# STATUS AND HABITAT REQUIREMENTS OF THE WHITE STURGEON POPULATIONS IN THE COLUMBIA RIVER DOWNSTREAM FROM MCNARY DAM

## Final Report of Research

## Volume II - Supplemental Papers and Data Documentation

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# PREFACE

This is the final report for research on white sturgeon *Acipenser transmontanus* funded by the Bonneville Power Administration (BPA) from 1986-92 and conducted by the National Marine Fisheries Service (NMFS), Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife Service (USFWS), and Washington Department of Fisheries (WDF). Findings are presented as a series of papers, each detailing objectives, methods, results, and conclusions for a portion of this research. Volume I of this report includes papers which directly address objectives of the research program. Volume II includes supplemental papers which provide background information needed to support results of the primary investigations addressed in Volume I. Volume I also includes an introductory section which summarizes important results, conclusions, and recommendations.

Construction and operation of the hydropower system have affected the productivity of white sturgeon populations restricted to a series of reservoirs and river segments. We define productivity as the capacity of a population to elaborate biomass and equate production with the capacity to provide yield. Several impounded populations can sustain little or no harvest and others risk extinction. Dams have restricted movements of two principal food sources, eulachon *Thaleichthys pacificus* and lamprey *Lampetra* spp. Impoundment and dam operation have also altered spawning and rearing habitat. Finally, reservoir habitat has favored new communities of potential prey, predators, and competitors.

This study addresses measure 903(e)(l) of the Northwest Power Planning Council's 1987 Fish and Wildlife Program that calls for "research to determine the impact of development and operation of the hydropower system on sturgeon in the Columbia River Basin." Study objectives correspond to those of the "White Sturgeon Research Program Implementation Plan" developed by BPA and approved by the Northwest Power Planning Council in 1985. Work was conducted on the Columbia River from McNary Dam to the estuary.

Research objectives included:

1. Describe the reproduction and early life history of white sturgeon.
2. Describe the life history and population dynamics of subadult and adult white sturgeon.
3. Define habitat requirements and quantify habitat availability for white sturgeon.
4. Evaluate the need and identify potential methods for protecting, mitigating, and enhancing populations of white sturgeon.

To ascertain effects of the hydropower system on white sturgeon, we compared populations and habitat in the three lowermost reservoirs between Bonneville and McNary dams, with the population and habitat in the unimpounded reach between 'Bonneville Dam and the estuary. The unimpounded population has unrestricted access to the ocean, exhibits seasonal migrations, spawns successfully each year, includes all life history stages, and sustains productive fisheries. Dam construction likely had little effect on population characteristics and habitat use in the lower Columbia River.

Tasks were apportioned among cooperating agencies as follows:

*NMFS* - Describe reproduction and early life history and define habitat requirements for spawning and rearing downstream from Bonneville Dam. Quantify habitat from Bonneville Dam to the estuary.

*ODFW* - Describe life history and population dynamics of subadults and adults between Bonneville and McNary dams. Evaluate the need and identify potential methods for protecting, mitigating, and enhancing populations between Bonneville and McNary dams.

USFWS - Describe reproduction and early life history and define habitat requirements for spawning and rearing between Bonneville and McNary dams. Quantify habitat available from McNary to Bonneville dams.

*WDF* - Describe life history and population dynamics downstream from Bonneville Dam. Describe reproduction and early life history downstream from Bonneville Dam. Describe white sturgeon fisheries between Bonneville and McNary dams.

## REPORT SUMMARY

### Methodology

A. Comparison of Efficiency and Selectivity of Three Gears Used to Sample White Sturgeon in a Columbia River Reservoir *(Elliott and Beamesderfer)*

1. Setlines provided greater catch rates of white sturgeon than did gill nets or angling. Setlines also caught a greater size range of white sturgeon and did not catch other species of fish.

B. Use of an Artificial Substrate to Collect White Sturgeon Eggs *(McCabe and Beckman)*

1. An artificial substrate consisting of latex-coated animal hair enclosed in a frame and anchored to the bottom effectively sampled eggs broadcast by spawning white sturgeon.

C. Retention, Recognition, and Effects on Survival of Several Tags and Marks on White Sturgeon *(Rien et al.)*

1. Retention rate of spaghetti tags exceeded 90% among fish recaptured within a year of tagging but declined significantly in subsequent years.

2. Removal of a combination of lateral scutes provides a long-term mark for white sturgeon. We recommend standard removal of the 2nd

right scute to indicate oxytetracycline injection and the 2nd left scute to indicate a PIT tag.

3. Tattoos and pectoral fin scars were often not evident after one year. Reduced recapture rates were associated with barbel removal.

D. Feasibilitv of Radio Telemetrv to Document Fish Movement and Habitat Use in Lower Columbia River Impoundments *(Anders et al.)*

1. Radio transmitter signals (0.27 milliwatts) could be detected at distances as great as 1.2 km and depths up to 30 m.
2. Radio telemetry is feasible for tracking white sturgeon but higher-powered transmitters and a higher-resolution receiver than those tested are recommended.

E. MOCPOP 2.0: A Flexible System for Simulation of Age-structured Populations and Stock Related Functions *(Beamesderfer)*

1. A computer program for simulating annual variation in numbers, production, and biomass of a population of organisms based on recruitment, mortality, and growth was documented.

## Reproduction and Recruitment

F. Maturation of Female White Sturgeon in Lower Columbia River Impoundments *(Welch and Beamesderfer)*

1. Maturing females as small as 92 cm were observed, but only 5% of females less than 166 cm fork length (6 ft total length) were mature.
2. Length-at-maturity was described with a sigmoid function based on a cumulative normal probability model fit with maximum likelihood methods. Median size at female maturity was estimated to be from 164 to 193 cm.
3. Large females (> 166 cm) appear to spawn about every 3 years, which is much more frequent than for other populations based on qualitative data or inferences from patterns on hard parts.
4. Differences in length-at-maturity among reservoirs were significant.

G. Gonadal Development of Female White Sturqeon in the Lower Columbia River *(North et al.)*

1. The onset or rate of vitellogenesis varied substantially among individuals, making it difficult to distinguish the duration of the maturation cycle from patterns of maturity.

2. Most females with ripe eggs were collected from February through May but several were collected from June through October.

3. Gonad size, fecundity, and egg size were all positively correlated with fish length among ripe females.

4. Gonadosomatic Index averaged 14% for ripe females and was not correlated with fish length.

### H. White Sturgeon Spawning Cues in an Impounded Reach of the Columbia River *and Beckman)*

1. High discharge (> 250 kcfs) appeared to stimulate spawning in Bonneville Pool (The Dalles Dam tailrace).

2. While spawning occurred within a range of water temperatures (12-20"C), temperature did not appear to act as a spawning cue (spawning cue defined as a factor initiating spawning within 24 hours or less).

### I. A Recruitment Index for White Sturgeon in the Columbia River Downstream from McNary Dam *(Miller and Beckman)*

1. Sampling for young of the year (YOY) is the most practical way to evaluate recruitment of white sturgeon in the impoundments and the lower river because age does not need to be estimated. Age-1 fish may provide a more accurate recruitment estimate, but age must be estimated. September or October sampling is best for YOY; spring sampling is best for age-1 fish.

2. Catches of eggs and larvae were less variable in plankton nets than in beam trawls, but egg and larvae catches are a poor indicator of recruitment to YOY.

3. Egg sampling with plankton nets could be used as an indicator of recruitment if a large enough boat is not available to sample YOY or age-1 white sturgeon with a high-rise trawl. However, beam trawls are better for sampling sparse populations because a greater area is sampled.

4 Only the three sites with the highest catch per effort need to be sampled to evaluate spawning and recruitment of white sturgeon in lower Columbia River impoundments using eggs, YOY, or age-i fish.

5 Recruitment was greater to the egg, larval, and YOY stages in average water years than in low water years in the three impoundments.

6 No recruitment trends existed in the unimpounded reach downstream from Bonneville Dam because water velocities suitable for white sturgeon spawning were more consistently available under variable flow regimes than at the other three dams, possibly due to differences in tailrace channel morphology. The effects of above average water years on spawning and recruitment are unknown.

## Age and Growth

J. Accuracy and Precision in Age Estimates of White Sturgeon Using Pectoral Fin Rays *(Rien and Beamesderfer)*

1. Recaptures of fish previously injected with oxytetracycline indicated inaccuracy in age assignment; age was underestimated by counts of translucent rings in cross sections of pectoral fin rays for impounded white sturgeon.

2. Translucent rings were deposited by May or June in most fish, but many slow-growing fish did not deposit an annual mark.

3. Aging methods based on counts of translucent rings in pectoral fin rays were also imprecise -- error and coefficient of variation in multiple readings averaged 6 and 8%.

K. Lensth at Age Relationships for White Sturgeon in the Columbia River Downstream from Bonneville Dam *(Tracy and Wall)*

1. An inflection point in the length at age relationship at age eight was identified, although its presence did not significantly affect von Bertalanffy growth functions.

2. Female white sturgeon grew to a significantly larger size than males.

3. Growth parameters were similar over the period studied, and were as good or better than other white sturgeon populations studied.

L. Age and Growth of Juvenile White Sturgeon in the Columbia River Downstream from McNary Dam (Miller *and Beckman)*

1. Mean lengths of 1 to 7 year-old white sturgeon were significantly greater in the three impoundments than in the unimpounded lower river.

2. Mean condition factors of 1 to 8 year-old white sturgeon were significantly greater in the three impoundments than in the unimpounded lower river.

3. Length-at-age and condition factor may be greater in the three impoundments than in the lower river possibly due to increased food abundance and decreased juvenile white sturgeon density in the three impoundments.

M. A Standard Weight (Ws) Equation for White Sturgeon *(Beamesderfer)*

1. A standard weight-length function was developed for white sturgeon based on parameters reported for samples from 15 populations distributed throughout the geographical range of this species.

2. Mean relative weights calculated based on this standard ranged from 77 to 117 with the lowest values observed in impounded portions of the Columbia and Fraser River systems and the greatest values observed among populations with access to marine or estuarine resources.

## Feeding and Food

N. Prey Selection by Juvenile White Sturgeon in Reservoirs of the Columbia River *(Sprague and Beckman)*

1. Amphipods *(Corophium)* and mysid shrimp *(Neomysis)* were the dominant food items for age-0 fish in reservoirs in summer.

2. Larger juveniles consumed a greater variety of benthic organisms, including insect larvae (Diptera and Ephemeroptera) and clams *(Corbicula)*.

O. Feeding Ecology of Juvenile White Sturgeon *(Acipenser transmontanus)* in the Lower Columbia River *(McCabe et al.)*

1. The tube-dwelling amphipod *Corophium salmonis* was the primary prey item of juvenile white sturgeon (fork length < 725 mm).

2. Feeding was greater in May-August than in September-October.

3. Correlations were generally poor between the importance of specific benthic organisms in the diet and the abundance of these organisms at sample locations.

P. Distribution, Abundance, and Community Structure of Benthic Invertebrates in the Lower Columbia River *(McCabe et al.)*

1. Benthic communities were dominated by Turbellaria, Oligochaeta, *Corbicula*, *Corophium*, Chironomidae larvae, and Heleidae larvae.

2. Numbers often exceeded 1,000 organisms/m$^2$ in 1988, whereas in 1989 numbers were generally less than 1,000 organisms/m$^2$. Consistent spatial or seasonal patterns in numbers or species diversity could not be distinguished.

## Mortality and Pathology

Q. Recreational and Commercial Fisheries in the Columbia River Between Bonneville and McNary Dams, 1987-91 *(Hale and James)*

1. Recreational fisheries were summarized for Bonneville (1988-90), The Dalles (1987-91)) and John Day (1989-91) reservoirs. Emphasis was on white sturgeon harvest with additional sections devoted to harvest of chinook, coho, steelhead, shad, walleye, smallmouth bass, and northern squawfish.

2. Recreational anglers in the three reservoirs averaged from 25,000 to 29,000 trips per year during census periods. White sturgeon were targeted in 47%, 35%, and 28% of the trips in Bonneville, The Dalles, and John Day reservoirs.

3. Recreational harvest of white sturgeon was greatest in Bonneville Reservoir, ranging from 1,532 (March-October, 1988) to 2,798 fish (March-October, 1989). White sturgeon harvest from The Dalles Reservoir peaked in 1987 at 1,990 fish (June-October) and declined to 499 fish by 1989 (March-October). White sturgeon harvest in John Day Reservoir ranged from 314 fish (March-December, 1990) to 143 fish (April-September, 1991).

4. Combined commercial landings for all three reservoirs peaked in 1987 at 11,150 white sturgeon, then declined to 1,540 fish by 1991.

5. Harvest was reduced in recreational and commercial fisheries in part by increased regulation.

## R. Predation on White Sturgeon Eggs by Sympatric Fish Species *in* Three Columbia River Impoundments (Miller *and Beckman)*

1. At least three endemic fish species (prickly sculpin, largescale sucker, and northern squawfish) and one introduced species (common carp) prey on white sturgeon eggs in Columbia River impoundments.

2. The four species known to prey on white sturgeon eggs are among the most abundant species in the three impoundments.

3. Predation on viable white sturgeon eggs occurred throughout the egg incubation period.

4. Predation can be intense: 70 white sturgeon eggs were collected from one largescale sucker and 9 were collected from one prickly sculpin.

5. More work is needed to determine the significance to sturgeon populations of predation on eggs by resident fishes and relations between water velocity and predation.

## S. Comparisons of White Sturgeon Egg Mortality and Juvenile Deformity Among Four Areas of the Columbia River *(Anders and Beckman)*

1. The proportion of dead eggs collected in samples from The Dalles Reservoir was at least twice that observed in Bonneville or John Day reservoirs, and more than twenty times higher than in samples collected downstream from Bonneville Dam.

2. Dead eggs were collected from 12-20°C water, but the greatest percentage of dead eggs was collected from water exceeding 18°C.

3. Eighteen percent (9 of 49) of captured YOY and juvenile white sturgeon were physically deformed in The Dalles Pool, compared

with 0.5% (3 of 640) in Bonneville Pool, and 0% (0 of 5) in John Day Pool.

T. Frequency of Occurrence of the Parasite Cystoopsis acipenseri in Juvenile White Sturgeon *Acipenser transmontanus* in the Lower Columbia River *(McCabe)*

1. The nematode parasite *Cystoopsis acipenseri* infested white sturgeon ranging in size from 240 mm to 452 mm.

2. Incidence of occurrence varied from 1% in 1989 to 14% in 1987.

# REPORTS

## Methodology

# REPORT A

# Comparison of Efficiency and Selectivity of Three Gears Used to Sample White Sturgeon in a Columbia River Reservoir

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*Oregon Department of Fish and Wildlife*

**Published in: California Fish and Game, 76:174-180, 1990**

# ABSTRACT

We compared the efficiency and size selectivity of setlines, gillnets, and angling to select a cost-effective means of capturing a large number of adult and subadult white sturgeon, *Acipenser transmontanus*, unharmed while minimizing size selectivity and catch of non-target game fish. Setlines provided the greatest catch rate per sampling week (61.4), followed by gillnets (49.4) and angling (34.4). Setlines also captured a wider size-range of sturgeon than gillnets or angling. No other game fish were caught with setlines or angling while gillnets caught other game fish including salmon and steelhead, *Oncorhynchus spp*.

## INTRODUCTION

White sturgeon, *Acipenser transmontanus*, is a valuable resource along the Pacific Coast of North America (Pycha 1956, Semakula and Larkin 1968, Kohlhorst 1980, Cochnauer 1983, Oregon Department of Fish and Wildlife 1988). In the Columbia River, white sturgeon support recreational, commercial, and tribal fisheries (Galbreath 1985). Withe the decline of anadromous salmonid fisheries (Raymond 1988), the white sturgeon fishery has rapidly increased in importance. Total effort and landings have increased several-fold since 1970 (Oregon Department of Fish Wildlife 1988), and effort by recreational white sturgeon anglers now exceeds effort by recreational salmon anglers downstream from Bonneville Dam (Hess and King 1988).

The status of white sturgeon varies within the Columbia River basin. Although the population below Bonneville Dam has supported a harvest of over 50,000 fish annually in recent years, populations in the Snake and Kootenai rivers (Columbia River tributaries) have diminished to the point where no harvest is allowed. Populations have declined in tributaries, possibly for several reasons: (i) migration of white sturgeon into the upper basin has been blocked by the construction and operation of hydroelectric dams (Bajkov 1951, Lukens 1981); (ii) habitat, including food availability, flow, and temperature has been altered by the creation of reservoirs formed by these dams (Bajkov 1951, Coon et al. 1977, Haynes et al. 1978, Lukens 1981); (iii) other biological and physical factors such as predation and the level of pesticides also may have changed (Bosley and Gately 1981).

We needed a gear that would collect a large sample of white sturgeon unharmed to evaluate effects of dam construction and operation on white sturgeon and to design management strategies to optimize yield (Rieman et al. 1987). Other considerations included sampling efficiently to minimize the cost of sampling hundreds of kilometers of river, gear size selection which might bias representation of the population (Beamesderfer and Rieman 1988), and incidental catch of other game fish. Hence, the objective of this report is to describe the most effective gear for capturing subadult and adult white sturgeon unharmed while minimizing size selectivity and catch of other game fish.

## STUDY AREA

We selected The Dalles Reservoir, a mainstem impoundment of the Columbia River (Figure 1), for our gear analysis because this reservoir is relatively small compared with other impoundments in the Columbia River access to all parts of the reservoir is good. The Dalles Reservoir is located between The Dalles and John Day dams (river kilometer 308 to 347). It was formed in 1957 with the closure of The Dalles Dam, a U.S. Army Corps of Engineers hydroelectric, navigation, and flood control project. At mean operating level, the reservoir has a surface area of 3,800.hectares, water elevation of 48.2 m above mean sea level, and depth as great as 61 m. The upper reservoir is riverine, and measurable current exists throughout the reservoir. Average daily inflow and outflow ranges from 3,000 to over 12,000 $m^3/s$.

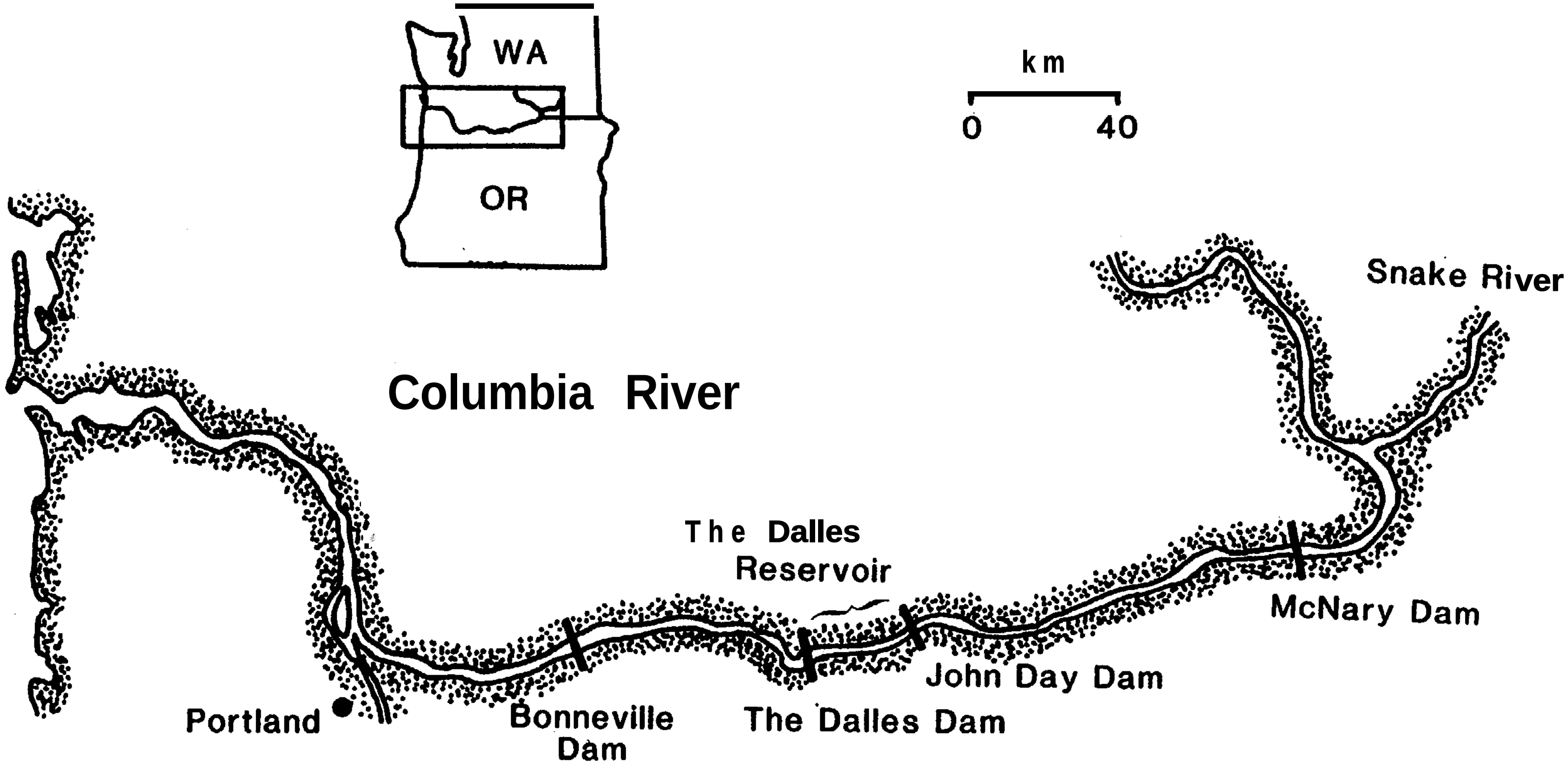

FIGURE 1. Location of The Dalles Reservoir.

# METHODS

We chose setlines, gillnets, and angling as potential ways to collect white sturgeon based on review of the literature and discussions with commercial fishermen. We sampled from March through September, 1987. Effort of each gear was evenly distributed throughout the reservoir and the period of sampling.

Setlines consisted of a 182-m long mainline of 6.4 mm diameter nylon rope, along which 40 hook lines (gangions) were equally spaced. Each gangion consisted of a removable, spring-loaded snap attached to a 0.5-m length of parachute cord by a swivel, with a hook attached to the other end of the cord. Each setline included 10 each of size 10/0, 12/0, 14/0 and 16/0 circle hooks. Circle hooks have the point bent at a 90" angle to the shaft to better retain hooked fish for long periods of time. Each end of a setline was held in place by a 15-20 kg anchor. Each anchor was also attached to a buoy with rope identical to the mainline. Lines were set for 4-48 h in depths from 3 to 50 m. Hooks were baited with 2.5- to 5-cm long cross-section slices of adult pacific lamprey, *Entosphenus tridentatus* or 2.5- to 10-$cm^2$ pieces of adult coho salmon, *Oncorhynchus kisutch*, with skin attached. Only one bait type was used on each line. Setlines were deployed and retrieved from a 7 m figerglass skiff equipped with a hydraulic pot hauler.

Gillnets were sinking type and set stationary and perpendicular to the current. Each net was 45.6 m long and consisted of six, equal length, alternating panels of 5,1 cm, 8.3 cm and 11.4 cm bar mesh. Net panels were constructed from multifilament and cable nylon. Each panel was hung with 4.6 m deep mesh on a framework with a 3-m long vertical slacker lines attached to the float and leadline at 3.8 m intervals along the length of the net. Gillnets were held in place by 4.5-20 kg anchors depending on current. A buoy marked each anchor. Gillnets were fished for 1-4 h in depths from 3 to 35 m. Nets were deployed and retrieved by hand from the boat..

Angling gear consisted of a medium heavy action rod with a sensitive tip, a bait casting reel with 18 kg breaking strength monofilament line and 7/0 and 9/0 J-type hooks. Rods were closely attended. Hooks were baited with Pacific lamprey pieces, coho salmon pieces, whole eulachon, *Thaleichtys pacificus*, whole juvenile coho salmon or pickled herring, *Clupea sp.* We fished from an anchored boat for durations of 1/2 to 3 h in depths from 15 to 45 m.

We measured fork length of captured white sturgeon to the nearest centimeter. Hook size and bait type were recorded for all sturgeon caught by setlines and angling. We also identified and counted the catch of other fish species.

We evaluated gear based on harm caused to white sturgeon, sampling efficiency, size selectivity, and catch of other game fish. Harm was evaluated by the number of dead white sturgeon in the catch by gear. Sampling efficiency was evaluated by comparing catch-per-unit-effort (CPUE) among gears. We standardize CPUE of gear by calculating mean catch per crew week (40 hours of sampling by a crew using the gear) based on 13.4 crew weeks of setlining, 3.7 crew weeks of gillnetting and 0.9 crew weeks of angling. We evaluated size selectivity by comparing length-frequency distributions of catch among gears. We assumed size selectivity was least where the range of lengths sampled was greatest. Statistical differences in length frequencies of fish captured among gears were identified with chi-square tests. We also used chi-square analysis to test for the selectivity associated with hook size and bait type used while setlining.

## RESULTS

All three gear sampled white sturgeon essentially unharmed. Direct mortality was only one fish for each gear.

Setlines were the most productive gear (Table 1). Catch per crew week with setlines was 1.24 times catch with gillnets and 1.78 times catch by angling.

Different gear caught different sizes of fish (Figure 2) and differences were significant between setlines and gillnets ($X^2 = 340.7$; df = 7; $p < 0.01$). Setlines captured white sturgeon over a much wider range of lengths and fish of a greater length than gillnets. Sample sizes from angling were inadequate to statistically compare length distribution differences with other gears.

Differences in length-frequency distributioy were significant for white sturgeon captured by various hook sizes ($X = 88.3$; df = 18; $p < 0.01$) (Figure 3). Larger hooks took larger fish and fish over a wider range of fork lengths. White sturgeon greater than 90 cm fork length appeared fully recruited to all setline hook sizes.

No significant difference in length-frequency distributions was detected between bait types ($X = 5.2$; df = 5; $p = 0.389$).

Gillnets frequently caught fish other than sturgeon including several game species (Table 2). Setlines caught only the nongame northern squawfish. No other fish were caught while angling for sturgeon.

## DISCUSSION

We concluded that setlines were the best available gear for our study. Setlines caught more white sturgeon per crew hour than the other gears and did not catch any other game fish. Setlines also appeared to take the most representative sample of white sturgeon over 90 cm based on length-frequency distributions of catches. We were primarily concerned with white sturgeon 90 cm and larger, corresponding to lengths harvested in the fisheries, and the reproductive stock (fish longer than 183 cm, the maximum legal length limit).

The gillnets had many drawbacks and few advantages over setlines. Whereas white sturgeon mortality was low in gillnets, the nets captured

TABLE 1. Summary of white sturgeon effort and catch in The Dalles Reservoir , 1987.

| *Gear* | *Number of Observations* | *Crew hours* | *Catch* | *Catch per 40 crew hours* |
|---|---|---|---|---|
| Setline................. | 233 | 538 | 826 | 61.4 |
| Gillnet................. | 87 | 149 | 184 | 49.4 |
| Hook and line........... | 25 | 36 | 31 | 34.4 |

TABLE 2. Incidental catch of fish other than sturgeon in The Dalles Reservoir, 1987.

| *Species* | *Setline* | *Gillnet* | *Hook and Line* |
|---|---|---|---|
| Carp, *Cyprinus carpio*.......................... | 0 | 4 | 0 |
| Channel catfish, *Ictalurus punctatus*............ | 0 | 1 | 0 |
| Chinook salmon, *Oncorhynchus tshawytscha*........ | 0 | 1 | 0 |
| Largescale sucker, *Catostomus macrocheilus*...... | 19 | 6 | 0 |
| Northern squawfish, *Ptychocheilus oregonensis*... | 0 | 14 | 0 |
| Sockeye salmon, *Oncorhynchus nerka*............. | 0 | 3 | 0 |
| Steelhead, *Oncorhynchus mykiss*.................. | 0 | 10 | 0 |
| Walleye, *Stizostedion vitreum*.................. | 0 | 2 | 0 |

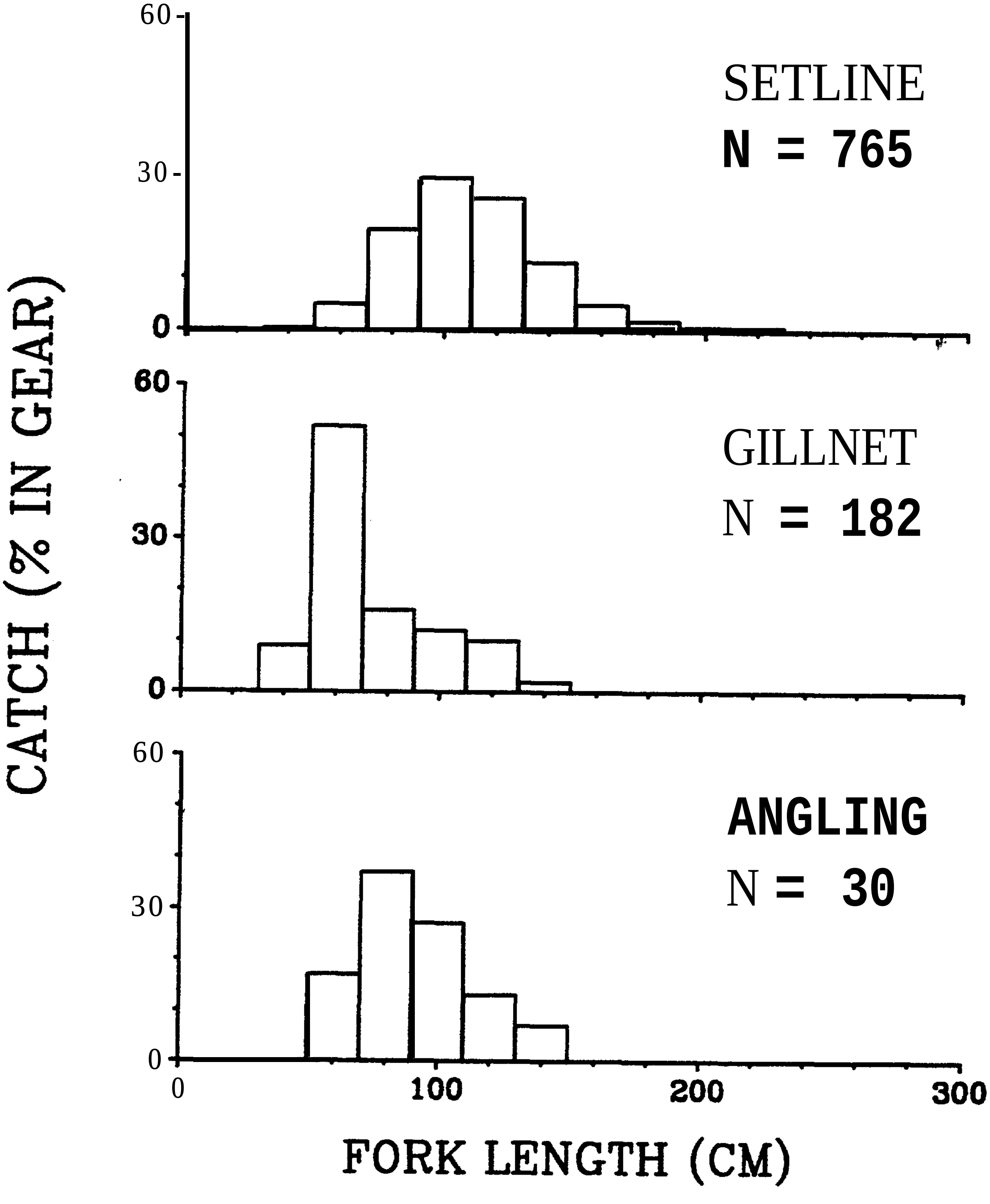

FIGURE 2. Length-frequency distributions of white sturgeon collected with various gear in The Dalles Reservoir of the. Columbia River, 1987.

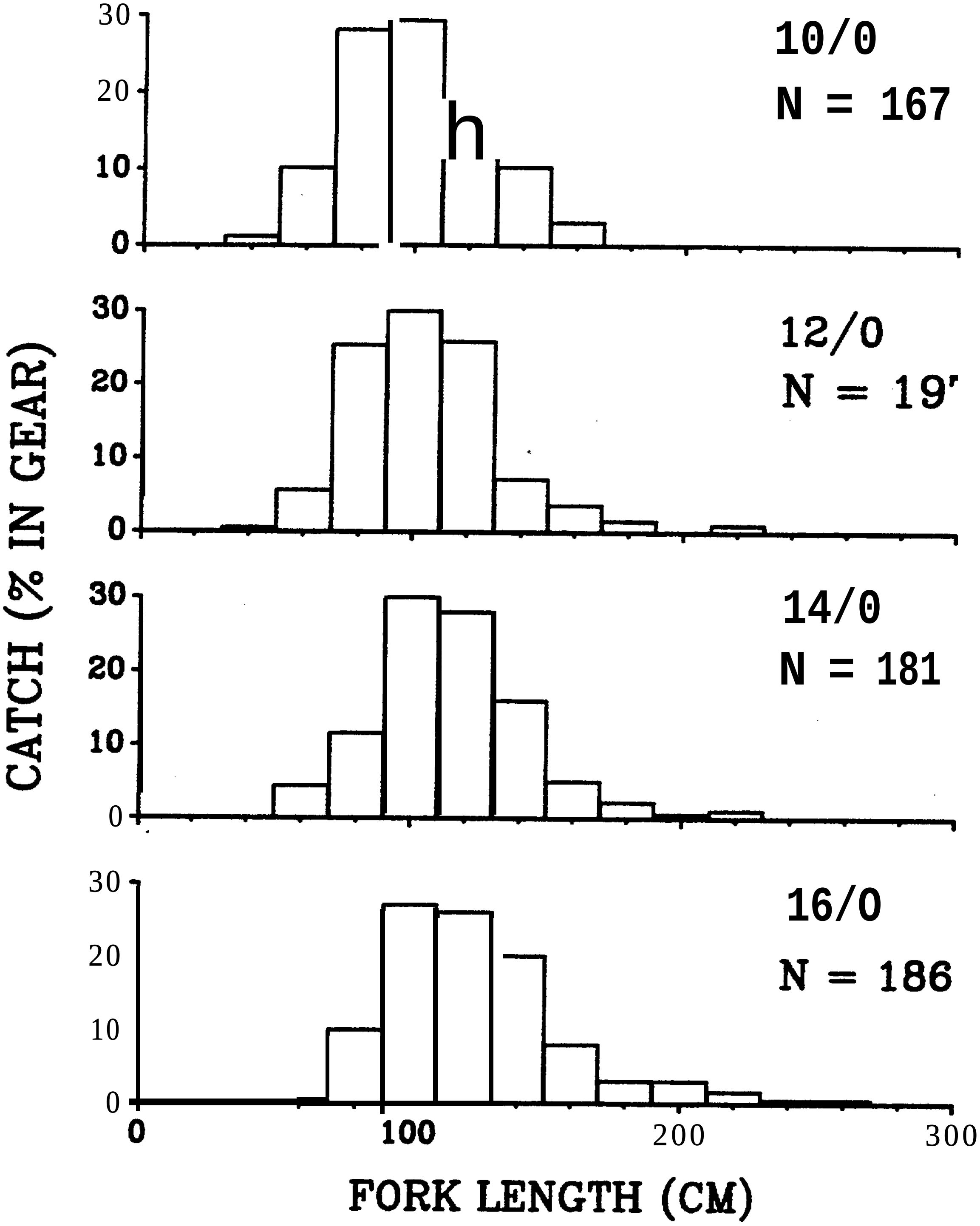

FIGURE 3. Length-frequency distributions of white sturgeon collected with various hook sizes on setlines in The Dalles Reservoir of the Columbia River, 1987.

fish other than sturgeon, particularly adult salmon and steelhead, often with a substantial mortality rate. This restricted use of gillnets to areas and times where salmon and steelhead were absent. Gillnets also captured white sturgeon from a narrower range of lengths than did setlines, and much of the catch consisted of fish under 90 cm fork length.

Angling was also inferior to setlines. Although mortality was low, the effort per fish was high. The length range of white sturgeon captured with hook line fell within that captured by setlines, although a similar distribution might.be expected with a greater sample size.

We will only sample with setlines for the remainder of the study. However, we have made a few modifications to address the efficiency and selectivity of our setlines. We are discontinuing using 10/0 hooks for the following reasons: (i) they required more crew hours to use because they were harder to sharpen and bait and required more frequent replacement; (ii) the white sturgeon they captured were within the range of those captured with 12/0 hooks; and (iii) these hooks were often straightened out or snapped off, apparently unable to hold larger fish. We will only use 136-kg test gangions because of the number of broken 68-kg test gangions observed.

Finally, we will only use Pacific lamprey for bait. Pacific lamprey slices appear to be an attractive bait for white sturgeon for more than one day. Coho salmon pieces often fell apart within 24 hours. Further, Pacific lamprey is relatively easy to obtain and minimizes preparation and gear deployment time.

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# REPORT B

# Use of an Artificial Substrate to Collect White Sturgeon Eggs

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The white sturgeon, Acipenser transmontanus, is an important recreational and commercial fish in the Columbia River, Oregon and Washington. In 1988, the estimated recreational and commercial harvests of this species downstream from Bonneville Dam (the lowermost dam on the Columbia River, River Kilometer 234) were 43,100 and 6,900 sturgeon, respectively (Hess and King 1989).

Despite the economic importance of white sturgeon, there are relatively little data on its early life history in the Columbia River. Accordingly, a study was initiated in 1987 to better describe where and when white sturgeon spawn downstream from Bonneville Dam. Early in this study white sturgeon eggs were collected with plankton nets and bottom trawls (McCabe and McConnell 1988). In 1988, an egg collection system utilizing an artificial substrate was developed to sample the highly adhesive eggs of this species. This paper describes the fabrication and use of this artificial substrate system.

The collection system was constructed by cutting a roll of latex-coated animal hair (AK725R-4, manufactured by Air Kontrol, Batesville, Mississippi[1]) into 76 X 91-cm pieces and securing two back to back pieces to an angle-iron frame with strips of flat iron bar (Figure 1). The strips of flat bar were held in place with nuts and bolts to facilitate removal of the substrate from the frame. Also, two strips of flat bar were welded in place across one side of the frame to provide additional support for the substrate. By placing the substrate pieces back to back in each frame, it made no difference which side of the frame rested on the river bottom. Two short sections (1.2 m) of 5-mm diameter cable were used to attach the frame to an anchor.

A three-fluke anchor similar to a grapnel was used to hold the substrate and frame in place on the river bottom, and proved successful in holding against strong currents on cobble-boulder bottoms. The anchor was constructed of a 30-cm section of PVC pipe (8-cm inside diameter), reinforcing steel bars (13-mm diameter), and concrete (Figure 1). One piece of reinforcing bar was bent to form two of the anchor flukes (each fluke was about 20 cm long) and a loop for an attachment for the cables. A short piece of reinforcing bar was bent to form the third fluke and welded to the other reinforcing bar. The reinforcing bars were placed inside the PVC pipe and held in place with concrete. Total weight of the anchor was about 5.4 kg.

A buoy line (8-mm diameter) was attached to the anchor to mark the location of the substrate. Length of the line varied depending upon water depth and velocity. Artificial substrate systems were placed at depths ranging from about 3 to 15 m and surface water velocities ranging from less than 1 m/s to greater than 2 m/s. In areas where surface water velocity was greater than 1.5 m/s, the length of the buoy line was at least four times the water depth. Depending upon water velocity, three to six buoys (30-cm long and 12-cm diameter) were secured to one end of the line; more buoys were required in swift water.

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[1] Reference to trade names does not imply endorsement by NMFS, NOAA.

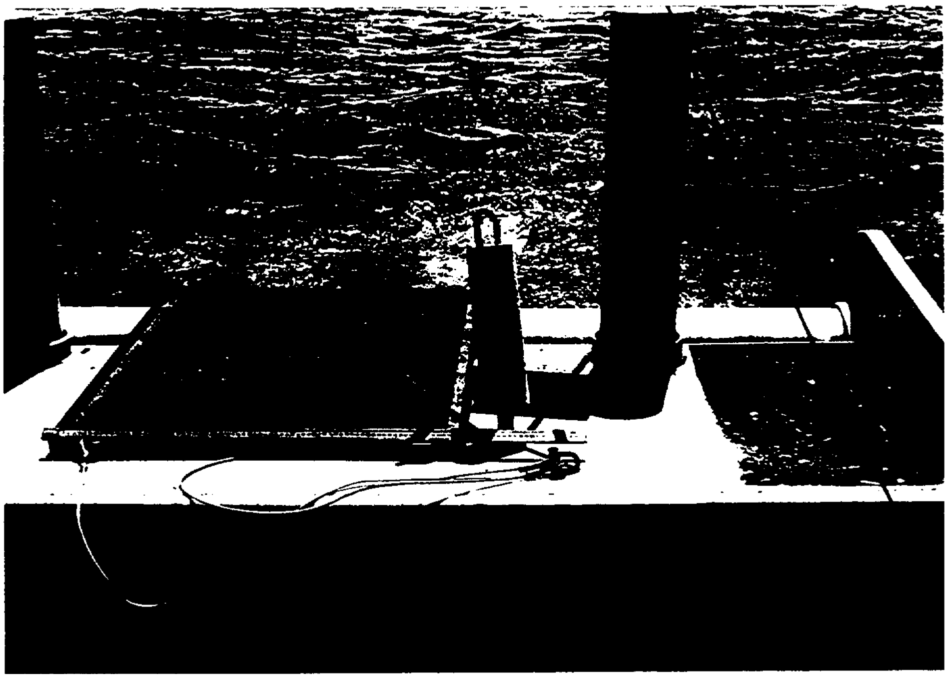

Figure 1. The artificial substrate, frame, and anchor used to collect white sturgeon eggs in the Columbia River downstream from Bonneville Dam.

In 1988 and 1989, 685 and 305 white sturgeon eggs were collected on artificial substrates deployed downstream from Bonneville Dam, respectively. Individual collections ranged from 0 to 423 eggs in 1988 and from 0 to 212 eggs in 1989. At least one egg was collected on 10 out of 22 sets in 1988 and on 7 out of 24 sets in 1989. Eggs were removed from the artificial substrate directly by hand or with the aid of a pointed instrument such as a net-mending needle. When large numbers of eggs were collected, after hand-picking, the substrate was washed with water to remove eggs that remained entangled. Eggs were preserved in a 4% or greater buffered formaldehyde solution for later estimation of developmental stages and spawning dates.

The artificial substrate is a useful tool for identifying white sturgeon spawning areas and determining timing of spawning. Ideally, both a plankton net (Kohlhorst 1976; McCabe et al. 1989) and artificial substrates should be used. Compared to the use of a net only, artificial substrates increase the chance of detecting spawning in an area because they can be fished for extended periods. In addition, artificial substrates can be placed in areas where it may not be safe or practical to use plankton nets. For example, if artificial substrates had not been used near the spillways at Bonneville Dam, we would not have detected spawning there. Disadvantages of the artificial substrate system are its vulnerability to theft and potential for the buoy line to become entangled in the propellers of passing vessels.

## ACKNOWLEDGMENTS

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## REPORT C

# Retention, Recognition, and Effects on Survival of Several Tags and Marks on White Sturgeon

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In press: <u>California Fish and Game</u>

# ABSTRACT

We evaluated retention and effects on survival of tags and marks we applied to 7,341 white sturgeon Acipenser transmontanus in the Columbia River between 1987 and 1991. Sturgeon were tagged and marked with combinations of spaghetti tags, Carlin disk tags, tattoos, barbel clips, leading pectoral fin ray sections, and lateral scute removals. Spaghetti tags placed below the anterior portion of the dorsal fin were initially retained at the highest rate but retention declined over time. Spaghetti tags below the posterior portion of the dorsal fin were retained at a slightly lower rate initially but were retained longer. Removal of a combination of dorsal scutes provides a mark that lasts more than two years, while tattoos and pectoral fin scars did not last as long. Barbel clips did not regenerate, but were subject to misinterpretation and reduced recapture rates. We recommend standardizing removal of the second right lateral scute to indicate oxytetracycline injection and the second left lateral scute to indicate passive integrated transponder (PIT) tagging for all white sturgeon studies in the Columbia River Basin.

# INTRODUCTION

Three concerns in any marking or tagging study are: Will the mark be retained for the duration of the study? Is the mark recognizable by those expected to recapture the fish? Finally, does the mark affect the survival of the fish (Wydoski and Emery 1983)? Tagging and marking of white sturgeon, Acipenser transmontanus, is particularly problematic because the fish are long lived and programs to collect population information often last several years.

A variety of methods have been used to mark sturgeon, but attempts to document success of these methods on wild sturgeon have been rare. Chadwick (1959) reported spaghetti and disk-dangler tags were shed over time and observed no difference in retention for placements below the dorsal fin, between dorsal scutes, and on the caudal peduncle of white sturgeon. Smith et al. (1990) evaluated retention of five externally visible tags (T-anchor, Carlin, Archer, Monel strap, and internal anchor) for captive shortnose, Acipenser brevirostrum, and Atlantic sturgeon, A. oxvrhvncus. Carlin tags placed at the base of the dorsal fin and internal anchor tags were both dependable, but gill net entanglement was noted as a problem with Carlin tags and severe tissue damage was associated with internal anchor tagged sturgeon released in brackish water. Sequentially numbered tattoos have been used on wild white sturgeon in Idaho (Cochnauer et al. 1985), but reports of retention are variable: Tattoos were clearly visible after one year on captive white sturgeon (Bordner et al. 1990)) but were barely visible on captive shortnose sturgeon after four months (Smith et al. 1990). Removal of the leading pectoral fin ray for age determination leaves a recognizable scar, but has been reported to adversely affect survival (Kohlhorst 1979). Silver nitrate marks and barbel removal have also been tried with limited success (personal communications with Fred Partridge, Idaho Department of Fish and Game, Boise, Idaho, and Robert Pipkin, University of California, Davis, California). Barbel clips on captive sturgeon did not regenerate, but Bordner et al. (1990) expressed concern that this mark may affect the fitness of wild fish.

Retention and recognition are interrelated and difficult to distinguish in a field study. Mark retention implies the mark remains distinct over time. Evaluation of retention is confounded by three factors: 1) failure to apply a mark or failure to apply it adequately for recognition, 2) failure to recognize an existing mark, and 3) recognition of a mark that was not actually applied. In this analysis retention may be thought of as the combination of true mark retention and correct recognition of marks by samplers. Mark loss may be due to factors 1 or 2, or regeneration of structures. Natural occurrence of a mark (factor 3) may be due to natural loss of the structure or an error by samplers.

Secondary marks typically need to convey information beyond the original presence of a tag. Specific combinations of secondary marks may be used to indicate year of tagging and identify treatment groups. Differences between recorded marks applied and marks at recapture may reflect inadequate mark application, mis-reading of the marks at recapture, or a partial loss of marks. Regardless of the reason for differences, the level of recording error indicates the utility of a mark to convey specific information.

During 1987-1991 we used spaghetti and disk tags, tattoos, barbel removal, pectoral fin ray scars, and lateral scute removal marks on white sturgeon to estimate population characteristics in Bonneville, The Dalles, and John Day reservoirs on the Columbia River (Beamesderfer and Rien 1992). This paper summarizes the retention, recognition (including how well marks conveyed specific information and the incidence of 'natural' marks), and survival effects of these tags and marks.

## METHODS

From 1987 through 1991 we tagged and marked 7,341 white sturgeon (Table 1). Combinations of marks changed over time as new information became available. White sturgeon were captured using setlines, gill nets, angling gear, and a creel survey (Elliott and Beamesderfer 1990).

All untagged white sturgeon over 64 cm fork length (FL) were tagged with one spaghetti tag inserted below the anterior portion of the dorsal fin (Table 1). Spaghetti tags were made of extruded vinyl with a hollow core. They were tied with an overhand knot one cm behind the dorsal fin. White sturgeon longer .than 84 cm FL were tagged with an additional tag inserted below the posterior portion of the dorsal fin. From 1987 through 1989 we used a spaghetti tag in the posterior position. During 1989 we switched to Carlin disk tags (Wydoski and Emery 1983) in the posterior position.

We applied sequentially numbered tattoos to the pelvic girdle of sturgeon longer than 75 cm FL (Table 1). The skin was rubbed with black tattoo ink and physical pressure was used to puncture the flesh over the pelvic girdle with the needles of a rotary tattoo. Tattoo numbers were about one cm tall.

All tagged fish were also marked using one or more of the following procedures: barbel clips, removal of fin-ray sections, and removal of scutes. We removed a single barbel from specific positions during 1987 through 1989 to identify the year we tagged the fish (Table 1). We removed right or left pectoral fin ray sections from sturgeon to determine age (Table 1). A small hacksaw blade or coping saw was used to make two cuts through the leading pectoral fin ray, the first cut was made about 5 mm distal of the articulation of the fin, and a second was made about 10 mm distal of the first cut. The fin ray piece was then removed using pliers and a knife inserted between the rays as needed. Done correctly, little bleeding was associated with this procedure, but it left a recognizable scar on the leading edge of the fin. We removed one or two scutes in various combinations from the first four lateral scutes on the right and left sides beginning in 1988 (Table 1). Scute removal patterns corresponded to the year the fish was tagged and whether or not the fish had been injected with oxytetracycline (used to validate our aging technique). Scutes were removed by shaving them off close to the skin surface using a knife. The site of scute removal heals over darker and smoother than the surrounding skin.

Table 1. Tags and marks applied to white sturgeon in three reservoirs of the Columbia River from 1987 through 1991.

| | Year of release | | | | | |
|---|---|---|---|---|---|---|
| Tag or mark | 1987 | 1988 | 1989 | 1990 | 1991 | Total |
| Anterior spaghetti tag | 830 | 1,704 | 2,684 | 516 | 1,[illegible]0 | 7,341 |
| Posterior spaghetti tag | 624 | 1,132 | 946 | 0 | 576 | 2,702 |
| Posterior disk tag | 0 | 0 | 9 | 207 | | 792 |
| Tattoo | 489 | 689 | 0 | 0 | 0 | 489 |
| Barbel clip | 829 | | 575 | 253 | 210 | 1,518 |
| Pectoral fin scar | 340 | 316 | | | 1 | 2,694 |
| Scute removal | 0 | 1,693 | 2,683 | 516 | 1,568 | 6,460 |

We compared retention of tags and marks over time. The year of tagging was determined from a tag remaining on the fish, or from secondary marks applied at the time of tagging. Mark retention was summarized only for fish that had a tag when recaptured. Evaluation of tag and mark retention was restricted to tags recovered by our sampling crews or creel interviews. Retention rates among years-at-large were compared using chi-square tests of independence unless cell frequencies were small, in which case we used Fisher's exact test (FET; Sokal and Rohl f 1981). Retention rates for spaghetti tags in anterior and posterior positions for fish at-large less than one year were compared using a chi-square test of independence. Statistical comparisons were performed with the Statistical Analysis System (SAS 1988).

