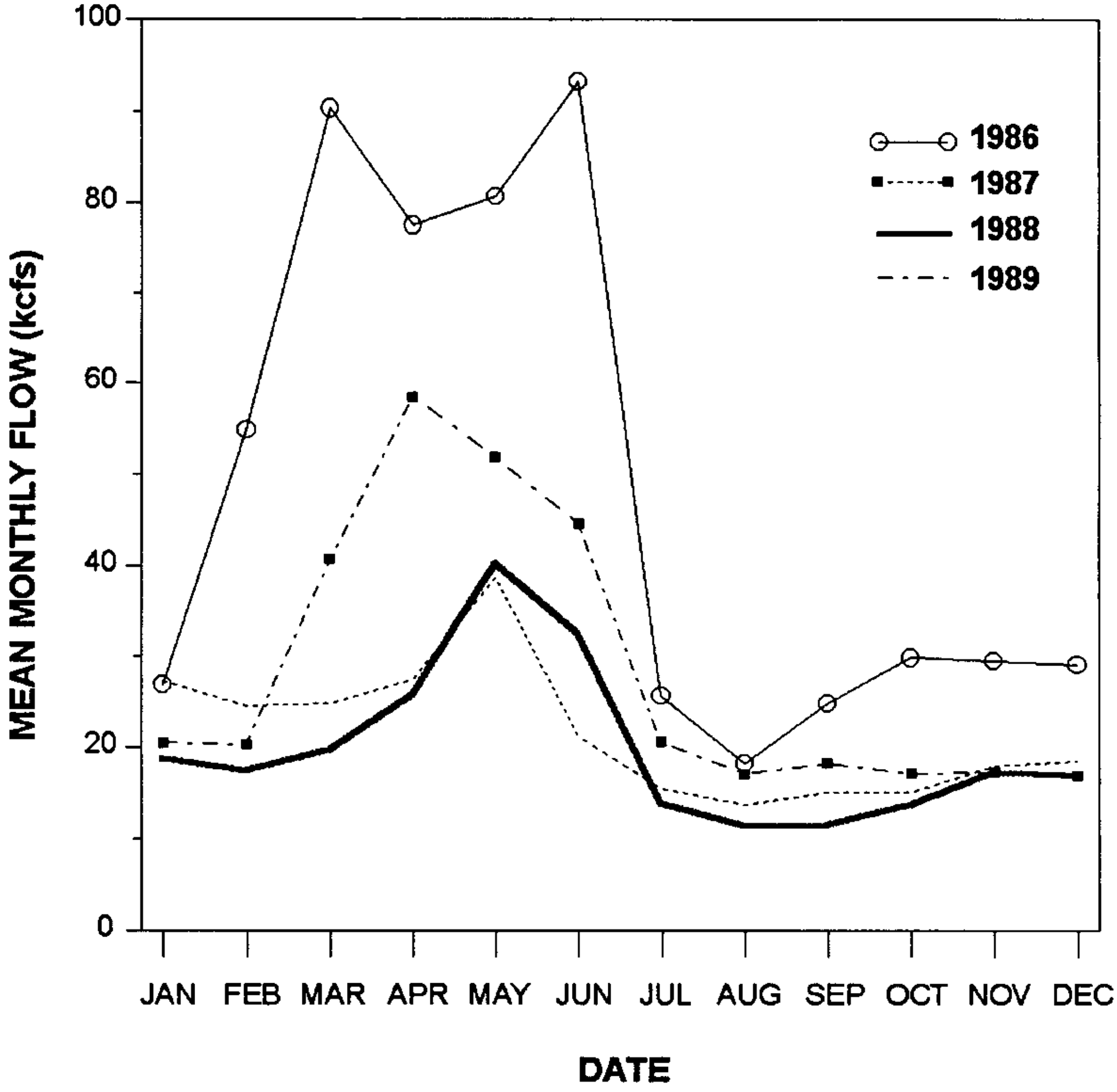


Figure 17. Mean monthly flow recorded on the Snake River from USGS gauging station 13334300 (RKm 269.0) located near Anatone, Washington.

rearing in this area. Buell (1992) reported suction dredging in the Columbia River seriously injured and killed juvenile white sturgeon and speculated that dredging operations attracted feeding white sturgeon which compounded mortality.

Comparison of length-weight relationships (Figure 18a) and relative weight indices (Table 5) from the Lower Granite - Hells Canyon reach indicated fish condition has continued to improve since previous studies conducted in 1972-75 (Coon et al. 1977) and 1982-83 (Lukens 1984). The mean relative weight indice (103; Table 5) and confidence limits (95%) derived from the LGR length-weight regression encompassed the standard weight W_s function indicating fish condition in LGR was equivalent to the condition expected in an average white sturgeon population (18b).

Relative weight of white sturgeon in LGR (103) was higher than condition reported in the Bliss - C.J. Strike Reach of the middle Snake River (83) but lower than populations in the lower Columbia River (117; Table 5). Devore et al. (1992) attributed higher growth rates and condition factor of lower Colombia River white sturgeon to abundant marine-based food resources. A declining Kootenai River sturgeon population in northern Idaho had the lowest observed mean relative weight (77; Table 5).

Mortality - Mortality rates based on observed age data varied widely between 1990-91. Adjusted mortality rates Z (0.70 -0.73) and A (0.50 - 0.52) were above upper limits reported for other white sturgeon populations (Z = 0.06 - 0.53 and A = 0.06 - 0.41; Semakula 1963; Kohlhorst 1980; Cochnauer 1983; Lukens 1985; Kohlhorst et al 1989; Devore et al. 1992; Beamesderfer and Rien 1992). These rates may indicate high juvenile mortality in LGR or rather sampling an open population where marked fish

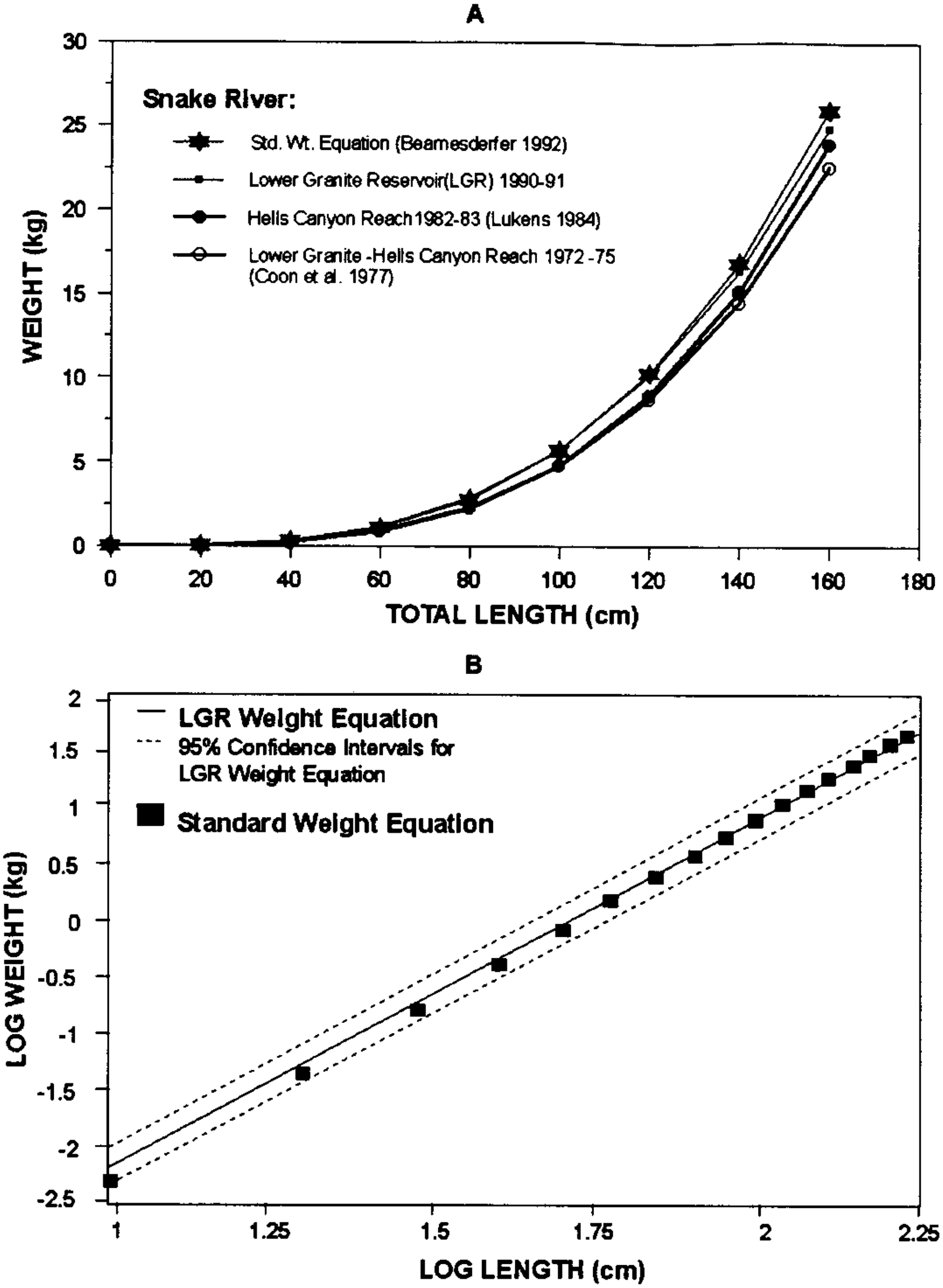


Figure 18. Length-weight relationships a) for white sturgeon captured in the Snake River and comparison log length-weight and standard weight equations b) for white sturgeon sampled in Lower Granite Reservoir 1990-91.

Table 5. Intercept (α), slope (β), and correlation coefficient for regression[a] of weight (kg, dependent variable) on total length (cm) and mean relative weight (W_r) for 15 white sturgeon samples, (sensu Beamesderfer 1993). W_r for white sturgeon captured in Lower Granite Reservoir was computed for comparison.

River	N	Lengths	α	β	r	W_r	Reference
Lower Granite Res. (1990-91)	651	45-189	3.3E-06	3.12	0.98	103	Author
Snake River							
Upper	560	46-270	3.00E-07	3.612	--	91	Cochnauer 1983
Middle (1972-75)	602	45-274	1.14E-06	3.31	--	83	Lukens 1985
Middle (1982-84)	478	45-280	6.50E-07	3.43	--	83	Lukens 1985
Sacramento-San Joaquin							
Delta (1965-70)	209	102-203	1.18E-06	3.348	0.954	103	Kohlhorst et al. 1980
Delta (1984-85)	124	31-224	2.19E-06	3.189	0.922	92	Brennan 1987
Columbia River							
Lower [b]	5,338	37-263	7.66E-06	2.958	0.961	117	Tracy, unpublished
Bonneville Res. (1976-78[b])	2,516	34-269	1.63E-06	3.277	0.990	103	Malm 1979
Bonneville Res. (1986-90)	2,405	31-292	2.65E-06	3.161	0.979	99	Beamesderfer, unpublished
The Dalles Res.	2,850	35-276	9.70E-07	3.376	0.984	96	Beamesderfer, unpublished
John Day Res.	1,024	32-254	1.81E-06	3.249	0.991	100	Beamesderfer, unpublished
Kootenai River							
(1980-82)	341	50-244	1.66E-06	3.26	0.990	97	Partridge 1983
(1989-92)	223	88-211	7.13E-07	3.394	0.917	77	Apperson, unpublished
Frazer River							
Lower (males)[b]	--	--	2.87E-06	3.13	--	93	Semakula and Larkin 1968
Lower (females)[b]	--	--	2.64E-06	3.15	--	94	Semakula and Larkin 1968
Upper	65	73-249	5.97E-07	3.444	0.999	82	Dixon 1986

[b] = Converted from fork length using TL=FL*1.110

emigrating from the reservoir would inflate mortality rate estimates. High mortality is unlikely based on the relative condition of fish (103) in LGR. Harvest and fishing mortality was assumed very low since 97% of the catch was outside the slot limit (122-152 cm TL) and few sturgeon anglers were encountered during my study in LGR. However, highest abundance and catch rates (0.32 fish/hour) were sampled near the upper boundary of my study area, therefore without adjusting for emigration and recruitment to the reservoir, accurate rates cannot be determined.

Distribution and Movement

Distribution of white sturgeon in LGR was similar to three lower mainstem Columbia River impoundments. North et al. (1992) reported white sturgeon densities were highest in the tailraces of Bonneville,The Dalles and John Day dams and declined downstream from each dam as conditions became less riverine. Similarly, white sturgeon densities were highest near the upper section of LGR and decreased progressively with downstream sampling into the pool. White sturgeon are not restricted to LGR and therefore densities may increase above my study area. Coon et al. (1977) estimated white sturgeon densities ranged from 35 - 53 fish/RKm between Lower Granite and Hells Canyon dams while my estimate for LGR was 12 - 45 fish/RKm (Table 4).

Seasonal movement within LGR did not appear significant when comparing catch rates at sample locations however significant seasonal exchange between LGR and the free-flowing river above the reservoir is plausible. White sturgeon evolved in a riverine environment and have adopted a nomadic life history strategy in response to dynamic seasonal changes in habitat and prey abundance (Bajkov 1951). This exchange between the upper section of the reservoir and riverine environment would be difficult to detect since my study area ended near the upstream end of the reservoir.

SUMMARY

1. A total of 946 white sturgeon were sampled with 9,951 gill net and 6,755 setline hours of effort in LGR 1990-91. Abundance of white sturgeon (>40 cm FL) was estimated at 1,372 (95% CI 578-2,166) with an average density of 0.38 fish/ha.

2. Density of white sturgeon in LGR (0.38 fish/ha; 28 fish/RKm) was similar to 24 fish/RKm reported above LGR by Lukens (1984) but lower than estimates by Coon et al. (1977; 35-53 fish/RKm). Density of fish in LGR was slightly higher than John Day (0.30 fish/ha) but substantially lower than Bonneville (6.12 fish/ha) and The Dalles (2.51 fish/ha) reservoirs.

3. Approximately 94% of white sturgeon sampled were <125 cm TL (112 cm FL) indicating a primarily juvenile population residing in LGR.

4. White sturgeon were aged from 0-29 years with juvenile fish (0-8) comprising 84% of the entire sample. Fish from 1986-87 indicated weak year-classes. Length at age data indicated growth was relatively consistent up to age 8 with increasing

variation in lengths occurring ≥8. Difference in mean length at age was greatest between 9 and 10 years (15.7 cm FL). Mean length at age has increased significantly for white sturgeon since previous surveys in the Lower Granite - Hells Canyon Reach.

5. Paired length and weight measurements from 733 white sturgeon ranged from 12-161 cm FL and weights from 0.005-37 kg. Mean relative weight (W_r) of white sturgeon >60 cm FL was 103. Comparison of length-weight relationships and relative weight indices indicated fish condition in LGR has improved since previous studies conducted in the Lower Granite - Hells Canyon Reach (Coon et al. 1977; Lukens 1984).

6. Mortality rates adjusted for gear selectivity were $Z = 0.70 \pm 0.10$; $A = 0.50$; $S = 0.50$ in 1990 and $Z = 0.73 \pm 0.16$; $A = 0.52$; $S = 0.48$ for 1991. Mortality rates based on observed age data varied widely between 1990-91 which probably was a result of sampling an open population.

7. White sturgeon abundance was not distributed uniformly in LGR with 56% (446) of the fish sampled near the Port of Wilma and Red Wolf Crossing Bridge (RKm 215.6-221.1). Catch rates for white sturgeon decreased considerably with downstream sampling from RKm 215.6 during both 1990-91.

8. Multiple comparison tests indicated seasonal use of mid and lower reservoir transects was not significant. Differences in fish size did not appear to affect distance travelled in the reservoir.

CHAPTER 2. Habitat Use by White Sturgeon in Lower Granite Reservoir

INTRODUCTION

Development and operation of the Columbia and Snake river hydrosystems have severely altered the natural riverine habitat by modifying historic flow regimes, temperature, dissolved oxygen and accessible food supplies (Coon et al. 1977; Haynes et al. 1978; Lukens 1981; Ebel et al. 1989; Parsley and Beckman 1992). The watershed has further been impacted by logging, agriculture, mining, stream channelization, water pollution and harvest allowing some species of fish to flourish while others decline.