Mark recognition was investigated by comparing the marks recorded at initial capture to the marks recorded when a tagged fish was recaptured. Two groups of trained samplers examined recaptured fish, the groups had different levels of expertise in recognizing marks. The observations of the two groups were compared. Samplers who applied marks and tags as part of their routine duties were considered to have greater expertise in mark recognition than creel samplers who were trained in the recognition of marks, but did not apply marks as part of their regular duties. Differences in recognition rates between the groups of samplers were considered to indicate how difficult particular marks were to identify. The utility of marks to convey specific information was examined by comparing the ratio of recaptured fish with the same recorded mark combination when tagged and when recaptured between sampler groups. Marks were considered useful for conveying information if they were interpreted consistently between the groups.

The rate of natural occurrence, or sampler error, for barbel removals, pectoral fin ray scars, and lateral scute removals was estimated as the proportion of recaptured fish that had acquired a mark while at-large. Such marks may represent natural losses of structures, errors in data recording, or mistakes in mark interpretation. Marks present on untagged fish were assumed to indicate tag loss and were not used in this analysis.

Recapture rates among unmarked fish and fish marked with barbel clips and pectoral fin ray scars were compared using FET. We were unable to compare recapture rates for other tags and marks because our pattern of releasing marked and unmarked fish did not lend itself to unbiased control group comparisons.

## RESULTS

Samplers recovered 645 sturgeon that had previously been tagged. Of these, all had been spaghetti tagged in the anterior position (anterior tag), 319 had been spaghetti tagged in the posterior position (posterior tag), and 30 had been tagged with a disk tag. Of all previously tagged fish we recaptured, 593 (92%) had retained at least one tag at recapture. Among recaptures of tagged fish, 64 had been tattooed, 204 had been barbel clipped, 174 had fin ray sections removed (fin marked), and 448 had lateral scutes removed (scute marked) at the time of marking.

Of the 645 sturgeon that had been anterior tagged, 99 lost their tag prior to recapture (Table 2). Anterior spaghetti tag retention rates were significantly different among years and declined with years-at-large. The first year tag retention rate for anterior spaghetti tags was significantly higher than for posterior spaghetti tags (chi-square test: df = 1, $x^{4}$- = 7.39, 1 = 0.007). Posterior tags were lost on 42 of the 319 recaptures. Posterior tag retention did not vary significantly among years. (Table 2). Of 30 disk tagged sturgeon recaptured, 4 had lost the tag.

Tattoos were retained only within the first year-at-large (Table 2). Barbel clips were retained by 93% of recaptures. The retention rate did not vary significantly among years-at-large. Fin marks were retained by 86% of recaptures. The trend in long term fin mark retention was not clear, but retention varied significantly among years and was highest during the first year at-large. Scute marks were retained by 96% of recaptures. Retention rate for scute marks did not vary significantly among years. First year retention did not vary significantly among marks (FET: df = 1, p = 0.429).

Tattoo recognition was low among all samplers, which reflects low retention after one year at-large (Table 3). Tagging crews saw and correctly recorded barbel clips, fin scars, and scute marks more often than creel samplers. Fin scars were difficult to recognize: tagging crews recognized scars twice as often as creel samplers. Barbel clips and scute marks were recognized and recorded correctly more often than other marks by both groups of samplers.

All marks had low natural occurrence rates: 3% of 362 for barbel loss, 6% of 380 for pectoral fin scars, and 5% of 104 for scute loss.

The recapture rate for 757 barbel clipped sturgeon was 11%, while 17% of 704 unclipped sturgeon were recaptured, this difference was significant (FET: df = 1, p = 0.008). We recaptured 7% of 618 fish from which we took pectoral fin ray samples, and 6% of 584 that were not fin-ray sampled, these rates were not significantly different (FET: df = 1, P = 0.538).

## DISCUSSION

Tagging sturgeon using two tags is the only method of ensuring retention rates near 100% rates over a period of several years. Posterior spaghetti tag retention was lower in the first year than anterior tags or disk tags, but the long term retention of posterior tags was better than other tags. We could not statistically compare spaghetti tag and Carlin disk tag retention, but both were retained at high rates in the first year after tagging. Unless Carlin disk tags are retained at significantly higher rates, we would choose to use spaghetti tags, because spaghetti tags are easier to apply and because Carlin tags

Table 2. Retention/recognition rates for various tags and marks applied to white sturgeon, Columbia River, 1987-1991.

| | Years-at-large | | | Chi-square results | | |
|---|---|---|---|---|---|---|
| Tag or mark | <1 | 1 | 2+ | df | $\underline{X}^2$ | $\underline{P}^a$ |
| Anterior spaghetti tag | | | | | | |
| retained | 244 | 167 | 135 | | | |
| lost | 11 | 35 | 53 | | | |
| retention rate | 96% | 83% | 72% | 2 | 48.37 | <0.001 |
| Posterior spaghetti tag | | | | | | |
| retained | 115 | 111 | 53 | | | |
| lost | 88% | 15 | 12 | | | |
| retention rate | | 88% | 82% | 2 | 2.00 | 0.367 |
| Posterior disk tag | | | | | | |
| retained | | 7 | -- | | | |
| lost | 19 | 2 | \-- | | | |
| retention rate | 90% | 78% | -- | -- | -- | -- |
| Tattoo[b] | | | | | | |
| retained | 9 | 0 | 0 | | | |
| lost | 1 | 33 | 4 | | | |
| retention rate | 90% | 0% | 0% | 2 | -- | <0.001[c] |
| Barbel clip[b] | | | | | | |
| retained | 60 | 83 | 35 | | | |
| lost | 4 | 5 | 4 | | | |
| retention rate | 94% | 94% | 88% | 2 | -- | 0.653[c] |
| Pectoral fin scar[b] | | | | | | |
| retained | 81 | 31 | 28 | | | |
| lost | 4 | 17 | 2 | | | |
| retention rate | 95% | 64% | 93% | 2 | 25.55 | <0.001 |
| Scute removal[b] | | | | | | |
| retained | 2 8 | 96 | 111 | | | |
| lost | 96% | 4 | 1 | | | |
| retention rate | | 96% | 99% | 2 | 2.41 | 0.300 |

[a] *Retention* rates' *among 'years-at-large'* groups *are considered significantly different if* $P \leq 0.05$.

[b] *Numbers reflect fish examined* for *a particular mark, not* all *previously marked fish recaptured.*

[c] *Fisher's exact test results*

Table 3. Recognition of marks on white sturgeon by trained personnel with varying experience, Columbia River, 1987-1991. Fish were tagged recaptures that samplers examined without knowledge of the original marks applied.

| Mark,<br>mark status at recapture | Modest[a] |  | Expert[b] |  |
|---|---|---|---|---|
|  | N | Percent | N | Percent |
| **Tattoo** |  |  |  |  |
| Mark seen and correctly recorded | 2 | 17% | 3 | 9% |
| Mark seen but number not legible | 0 | 0% | 4 | 11% |
| No mark seen | 10 | 83% | 28 | 80% |
| **Barbel clip** |  |  |  |  |
| Mark seen and correctly recorded | 31 | 68% | 129 | 89% |
| Mark seen but incorrectly recorded[c] | 9 | 20% | 9 | 6% |
| No mark seen | 6 | 13% | 7 | 5% |
| **Pectoral fin scar** |  |  |  |  |
| Mark seen and correctly recorded | 6 | 38% | 111 | 75% |
| Mark seen but incorrectly recorded[c] | 3 | 18% | 20 | 14% |
| No mark seen | 7 | 44% | 16 | 11% |
| **Scute removal** |  |  |  |  |
| Mark seen and correctly recorded | 37 | 74% | 349 | 93% |
| Mark seen but incorrectly recorded[c] | 4 | 8% | 23 | 6% |
| No mark seen | 9 | 18% | 4 | 1% |

[a] *Personnel of modest experience were primarily creel clerks who were trained in mark recognition but did not apply marks.*

[b] *Expert personnel tagged and recaptured fish as part of their regular duties.*

[c] *Personnel observed the mark but the exact position or combination recorded differed from that recorded at marking.*

may increase susceptibility to capture with gill nets (Smith et al. 1990).

Scute removal proved to be a long-term mark that is recognizable by samplers with varying levels of experience. Patterns of scute removals may be used to convey information about fish handling at tagging to trained samplers. Retention of tattoos, barbel clips, fin marks, and scute was similar in the year of tagging, but declined for tattoos and fin marks in subsequent years.

Barbel clips were retained over long periods, but reduced recapture rates of barbel clipped fish suggest they reduce survival. In contrast, removing a section of the leading pectoral fin ray did not reduce recapture rates, suggesting this did not affect survival. Kohlhorst (1979) observed that removal of the first pectoral fin ray resulted in "substantial" mortality of white sturgeon during the first year following removal. We believe the difference in mortality rate may be attributed to the techniques used: Kohlhorst removed the entire fin ray starting as close to the articulation as possible. We removed a small (10 mm) section of the fin ray and leave the basal portion of the fin-ray intact. Sequential fin-ray cross-sections outward from the articulation indicate the first annuli are still visible in sections adjacent to the basal portion.

Scute marks appear to be an ideal secondary mark. We were not able to evaluate the effect of scute marks on survival, but suspect it is minor. We removed the second right lateral scute to identify fish that had been injected with oxytetracycline. We propose this mark be adopted region-wide and further propose reserving removal of the second left lateral scute as a standard to indicate a sturgeon that has been PIT (passive integrated transponder) tagged. The PIT tag has shown promise as a long-term tagging technique for sturgeon, but one problem noted was the lack of a readily identifiable external mark (Smith et al. 1990)

While spaghetti tags were the most effective of the tags we examined, they are less than satisfactory. Spaghetti tags left a wound that we occasionally saw on fish at-large more than one year and tag numbers become difficult to read over time. The legibility of tags is particularly important in studies that depend on voluntary tag returns from anglers. We use returns from anglers to correct the number of tagged fish at-large in estimates of abundance and also to calculate exploitation rates. Anglers must be able to recognize the tag to report harvest of tagged fish. Continued evaluation of tag types that may be less irritating to the fish and remain more legible over time is recommended. Among potential alternative tag types subcutaneous implants and PIT tags may be less irritating and remain legible; however, these are difficult for anglers to recognize. Latex-coated spaghetti tags with a stainless steel wire core may improve legibility and retention over vinyl hollow core spaghetti tags in studies that rely on angler reporting.

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## REPORT D

# Feasibility of Radio Telemetry to Document Fish Movement and Habitat Use in Lower Columbia River Impoundments

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## Abstract

The feasibility of using radio telemetry to document fish movement and habitat use was assessed in Bonneville Pool. Transmitters (280 day,49.401 MHz peak output 0.27 milliwatts) were lowered to various depths in areas with physical obstructions to assess the effects of depth and obstruction on signal detection. Individual transmitters were located to within a 15 to 30 m circle, and detected to a distance of 0.75 miles. Radio transmitter signal detection was reduced by rough substrate and depth. High voltage powerlines and water turbulence had no effect on signal detection. With the equipment tested, signals were lost when transmitters were submerged at depths of over 30 m. Radio telemetry appeared feasible for tracking white sturgeon if more powerful transmitters than the ones tested were used.

## Introduction

Study of white sturgeon *Acipenser transmontanus* population dynamics, reproduction, and early-life history in the lower Columbia River has been ongoing for five years (Palmer et al. 1988; Parsley et al. 1989; Duke et al. 1990; Miller et al. 1991). However, with the exception of mark-and-recapture location data, daily and seasonal movement of white sturgeon remains largely uninvestigated. More site specific observations would be helpful to generate white sturgeon habitat use curves. The objective of this study was to assess the feasibility of using radio telemetry to document daily and seasonal movement and habitat use of white sturgeon and northern squawfish *Ptychocheilus oregonensis* under conditions of physical obstruction, underwater structure, electrical and radio interference, extreme water turbulence, and depths >30m.

## Methods

This study was conducted in the uppermost 22 km of Bonneville Pool which has depths and substrates representative of the entire reservoir and other lower Columbia river impoundments (Fig. 1).

A 280 day radio transmitter (49.401 MHz, peak output 0.27 milliwatts) obtained from Advanced Telemetry Systems (ATS[1], Model 22, Bethell MN.) was surgically implanted in a dead common carp *Cyprinus carpio* using procedures presented by Faler et al.( 1988), and was submerged to < 1 m above the substrate in a variety of habitats to evaluate transmitter signal reception. In habitat with water velocity exceeding 1-1.5 m/s, an identical transmitter was enclosed in a weighted piece of PVC pipe (2.5 cm outer diameter X 15.2 cm long) to ensure retrieval. Transmitters were attached to an anchor line with a float attached at the surface for retrieval.

A radio receiver (ATS Model "Challenger 200"), a four element yagi antenna, and a hand-held loop antenna were used to detect transmitter signals. In a 6.0 m fiberglass boat, the yagi antenna was attached to a mast 3.0 m high which rotated 360'. Signal reception was tested at eleven sites: four shallow water (depth 5.5-10.7 m), five deep water (16.2-48.8 ml, and two which provided physical obstruction and electrical interference (Table 1). Shallow and deep water sites were further subdivided as havung smooth or rough substrates. Rough substrate referred to frequent or continuous bottom contour irregularity >1.5 m. Two of the four shallow water sites had smooth substrates and two had rough substrates. Two of the five deep water sites had smooth substrates, while the remaining three had rough substrates. A five-digit location code was assigned to each test site: the first four digits were river mileage to the nearest tenth; the fifth digit was a value from 1 to 4, representing four longitudinal quarters of the river, from the Washington to the Oregon shoreline.

After anchoring transmitters at a site, the boat was driven directly away from the transmitter until the signal was lost using the Yagi antenna. The boat was then turned 180° and driven until a discernable transmitter signal was detected. This was the maximum transmitter

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[1] Reference to trade name does not imply endorsement by USFUS.

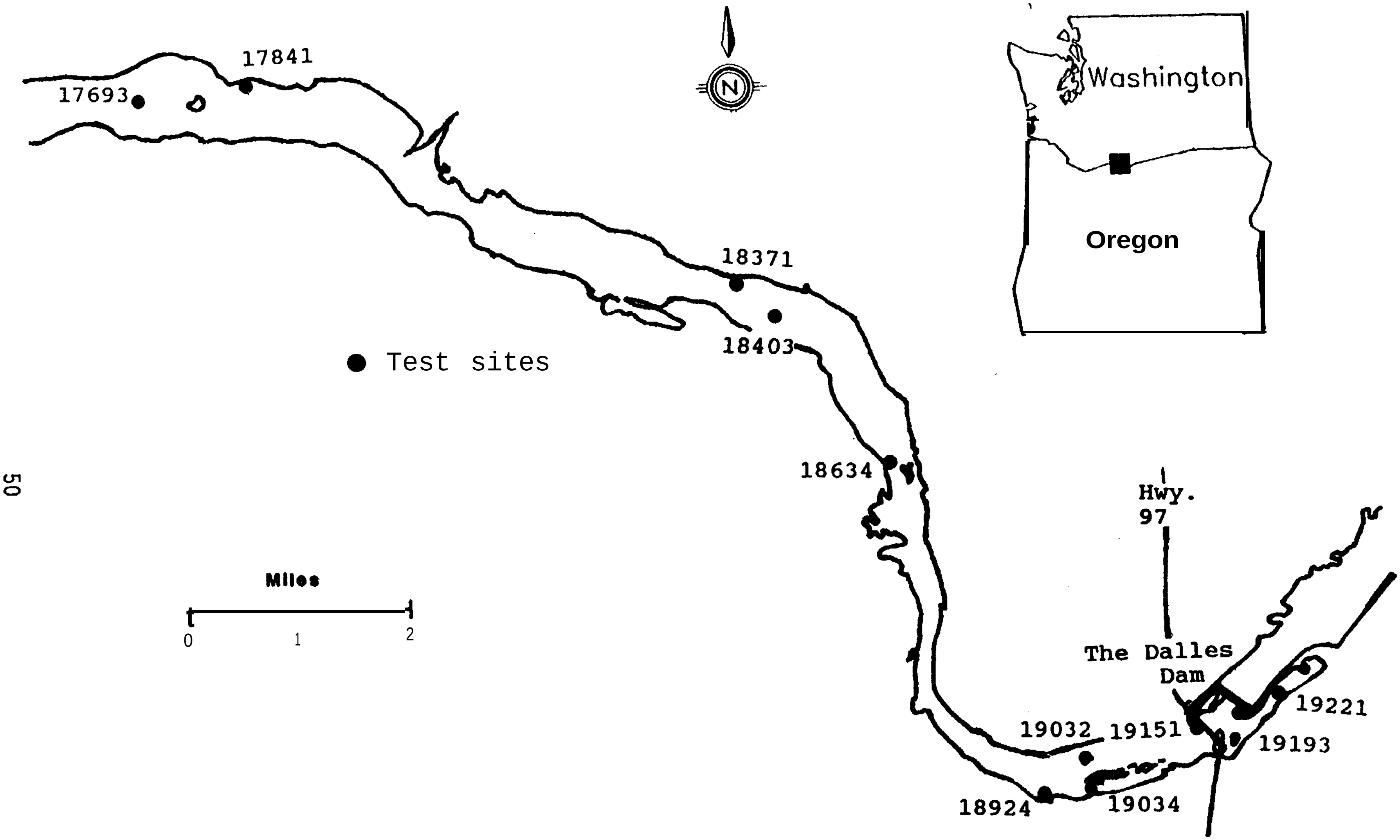

Figure 1. Location of study area and radio transmitter test sites in Bonneville Pool.

reception distance for a particular direction. Using visual triangulation, this point was marked on a National Oceanic and Atmospheric Administration (NOAA) 1:40,000 scale navigation chart for later measurement to the nearest 100 m. Maximum transmitter detection distances were measured in 3 to 7 radiating directions at each site, depending on channel morphology, presence or absence of physical obstructions, and the site location; more measurements to determine reception area were made at sites with obstructions to radio wave transmittance, such as rough substrates, man-made structures, or deep water, than at sites lacking these characteristics. In addition to the Yagi antenna, a hand-held loop antenna was used to pinpoint transmitter location. Locations were noted in relation to features on NOAA navigation charts.

## Results

Maximum distances that transmitter signals were detected using the boat-mounted yagi antenna ranged from 0.2 miles at a depth of 27.4 m, over rough substrate, to 0.75 miles from a transmitter at a depth of 10.7 m over a smooth substrate (Table 1). No detectable signal strength differences were apparent between the transmitter in the fish or in the section of PVC pipe. Transmitter signals became undetectable from the boat when transmitters were submerged to depths > 30.5 m (Table 1). Due to obstructive substrates and locations of test sites in the river channel, multiple measurements of maximum transmitter reception distance at individual sites varied considerably (Table 2).

Depth and physical interference were the two main factors which affected transmitter signal detection. Maximum transmitter reception was reduced in areas of rough substrate at any depth, however depth further reduced signal transmission. Water turbulence and interference from high-voltage powerlines had no apparent detrimental effects on transmitter signal reception. After approximating transmitter location with the yagi antenna we used a hand-held loop antenna to locate transmitters to within a 15-30 m circular area.

## Discussion

Radio telemetry appears to be a feasible method to track white sturgeon movements in the Columbia River at depths less than 30 m. With higher powered transmitters than the ones tested (peak output 0.27 milliwatts) depths over 30 m may be sampled. White sturgeon are large enough that being tagged with more powerful, longer lasting transmitters would be feasible. White sturgeon often inhabit depths over 30 m in the Columbia River, and the tested transmitters lacked sufficient signal strength for use on fish at such depths. In addition to stronger transmitters, a state-of-the-art receiver would likely improve the efficiency of a telemetry study. Transmitter detection could also be improved by supplemental tracking from aircraft or from vehicles on roads which parallel the Washington and Oregon shorelines.

Table 1. Characteristics of radio transmitter test sites.

| Description | Location Number | Site Type[a] | Depth (m) | Max. reception distance (mi.) |
|---|---|---|---|---|
| The Dalles backwater | 190.3 | R | 5.4 | 0.45 |
| Inside spillgate | 191.9 | I | 6.4 | 0.35 |
| Doug's Beach shallow | 184.0 | S | 8.5 | 0.75 |
| Ice/Trash sluiceway | 192.2 | I | 9.1 | 0.30 |
| Flat at The Dalles Ramp | 190.3 | S | 10.7 | 0.70 |
| Below The Dalles Bridge | 191.5 | R | 10.7 | 0.35 |
| Memaloose Isl. Dunes | 176.9 | R | 16.2 | 0.30 |
| Wa. shore, Memaloose | 178.4 | R | 27.4 | 0.20 |
| Water intake, OR. shore | 189.2 | S | 29.9 | b |
| Doug's Beach Deep | 183.7 | S | 35.1 | c |
| Squally Pt. OR. shore | 186.3 | S | 48.8 | c |

a (R=rough substrate, S=smooth substrate, I=interference)
b transmitter signal lost at depth of substrate
c transmitter signal lost before depth of substrate

Table 2. Maximum transmitter reception distance measurements.

| Site Name | Site Number (River mile) | Max. transmitter detection distance (mi) |
|---|---|---|
| The Dalles backwater | 190.3 | 0.45 |
| | | 0.35 |
| | | 0.40 |
| Inside spillgate | 191.9 | 0.20 |
| | | 0.20 |
| | | 0.20 |
| | | 0.25 |
| | | 0.35 |
| | | 0.30 |
| Doug's Beach shallow | 184.0 | 0.75 |
| | | 0.70 |
| | | 0.60 |
| | | 0.65 |
| | | 0.30 |
| Ice/Trash sluiceway | 192.2 | 0.10 |
| | | 0.10 |
| | | 0.30 |
| | | 0.25 |
| Flat at The Dalles Ramp | 190.3 | 0.70 |
| | | 0.30 |
| | | 0.40 |
| | | 0.65 |
| Below The Dalles Bridge | 191.5 | 0.35 |
| | | 0.30 |
| Memaloose Isl. Dunes | 176.9 | 0.25 |
| | | 0.30 |
| | | 0.20 |
| | | 0.25 |
| | | 0.25 |
| | | 0.20 |
| Wa. shore, Memaloose | 178.4 | 0.20 |
| | | 0.15 |
| | | 0.10 |
| Water intake, DR. shore | 189.2 | to. 10 |
| Doug's Beach Deep | 183.7 | <0.10 |
| Squally Pt. OR. shore | 186.3 | <0.10 |

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# REPORT E

# MOCPOP 2.0: A Flexible System for Simulation of Age-structured Populations and Stock Related Functions

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## WHAT IS MOCPOP?

MOCPOP is a program for simulating annual variation in numbers, production and biomass of a population of organisms based on recruitment, mortality, and growth. Commonly used models of population dynamics (Vaughan et al. 1982), including stock-recruitment, logistic (surplus production), dynamic pool (yield), and Leslie matrix or combinations or portions of these models can be approximated with MOCPOP. MOCPOP tracks population size in numbers and biomass, and also calculates numbers of particular interest to harvest managers including yield, number of harvestable individuals, and an index of population size structure. MOCPOP also allows weighting of age-specific numbers, production, or biomass to project potential effects of a population.

This software was written to simplify use of the computer in modeling populations. It provides the flexibility to simulate a variety of populations and population processes with a minimum of experience with microcomputers and no knowledge of computer language or programming. MOCPOP is based on population models outlined by Taylor (1981) and Walters (1969)) but is much more flexible in its ‘consideration of reproduction and recruitment processes. Input population parameters and simulation results can also be more easily manipulated and inspected.

MOCPOP 2.0 uses pull-down menus off a single main menu to increase flexibility in moving around within the program. MOCPOP 2.0 also offers improved file handling and editing capabilities, more complete screening for inappropriate inputs, and additional options for inputs of population parameters.

This guide documents the operation of and calculations made by MOCPOP 2.0. Several examples are included to demonstrate the program's operation, but a broader discussion of modeling and model building can be found in other references such as Grant (1986).

## HOW TO RUN MOCPOP 2.0

To run MOCPOP 2.0:

1. Boot machine with PC-DOS or MS-DOS.
2. Place diskette containing model in default drive.
3. Start the model (type MOCPOP20 after the > prompt and press Enter).

MOCPOP 2.0 will run much faster if you copy all associated files to your hard disk and execute from there.

MOCPOP 2.0 is written in compiled Microsoft QuickBASIC 4.0 to run on IBM and IBM-compatible machines. Graphics require an IBM color graphics adaptor or a functional equivalent. MOCPOP 2.0 will support monochrome graphics cards if the program is executed using the batch file MP (type MP after the > prompt and press Enter) and if you own software using the file HGCIBM.COM and that file is in your path.

## HOW MOCPOP 2.0 WORKS

The program is executed from a main menu bar displayed across the top of the screen. Commands in the main menu (Name, Edit, Run, Predict, and Write) are typically executed in sequence to build and run a model, inspect results, and write results to a printer or file. The main menu also contains commands to get help, exit temporarily to DOS, and quit. A series of pull-down menus off the main menu bar list other options. Pop-up menus for each option may be displayed for even more detail. Commands are selected by typing designated capital letters (typically the first). The escape key may be pressed at any time to exit a pull-down or pop-up menu.

The name of the current model is displayed in the upper right corner of the screen in the main menu bar. After a model has been named, model parameters and starting values are displayed on the screen following the main menu bar. This information is contained in two screens that can be swapped by pressing the Fl key.

## NAMING A MODEL

A name must be assigned to a model before it can be edited or run. You may create a new model by pressing N to select Name in the main menu bar, then C to select Create from the Name pull-down menu. You are prompted for a name for your model. Names may have up to eight characters, typed in upper or lower case with characters following DOS conventions. All input parameters, options, and start values for variables are initially set to 1 in a newly created model.

You may save up to 30 models for future use by selecting Save in the Name pull-down menu. You are prompted for a file name to which MOCPOP 2.0 adds the extension .K20. Instead of reentering inputs each time you use MOCPOP 2.0, you may load inputs saved previously and rerun a simulation, or you may edit previous inputs and run a new simulation. To load a saved model, select Load in the Name pull-down menu. MOCPOP 2.0 will check the diskette for files with the extension .K20, list these files, and prompt you to select one. The selection is made by using cursor control keys to highlight the desired model then pressing enter. Files created using the original MOCPOP (Beamesderfer 1988) cannot be accessed by MOCPOP 2.0.

Each time a model is run, inputs are stored automatically in a file named LASTRUN. This file may be recalled for reuse, but it is not necessary to reload this file before each run because the last file loaded is retained. Files may be erased by selecting Delete in the Name pull-down menu.

## EDITING INPUTS

After a model is named, the Edit option in the main menu bar is used to change inputs and select processes that describe your population. Inputs are organized into eight categories that are listed in the Edit pull-down menu. Each category has a pop-up menu that displays current values for inputs.

A new value is entered by typing over all or part of an old value. Changes are logged by pressing Enter or one of the cursor control keys (Up, Down, Tab, End, Home) to move among the listed inputs. Remember to *press* Enter *after typing over old values before escaping the* Edit *pop-up screen. Otherwise, your last change will not be logged.* Inappropriate values will not be accepted, and you will have to. enter a new value before you can continue. Commas in numbers are not accepted. Decimal fraciions may or may not be preceded with a zero. Large $(>10^6)$ or small (<10 ) numbers should be entered in exponential format. For instance, 1,500,000 should be entered as 1.5Et06 and 0.0000015 should be entered as 1.5E-06. Additional details on each Edit pop-up screen follow.

### Start Population

Selection of this Edit option displays a list of age-specific numbers of individuals in the population at the start of Year 1. Inputs are listed for all ages up to the maximum age listed in the Mortality pop-up screen.

### Reproduction

Selection of this Edit option displays input parameters for an exponential length-fecundity equation (coefficient and exponent), the age at which females first mature, the proportion of the population over the age of maturity that is female, and the proportion of mature females that spawn in any year. You have two options for entering the spawning proportion:

1. Input for up to three groups.

2. Cumulative normal function of length.

Option 1 allows you to enter different numbers for the proportion for females spawning in any year for one to three age groups. After each entry you must supply the maximum age to which it applies. The minimum age is one greater than the previous entry except for the first entry where the minimum age is the age at which females first mature.

Option 2 sets the spawning proportion as a function of length adapted from that of Welch and McFarlane (In press). This function is based on a cumulative normal distribution function.

$$\Phi = \frac{1}{\sqrt{2\pi}} e^{-(L_x - \mu)^2/2\sigma^2} \sum_{i=1}^{5} b_i \{1 + p \left|\frac{L_x - \mu}{\sigma}\right|\}^{1-i}$$

$$ps_X = c\ 0 \text{ for } L_X \le \mu$$

$$ps_X = c\ (1 - \Phi) \text{ for } L_X > p$$

where

0 = cumulative normal distribution function dependent variable,
n = 3.141593,
e = 2.718282,
Lx = age-specific length,
p = mean length of sexual maturity,
o = variance about mean length of sexual maturity,
$b_1$ = 0.31938153,
$b_2$ = -0.356563782,
$b_3$ = 1.781477937,
$b_4$ = -1.821255978,
$b_5$ = 1.330274429,
p = 0.2316419,
$ps_X$ = age-specific proportion of females that spawn in any year, and
c = spawning proportion equation coefficient corresponding to maximum proportion.

## Recruitment

Selection of this Edit option displays choices for the mechanism of recruitment and associated parameters. Recruitment is defined as the number of age-1 individuals at the start of the year. Recruitment can be varied independently or as a function of parental stock size.

Nine recruitment options exist:

1. CONSTANT--Number entered for age 1.

2. BIG YEAR CLASSES--At fixed intervals, otherwise constant.

3. BIG YEAR CLASSES--At random intervals, otherwise constant.

4. RANDOM--Uniformly distributed.

5. RANDOM--Normally distributed.

6. STOCK RELATED--Proportional to reproductive potential.

7. STOCK RELATED--Beverton-Holt relationship.

8. STOCK RELATED--Ricker relationship.

9. STOCK RELATED--Gushing equation.

Recruitment Options 1-3 use the number of age-1 individuals entered in the starting population screen as an average condition. Recruitment Options 2-3 allow replacing this average recruitment with a severalfold increase at fixed or random intervals. If Recruitment Option 2 or 3 is selected, you will be prompted for this multiplication factor. For Recruitment Option 2, you will also be prompted for the interval at which big year classes occur and the first year of a big year class. For Recruitment Option 3, you will be prompted for the average frequency with which big year classes occur. The probability of a big year class in any given year would thus be the inverse of this frequency.

Recruitment Options 4 and 5 select recruitment as random either with equal probability between a specified minimum and maximum (Option 4) or with varying probability distributed normally with a specified mean and standard deviation (Option 5).

Recruitment Options 6-9 select recruitment as a function of stock size and factor in parental stock size indirectly by calculating reproductive potential for each parental age class. Recruitment at age 1 is calculated as the product of this potential egg deposition, and an egg-to-age-1 survival rate calculated from an input on the Mortality pop-up screen (Input Option 4). In Recruitment Option 6, recruitment is thus calculated directly from reproductive potential. In Recruitment Options 7-9, a realized egg deposition is calculated from the potential egg deposition using the density-dependent relationship indicated. Age-1 numbers are then calculated as the product of this realized egg deposition and the egg-to-age-1 survival rate. All density-dependent mortality thus takes place at the egg and larval stages. There is no provision for density-dependent mortality occurring beyond age 1.

Density-dependent relationships between reproductive potential and realized egg deposition include those described by Beverton-Holt, Ricker, and Cushing.

The Beverton-Holt equation (Ricker 1975) is

$$R = P/[1 - A(1 - P/P_r)]$$

where

$R$ = actual egg deposition,
$P$ = potential egg deposition,
$A$ = parameter describing the shape of the curve. If you select this equation, you will be prompted for "A," and
$P_r$ = replacement egg deposition at equilibrium.

The Ricker equation (Ricker 1975) is

$$R = Pe^{a(1 - P/P_r)}$$

where

$e$ = 2.718282,
$a$ = parameter describing the shape of the curve,
$P$ = potential egg deposition, and
$P_r$ = replacement egg deposition at equilibrium.

You will be prompted for "$P_r$" and "a" if you select this option. See Ricker (1975) for a discussion of these functions and methods for estimating parameters.

The Cushing equation (Kimura et al. 1984),is

$$R = E_{max} (P / P_{max})^c$$

where

$P$ = population size,
$E_{max}$ = maximum egg deposition,
$P_{max}$ = population size at $E_{max}$, and
$c$ = a constant describing strength of relationship.

If you select this option, you will be prompted for "$E_{max}$," "$P_{max}$," and "c."

## Growth

Selection of this Edit option displays parameters related to calculations of length and weight at age including parameters for a von Bertalanffy age-length equation ($L_\infty$ k, $t_0$), and an exponential length-weight equation (coefficient and exponent).

## Mortality

Selection of this Edit option displays inputs for maximum age and natural mortality rate. A maximum age of up to 100 may be entered. If the population has no age structure, enter a maximum age of 1.

You have the following options for egg-to-age-1 mortality rate:

1. CONSTANT.

2. RANDOM--Uniformly distributed.

3. RANDOM--Normal.

You will be prompted for numbers appropriate for the option you select. Egg-to-age-1 mortality rate is used by the model only when stock-related recruitment options were specified. Recruitment Options 1-5 (constant, big year classes, or random) over-ride the calculation of age-1 number from egg number.

You are also prompted for a series of natural mortalities for ages 1 and above. Enter the conditional annual rate. The following options are provided:

1. Set for up to three age groups.

2. Linear function of age.

3. Pauly regression (Pauly 1980) versus growth and temperature.

Option 1 allows you to enter different rates for one to three age groups. After each entry you must supply the maximum age to which it applies. The minimum age is one greater than the previous entry except for the first entry where the minimum age is 1.

Option 2 allows you to vary rate as a linear function of age using the equation

$$nx = \alpha n \ t \ (Bn)(x)$$

where

$n_x$ = age-specific conditional natural mortality rate,
on = rate-age equation intercept parameter,
Bn = rate-age equation slope parameter, and
x = age.

Option 3 sets natural mortality rate for all ages greater than 0 to a constant predicted from a regression on parameters in the age-length equation and temperature (Pauly 1980)

$$M = 10^{[-0.0066 \ - \ 0.279 \ \log_{10}(L_\infty) \ t \ 0.6543 \ \log_{10}(k) \ t \ 0.4634 \ \log_{10}(T)]}$$

$$_n x = 1 - e^{-M}$$

where

M = instantaneous rate of annual natural mortality,
$L_\infty$ = von Bertalanffy equation length at infinity based on total length in cm,
k= von Bertalanffy equation parameter based on total length in cm,
T = mean annual water temperature in °C,
$n_x$ = conditional natural mortality rate, and
e = 2.718282.

Length-weight equation parameters input for this option are used only in calculation of mortality rate and are independent of those input for growth.

## Exploitation

Selection of this Edit option displays inputs for exploitation rate. Exploitation rates may be input for one or two fisheries. Rates for two fisheries are added for a total rate. Rates input or calculated from inputs are limited to the range 0 to 1 when the model is run. Rates may be input directly or based on effort and catchability (q). The following options are provided:

1. Set for up to three size groups.

2. f{effort & catchability}--q set for up to three groups.

3. f{effort & catchability}--q a normal function of size.

Upon selection of Option 1, you are prompted for the minimum and maximum exploitable sizes, and the annual rate of exploitation. Size classes must not overlap.

Options 2 and 3 prompt for input of fishing effort and inputs for catchability. An assumption that spatial and temporal variations in fishing effort and stock catchability can be approximated by an average catchability is implicit in the use of these options. Option 2 prompts for direct input of catchability for one to three groups and corresponding minimum and maximum sizes. Exploitation rate is calculated as

$$m_x = 1 - e^{-fq}$$

where

$m_x$ = exploitation (harvest mortality rate),
f = fishing effort,
e = 2.718282, and
q = catchability.

Option 3 prompts for parameters in a normal function of catchability versus size:

$$q = (aq)\ e^{-(bq - L_x)^2 / (2)(cq)^2}$$

where

aq = catchability-size equation parameter corresponding to maximum catchability,
bq = catchability-size equation parameter corresponding to size of maximum catchability,
cq = catchability-size equation parameter corresponding to size increment in 1 SD from the size of maximum catchability,
e = 2.718282, and
$L_x$ = age-specific length.

## Weight Factor

Selection of this Edit option displays a list of age-specific weighting factors that can be used to project the effect of the population on another component of the system (the weighted effect). Values are listed for all ages up to the maximum age listed in the Mortality pop-up screen. You are also prompted for the expression of population size or growth that is to be weighted. Choices include number, biomass, and production.

## Size Index

Selection of this Edit option lists sizes used in calculating an index of population size structure analogous to proportional stock density (PSD; Anderson 1980). The index is calculated as the number of individuals within one pair of minimum and maximum sizes (the numerator) divided by the number within a second pair of minimum and maximum sizes (the denominator).

## RUNNING THE MODEL

Using the Run option in the main menu, you have the options of running a new simulation starting at Year 1 (New in the Run pull-down menu) or of extending the current simulation for more years (Continue in the Run pull-down menu). You may thus structure the population based on one set of inputs, edit the inputs, and examine the corresponding effect on the population without having to enter the results of the first simulation as a new starting condition. After specifying New or Continue, you will be prompted for the number of years to run or extend the simulation. A maximum of 300 years may be run.

Processing of inputs is based on a series of difference equations. Given a number of individuals at the start of the year, the sequence of events is reproduction, exploitation, and death from natural causes.

The age-specific numbers of individuals at the start of the first year of the simulation are an input. Age-specific numbers of individuals ($N_x$) after the first year are calculated by the equation

$$N_{x+1,t+1} = (N_{x,t})(S_x)$$

where

$t$ = year, and
$S_x$ = age-specific annual survival rate.

Age-specific annual survival ($S_x$) is calculated as

$$S_x = 1 - (m_x + n_x - (m_x)(n_x))$$

where

$m_x$ = exploitation (harvest mortality rate), and
$n_x$ = conditional natural mortality rate.

Biomass present in each age class ($B_x$) is estimated as

$$B_{x,t} = (N_{x,t})(W_x)$$

where

$W_x$ = age-specific weight (units same as those supplied in length-weight equation).

Age-specific weights are calculated with age-length and length-weight equations using input parameters

$$L_x = L_\infty(1 - e^{-k(x - t_0)})$$ and

$$W_x = (\alpha w)\left(L_x^{\beta w}\right)$$

where

$L_x$ = length at age,
$L_\infty$ = von Bertalanffy equation length at infinity,
$k$ = von Bertalanffy equation parameter,
$t_0$ = von Bertalanffy equation parameter,
$\alpha w$ = length-weight equation coefficient, and
$\beta w$ = length-weight equation exponent.

Reproductive potential of each age class ($P_x$) at or above the age of female maturity is estimated by

$$P_{x,t} = (N_{x,t})(F_x)(pf)(ps_x)$$

where

$F_x$ = age-specific fecundity of females,
$pf$ = proportion of population that is female, and
$ps_x$ = age-specific proportion of females that spawn in any year.

Fecundity ($F_x$) is estimated by

$$F_x = (\alpha f)(L_x\beta f)$$

where

$\alpha f$ = length-fecundity equation coefficient, and
$\beta f$ = length-fecundity equation exponent.

The net reproductive potential of all ages in any given year is

$$P = \Sigma(P_x).$$

This is the number upon which stock-related recruitment functions, discussed under EDITING INPUTS, Recruitment, operate to calculate recruitment at age 1 ($N_1$).

All animals are harvested at one time. All mortality occurs following spawning. Harvest in number (catch) and weight (yield) from an age class are calculated by

$$H_x = (N_x)(m_x) \text{ and}$$

$$Y_x = (N_x)(m_x)(W_x)$$

where

$H_x$ = age-specific numbers of individuals removed by exploitation, and
$Y_x$ = age-specific weight of individuals removed by exploitation.

Annual production of any age class ($PD_{x,t}$) is calculated by

$$PD_{x,t} = ((N_{x+1,t+1}\, W_{x+1} + N_{x,t}\, W_x)/2)(\log W_{x+1} - \log W_x).$$

The weighted effect of any age class ($E_x$) is calculated by

$$E, = (N_x)\,(WF_x)$$

where

$WF_x$ = age-specific weighting factor.

## INSPECTING MODEL PREDICTIONS

Simulation results in the form of tables, summary statistics, or graphs may be displayed using the Predict option in the main menu. Selecting this option displays a pull-down menu containing six choices. Details on these options follow.

### Reproduction by Age

Selection of this option displays a pop-up screen that contains a table of information similar to the following:

```
                    AGE-SPECIFIC REPRODUCTION IN YEAR 8
Age  Leng   Wgt     Num    Fecund    P Fem   P Spn  Per Fish      Eggs

 1    76     4    10000      76      0.50    1.000      38     0.3803E+06
 2   137    28     5000     137      0.50    1.000      69     0.3432E+06
 3   191    79     2500     191      0.50    1.000      95     0.2386E+06
 4   238   160     1250     238      0.50    1.ooo     119     O.1487E+06
 5   279   266      900     279      0.50    1.ooo     140     0.1256Et06
 6   315   392      648     315      0.50    1.000     158     O.1021E+06
 7   347   532      467     347      0.50    1.000     173     0.8091E+05
 8   375   680      336     375      0.50    1.000     187     0.6291E+05

    TOTAL         21100.48                         Potential   1482316
                                                   Realized    1482316
```

where

Leng = length in units from age-length equation ($L_x$),
Wgt = weight in units from length-weight equation ($W_x$),
Num = number of individuals in population (N,),
Fecund = fecundity of females in age class ($F_x$),
P Fem = proportion of population that is female (pf),
P Spn = proportion of females that spawn in any year ($ps_x$),
Per Fish = fecundity per individual in population [($F_x$)(pf)($ps_x$)], and
Eggs = reproductive potential in age class (P).

Potential egg deposition is total eggs produced by all age classes. Realized egg deposition is the potential deposition modified by the effects of the stock-recruitment function.

### Population by Age

Selection of this option displays a pop-up screen that contains a table of information similar to the following:

```
                   AGE-SPECIFIC POPULATION INFORMATION IN YEAR 8
Age  Leng   Wgt      Start        Fshg   Ntrl   Surv    Biomass     Prod

 0                148232E+01             0.000  1.000
 1    76     4        10000      0.000  0.500  0.500      42089   169926
 2   137    28         5000      0.000  0.500  0.500     138368   177032
 3   191    79         2500      0.000  0.500  0.500     198136   139752
 4   238   160         1250      0.100  0.200  0.720     199929   111938
 5   279   266          900      0.100  0.200  0.720     239571    95802
 6   315   392          648      0.100  0.200  0.720     254256    76673
 7   347   532          467      0.100  0.200  0.720     248372    58493
 8   375   680          336      0.100  0.200  0.000     228542        0

   TOTAL              21100                           15493E+02   829616
```

where

Age = 0 refers to reproductive potential,  
Leng = length in units from age-length equation ($L_x$),  
Wgt = weight in units from length-weight equation ($W_x$),  
Start = number of individuals at the start of the year ($N_{x,t}$),  
Fshg = exploitation or harvest mortality rate ($m_x$),  
Ntrl = conditional natural mortality rate ($n_x$),  
Surv = age-specific annual survival rate ($S_x$),  
New = number of individuals surviving to the start of the next year from the previous age class ($N_{x,t+1}$),  
Biomass = weight of all individuals at the start of the year ($B_{x,t}$), and  
Prod = production in biomass including individuals that die ($PD_x$).

### Fishery by Age

Selection of this option displays pop-up screen that contains a table of information similar to the following:

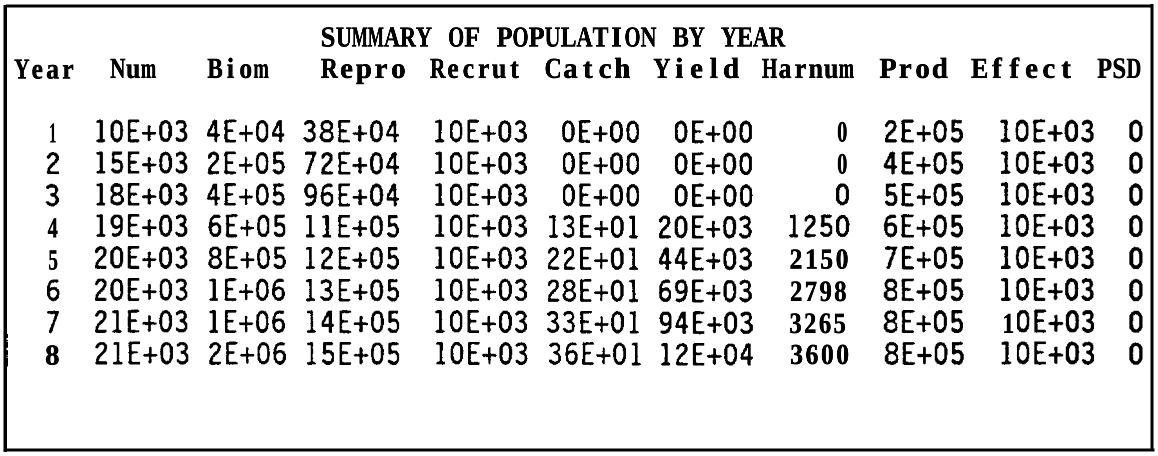
```
   AGE-SPECIFIC HARVEST, YIELD, AND EFFECT INFORMATION IN YEAR 8
 Age  Leng  Wgt  Start  Expl  Catch     Yield   Wt Var  Factor   Effect

  1    76     4  10000  0.00      0    OE+00    10000    1.00    10000
  2   137    28   5000  0.00      0    OE+00     5000    0.00        0
  3   191    79   2500  0.00      0    OE+00     2500    0.00        0
  4   238   160   1250  0.10   .125 1999E+01     1250    0.00        0
  5                                               900    0.00        0
  6   279   392    648  0.10     65 2543E+01      648    0.00        0
  7   347   532    467  0.10     47 2484E+01      467    0.00        0
  8   375   680    336  0.10     34 2285E+01      336    0.00        0

    TOTAL        21100          360 1171E+02                     10000
```

where

Leng = length in units from age-length equation ($L_x$),
Wgt = weight in units from length-weight equation ($W_x$),
Start = number of individuals at the start of the year ($N_{x,t}$),
Expl = exploitation or harvest mortality rate ($m_x$),
Catch = harvest in numbers ($H_x$),
Yield = harvest in weight ($Y_x$),
Wt Var = variable weighted by Factor to calculate Effect,
Factor = age-specific weighting factor ($WF_x$), and
Effect = age-specific weighted effect ($E_x$).

### By Year

Selection of this option displays a pop-up screen that contains a table of information similar to the following:



```
                      SUMMARY OF POPULATION BY YEAR
Year   Num     Biom    Repro  Recrut  Catch  Yield  Harnum  Prod   Effect  PSD

  1  10E+03  4E+04  38E+04  10E+03  0E+00  0E+00      0  2E+05  10E+03   0
  2  15E+03  2E+05  72E+04  10E+03  0E+00  0E+00      0  4E+05  10E+03   0
  3  18E+03  4E+05  96E+04  10E+03  0E+00  0E+00      0  5E+05  10E+03   0
  4  19E+03  6E+05  11E+05  10E+03 13E+01 20E+03   1250  6E+05  10E+03   0
  5  20E+03  8E+05  12E+05  10E+03 22E+01 44E+03   2150  7E+05  10E+03   0
  6  20E+03  1E+06  13E+05  10E+03 28E+01 69E+03   2798  8E+05  10E+03   0
  7  21E+03  1E+06  14E+05  10E+03 33E+01 94E+03   3265  8E+05  10E+03   0
  8  21E+03  2E+06  15E+05  10E+03 36E+01 12E+04   3600  8E+05  10E+03   0
```

where

Num = total number of individuals in population ($\Sigma N_x$),
Biom = total weight of all individuals in population ($\Sigma B_x$),
Repro = realized egg deposition of all ages (R),
Recrut = number of age 1 individuals ($N_1$),
Catch = total numbers of individuals harvested ($\Sigma H_x$),
Yield = total weight of individuals harvested ($\Sigma Y_x$),
Harnum = number of individuals in the harvestable size range (should be proportional to catch per unit effort in the fishery),
Prod = total production of biomass ($\Sigma PD_x$),
Effect = total effect of population weighted by age, and
PSD = size structure index (relative numbers of individuals in 2 size classes).

### Summary Statistics

Summary statistics include mean, standard deviation, minimum, and maximum for annual summary variables selected from a list. The same variables displayed in the By Year selection from the Predict pull-down menu may be selected. Select a .variable by highlighting with cursor control keys then pressing enter. Statistics are calculated over a range of years ending with the last year of the simulation. You also have the option of beginning at a year greater than 1 if you wish to allow a population to reach some equilibrium.

### Graph

You may plot yearly totals versus time, yearly totals versus each other, age-specific results in the last year of the simulation versus age, or age-specific results versus each other. You are prompted to select age-specific or year-specific results. Variables that can be plotted for each option are displayed once you make your selection. You select variables for X and Y axes by highlighting with cursor control keys and pressing Enter. X-axis variables are automatically sorted from minimum to maximum. Plotable variables and definitions correspond with those listed in tables. The plot is automatically scaled so that the plot fills the Y-axis. You may print graphs by pressing P after the plot is drawn on the screen. (This print graph option was programmed for an IBM graphics printer and may not work on other printers.)

## PRINTING OR SAVING MODEL PREDICTIONS

Selection of the Write option in the main menu bar allows you to send simulation results to a file or to your printer. These results are then available for other applications such as plotting with graphics software or for later review. If you select File, you will be prompted to select age-specific or year-specific results. You are also prompted for a name for the file in which results are saved. You may enter a name up to eight characters long or accept the default name. MOCPOP 2.0 will add the extension .DAT to the name you select. The default name is BYAGE for age-specific results. All age-specific variables included in tables listed in Predict By Age pop-up tables will be written to the file, and the first line in the file will contain variable names. If you are saving year-specific results, the default name is BYYEAR. Variables listed in the Predict By Year pop-up table, will be written to the file and the first line in the file will contain variable names.

The Print option prints a summary of model inputs similar to that displayed under the main menu bar, all age-specific numbers such as those listed in Predict by Age pop-up tables, and all year-specific numbers such as those presented in the Predict By Year pop-up table.