Historically, diadromus white sturgeon in the Columbia and Snake river system ranged freely and made extensive seasonal migrations to optimize changing habitats (Bajkov 1951). Dams and resulting impoundments have isolated white sturgeon populations (North et al. 1992) and reduced habitat diversity by replacing riverine habitats with lentic environments. Fish previously adapted to riverine conditions have suffered and declined the most (Parsley et al. 1992).

Existing knowledge about specific habitat used or preferred by white sturgeon is largely unknown (Parsely and Beckman 1992) and a better understanding of ecological relationships influencing landlocked populations of white sturgeon is needed from each impoundment (Hanson et al. 1992). Rochard et al. (1990) suggested this lack of knowledge has contributed to the depressed or endangered status of sturgeon populations. Evaluation of habitat components associated with white sturgeon in LGR would provide needed information on reservoir habitat use and impacts to white sturgeon by altering existing reservoir habitat through in-water disposal of dredged material in LGR.

Experimental in-water disposal of sediment dredged near the confluence of the Snake and Clearwater rivers was conducted in LGR during 1988-89, creating an island and underwater plateau at RKm 192.7 with the dredged material (Bennett et al. 1991). Bennett and Shrier (1986) reported deep water habitat in LGR generally supported fewer fishes that comprised mostly non-game catostomids and cyprinids. Prior to this study, the extent and importance of water depth used by white sturgeon, a bottom dwelling species, in LGR was unknown. Coon et al. (1977) reported low numbers of white sturgeon in LGR (44) with the majority sampled near Blyton Landing (RKm 191). Recent fish monitoring surveys in LGR by Bennett et al. (1989, 1990) suggested abundance of white sturgeon was higher than originally anticipated which has raised concern over deep water disposal (Bennett et al. 1992). I present specific information on habitat use by white sturgeon in LGR and evaluate potential impacts to white sturgeon from reservoir disposal of dredge material.

OBJECTIVES

1. Describe habitat use by white sturgeon in Lower Granite Reservoir; and
2. Evaluate water depth use and potential impacts to white sturgeon from "deep" (>18 m) water disposal of dredged material at lower reservoir locations in Lower Granite Reservoir.

METHODS

Habitat Use

White sturgeon were collected with gill net and setline gears (Chapter 1). Physical habitat used by white sturgeon was determined by measuring water temperature, dissolved oxygen, depth, and velocity at each gear set. A Swoffer™ digital current flowmeter with a 6.8 kg sounding weight was used to measure water velocities. Temperature and dissolved oxygen readings were quantified with a YSI™ Model 33 meter. Water depth was recorded to the nearest 0.3 m with a Lowrance Mach 1 Eagle echosounding chart recorder. Substrate type was determined by visual observation using a ponar dredge (Table 6).

Evaluation of habitat use by white sturgeon also included sampling for crayfish. Sixteen cylindrical "minnow" traps, approximately 0.9 m in length, were constructed of fine wire mesh and attached to two 61.1 m mainlines. Each mainline consisted of 8 traps spaced 6.1 m apart. Traps were placed on the bottom at each transect and fished 24 hours for a total of 384 trap hours during 1990 and 1991. Captured crayfish were counted and released alive.

Water depth, mean velocity and near substrate velocity data were used to develop habitat suitability criteria (HSC) for white sturgeon. Habitat use curves describe relative suitability of use independent of habitat availability. Habitat suitability criteria for each habitat descriptor range from 0 to 1 with 0 = unsuitable and 1 = suitable.

Table 6. Substrate classification by particle size.

Substrate Description	Particle Size
Fines	< 2 mm
Sand	2 - 4 mm
Small Gravel	4 - 25 mm
Medium Gravel	25 - 50 mm
Large Gravel	50 - 75 mm
Small Cobble	75 - 150 mm
Medium Cobble	150 - 225 mm
Large Cobble	225 - 300 mm
Small Boulder	300 - 600 mm
Large Boulder	> 600 mm
Bedrock	

These curves were fit to habitat data based on catch-per-unit-effort (CPUE) computed for each habitat type. Highest catch rates at a given habitat condition were assigned a value of 1 and the catch rates at remaining habitat conditions were scaled in proportion to 1. Suitability curves were smoothed by enveloping peak points across points of lower value.

Two sample t-tests were used to analyze physical habitat variables associated with presence and absence of white sturgeon (Table 7). MANOVA and stepwise discriminant analysis (PROC STEPDISC, SAS Institute 1988) was then used to determine which habitat variables provided significant separation between presence and absence. The best model described by stepwise discriminant analysis was used to produce linear discriminant habitat functions (PROC DISCRIM, SAS Institute 1988) for prediction of white sturgeon presence and absence.

Deep Water Use

Transects were randomly selected and sampled with effort distributed evenly between thalweg and adjacent thalweg areas (Chapter 1). Maximum water depth for each gill net set was measured to the nearest 0.3 m with a Lowrance Mach 1 Eagle™ recording depth sounder. Depth use was evaluated by comparing catch rates for white sturgeon by location, depth and season with analysis of variance (SAS Institute, 1988).

RESULTS

Habitat Use

White sturgeon used depths from 6.1 m to 39.6 m in LGR with a mean depth of 20.3 m. Catch rates (0.19 fish/hr) and suitability indices (1.0) were highest at intermediate depths of 18-22 m. No white sturgeon were sampled from depths <6 m and >40 m (Figure 19). White sturgeon used water velocities from 0.0- 0.58 m/sec. Highest velocities were typically recorded in the main channel near the upper end of LGR during spring (RKm 215.6-221.1). Catch rates (0.15-0.17 fish/hr) and suitability indices (1.0) for mean and near substrate velocities were highest at 0.38 m/sec (Figure 19). The majority (73%) of water velocity observations ranged from 0.0-0.15 m/sec (Figure 20).

A wide range of temperatures were measured with highest catch rates (0.18 fish/hr) occurring at 20-22 °C. Near substrate dissolved oxygen ranged from 1.71 to 13 mg/l with no white sturgeon sampled at locations <5.0 mg/l (Figure 21). Sufficient levels

Table 7. Description of physical habitat variables measured to evaluate presence and absence of white sturgeon in Lower Granite Reservoir, 1990-91.

Habitat Variable	**Description**
1. Maximum depth ($Depth_{max}$)	Depth (m) at deepest cross section of channel.
2. Substrate	Particle size (mm) of substrata.
3. Surface velocity (Vel_{surf})	Water velocity (m/sec) 0.3 m below surface.
4. Near substrate velocity (Vel_{ns})	Water velocity (m/sec) 0.3 m above substrate.
5. Mean velocity (Vel_{mean})	Water velocity (m/sec) averaged by (Vel_{surf} + Vel_{ns})/2.
6. Near substrate temperature ($Temp_{ns}$)	Water temperature (°C) 0.3 m above substrate.
7. Mid-column temperature ($Temp_{mid}$)	Water temperature (°C)at 1/2 depth of water column.
8. Near substrate dissolved oxygen (DO_{ns})	Dissolved oxygen (mg/l) 0.3 m above substrate.
9. Mid-column dissolved oxygen (DO_{mid})	Dissolved oxygen (mg/l) at 1/2 depth of water column.

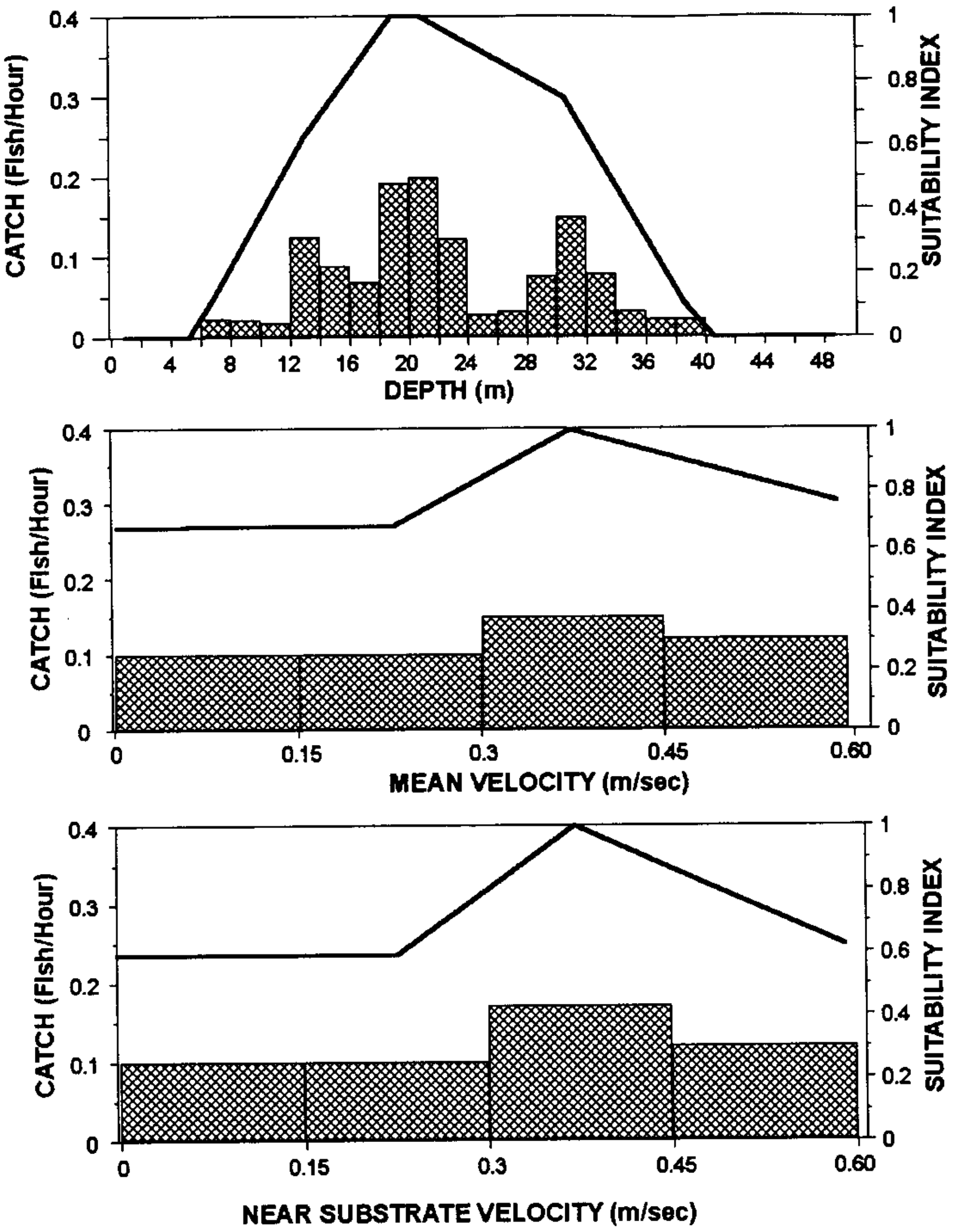


Figure 19. Catch rates and habitat criteria depicting suitability of water depth, mean velocity and near substrate velocity for white sturgeon sampled in Lower Granite Reservoir, Washington 1990-91

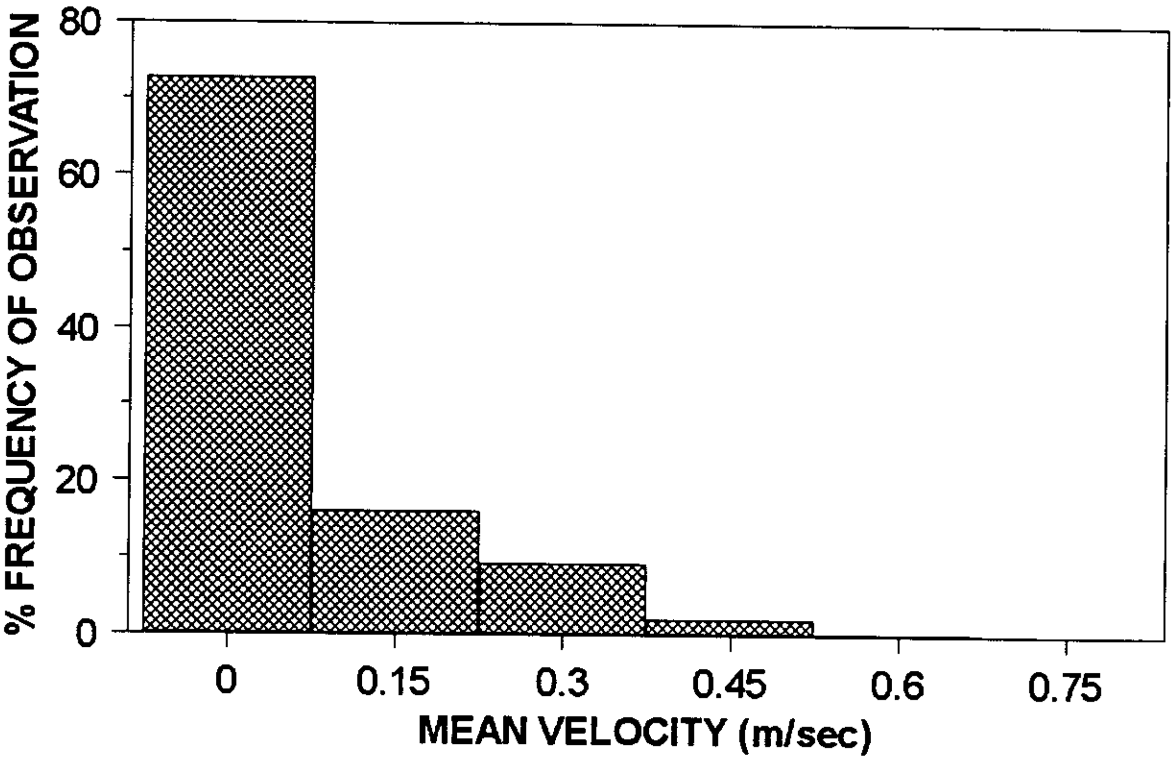


Figure 20. Mean water velocity observations recorded in Lower Granite Reservoir, Washington 1990-91.