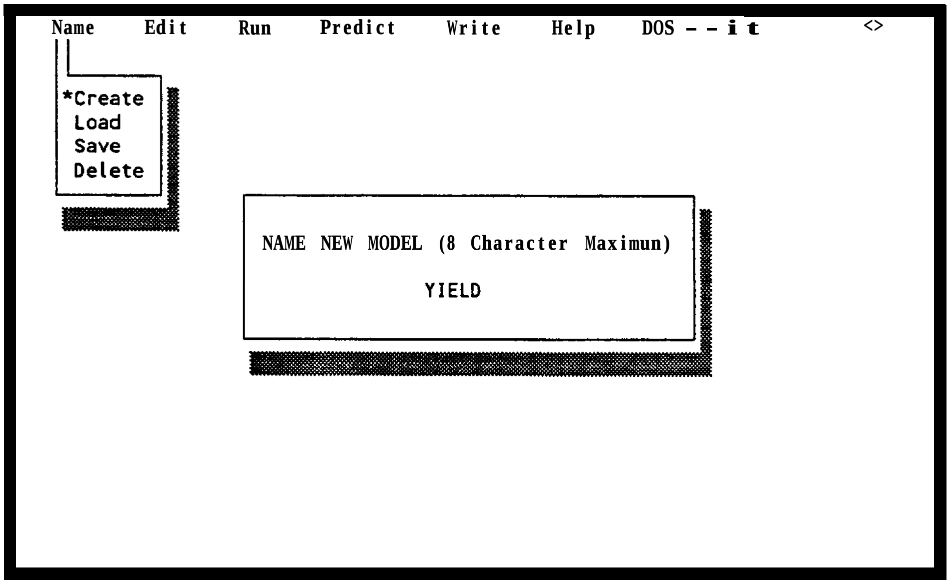
## EXAMPLE APPLICATIONS

### Problem 1--Yield

Estimate yield at 10% exploitation for a population with the following characteristics:

1. Recruitment constant at 10,000 age-1 individuals.
2. von Bertalanffy age-length(mm) equation coefficients:
   $L_\infty = 571$; $k = 0.132$; $t_0 = -0.083$.
3. Length(mm)-weight(gm) equation coefficients:
   intercept = 0.0000042; slope = 3.19.
4. Maximum age, 8.
5. Natural mortality: age 1 through age 3, 50% per year; age 4 through age 8, 20% per year.
6. Harvestable size range, 200-400 mm.

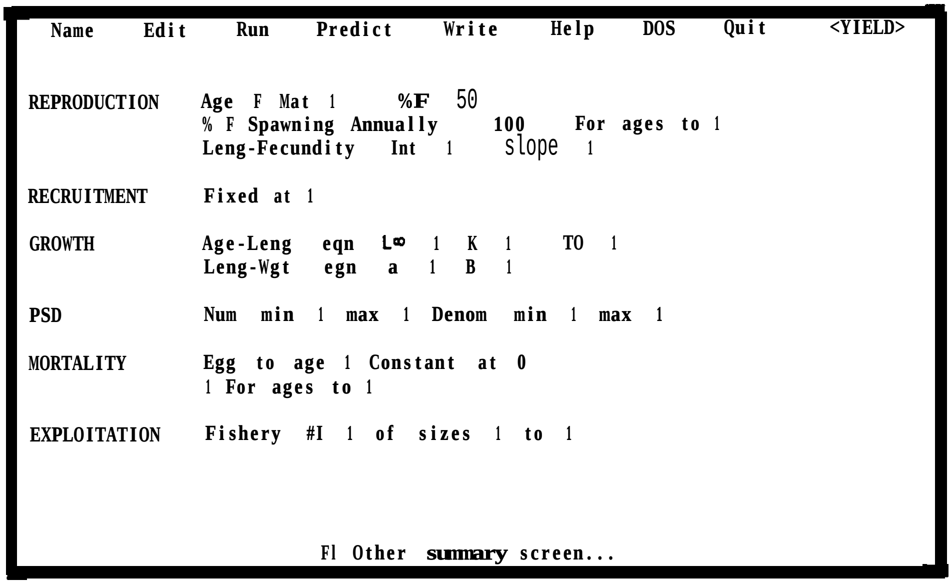
Start MOCPOP 2.0. MOCPOP 2.0 first displays two introductory pages and the help screen. Press any key for each to advance to a screen that is blank, except for the menu bar across the top. Press N to select Name, then C to select Create, then type in a name for the model you are creating ("YIELD"). The following screen should appear.



NAME NEW MODEL (8 Character Maximun)

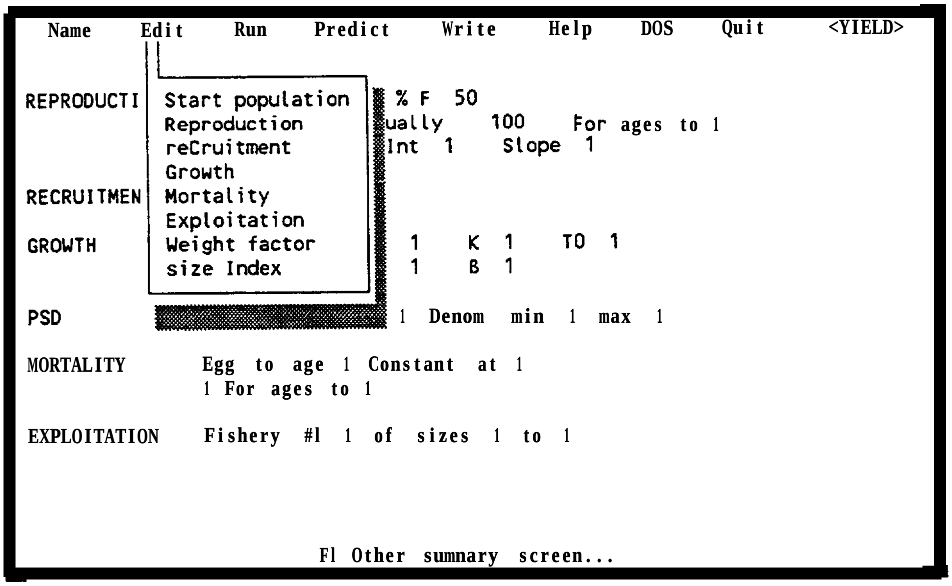
YIELD

Pressing Enter will then display Page 1 of the default input parameters in the newly created model.



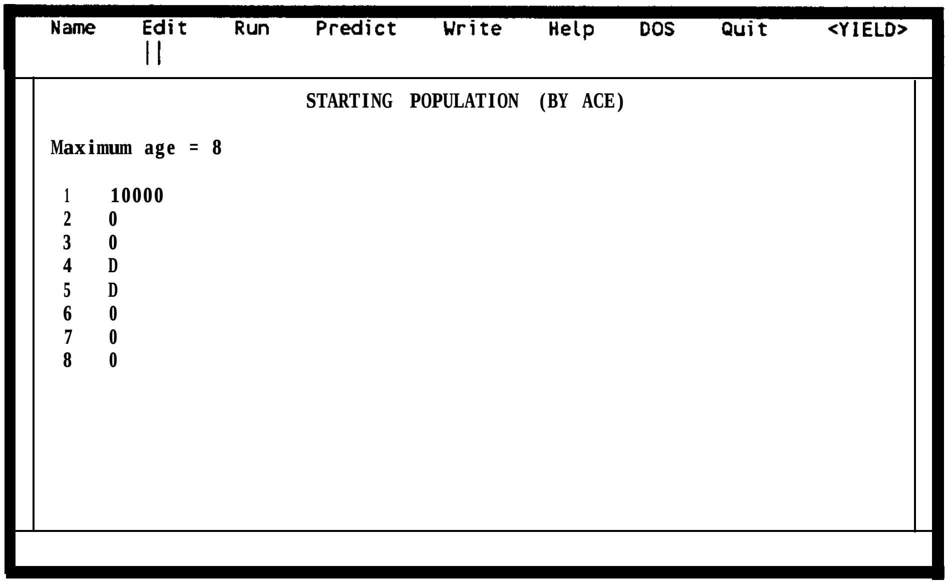
```
 Name     Edit     Run     Predict     Write     Help     DOS     Quit        <YIELD>


REPRODUCTION    Age  F  Mat  1      %F  50
                % F Spawning Annually       100     For ages to 1
                Leng-Fecundity    Int  1    Slope  1

RECRUITMENT     Fixed at 1

GROWTH          Age-Leng   eqn  L∞  1  K  1     TO  1
                Leng-Wgt   egn   a  1  B  1

PSD             Num  min  1  max  1  Denom  min  1  max  1

MORTALITY       Egg  to  age  1  Constant  at  0
                1 For ages to 1

EXPLOITATION    Fishery  #I  1  of  sizes  1  to  1



                             Fl Other summary screen...
```

Press E to display the Edit pull-down menu so that you can enter the appropriate numbers for your population.



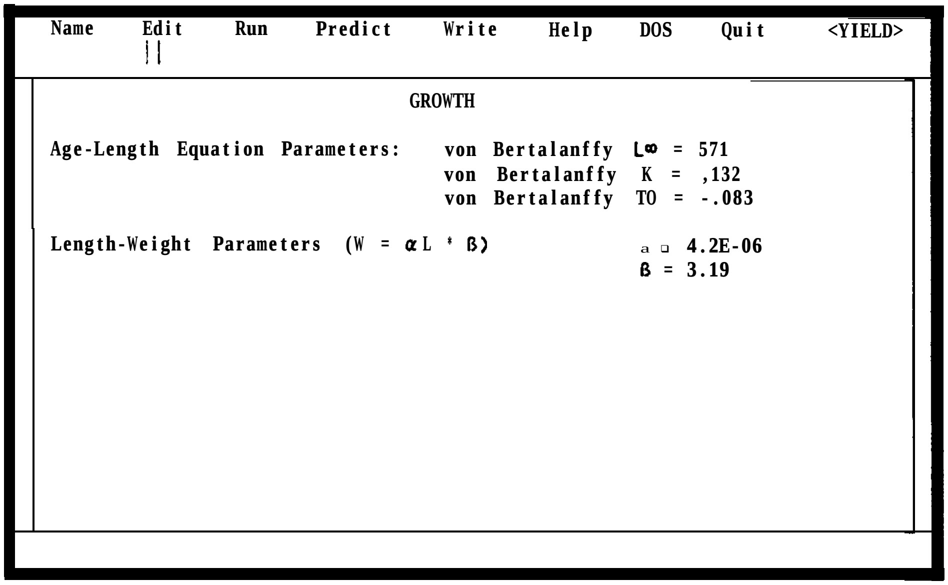
```
 Name     Edit     Run     Predict     Write     Help     DOS     Quit        <YIELD>

REPRODUCTI  Start population    % F  50
            Reproduction       ually    100    For ages to 1
            reCruitment        Int  1    Slope  1
            Growth
RECRUITMEN  Mortality
            Exploitation
GROWTH      Weight factor        1    K  1    TO  1
            size Index           1    B  1

PSD                              1  Denom  min  1  max  1

MORTALITY       Egg  to  age  1  Constant  at  1
                1 For ages to 1

EXPLOITATION    Fishery  #l  1  of  sizes  1  to  1



                             Fl Other summary screen...
```

Press S to pop up the Start Population edit screen then overtype the 1 displayed for maximum age with 8. Overtype the 1 displayed for age 1 with 10000. Press Enter to log the change. Press Escape to return to the Edit pull-down menu. Editing the recruitment screen is not necessary because recruitment is set to the fixed option by the default of 1.



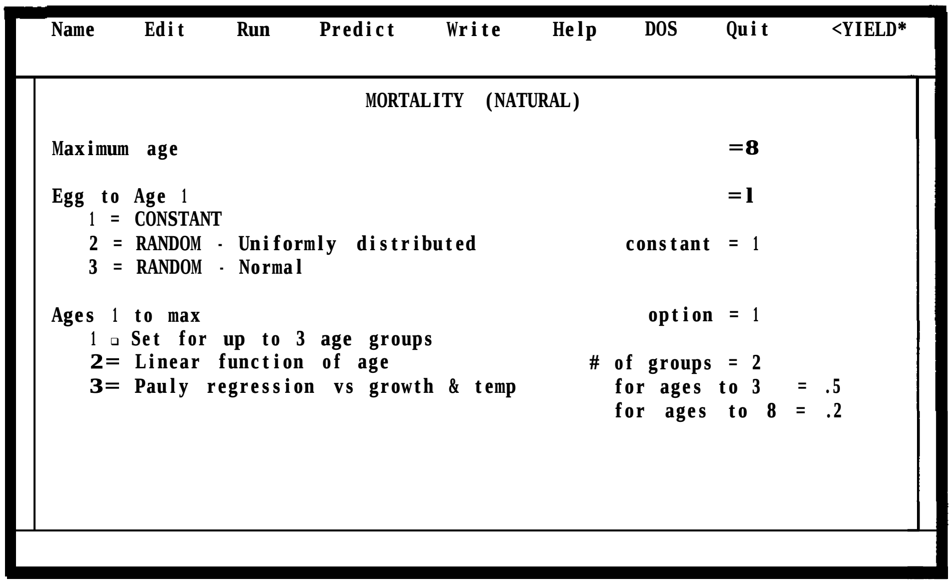
```
                    STARTING POPULATION (BY ACE)

Maximum age = 8

 1   10000
 2   0
 3   0
 4   0
 5   0
 6   0
 7   0
 8   0
```

Press G to pop up the Growth edit screen, then overtype new parameters for the von Bertalanffy and length-weight equations. Use the tab or down arrow keys to move among entries. Remember to press Enter to log your last entry before pressing Escape to return to the Edit pull-down menu.



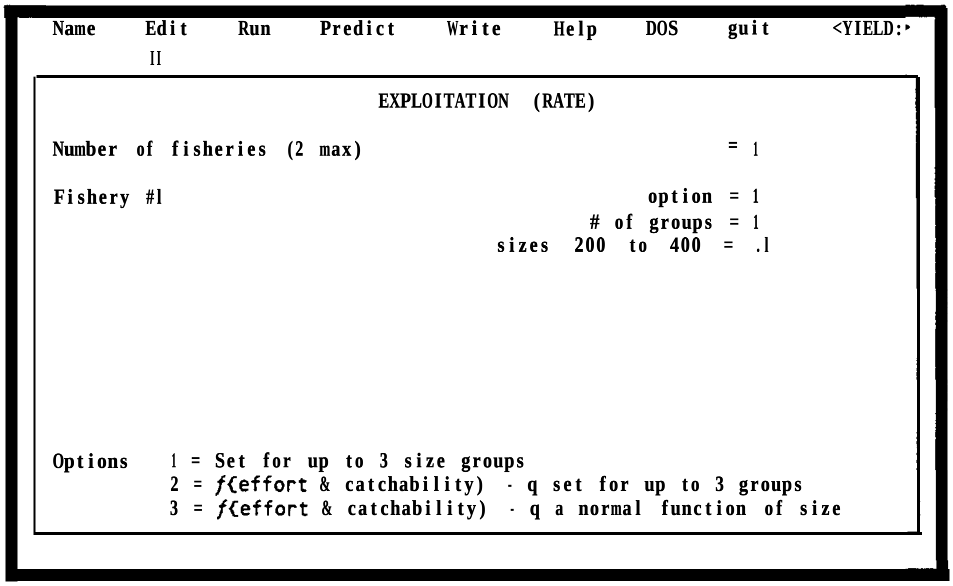
```
                          GROWTH

Age-Length Equation Parameters:    von Bertalanffy L∞ = 571
                                   von Bertalanffy K  = ,132
                                   von Bertalanffy TO = -.083

Length-Weight Parameters (W = αL * ß)          α = 4.2E-06
                                               ß = 3.19
```

Press M to pop up the Mortality edit screen. Note that maximum age is displayed here as well as on the Start Population edit screen. Skip entries related to egg-to-age-l natural mortality as they are not used when recruitment is fixed. Change the number of groups for ages 1 to max from 1 to 2 then press Enter. Note the screen changes to display space for two groups. Type ages, rates, and sizes as shown in the following screen. Press Escape to return to the Edit pull-down menu.



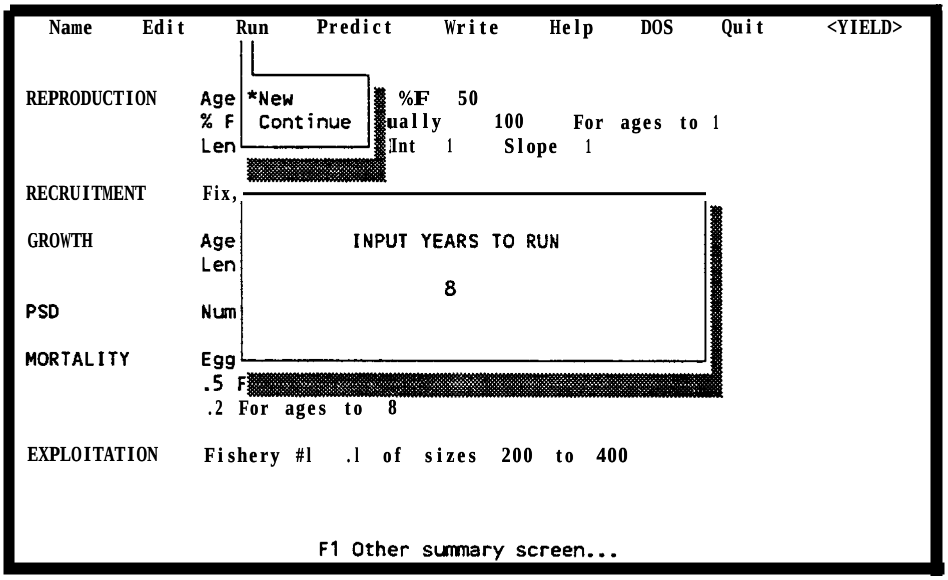
```
                          MORTALITY (NATURAL)

Maximum age                                               =8

Egg to Age 1                                              =1
   1 = CONSTANT
   2 = RANDOM - Uniformly distributed           constant = 1
   3 = RANDOM - Normal

Ages 1 to max                                     option = 1
   1 ❑ Set for up to 3 age groups
   2= Linear function of age                 # of groups = 2
   3= Pauly regression vs growth & temp       for ages to 3   = .5
                                              for ages to 8 = .2
```

Press E to pop up the Exploitation edit screen and type sizes and rates as shown in the following screen.



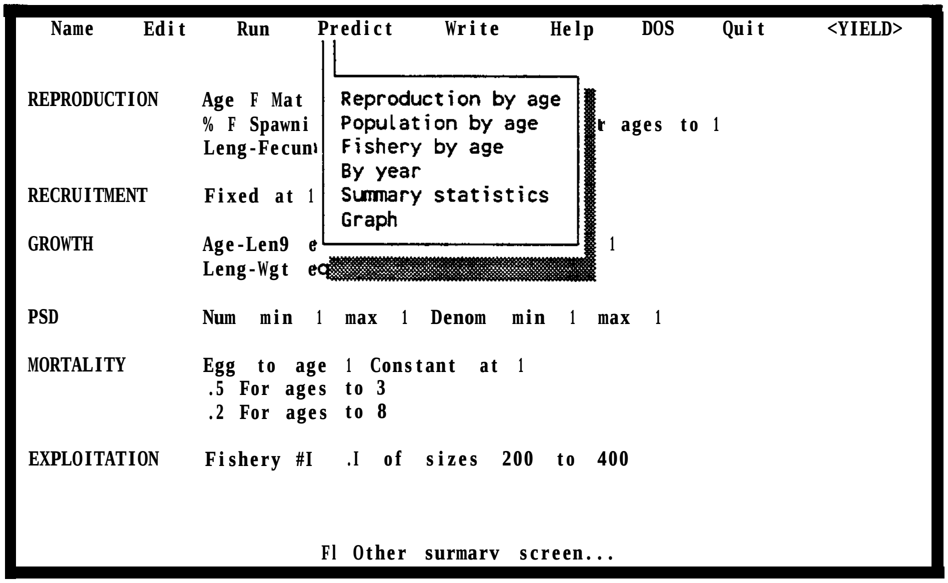
```
                          EXPLOITATION (RATE)

Number of fisheries (2 max)                                = 1

Fishery #l                                        option = 1
                                             # of groups = 1
                                   sizes 200 to 400 = .l








Options   1 = Set for up to 3 size groups
          2 = f(effort & catchability) - q set for up to 3 groups
          3 = f(effort & catchability) - q a normal function of size
```

You are now ready to run the simulation. Press Escape again to exit the Edit pull-down menu. Press R to display the Run pull-down menu. Press N to indicate a new simulation, then type 8 for years to run. The following screen is displayed at this point. Press Enter to start the simulation.



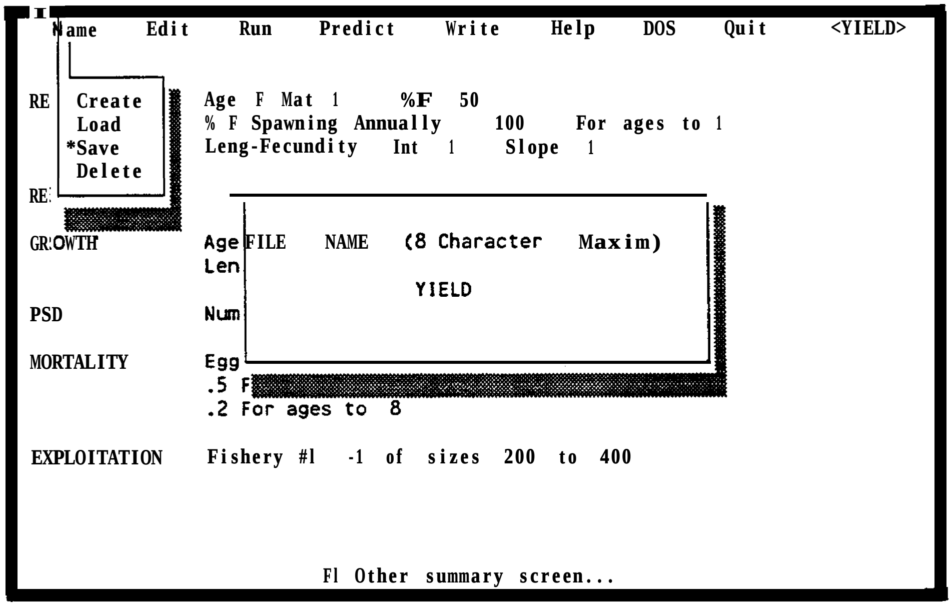
```
 Name    Edit    Run    Predict    Write    Help    DOS    Quit     <YIELD>

REPRODUCTION     Age *New       %F  50
                 % F  Continue ually    100    For ages to 1
                 Len           Int  1    Slope  1

RECRUITMENT      Fix,

GROWTH           Age            INPUT YEARS TO RUN
                 Len
                                        8
PSD              Num

MORTALITY        Egg
                 .5 F
                 .2 For ages to  8

EXPLOITATION     Fishery #l   .l  of  sizes  200  to  400


                          F1 Other summary screen...
```

When the simulation is completed, the Predict pull-down menu will be displayed automatically. You will find the answer to this yield problem under the Fishery by Age option. Yield for this example is 117,067 gm. The example output tables shown on Pages 14-16 correspond to this simulation.



```
 Name    Edit    Run    Predict    Write    Help    DOS    Quit     <YIELD>

REPRODUCTION     Age F Mat    Reproduction by age
                 % F Spawni   Population by age    r ages to 1
                 Leng-Fecun   Fishery by age
                              By year
RECRUITMENT      Fixed at 1   Summary statistics
                              Graph
GROWTH           Age-Len9  e                        1
                 Leng-Wgt  e

PSD              Num  min 1  max 1  Denom  min 1  max 1

MORTALITY        Egg  to  age  1  Constant  at  1
                  .5 For ages to 3
                  .2 For ages to 8

EXPLOITATION     Fishery #I   .I  of  sizes  200  to  400



                          Fl Other surmarv screen...
```

Before quitting, save the current inputs in a file by selecting Name in the main menu bar, selecting Save in the Name pull-down menu, and entering YIELD at the pop-up screen prompt.

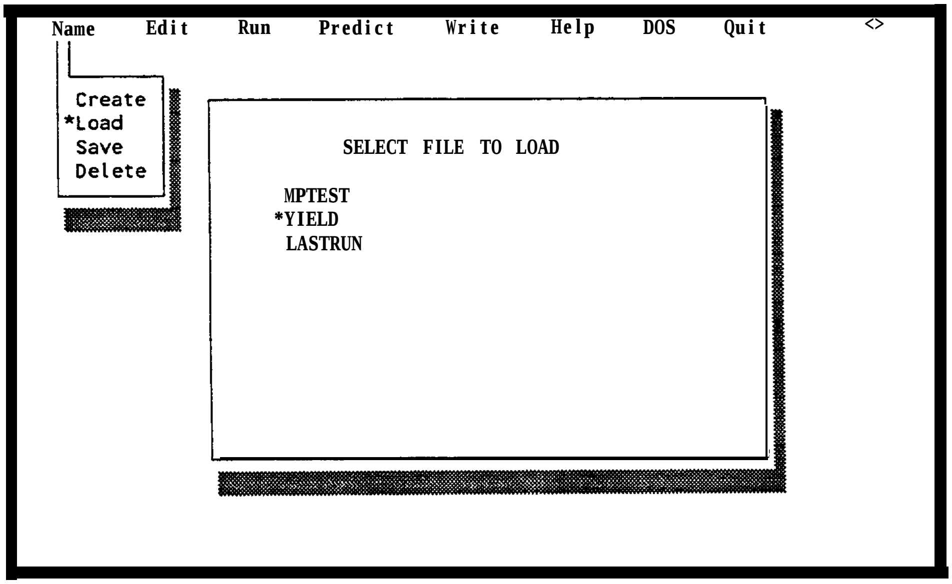


```
RE          Age F Mat 1     %F  50
            % F Spawning Annually    100    For ages to 1
            Leng-Fecundity   Int  1    Slope  1
RE
GROWTH      Age FILE   NAME   (8 Character   Maxim)
            Len
                          YIELD
PSD         Num

MORTALITY   Egg
            .5 F
            .2 For ages to  8

EXPLOITATION   Fishery #1   -1  of  sizes  200  to  400

                       F1 Other summary screen...
```

## Problem Z--Uncertainty

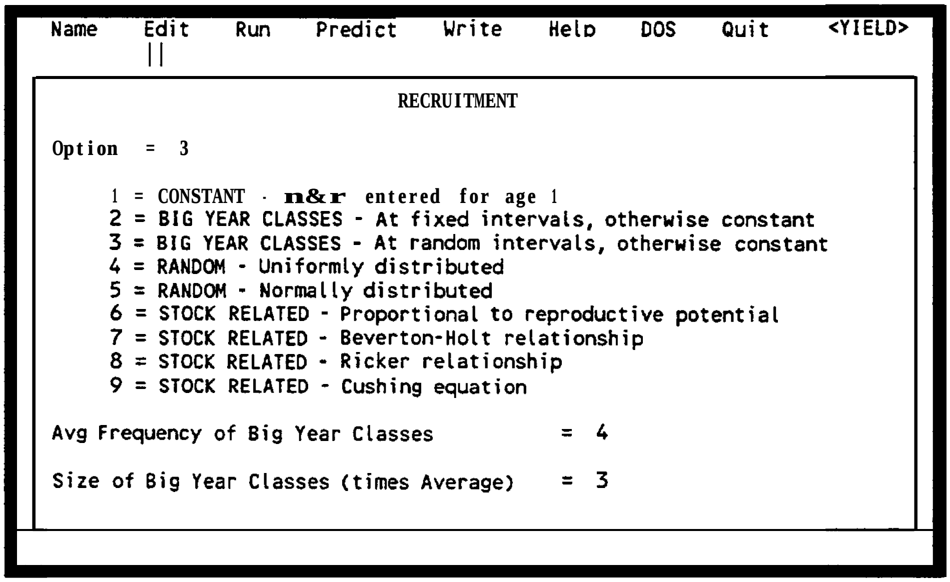
Estimate the range over which a population may vary as a result of variable recruitment. Use inputs as in Problem 1 (Page 18, except set recruitment to include big year classes that occur every four years on the average and are three times greater than normal.

Start MOCPOP 2.0 and load the model YIELD created in problem 1. Select Name in the main menu bar, select Load from the Name pull-down menu, and use the cursor movement keys to highlight YIELD. The following screen should be displayed. Press Enter to load the model.



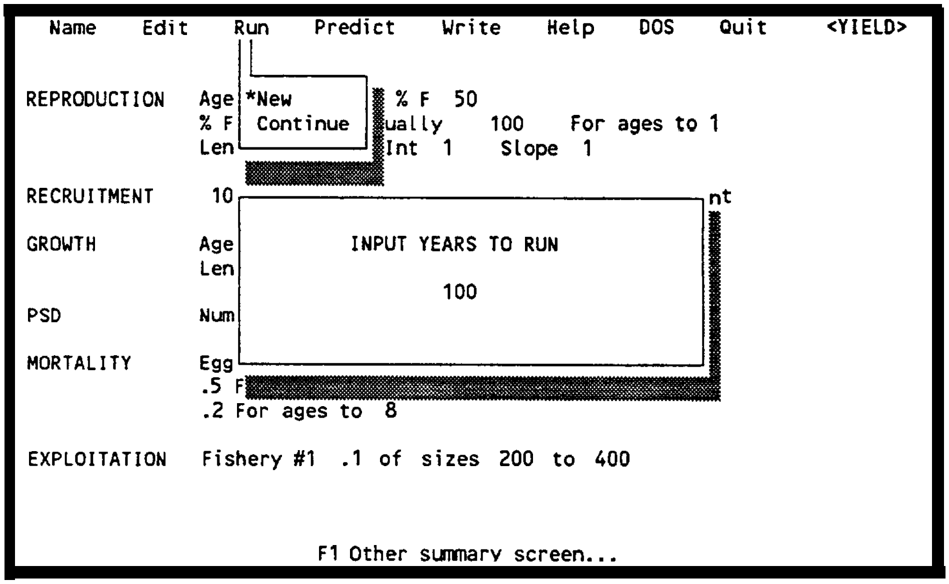
```
SELECT FILE TO LOAD

 MPTEST
*YIELD
 LASTRUN
```

Change the recruitment option from 1 to 3 and indicate the relative frequency and size of big year classes. You must press Enter after overtyping the recruitment option to display inputs associated with the big year class option.



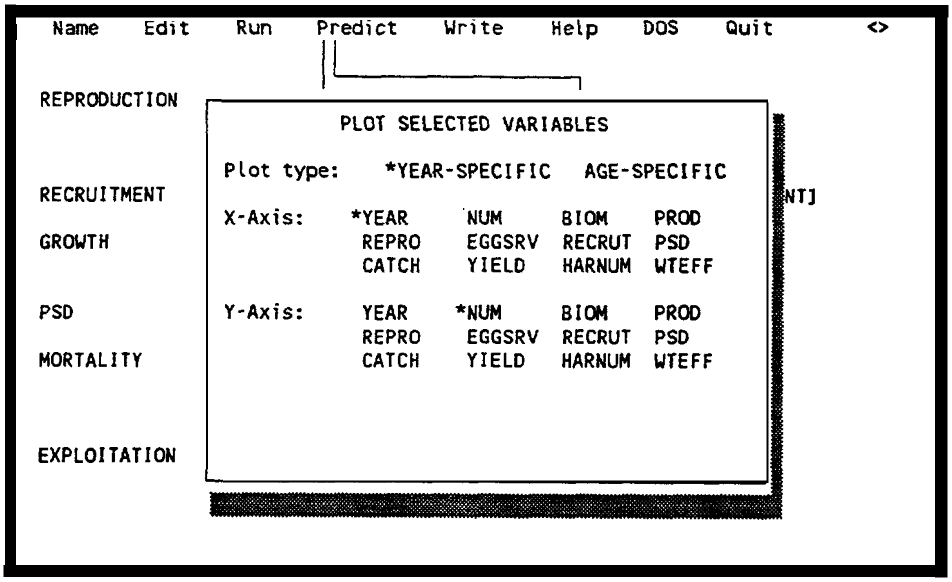
```
                         RECRUITMENT

Option  =  3

     1 = CONSTANT - n&r entered for age 1
     2 = BIG YEAR CLASSES - At fixed intervals, otherwise constant
     3 = BIG YEAR CLASSES - At random intervals, otherwise constant
     4 = RANDOM - Uniformly distributed
     5 = RANDOM - Normally distributed
     6 = STOCK RELATED - Proportional to reproductive potential
     7 = STOCK RELATED - Beverton-Holt relationship
     8 = STOCK RELATED - Ricker relationship
     9 = STOCK RELATED - Cushing equation

Avg Frequency of Big Year Classes          =  4

Size of Big Year Classes (times Average)   =  3
```

Run the simulation for 100 years by escaping from the Edit pull-down menu, selecting Run, selecting New, and entering 100.



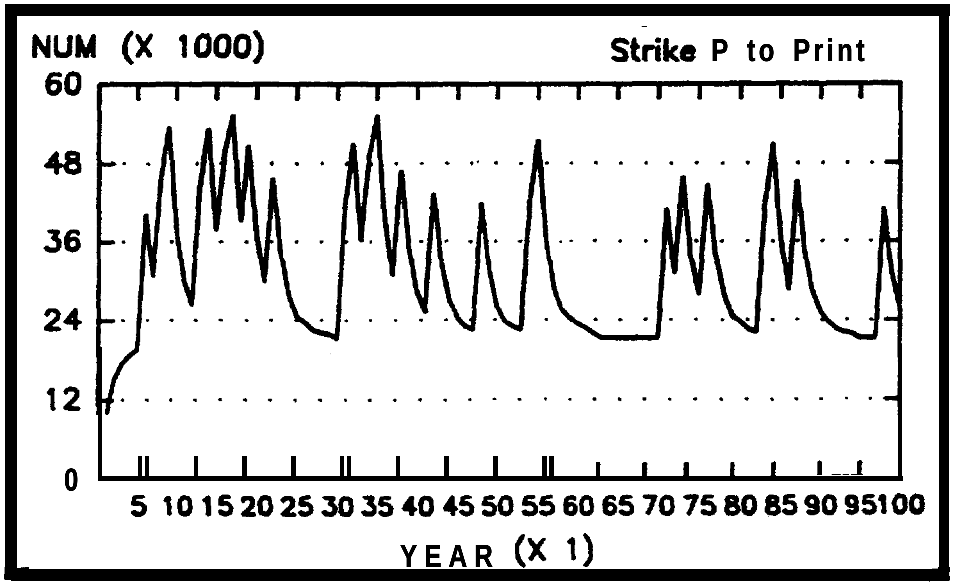
```
REPRODUCTION   Age            % F  50
               % F           ually    100   For ages to 1
               Len            Int  1    Slope  1

RECRUITMENT     10                                      nt

GROWTH         Age          INPUT YEARS TO RUN
               Len
                                   100
PSD            Num

MORTALITY      Egg
               .5 F
               .2 For ages to  8

EXPLOITATION   Fishery #1  .1 of sizes  200  to  400


                          F1 Other summary screen...
```

After the run is complete, you might wish to plot numbers versus years to examine the pattern of variation. Select the Graph option in the Predict pull-down menu and use the cursor control keys to highlight the choices Year-specific for plot type, Year for the X-axis, and Num for the Y-axis. Press Enter after highlighting each choice to proceed to the next option.



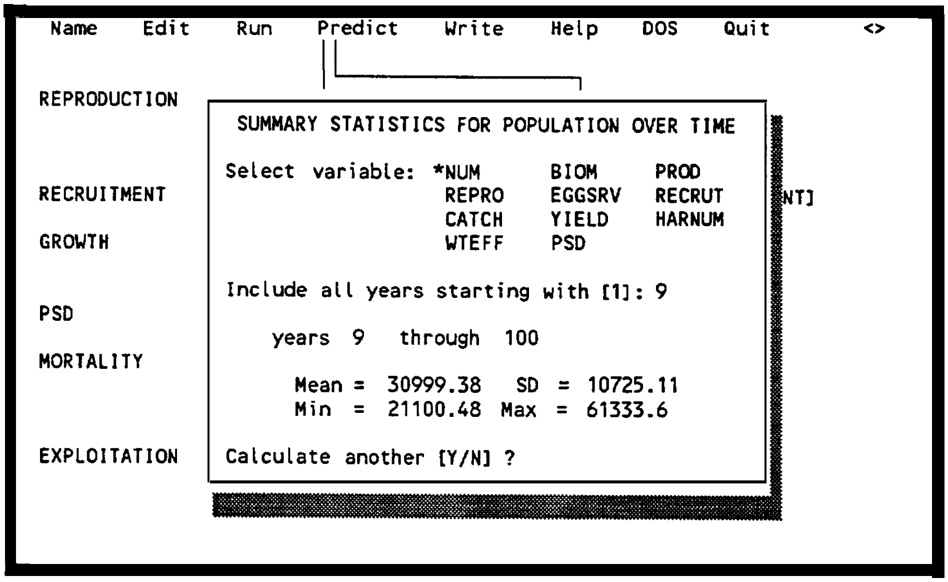
```
Name    Edit    Run    Predict    Write    Help    DOS    Quit        <>

REPRODUCTION
                        PLOT SELECTED VARIABLES

              Plot type:    *YEAR-SPECIFIC   AGE-SPECIFIC
RECRUITMENT                                                     NT]
              X-Axis:     *YEAR     NUM      BIOM     PROD
GROWTH                     REPRO    EGGSRV   RECRUT   PSD
                           CATCH    YIELD    HARNUM   WTEFF

PSD           Y-Axis:      YEAR    *NUM      BIOM     PROD
                           REPRO    EGGSRV   RECRUT   PSD
MORTALITY                  CATCH    YIELD    HARNUM   WTEFF



EXPLOITATION
```

A figure similar to the following will appear. Figures will vary because the years when big year classes occur are randomly selected.



You see that number of individuals started low and increased as a population containing all age classes was built. After that, the population fluctuated as big year classes occurred and moved through the population.

You may also use the Summary Statistics option in the Predict pull-down menu to calculate the mean, standard deviation, and range over which population numbers varied. In this example, we start with Year 9 to avoid including years before all age classes were represented in the population. Remember to save model inputs for future use before ending the current session.



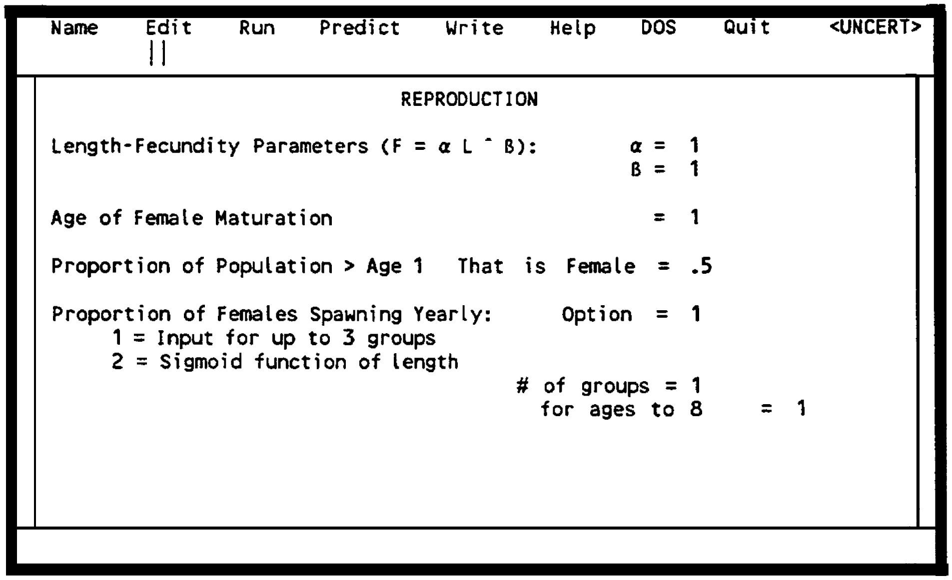
```
SUMMARY STATISTICS FOR POPULATION OVER TIME

Select variable: *NUM      BIOM     PROD
                  REPRO     EGGSRV   RECRUT
                  CATCH     YIELD    HARNUM
                  WTEFF     PSD

Include all years starting with [1]: 9

    years  9   through  100

      Mean =  30999.38   SD  =  10725.11
      Min  =  21100.48  Max  =  61333.6

Calculate another [Y/N] ?
```

## Problem 3--Response Time

Estimate how quickly a population will recover after a reduction of 50%. Assume a Beverton-Holt stock-recruitment relationship of low to moderate resilience (A = 0.2)[*see* Ricker (1975), page 292]. Assume no age structure, weights and lengths as in Problems 1 and 2, fecundity equal to length, and a sex ratio of 1:1 with all females spawning.

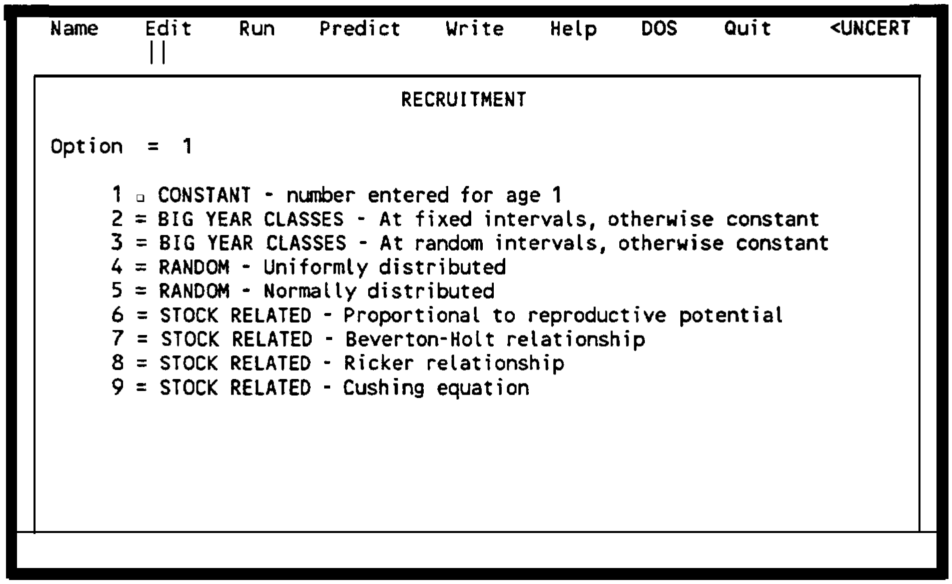
This situation approximates a simple stock-recruitment-type model, but instead of calculating a progeny stock size directly from parental stock size, MOCPOP 2.0 works by calculating a reproductive potential for parental stock, then multiplying that potential by an egg-to-adult survival rate. You must supply reproductive potential at equilibrium (A in the Beverton-Holt equation) and egg-to-adult (age 1) mortality to run this simulation. You can use MOCPOP 2.0 to simplify calculation of these numbers by first running a one-year simulation to calculate reproductive potential, then solving for the mortality rate that will give you the starting stock size you supplied.

**Start** MOCPOP 2.0 **and load the model used in Problem 2** (UNCERT). **Use the Edit pull-down** options **to double check that** reproduction **inputs are as follows:**

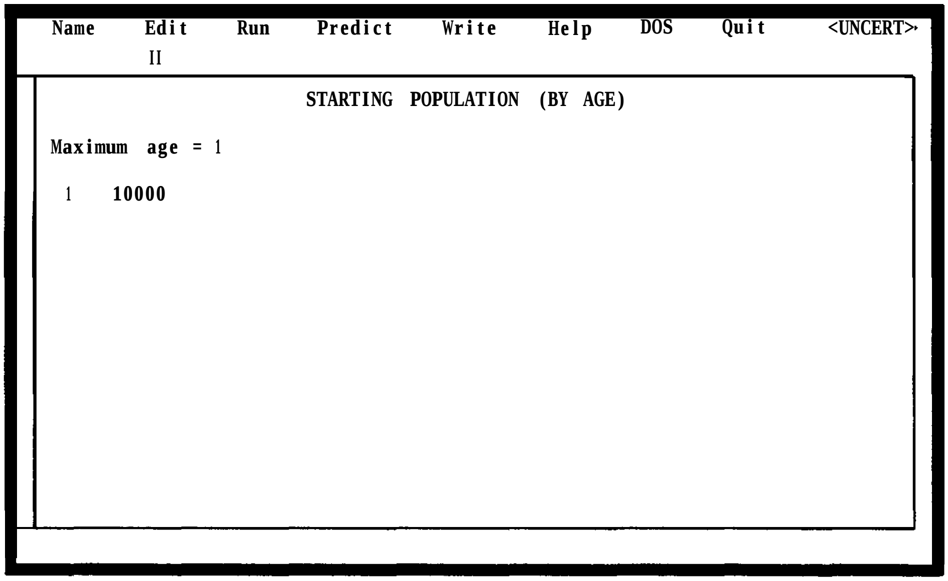


```
                              REPRODUCTION

Length-Fecundity Parameters (F = α L ^ ß):        α =  1
                                                  ß =  1

Age of Female Maturation                            =  1

Proportion of Population > Age 1  That  is  Female  =  .5

Proportion of Females Spawning Yearly:     Option   =  1
     1 = Input for up to 3 groups
     2 = Sigmoid function of length
                                       # of groups = 1
                                         for ages to 8     =  1
```

**Next, fix recruitment at** 10000 **and set maximum age to** 1.

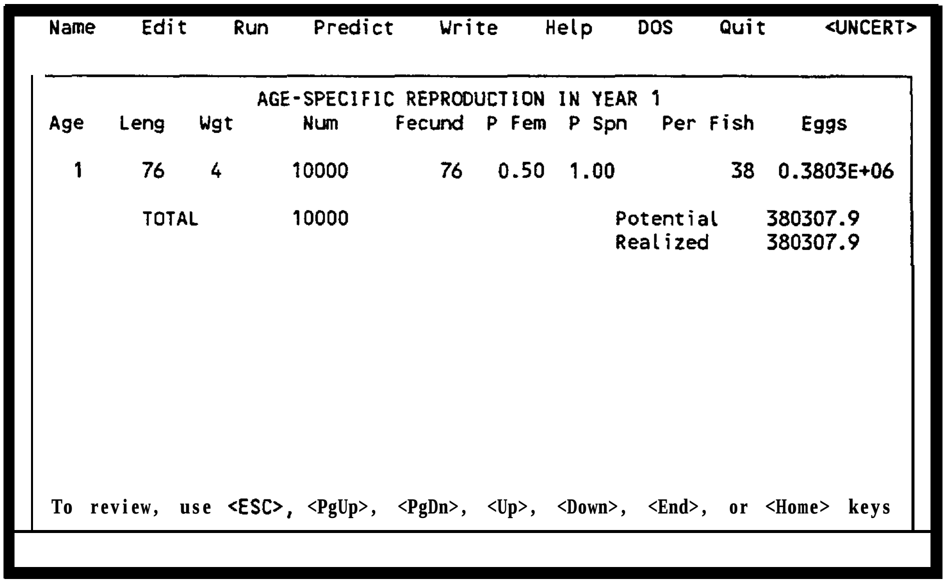


```
                              RECRUITMENT

Option  =  1

     1 □ CONSTANT - number entered for age 1
     2 = BIG YEAR CLASSES - At fixed intervals, otherwise constant
     3 = BIG YEAR CLASSES - At random intervals, otherwise constant
     4 = RANDOM - Uniformly distributed
     5 = RANDOM - Normally distributed
     6 = STOCK RELATED - Proportional to reproductive potential
     7 = STOCK RELATED - Beverton-Holt relationship
     8 = STOCK RELATED - Ricker relationship
     9 = STOCK RELATED - Cushing equation
```



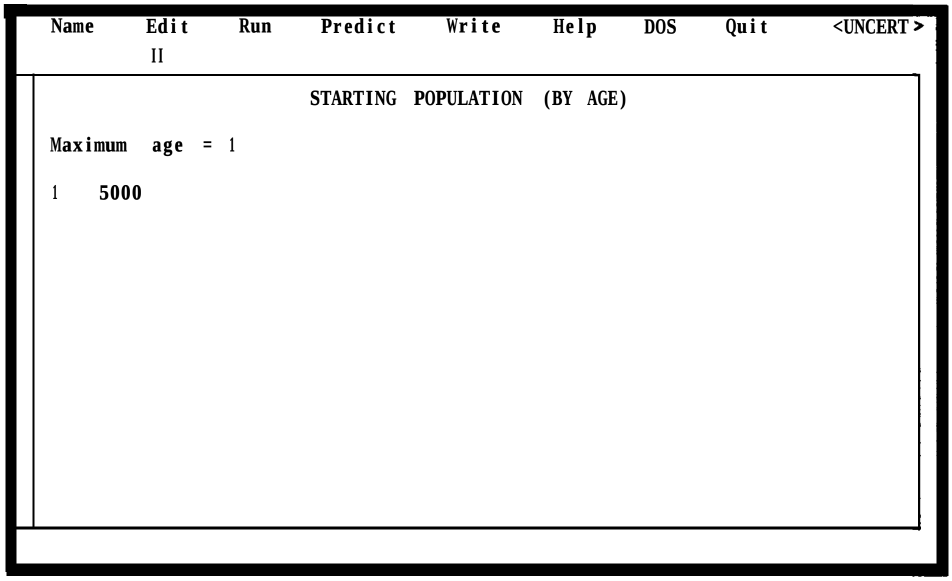
```
                    STARTING POPULATION (BY AGE)

Maximum age = 1

 1    10000
```

For the present, you may ignore inputs for mortality rate as these are not needed in the one-year simulation. Run a new simulation for one year and inspect the age-specific reproduction information screen. The reproductive potential of the population you input is 380,308.



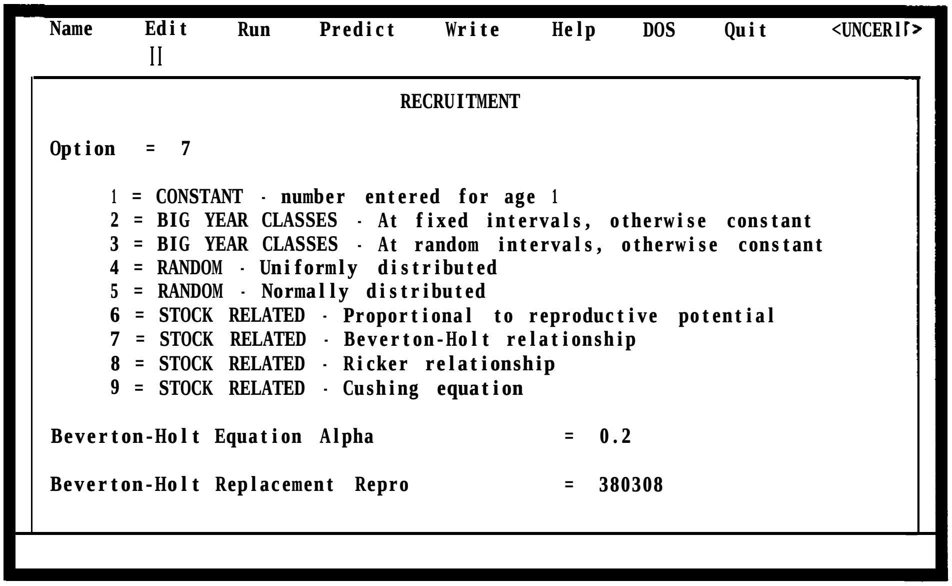
```
                 AGE-SPECIFIC REPRODUCTION IN YEAR 1
Age   Leng   Wgt      Num      Fecund  P Fem  P Spn   Per Fish    Eggs

 1     76     4      10000        76    0.50   1.00         38  0.3803E+06

      TOTAL          10000                       Potential     380307.9
                                                 Realized      380307.9








To review, use <ESC>, <PgUp>, <PgDn>, <Up>, <Down>, <End>, or <Home> keys
```

Now run a new simulation to determine how long it will take for the population to recover from a 50% reduction. First reduce starting population size to 5000.