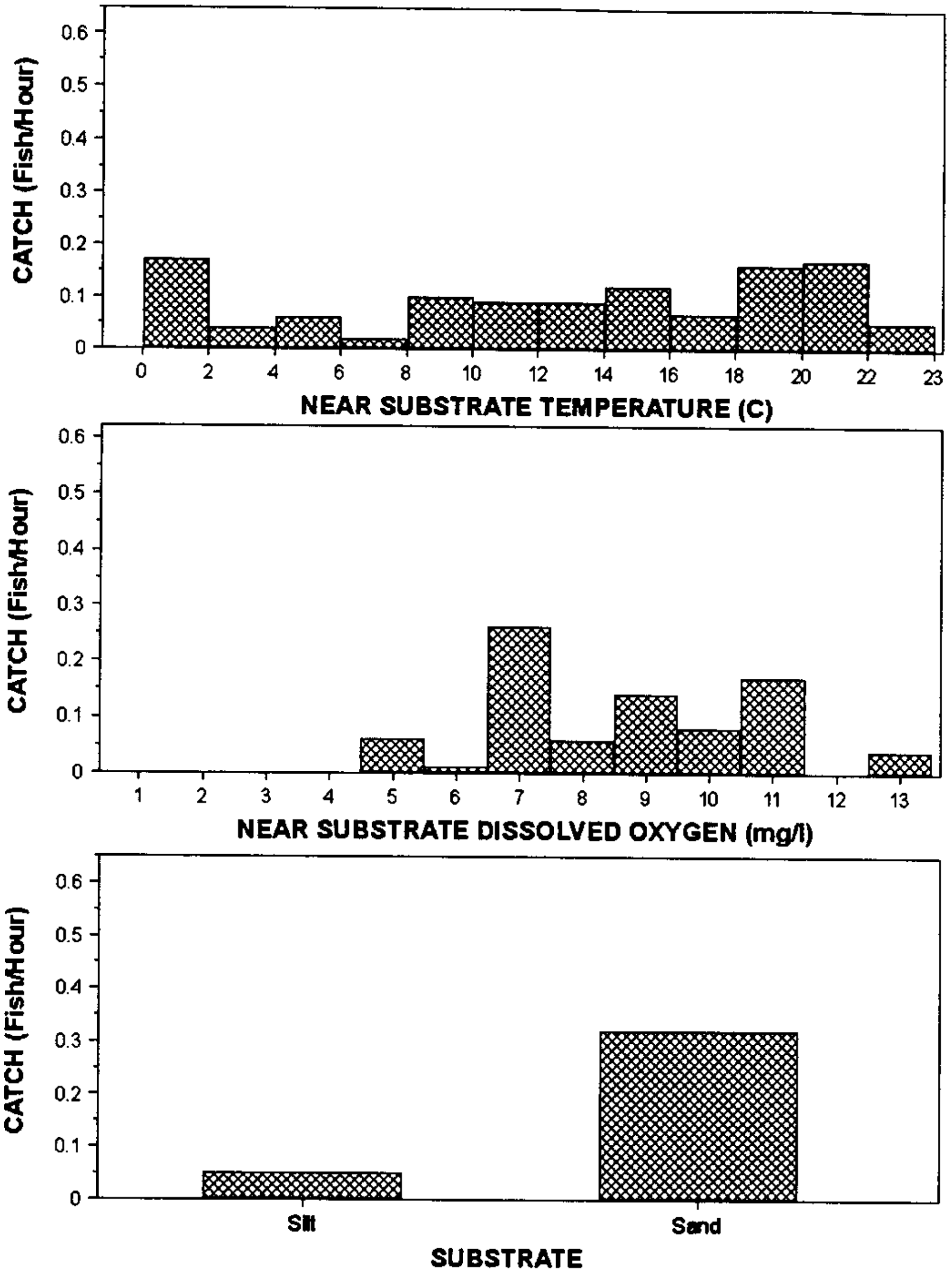


Figure 21. Catch rates of white sturgeon associated with temperature, substrate and dissolved oxygen in Lower Granite Reservoir, Washington 1990-91.

of dissolved oxygen ($>$5.6 mg/l) were generally maintained in LGR throughout 1990-91 with exception to low oxygen readings ($<$5.0 mg/l) at water-substrate interface $<$RKm 192.9 on 06 August 1990. Levels returned $\geq$6.0 mg/l by 20 August 1990 throughout the reservoir.

Substrate from mid and lower reservoir transects ($<$208 RKm) was predominantly silt, while sand was dominant at upper main channel transects $>$208-221 RKm. Catch rates were highest (0.31 fish/hr) over sand substrate (Figure 21).

Number of crayfish ranged from 0-1 at lower reservoir (174 RKm) transects to 267 at 215 RKm. The majority (81%) of crayfish were sampled at upper reservoir transects. A Spearman's rank correlation indicated a high correlation between crayfish and white sturgeon distribution (r_s = 0.81; Figure 22).

Comparison of depth, velocity and temperature data showed significant differences between mean habitat variables measured at locations classified as presence or absence of white sturgeon (Table 8). MANOVA for these habitat variables also indicated significant separation between presence and absence (Wilks' Lambda=0.70, F=25.8, P=0.0001). Stepwise discriminant analysis of nine variables indicated that maximum depth, substrate, near substrate velocity, and near substrate dissolved oxygen provided the best separation between presence and absence of white sturgeon (Table 9). Physical habitat variables that were highly correlated and providing similar information were dropped from the analyzes (Table 10). Approximately 26% of the variation between locations classified as present or absent were explained by the habitat variables measured (Table 9).

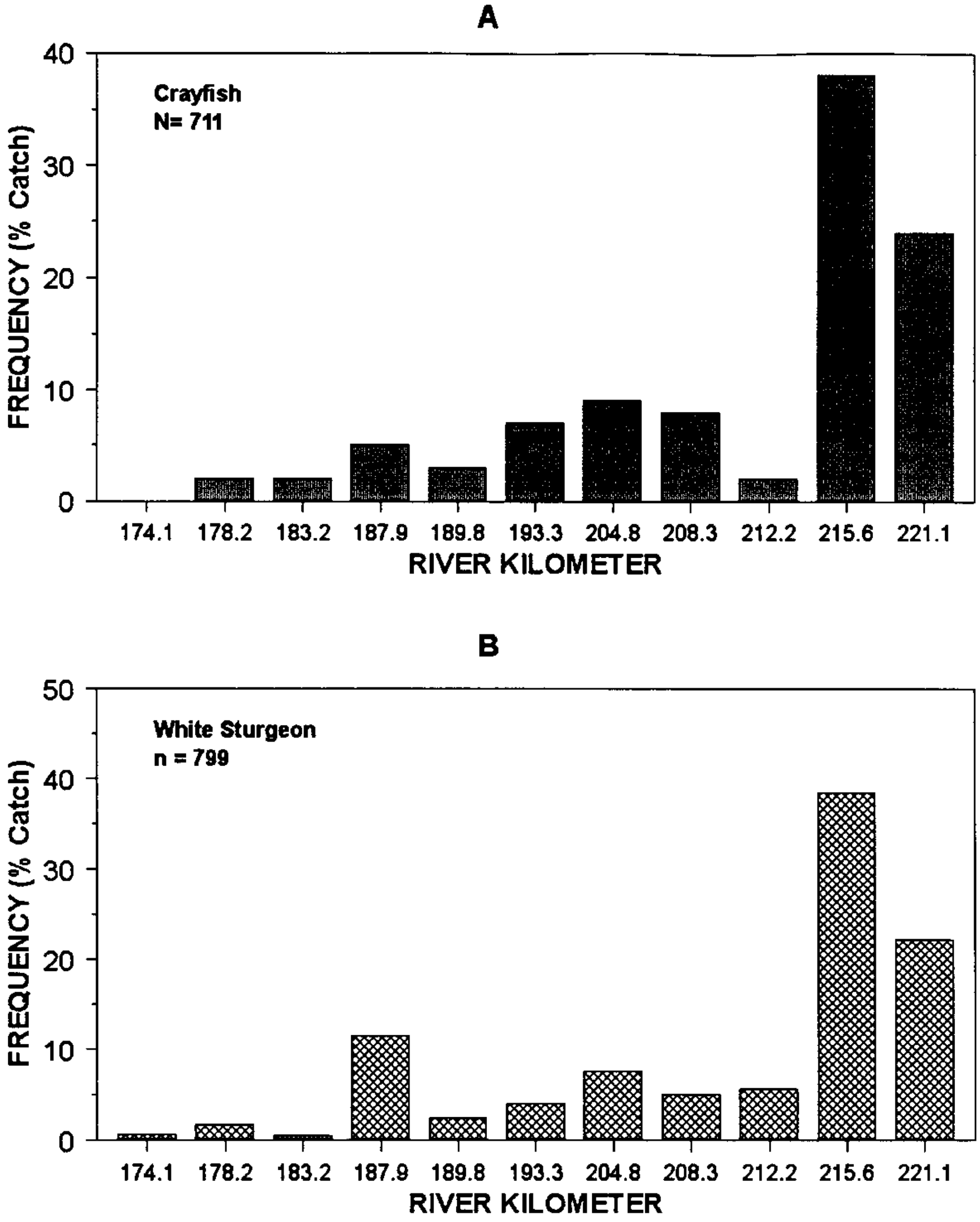


Figure 22. Frequency of crayfish a) and white sturgeon b) at locations in Lower Granite Reservoir, Wa. 1990-91. Spearman's rank correlation between crayfish and white sturgeon $r_s = 0.81$.

Table 8. Summary statistics and two-sample t-tests for physical habitat variables measured at locations in Lower Granite Reservoir, Washington to compare presence (P) and absence (A) of white sturgeon 1990-91.