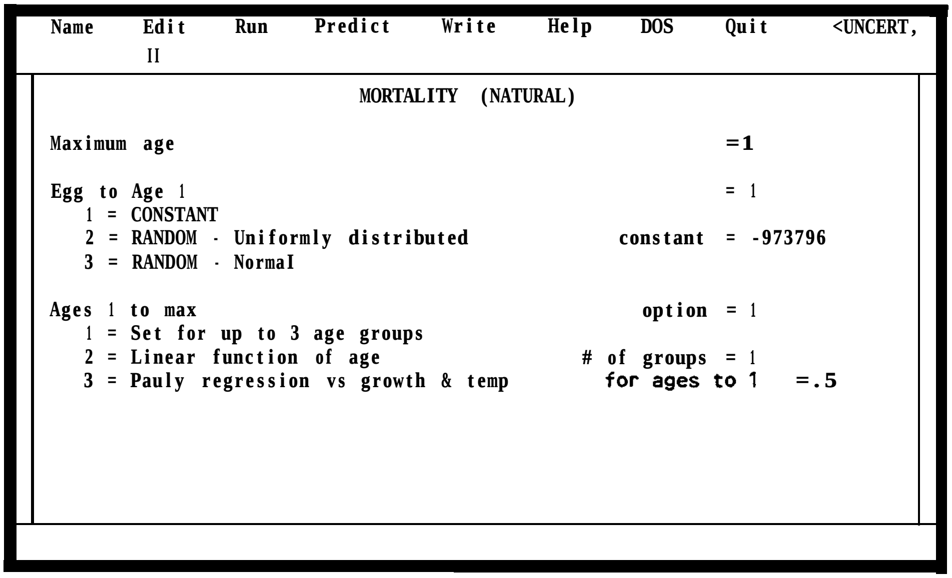
```
                    STARTING POPULATION (BY AGE)

Maximum age = 1

1   5000
```

Next, indicate that recruitment is based on a Beverton-Holt equation and supply parameters.



```
                              RECRUITMENT

Option  =  7

    1 = CONSTANT - number entered for age 1
    2 = BIG YEAR CLASSES - At fixed intervals, otherwise constant
    3 = BIG YEAR CLASSES - At random intervals, otherwise constant
    4 = RANDOM - Uniformly distributed
    5 = RANDOM - Normally distributed
    6 = STOCK RELATED - Proportional to reproductive potential
    7 = STOCK RELATED - Beverton-Holt relationship
    8 = STOCK RELATED - Ricker relationship
    9 = STOCK RELATED - Cushing equation

Beverton-Holt Equation Alpha              =  0.2

Beverton-Holt Replacement Repro           =  380308
```

Lastly, edit mortality inputs and input the egg mortality rate.



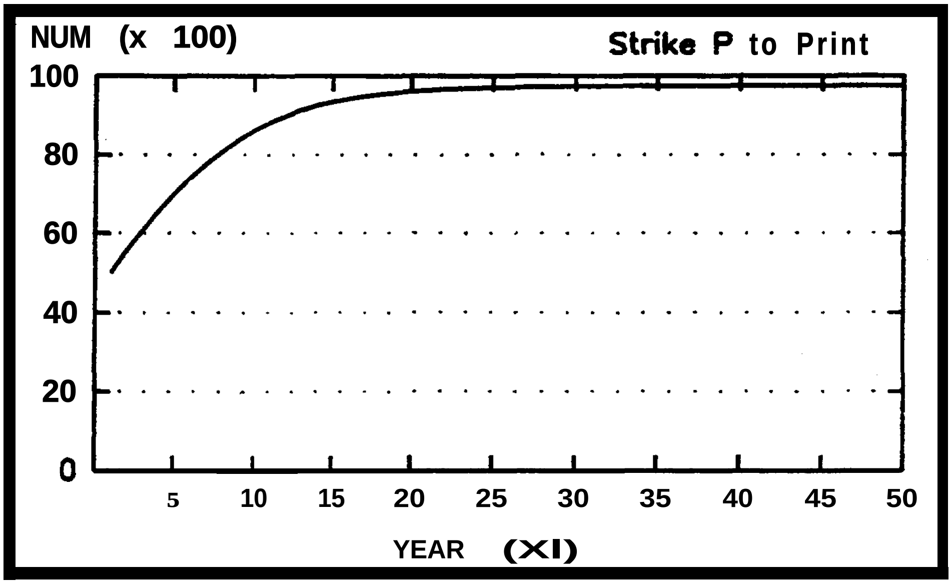
```
Name     Edit     Run     Predict     Write     Help     DOS     Quit     <UNCERT,
         II
                              MORTALITY (NATURAL)

Maximum age                                                   =1

Egg to Age 1                                                  = 1
   1 = CONSTANT
   2 = RANDOM - Uniformly distributed             constant  = -973796
   3 = RANDOM - Normal

Ages 1 to max                                       option  = 1
   1 = Set for up to 3 age groups
   2 = Linear function of age                    # of groups = 1
   3 = Pauly regression vs growth & temp          for ages to 1   =.5
```

This rate is calculated as

$$\text{Rate} = 1 - 10000/380308 = 0.973796$$

You are also prompted for natural and harvest mortality rates on the Mortality edit screen, but these numbers are not used in, our simulation because no fish live past age 1. Age 1 mortality is automatically set to 100% by MOCPOP 2.0 regardless of what you enter here because 1 is the maximum age.

You are now ready to run the simulation. Do so by escaping from edit screens, selecting Run and New, and entering 50 years. When the simulation is complete, plot numbers versus years. You see approximately 25 years are required for the population to recover to equilibrium levels.



## COPIES AND BUGS

A copy of MOCPOP 2.0 may be obtained by sending a diskette and self-addressed mailer with stamp to the author. MOCPOP 2.0 may be copied and distributed freely; no person or organization is authorized to charge any fee or price for MOCPOP 2.0. MOCPOP 2.0 includes the following files:

1. MOCPOPZO.EXE: Executable program file.
2. MPZOEDIT.OBJ: Program module called by main file.
3. MPZOMISC.OBJ: Program module called by main file.
4. MPTEST.MPK: File containing example input data.
5. MP.BAT: Batch file for running program with monochrome graphics card (see Page 1).

MOCPOP 2.0 is distributed without warranty. If you find a bug, I will attempt to repair it in future versions if you notify me in writing.

## ACKNOWLEDGEMENTS

I thank B.E. Rieman and H.A. Schaller for thoughtful review of this program and W.A. Burck and A.A. Nigro for helpful comments on the documentation. This work was supported by funds from the Bonneville Power Administration (Contract DE-AI79-86BP63584).

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# Reproduction and Recruitment

## REPORT F

# Maturation of Female White Sturgeon in Lower Columbia River Impoundments

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and

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*Abstract.-* Following construction of a series of hydroelectric power dams on the Columbia River, the original white sturgeon *(Acipenser transmontanus)* population was isolated in a series of impoundments with different biological characteristics. We examine two aspects of sturgeon maturation within these Columbia River impoundments: (1) whether statistical evidence supports histological studies indicating that completion of the maturation cycle requires two or more years for female white sturgeon, and (2) whether maturity characteristics (median size-at-maturity and rate of maturity) differ among impoundments. We estimate the maturity characteristics and their associated uncertainty by maximum likelihood. The results suggest that maturity characteristics may vary between reservoirs, and that the maturation cycle of white sturgeon may indeed take two or more years; however, the statistical uncertainty of the estimates is large, and the conclusions need to be interpreted with caution.

## Introduction

Prior to the development of hydroelectric power dams, white sturgeon *(Acipenser transmontanos)* ranged throughout the Columbia and Snake rivers as far as 1,300 km upstream from the ocean. However, construction of several dams between 1938-75 divided the original sturgeon population into a series of reservoirs. Because white sturgeon require many years to attain sexual maturity, the intrinsic capacity of populations to withstand even relatively low levels of mortality may be limited (Cochnauer et al. 1985; Elliott and Beamesderfer 1990; Rieman and Beamesderfer 1990). Small differences in maturation can also have large effects on sustainable rates of fishing mortality in some fish populations (Welch and Foucher 1988). Establishing the maturity characteristics of white sturgeon is therefore an important aspect of evaluating the reproductive potential and sustainable yield of sturgeon populations in these reservoirs.

Relatively little is known about the maturation process in most species of sturgeon. Sturgeon generally mature at an advanced age (at least 14 years for females) and have protracted (3 year or longer) spawning cycles (Rochard *et al.* 1990). Based on an assessment of gonad condition, Dadswell (1979) concluded that female shortnose sturgeon *(A. brevirostrum)* probably take 5-8 years to repeat spawning after becoming sexually mature, with minimum spawning intervals thereafter of 3 years. Banding patterns evident within age structures have also been interpreted as periods of reproductive hiatuses in sturgeon. Roussow (1957) and Guenette *et al.* (1992) interpreted annular bands of varying width on pectoral fin ray sections from eastern lake sturgeon *(A. fu7vescens)* as evidence that spawning may occur only every 5-11 years, but the correspondence between these banding patterns and reproductive status is unclear (Guenette *et al.* 1992).

Similar reproductive hiatuses may occur in white sturgeon. Chapman (1989) suggested that the maturation cycle of female white sturgeon requires at least two years to complete, with vitellogenesis beginning in the fall, and spawning occurring in the spring some 18-20 months later. However, the ovaries of large females are frequently found to contain only non-developing eggs, which suggests that a resting period may occur, and that the maturation cycle may be even longer. For example, female white sturgeon from San Francisco Bay appear to spend at least one year in a resting stage, with gonads containing immature eggs only, following each two year period of gonadal development (Chapman 1989). If, on average, a resting period of one year occurs before the two year developmental cycle begins again, then the remaining females in fully mature length groups will consist of one-third with developing eggs, and one-third either in a spent condition or containing fully developed eggs (depending on when sampling occurs relative to the spawning season). Thus for fully mature length groups the maximum fraction mature would not exceed 33%.

Maturity characteristics may also vary among populations of white sturgeon. Female white sturgeon in the unimpounded portion of the Columbia River mature at 15- 20 years and 150-165 cm fork length, with variable intervals between spawning (Galbreath 1985). In San Francisco

Bay, female white sturgeon appear to mature at fork lengths between 104-150 cm with most maturing between 140-150 cm, and may subsequently require 4-5 years to complete one maturation cycle (Chapman 1989). Essentially 100% of females examined in San Francisco Bay were either maturing or mature by 200 cm. In the Fraser River, banding on pectoral fin ray sections suggested that age at first spawning ranged from 11 to 34 years for female white sturgeon, with 4-9 year intervals between spawning (Semakula and Larkin 1968). These ages correspond to female maturation at 82-175 cm fork length.

All of these studies are based on rather qualitative analyses of small numbers of sturgeon, and the uncertainty in the reported values is difficult to assess. To our knowledge, quantitative estimates of size-at-maturity and spawning periodicity, and their between-population variability, have not previously been reported for any sturgeon species. In this paper, we estimate length-at-maturity and spawning periodicity for white sturgeon from three impoundments within the Columbia River, and assess the evidence that maturity characteristics vary between populations.

## Study Sites

John Day, The Dalles, and Bonneville reservoirs form a series of three sequential impoundments operated for hydroelectric power generation, navigation, and flood control on the mainstem of the Columbia River (Figure 1). In all three reservoirs, littoral zones are limited, average hydrologic retention times are short (1-5 d), and current is measurable throughout most of the year.

In other respects, the three reservoirs are dissimilar. John Day Reservoir is the largest (123 km; 21,000 Ha; average depth 8.0 m) and most limnologically diverse of the three. The reservoir grades from a riverine upper region with gravel and cobble substrate to a shallow transition zone with sand substrate, and finally into a more lentic lower section with steep cliff and boulder sides. The Dalles Reservoir is the smallest (38 km; 4,500 Ha; average depth 7.5 m) and most riverine, with cobble, gravel, and sand substrates distributed throughout most of its length. Bonneville Reservoir (74 km; 8,400 Ha) is shallow (average depth 6.7 m) with a mostly sand substrate which supports large beds of rooted aquatic macrophytes during summer.

Sturgeon densities vary substantially among reservoirs, probably as a result of differences in the amounts of spawning habitat available and the levels of fishing pressure exerted. Densities are greatest in Bonneville (the farthest downstream) and least in John Day (the farthest upstream) reservoirs, with growth rates possibly varying inversely with density (Beamesderfer and Rien 1992). However, no direct estimates of biological productivity are available, so the influence of environment is unknown.

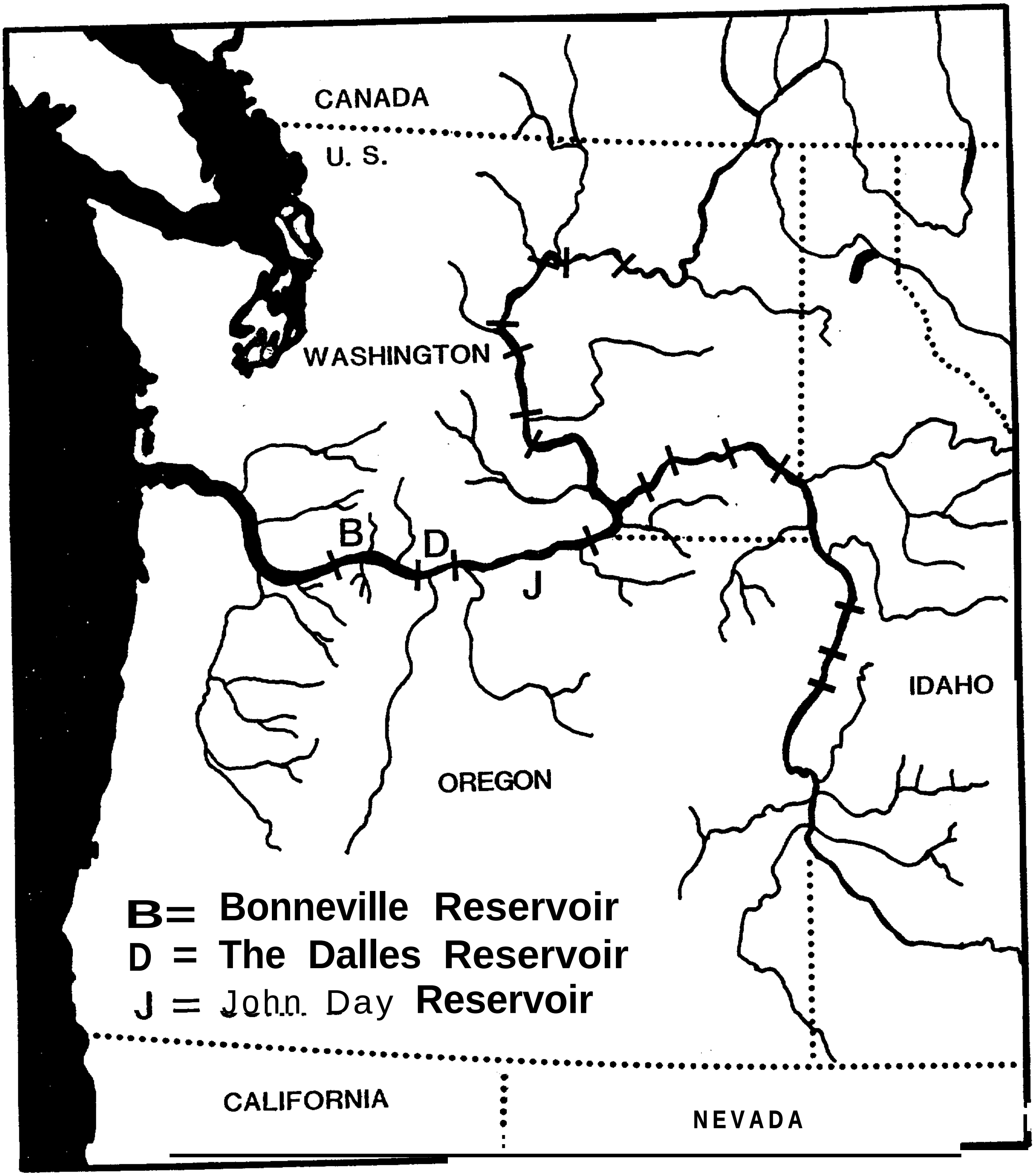

Figure 1. Columbia River dam locations. The three reservoir impoundments discussed in the text are indicated.

## Methods

Maturity data for female white sturgeon (82-166 cm fork length) were collected from sport and commercial fisheries operating in the three reservoirs. Size ranges that could be legally harvested in sport and commercial fisheries were 82-166 cm and 110-166 cm fork length, respectively, with the upper retention limits specified to conserve mature sturgeon. Maturity data for large female white sturgeon (> 166 cm) were collected in a catch-and-release research program using baited setlines (Elliott and Beamesderfer 1990). Setlines were evenly distributed throughout the reservoirs to obtain a geographically representative sample of the white sturgeon population.

A total of 1,899 white sturgeon were collected in 1987-91 (Table 1). Most fish were collected between February and October. All fish were measured to the nearest 1 cm fork length and mature or maturing individuals were sexed. Gonads of large sturgeon caught on setlines were examined using an otoscope inserted through a 2-3 cm ventral incision which was then sutured prior to release of the fish (Conte et al. 1988). Samples of gonad were removed from all females and preserved in 10% formalin.

Classification into immature, maturing, and mature categories was based on a qualitative histological assessment of oocyte development (Chapman 1989): females with translucent oöcytes <1 mm in diameter were classed as immature or resting, females with opaque oöcytes 1-3 mm in diameter were classed as maturing, and females with dark grey or black oöcytes >3 mm in diameter were considered mature. Immature oöcytes could not be distinguished in maturing and mature gonad samples. A fraction of the oöcytes in some gonad samples were enlarged, opaque, and apparently maturing, but the majority remained in the immature (ca. 0.5mm) stage. We classified females in this condition as resting, and pooled all data for resting and immature females along with those sturgeon whose sex could not be established. All identifiable males were excluded from the analyses. However, sex could be difficult to ascertain for surgically-examined fish except when gonads partially filled the body cavity of maturing and mature fish, so an unknown (but probably small) number of maturing males were included in the immature category. This was a negative aspect of the catch-and-release setline program, but was necessary in order to reduce the impact of the program on the reservoir populations.

In theory, the ratio of maturing females to mature or spent females should reflect the length of the developmental period for gonads. Our observation of only 31 mature or spent females versus 111 maturing females implies that either the period of egg development is nearly five times longer than the fully mature period, or that catchabilities are unequal. Although available data are insufficient to reliably assess the relative catchability of females in the maturing and mature categories, Dadswell (1979) found that female shortnose sturgeon had empty stomachs in the last nine months of the maturation cycle, when gonads fill the body cavity. We therefore excluded mature and spent females from the length-at-maturity data sets used to estimate the proportion of maturing females relative to the total sample of immature fish plus maturing or resting females for each length cohort. We refer to this statistic as the proportion maturing (P) to distinguish it from the fraction mature (0). These quantities are related

$$\Phi = 1 - [l / (1 t P)].$$

Differences in maturity with size were analyzed by maximum likelihood, assuming a binomial probability distribution for the uncertainty in maturation estimates (Welch and Foucher, 1988; Richards et al., 1990). Fork length data were preserved in the original 1 cm intervals, and not further rounded or aggregated. We fit the cumulative normal probability model to the length-at-maturity data to describe the change in maturity as a function of three parameters:

$$p = \frac{c}{\sqrt{2\pi}} e^{-(L_X - \mu)^2/2\sigma^2} \sum_{i=l}^{5} b_i \{1 + p \left|\frac{L_X - \mu}{\sigma}\right|\}^{1-i} \quad \text{for } L_X \leq \mu$$

or

$$p = 1 - [\frac{c}{\sqrt{2\pi}} e^{-(L_X - \mu)^2/2\sigma^2} \overset{5}{\underset{i=l}{I}} b_i \{1 \; t \; p \left|\frac{L_X - \mu}{\sigma}\right|\}^{1-i}] \quad \text{for } L_X > \mu,$$

where $L_X$ = age-specific length, $\mu$ = the size at which 50% of the maximal proportion maturing occurs, o = a measure of the length range over which the change from an immature to mature state occurs, c = the asymptotic maturity level, $b_1$ = 0.31938153, $b_2$ = -0.356563782, $b_3$ = 1.781477937, $b_4$ = -1.821255978, $b_5$ = 1.330274429, and p = 0.2316419.

If the cumulative normal model is appropriate as a descriptor of maturation, 95% of females become sexually mature over a length interval of centered on the mean size at maturation. As c predicts the maximum proportion of large females maturing in any one year, its reciprocal is the estimate of the duration of the resting and egg developmental phases. We need to add 1 year to calculate the length of the full maturation cycle (1 t l/c) because mature and spent samples were excluded from analyses.

We used the simplex algorithm (Mittertreiner and Schnute 1985) to estimate the parameters for this modified cumulative normal probability function assuming binomially distributed errors (Welch and Foucher 1988). An equivalent approach using commercially available software would be to fit the data using GLIM (McCullagh and Nelder 1989) using a binomial link function and the probit (cumulative normal) model. Alternatively, Schnute and Richards' (1990) 4 parameter model could be fitted, as applied to maturity data (Richards *et al.* 1990).

One advantage to our use of the cumulative normal model is that it easily allows for the possibility of an abrupt transition from a completely immature to a fully mature state, simply by allowing the parameter $\sigma^2$ to approach zero. Trippel and Harvey (1991) found that the maximum likelihood method described by Welch and Foucher (1988) performed as well as or better than the alternative estimation methods they considered in the usual situation where maturity gradually increases with size or age. However, they found that all methods performed poorly when applied to maturity data with abrupt transitions from an immature to a completely mature state, or where the maximum fraction mature was less than 100%. Using the modified cumulative normal probability curve described above as a model of maturity, and combining it with the maximum likelihood estimation methodology described in Welch and Foucher (1988) removes these shortcomings.

An objective estimate of the uncertainty in estimates of maximum percent mature can be obtained by calculating twice the differsnce in log-likelihoods between the maximum likelihood estimates $H_0 = (\mu^*, \sigma^{2*}, c^*)$ and some competing hypothesis, $H_1 = (\mu^*, \sigma^{2*}, c_{alt})$. For differences

$$\Delta \ln(\mathcal{L}) = 2\ln(\mathcal{L}_0) - 2\ln(\mathcal{L}_1) \le X^2_{s,1-a},$$

the hypothesis that the alternate parameter values are a plausible description of the data cannot be rejected (Kendall and Stuart, 1979). Here s = 1 is the number of parameters specified under the competing hypothesis $H_1$, and $\ln(\mathcal{L}_1)$ is the log-likelihood for the competing hypothesis. The log-likelihood for this constrained model is then maximized by allowing the remaining (unconstrained) parameters $\mu, \sigma^2$ to take on those values leading to the maximum likelihood subject to the constraint on c.

Between-reservoir differences in the estimated median length-at-maturity could be the result of either sampling error or true biological differences. To test this possibility, we calculated the joint 95% confidence region about the maximum likelihood parameter estimates, which we defined as that area bounding the region of log- likelihoods within $X^2_{2.0.95/2} = 3.0$ of the maximum likelihood estimates. maturity parameters were estimated subject to a constraint of c = 0.5 to increase the consistency of median length-at-maturity and spread estimates among areas, as estimates of $\mu$ now all refer to the length at which maturity equals c/2, or 25%.

A 95% confidence region shows those combinations of $\mu$ and $\sigma^2$ which, considered <u>jointly</u>, can be considered plausible alternative estimates to the maximum likelihood estimates of the maturation process, and which cannot be rejected by the available data. Points outside these confidence regions can be considered as combinations of median size-at-maturity and rates of increase in maturity with size that can be rejected as plausible joint descriptions of the maturation process. Alternatively, the maximum and minimum limits to $\mu$ and $\sigma$ defined by these regions can be considered as 95% confidence intervals on the individual parameters which also take into account the uncertainty in the other estimated parameter.

## Results

Maturing females were observed throughout the year but no obvious groupings could be established (Figure 2). We therefore retained Chapman's (1989) classification for defining the maturity condition of individual fish based on egg size, although the absence of sharp delineations between maturity categories suggests significant uncertainty in Chapman's maturity classifications.

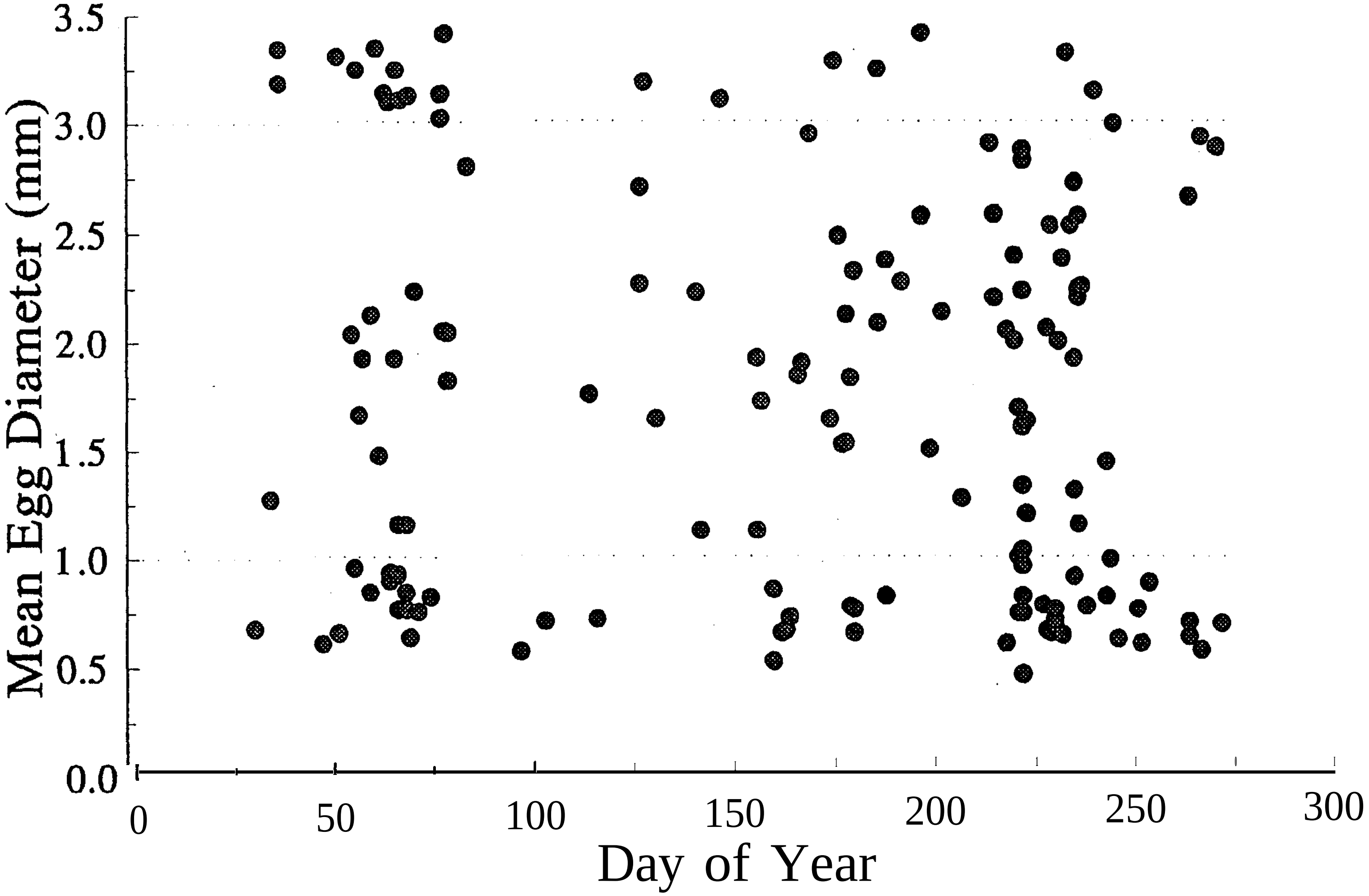

**Figure 2.** Scatter plot of egg sizes over time for female white sturgeon taken from the reservoirs described in the text. Horizontal lines indicate the egg sizes defining the 3 maturity stages (immature, maturing, and mature) described by Chapman (1989).

Maturing females as small as 92 cm were observed; however, only 5% of females collected in the 82-166 cm size range were in the maturing, mature, or spent category (Table 1). Thirty-seven percent of females greater than 166 cm (i.e. those collected in the research set-line fishery) were maturing and only 10% were in the mature or spent category.

The unconstrained maximum likelihood estimate of c is 1.0 for white sturgeon from the Bonneville reservoir and for the combined data, indicating that the best estimate of the duration of the entire maturation cycle, including spawning, is two years (Table 2). Maximum likelihood parameter estimates for The Dalles and John Day reservoirs suggest that the duration of the maturational cycle is roughly three and 4.5 years, respectively.

The predicted maximum percent mature in all reservoirs would only occur for sturgeon well outside the observed size range (Figure 3). Plots of log-likelihood profiles for c show that maturation cycles of three years or less are compatible with the combined data set, and that the uncertainty (indicated by the width of the likelihood profiles) is larger for individual data sets (Figure 4). However, with the exception of the data collected from sturgeon in The Dalles reservoir, a 2 year maturation cycle is statistically plausible for all data sets. Using the data sets collected from individual reservoirs, upper limits on the length of the maturation cycle are roughly 3.5, 4, and >11 years. Note that the data collected on the John Day population is essentially non-informative concerning the duration of the maturation cycle (Figure 4).

A maturation cycle of two years (c = 1) is consistent with histological studies that indicate a 16 month (or 2 year) egg developmental period occurs, as females can spawn in the second year of the cycle. However, the estimated proportion maturing only approaches 100% for sizes well outside the size range of the data (92-260 cm). We therefore re-estimated the parameters subject to the common constraint that c = 0.5 (Table 2), which is approximately the lower 95% confidence limit on c for the combined data. From a biological viewpoint, an estimate of c = 0.5 would be consistent with a one year resting period and a two year egg developmental period, followed by spawning in the third year.

Over most of the observed range of maturity data the fit of the constrained and unconstrained models is virtually identical (Figure 3). As the number of maturity observations for females larger than the median length-at-maturity (ca. 180cm) is quite limited, we therefore provisionally accepted a common maturational cycle length of 3 years (c = 0.5) for all areas.

Based on the assumption of a common maturation cycle of three years, the median length-at-maturity for sturgeon in the Bonneville and The Dalles reservoirs is approximately 165 cm, and roughly 193 cm for sturgeon in John Day reservoir. Considered separately, the uncertainty in these estimates of the maturity characteristics leave little reason to reject the hypothesis that sturgeon maturation in Bonneville and John

Table 1. Summary of data on white sturgeon collected in three Tower Columbia River reservoirs, 1987-91.

| Reservoir | Size class (cm)[1] | Number of length groups[2] | Unknown sex[3] | Immature female[4] | Maturing | Mature & spent | Total sample size[5] |
|---|---|---|---|---|---|---|---|
| Combined | 82-166 | 149 | 13 | 1,679 | 65 | 19 | 1,776 |
| | >166 | | 35 | 30 | 46 | 12 | 123 |
| Bonneville | 82-166 | 105 | 1 | 777 | 35 | 12 | 825 |
| | >166 | | 11 | 10 | 24 | 9 | 54 |
| The Dalles | 82-166 | 106 | 10 | 674 | 28 | 6 | 718 |
| | >166 | | 7 | 13 | 15 | 2 | 37 |
| John Day | 82-166 | 90 | 2 | 228 | 2 | 1 | 233 |
| | >166 | | 17 | 7 | 7 | 1 | 32 |

---

[1] Fork length.

[2] Combined value for commercial and sport fishery samples (82-166 cm) and the setline fishery (>166cm).

[3] Either completely immature fish or fish with gonads too undeveloped to reliably determine sex.

[4] Females only; unknown sex fish excluded.

[5] Includes all randomly selected female or unknown-sex fish.

Table 2. Estimates of median fork length (cm) at maturity ($\mu$), the rate of change in maturity with length ($\sigma^2$), and the maximal fraction mature (c) for female white sturgeon collected from the Columbia River. The log-likelihood is represented as $\ln(\mathcal{L})$.

| Reservoir | $\mu$ | $\sigma^2$ | c | $\ln(\mathcal{L})$ |
|---|---|---|---|---|
| | | Unconstrained Parameter Estimates | | |
| Combined | 227.1 | 67.6 | 1.00 | 398.15 |
| Bonneville | 219.7 | 73.3 | 1.00 | 200.79 |
| The Dalles | 164.9 | 26.6 | 0.51 | 140.51 |
| John Day | 156.9 | 22.9 | 0.27 | 39.03 |
| | | Constrained Parameter Estimates | | |
| Combined | 180.7 | 50.6 | 0.50 | 399.81 |
| Bonneville | 168.2 | 53.2 | 0.50 | 202.20 |
| The Dalles | 164.2 | 26.3 | 0.50 | 140.51 |
| John Day | 193.5 | 40.3 | 0.50 | 39.20 |

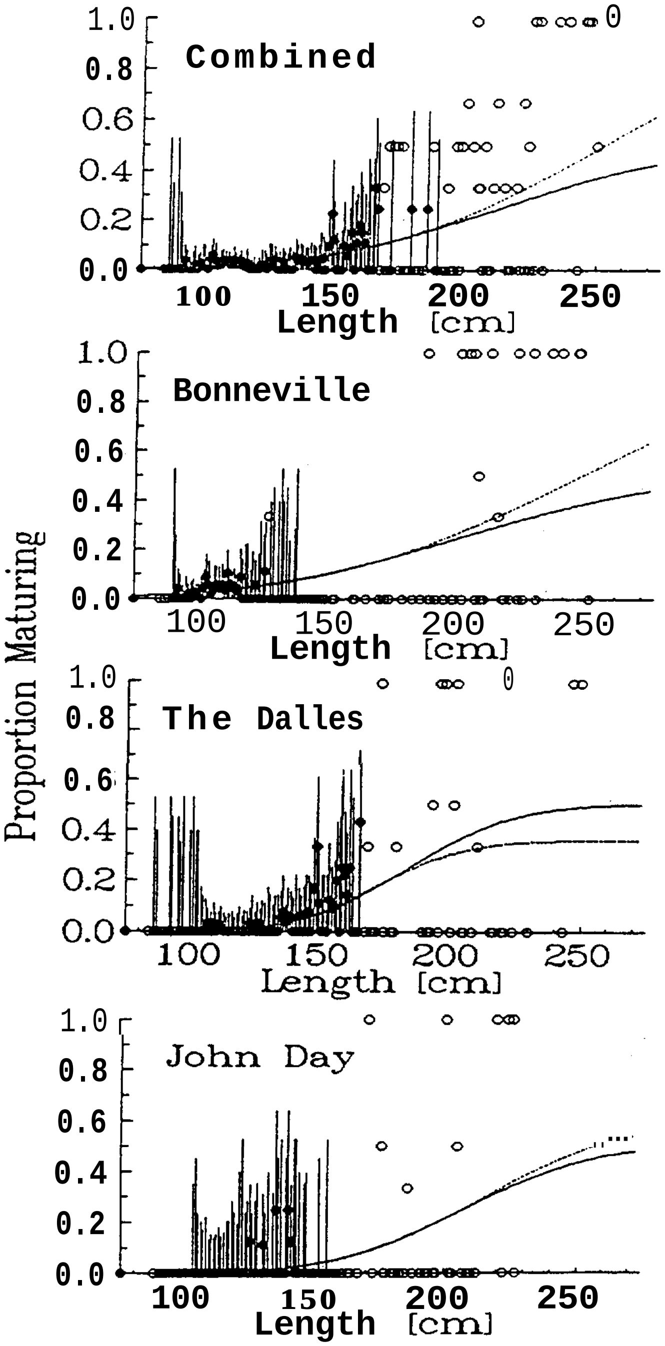

Figure 3. Proportion of Columbia River female white sturgeon maturing at various sizes. Vertical bars indicate the 95% confidence limits on individual maturity observations for length groups with four or more observations assuming binomial errors (filled circles). To avoid clutter, confidence limits are not drawn for length groups with three or fewer observations (open circles). The dotted line shows the unconstrained estimate of the maturity-length relationship obtained using the cumulative normal maturity model, and the solid line shows the ,constrained (c = 0.5) relationship.

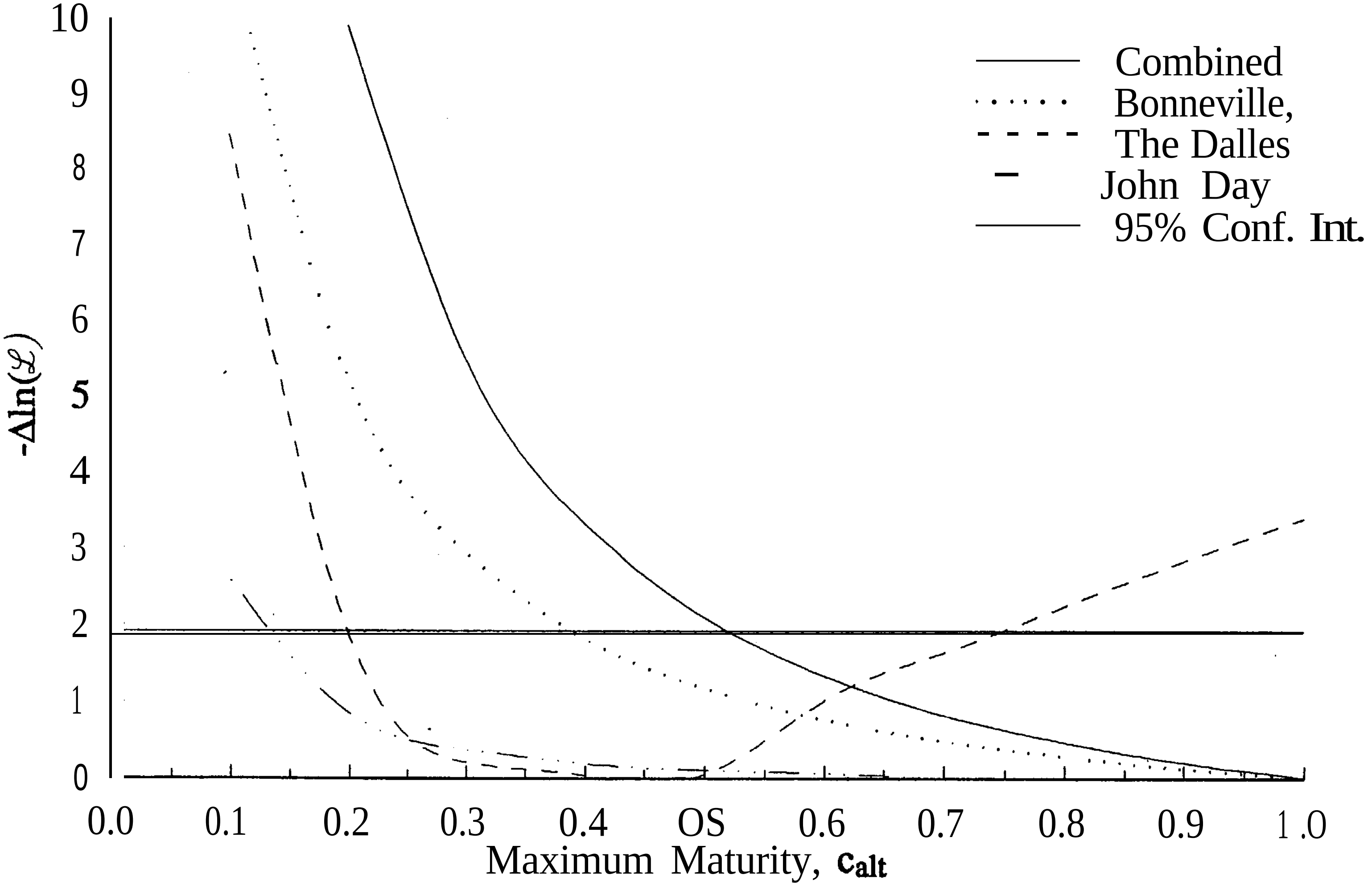

Figure 4. log-likelihood profiles for the aggregate data on Columbia River white sturgeon and the three reservoir populations. For each data set, log-likelihood profiles were calculated by holding the parameter $c_{alt}$ at fixed values, and then finding the values of $\mu$ and $\sigma^2$ that maximized the log-likelihood subject to this constraint. The values plotted are relative to the maximum likelihood, $|\Delta\ln(\mathcal{L})| = |\ln(\mathcal{L}_1) - \ln(\mathcal{L}_0)|$. The maximum likelihood estimate of c is indicated by the value at which the profile is zero. The estimated length of the maturational cycle is shown on the lower axis assuming females spawn the year after the maturation process is completed.

Day reservoirs was similar. However, none of the joint confidence regions include the maximum likelihood estimate of the maturity parameters for the other reservoirs, although in all cases the confidence regions are not widely separated, and the confidence limits on $\mu$ overlap (Figure 5). There is therefore some evidence that the maturation characteristics of sturgeon differ among regions of the Columbia River.

## Discussion

Histological studies indicate that the development of oöcytes in female sturgeon requires over 16 months. Our empirical estimates are also consistent with a two year maturational cycle, but the maximum proportion maturing in any year only approaches 100% for female sturgeon much larger than any so far collected from the Columbia River. Because of the paucity of large females in the samples collected, maximum likelihood estimates of the length of the maturation cycle using currently available data are also consistent with a three year cycle, which would occur if a resting period of one year occurred prior to re-initiation of gonadal development. A hiatus between periods of gonadal development has been suggested before for female sturgeon; however, our estimates of the maximum fraction maturing are inconsistent with five year or greater maturation intervals, which has been suggested for other sturgeon populations based on the existence of banding patterns on bony structures (Dadswell 1979; Rochard et *al.* 1990; Roussow 1957; Semakula and Larkin 1968; Guenette et *al.* 1992).

Analysis of maturity data from various impoundments within the Columbia River suggests that many more female white sturgeon from Bonneville Reservoir mature at smaller sizes than female white sturgeon from The Dalles and John Day reservoirs. For all three reservoirs, an approximate 95% lower confidence bound on the mean size at maturation is ca. 165 cm (Fig. 5). Partly owing to the difficulty of collecting large (>2m) sturgeon, the uncertainty in both the range over which females initiate maturity and the length at which 50% of the maximal maturing fraction is attained is still substantial (156-195 cm).

Chapman (1989) found that the mean size-at-maturity of female white sturgeon in San Francisco Bay was roughly 140-150 cm, at or below our lower bound of 165 cm for Columbia River white sturgeon. It is therefore possible that other aspects of the biology, such as the duration of the maturation process, may also differ in response to environmental conditions.

Both the joint confidence regions and the likelihood profiles for the maximum fraction maturing are probably conservative. Much of the apparent separation in maturity characteristics is due to the estimated differences in the rates of maturation with size for large females, where sample sizes are small. In addition, difficulties involved in assessing the maturity condition of live white sturgeon suggest that the binomial error assumption is likely to underestimate the true uncertainty in maturity estimates. Extra-binomial error is unlikely to bias maturity parameter estimates, but will result in parameter

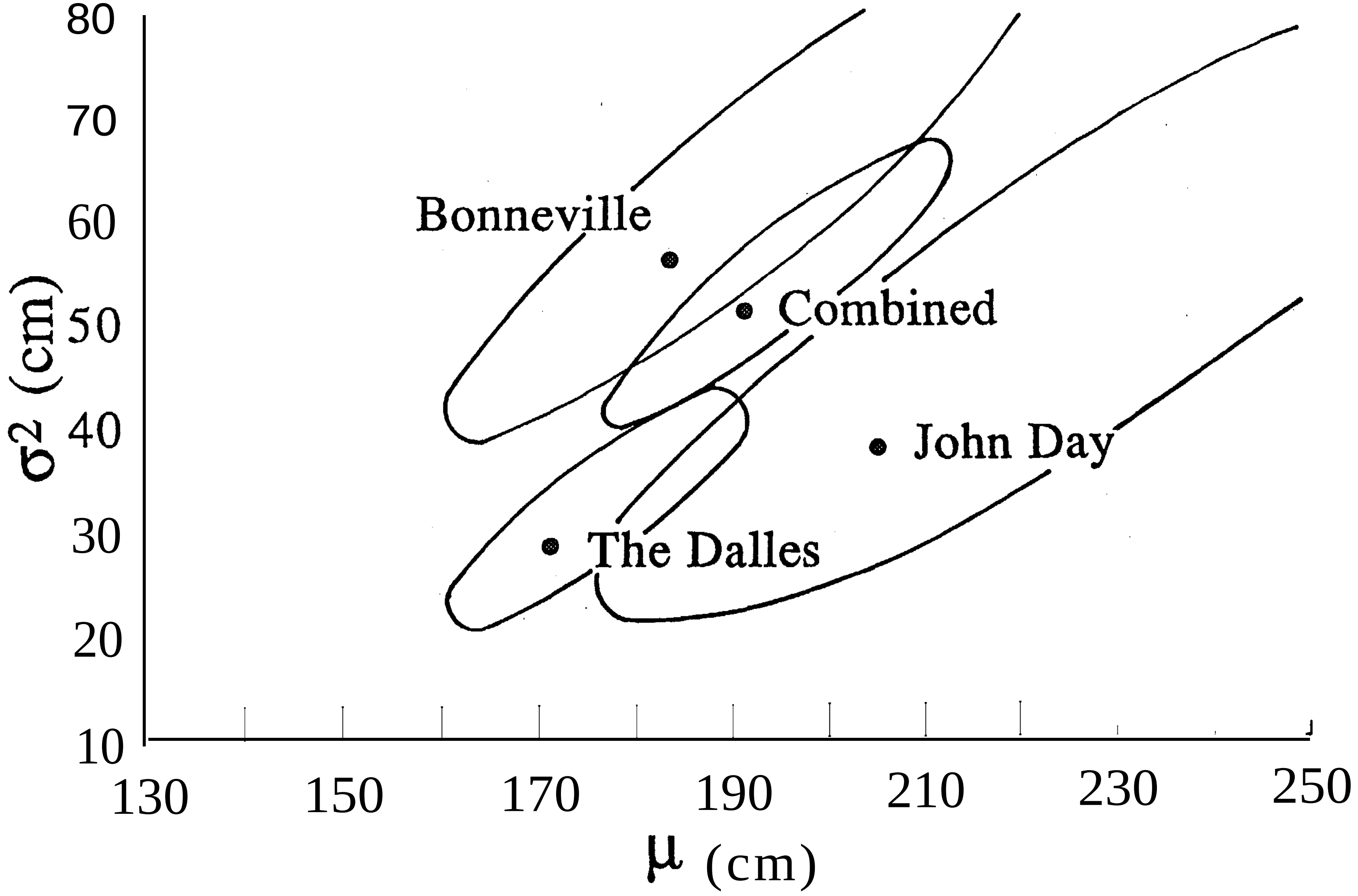

Figure 5. Approximate 95% joint confidence regions about the constrained estimates of the mean and variance of the maturation process, assuming c = 0.5.

uncertainty being underestimated (McCullagh and Nelder 1989). Finally, confidence profiles and regions will underestimate the true uncertainty in the data because the confidence contours are slices through parameter space, as we held c at 0.5.

Despite uncertainty in the estimates of the mean length at maturation and the associated variance, we conclude that there is evidence for a statistically distinguishable difference in the maturity characteristics of female white sturgeon among Columbia river reservoirs. There is also evidence that the mean size-at-maturation differs from that reported for other river systems, with female white sturgeon apparently maturing at smaller body sizes in both the Fraser River to the north (Semakula and Larkin, 1968), and San Francisco Bay to the south (Chapman, 1989). The reasons for these differences are unknown, but might be related to the restriction of the once free-roaming sturgeon to specific impoundments within the Columbia River system.

## Acknowledgments

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# REPORT G

# Gonadal Development of Female White Sturgeon in the Lower Columbia River

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## Abstract

We sampled 1635 female white sturgeon (Acioenser transmontanus) in three impoundments of the lower Columbia River from 1987 through 1991 to investigate the duration of the maturation cycle, the period of spawning, size-related differences in reproductive effort, and indicators of maturation stage. We were unable to determine the duration of the maturation cycle due to variations in the onset and rate of vitellogenesis among individual females. Patterns in gonadosomatic index (GSI) values and the frequency of collection of ripe females imply that female white sturgeon in the lower Columbia River could begin spawning as early as February and continue through September although the majority of spawning likely occurs from late April through early July. Ripe eggs were collected from females ranging from 98 to 249 cm fork length (FL). Fecundity increased with FL, but GSI values were independent of fish size. We were unable to establish a relationship between plasma protein levels and stage of egg maturity, but found the GSI to be a potential alternative for determining maturation stage.

## Introduction

The reproductive biology of sturgeons (Family Acipenseridae) in wild populations is poorly understood because of difficulties with sampling the large river systems they typically inhabit, small numbers of mature fish in the population because of delayed maturation, and difficulties with obtaining samples from depressed populations. This is especially true of white sturgeon (*Acipenser transmontanus*) where studies of maturation have been primarily directed towards the propagation of domesticated individuals (Bee 1981, Doroshov and Lutes 1984, Lutes 1985, Kroll 1990, Doroshov *et al.* 1991).

Sturgeon differ from most other fishes in the length of the ovarian cycle (oogenesis), which exceeds 1 year (Dumont et al. 1987, Chapman 1989, Kroll 1990, Doroshov *et al.* 1991). During this cycle the oogenia undergo two periods of growth, the first associated with an increase in gonadal volume (previtellogenesis) and the second with deposition of yolk platelets (vitellogenesis). The previtellogenic period of gonadal development extends for 2 or more years, whereas vitellogenesis occurs within 1 or 2 years (Conte *et al.* 1988).

The length of the spawning cycle varies among sturgeon species. The minimum time between spawning for shortnose sturgeon (*A. brevirostrum*) is 3 years (Dadswell 1979). Roussow (1957) reported female lake sturgeon (*A. fulvescens*) repeat spawning in 4-7 year intervals. Conte et al. (1988) reported spawning intervals of 2 to 8 years for some sturgeon species. Scott and Crossman (1973) reported white sturgeon spawned every 4-9 years in large river systems in western Canada. The duration of one reproductive cycle among wild female white sturgeon in the San Francisco Bay estuary was approximately 4 to 5 years with vitellogenesis persisting over the last year of the cycle (Chapman 1989).

The seasonal timing of spawning also varies among species and populations of sturgeon. Shortnose sturgeon in the Savannah River, South Carolina-Georgia spawn from mid-February to mid-March (Hall et al. 1991). Persian sturgeon (*A. persicus*) spawn in June and July in the Volga River, Russia (Artyukhin *et al.* 1979). Graham (1986) found lake sturgeon spawn in late-April through May. Spring and fall spawning migrations were reported for Gulf of Mexico sturgeon (*A. oxyrhynchus desotoi*) in the Suwannee River, Florida (Huff 1975), and for Russian sturgeon (*A. gueldenstaedti*) in the Volga River (Raspopov and Putilina 1989). Sokolov and Malyutin (1978) reported the period of spawning migrations of Siberian sturgeon (*A. baeri*) varied annually and was determined primarily by water temperature. White sturgeon are reported to spawn from February through July (Stevens and Miller 1970, Scott and Crossman 1973, Kohlhorst 1976, Anders and Beckmman 1992, McCabe and Tracy 1992).

Female sturgeon exhibit substantial variation in gonad weight, egg number and size, and body size at maturity. For instance, maturing female white sturgeon in the lower Columbia River were observed to range in size from 92 to 273 cm fork length (FL) (Welch and Beamesderfer

1992). Total ovary weight of Volga (Russian) sturgeon increased with increasing length of the female but decreased in the oldest individuals (Krivobok and Storozhuk 1970). Fecundity was directly related to total body weight in shortnose sturgeon (Crance 1986). Kohlhorst (1980) found that older, larger female white sturgeon had a higher fecundity than smaller, first-time spawners.

Vitellogenesis and ovulation of many fish species occurs annually during well-defined periods. In AciDenser species, the vitellogenic cycle develops over several years, during which a complex series of physiological changes occur (Craik 1978). Maturation is characterized by increased blood hormone levels, changes in blood chemistry, gonadal growth, and physical development of the ova. One or more of these parameters may provide a means of assessing maturation stage.

Most sturgeons mature at a late age and exhibit diadromous migrations which make them vulnerable to anthropogenic changes in natural habitat and slow to recover from exploitation (Kohlhorst 1980, Rochard & al. 1990). Understanding the reproductive and life history strategies of sturgeon is essential for proper management. We investigate the duration of the maturation cycle, the period of spawning, size-related differences in reproductive effort, and relationships among gonad size, blood chemistry, and stage of maturity of female white sturgeon in three impoundments- of the lower Columbia River.

## Methods

Gonad condition, gonad size, fish length, and fish weight were collected from 1560 female, 1903 male, and 265 unknown sex white sturgeon, between 84-250 cm FL, harvested from 1987 through 1991 in Columbia River sport and commercial fisheries between Bonneville and McNary dams (Hale and James 1992). The sport fishery was sampled throughout the year. The commercial season occurred periodically between January and October. Most samples were collected between May and September, and few were obtained during the winter. Gonad data were also collected from 75 female white sturgeon 170 cm FL or larger, which were captured with setlines from April through September in 1988-1991. We collected total ovary weights only from harvested females.

A surgical procedure was used on setlined sturgeon to determine the sex of fish, identify the stage of sexual maturity, and measure egg diameter. Fish were placed ventral side up in a trough and secured with straps. The gills were continuously flushed with water during the procedure either with a bucket, an electric pump, or by submersing the head. Wet burlap was placed over the fish to reduce dehydration and keep the fish cool. Surgical instruments, hands, and the area to be incised were disinfected with Nolvosan or Betadyne. A 1-2 cm incision was made through the body wall, near the mid-ventral line,, three ventral scutes anterior of the pelvic fin insertion. An otoscope was used to locate and examine the gonad if not visible through the incision. A sample of approximately 3-5 g was excised from ovaries and preserved in 10% formalin. The incision was closed with three to four mattress stitches using a half-circle, reverse cutting edge needle (size CP-2), swedged with a 3-0 PDS (polydioxanone) suture. The incision was sealed with a surgical adhesive before release of the fish.

Ovary samples were measured and classified according to criteria modified slightly from Chapman (1989): pre-vitellogenic (eggs translucent, <0.6 mm average diameter), early vitellogenic (eggs opaque, ≈0.6-2.1 mm average diameter), late vitellogenic (eggs pigmented, =2.2-2.9 mm average diameter), ripe (eggs fully pigmented and detached from ovarian tissue, >3.0 mm average diameter), and spent (gonads flaccid with some residual fully pigmented eggs). We utilized gonad appearance and coloration alone for those samples where egg diameter and color did not both match the staging criteria. The presence of attritic oocytes was noted when black, disintegrating and convoluted eggs comprised the majority of the gonad.

Blood samples were removed from 18 females (FL >169 cm). Blood was withdrawn into a vacutainer tube through an 18 gauge needle inserted into the caudal vein in the ventral surface of the caudal peduncle. Blood samples were immediately centrifuged for several minutes to separate the red blood cells from the plasma, which was removed, frozen, and later analyzed for alkaline-labile phosphoproteins (ALPP).

Gonadosomatic index (GSI: Wootton 1979) was calculated:

$$\mathrm{GSI} = 100.[\text{gonad weight} / \text{total fish weight}]$$

Statistical tests for significant differences (p t0.05) were conducted on raw or log-transformed data with programs of the Statistical Analysis System (SAS 1988a, SAS 1988b). Simple regressions were used to determine relationships between fish size and fecundity and gonad weight. Comparisons between sample means were made using analysis of variance (ANOVA ) and Tukey's studentized range test.

## Results

Mean egg diameters for 170 vitellogenic sturgeon ranged from 0.5 to 3.6 mm (early vitellogenic: 0.5-2.5 mm; late vitellogenic: 1.2 -3.4 mm; ripe: 2.6-3.6 mm). No discernable pattern in mean egg diameters existed over time (Figure 1A).

Of 1635 ovary samples, 89.7% were undeveloped or previtellogenic, 6.1% were early vitellogenic stage, 2.7% were late vitellogenic stage, and 1.5% were ripe. We were unable to discern any pattern from the number of undeveloped or early vitellogenic females collected over time. Most (62.2%) late vitellogenic female sturgeon were collected from July through September (Figure 1B). The highest number of ripe female sturgeon were collected in March, although 78.8% were sampled from February through June (Figure 1B).

The average GSI calculated for 224 female sturgeon fluctuated throughout the year with considerable overlap for all months (Figure 1C).

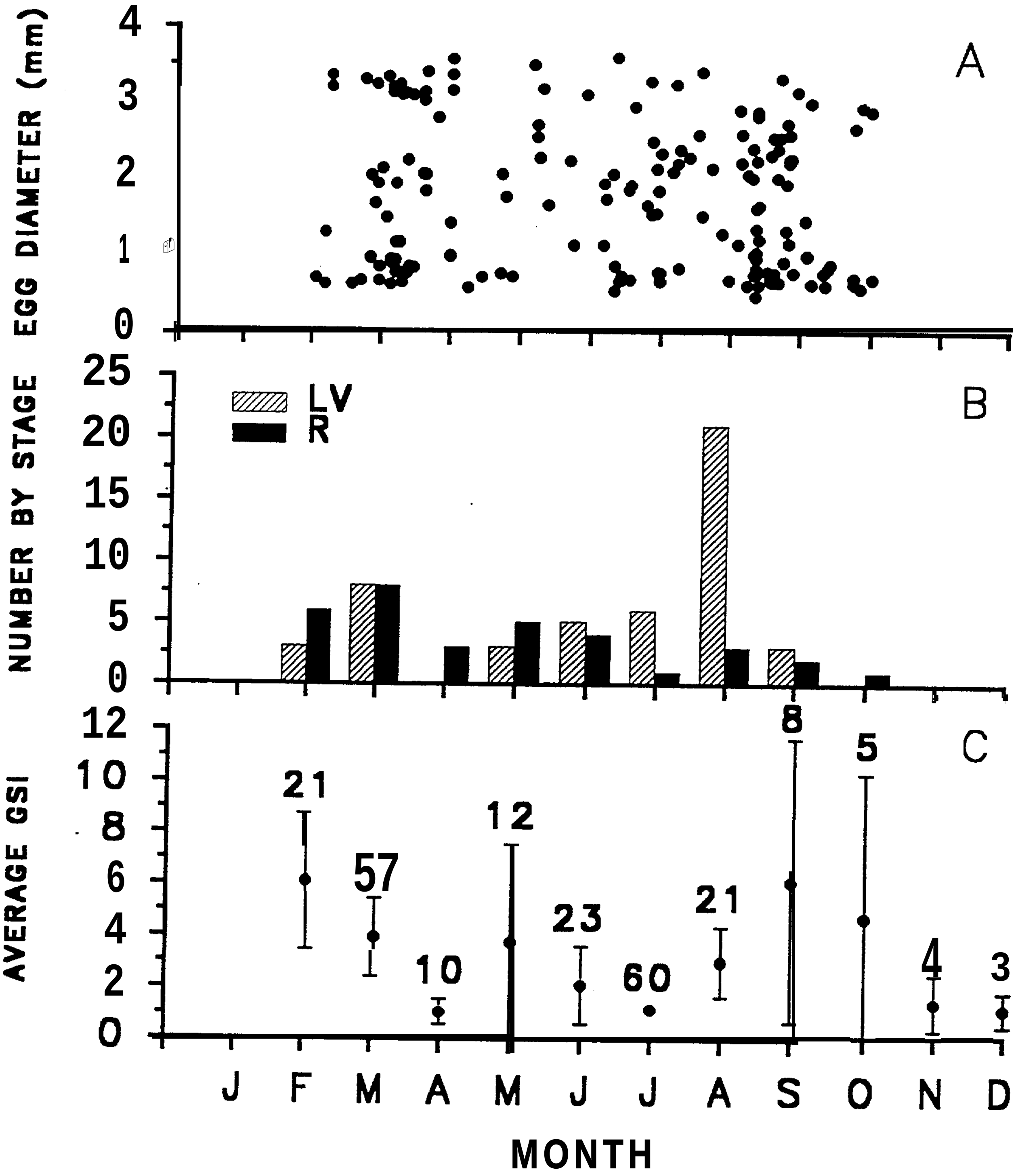

Figure 1. Mean egg diameter of early, late, and ripe vitellogenic female white sturgeon (A); number by stage of late (LV) and ripe (R) vitellogenic female white sturgeon (B); and average gonadosomatic index (GSI) of spent, pre-, early, late, and ripe vitellogenic female white sturgeon (C) in the lower Columbia River by the day of the year, 1987-1991. The sample size and 95% confidence intervals (based on two standard errors) for monthly GSI values are shown.

We collected ripe eggs from 25 female sturgeon with fork lengths from 98 to 249 cm. Gonad weight increased with fork length to a maximum of 34.0 kg (Figure 2A). Egg number varied from 32,000 to 1,650,000, and also increased with fork length (Figure 2B). GSI values for ripe females ranged from 6.7 to 22.9% and were not correlated with the length of the fish (Figure 2C). The mean diameter of ripe eggs increased slightly with increasing length of the female (Figure 2D).

The GSI increased with advancing stages of maturity (Figure 3A). Ovaries comprised 10.4% of the total body weight for late vitellogenic fish and 14.0% for ripe fish as compared to 1.2% for undeveloped fish. The GSI for late vitellogenic and ripe fish were similar and significantly different from the GSI for all other stages (Tukey, p c0.05).

The level of ALPP in the blood increased with advancing maturation stage, but our sample size from fish with developing gonads (5) was too small to establish criteria for identifying stage (Figure 3B).

## Discussion

We were unable to confirm a biennial maturation cycle for female white sturgeon in the lower Columbia River similar to cycles reported by Burtzev (1969) and Williot & al. (1990) for domestic sturgeon stocks. We expected most early vitellogenic females in the fall and winter, most late vitellogenic females in the summer and fall, and most ripe fish in the spring sampling as found by Doroshov et al. (1989) for white sturgeon in San Francisco Bay. However, variability in the onset of the maturation cycle or in the individual maturation rate complicated the pattern of development.

White sturgeon in the three lowest Columbia River impoundments could spawn over a 8 month period from February through September based on the presence of females with ripe eggs. However, spawning has been observed only from late April through early July. Anders and Beckman (1992) reported white sturgeon in the three lowermost impoundments of the Columbia River spawned from mid May or early June through mid July. Samples of ripe eggs collected from spawning areas indicate white sturgeon in the free-flowing lower Columbia River spawned from late April through the beginning of June (McCabe and Tracy 1992). Either spawning occurs outside the observed May-July period or gonadal development is suspended at a given size and weight until environmental conditions such as water column velocities and temperature are favorable for successful spawning. Artyukhin et al. (1979) reported female Persian sturgeon suspending ovarian development from September through November with final gonadal evolution occurring during the winter and early spring preceding spawning. Chapman (1989) reported vitellogenesis was completed 3-6 months before spawning in wild white sturgeon populations.

We found that ripe females had a GSI value between 6.9 and 23.0%, regardless of length. Large, mature females did not devote a higher percentage of their body weight to reproduction than did the smallest reproducing females, but produced many more eggs because of their larger

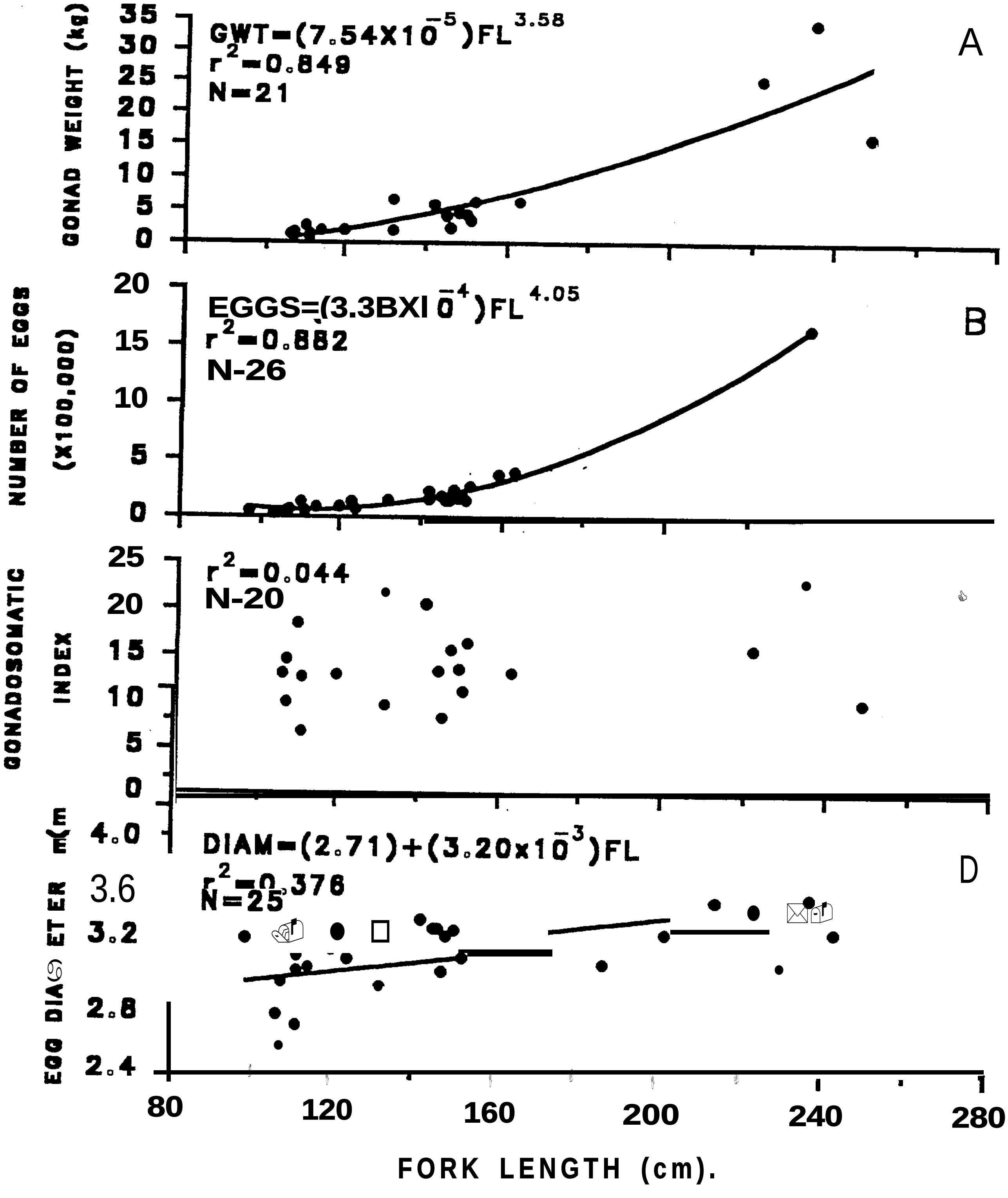

figure 2. Total gonad weight (A), number of eggs (B), gonadosomatic index (C), and mean egg diameter (D), of ripe female white sturgeon in the lower Columbia River by fork length, 1987-1991. Figure B includes late vitellogenic samples for which a total gonad weight was measured.

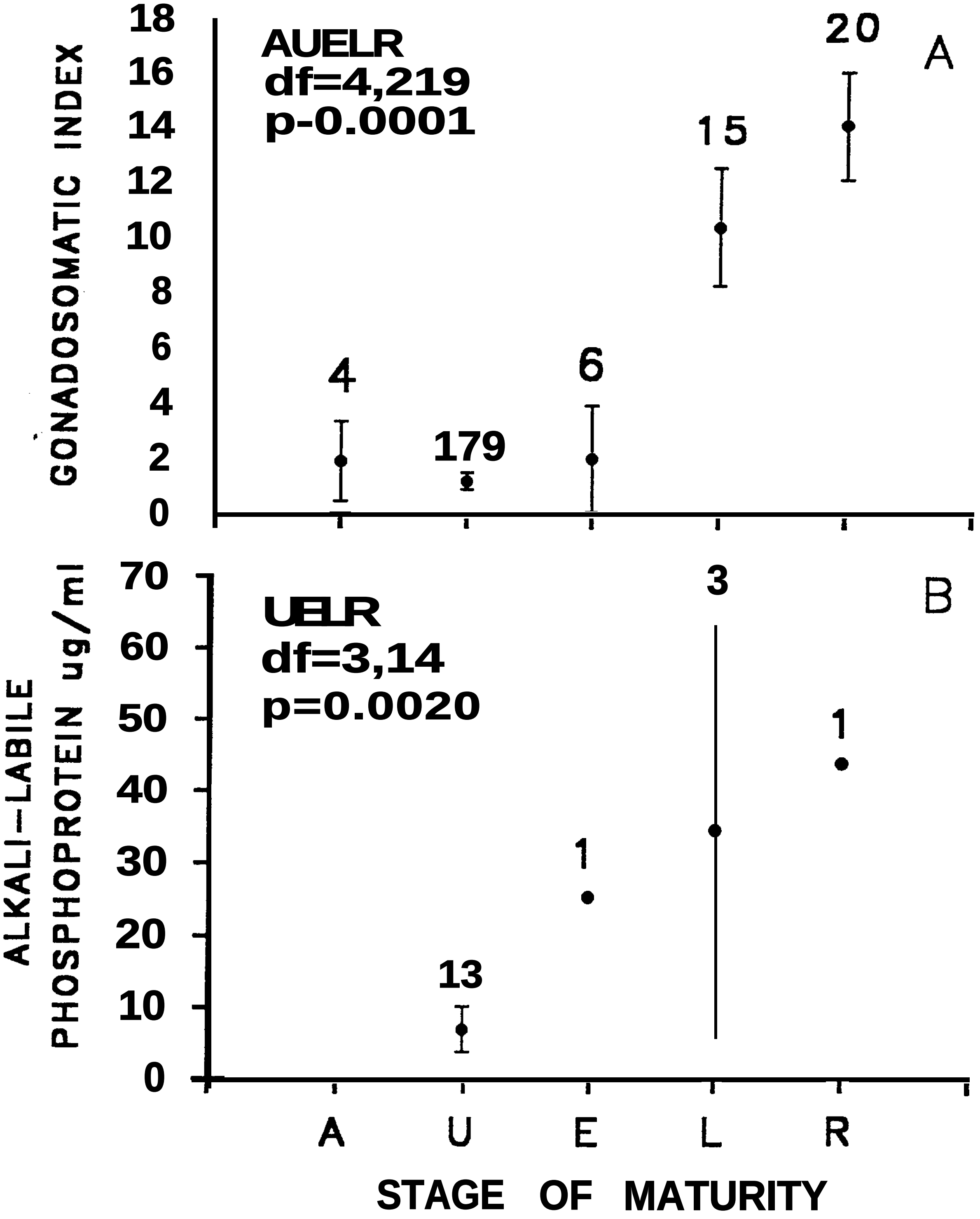

Figure 3. Gonadosomatic index (A) and alkali-labile phosphoprotein levels (B) of female white sturgeon in the lower Columbia River by stage of maturity, 1987-1991. The sample size and 95% confidence intervals (based on two standard errors) for each stage are shown. Maturity stages are: A = attritic, U = undeveloped (pre-vitellogenic), E = early vitellogenic, L = late vitelloaenic. and R = ripe.

size. The mean GSI of 14.0% for ripe females from the Columbia River was lower than reported by Chapman (1989) for domestically reared white sturgeon in California (26.0%). This difference may be the result of reduced food availability or interspecific competition. Wootton (1979) reported that brown trout (Salmo trutta) from fertile streams in Pennslyvania produced a greater weight of eggs than similar-sized fish from infertile streams.

Because we only collected blood samples from five maturing fish, we were unable to establish a relationship between ALPP levels and stage of maturity similar to work conducted by Doroshov et al. (1986), Chapman et al. (1987), Chapman (1989), and Kroll (1990). Therefore, we could not rely on blood samples as indicators of sturgeon gonadal maturation. The gonadosomatic index may be useful for differentiating late and ripe vitellogenic stages but only for dead fish.

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## REPORT H

# White Sturgeon Spawning Cues in an Impounded Reach of the Columbia River

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# Abstract

White sturgeon *Acipenser transmontanus* spawning cues in the furthest downstream Columbia River impoundment (Bonneville Pool) from 1988 through 1991 were investigated. White sturgeon spawned exclusively in The Dalles Dam (Rkm 309) tailrace, in the upstream end of Bonneville Pool. Two types of nets were used to collect newly spawned white sturgeon eggs (in the water column < 3 hr. before collection); spawning occurred at least each day one or more newly spawned eggs were collected.

Mean river discharge and mean discharge coefficient of variation during the 3, 6, 12, and 24 hours before sampling, mean water column velocity, and water temperature were tested as potential white sturgeon spawning cues using logistic regression; the dependent variable had two response levels (spawning or no spawning). Mean discharge during the pre-sampling periods'had significant effects on white sturgeon spawning. Mean discharge was higher in pre-sampling periods before spawning (>265 kcfs) than during pre-sampling periods when fish did not spawn. Higher discharge coefficient of variation accompanied spawning during lower water years,.while higher discharge (>265 kcfs) was associated with spawning in higher water years; white sturgeon spawning was not associated with lower discharges (<200 kcfs).

Heterogeneity testing allowed pooling mean discharge only during the 12 hour pre-sampling periods for logistic regression analysis. Pooled mean discharge (1988-1991) during the 12 hour pre-sampling periods had no significant effect on white sturgeon spawning. However, when 1988 (lowest water year in the study) data were removed from logistic regression analysis, mean discharge had a significant effect on white sturgeon spawning, appearing as a spawning cue.

Mean discharge coefficient of variation during the 12 hour pre-sampling periods had significant effects on white sturgeon spawning in lower water years (1988 and 1989) but not in higher water years (1990 and 1991).

Since more than 75% of egg collection occurred at the same 5 sites (peak sites), data from these 5 peak sites were analyzed separately using logistic regression and the same independent and dependent variables. At peak sites in 1991, mean discharge had a significant effect on white sturgeon spawning; mean discharge coefficient of variation at peak sites also had significant effects on white sturgeon spawning in 1989.

Mean water column velocity and water temperature had no significant effects on white sturgeon spawning when analyzed by year, however, when data from all years were pooled, temperature and velocity had significant effects on spawning.

As a result of these analyses, discharge of at least 250 kcfs was recommended in The Dalles Dam tailrace from mid-May through July to create favorable conditions for white sturgeon spawning.

## Introduction

During the past 50 years, white sturgeon *Acipenser transmontanus* populations in large rivers of the western United States have been affected, often adversely, by the creation and operation of hydroelectric dams, and by recreational and commercial overharvest. Hydropower generation has drastically altered annual and seasonal flow regimes (Elliot and Beamesderfer 1990; Anders 1991; Apperson and Anders 1990; Cochnauer et al. 1985; Coon et al. 1977) and reduced sturgeon migration (Bajkov 1951; Setter 1988), while overharvest has reduced the size and broodstock component of white sturgeon populations (Rieman and Beamesderfer 1990; Miller 1972). Understanding environmental conditions and cues necessary for successful white sturgeon spawning is essential for preserving healthy, self-sustaining populations.

Environmental conditions during white sturgeon spawning from 1987 through 1991 have been documented in impounded (Miller and Beckman 1992; Parsley et al. 1992; Anders and Beckman 1992) and unimpounded- reaches of the Columbia River (McCabe and Tracy 1992). Our objective was to identify and describe white sturgeon spawning cues in the furthest downstream Columbia River impoundment (Bonneville Pool).

Miller and Beckman (1992) reported higher catch-per-effort (CPUE) values for white sturgeon eggs, larvae, and YOY in years of average river discharge than in years of low discharge from 1987 through 1991 in the three furthest downstream Columbia River impoundments. Potential effects of river discharge, current velocity, and other environmental variables on white sturgeon spawning are absent from the literature, however, water velocity is important to the spawning success of Russian, shortnose, and lake sturgeon *Acipenser guldenstadti*, *A. brevirostrum*, and *A. fulvescens* (Khoroshko 1972; Dadswell et al 1984; Taubert 1980; Buckley and Kynard 1985). Studies of paddlefish *Polyodon spathula* also reported that spawning was enhanced by high flows (Purkett 1961; Pasch et al. 1978; Alexander and McDonough 1983).

## Study Area

Bonneville Pool (Fig 1.)(RKm 237-309) covers 7,600 ha of predominantly sand substrate (Miller et al. 1991). Impoundment created lacustrine conditions in some areas of the river by increasing water depth and surface area, and by reducing water velocity. For a more complete study area description, refer to Parsley et al. (1992). These authors reported that depth and substrate components of white sturgeon spawning habitat in the study area were not limiting in years of average discharge.

## Methods

The timing and location of white sturgeon spawning was determined by collecting newly-spawned eggs from April or May through July, 1988 through 1991. Newly spawned white sturgeon eggs referred to eggs in the pre-cleavage, changing pigmentation stage (Beer 1981), which were spawned < 3 hours before collection. White sturgeon eggs were collected from the drift in plankton nets (0.78 m max. width, 0.54 m high, 1.59 mm knotless

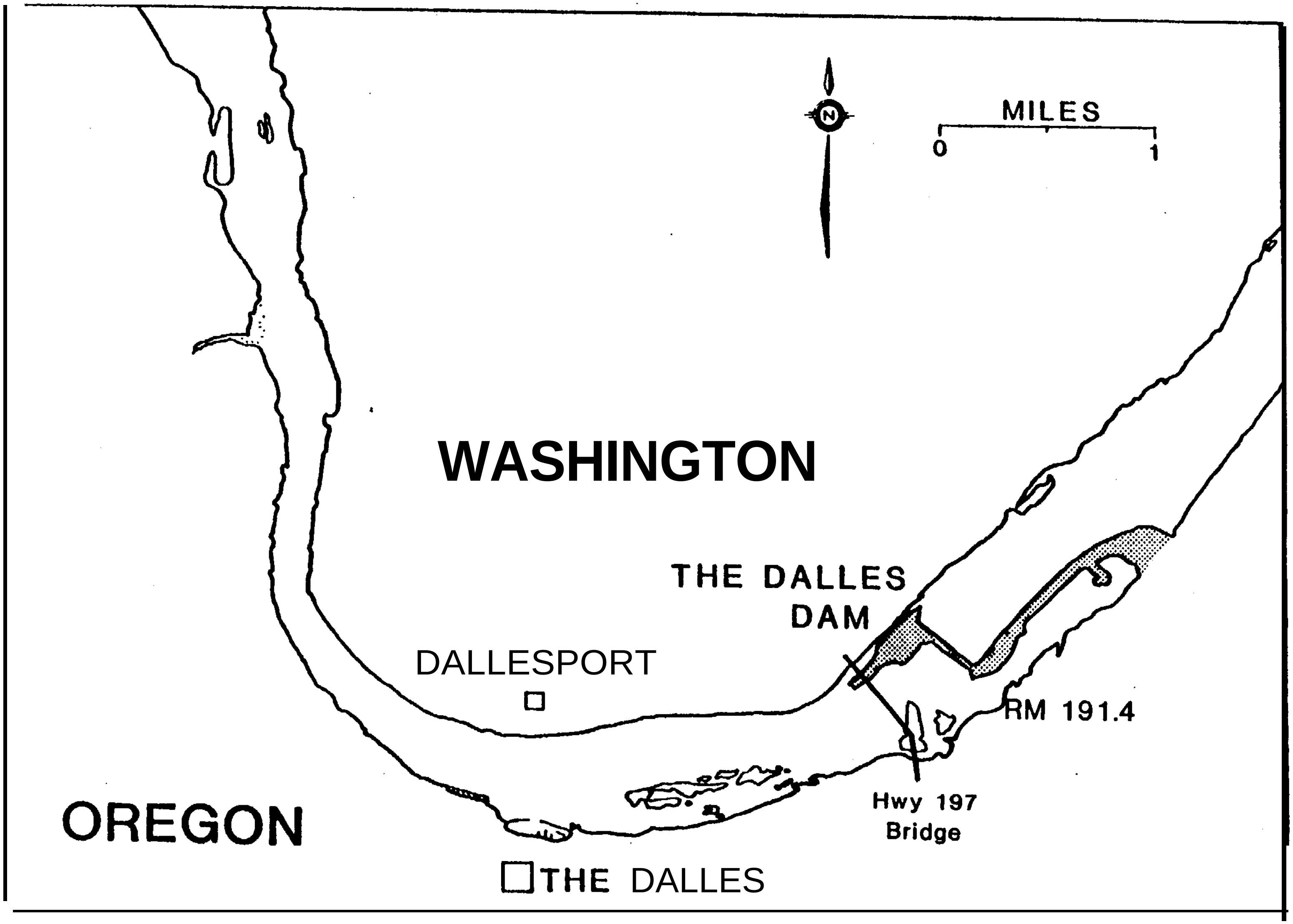

Figure 1. Columbia River showing sampling area downstream from The Dalles Dam.

mesh) and in a beam trawl net (2.7 m X 0.5 m, 1.59 mm knotless mesh) following the techniques presented by Miller et. al 1991. Mean water column velocity (sum of the velocity values measured at 20% and 80% of max. depth/2) was measured with a Price "AA" current velocity' meter wired to a Swoffer Instruments Model 2200 digital current velocity meter. Water temperature (°C) was measured with digital (YSI Model 58) or laboratory thermometers. River discharge data were provided by the U.S Army Corps of Engineers.

River discharge, discharge variation, mean water column velocity, and water temperature were tested as potential white sturgeon spawning cues using logistic regression analysis (SAS/STAT Users Guide, Version 6.03, 1988. Logistic regression was used because it was designed for use when a dependent regression variable (spawning) has only two response levels (spawning or no predicted spawning). Independent variables were: mean of hourly river discharge, and discharge coefficient of variation (CV) during the 3, 6, 12, and 24 hours prior to sampling of newly spawned eggs, and mean water column velocity and water temperature measured at-egg collection sites. Discharge coefficient of variation (CV) (standard deviation divided by mean) was used to compare the amount of variation among hourly discharge values during the following periods of time. These 3, 6, 12, and 24 hour periods before sampling are referred to as pre-sampling periods. Data analyzed using logistic regression were collected only from sites where at least one newly-spawned white sturgeon egg was collected from 1988 through 1991. Annual data were pooled in all regression analyses when heterogeneity testing (Zar 1984) allowed pooling.

Since more than 75% of egg collection occurred at the same 5 sites (peak sites), data from these 5 peak sites were analyzed separately using logistic regression and the same independent and dependent variables. However, due to few occurrences of newly-spawned egg collection, 1988 data were omitted from logistic regression analysis of peak site data.

## Results

*Discharge* Mean discharge during the pre-sampling periods had significant effects on white sturgeon spawning. Mean discharge was higher during all pre-sampling periods before spawning (>265 kcfs) than during pre-sampling periods when fish did not spawn (<235 kcfs)(Fig. 2). Mean discharge during the 6 and 24 hour pre-sampling periods had a significant effect on white sturgeon spawning in 1991 ($P \leq 0.01$), while mean discharge during the 3 and 12 hour pre-sampling periods did not (Table 1). Mean discharge during the 3, 6, 12, and 24 hour pre-sampling periods had no significant effect on white sturgeon spawning in 1988, 1989, or 1990, with the exception of the 12 hour pre-sampling period in 1988.

Heterogeneity testing allowed pooling of mean discharge only during the 12 hour pre-sampling period for logistic regression analysis. This pooled mean discharge (1988-1991) during the 12 hour pre-sampling period had no significant effect on white sturgeon spawning. However when 1988 (lowest water year in the study) was excluded from regression analysis,

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[1] Use of trade names does not imply endorsement by U.S. Fish and Wildlife Service

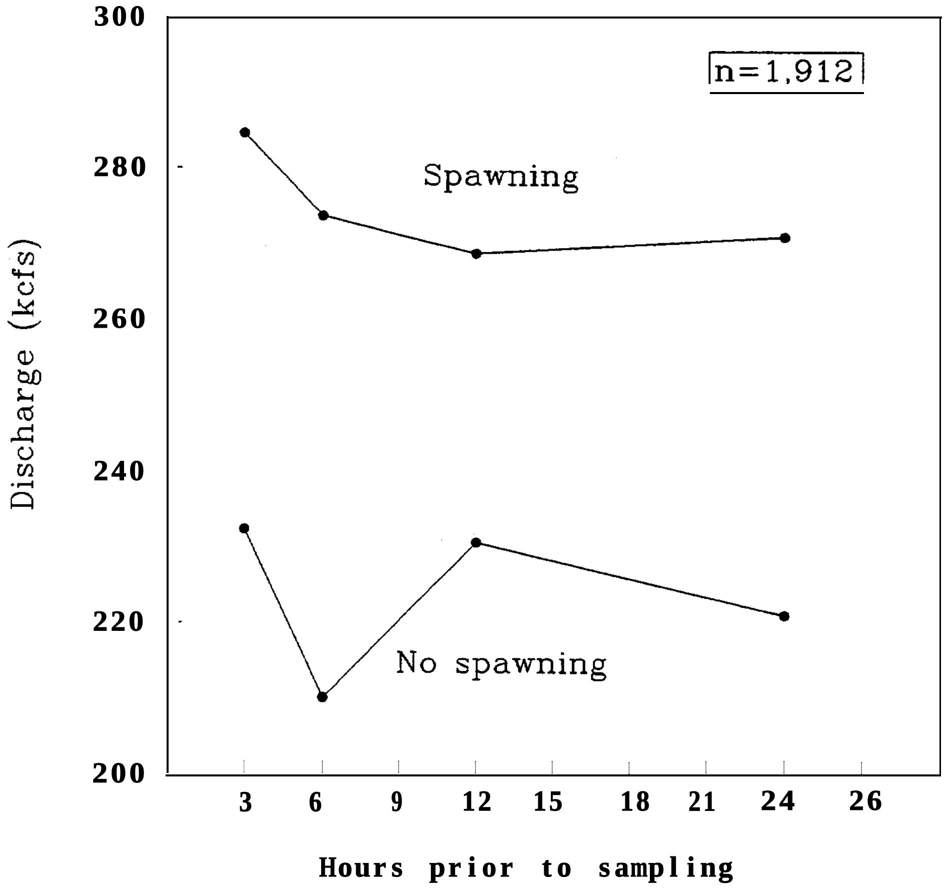

Figure 2. Mean discharges during the 3, 6, 12, and 24 hour pre-sampling periods between May and August in Bonneville Pool(1988-1991).

Table 1. Effects of mean river discharge on adult white sturgeon during the 3, 6, 12, and 24 hours before spawning in Bonneville Pool (1989-1991).

| Pre-sampling[a] time periods | Sample Size | DF | Chi-Square | Probability |
|---|---|---|---|---|
| | | 1988 | | |
| 3 | 125 | 1 | 0.13 | 0.72 |
| 6 | | 1 | 2.15 | 0.14 |
| 12 | | | | |
| 24 | | 1 | 0.76 | 00.38* |
| | | 1989 | | |
| | | 1 | | |
| 3 | 100 | 1 | 3.59 | 0.06 |
| 6 | | | 1.78 | 0.18 |
| 12 | | 1 | | |
| 24 | | 1 | 0.60 | 0.44 |
| | | 1990 | | |
| 3 | 92 | 1 | 2.52 | 0.11 |
| .6 | | 1 | 1.28 | 0.26 |
| 12 | | | 0.51 | 0.47 |
| 24 | | 1 | 2.66 | 0.10 |
| | | 1991 | | |
| 3 | | 1 | | |
| 6 | 89 | 1 | 1.96 | <0.01** |
| 12 | | 1 | 0.06 | 0.80 |
| 24 | | 1 | 12.47 | <0.01** |
| | | Pooled (1988-1991) | | |
| 12 | 406 | 1 | 6.27 | <0.01** |

a=number of hours in time periods before sampling

*=significant at the $P \leq 0.05$ level

**=significant at the $P \leq 0.01$ level

mean discharge had a significant effect, on spawning ($P \leq 0.01$).

At peak sites in 1991, one of the higher water years of during the study, mean discharge during the 6 and 24 hour pre-sampling periods had a significant effect on white sturgeon spawning (Table 2). At peak sites, as with regression analysis using data from all sites, heterogeneity testing allowed pooling of average discharge only during the 12 hour pre-sampling periods, which had a significant effect on white sturgeon spawning ($P<0.01$)(Table 2).

*Discharge variation* Discharge was more variable during pre-sampling periods when white sturgeon spawned than when fish did not spawn (Fig 3). Mean CV had a significant effect on white sturgeon spawning only in lower water years (1988 and 1989). Mean CV during the 12 hour pre-sampling periods had a significant effect on spawning in 1988 and 1989, and during the 24 hour pre-sampling period in 1988 (Table 3).

At peak sites, mean CV during the 12 and 24 hour pre-sampling periods had significant effects on white sturgeon spawning in 1989 (Table 4). Coefficient of variation at peak sites during all other years and pre-sampling periods had no significant effects on spawning (Table 4).

***Mean velocity,*** *water temperature* Heterogeneity testing allowed pooling mean velocity and water temperature data from all years. Mean water column velocity and water temperature measured in and downstream from white sturgeon spawning areas had no significant effect on white sturgeon spawning in each year of the study when analyzed separately by year (Table 5). However, when pooled, mean column velocity and water temperature from all years had a significant effect on spawning ($P \leq 0.01$)(Table 5). Water temperature measured in and downstream from white sturgeon spawning areas had no significant effect on white sturgeon spawning, however, pooled water temperature from all years also had a significant effect on spawning ($P \leq 0.01$)(Table 5).

At peak sites, mean column velocity had no significant effects on white sturgeon spawning when analyzed by year, but had a significant effect ($P \leq 0.01$) on spawning when pooled (Table 6). Water temperature at peak sites had a significant effect on spawning ($P \leq 0.05$) in 1989, but not in 1990 or 1991 (Table 6). When pooled, water temperature at peak sites had a significant effect on spawning ($P<0.01$) (Table 6)

## Discussion

River discharge, CV, and mean water column velocity appeared to function as spawning cues for white sturgeon in The Dalles Dam tailrace.

*Discharge* Spawning in response to higher discharge (>260 kcfs) as a spawning cue occurred after six and up to 24 hours following such discharge. Differences in discharge during pre-sampling periods before spawning and before no spawning strongly supported this conclusion. Spawning may have occurred more than 24 hours after high discharge, however, due to confounding effects of diurnal discharge patterns,

Table 2. Effects of mean river discharge on adult white sturgeon during the 3, 6, 12, and 24 hours before spawning in Bonneville Pool at peak sites only (1989-1991).

| Pre-sampling[a] time periods | Sample Size | DF | Chi-Square | Probability |
|---|---|---|---|---|
| | | 1989 | | |
| 3 | 45 | 1 | 3.00 | 0.08 |
| 6 | | 1 | 2.34 | 0.12 |
| 12 | | 1 | 0.69 | 0.40 |
| 24 | | 1 | 1.31 | 0.25 |
| | | 1990 | | |
| 3 | 45 | 1 | 3.44 | 0.06 |
| 6 | | 1 | 2.41 | 0.12 |
| 12 | | 1 | 0.11 | 0.74 |
| 24 | | 1 | 2.41 | 0.12 |
| | | 1991 | | |
| 3 | 38 | 1 | 2.31 | 0.12 |
| 6 | | 1 | 6.06 | 0.01** |
| 12 | | 1 | 0.01 | 0.93 |
| 24 | | 1 | 7.00 | <0.01** |
| | | Pooled | | |
| 12 | 128 | 1 | 6.31 | 0.01** |

a=number of hours in time periods before sampling
*=significant at the $P \leq 0.05$ level
**=significant at the $P \leq 0.01$ level

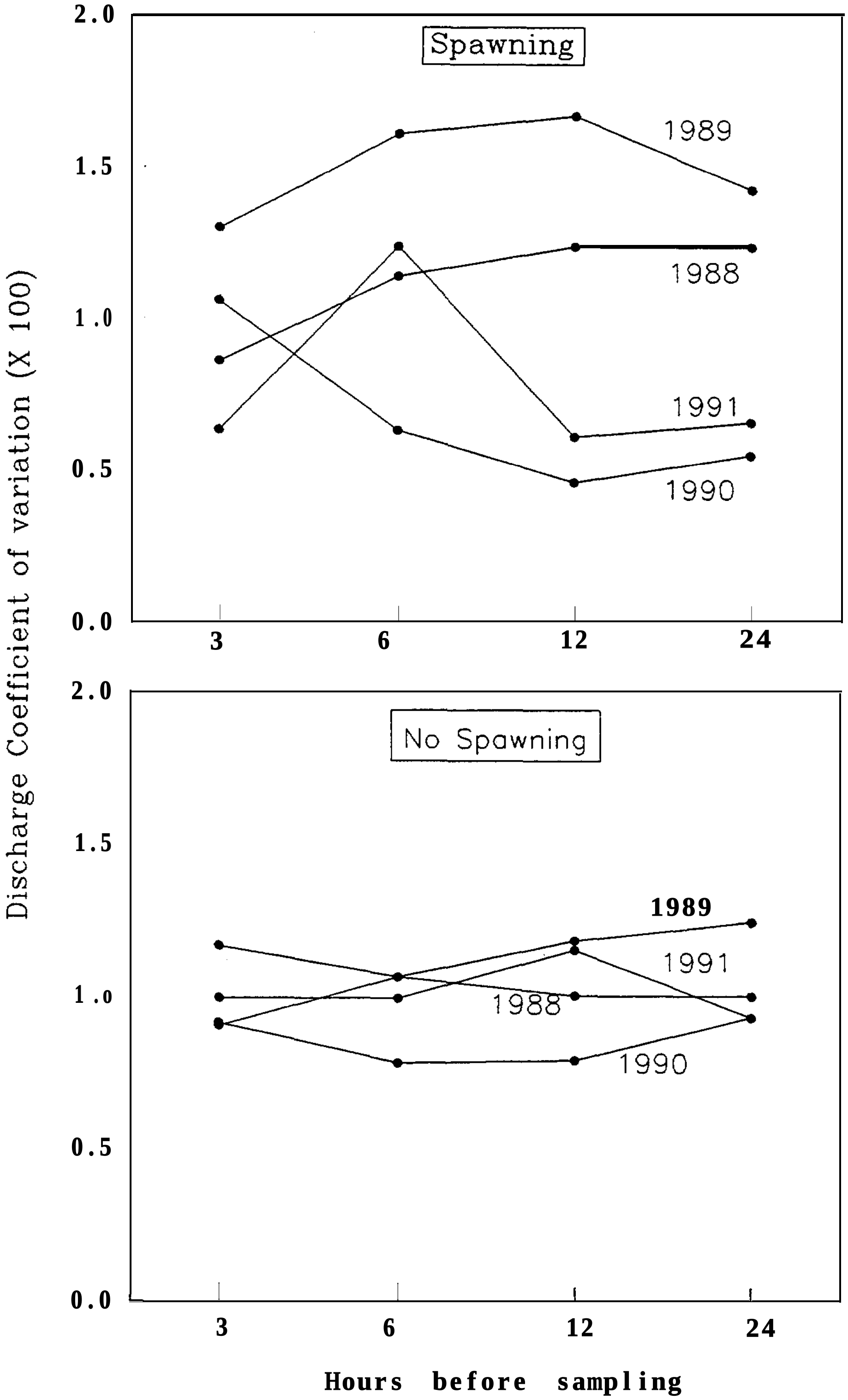

Figure 3. Discharge coefficient of variation during the 3, 6, 12, and 24 hour pre-sampling periods between May and August in Bonneville POol (1988-1991).

Table ,3. Effects of coefficient of variation of mean river-discharge on adult white sturgeon during the 3, 6, 12, and 24 hours before spawning in Bonneville Pool (1989-1991).

| Pre-sampling[a] time periods | Sample Size | DF | Chi-Square | Probability |
|---|---|---|---|---|
| | | 1988 | | |
| 3 | | 1 | 2.26 | 0.13 |
| 6 | 161 | 1 | 0.04 | 0.83 |
| 12 | | 1 | 0.00 | 0.98 |
| 24 | | 1 | 5.64 | 0.02* |
| | | 1989 | | |
| 3 | 100 | 1 | 1.42 | 0.23 |
| 6 | | 1 | 0.71 | 0.40 |
| 12 | | 1 | 9.74 | to. 01** |
| 24 | | 1 | 5.75 | 0.02* |
| | | 1990 | | |
| 3 | 92 | 1 | 3.72 | 0.06 |
| 6 | | 1 | <0.01 | 0.95 |
| 12 | | 1 | 0.61 | 0.43 |
| 24 | | 1 | 0.82 | 0.36 |
| | | 1991 | | |
| 3 | | 1 | 0.20 | 0.83 |
| 6 | 89 | 1 | 1.59 | 0.20 |
| 12 | | 1 | 0.90 | 0.34 |
| 24 | | 1 | 0.69 | 0.41 |

a=number of hours in time periods before sampling
*=significant at the $P \leq 0.05$ level
**=significant at the $P \leq 0.01$ level

Table 4. Effects of discharge CV on adult white sturgeon during the 3, 6, 12, and 24 hours before spawning in Bonneville Pool at peak sites only (1989-1991).

| Pre-sampling[a] time periods | Sample Size | DF | Chi-Square | Probability |
|---|---|---|---|---|
| | | 1989 | | |
| 3 | 45 | 1 | 0.94 | 0.33 |
| 6 | | 1 | 0.23 | 0.63 |
| 12 | | 1 | 5.35 | 0.02* |
| 24 | | 1 | 3.75 | 0.05* |
| | | 1990 | | |
| 3 | 45 | 1 | 3.65 | 0.06 |
| 6 | | 1 | 0.39 | 0.53 |
| 12 | | 1 | 1.58 | 0.20 |
| 24 | | 1 | 1.11 | 0.30 |
| | | 1991 | | |
| 3 | 40 | 1 | 0.73 | 0.39 |
| 6 | | 1 | 3.05 | 0.08 |
| 12 | | 1 | 2.82 | 0.09 |
| 24 | | 1 | 1.18 | 0.27 |
| | | Pooled | | |
| 3 | 130 | 1 | 0.25 | 0.62 |
| 6 | | 1 | 1.38 | 0.24 |
| 12 | | 1 | 3.91 | 0.05* |
| 24 | | 1 | 2.92 | 0.09 |

a=number of hours in time periods before sampling
*=significant at the $P < 0.05$ level

Table 5. Effects of mean column velocity and temperature on spawning activity of white sturgeon at all sampling sites in Bonneville Pool (1988-1991).

| Year | Variable | Sample size | DF | Chi-Square | Probability |
|---|---|---|---|---|---|
| | | | 1 | | |
| 1988 | Velocity | 62 | 1 | 0.58 | 0.50 |
| 1989 | | 50 | | 1.99 | 0.16 |
| 1990 | | 43 | 1 | 1.07 | 0.30 |
| 1991 | | 52 | 1 | 1.35 | 0.25 |
| Pooled | | 231 | 1 | 9.75 | <0.01** |
| | Temperature | | | | |
| 1988 | | 140 | 1 | 0.01 | 0.93 |
| 1989 | | 900 | 1 | 6.53 | 0.01** |
| 1990 | | 87 | | 1.64 | 0.20 |
| 1991 | | | 1 | 2.46 | 0.12 |
| Pooled | | 451 | 1 | 11.0 | <0.01** |

**=significant at the $P \leq 0.01$ level

Table 6. Effects of mean column velocity and temperature on spawning activity of white sturgeon at peak sites in Bonneville Pool (1989-1991).

| Year | Variable | Sample size | DF | Chi-Square | Probability |
|---|---|---|---|---|---|
| | Velocity | | | | |
| 1989 | | 24 | 1 | 1.85 | 0.17 |
| 1990 | | 19 | 1 | 0.59 | 0.44 |
| 1991 | | 24 | | 1.74 | 0.18 |
| Pooled | | | 1 | 6.98 | 0.01** |
| | Temperature | | | | |
| 1989 | | 16 | 1 | 5.63 | 0.01** |
| 1990 | | 15 | 1 | 1.49 | 0.22 |
| 1991 | | | | 1.93 | 0.16 |
| Pooled | | | 1 | 11.48 | to. 01** |

**=significant at the $P \leq 0.01$ level

responses after 24 hours were not addressed.

*Discharge variation* Discharge CV appeared to be a spawning cue in the lower water years of 1988 and 1989, but not in the higher water years of 1990 and 1991. Discharge variation was greater in lower water years (1988,1989) than in the higher, more normal water years (1990, 1991), due to the discharge pattern, and to the fact that a given amount of change in discharge has a greater effect on total discharge in a low water year than in a higher water year.

***Mean velocity*** Mean water column velocity was also identified as a spawning cue, as it was directly dependent upon discharge, and is the component of discharge encountered by the fish. Instances when discharge had significant effects on spawning, but mean velocity did not, could have been due to the different relation between discharge and mean velocity in different sampling areas, or to confounding effects of sampling.