Variable	A/P	N	Mean	95% CI	S.D.	Min.	Max.	P(t-test)	
Depth_{max} (m)	A	1968	22.1	21.7-22.5	8.9	1.8	48.7		
	P	897	20.3	19.8-20.7	6.5	6	39.6	0.0001	1
Substrate	A	2045	-	-	-	silt	sand		
	P	908	-	-	-	silt	sand	0.0001	1 1st most import
Vel_{surf} (m/sec)	A	946	0.11	0.10-0.12	0.12	0.00	0.58		
	P	490	0.16	0.14-0.17	0.13	0.00	0.57	0.0001	1
Vel_{mean} (m/sec)	A	943	0.09	0.08-0.10	0.09	0.0	0.52		
	P	489	0.11	0.10-0.12	0.10	0.00	0.51	0.0001	1
Temp_{mid} (^{0}C)	A	889	12.3	12.0-12.6	4.75	3.0	23.0		
	P	471	13.3	12.8-13.7	4.51	3.0	23.0	0.0002	2 5th most import
Vel_{ns} (m/sec)	A	962	0.06	0.05-0.064	0.08	0.0	0.49		
	P	492	0.77	0.07-0.08	0.88	0.0	0.46	0.0004	3
Temp_{ns} (^{0}C)	A	1414	13.1	12.8-13.3	4.72	1.25	23.0		
	P	641	13.8	13.4-14.1	4.61	1.25	22.8	0.0029	4 7th most import
$\mathrm{D0}_{mid}$ (mg/l)	A	900	9.73	9.63-9.82	1.46	5.7	13.4		
	P	462	9.63	9.49-9.76	1.42	6.0	13.4	0.2191	5
$\mathrm{D0}_{ns}$ (mg/l)	A	935	9.45	9.33-9.57	1.84	1.71	13.5		
	P	467	9.59	9.47-9.71	1.50	5.10	13.5	0.0898	6

Table 9. Summary of stepwise discriminant analysis of five physical habitat variables and 499 observations. A significance level of 0.15 was used for entry and removal of habitat variables.

Variable	**Partial R^2**	**F**	**P**
Substrate	0.232	174.3	0.0001
DO_{ns}	0.017	9.8	0.0018
Vel_{ns}	0.008	4.4	0.0346
Depth_{max}	0.006	3.5	0.0590

Table 10. Pearson correlation matrix for 9 physical habitat variables measured to evaluate presence and absence of white sturgeon in Lower Granite Reservoir, 1990-91.

	Depth_{max}	Vel_{surf}	Vel_{mean}	Vel_{ns}	Substrate
Depth_{max}	1.00				
Vel_{surf}	-0.14	1.00			
Vel_{mean}	-0.15	0.96	1.00		
Vel_{ns}	-0.16	0.77	0.91	1.00	
Substrate	-0.23	0.34	0.33	0.27	1.00
DO_{mid}	0.01	0.25	0.26	0.27	0.10
DO_{ns}	-0.05	0.31	0.32	0.31	0.17
Temp_{mid}	-0.19	0.12	0.10	0.07	0.02
Temp_{ns}	-0.09	-0.03	-0.05	-0.08	0.01

Table 10. cont'd.

	DO_{mid}	DO_{ns}	Temp_{mid}	Temp_{ns}
DO_{mid}	1.00			
DO_{ns}	0.93	1.00		
Temp_{mid}	-0.75	-0.69	1.00	
Temp_{ns}	-0.82	-0.77	0.97	1.00

Linear discriminant functions calculated from the variables selected to classify presence or absence of white sturgeon based on the higher value of the discriminant function are:

Presence

$$Y_1 = -39.49322 + 3.12088\text{Substrate} + 0.59643\text{Depth}_{\text{max}} + 6.96347\text{DO}_{\text{near substrate}} - 23.99350\text{Vel}_{\text{near substrate}}$$

Absence

$$Y_2 = -35.15444 + 0.12884\text{Substrate} + 0.57085\text{Depth}_{\text{max}} + 6.63906\text{DO}_{\text{near substrate}} - 21.05677\text{Vel}_{\text{near substrate}}$$

To determine presence or absence of a location, I applied a set of hypothesized values for the five variables in each function. The function with the highest value indicated presence or absence of white sturgeon at that location. Larger differences between values of functions indicated more reliable predictions. The linear discriminant functions provided correct classification for 89% absence and 56% of locations where white sturgeon were present (Table 11). Overall, both discriminant functions correctly classified 76% (423/558) of all observations.

Deep Water Use

Catch and depth information from 909 white sturgeon were used to evaluate depth use in LGR. Maximum depths at transects ranged from 13.3-48.7 m in the main channel thalweg while areas sampled adjacent to the thalweg were 11-26.2 m (Figure 23). Approximately 77% (689) of the white sturgeon were collected in the thalweg with higher catch rates (0.13 fish/hour) than areas adjacent to the thalweg (0.04 fish/hour). Highest catch rates (0.23-0.32 fish/hour)of white sturgeon occurred in the thalweg at

Table 11. Classification summary for linear discriminant functions separating sturgeon presence and absence based on maximum depth and substrate size. Parentheses indicate correct classification of predictions.

	Predictions		Observed
	Absence	Presence	
Absence	298 (89%)	35 (10%)	333
Presence	100 (44%)	125 (55%)	225
Total	398 (71%)	160 (27%)	558

upper reservoir transects (RKm 215.6 and RKm 221.1) where maximum depths were <23 m (Figures 9, 23). Catch rates at transects below RKm 208.3 were significantly lower where main channel depths ranged from 23.4-48.7 m (Figures 10, 23).

Use of thalweg and areas adjacent to the thalweg by white sturgeon were similar between day and night sampling. Catch rates during daylight periods were higher in the thalweg (0.13 fish/hour) than adjacent areas (0.04 fish/hour). Similarly, catch rates at night were 0.14 fish/hour in the thalweg and 0.04 fish/hour at areas adjacent to the thalweg. Multiple comparison tests indicated catch rates were significantly higher in the thalweg at transects sampled upstream of RKm 208.3. No significant difference (P>0.05) in catch rates occurred between thalweg and adjacent areas below RKm 208.3 with exception of RKm 187.9 (Figure 24). Catch rates were relatively high in the thalweg

, near [illegible]

at RKm 187.9 during spring sampling in 1991 and decreased as summer progressed.

Distribution of white sturgeon in LGR did not appear to be influenced by seasonal periods. Catch rates were typically low at mid and lower reservoir locations throughout

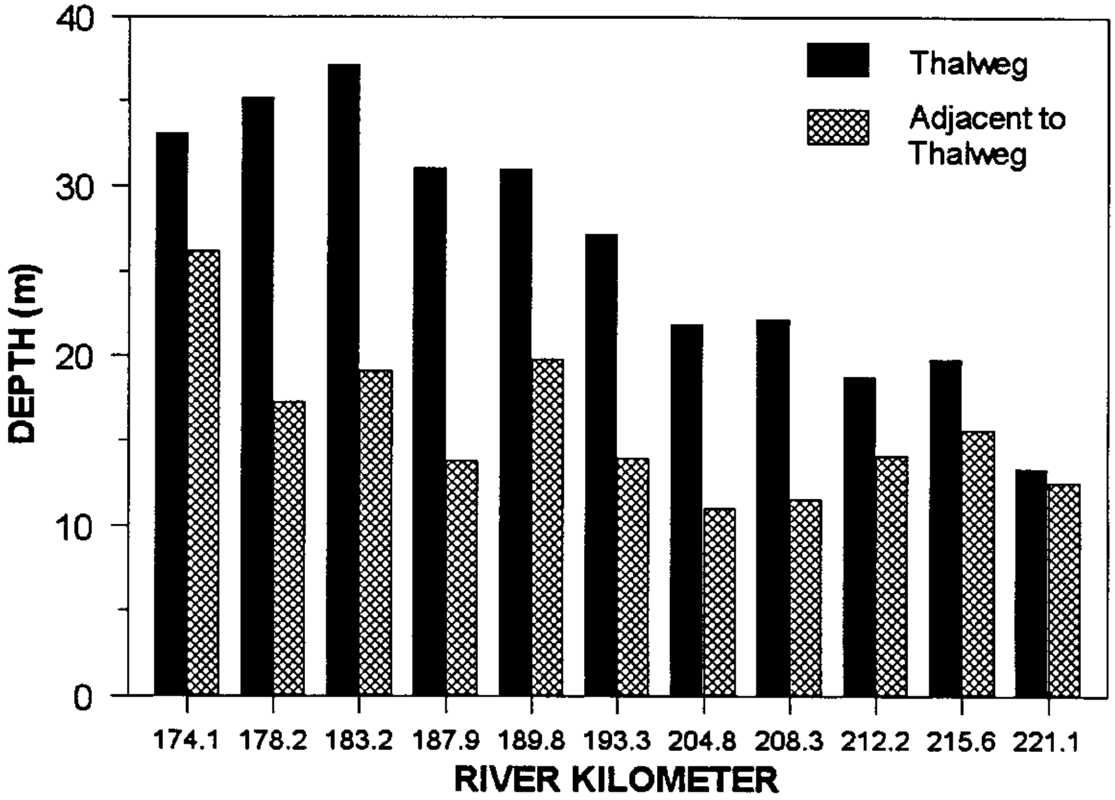


Figure 23. Maximum water depths at transects sampled for white sturgeon in Lower Granite Reservoir, Washington 1990-91.

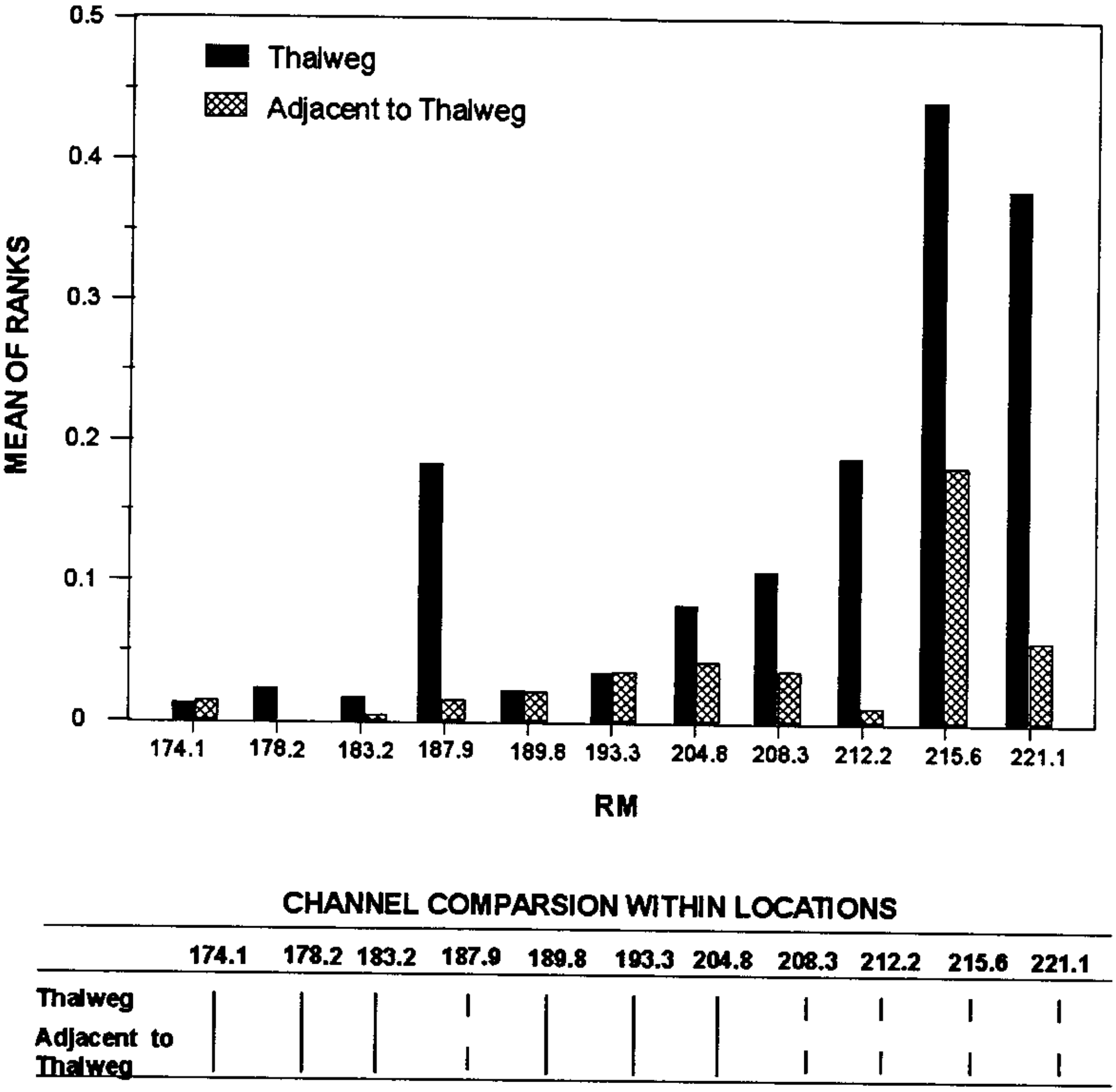


Figure 24. Comparison of white sturgeon catches between thalweg and areas adjacent to the thalweg. Channels joined by a continuous vertical line indicate no significant difference (P>0.05).

seasonal intervals. No significant difference ($P > 0.05$) in use of deep water locations between seasons was apparent at most locations <RKm 204.8 with exception of RKm 187.9 (Figure 25). Catch rates at RKm 187.9 were relatively high during spring sampling in 1991 otherwise, numbers of white sturgeon sampled from mid and lower reservoir transects were generally low throughout seasonal intervals (Figure 13).

DISCUSSION

Habitat Use

Prior to impoundment of the Columbia and Snake rivers, white sturgeon were nomadic and used optimal habitats during each life stage. Dams and resulting impoundments have divided these habitats into subsets and often reduced diversity by altering riverine habitats to lentic environments. It would seem intuitive that landlocked populations would continue to use areas in each impounded reach where habitat remained most suitable. A predominantly juvenile white sturgeon population in LGR would seek and optimize areas for rearing.

Catch rates and suitability indices indicated white sturgeon used habitat at the upper end of LGR with greater frequency than mid and lower reservoir transects. These upper areas coincided with higher velocity, larger substrate and shallower depths relative to transects sampled downstream. However, white sturgeon in LGR have indicated a wide tolerance of habitat conditions as identified by the range of observations. White sturgeon were captured at temperatures spanning the ranged observed in LGR. Scott and Crossman