The conclusion that river discharge, discharge CV, and mean column velocity were white sturgeon spawning cues is consistent with other published studies. White sturgeon in Columbia River reservoirs spawned in areas where mean column velocity were greater than 0.8 m/s (Parsley et al. 1992). Khoroshko (1972) reported that spawning success of the Russian sturgeon *Acipenser queldenstaedti* in the Volga River was dependent on discharge. Taubert (1980)) and Buckley and Kynard (1985) reported water velocity as a governing factor in the spawning success of shortnose sturgeon *Acipenser brevirostrum*. Dadswell et al. (1984) reported spawning for this species to occur only in areas of relatively high flow (0.3-1.3 mps). Vladykov and Greely (1963) reported that Gulf of Mexico sturgeon *Acipenser oxyrhynchus desotoi* typically spawned in deep water with fast currents. Studies of paddlefish *Polyodon spathula* reported that spawning was enhanced by high discharge (Purkett 1961; Pasch et al. 1978) along with water temperature above 10°C (Alexander and McDonough 1983).

*Water temperature* While water temperature had statistically significant effects on white sturgeon spawning, we do not believe that it acted as an acute spawning cue, which could trigger spawning within 24 hours, as was seen with discharge, discharge coefficient of variability, or mean velocity. White sturgeon spawned in The Dalles Dam tailrace when water was 12°C to 18°C, however water temperature was very similar among sampling areas an any given day, and the same range of water temperature existed when spawning and no spawning were reported. However, the thermal regime during the 1 to 2 years of vitellogenesis (egg maturation) may affect the timing of spawning since vitellogenic and metabolic rates are regulated by temperature.

We could not assume that white sturgeon did not spawn on days when sampling did not collect newly spawned white sturgeon eggs. Therefore, our regression analyses may have been biased by using measured conditions to reflect no spawning, while fish may have actually spawned during those conditions. The fact that we could not sample newly spawned eggs from every spawning episode may have reduced our ability to estimate the biological and statistical importance of discharge, discharge CV, and mean velocity as spawning cues.

From this study, statistical validation of discharge and mean water column velocity as spawning cues can be used to support discharge recommendation of at least 250 kcfs from mid-May through June or into July in Bonneville Pool. This discharge in Bonneville Pool should create favorable mean water column velocity for white sturgeon spawning. However, such a recommendation for discharge should not be assumed to create favorable spawning conditions at spawning sites in adjacent impoundments, unless the relation of discharge to velocity is known to be similar.

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# REPORT I

## A Recruitment Index for White Sturgeon in the Columbia River Downstream from McNary Dam

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## Abstract

Fall sampling for Young-of-the-year (YOY) is the most practical method for evaluating recruitment of white sturgeon *Acipenser transmontanus* in the Columbia River because YOY are closer to recruiting to the fishery than eggs and larvae, they do not require age to be estimated as is required for older juveniles, they are less likely to be preyed upon than eggs or larvae, they are less likely to be preyed upon in fall than in summer, and variability in catch is .relatively low. Spring sampling for age-l fish may provide a more accurate white sturgeon recruitment estimate than fall sampling for YOY in lower Columbia River impoundments. However, this method is more labor intensive than fall sampling for YOY because age must be estimated to distinguish age-l and age-2 white sturgeon, which overlap in length in lower Columbia River impoundments. Use of older year-classes of white sturgeon are not as accurate for estimating recruitment because current ageing techniques for white sturgeon are precise and accurate only for very young age groups. Evaluation of white sturgeon spawning and recruitment could be simplified by sampling only the three sites in each impoundment with the greatest catch per unit effort. Catch per unit effort was greater in two average water years than in two low water years in three Columbia River impoundments; no trends were evident for the free-flowing Columbia River downstream from Bonneville Dam, where white sturgeon reproduction is more consistent.

## Introduction

A reliable indicator of recruitment would aid management of white sturgeon *Acipenser transmontanus* in the Columbia River. Recruitment mechanisms of white sturgeon have not been reported in the literature, however, numerous researchers have reported that larval stages regulate year-class size in many other fishes (Hjort 1926; Sette 1943; Theilacker and Lasker 1974; Houde 1987; Lasker 1987). Small changes in mortality rate, growth rate, or lifestage duration can cause order of magnitude fluctuations in recruitment of fishes (Houde 1987). Changes in mortality and growth during early lifestages are caused by environmental conditions such as water temperature, food supply, and predation (Gulland 1983). Year-class size may be determined early in the young-of-the-year (YOY) stage for some species (Houde 1987; Peterman et al. 1988; Campbell and Graham 1991).

Overwinter mortality of age-0 fish is often high in populations of temperate zone fishes, especially those near the northern or upstream limit of their range (Lindroth 1965; Oliver et al. 1979; Gutreuter and Anderson 1985; Kaeding and Osmundson 1988; Shuter and Post 1990; Thompson et al. 1991). For many of these populations, year-class size may be determined during the first winter. Reported causes of first winter mortality include: predation (Chevalier 1973; Gutreuter and Anderson 1985; Seelbach 1987), inadequate lipid reserves causing starvation in small or slow growing fish (Oliver and Holeton 1979; Shuter et al. 1980; Seelbach 1987; Thompson et al. 1991)) water level fluctuation (Gutreuter and Anderson 1985; Seelbach 1987), temperature extremes (Shuter et al. 1980; Seelbach 1987), and physical damage from anchor ice and frazil ice (Seelbach 1987). These causes of mortality may not be limiting YOY white sturgeon in the Columbia River during their first winter. Predation on YOY white sturgeon by other fishes probably is not common in the Columbia River. Poe et al. (1991) reported that no white sturgeon were detected in stomach samples from 11,300 northern squawfish *Ptychocheilus oregonensis*, walleye *Stizostedion vitreum vitreum*, smallmouth bass *Micropterus dolomieui*, and channel catfish *Ictalurus punctatus* collected in the study area. Overwinter lipid reserves of white sturgeon have not been reported in the literature. However, YOY white sturgeon in lower Columbia River impoundments are neither small or slow growing (Miller and Beckman 1992), nor are they at the northern or upstream limit of their range. Fluctuations in water level and temperature are probably less frequent and of lesser magnitude in large river systems than in smaller rivers or impoundments. Physical damage to fish from anchor ice or frazil ice is unlikely to occur since ice formation is rare in the lower Columbia River.

Recruitment most commonly refers to fish becoming potentially vulnerable to fishing (Gulland 1983), but can refer to the entry of individuals of one lifestage to the next (Connell 1985). We use recruitment to refer to white sturgeon reaching the YOY stage. For recruitment purposes we consider white sturgeon to become YOY when they develop scutes. White sturgeon YOY are less likely to be preyed on than YOY of many other species for several reasons: white sturgeon develop five rows of sharp scutes by the YOY stage, growth of white sturgeon in the Columbia River is very rapid in the first year (Miller and Beckman 1992), and YOY white sturgeon primarily use deep main channel habitat (Parsley and Beckman 1992) where predators may be less abundant.

The study area included the three furthest downstream reservoirs (pools) on the Columbia River (Bonneville, The Dalles, and John Day) and an unimpounded reach (lower river) extending from the furthest downstream dam to the river mouth (Figure 1). Impoundment of the Columbia River has increased the surface area and the amount of deep water habitat. Dam operation has reduced peak spring discharge and increased winter discharge. Water velocities have declined during spring due to decreased discharge and from decreased water surface slope caused by the backwater effect from dams. Water velocities are highest in the first few km downstream from each of the four dams, where white sturgeon spawning occurs (Anders and Beckman 1992). Water velocities tend to be higher in Bonneville Dam tailrace than in the other three tailraces; mostly due to differences in channel morphology and the backwater effect from the downstream dam effecting all but Bonneville Dam tailrace. The relative abundance of white sturgeon of all life stages combined is highest in the lower river (Devore et al. 1992) followed by Bonneville, The Dalles, and John Day pools (Beamesderfer and Rien 1992). Water temperatures do not differ significantly among the four tailraces, and stratification has not been observed.

Trawling gear has been used to develop recruitment indices for other species in riverine and estuarine environments. Rulifson and Manooch (1990) used a balloon trawl to estimate abundance of age-0 striped bass *Morone saxatilis* in' the Roanoke River, North Carolina. Turner and Chadwick (1972) used trawling gear to develop an index of year-class strength for striped bass in the Sacramento-San Joaquin River Delta, California. This report investigates which lifestages, sampling gear, and locations are best for determining recruitment of white sturgeon in lower Columbia River impoundments and the unimpounded lower river, and determines differences in recruitment in each area and year.

## Methods

White sturgeon eggs and larvae were collected from the drift in single or paired plankton nets; eggs, larvae, and YOY were collected with a single 3-m wide beam trawl net. Both gears were fished on the substrate, usually for 30 min. The plankton nets were constructed of 1.59-mm knotless nylon mesh attached to a "D" shaped frame constructed of 1.3-cm diameter stainless steel (0.76 m wide and 0154 m high). Two to six lead weights (4.5 or 9.1 kg each) were attached to the two corners of the frame to hold the frame stationary and upright on the substrate. A digital flow meter suspended across the frame was used to estimate water volume sampled. The beam trawl consisted of a 1.59-mm knotless nylon mesh codliner enclosed in a coarser mesh net, and was attached to two triangular aluminum frames with weighted skids separated by a 3-m long 4 inch diameter pipe. This trawl was fished in a stationary position or towed slowly upstream. After 1987 the height of the beam trawl was reduced from 1.0 m to 0.5 m. Plankton nets were primarily fished in the tailrace area below each dam; beam trawls were fished in the tailrace areas below each of the dams and throughout the lower river. Sites were sampled weekly from early April or May through July of each year.

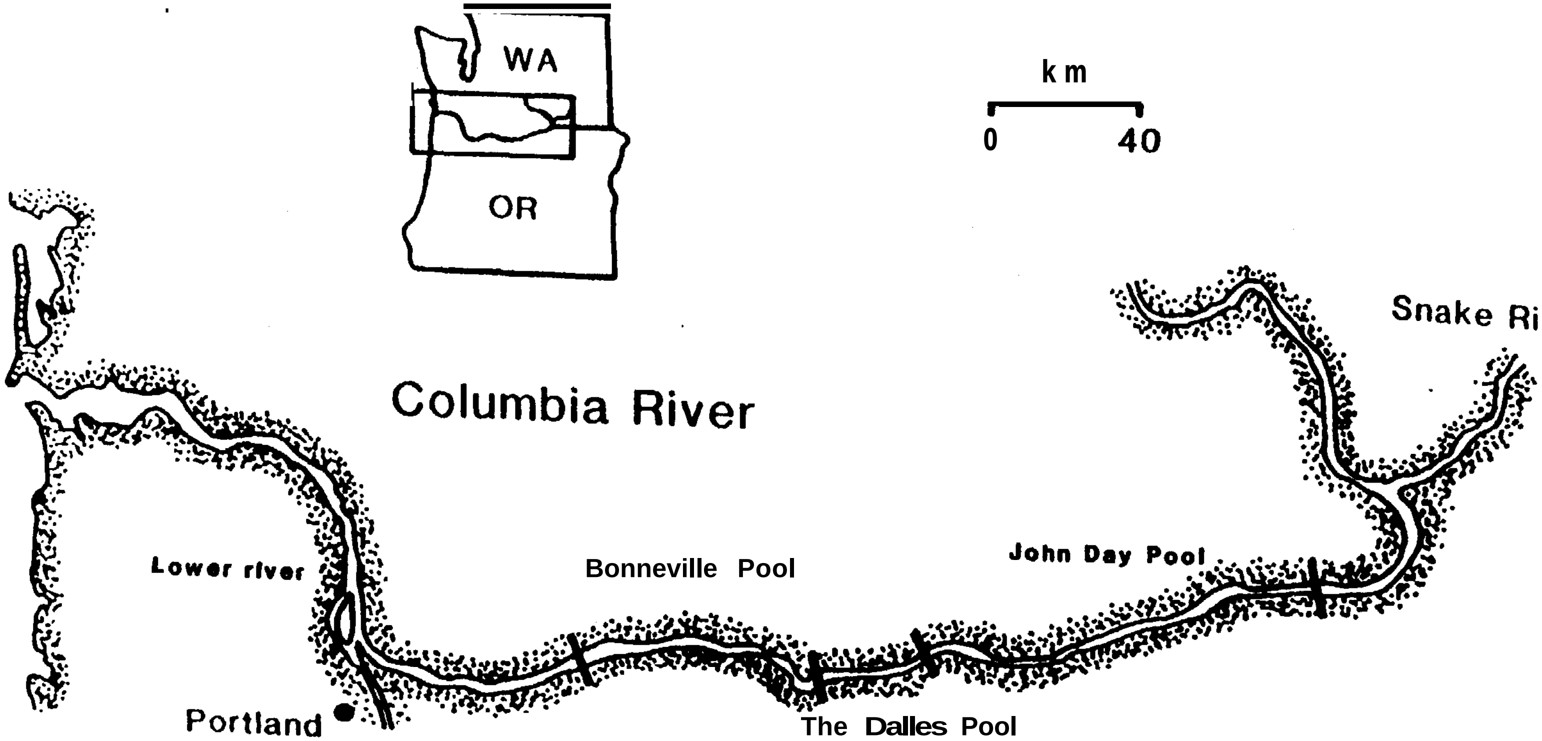

Figure 1. Location of the three furthest downstream impoundments of the Columbia River and the unimpounded lower river.

Young-of-the-year white sturgeon were also collected with a 7.9-m semiballoon shrimp trawl in the lower river and a 6.2-m high-rise trawl (Normandeau Associates, Inc 1985) in the three pools; both were towed upstream on the substrate for 5-15 min. The high-rise and semiballoon trawls were fished bi-weekly in April and August through September. The Dalles Pool and the lower river were sampled from 1987 through 1991, Bonneville Pool was sampled from 1988 through 1991, and John Day Pool was sampled from 1989 through 1991. McCabe and McConnell (1988) and Palmer et al. (1988) provide more detailed gear descriptions and sampling schedules.

Catch per unit of effort (CPUE) was calculated for each of the three pools by year and lifestage for two types of sampling sites: sites sampled each year a pool was sampled (standard sites) and the three standard sites with the greatest number of that lifestage collected (peak sites). Five to 22 standard sites were used for each gear in each pool (Appendix 1). For the lower river, CPUE values for eggs and larvae were calculated only for the Ives Island site located at river kilometer (Rkm) 230, because it was used as an index site in the past by Washington Department of Fisheries and National Marine Fisheries Service, and because catches of eggs and larvae at the Ives Island site were higher and more consistent than at any other sampling site in the lower river.

Spawning occurred at 10 to 19°C during the study and larvae were collected at 10 to 21°C but we used egg and larval sampling efforts from the first day water temperatures in a pool reached 12°C to the first day temperatures in that pool reached 19°C for eggs and 20°C for larvae for CPUE calculations because sampling did not occur in one pool until water temperature reached 12°C, and 21°C was not reached in every pool in every year.

For YOY CPUE calculations we used sampling efforts from 20 days after the first back-calculated date of spawning for each pool and year to the last day sampling occurred with the high-rise trawl in that year and pool, because white sturgeon cultured at temperatures similar to those found during spawning in the Columbia River, reach the YOY stage in about 20 days (Beer 1981). Only efforts from the furthest downstream site that YOY were collected in each pool, upstream to the next dam, were used in CPUE calculations. Water temperature was measured at the surface in the three impoundments and near the substrate in the lower river.

Variability in catch for each lifestage with each gear was assessed using bias corrected coefficient of variation (V) in CPUE (Sokal and Rohlf 1981) for standard sites. Effort (minutes sampled) varied by 13% or less between gears. This analysis was done only for 1989-91 for Bonneville Pool; sample size was not sufficient to produce meaningful values for the other pools, or in 1988 in Bonneville pool. Variability in catch at sampling sites was also compared using V, to see which sites were the most consistent for sampling white sturgeon early life stages.

## Results

Differences between CPUE values for standard and peak egg, larvae, and YOY sites were similar among years within the three pools except for larvae in John Day Pool. The percentage of all eggs, larvae, and YOY collected at peak sites ranged from 67 to 100, 56 to 100, and 62 to 100 (excluding YOY from 1989 when sample size was < 10).

Egg CPUE was higher in average water years (1990-1991) than in low water years (1987-1988) in Bonneville and The Dalles pools for both gears (Figure 2);. no trends were evident for the lower river. Catch per unit effort for larvae collected with the beam trawl was also higher in average water years than in low water years in Bonneville and The Dalles pools (Figure 3). However, only Bonneville Pool exhibited this trend for CPUE of larvae collected with plankton nets. Young-of-the-year CPUE was greater in average water years than in low water years in Bonneville and The Dalles pools (Figure 4). Catch per unit effort in John Day Pool was not compared between average and low water years since it was not sampled before 1989.

Catch per unit effort values for eggs and larvae collected in Bonneville pool using plankton nets were about one-half as variable as CPUE for the beam trawl (Table 1). Larval collections were less variable than egg collections for both gears. Larval catches with plankton nets and YOY catches with high-rise trawls were the least variable (Table 1). Catches of eggs with both gears combined were the most variable (119%) followed by larvae (73%) and YOY (63%). Variability at peak sites was not determined due to ineffective sample size.

## Discussion

To bypass mechanisms of year-class regulation acting upon early lifestages, recruitment estimates should be based on catches of fish as close to the age of recruitment to the fishery as practical (Peterman et al. 1988; Pepin and Myers 1991). Recruitment can be estimated for white sturgeon using eggs, larvae, YOY, or a number of juvenile year-classes since white sturgeon do not recruit to the 101.6 cm minimum harvest size restriction for Columbia River white sturgeon until at least age-8 (Rien et al. 1991). To assess year-class strength, cohorts must be distinguishable. Fish length is not useful in identifying age-1 or older white sturgeon, because age-1 and older white sturgeon from the Columbia River overlap in length (McCabe and Hinton 1991; Parsley et al. 1989). White sturgeon age-1 and older could be used to estimate year-class strength if ages were estimated. However, current methods used to estimate age of white sturgeon are labor intensive, and except for very young fish, are not precise or accurate (Rien and Beamesderfer 1992).

To evaluate spawning and recruitment in lower Columbia River impoundments, peak sites should be sampled (Appendix 1). Numbers of eggs, larvae, and YOY collected were nearly equal at peak and standard sites, but effort at peak sites was only about one-half as great. The ratio between CPUE at peak sites and standard sites is less variable for eggs and YOY than for larvae.

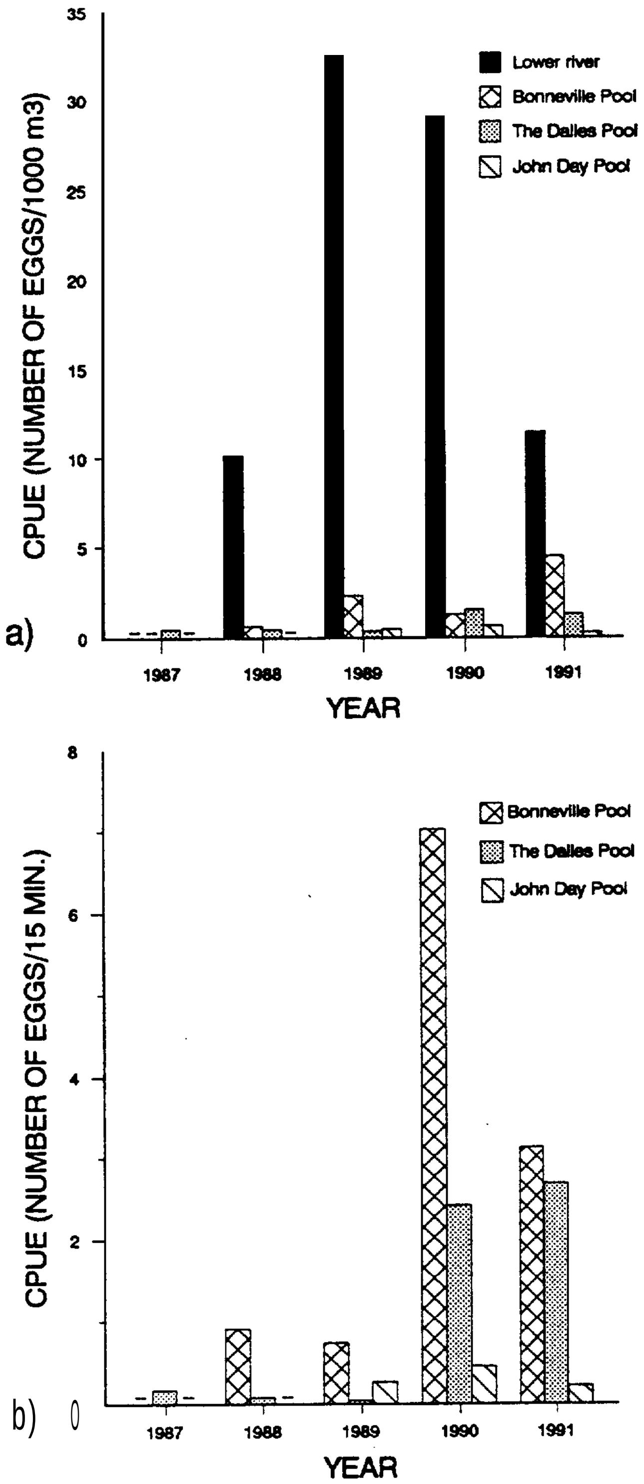

Figure 2. Catch per unit effort (CPUE) for eggs collected with plankton nets in Bonneville, The Dalles, and John Day pools and the unimpounded lower Columbia River (a), and CPUE for eggs collected with beam trawls in Bonneville, The Dalles, and John Day pools (b). Dashes indicate no sampling.

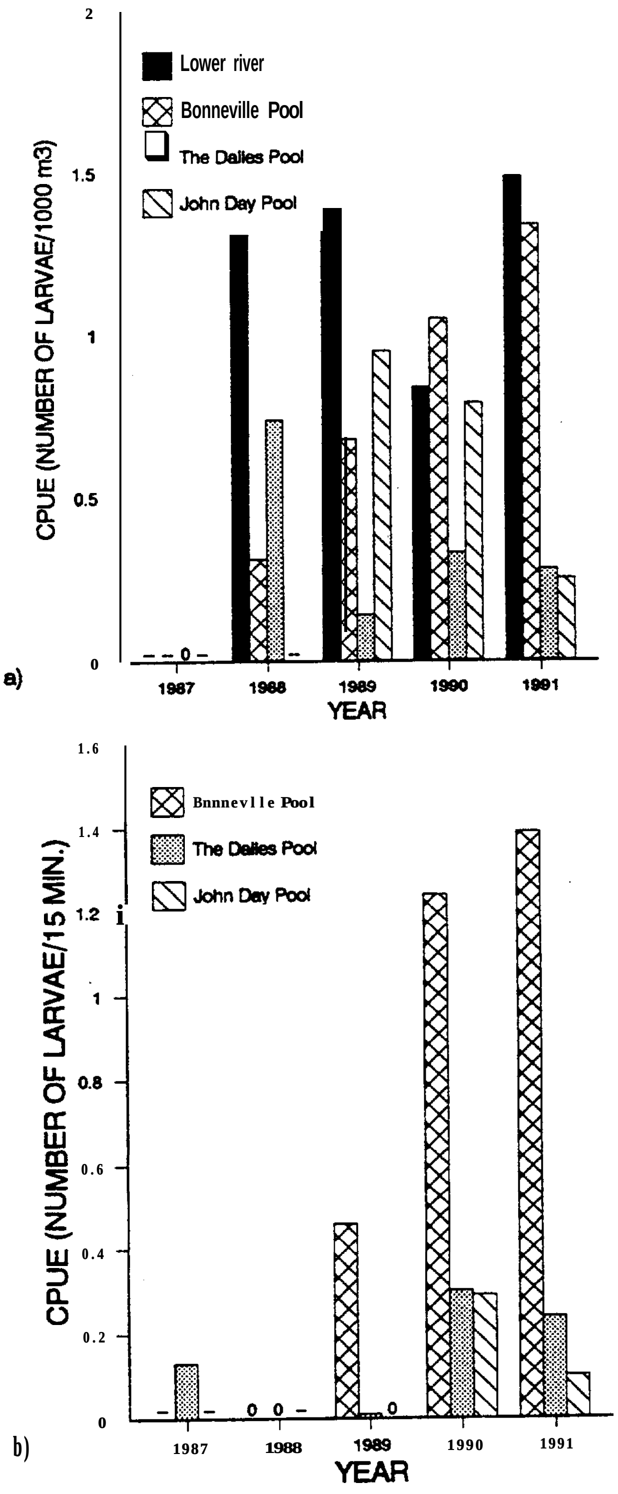

Figure 3. Catch per unit effort (CPUE) for larvae collected with plankton nets in Bonneville, The Dalles, and John Day pools and the unimpounded lower Columbia River (a),. and **CPUE** for larvae collected with beam trawls in Bonneville, **The** Dalles and John Day pools (b). Dashes indicate no sampling, zero indicates no catch.

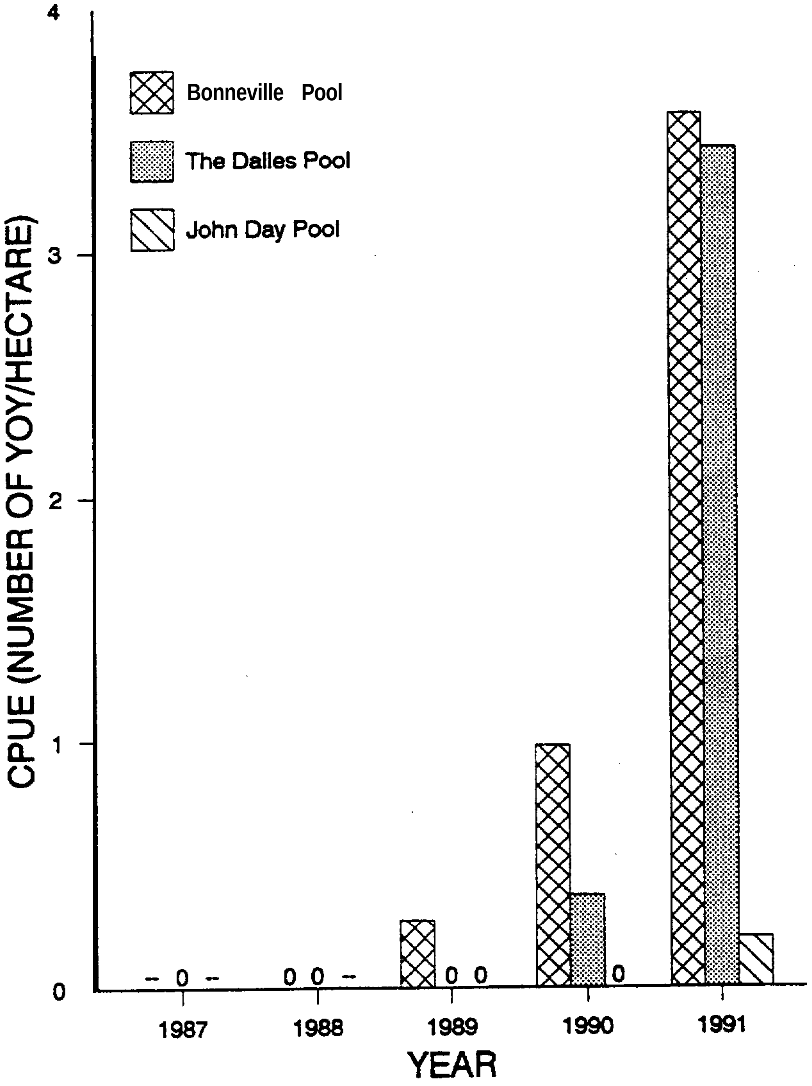

Figure 4. Catch per unit effort (CPUE) for young-of-the-year (YOY) collected with high-rise trawls in Bonneville, The Dalles, and John Day pools. Dashes indicate no sampling, zero indicates no catch.

Table 1. Coefficients of variation in catch per unit effort (expressed as a percentage) for eggs, larvae, and young-of-the-year (YOY) collected in Bonneville Pool at standard sites. Number of efforts that collected each lifestage are in parenthesis.

| YEAR | LIFESTAGE | | |
|---|---|---|---|
| | eggs | larvae | YOY |
| 1989 | | | |
| Beam trawl | 48 (29) | 66 (9) | |
| Plankton net | 98 (10) | 47 (8) | |
| High-rise trawl | | | 32 (8) |
| 1990 | | | |
| Beam trawl | 248 (88) | 107 (15) | |
| Plankton net | 57 (26) | 48 (10) | |
| High-rise trawl | | | 74 (12) |
| 1991 | | | |
| Beam trawl | 176 (79) | 114 (13) | |
| Plankton net | 86 (46) | 53 (15) | |
| High-rise trawl | | | 83 (35) |
| 1989-1991 | | | |
| Beam trawl | 157 (65) | 96 (12) | |
| Plankton net | 80 (27) | 50 (11) | |
| Combined beam trawl and plankton nets | 119 (45) | 73 (12) | |
| High-rise trawl | | | 63 (18) |

September or October sampling for YOY is the most practical method to evaluate recruitment of white sturgeon populations in the impoundments and the lower river, for the following reasons. Catches of YOY white sturgeon with high-rise trawls were less variable than any other lifestage or gear combination except larvae collected with plankton nets. Though larval CPUE was less variable, YOY are past this stage, which regulates year-class size in many fish species. Ages do not have to be estimated for YOY. Predation on YOY white sturgeon is probably slight because of scute armoring, fast growth (YOY white sturgeon in the lower Columbia River range from 130 to 250 mm total length by September), and deepwater habits. Fall sampling may be better logistically, since fisheries personnel and equipment are often more available in fall than in summer.

Spring sampling for age-1 fish may provide a more accurate white sturgeon recruitment estimate than fall sampling for YOY in lower Columbia River impoundments, because age-1 fish are closer to recruiting to the fishery than YOY, having survived their first winter, which regulates year-class size in some fish species. However, this method is not as practical as fall sampling for YOY, because ages must be estimated to distinguish age-1 and age-2 white sturgeon. Use of older year-classes of white sturgeon is not as accurate for estimating recruitment because of accuracy limitations of current ageing techniques.

Egg sampling with plankton nets could be used as an indicator of recruitment if a large enough boat is not available to sample YOY or age-1 white sturgeon with a high-rise trawl. Sampling should be done during the range of temperatures at which white sturgeon spawning occurred in the study area (10-19°C) (Anders and Beckman 1992; McCabe and Tracy 1992). Plankton nets may provide a more accurate recruitment estimate than beam trawls because catch is less variable than with beam trawls. However, beam trawls are better for sampling sparse populations because sampling area is greater, although the gear requires a larger vessel with hydraulic winches.

The difference between egg CPUE for the lower river and the pools was greatest in low water years. This may have been because Bonneville Dam tailrace had considerable white sturgeon spawning habitat even in low water years, while tailraces in the three pools have adequate spawning habitat only in average or high water years (Parsley and Beckman 1992).

The most consistent spawning and the highest CPUE in the study area for all lifestages occurred in the lower river. The study period included two low water years, two average water years, and one with water conditions intermediate to those four years. Recruitment was greater to the egg, larvae, and YOY stages in average water years than in low water years in the three impoundments.

Mean CPUE values for 1989 in the lower river defined the upper limit of spawning and recruitment that occurred during the study (Appendices 2-4). Mean CPUE values for Bonneville Pool in 1990 and 1991 defined the upper limit of spawning and recruitment that occurred in any of the three impoundments. In the absence of data from a high water year, these values could be used to gauge spawning and recruitment in the lower river and the three impoundments. We caution however, that spawning and recruitment could be greater in above average water years since discharge can have a significant effect on white sturgeon spawning (Anders and Beckman 1992). Evaluation of CPUE information from a high water year could help answer this question. The year previous to initiation of this study (1986) was a high water year; high catches of juvenile white sturgeon in 1987 and 1988 in The Dalles Pool and in 1988 in Bonneville Pool suggest that recruitment was much greater in those pools in 1986 than in 1987 or 1988.

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Appendix 1. **Location**[a] of standard and peak sampling **sites**[b] for the beam trawl, plankton nets, and high-rise trawl in Bonneville, The Dalles, and John Day pools during 1988 through 1991.

| Egg and larvae standard sites | Em peak site | Larvae peak site |
|---|---|---|
| BEAM TRAWL | | |
| Bonneville Pool | | |
| 19003 | X | X |
| 19141 | X | X |
| 19153 | | X |
| 19152 | | |
| 19143 | | |
| 18991 | X | |
| The Dalles Pool | | |
| 20983 | | |
| 20984 | | |
| 21302 | | |
| 21402 | X | X |
| 21403 | X | X |
| 21442 | X | X |
| 21502 | | |
| John Day Pool | | |
| 27284 | | |
| 29044 | x | X |
| 29052 | | |
| 29072 | x | X |
| 29092 | | |
| 29164 | x | X |
| PLANKTON NETS | | |
| Bonneville Pool | | |
| 18653 | | X |
| 18734 | | |
| 19022 | X | X |
| 19141 | X | X |
| 19142 | X | |
| The Dalles Pool | | |
| 20822 | | |
| 21004 | | |
| 21163 | | |
| 21302 | | |
| 21381 | x | X |
| 21383 | | |
| 21424 | x | X |
| 21501 | | X |
| 21504 | x | |
| John Day Pool | | |
| 28723 | | |
| 28861 | | |
| 29032 | | |
| 29034 | X | X |
| 29102 | X | X |
| 29121 | | |
| 29134 | X | X |

Appendix 1 Continued.

| YOY standard sites | YOY peak site |
|---|---|
| HIGH-RISE TRAWL | |
| Bonneville Pool | |
| 15052 | |
| 15053 | |
| 15502 | |
| 15734 | |
| 16072 | |
| 16522 | |
| 16851 | |
| 16903 | |
| 17374 | X |
| 17652 | X |
| 17911 | |
| 18351 | |
| 18502 | |
| 18523 | |
| 17063 | X |
| The Dalles Pool | |
| 19433 | X |
| 19901 | X |
| 21024 | |
| 20652 | |
| 20904 | |
| 21075 | |
| 21302 | X |
| 21402 | |
| 21501 | |
| John Day Pool | |
| 21805 | X |
| 23262 | |
| 24013 | |
| 24742 | |
| 25141 | |
| 25255 | |
| 26751 | |
| 26783 | |
| 27284 | |
| 29072 | X |
| 26272 | X[c] |

[a] The first four digits of the location number are river mile to the nearest tenth, the last digit refers to river cross-section (0-5). Zero and five are backwaters on the Washington and Oregon sides of the river, one through four are **river quarter** from the Washington to the Oregon shore.

[b] Standard sites are those sampling sites which were sampled from 1987 through 1991 in The Dalles Pool, 1988 through 1991 in Bonneville Pool, and 1989 through 1991 in John Day Pool. Peak sites are the three standard sites which had the greatest number of a particular lifestage collected during the study.

[c] YOY were collected at only one sites in John Day Pool.

APPENDIX 2. Number collected (N), catch per time (15 min) (CPT), and catch per volume (1000 $m^3$) (CPV) of white sturgeon eggs and larvae collected with plankton nets.

| Lifestage and pool | 1987 N | 1987 CPT | 1987 CPV | 1988 N | 1988 CPT | 1988 CPV | 1989 N | 1989 CPT | 1989 CPV | 1990 N | 1990 CPT | 1990 CPV | 1991 N | 1991 CPT | 1991 CPV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EGGS | | | | | | | | | | | | | | | |
| <u>Lower river</u> | | | | | | | | | | | | | | | |
| Standard sites | - | - | - | 559 | 7.15 | 10.17 | 1151 | 23.62 | 32.67 | 1175 | 24.48 | 29.23 | 279 | 7.78 | 11.42 |
| <u>Bonneville Pool</u> | | | | 11 | | | | | | | | | | | |
| Standard sites | - | - | - | 10 | 0.08 | 0.68 | 35 | 0 40 | 2 34 | 34 | 0 22 | 1 31 | 71 | 0 89 | 4 47 |
| Peak sites | - | - | - | | 0.08 | 0.65 | 35 | 0:40 | 2:34 | 34 | 0:43 | 1:94 | 71 | 0:89 | 4:47 |
| <u>The Dalles Pool</u> | | | | | | | | | | | | | | | |
| Standard sites | 1 | 0.19 | 0.50 | 9 | 0.09 | 0.49 | 18 | 0.10 | 0.39 | 67 | 0.47 | 1.54 | 46 | 0.34 | 1.30 |
| Peak sites | - | - | - | 8 | 0.15 | 0.80 | 18 | 0.20 | 0.71 | 65 | 0.93 | 2.81 | 42 | 0.66 | 2.28 |
| <u>John Day Pool</u> | | | | | | | | | | | | | | | |
| Standard sites | - | - | - | - | - | - | 6 | 0.09 | 0.48 | 26 | 0.15 | 0.68 | 13 | 0.06 | 0.29 |
| Peak sites | - | - | - | - | - | - | 6 | 0.15 | 0.80 | 26 | 0.20 | 0.91 | 13 | 0.10 | 0.46 |
| LARVAE | | | | | | | | | | | | | | | |
| <u>Lower river</u> | | | | | | | | | | | | | | | |
| Standard sites | - | - | - | 75 | 0.91 | 1.31 | 55 | 0.97 | 1.39 | 38 | 0.68 | 0.84 | 40 | 1.00 | 1.49 |
| <u>Bonneville Pool</u> | | | | | | | | | | | | | | | |
| Standard sites | - | - | - | 5 | 0.04 | 0.31 | 13 | 0.09 | 0.68 | 21 | 0.17 | 1.05 | 26 | 0.24 | 1.34 |
| Peak sites | - | - | - | 5 | 0.04 | 0.31 | 13 | 0.13 | 0.82 | 21 | 0.26 | 1.24 | 24 | 0.32 | 1.68 |
| <u>The Dalles Pool</u> | | | | | | | | | | | | | | | |
| Standard sites | 0 | 0.00 | 0.00 | 14 | 0.13 | 0.74 | 10 | 0.03 | 0.14 | 22 | 0.09 | 0.33 | 13 | 0.07 | 0.28 |
| Peak sites | - | - | - | 10 | 0.17 | 0.99 | 7 | 0.04 | 0.18 | 20 | 0.18 | 0.55 | 8 | 0.11 | 0.39 |
| <u>John Dav Pool</u> | | | | | | | | | | | | | | | |
| Standard sites | - | - | - | - | - | - | 3 | 0.15 | 0.95 | 48 | 0.16 | 0.79 | 16 | 0.05 | 0.25 |
| Peak sites | - | - | - | - | - | - | 3 | 0.15 | 0.95 | 47 | 0.36 | 1.64 | 15 | 0.11 | 0.49 |

APPENDIX 3. Number collected (N), and catch per time (15 min) (CPT) of white sturgeon eggs and larvae collected with beam trawls.

| Lifestage and pool | YEAR<br>1987 | | 1988 | | 1989 | | 1990 | | 1991 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | CPT | N | CPT | N | CPT | N | CPT | N | CPT |
| EGGS | | | | | | | | | | |
| Bonneville Pool | | | 28 | | | | | | | |
| Standard sites | - | | 28 | 0.91 | 47 | 0.74 | 638 | 7.03 | 250 | 3.13 |
| Peak sites | - | | | 1.02 | 45 | 0.95 | 632 | 9.41 | 248 | 4.13 |
| The Dalles Pool | | | | | | | | | | |
| Standard sites | 1 | 0.17 | 3 | 0.08 | 2 | 0.04 | 196 | 2.42 | 236 | 2.68 |
| Peak sites | - | | 2 | 0.06 | 2 | 0.07 | 193 | 4.11 | 231 | 5.25 |
| John Day Pool | | | | | | | | | | |
| Standard sites | - | | | | 10 | 0.26 | 45 | 0.45 | 26 | 0.22 |
| Peak sites | - | | | | 9 | 0.45 | 45 | 0.76 | 24 | 0.33 |
| LARVAE | | | | | | | | | | |
| Bonneville Pool | | | | | | | | | | |
| Standard sites | - | - | 0 | | | | 86 | | 92 | |
| Peak sites | - | - | 0 | 0.00 | 16 | 0.46 | 48 | 1.02 | 53 | 1.20 |
| The Dalles Pool | | | 0 | | 1 | | | | | |
| Standard sites | 1 | 0.13 | 0 | 0.00 | 0 | 0.01 | .26 | 0.30 | 23 | 0.24 |
| Peak sites | - | | | 0.00 | | 0.00 | 22 | 0.45 | 21 | 0.44 |
| John Day Pool | | | | | 0 | | 32 | | | |
| Standard sites | - | | | - | 0 | 0.00 | 32 | 0.29 | 12 | 0.10 |
| Peak sites | - | | | | | 0.00 | | 0.49 | 12 | 0.17 |

APPENDIX 4. Number collected (N), catch per time (15 min) (CPT), and catch per hectare (CPHA) of white sturgeon YOY collected with high-rise trawl nets in three Columbia River pools.

| | YEAR | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1987 | | | 1988 | | | 1989 | | | 1990 | | | 1991 | | |
| Pool | N | CPT | CPHA | N | CPT | CPHA | N | CPT | CPHA | N | CPT | CPHA | N | CPT | CPHA |
| **Bonneville Pool** | | | | | | | | | | | | | | | |
| Standard sites | - | - | - | 0 | 0.00 | 0.00 | 9 | 0.11 | 0.27 | 24 | 0.38 | 0.98 | 95 | 1.37 | 3.57 |
| Peak sites | - | - | - | 0 | 0.00 | 0.00 | 3 | 0.12 | 0.31 | 16 | 1.41 | 3.67 | 59 | 4.21 | 10.63 |
| **The Dalles Pool** | | | | | | | | | | | | | | | |
| Standard sites | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 3 | 0.14 | 0.37 | 25 | 1.17 | 3.43 |
| Peak sites | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 3 | 0.38 | 1.03 | 25 | 3.41 | 8.89 |
| **John Day Pool** | | | | | | | | | | | | | | | |
| Standard sites | - | - | - | - | - | - | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 0.08 | 0.20 |
| Peak sites | - | - | - | - | - | - | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 0.19 | 0.52 |

# Age and Growth

# REPORT J

# Accuracy and Precision in Age Estimates of White Sturgeon Using Pectoral Fin Rays

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Abstract. -- Estimates of age from cross sections of pectoral fin-rays from white sturgeon Acipenser transmontanus collected in impoundments of the Columbia River were not precise or accurate. Percent error among multiple readings by two persons averaged 5.89, while coefficient of variation averaged 7.80%. A dosage of 25 mg oxytetracycline (OTC)/ kg of body weight marked 216 of 220 fin-ray samples for validation and did not reduce growth. Accuracy was improved by identifying the period of annulus formation (May-June) from the position of an OTC mark relative to translucent rings in fin-ray cross sections. However, counts of periodic rings formed after injection with OTC under-estimated age, especially among slow growing and large fish. We recommend development of alternative methods for aging white sturgeon to supplement the fin-ray method.

## INTRODUCTION

Estimates of growth and mortality biased by inaccurate aging of fish can lead to gross errors in management of long-lived stocks (Beamish and Chilton 1982; Beamish and McFarlane 1983; Archibald et al. 1983; Leaman and Nagtegaal 1987). Validation is therefore a crucial component of age and growth studies (Brothers 1982; Beamish and McFarlane 1983; Jearld 1983). Even when valid methods are used, difficulties in interpretation contribute uncertainty to age estimates. This uncertainty may affect confidence in applications of age data for management decisions (Lai, and Gunderson 1987).

Oxytetracycline (OTC) has been used to validate ages assigned from counts of periodic marks on bony structures of fish (Beamish and McFarlane 1983; Leaman and Nagtegaal 1987) but its use has not been evaluated for sturgeon *Acipenser* spp. McFarlane and Beamish (1987) found mortality rates for sablefish *Anoplopoma fimbria* increased in direct proportion to dosage rate of OTC, while OTC marking effectiveness was substantially reduced at low dosages. They recommended using dosages that maximize the number of marked fish recaptured.

Sturgeon ages are commonly estimated from cross sections of pectoral fin-rays (Cuerrier 1951; Probst and Cooper 1954; Kohlhorst et al. 1980; Jearld 1983). Brennan and Cailliet (1989) evaluated a variety of calcified age structures (pectoral fin-rays, opercles, clavicles, cleithra, medial nuchals, and dorsal scutes) to age white sturgeon *Acipenser transmontanus* and found ages estimated from these structures did not vary significantly. They concluded that pectoral fin-rays provided the greatest reader precision, and unlike other structures (opercles, clavicles, cleithra, and medial nuchals) fin-rays can be collected from live fish. However, the validity of this method has not been established. For instance, Sokolov and Malyutin (1978) suggest two growth rings may form annually in some sturgeon.

In this paper we report on the precision and accuracy of aging white sturgeon from impoundments of the Columbia River using pectoral fin-rays.

## METHODS

Age of white sturgeon was estimated by counting periodic rings on cross sections -of the anterior pectoral fin-ray. We sampled white sturgeon in three Columbia River impoundments between Bonneville and McNary dams, Oregon and Washington, using set lines and an angler survey (Elliott and Beamesderfer 1990; Hale and James 1992).

From live fish, we took a section of the leading pectoral fin-ray by making two cuts with a hacksaw blade or coping saw through the leading ray: the first about 5 mm distal from the point of articulation, the second about 10 mm distal from the first. We took care not to sever the artery running close to the fin-ray articulation. The fin-ray section was then removed by twisting it free with a pair of pliers and inserting a knife between the first and second fin-ray as needed. From dead fish, we removed the entire leading fin-ray. For recaptured white sturgeon, we removed fin-ray samples from fish previously injected with OTC. We dried the fin-ray samples and cut them into several thin (0.3 - 0.6 mm) transverse sections using a Buehler Isomet low speed saw. The sections were mounted on glass microscope slides using clear fingernail polish.

Fin-ray sections were examined using a dissecting microscope (15 to 40X) and transmitted light. We considered translucent rings in the sample to be an annuli (Brennan and Cailliet 1989). We observed that single rings in the anterior portion of a sample often split into several rings in the lobes, a pattern we refer to as banding. Each ring of a banding pattern was counted as an annulus. Translucent rings on the outer edge of a sample were not counted, because we could not distinguish between rings on the edge and the fleshy zone surrounding the sample. Instead, we assumed all samples collected prior to July 1 would form a ring in that calendar year and grouped them with the appropriate cohort.

Precision of aging was estimated by comparing ages assigned to 935 samples aged twice each by two experienced readers. Precision was described using percent agreement between readers, average percent error (APE), coefficient of variation (V), and an index of precision (D). Percent agreement is the percent of age assignments that fall within a specified number of years. We calculated APE and V to allow comparisons of aging precision among species with widely different life spans (Beamish and Fournier 1981, Chang 1982). Beamish and Fournier- (1981) presented APE as

$$\text{APE} = \frac{1}{\underline{N}} \sum_{\underline{j}=1}^{\underline{N}} \left[ \frac{1}{\underline{R}} \sum_{\underline{i}=1}^{\underline{R}} \frac{| \underline{X}_{ij} - \underline{X}_j |}{\underline{X}_j} \right] \times 100$$

where $\underline{N}$ is the number of fish aged, $\underline{X}_{ij}$ is the ith reading of the jth fish, $\underline{X}_j$ is the average age of the jth fish, and $R$ is the number of fish aged. ae present V as the mean value calculated for all samples. Lower values for APE and V represent greater precision. To provide an estimate of the percent error contributed by each observation we calculated D as $V/\underline{R}^{1/2}$ and present the mean value for all samples (Chang 1982).

Accuracy of aging was estimated using OTC marks in sections from fish recaptured at a known interval after injection. We injected 6,056 white sturgeon with OTC during April through August, 1988 through 1991. A concentration of 100 mg/ml OTC was injected into red muscle tissue under the dorsal scutes just behind the head. A dosage of 25 mg OTC/kg of body weight was used (McFarlane and Beamish 1987, Leaman and Nagtegaal 1987). Only white sturgeon with fork lengths (FL) less than 85 cm or greater than 170 cm were injected, so that anglers, who can legally keep fish with total lengths from 102 through 183 cm (40 through 72 inches), would not risk eating flesh from an injected fish within the 15-day withdrawal period suggested by the U.S. Food and Drug Administration. We marked all injected fish by removing the second right lateral scute. We tagged white sturgeon longer than 64 cm FL with uniquely numbered spaghetti tags.

OTC marks on fin-ray samples from recaptured fish were located using reflected ultraviolet light. We determined the proportion of samples that were marked to describe marking effectiveness of the OTC dosage. We compared growth in FL among groups of recaptured fish that were and were not injected, through analysis of variance performed with the Statistical Analysis System (SAS) (SAS Institute 1988a). We assumed poor growth would indicate negative effects of OTC injection. We compared proximity of OTC marks to the translucent ring we interpreted as an annulus to month of injection to infer the month of annulus formation. We assumed that OTC marks within or abutting the ring indicated injection during the period of annulus formation (Figure lA), and OTC marks separate from the ring indicated injection after annulus formation was complete (Figure 1B). Statistical comparisons of OTC mark position among injection months were made using Fisher's exact test of independence performed with SAS (Sokal and Rohlf 1981; SAS Institute 1988b).

To validate our aging technique, six readers, with one or more years experience aging white sturgeon, independently assigned an age to samples from OTC injected fish using the OTC mark as zero. We will refer to this assignment as the OTC age. Translucent rings were counted only when part of the OTC mark was within the opaque zone formed prior to the ring. We compared the OTC age assignment to the number of winters at-large for each sample examined. Accuracy rate was calculated as the percent of all OTC age assignments that matched the number of winters at-large, and was compared among samples grouped by number of winters at-large, and among FL groups. We also compared the average error in OTC age assigned to the annual growth increment and examined variability in growth among all tagged fish that were recaptured (including white sturgeon not injected with OTC).

## RESULTS

Ages assigned to 935 fin-ray samples in four readings by two readers ranged from 2 to 104 years, only 37% of the samples were assigned the same age by both readers (Table 1). Measurements of precision among all readings were: APE = 5.89, V = 7.80%, and Cl = 3.91.

We detected an OTC mark in 216 of 220 fin-rays (98%) from white sturgeon injected with OTC up to three years earlier. White sturgeon injected with OTC appeared to grow faster than fish that were not injected (Table 2), but differences were not significant. Two-way analysis of variance (Type III sum of squares) showed growth in FL did not vary significantly between fish injected with oxytetracycline and those not injected (df = 3, 260; E = 3.50; p = 0.063), nor was the interaction between injection status and winters at-large significant (df = 3, 260; E = 2.60; p = 0.108).