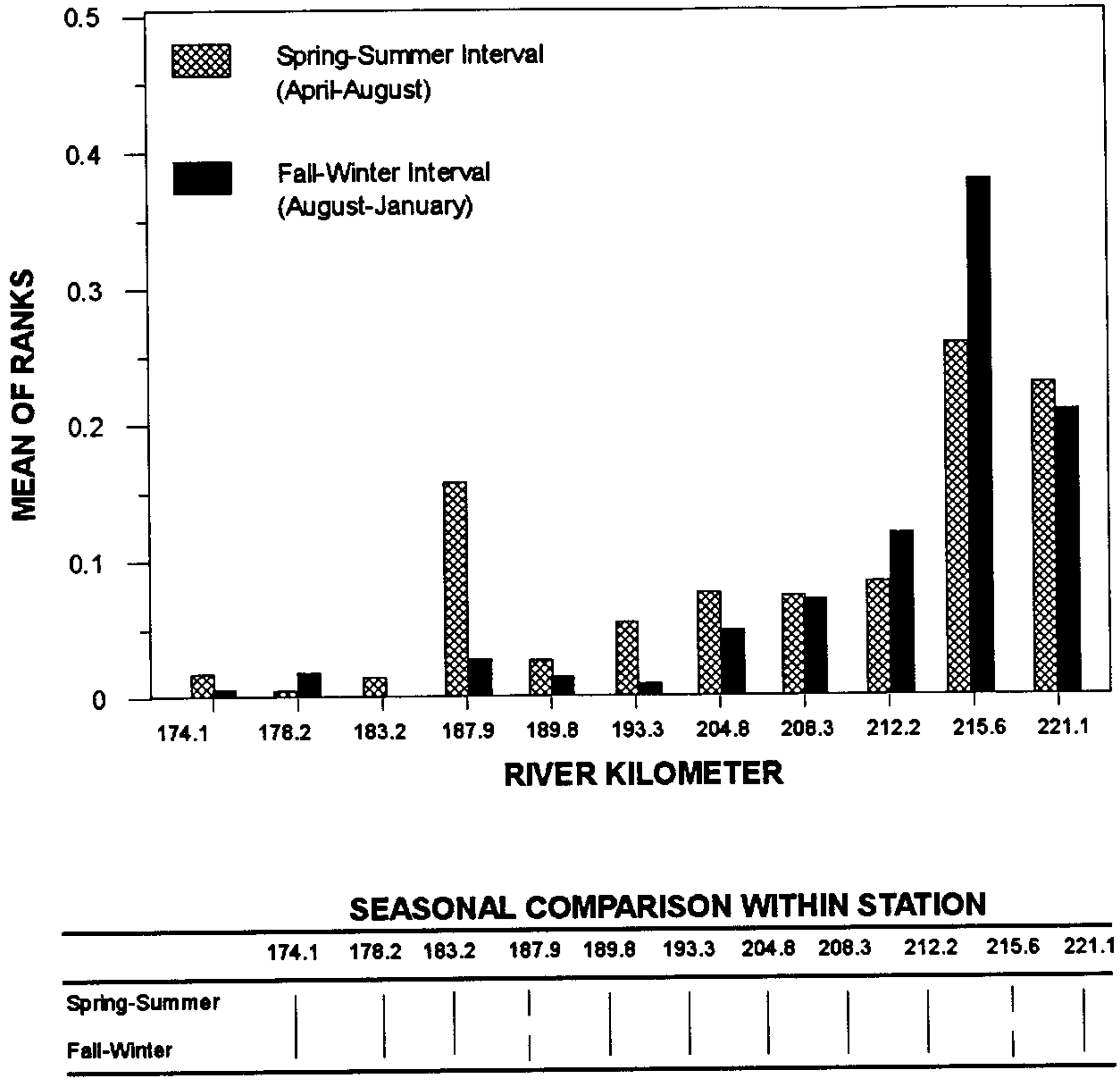


Figure 25. Comparison of white sturgeon catch rates between spring-summer and fall-winter periods within sample locations. Sample periods joined by a continuous vertical line indicate no significant difference (P>0.05).

(1973) reported white sturgeon were captured at temperatures from 0° to 23 °C which was similar to my collections in LGR. Dissolved oxygen levels were <5.0 mg/l at lower reservoir transects during a brief period in 1990 but did not appear to affect white sturgeon since few fish were sampled at those locations during the 1990-91. Suitability curves indicated velocity >0.45 m/sec was becoming less suitable for white sturgeon in LGR which is lower than reported for juvenile white sturgeon (0.1-1.3 m/sec) in the Columbia River (Parsley and Beckman 1992). This may in part reflect sampling a reservoir environment. Data collected throughout the entire Lower Granite-Hells Canyon Reach would provide a more accurate curve for velocity since a wider range of velocities would be sampled.

Parsley and Beckman (1992) concluded juvenile white sturgeon used a wide range of habitat conditions and that any one physical habitat variable was probably no more important than another for these life stages. This lends support to habitat use in LGR since physical habitat variables selected by discriminant analysis explained only 26% of the variation indicating other criteria were responsible for white sturgeon distribution in LGR. Based on similarities between crayfish and white sturgeon distribution (Figure 23), I speculate prey abundance and availability are important factors in determining white sturgeon distribution.

Recent studies on the Columbia River have shown the importance of benthic invertebrates, particularly *Corophium salmonis*, in diets of juvenile white sturgeon. However more extensive research is needed to determine significant links between sturgeon distribution, growth and invertebrate abundance (McCabe et al. 1992a; McCabe et al. 1992b). Sprague et al. (1992) indicated that white sturgeon may be feeding on organisms in the water column rather than exclusively on the substrate. *Corophium spp.*, river drift organisms, were the predominant prey item young-of-the-year and juvenile white sturgeon in two Columbia River impoundments and the lower Columbia River (Sprague et al. 1992; McCabe et al. 1992; Muir et al. 1988). *Corophium spp.* numbers in LGR appear low (Bennett et al. 1991) however, crayfish were abundant near the upper end of LGR. Cochnauer (1981) reported crayfish and chironomid species were dominant food items identified from white sturgeon stomachs in the middle Snake River. This may explain the high density of juvenile white sturgeon in the upper section of LGR relative to lower areas. Highest densities of crayfish in LGR, a prey item of white sturgeon > 45 cm (Scott and Crossman 1973), occurred near the upper end of the reservoir which coincided with highest densities of juvenile white sturgeon. Bennett et al. (1990) ~~also~~ reported high abundance of larval fishes above RKm 204.8 ~~which also~~ may contribute to food resources. Sampling in 1990-91 has shown that the upstream portion of LGR is the most critical portion of the reservoir ~~for~~ juvenile white sturgeon rearing.

Data regarding recent changes in the status of white sturgeon above LGR in unimpounded reach to HC remains unknown. Without use of consistent sampling strategies and gears throughout the Lower Granite-Hells Canyon Reach, comparisons with past studies must be interpreted with caution. Stock assessment, habitat evaluation and prey abundance above LGR, using similar gears, will not only provide the status of the entire population but may aid in determining the significance that LGR plays for rearing juvenile white sturgeon and resulting recruitment to the Lower Granite - Hells Canyon population.

Deep Water Use

Deep water areas at mid and lower sections of LGR were not considered significant since use of these areas by white sturgeon was markedly lower than at upstream locations. Catch rates of white sturgeon decreased considerably as sampling progressed downstream into LGR during both 1990-91. Catch rates were also highest in the thalweg areas. so maybe not good (beneficial) to dispose in deep? Parsley et al. (1992) reported young-of-the-year and juvenile white sturgeon were most often captured within the thalweg which supports my findings. Efforts adjacent to the thalweg in shallower water captured fewer sturgeon. so no impact to dispose shallow water Haynes and Gray (1981) suggested that white sturgeon made feeding forays into shallow waters during hours of darkness. good to develop crayfish, Corophium, midge production habitats Comparison of catch rates between the thalweg and areas adjacent to the thalweg during hours of daylight and darkness in LGR were similar indicating no increased movement of fish into shallow areas during night sampling.

Seasonal differences in catch rates between transects were apparent only at three upper reservoir transects where abundance of white sturgeon was high. Seasonal differences in catch rates were not significant for mid and lower reservoir transects where abundance of white sturgeon was consistently low.

These data indicate white sturgeon in LGR used thalweg and upper reservoir locations with water depths <23 m. Mid and lower reservoir locations were not used with the same frequency as upper reservoir transects regardless of season. Sediment dredged near the confluence and deposited at lower and mid reservoir locations may alter the physical habitat in these areas by decreasing water depth, increasing water velocity and establishing larger substrate sizes. These physical habitat changes will probably have minimal effect since physical habitat variables explained a low percentage of the variation of white sturgeon distribution in LGR (Table 9). However, disposal sites may attract foraging white sturgeon if prey availability increases as a result of disturbance and exposure of the benthic community. This study strongly suggests that negative impacts from deep-water sediment disposal would be minimal to white sturgeon if conducted at lower reservoir locations.

SUMMARY

1. White sturgeon used depths from 6.1-39.6 m with highest catch rates at intermediate depths of 18-22 m. Water velocities used ranged from 0.0-0.58 m/sec with suitabilities (1) for mean and near substrate velocities near 0.38 m/sec. Substrate use was predominantly sand.

2. Habitat use by white sturgeon in LGR indicated a wide tolerance of habitat conditions. Catch rates and suitability indices indicated white sturgeon used habitat at the upper end of LGR with greater frequency than mid and lower reservoir transects. These upper areas coincided with higher velocity, larger substrate and shallower depths relative to transects sampled downstream.

3. Stepwise discrimant analysis of habitat variables indicated maximum depth, near substrate velocity, near substrate dissolved oxygen and substrate provided best

separation between presence and absence of white sturgeon. However, only 26% of the variation between locations classified as present or absent were explained by the habitat variables measured suggesting other criteria were responsible for white sturgeon distribution in LGR.

4. Deep water areas (23.4-48.7 m) at mid and lower sections of LGR were not considered significant since use of these areas by white sturgeon was markedly lower than at upstream locations. Approximately 77% (689) of the white sturgeon were collected in the thalweg with highest catch rates (0.23-0.32 fish/hour) at upper reservoir transects (RKm 215.6 and RKm 221.1) where maximum depths were <23 m.

5. Use of thalweg and areas adjacent to the thalweg by white sturgeon were similar between day and night sampling. Seasonal difference in catch rates were not significant for mid and lower reservoir transects where abundance of white sturgeon was consistently low. This study strongly suggests that impacts from deep-water sediment disposal would be minimal to white sturgeon if conducted at lower reservoir (RKm 120-173.3) locations.

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