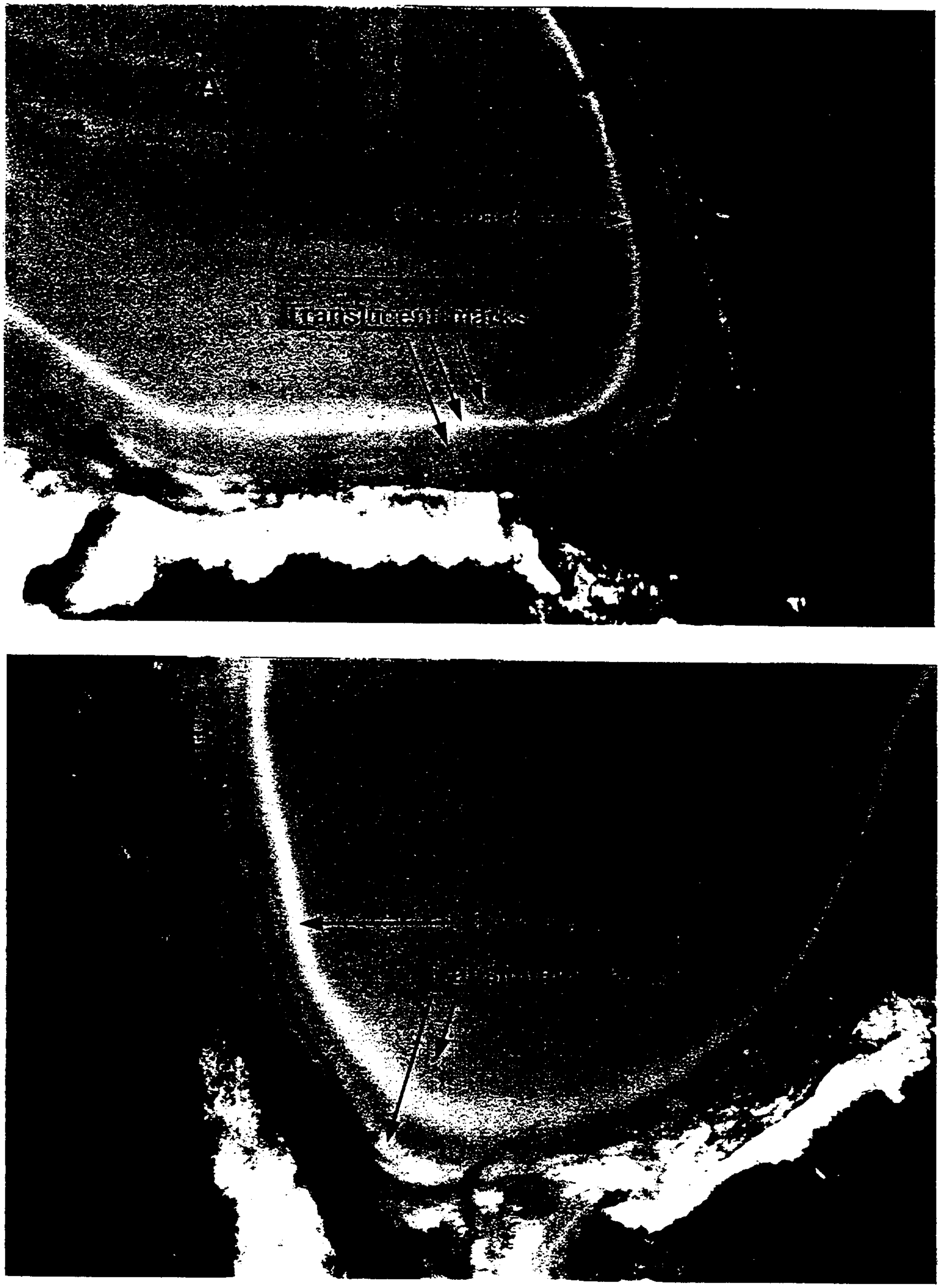

FIGURE 1. — Relative positions of translucent ring and mark resulting from injection of oxytetracycline; (A) during period of annulus formation and (B) outside the period of annulus formation in sections of leading pectoral fin-rays of white sturgeon from the Columbia River.

Table 1. -- Frequency of differences in final assigned ages by two readers of white sturgeon fin-rays collected in three reservoirs of the Columbia River, 1987 through 1991.

| Age difference | Final assigned age |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11-15 | 16-20 | 21-25 | 26-30 | 31-104 | All | Percent |
| -10 |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 1 | 0.1 |
| -9 |  |  |  |  |  |  |  |  |  |  |  |  |  | 1 | 1 | 0.1 |
| -8 |  |  |  |  |  |  |  |  |  |  |  | 1 |  | 1 | 2 | 0.2 |
| -7 |  |  |  |  |  |  |  |  |  |  |  |  |  | 2 | 2 | 0.2 |
| -6 |  |  |  |  |  |  |  |  |  | 2 | 1 | 1 |  | 2 | 6 | 0.6 |
| -5 |  |  |  |  |  |  |  |  |  | 1 | 2 | 2 | 1 | 2 | 8 | 0.9 |
| -4 |  |  |  |  |  |  |  | 1 |  | 2 | 3 | 6 | 3 | 3 | 18 | 1.9 |
| -3 |  | 1 |  |  | 5 | 1 |  | 3 |  | 4 | 16 | 6 | 5 | 3 | 44 | 4.7 |
| -2 |  | 1 |  | 5 | 2 | 5 | 4 | 4 | 5 | 16 | 20 | 11 | 9 |  | 82 | 8.7 |
| -1 | 1 | 4 | 2 | 3 | 13 | 15 | 13 | 10 | 14 | 30 | 25 | 24 | 7 | 6 | 167 | 17.9 |
| 0 | 2 | 8 | 24 | 26 | 26 | 24 | 16 | 28 | 19 | 62 | 81 | 25 | 7 | 2 | 350 | 37.4 |
| 1 |  | 1 |  | 1 | 3 | 4 | 8 | 5 | 5 | 29 | 40 | 21 | 3 | 1 | 123 | 12.9 |
| 2 |  |  |  | 1 |  |  |  | 2 | 1 | 14 | 18 | 12 | 10 | 1 | 59 | 6.3 |
| 3 |  |  |  |  |  |  |  |  | 2 | 7 | 10 | 12 | 4 | 2 | 37 | 4.0 |
| 4 |  |  |  | 1 |  |  |  |  | 1 | 2 | 3 | 2 | 1 | 2 | 12 | 1.3 |
| 5 |  |  |  |  |  |  |  |  |  | 2 | 2 | 4 | 2 |  | 10 | 1.1 |
| 6 |  |  |  |  |  |  |  |  |  | 1 | 3 | 3 |  |  | 7 | 0.8 |
| 7 |  |  |  |  |  |  |  |  |  |  |  | 3 |  |  | 3 | 0.3 |
| 8 |  |  |  |  |  |  |  |  |  |  | 1 | 1 |  | 1 | 3 | 0.3 |
| 9 |  |  |  |  |  |  |  |  |  |  | 1 |  |  |  | 1 | 0.1 |
| 10 |  |  |  |  |  |  |  |  |  |  |  |  | 1 |  | 1 | 0.1 |
| All | 3 | 15 | 26 | 37 | 49 | 49 | 41 | 53 | 47 | 172 | 226 | 134 | 53 | 30 | 935 | 100.0 |

Table 2. -- Comparison of mean growth (cm FL) for tagged white sturgeon recaptured after up to four winters at-large among groups injected with oxytetracycline (25 mg OTC/kg of body weight) and fish that were not injected (control). Fish were injected with OTC from 1988 through 1991; control group fish were initially captured primarily in 1987 and 1988. All fish were less than 84 cm FL or larger than 170 cm FL at marking.

| Winters at-large | Injected | | Control | | All | |
|---|---|---|---|---|---|---|
| | Mean | N | Mean | N | Mean | N |
| 0 | 0.76 | 100 | 0.22 | 23 | 0.66 | 123 |
| 1 | | 38 | | | | 63 |
| 2 | 1.79 | 46 | 0.72 | 25 | 1.37 | 50 |
| 3 | 6.19 | 21 | 1.50 | 2 | 5.78 | 23 |
| 4 | -- | 0 | 13.20 | 5 | 13.20 | 5 |
| All | 2.33 | 205 | 1.80 | 59 | 2.21 | 264 |

Table 3. -- Distribution of interpreted winters at-large from pectoral fin-ray sections of white sturgeon previously injected with oxytetracycline. Samples were independently examined by six trained readers with one to six years experience aging white sturgeon.

| Winters at-large | No. samples | No. readings | Intepreted winters at-large | | | | | Accuracy[a] |
|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3 | 4 | |
| 0 | 65<br>47 | 376 | 342 | 33 | 1<br>35 | 0 | 0 | 91% |
| 1 | | | | | | | | |
| 2 | 73 | 278 | 167 | 105 | 119 | 40 | 12 | 28% |
| 3 | 31 | 184 | 23 | 36 | 54 | 61 | 10 | 33% |
| ALL | 216 | 1,271 | | | | | | 51% |

[a] The proportion of readings that matches actual winters at-large.

We recaptured 96 white sturgeon for which we could determine the month and year of OTC injection. Fin-ray samples from white sturgeon injected before July 1 had a higher proportion of OTC marks within or abutting a translucent ring than those injected on or after July 1 (Figure 2). The proportion of fin-ray samples that showed an OTC mark within or abutting a translucent ring varied significantly among injection months (Fisher's exact test results: df = 4, $p < 0.001$).

Accuracy of OTC age interpretations declined dramatically as period at-large increased (Table 3). Many samples at-large one or more winters were underaged. Accuracy of OTC age interpretations was higher for white sturgeon less than 60 cm FL than for larger fish up to 100 cm FL (Figure 3). Average error in OTC age assignment was lower among faster growing white sturgeon (Figure 4), however most white sturgeon (57%), among recaptures of tagged fish at-large one or more winters, grew less than 4 cm FL per year (Figure 5).

## DISCUSSION

Precision of age estimates from white sturgeon pectoral fin-rays is low compared to precision measures reported for other species (Table 4). The coefficient of variation is an unbiased estimator of precision that allows comparison among species with widely different maximum ages (Chang 1982). Among literature values reported for seven species, only sablefish have a higher coefficient of variation for between reader comparisons. Our measures of percent agreement are similar to those reported for white sturgeon in California. This lack of precision will limit the utility of age assignments for analysis of population dynamics. For instance, relative year-class-strength would be difficult to detect from age frequencies, except among very young fish.

OTC, injected at a dosage of 25 mg/kg of body weight, effectively marked white sturgeon at a rate greater than Beamish and McFarlane (1987) reported for similar dosage rates on sablefish (98% versus 70%). Beamish and McFarlane (1987) also noted increased mortality at high dosages. Our sampling design did not allow us to measure differences in mortality, but we observed a slight increase rather than a reduction in growth. While this difference was not significant, it may suggest an antibiotic effect of OTC.

Annulus formation is complete by July. We observed some samples without annuli in July and August, but these may be fish that failed to form an annulus during that year. Accuracy of aging could be reduced by failure to consider this period of annulus formation because of difficulty distinguishing annuli at the edge (Sheri and Power 1969; Crawford et al. 1989), but collection of fin-ray samples before May and after July will improve accuracy of interpretation.

Counts of annular rings on white sturgeon pectoral fin-rays underestimate age. Accuracy of age interpretation is related to growth rate: fish that grow slowly do not appear to form a growth ring every year. Accuracy of age assignments declines with increasing size and age as fish respond to more of these reduced growth periods.

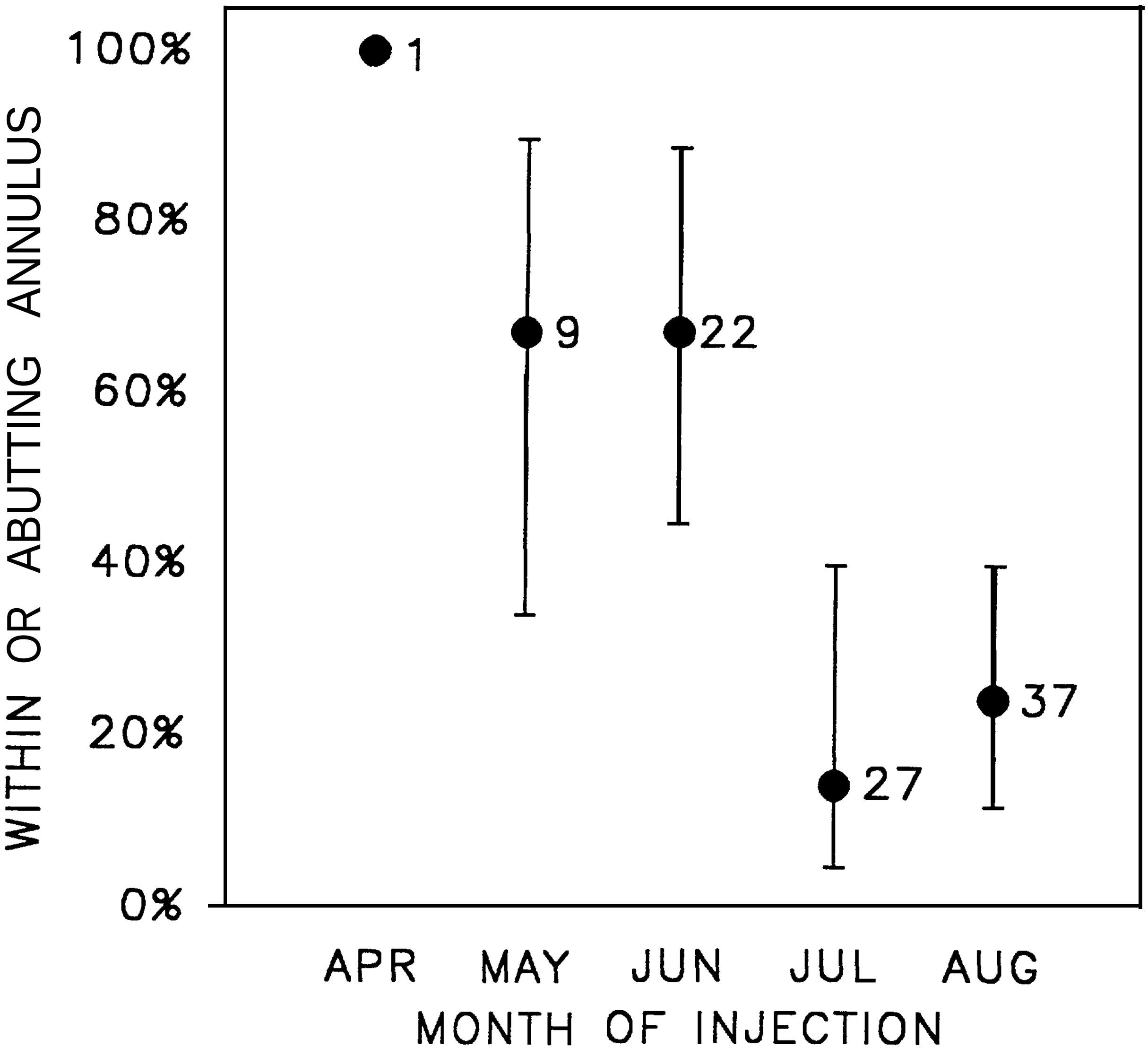

Figure 2. -- Percent of pectoral fin-ray samples showing an OTC mark within or abutting a translucent ring for white sturgeon previously injected with oxytetracycline in the Columbia River, 1988-1989. Verticle lines represent 95% confidence limits.

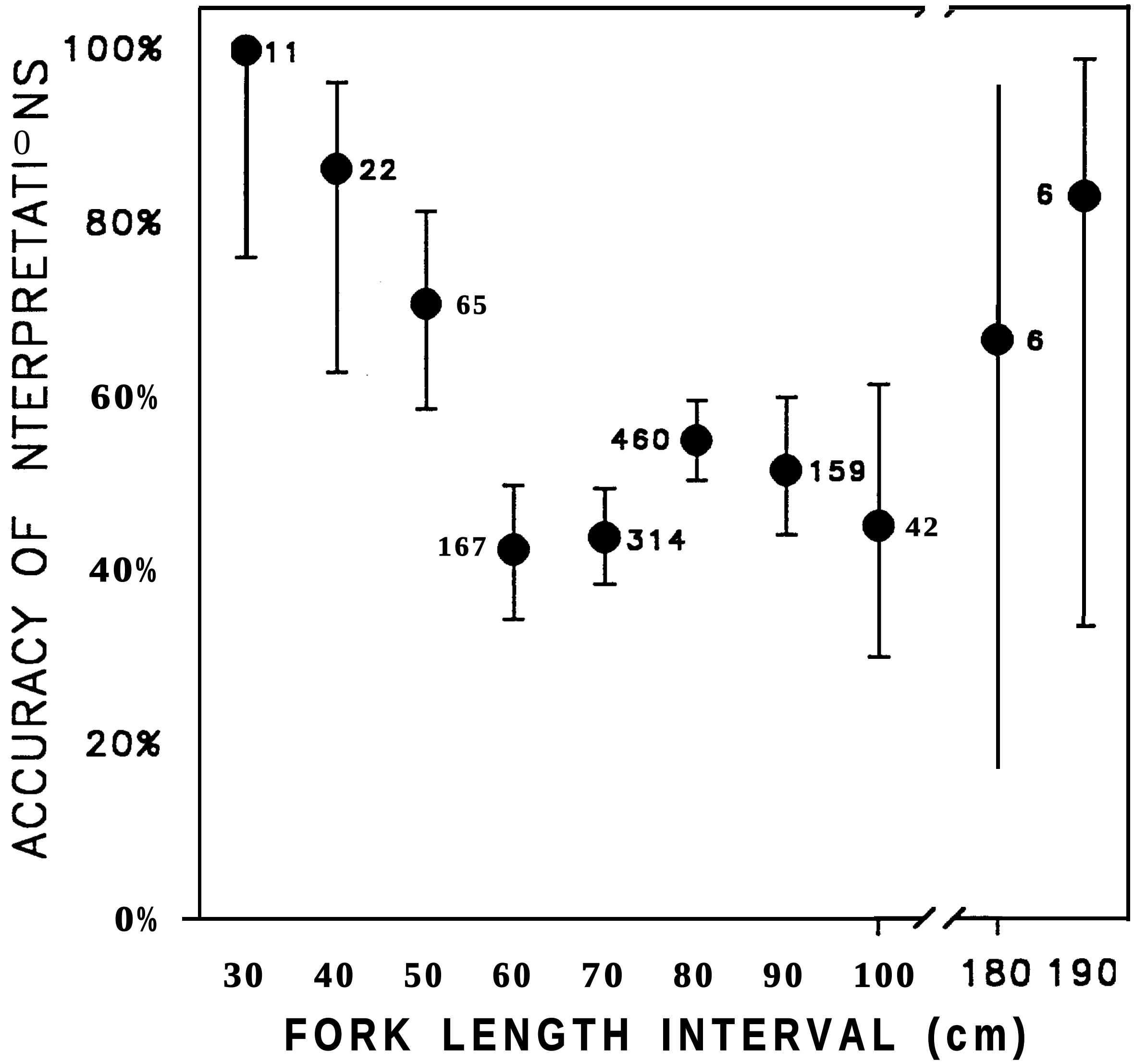

Figure 3. -- Accuracy of interpreted period at-large by six experienced readers examining white sturgeon pectoral fin-ray sections collected from fish injected with oxytetracycline and recaptured after a period of up to three winters, Bonneville, The Dalles, and John Day reservoirs, Columbia River, 1988-1991. We defined accuracy as the percent of interpretations that matched the actual number of winters at-large. The number of readings for fish from each fork length interval is shown with each data point. Verticle lines represent 95% confidence limits.

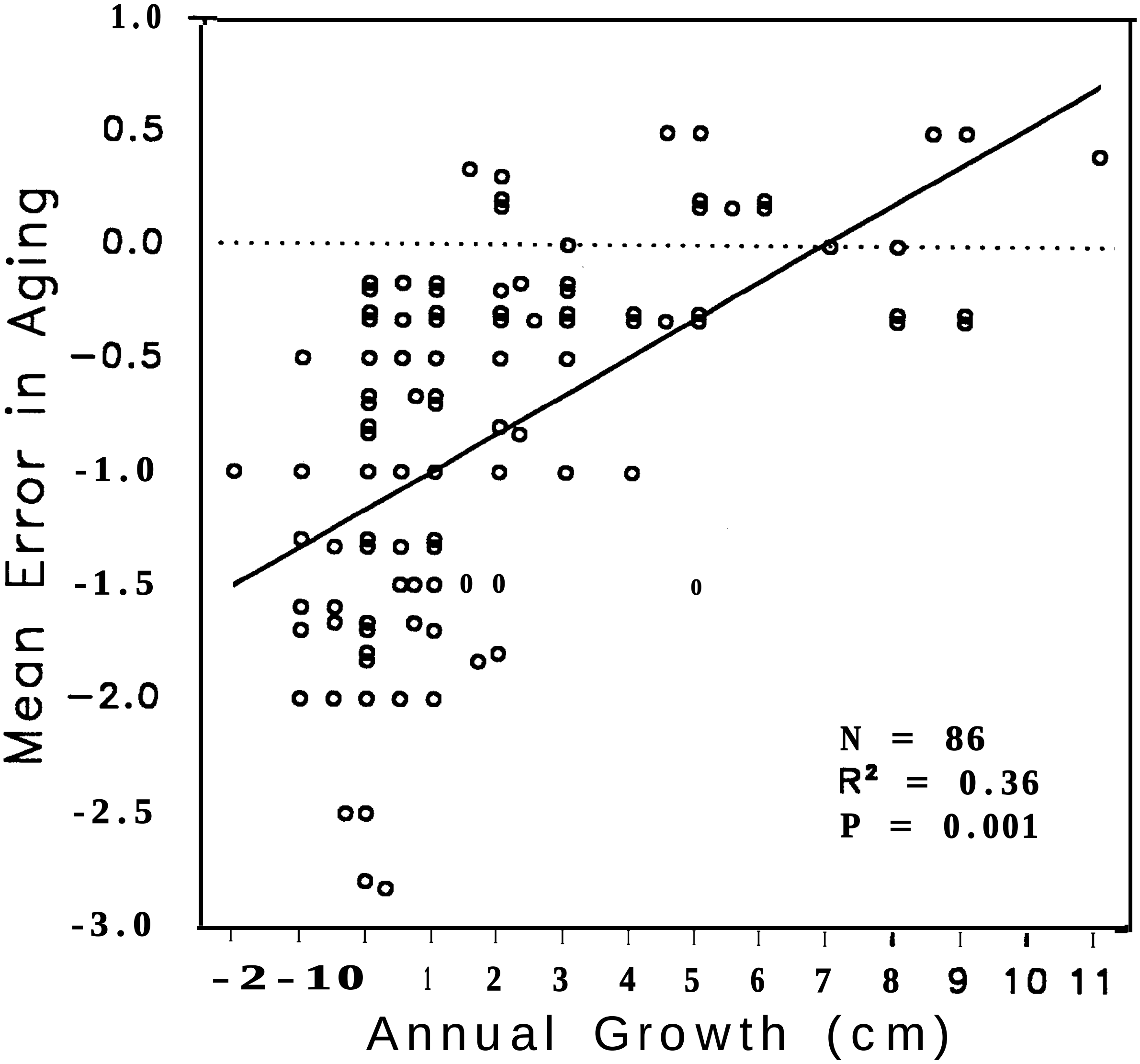

Figure 4. -- Mean error in interpreted winters at-large from white sturgeon pectoral fin-ray samples versus annual growth in fork length, Bonneville, The Dalles, and John Day reservoirs, Columbia River, 1989-1991. White sturgeon were at-large at least one winter after injection with oxytetracycline. Each sample was independently examined by six experienced readers.

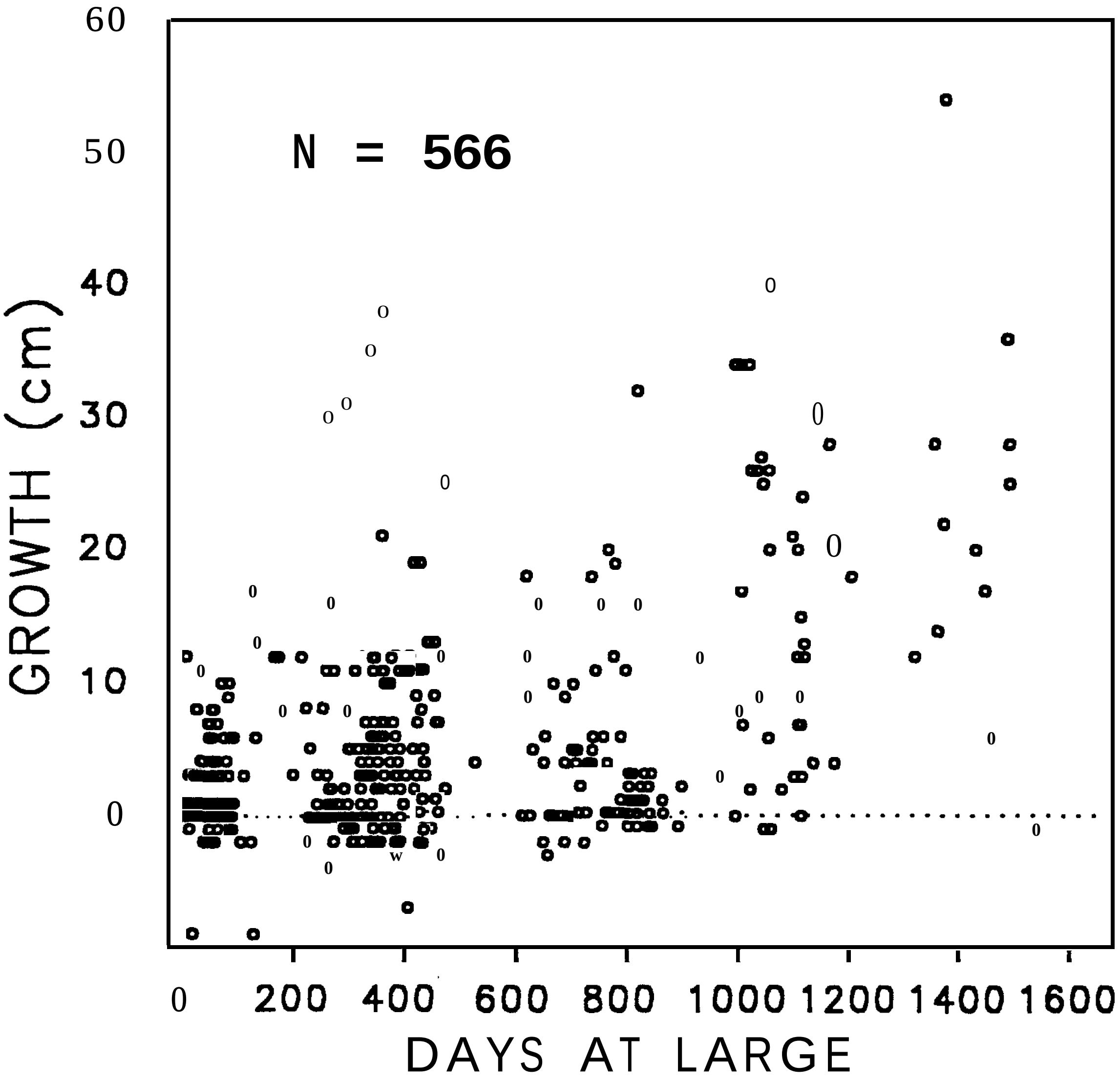

Figure 5. -- Increase in fork length of tagged white sturgeon at-large for up to 4 years prior to recapture, Bonneville, The Dalles, and John Day reservoirs, Columbia River, 1987-1991. Fish may or may not have been injected with oxytetracycline prior to recapture. Extreme values may represent errors in measurement or data recording.

Table 4. -- Percent agreement, average percent error (APE), coefficient of variation (V), and indices of precision (D) for between reader aging precision reported for various species.

| Species | Percent agreement | | | APE | V | D | Maximum Age |
|---|---|---|---|---|---|---|---|
| | 0[a] | ±1[b] | ±2[c] | | | | |
| White sturgeon<br>*Acipenser transmontanus* | 37 | 68 | 83 | 5.9 | 7.8 | 3.9 | 104 [d] |
| | 17-31 | 57-63 | 77-84 | -- | -- | -- | -- [e] |
| | 23 | 55 | 74. | -- | -- | -- | -- [f] |
| | 32 | 74 | 95 | -- | -- | -- | ≥20 [g] |
| Pacific hake<br>*Merluccius productus* | 79 | -- | -- | -- | 3.2 | -- | 16 [h] |
| Yellowfin sole<br>*Pleuronectus asper* | 61 | -- | -- | -- | 3.2 | -- | 26 [h] |
| Pacific ocean perch<br>*Sebastes alutus* | 41 | -- | -- | -- | 4.9 | -- | 78 [h] |
| Walleye pollock<br>*Therasra chalcoqramma* | 64 | -- | -- | -- | 5.0 | -- | 13 [h] |
| Atka mackerel<br>*Pleurooram mus monoptervaius* | 67 | -- | -- | -- | 6.8 | -- | 10 [h] |
| Sablefish<br>*Anoplopoma fimbria* | 43 | -- | -- | -- | 12.9 | -- | 29 [h] |
| Northern pike<br>*Esoxus* | 88 | 93 | 98 | 1.2 | 1.2 | 0.8 | 11 [i] |

[a] Ages assigned were identical.

[b] Ages assigned were within 1 year.

[c] Ages assigned were within 2 years.

[d] This study.

[e] Brennan and Cailliet 1987.

[f] Shirley 1987.

[g] Kohlhorst et al. 1980.

[h] Kimura and Lyons 1991.

[i] Laine et al. 1991.

We have shown that tagged white sturgeon from impounded reaches of the Columbia River grow substantially slower than the 10 cm/year expected for fish in the free-flowing reach below these impoundments (DeVore et al. 1992). It is clear the potential for under-aging white sturgeon from impounded reaches is great and that a conservative approach to fishery management is justified.

Sustainable exploitation and yield of white sturgeon are sensitive to growth and natural mortality rates (Rieman and Beamesderfer 1990). Studies based on age estimates from pectoral fin-rays will overestimate growth rate and underestimate natural' mortality. The likely result of underaging is that the sustainable exploitation rate for reservoirs of the Columbia River has been overestimated. Overestimates of annual growth may account for observed delays in recruitment of white sturgeon recreational fisheries below Columbia River impoundments following a 10 cm increase in the minimum size limit in April 1989. Given the estimated growth rate of sub-legal sturgeon, catch rates of legal-sized fish did not recover in 1991 as expected (Melcher and King 1992; personal communication, Steve King, Oregon Department of Fish and Wildlife).

Ages determined from white sturgeon pectoral fin-rays are not precise and underestimate the true age of larger fish. Despite these problems with aging, estimates based on fin-ray sections may be compared among populations if biases are assumed to be similar. Recent advances in aging otoliths using break-and-burn methodology (Chilton and Beamish 1982) may provide a more accurate alternative for aging white sturgeon. Otoliths have been used to age lake sturgeon Acipenser fulvescens (Harkness 1923, Schneberger and Woodbury 1944) but were reported difficult to process and read for white sturgeon in California (Brennan and Cailliet 1989): Other new methods, including radiometric dating and evaluation of stable isotopes, may also prove useful (Cailliet and Tanaka 1990). Until alternatives are developed to determine age of white sturgeon, interpretations based on pectoral fin-ray sections should be applied with caution.

## ACKNOWLEDGMENTS

We are indebted to people who aged the fin-ray samples used in this study: Mike Wall of Washington Department of Fisheries; Allen Miller and Calvin Sprague of U.S. Fish and Wildlife Service; and Ruth Farr, Craig Foster and John North of Oregon Department of Fish and Wildlife. The work was funded by Bonneville Power Administration (Contract Number DE-AI79-86BP63584).

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## REPORT K

# Length at Age Relationships for White Sturgeon in the Columbia River Downstream from Bonneville Dam

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For Submission to: <u>Transactions of the American Fisheries Society</u>

*Abstract.-* Ages of white sturgeon, *Acipenser transmontanus*, collected in the lower Columbia River downstream from Bonneville Dam (LCR) between 1949-1953, 1979-1983, and 1987-1992 were estimated from pectoral fin ray sections. An age validation test using oxytetracycline confirmed the ageing criteria.. Von Bertalanffy growth functions (VBGF) were generated for the 1979-1983 and the 1987-1992 collections and for male and female subsets of the 1987-1992 collection. The VBGF that best described LCR white sturgeon growth was $L_t=276.3(1-e^{-0.0346(t+1.125)})$. Comparisons of the VBGFs made using bivariate confidence regions and likelihood ratio tests indicated that an inflection point at age 8 did not significantly influence the VBGF. There were significant differences in VBGFs between male and female white sturgeon, but not between the 1979-1983 and 1987-1992 collections. Paired t-tests indicated no significant differences between mean length at age for the 1987-1992 collection and either the 1949-1953 or 1979-1983 collections. Growth of LCR white sturgeon compared favorably with other Columbia, Fraser, Sacramento and Snake River populations.

The white sturgeon, *Acipenser transmontanus,* is the largest freshwater fish in North America (Scott and Crossman 1973). Age estimates for white sturgeon have exceeded 100 years (Rien and Beamesderfer 1992). The relationship between length and age of a fish species or stock is basic biological information that is useful for comparisons among stocks or life stages, and within a stock over time (Misra 1986; Pauly 1987; Cerrato 1990). The information can be applied to stock assessment models used for fisheries management (Moreau 1987).

Sturgeon do not have scales like most teleost fish, so they are usually aged using the leading ray from a pectoral fin (Brennan and Calliet 1989). An age validation study conducted by Rien and Beamesderfer (1992) using oxytetracycline (OTC) injections indicated that visible annuli may not be deposited each year for some impounded populations of white sturgeon. They concluded that there was a tendency to underestimate the actual age of white sturgeon, especially if faint rings are ignored. It is possible that researchers in earlier studies may not have considered faint rings to be true annuli, thereby underageing the samples. However, Brennan and Calliet (1991), also using OTC validation, found that annuli were deposited each year for San Francisco Bay white sturgeon.

Most of the early investigations of white sturgeon growth have used single linear regression analysis to describe the length at age (LAA) relationship including: Hess (1984) for the lower Columbia River white sturgeon population; Malm (1981) for the Bonneville Reservoir (Columbia River) population; Coon et al. (1977) and Lukens (1981, 1984) for Snake River populations; and Semakula and Larkin (1968) and Dixon (1986) for Fraser River populations. These relationships are useful for comparing LAA over short intervals, although the relationship may not be accurate throughout the life of the fish. Kohlhorst et al. (1980) and Brennan and Calliet (1989) fitted age-length data for the Sacramento River population to a von Bertalanffy growth function (VBGF):

$$L_t=L_\infty(1-e^{-K(t-t_0)}),$$

where $L_t$ = Length (cm) at age $t$, $L_\infty$ = asymptotic maximum length, K = growth coefficient, t = age (years) and $t_0$ = thgoretical age when length = 0 (Ricker 1975).

The VBGF is used widely in yield models (Beaverton and Holt 1957) and population simulation models such as MOCPOP 2.0 (Beamesderfer 1992). There has been some debate as to the validity of the VBGF (Roff 1980), although it does reflect variation in growth over the life of a fish and can be used to compare LAA estimates. However, many fish species, especially diadromous.types, demonstrate sigmoidal LAA relationships, with an inflection point early in life (Moreau 1987). This inflection point is usually associated with changes in physiology and food or habitat availability. The VBGF does not describe growth throughout the inflection point, therefore, its application should exclude ages less than the inflection point (Yamaguchi 1975).

The purpose of this investigation was to describe the LAA relationship for white sturgeon from the lower Columbia River downstream from

Bonneville Dam (LCR). Specific objectives were: 1) to validate the criteria used to age LCR white sturgeon, 2) fit a von Bertalanffy growth function to LAA data collected from adult and sub-adult white sturgeon, 3) to look for evidence of an inflection point in the LAA relationship, 4) to compare male and female growth functions and, 5) to compare growth characteristics of LCR white sturgeon with other populations.

## Hethods

Sections of the leading rays from pectoral fins were used to age white sturgeon captured during LCR research, commercial and recreational fisheries, and broodstock collection from 1987 to 1992. Capture gears included gillnets ranging from 15.9 cm to 30.5 cm (6¼-12 in) stretch mesh, trawls and hook and line. Samples from large fish were difficult to obtain and were collected whenever possible, including from natural mortalities and from monitoring private broodstock collection activities.

Fin ray samples were air dried then sectioned using a Buhler Isomet low speed saw. Two or three sections approximately 0.5 mm thick were cut from each fin ray approximately 1 cm distal to the articulation of the fin ray. The sections were placed on a glass microscope slide and pressure was applied to prevent curling while the sections completed the drying process. The sections were then mounted on the slide with clear fingernail polish. Ages were assigned by counting pairs of opaque and translucent rings on the sections with the aid of a dissecting microscope (Cuerrier 1951). The translucent ring was assumed to have been formed during the winter growth phase and represented a completed annulus. Samples collected between January and June that displayed a large opaque ring but did not display a translucent ring were assigned an age one year greater than the number of annuli present because the translucent ring does not become visible until late June (Beamesderfer et al. 1989). Only rings that were distinct and continuous were considered to be true annuli (Beamesderfer et al. 1989; Brennan and Calliet 1989). Only our most experienced reader aged most fin sections. Sections that were difficult to assign an age were read by more than one reader. An age was assigned if an agreement between the readers could be reached, otherwise the sample was rejected.

A length measurement was made for each fish from which a fin ray sample was collected. Fork length (FL) was the preferred measurement, although total length was occasionally measured then converted to fork length using the equation: $TL = 2.06 + 1.09 * FL$ ($n=2,039$ $r^2=.997$) Sex was determined by biopsy of dead fish and live broodstock fish.

Validation of the ageing criteria was evaluated using fin sections from recaptured oxytetracycline (OTC) injected fish. Sturgeon captured during research fisheries were injected in the dorsal musculature with 100 mg/l OTC at a dosage of 25 mg OTC/kg body weight (McFarlane and Beamish 1987). Only fish less than 96 cm TL, i.e. less than the legal minimum sport size, were injected to comply with a 15 day waiting period for consumption of OTC treated meat recommended by the U.S. Food and Drug Administration. These fish were tagged with spaghetti tie tags and marked by lateral scute removal which identified the year of injection. Fin sections from OTC recoveries were examined under ultraviolet light which illuminated the OTC mark. The number of translucent rings distal to the OTC mark was compared with the number of winters at large.

Lower Columbia River pectoral fin ray collections assembled by Hess (1984) and Bajkov (Unpublished data) during 1979-1983 and 1949-1953, respectively, were sub-sampled and re-aged. Fin ray sections were re-aged because the other investigators used unvalidated ageing techniques and variation between readers can be significant (Kohlhorst et al. 1980; Rien and Beamesderfer 1992). A significant difference in ageing techniques was confirmed with a paired t-test (Sokal and Rohlf 1981) comparing ages assigned by Hess (1984) with those assigned to the same samples during this investigation ($P < 0.0001$).

The 1987-1992 LAA data was plotted and examined for evidence of an inflection point. The inflection point was located by determining the age interval with the greatest difference in mean length, and selecting the smaller of the two ages.

Length at age data were fitted to a von Bertalanffy growth function. Parameters were fit using nonlinear least squares parameter estimation (SAS 1988). VBGFs were generated for the entire 1987-1992 collection, for ages greater than the inflection point, male and female subsets, and for the entire 1979-1983 collection. Male and female subsets were restricted to ages $\geq 16$. At this age female LCR white sturgeon begin to mature (DeVore et al. 1992), and differences in growth between males and females should be evident.

Confidence regions were generated for parameters of the VBGFs to look for possible differences in growth relationships. The LAA data from two sources were fit to one VBGF to obtain a common value for $t_0$. Separate VBGFs were then generated with $t_0$ fixed at the common value. Confidence regions for the two sources were generated by plotting bivariate 95% confidence limits for K vs. $L_\infty$ (Kimura 1980; Draper and Smith 1986). Point estimates of K and $L_\infty$ from one source that did not fall within confidence regions of the other indicated significant differences between the equations being compared (Draper and Smith 1986). Significance levels between individual parameters and equations were estimated using likelihood ratio (LR) tests (Kimura 1980; Kirkwood 1983; Cerrato 1990).

Paired t-tests were used to compare mean LAA of the 1987-1992 and the 1949-1953 collections because there were so few older fish in the latter collection that a VBGF could not be fit. Much of the original Bajkov collection was not located, and part of the collection was damaged and could not be used. Other white sturgeon investigations that provided mean LAA data were also compared to 1987-1992 LCR mean LAA estimates. Comparisons were restricted to like ages with at least 10 samples per age.

## Results

Oxytetracycline was injected into 2,492 fish between 1988 and 1991. Thirty four fish were recaptured that were at large one to two winters. Assigned ages ranged from 7-13 years. All fin sections showed an identifiable OTC mark, and the number of periodic rings between the OTC mark and the distal edge of the fin section corresponded to the number of winters at large. These results indicate that visible annuli were deposited each year, and that the ageing criteria were valid; at least for fish less than age 14.

A plot of length at age for 1987-1992 samples showed an increase in the variation of lengths for ages $\geq 6$ (Figure 1A). The maximum length for fish between ages 5 and 6 increased 28 cm while the mean increased only 6.9 cm. This indicates an increased growth rate for some individuals beginning at age 6. The difference in mean LAA was greatest between 8 and 9 years (11.4 cm) which indicated an inflection point at age 8. The VBGF parameter estimates generated for the entire collection and for ages 28 were similar (Table 1). Plots of bivariate 95% confidence regions of $L_\infty$ and K indicated no significant difference between the VBGFs (Figure 2A). The lack of significant differences in estimates of $L_\infty$ and K ($P > 0.25$) were confirmed with LR tests (Table 2,). The LR tests also indicated no significant difference in estimates of to ($P > 0.10$) or in the combined (three parameter) functions ($P > 0.50$). The lack of significant differences in parameter estimates indicated that the inflection point did not affect the LAA relationship described by the VBGF.

Male and female VBGFs indicated that females attained a larger ultimate length (Table 1; Figure lB), and plots of 95% confidence regions did not overlap point estimates for L, and K (Figure 2B). Likelihood ratio tests confirmed that there were significant differences between $L_\infty$ estimates ($P < 0.01$) and between the combined (three parameter) functions ($P < 0.005$) (Table 2). However, there were no significant differences between estimates of K ($P > 0.05$) or to ($P > 0.25$).

Many of the samples from larger fish included in the original analysis by Hess (1984) could not be reliably aged for this study, and therefore older fish were probably not well represented in the 1979-1983 collection (Figure 1C). However, the VBGF fitted to the 1979-1983 collection had parameter estimates that were similar to those from. the 1987-1992 collection (Table 1). A comparison of confidence regions between the 1987-1992 and the 1979-1983 collections did not indicate significant differences in estimates of L, and K (Figure 2C). This was confirmed with LR tests ($P > 0.50$); nor were estimates of to ($P > 0.10$) and the combined functions ($P > 0.05$) significantly different (Table 2).

The 1949-1953 collection ranged from age 2 to 19 and 38 to 163 cm FL (Table 1). The central star region as well as the annuli were poorly defined when compared to samples from the 1987-1992 and 1979-1983 collections. There were also large numbers of occlusions and cartilaginous interstices present, indicating damage to the fins prior to collection. Samples that were severely damaged could not be aged and were omitted from the analysis. Results of the paired t-test indicated that there were no significant differences ($P >, 0.599$) in mean length at age between the 1949-1953 and 1987-1992 collections (Table 3).

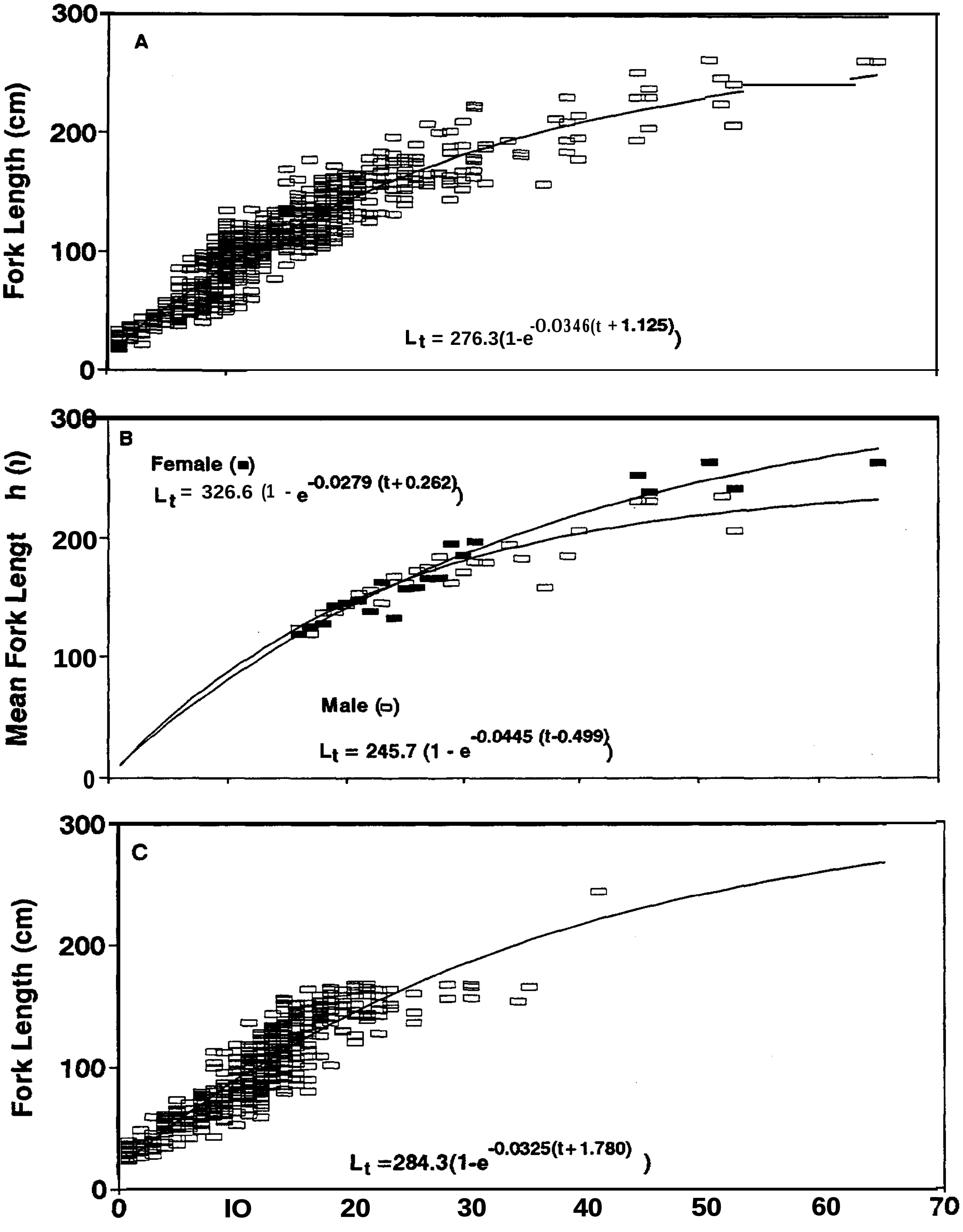

Figure 1. Lower Columbia River white sturgeon length at age data and von Bertalanffy growth functions for (A) 1987-1992 all samples, (B) 1987-1992 male and female mean length for ages ≥ 16, and (C) 1979-1983 all samples.

Table 1. Length at age data and parameter estimates for von Bertalanffy growth functions for lower Columbia River white sturgeon.

| Years | sex | n | Age Range (years) | FL Range (cm) | $L_\infty$ (cm) | K | $t_0$ (years) |
|---|---|---|---|---|---|---|---|
| 1987-1992 | All | 783 | 1 - 65 | 40 - 262 | 276.3 | 0.0346 | -1.125 |
| | All | 667 | 8 - 65 | 92 - 262 | 286.2 | 0.0315 | -1.944 |
| | Male | 251 | 8 - 53 | - 246 | 245.7 | 0.0445 | 0.499 |
| | Female | 179 | 9 - 65 | 100 - 262 | 326.6 | 0.0279 | -0.262 |
| 1979-1983 | All | 505 | 1 - 42 | 25 - 266 | 284.3 | 0.0325 | -1.780 |

Table 2. Likelihood ratio tests comparing von Bertalanffy parameters estimates for lower Columbia River white sturgeon length at age data.

| | $P(\chi^2 > \hat{\chi}^2)$ | | | |
|---|---|---|---|---|
| Hypothesis<br>Comparison | $L_{\infty 1} = L_{\infty 2}$ | $K_1 = K_2$ | $t_{01} = t_{02}$ | $L_{\infty 1} = L_{\infty 2}$<br>$K_1 = K_2$<br>$t_{01} = t_{02}$ |
| <u>1987-1992</u> | | | | |
| All vs. All age $\geq$ 8 | > 0.25 | > 0.25 | > 0.10 | > 0.50 |
| Male vs. Female | < 0.05 | > 0.25 | > 0.50 | < 0.025 |
| 1987-1992 vs. 1979-1983 | > 0.50 | > 0.50 | > 0.10 | > 0.05 |

Table 3. Paired t-test comparisons of mean length at age between lower Columbia River white sturgeon sampled from 1987-1992 and other populations of white sturgeon.

| Comparison | Ages Compared (Years) | Mean Difference in Length (cm) | $P(t > \hat{t})$ |
|---|---|---|---|
| Lower Columbia R. 1949-1953 | | 1.67 | 0.599 |
| Lower Columbia R. 1979-1983 | 1:; | 1.76 | 0.139 |
| Columbia R. Bonneville Pool[a] | 4-11 | -14.60 | 0.009 |
| Snake R. Hells Canyon[b] | 4-16 | -26.13 | 0.001 |
| Snake R. Hells Canyon[c] | 5-14 | -22.74 | 0.004 |
| Snake R. C.J. Strike Pool[d] | 4-11 | 9.02 | 0.002 |
| Fraser R.[e] | 8-16 | -12.28 | 0.008 |

[a] *Malm (1981).*

[b] *Coon et al. (1977).*

[c] *Lukens (1984).*

[d] *Lukens (1982).*

[e] *Semakula (1963).*

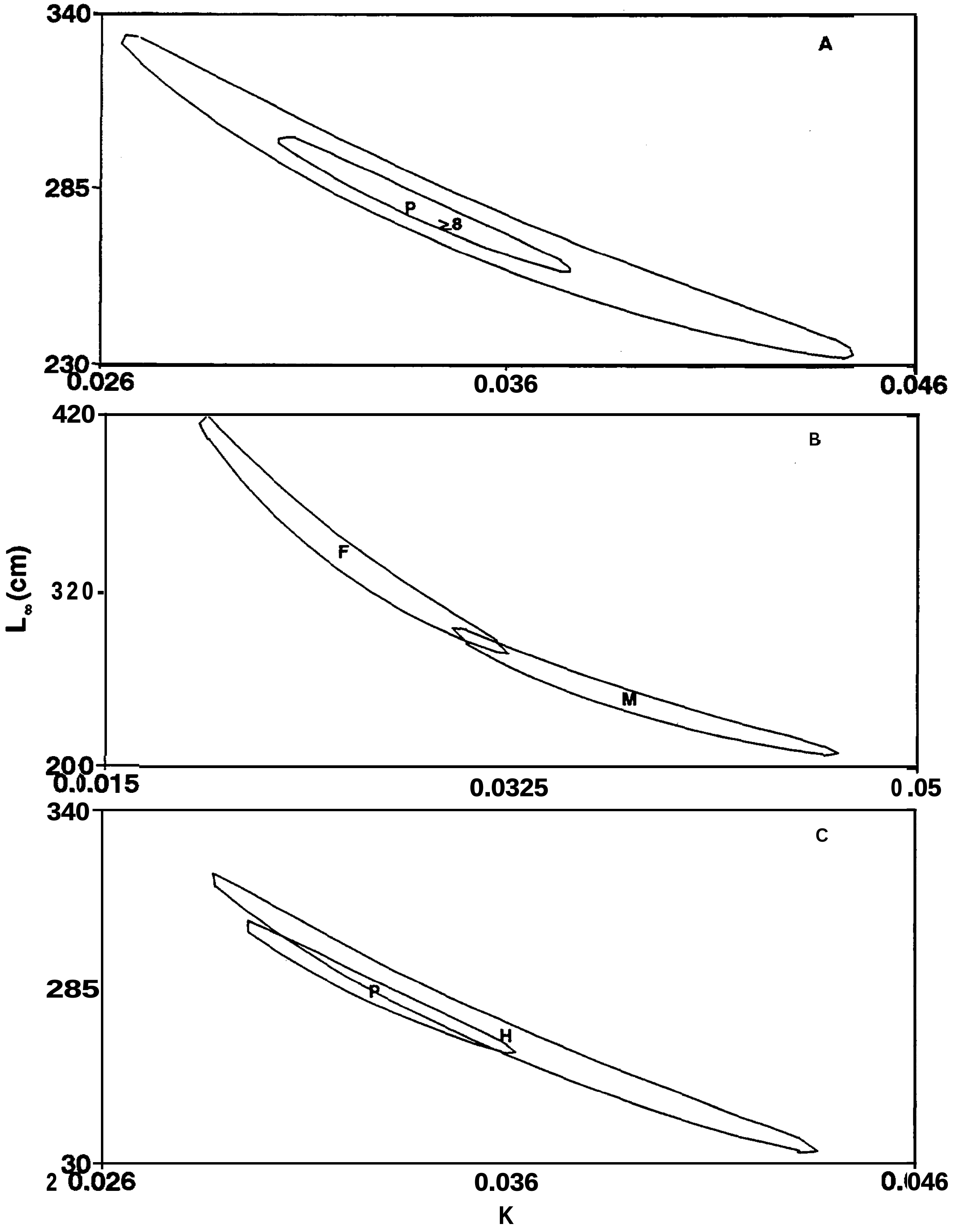

Figure 2. Bivariate 95% confidence regions for $L_\infty$ and K with $t_0$ fixed from lower Columbia River white sturgeon von Bertalanffy growth functions: (A) 1987-1992 all samples (P) vs. all samples ages ≥ 8, (B) 1987-1992 male vs. female ages ≥ 16, and (C) 1987-1992 all samples (P) vs. 1979-1983 all samples (H). Letters are centered on least squares estimates.

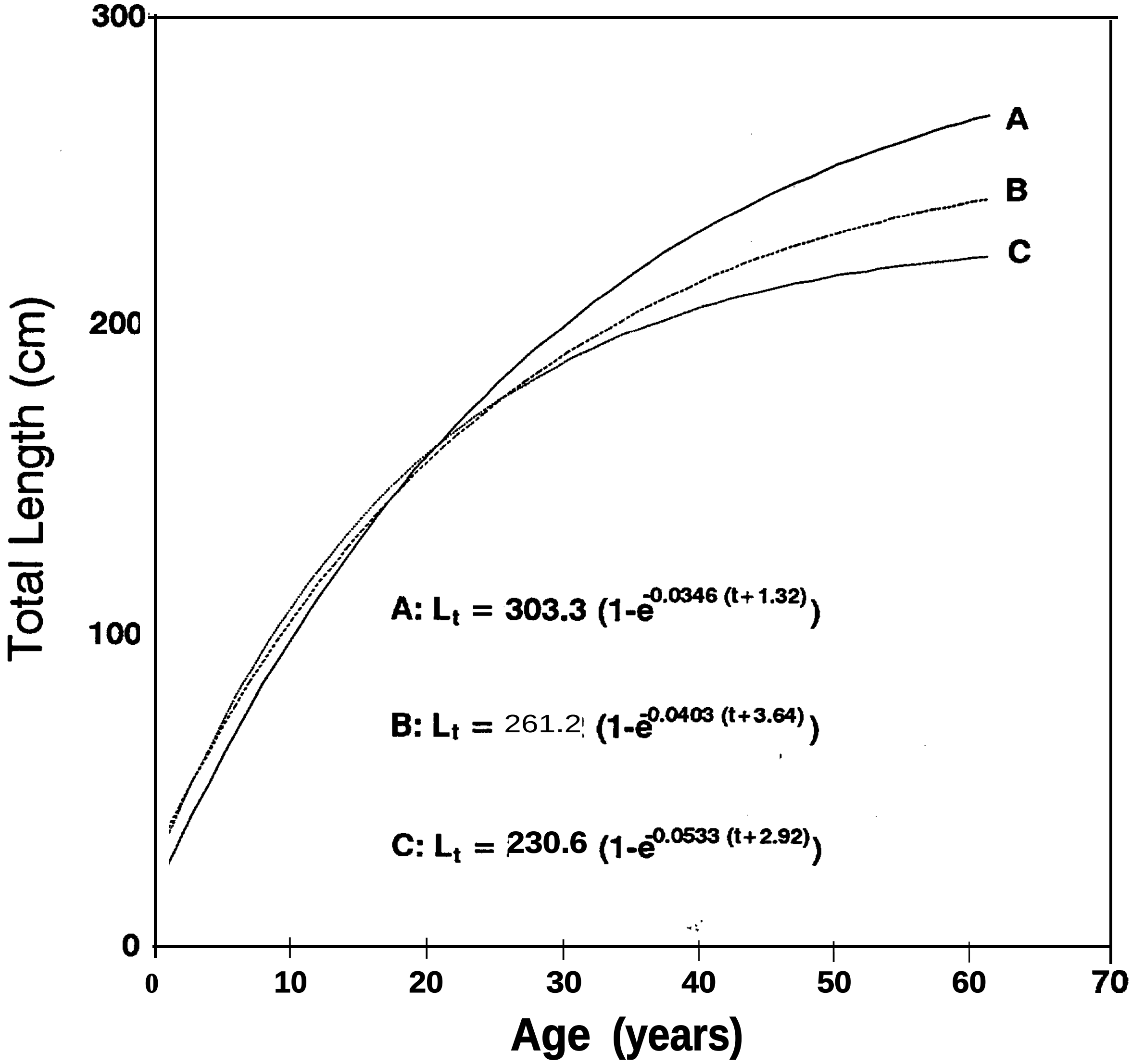

Figure 3. Von Bertalanffy growth functions for (A) 1987-1992 lower Columbia River (converted to total length), (B) 1973-1976 (Kohlhorst 1980) and (C) 1984-1985 (Brennan and Calliet 1989) Sacramento River system white sturgeon.

## Discussion

The age validation test indicated that LCR white sturgeon deposited a distinct annulus for each winter at large, much different from Rein and Beamesderfer (1992), who found detectable annuli were not deposited in 55% of samples from impounded Columbia River populations. Coon et al. (1977) also found that visible annuli were not deposited each year for Snake River sturgeon. However, Brennan and Calliet (1991) found that San Francisco Bay white sturgeon deposited distinct annuli each year. Both populations with annual deposition patterns had access to the marine environment whereas those that did not show annual patterns were impounded. This indicates that growth may be affected by restricting access to marine or anadromous food sources (DeVore et al. 1992). The difference in these results also illustrates the importance of validation studies when comparing growth relationships (Beamish and McFarlane 1983).

Inflection points in the growth of diadromous fish are commonly associated with changes in physiology, and expanded habitat and food resources accompanying utilization of the marine environment (Moore and Moore 1974; Moreau 1987). Dadswell (1979) observed an inflection point at age 9 for short nose sturgeon (Acipenser *brevirostrum)* from the Saint John River, Canada, which he associated with dietary changes. Although there was some evidence of an inflection point for LCR white sturgeon at age 8, it did not appear to affect the VBGF significantly. The difference in VBGFs between fish aged <8 years and those ≥8 years was not well represented, possibly because the LCR population was not at carrying capacity where habitat and food resources would limit growth. Rieman and Beamesderfer (1990) indicated that the LCR white sturgeon population was still increasing through 1985 and was possibly overexploited in the mid to late 1980s. It is also possible that an inflection point related to body size could be obscured because of the wide variation in length at age for white sturgeon. Body size is important to salinity tolerances in some salmonid species (Conte and Wagner 1965; Farmer et al. 1978; Wagner et al. 1969). We are unaware of any studies on age or size at which white sturgeon become capable of tolerating salt water, although McEnroe and Cech (1985) found significant differences in salinity tolerance of juvenile (<56 g) and adult white sturgeon.

Female white sturgeon appear to grow to a larger size than males (Bajkov 1949; Semakula 1963; Brennan and Calliet 1989), although linear regressions of LAA data by Semakula and Larkin (1968) and Kohlhorst et al. (1980) showed no significant differences in growth rates of male and female white sturgeon from the Sacramento and Fraser river systems, respectively. Brennan and Calliet (1989) calculated VBGFs with a higher $L_\infty$ value for female than for male white sturgeon from the Sacramento River system, but did not compare the estimates statistically. Dadswell et al. (1984) observed that female shortnose sturgeon grew slower but attained a larger ultimate length than males. All of the authors cited above calculated either point estimates of a larger ultimate size or a higher growth rate for female sturgeon, however, the difference detected in this investigation for LCR white sturgeon was the first reported in literature supported by a statistical analysis.

The LR tests between parameter estimates for the 1987-1992 samples and the 1979-1983 samples were not significantly different, although a real difference would be unlikely because of the close proximity in time of the collections. The average difference in collection time was about 8 years; less than one generation time for white sturgeon. Differences in growth functions would not have had time to manifest themselves in a representative sample of the population. However, differences in LAA for age 4-9 fish probably would be evident, but paired t-tests did not detect any significant differences between the 1949-1953 ($P > 0.599$) nor 1979-1983 ($P > 0.139$) collections and the 1987-1992 collection (Table 3). This indicates that growth rates of LCR white sturgeon have not changed much in the last 50 years. The consistent growth implies that environmental conditions that affect growth have changed little, or the positive and negative have been offset. For instance food sources such as lamprey may have decreased but shad runs have increased (WDF and ODFW 1992).

Von Bertalanffy growth function parameter estimates for the 1987-1992 LCR samples (converted to total length) were higher for $L_\infty$ and lower for K and $t_0$ than for Sacramento River white sturgeon (Brennan and Calliet 1989; Kohlhorst et al. 1980) (Figure 3). This indicates that LCR white sturgeon grow slower than Sacramento River white sturgeon early in life, but attain a larger ultimate length. The validation study conducted by Brennan and Calliet (1991) supports a direct comparison between their results and the results obtained in this study. The faster growth of Sacramento River fish may reflect the warmer environment of the more southerly population, a phenomenon common in fishes with distinct north-south populations (Jones 1976). Comparisons using paired t-tests of mean LAA with other Columbia (Malm 1981), Snake (Coon et al. 1977; Lukens 1982, 1984) and Fraser River (Semakula 1963) populations indicated that LCR white sturgeon were significantly larger ($P < 0.01$) for the ages tested except for one impounded population on the Snake River (Table 3). If the samples from populations with smaller mean LAA were underaged as suggested by Coon et al. 1977 and Rien and Beamesderfer 1992, the true mean LAA would be smaller, and the results of the t-test would be similar. If the samples from the Snake River population that had higher mean LAA were underaged, the difference may not have been significant.

Validated ageing criteria, consistent readers, and samples spanning more than 50 years contributed to a comprehensive analysis of LCR white sturgeon growth. The growth parameters were similar over the period studied and reflected growth that was as good or better than other white sturgeon population studied to date.

## Acknowledgments

We thank the National Marine Fisheries Service crew of the 'NERKA', the Oregon Department of Fish and Wildlife Columbia River Management and Washington Department of Fisheries Battle Ground staffs for their assistance in collecting samples, and the U.S. Fish and Wildlife Service Columbia River Field Station staff for cutting and mounting many of the fin sections. This work was funded through the Federal Aid to Fish Restoration, Dingell-Johnson project F-77-R.

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# REPORT L

# Age and Growth of Juvenile White Sturgeon in the Columbia River Downstream from Bonneville Dam

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## Abstract

Agreement in age estimates of juvenile white sturgeon *Acipenser transmontanus* using pectoral fin-ray sections was 64%. Juvenile white sturgeon length-at-age was significantly greater in three lower Columbia River impoundments (pools) than in the unimpounded Columbia River downstream from Bonneville Dam (lower river) through age-7, but no differences were evident among pools. Growth during the first year of life was greater in the pools than in the lower river. Condition factors of juvenile white sturgeon were significantly greater in each of the three pools than in the lower river, but there were no differences among pools. Greater length-at-age and better condition of juvenile white sturgeon from the three pools than from the lower river may have been due to food availability and density of white sturgeon. Loss of monel tags applied to pectoral fin-rays was 64% among white sturgeon at-large at least one winter.

## Introduction

Physical and biological changes to the lower Columbia River caused by construction and operation of dams may have affected growth and condition of white sturgeon *Acipenser transmontanus* inhabiting this reach. Since impoundment, the areas inundated by Bonneville, The Dalles, and John Day dams have become less riverine. Changes in substrate, water velocity, temperature, and depth, may affect the food supply and therefore the growth rates of white sturgeon. The Columbia River downstream from Bonneville Dam is free-flowing and white sturgeon growth in this reach is more likely to resemble pre-dam conditions than growth in the impounded reaches. The relative abundance of white sturgeon of all life stages is highest in the lower river followed by Bonneville, The Dalles, and John Day pools (Beamesderfer and Rien 1992; DeVore et al. 1992).

Estimating age of adult white sturgeon from pectoral fin-rays is neither precise nor accurate (Rien and Beamesderfer 1992), but estimating age for juveniles may be easier. Age estimates can be compared among populations if biases are assumed to be similar (Rien and Beamesderfer 1992). Oxytetracycline (OTC) has been used to validate ages assigned to white sturgeon using counts of periodic marks on pectoral fin-rays (Rien and beamesderfer 1992); however, few fish < age-4 were aged.

A suitable longterm tag is needed to evaluate movement and growth of individual white sturgeon. To be suitable, a tag must be identifiable, be retained, and not affect survival, behavior, or growth of the tagged fish (Wydoski and Emery 1983).

The Columbia River downstream from McNary Dam is divided into three impoundments (Bonneville, The Dalles, and John Day pools) and an unimpounded reach (lower river) from Bonneville Dam to the Pacific Ocean (Figure. 1). Substrates in the lower river and Bonneville Pool are predominantly sand; The Dalles and John Day pools have more diverse substrates, ranging from mud to bedrock (Parsley et al. 1992). Water temperatures do not differ significantly among areas. McCabe and Hinton (1991) and Parsley et al. (1992) provide additional information about the study area.

In this paper we compare juvenile white sturgeon length-at-age and condition factors among four areas: the three lower Columbia River impoundments and the unimpounded lower river. We compare precision and accuracy of age estimates for juvenile white sturgeon to precision and accuracy for adult white sturgeon. We evaluate movement of recaptured fish, retention of Monel bands, and the effects of tagging on growth. We also compare length of young-of-the-year (YOY) white sturgeon in Bonneville Pool to length of those in the lower river. Juvenile refers to white sturgeon from ages 1-8, YOY refers to age-0 fish.

## Methods

Juvenile white sturgeon *were* collected with high-rise and beam trawls (McCabe and McConnell 1988; Palmer et al. 1988; Parsley et al.

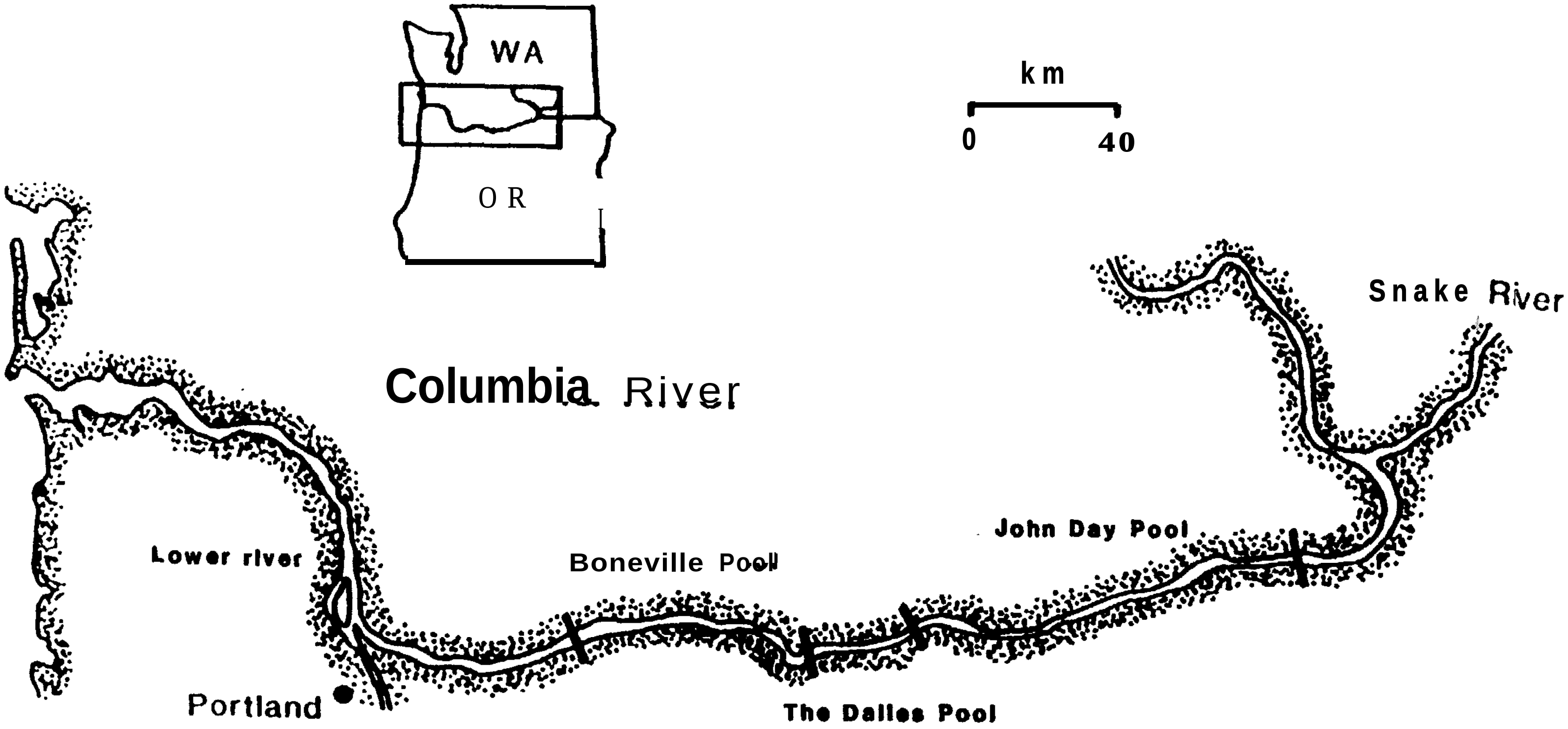

Figure 1. Location of the three furthest downstream impoundments of the Columbia River and the unimpounded lower river.

1989) from April through September from 1987-1991. We collected YOY from June or July through September or November.

One tag and three marks were used on captured juvenile white sturgeon. A individually numbered Monel band was applied to the right pectoral fin by clamping it around the anterior ray with a pliers constructed for that purpose. A 6-mm hole was punched in the right pelvic fin as a secondary mark to evaluate tag retention. We injected most white sturgeon <800 mm fork length (FL) with 25 mg OTC per kg of, body weight (McFarlane and Beamish 1987) to validate the aging technique and as an antibiotic to reduce infection related to handling. To identify the year of injection for recaptured fish, a combination of lateral scutes unique to each year was removed.

Age was estimated from cross sections of the leading pectoral fin-ray (Brennan and Cailliet 1989). A segment of the leading pectoral fin-ray was removed by making two cuts through the ray with wire cutters; the first less than 5 mm from the knuckle, the second about 15 mm distal from the first. Fin-ray segments were removed by grasping the segment with pliers and twisting. The entire leading fin-ray of YOY was removed by making the first cut and twisting it free. Fin-rays were air-dried, and 3 to 6 transverse sections were cut (0.3 to 0.7-mm thick) from the proximal end of the ray with a Dremel Tool[1] fitted with a 0.127-mm thick saw blade. Sections were washed in tap water and mounted on microscope slides with clear fingernail polish.

Fin-ray sections were viewed with a dissecting microscope with 1.5x to 4x magnification and transmitted light. Some obscure sections were cleared with ethyl alcohol or xylene. Translucent rings were considered annuli (Chilton and Beamish 1982). Some rings split into multiple rings in the lobes of fin-ray sections, a pattern referred to as banding by Rien and Beamesderfer (1992). Each continuous ring was counted as an annulus. If an opaque ring was observed beyond the final counted ring, and the sample was collected prior to the period of annulus formation, it was grouped with fish from the next older cohort. Annulus formation in Columbia River white sturgeon is usually complete by July (Rien and Beamesderfer 1992).

Ages were assigned independently by two or three experienced readers. Precision of estimates was determined by calculating percent agreement between ages for two readers. Accuracy of age estimates was assessed by comparing the number of annuli deposited after an OTC mark to the number of annulus formation periods that elapsed between OTC injection and recapture.

Condition factors of juvenile white sturgeon were calculated using the formula $C=(W/L^3)*10^5$ (Ricker 1975). Growth in each pool and the lower river was compared by plotting mean fork length-at-age. Mean condition factor and length-at-age in each area were compared using general linear model analysis of variance ($P \leq 0.05$) which is preferable to standard

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[1] Use of trade names does not imply endorsement by U.S. Fish and Wildlife Service.

analysis of variance for unbalanced designs (SAS Institute 1988). A Tukey multiple comparison test was used to detect significant differences in length-at-age and condition factor between areas (SAS Institute 1988). Movement of white sturgeon and the effects of tagging on growth were assessed by comparing capture location, FL, and weight of fish on the date of tagging to those values on the date of recapture.

## Results

We estimated ages for 1,861 white sturgeon ranging from age-1 to age-8 (Table 1). Precision was 64% among areas and was lowest for white sturgeon from John Day Pool (Table 1).

Mean lengths of white sturgeon ages 1-7 were significantly greater in the three pools than in the lower river (Table 2); length of age-8 white sturgeon was not significantly different among areas, however sample size was small (Appendix 1). Mean lengths of juvenile white sturgeon were not significantly different among the three pools except between age-1 white sturgeon in Bonneville and The Dalles pools and age-6 white sturgeon in Bonneville and The Dalles pools, and age-6 fish in Bonneville and John Day pools; Overall, mean lengths of white sturgeon ages 1-7 were greatest in The Dalles and John Day pools followed by Bonneville Pool and the lower river (Figure 2). Length-at-age of YOY was greater in the lower river than in the three pools until October or November of each year, however, sample sizes were to small for statistical tests.

Mean condition factors of white sturgeon ages 1-8 were highest for Bonneville and The Dalles pools and lowest for the lower river (Table 3). Mean condition factor was significantly lower for white sturgeon from the lower river than from each of the three pools; mean condition factors among the pools were not significantly different. Condition factors were more variable among white sturgeon from Bonneville and The Dalles pools than from John Day Pool or the lower river (Table 3).

We released 2,784 Monel tagged white sturgeon in the three pools and 60 (2.1%) were recaptured. We determined the number of winters at-large for 55 of the 60 recaptured white sturgeon; 35 (64%) shed their Monel tag before recapture. We were unable to evaluate aging accuracy using OTC injected fish because only one recaptured white sturgeon retained its tag and had a visible OTC mark.

Twenty white sturgeon, at-large an average of 183 days, increased in length an average of 21 mm (range: 0 to 148 mm); weight increased an average of 99 g (range: -170 to 725 g). Three of those fish decreased in weight and did not increase in length. Fifteen white sturgeon were recaptured in the location of initial capture, four were recaptured from 0.5 to 7.7 km upstream, and one was recaptured 16.1 km downstream.

## Discussion

Percent agreement in age estimates in this study was greater than reported for aging of white sturgeon in other studies. Rien and

Table 1. Percent agreement in age estimates assigned by two readers for white sturgeon collected in the unimpounded lower Columbia River and three Columbia River pools. Dashes indicate years when ages were not estimated.

| | **Percent agreement**[a] | | | | | |
|---|---|---|---|---|---|---|
| Area | 1987 | 1988 | 1989 | 1990 | 1991 | All years |
| **Lower river** | -- | 79<br>(185) | 55<br>(159) | 67<br>(72) | 49<br>(118) | 64<br>(534) |
| **Bonneville Pool** | -- | 73<br>(310) | 62<br>(114) | 32<br>(84) | 60<br>(227) | 63<br>(735) |
| **The Dalles Pool** | 54<br>(84) | 74<br>(298) | 69<br>(114) | -- | 58<br>(36) | 69<br>(532) |
| **John Day Pool** | -- | -- | 51<br>(58) | -- | 0<br>(2) | 50<br>(60) |
| **Combined areas** | | | | | | 64<br>(1861) |

[a] Number aged is in parentheses.

Table 2. Comparisons of mean lengths-at-age for juvenile white sturgeon from the unimpounded lower Columbia River (L), and Bonneville (B), The Dalles (D), and John Day (J) pools using the Tukey multiple comparison test applied to general linear model analysis of variance (SAS institute 1988). NS=no significant difference S = significant difference, $P \leq 0.05$).

| | Lower Columbia river X pool comparisons | | | Among pool comparisons | | |
|---|---|---|---|---|---|---|
| Age | L-B | L-D | L-J' | B-D | B-J[a] | D-J[a] |
| 1 | S | S | | S | - | - |
| 2 | S | S | - | NS | | - |
| 3 | S | S | S | NS | NS | NS |
| 4 | S | S | S | NS | NS | NS |
| 5 | S | S | S | NS | NS | NS |
| 6 | S | S | S | S | S | NS |
| 7 | S | S | S | NS | NS | NS |
| 8 | NS | NS | NS | NS | NS | NS |

[a] No 1 or 2 year old white sturgeon were captured in John Day Pool.

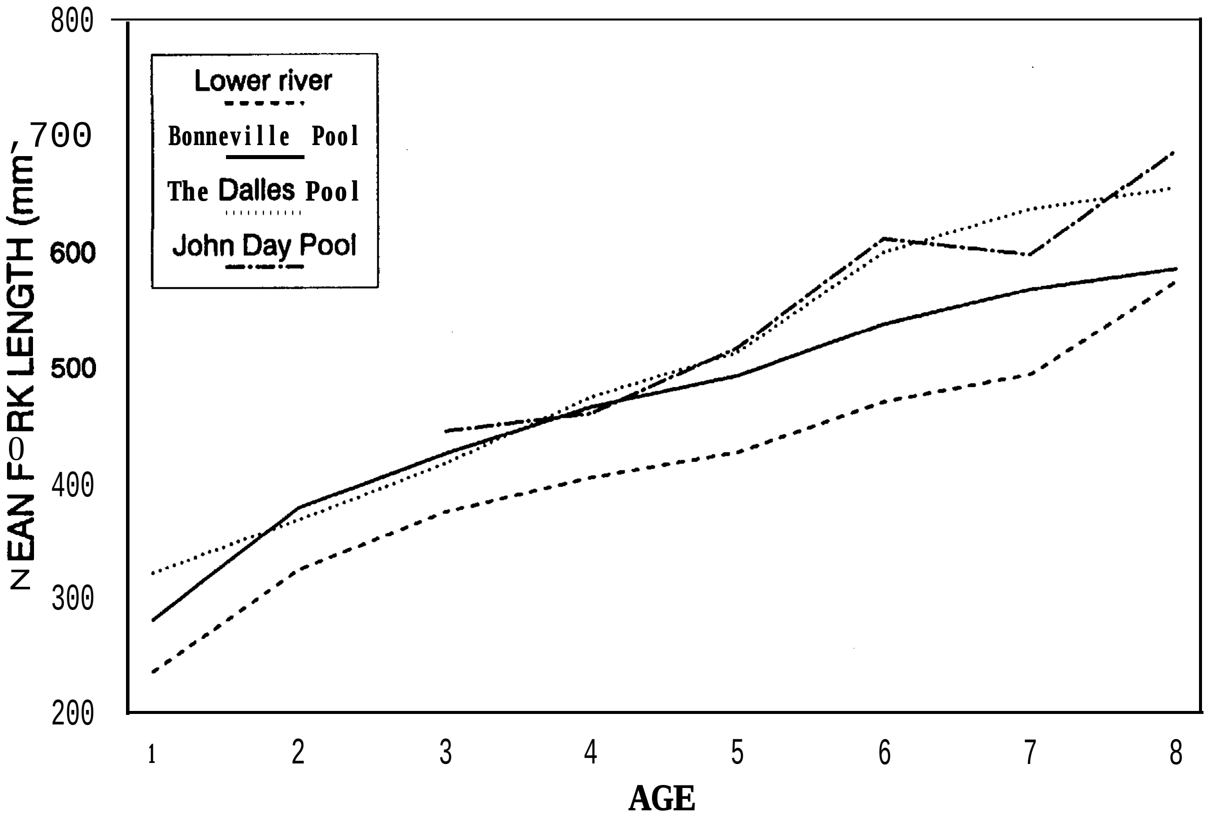

Figure 2. Mean fork length of 1 to 8 year old white sturgeon collected in the unimpounded lower Columbia River and three lower Columbia River pools, 1987-1991.

Table 3. Condition factor for white sturgeon collected in the unimpounded lower Columbia River and three lower Columbia River pools, 1987-1991.

| Area | N | Condition factor[a] Range | Condition factor[a] Mean | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|
| Lower River | 6460 | 0.41-1.19 | 0.66 | 0.066 | 9.97 |
| Bonneville Pool | 2132 | 0.36-1.04 | 0.71 | 0.072 | 10.09 |
| The Dalles Pool | 1247 | 0.44-1.07 | 0.71 | 0.074 | 10.43 |
| John Day Pool | 73 | 0.54-0.82 | 0.70 | 0.054 | 7.76 |

[a] $C=(W/L^3)*10^5$

Beamesderfer (1992), Brennan and Cailliet (1987)) and Kohlhorst et al. (1980) reported agreement from 17-37%; however, those studies included fish older than in this study. Percent agreement was lower in John Day pool because only age 3-8 white sturgeon were collected; agreement is inversely related to age (Rien and Beamesderfer 1992).

Although too few OTC injected white sturgeon were recaptured to evaluate aging accuracy, inferences can be made from other studies that used OTC to validate ages estimated for white sturgeon using pectoral fin-ray sections. Rien and Beamesderfer (1992) reported that accuracy in aging white sturgeon 300, 400, and 500 mm FL captured in the three pools was 100, 85, and 70%, and aging accuracy for 600 to 800 mm FL fish ranged from 42-553. Many fish injected with OTC failed to from annuli in some years after injection. DeVore et al. (1992) used OTC and reported that estimated ages of white sturgeon from the lower river using pectoral fin-rays were valid through age 14. Annulus formation may be more consistent, and thus accuracy of age estimates greater, in the lower river than in the pools.

Faster growth of white sturgeon from the pools than from the lower river may be due to increased food abundance in the pools. Sprague and Beckman (1992) reported that 20 to 591 mm FL white sturgeon in the three impoundments fed almost exclusively on amphipods of the genus Corophium. Muir et al. (1988) and McCabe et al. (1992) reported that *Corophium* was the dominant food item of white sturgeon <800 mm FL in the lower river. Total benthic invertebrate densities in The Dalles pool in May and September (Sprague and Beckman 1992) were higher than in April and May in the *lower* river (McCabe et al. 1992). It is unknown if *Corophium* densities are greater in the pools than in the lower river; McCabe et al. (1992) and Sprague and Beckman (1992) recommended further investigation.

Density of juvenile white sturgeon may also affect food abundance which may affect length-at-age and condition; density was greater in the lower river than in the three pools. Beamesderfer and Rien (1992) reported that greater numbers of recruits in Bonneville Pool than in The Dalles or John Day pools caused increased densities of white sturgeon in Bonneville Pool, and average size, growth rate, and condition factor were lower than in the other two pools. We found length-at-age to be less in Bonneville Pool than the other pools but condition factor was not.

Spawning occurred up to several weeks earlier in the lower river than in the pools from 1987 through 1991 (Anders and Beckman 1992), thus YOY collected from the lower river during the summer and early fall were generally longer than YOY from the pools. However, because growth of YOY in the pools was faster than growth of YOY in the lower river, no differences in length were evident by October or November.

White sturgeon from the pools were larger than white sturgeon from the lower river until about age-8. This finding is consistent with Tracy and Wall (1992) who reported an inflection point occurred at age-8 in the length-at-age relationship of white sturgeon from the lower river. This may be due to increased availability of food for older white sturgeon from the estuary, such as eulachon Thaleicthys *pacificus*, longfin smelt *Spirinchus thaleicthys*, and northern anchovy *Engraulis mordax*.

We don't recommend tagging white sturgeon with Monel tags because of low tag retention rates. White sturgeon which were injected with OTC, tagged with a Monel band, pelvic fin punched, and had two scutes removed, increased in length and weight while at-large, suggesting that these techniques were not detrimental. However, several of those fish lost weight and remained the same length while at-large. Juvenile white sturgeon were usually recaptured at the initial capture location, suggesting that movement is somewhat limited. We recommend that OTC only be injected into white sturgeon before or after the period of annulus formation but not both, so that ages can be validated for fish that have an annular mark (scute removal) even if they shed their tag. Use of OTC prior to May or after August would be best for juvenile white sturgeon in the Columbia River.

Impoundment appears to have led to faster growth of juvenile white sturgeon through age-7. Growth of age-8 fish was similar between areas, supporting the findings of DeVore et al. (1992) who reported that growth of adult white sturgeon is faster in the lower river than in the pools.

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Appendix 1. Length-at-age for white sturgeon collected in the unimpounded lower Columbia River and three lower Columbia River pools, 1987-1991. No 1 or 2 year old fish were captured in John Day Pool.

| Area | Age | N | Range | Mean | SD |
|---|---|---|---|---|---|
| | | | Fork length (mm) | | |
| Lower River | 1 | 46 | 157-363 | 236 | 41.46 |
| | 2 | 112 | 252-404 | 324 | 25.47 |
| | 3 | 76 | 294-469 | 375 | 33.25 |
| | 4 | 54 | 320-551 | 404 | 43.67 |
| | 5 | 63 | 327-581 | 425 | 52.68 |
| | 6 | 50 | 358-695 | 468 | 59.79 |
| | 7 | 30 | 382-704 | 491 | 72.06 |
| | 8 | 37 | 394-776 | 570 | 86.75 |
| Bonneville Pool | 1 | 55 | 199-372 | 281 | 39.36 |
| | 2 | 90 | 206-475 | 379 | 40.65 |
| | 3 | 85 | 337-543 | 425 | 45.17 |
| | 4 | 78 | 362-554 | 465 | 44.07 |
| | 5 | 76 | 355-604 | 490 | 62.95 |
| | 6 | 53 | 398-714 | 535 | 73.43 |
| | 7 | 28 | 397-745 | 564 | 87.59 |
| | 8 | 12 | 465-690 | 581 | 84.40 |
| The Dalles Pool | 1 | 24 | 245-424 | 322 | 50.25 |
| | 2 | 118 | 283-488 | 368 | 42.74 |
| | 3 | 96 | 320-580 | 416 | 54.45 |
| | 4 | 79 | 330-621 | 473 | 64.57 |
| | 5 | 67 | 325-685 | 511 | 70.76 |
| | 6 | 15 | 471-785 | 596 | 91.52 |
| | 7 | 5 | 578-780 | 634 | 85.00 |
| | 8 | 3 | 549-798 | 651 | 130.29 |
| John Day Pool | 3 | 6 | 421-462 | 445 | 15.94 |
| | 4 | 18 | 317-600 | 458 | 68.19 |
| | 5 | 18 | 360-635 | 515 | 70.60 |
| | 6 | 7 | 527-721 | 609 | 60.56 |
| | 7 | 7 | 429-700 | 594 | 90.75 |
| | 8 | 1 | 684-684 | 684 | -- |

## REPORT M

# A Standard Weight (Ws) Equation for White Sturgeon

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The relative weight index ($W_r$) allows easy interpretation of fish condition, eliminating problems with length, population, and species dependence of more traditional assessments such as Fulton or Le Cren condition factors (Murphy et al. 1990, Murphy et al. 1991, Willis et al. 1991). Relative weight values are obtained by dividing the actual weight of a fish by a standard weight ($W_s$) for fish of that length and then multiplying by 100 (Wege and Anderson 1978). This index thus requires a standard weight equation for the fish species of interest. This paper describes a standard weight equation for white sturgeon (Acipenser transmontanus), a valuable fish in sport and commercial fisheries, and in commercial hatcheries along the Pacific coast of North America.

Weight-length equations were compiled from the literature for 15 white sturgeon samples collected from locations representative of the geographical range of the species (Figure 1, Table 1). Equations were standardized algebraically to the form

$$W = \alpha L^{\beta}$$

where W = weight in kg and L = total length in cm. Fork lengths were converted to total lengths using a factor of 1.110. This conversion factor was derived from a linear regression of paired total length and fork length data (N = 1,750) calculated for fork lengths from 1 cm to 250 cm in l-cm intervals using each of seven conversion equations from various white sturgeon samples (Table 2). Fits of conversion equations of forms with ($b_0$ = 2.216, $b_1$ = 1.096) and without ($b_0$ = 0, bl = 1.110) the intercept parameter normally used were similar (r = 0.998), however, omitting the intercept parameter simplified algebraic solution for equations based on total length.

The standard weight-length relationship for white sturgeon (Table 3) was calculated from literature weight-length functions with the regression-line-percentile technique (RLP) recommended as the standard by Murphy et al. (1991). The 15 weight-length functions in Table 1 were used to calculate mean weights for each l-cm total length from 1 cm to 250 cm. The 75 percentile weights for each l-cm interval in this statistical population (N = 3,750) were then regressed on length to develop the proposed standard weight equation. The standard weight function thus represents the condition that could be expected in a better than average white sturgeon population, which might represent a typical management goal (Murphy et al. 1991). All statistical analyses were performed with the Statistical Analysis System (SAS) for personal computers (SAS Institute 1988). Equivalent equations for English units and fork lengths were calculated algebraically from the standard metric equation based on total length (Table 3).

Weight-length parameters for the 15 samples were generally based on a broad range of fish sizes from minimum total lengths of 30-50 cm to maximum lengths exceeding 200 cm (Table 1). Murphy et al. (1990, 1991) recommended a comparison of the ratio of variance to mean $\log_{10}$weight for fish among l-cm length intervals be used to specify minimum applicable weights. This comparison was made for 6,279 white sturgeon collected from Bonneville, The Dalles, and John Day reservoirs in the

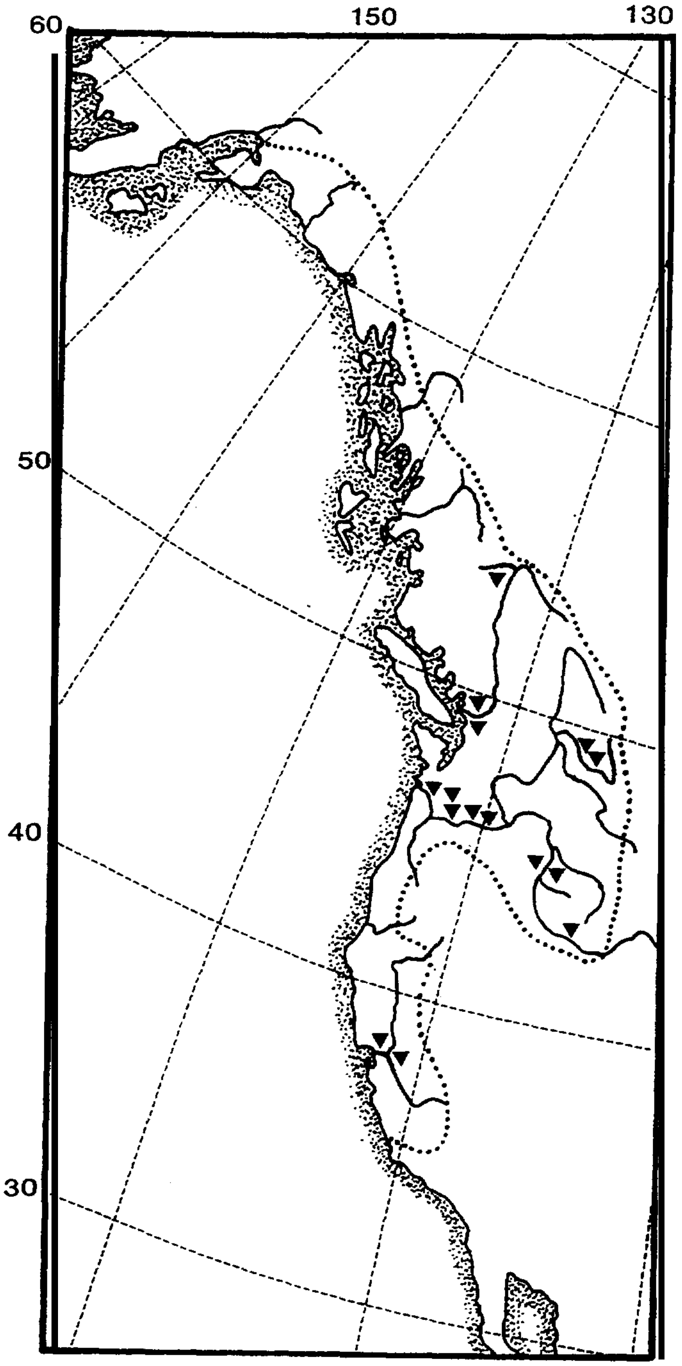

Figure 1. Geographical distribution of samples (denoted by triangles) of weight-length data used for estimation of a standard weight equation for white sturgeon. The range of white sturgeon (Scott and Crossman 1973) is circumscribed with a dotted line.

Table 1. Intercept ($\alpha$), slope ($\beta$), and correlation coefficient for regression[a] of weight (kg, dependent variable) on total length (cm) and mean relative weights ($W_r$) for 15 white sturgeon samples.

| River | N | Lengths | a! | $\beta$ | r | $W_r$ | Reference |
|---|---|---|---|---|---|---|---|
| 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. (1988-90) | 2.405 | 31-292 | 2.65E-06 | 3.161 | 0.979 | 99 | Author, unpublished |
| The Dalles Res. | 21850 | 35-276 | 9.70E-07 | 3.376 | 0.984 | 96 | Author, unpublished |
| John Day Res. | 1,024 | 32-254 | 1.81E-06 | 3.249 | 0.991 | 100 | Author, unpublished |
| Kootenai River | | | | | | | |
| (1980-82) | 341 | 50-224 | 1.66E-06 | 3.26 | 0.990 | 97 | Partridge 1983 |
| (1989-91) | 223 | 88-211 | 7.13E-07 | 3.394 | 0.917 | 77 | Apperson, unpublished |
| Snake River | | | | | | | |
| Upper | 560 | 46-270 | 3.0 E-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 |
| Fraser 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 |

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[a] $W = \alpha * TL^{\beta}$

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

Table 2. Fork length to total length (cm) conversion equations[a] reported for several populations of white sturgeon.

| Location | n | $b_0$ | $b_1$ | r | Reference |
|---|---|---|---|---|---|
| Sacramento-San Joaquin Delta | 366 | 1.343 | 1.093 | 0.960 | Kohlhorst 1980 |
| Columbia River (lower)[b] | 2,039 | 2.06 | 1.09 | 0.997 | Tracy, unpublished |
| Columbia River (middle)[c] | 3,612 | 1.240 | 1.095 | 0.986 | Author, unpublished |
| Columbia River (middle)[d] | 2,516 | 5.06 | 1.08 | -- | Malm 1979 |
| Fraser River | 14 | 4.91 | 1.088 | 0.999 | Dixon 1986 |
| Kootenai River | 341 | 0.77 | 1.104 | -- | Partridge 1983 |
| Kootenai River | 223 | 0.13 | 1.124 | 0.992 | Apperson, unpublished |

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[a] TL = bn t bl * FL.

[b] Downstream from Bonneville Dam.

[c] Bonneville, The Dalles, and John Day Reservoirs.

[d] Bonneville Reservoir.

Table 3. Standard weight-length equations[a] for white sturgeon in metric and English units for total length and fork length measurements.

| Length measurement | Length units | Weight units | α | β |
|---|---|---|---|---|
| Total | centimeters | kilograms | 1.952E-6 | 3.232 |
| Total | inches | pounds | 8.747E-5 | 3.232 |
| Fork | centimeters | kilograms | 2.735E-6 | 3.232 |
| Fork | inches | pounds | 1.226E-4 | 3.232 |

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[a] $W = \alpha * L^{\beta}$

Columbia River using techniques outlined by Elliott and Beamesderfer (1990). This comparison indicated that restricting analyses to lengths of 60 cm or more will minimize effects of errors in weighing small fish and of developmental changes in body form from juveniles to adults.

Mean relative weights for the 15 samples varied from 77 to 117 (Table 1). Samples with the lowest mean relative weights were all from isolated portions of the Columbia and Fraser River systems, which often support unproductive white sturgeon populations (Cochnauer et al. 1985). The Kootenai River population, which is declining and in danger of extinction, had the lowest observed mean relative weight. White sturgeon with access to marine and estuarine resources in the lower Columbia River had the largest mean relative weight. Patterns suggest that more detailed comparisons including size-specific differences in relative weight among populations may provide insight into factors affecting white sturgeon abundance and productivity.

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# Feeding and Food

# REPORT N

# Prey Selection by Juvenile White Sturgeon in Reservoirs of the Columbia River

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## Abstract

The primary prey of white sturgeon Acipenser transmontanus in Bonneville and The Dalles pools of the Columbia River from 1987-1991 was the tube-dwelling amphipod *Corophium (C. sa7monis* and *C. spinicorne)*. Bottom trawls were used to capture subyearling, yearling, and older juvenile white sturgeon from 20 mm total length to 591 mm fork length. Stomachs from 149 subyearlings and 22 yearlings were dissected and contents were analyzed. Non-lethal techniques to remove stomach contents from juvenile white sturgeon proved ineffective. Diet composition was less diverse in subyearling and yearling fish than among older juveniles. Other temporally minor prey organisms included *Neomysis mercedis*, *Corbicula spp.*, and Chironomidae larvae.

## Introduction

The white sturgeon *Acipenser transmontanus* is the largest freshwater fish species in North America. This species is long-lived and may exceed 100 years of age. White sturgeon are known to occur in marine and fresh waters of large rivers along the Pacific coast from Monterey, California, to Cook Inlet, Alaska (Wydoski and Whitney, 1979). White sturgeon are also found in the Pacific Ocean and may ascend rivers to spawn, but the species is not truly anadromous (Haynes and Gray, 1981). They historically occurred throughout the Columbia River drainage ranging upstream into the Kootenai River in Idaho, Montana, and British Columbia, Canada, and also in Snake River drainages upstream to Shoshone Falls. Populations in the Columbia River drainage are essentially landlocked due to dam construction (Cochnauer et al. 1985), although some passage occurs through fishways (Warren and Beckman 1992).

Diets of white sturgeon in riverine environments have been described, but not the diets of white sturgeon in reservoirs. Schreiber (1962) and Radtke (1966) described the diets of subyearling and yearling' white sturgeon in the Sacramento-San Joaquin River system in California. Muir et al. (1988) and McCabe et al. (1992) described diets of juvenile white sturgeon in the Columbia River downstream from Bonneville Dam to the estuary. The objective of this study was to describe prey selection by three age-classes of white sturgeon: subyearling (Age 0) including larvae and young-of-the-year (YOY), yearling (Age l), and juvenile (Age 2-7), in two Columbia River impoundments. We also compared invertebrate prey occurrence in the diet of white sturgeon to benthic invertebrate availability in The Dalles Pool.

The study area included Bonneville Pool and The Dalles Pool, the two furthest downstream reservoirs of the Columbia River. Bonneville Pool, Rm 145-192 (Rkm 234-309), has an mean depth of 6.7 m; The Dalles Pool, Rm 192-216 (Rkm 309-348), has an mean depth of 7.5 m. More detailed descriptions of these pools are provided by Parsley and Beckman (1992).

## Methods

White sturgeon were collected during 1987-1991 with a 2.7x0.5 m beam trawl fished stationarily on the substrate for 30 minutes per set, and with a 4.4 m wide high-rise shrimp trawl towed along the substrate for 10 minutes per tow. Both nets utilized a 1.59 mm knotless cod-end liner. Up to ten white sturgeon from each age-class were retained at each site for stomach content analysis. Subyearling white sturgeon shorter than 25 mm are designated larvae and those 25 mm or longer are YOY. White sturgeon ages were estimated using pectoral fin ray cross-sections (Pycha, 1955).

Three techniques were used in the field to obtain stomach contents from white sturgeon. In 1989-1991, subyearling and yearling white sturgeon were sacrificed and preserved whole in 10% buffered formalin tinted with phyloxin B to enhance contrast of invertebrates in stomach content samples. The abdomen walls were slit to allow formalin to enter the body cavity. In 1987, a stomach pump was used to force water into juvenile white sturgeon stomachs to flush out the contents. In 1988 and 1989, hydrogen peroxide was used as an emetic to cause regurgitation of stomach contents from juveniles. Prey items were preserved with 70% ethanol in specimen cups. Some juveniles were sacrificed and the digestive tracts were removed and examined for degree of regurgitation. All other juvenile white sturgeon sampled with emetics and stomach pumps were released unharmed.

In the lab, the stomachs of sacrificed white sturgeon were excised anterior to the pyloric sphincter. Only material from the esophagus and stomach was examined. Stomach contents were rinsed in water, sorted, counted and weighed to the nearest 0.001 g.

Prey items from subyearling and yearling white sturgeon were quantified. Percent occurrence, range and mean number of organisms per stomach, percent weight, and relative abundance of food items were calculated for each taxa. Juvenile white sturgeon stomach contents were not quantified.

Benthic invertebrates were sampled at seven sites in The Dalles Pool on 2 May and 2 September 1988 with a 0.1-$m^2$ Van Veen dredge. Organisms were identified to species when possible. When a sample was too large to sort efficiently, a subsampler was used to divide the sample into ten subsamples (Waters, 1969). Three random subsamples were then processed and total invertebrate numbers were estimated for the entire sample. The first four digits of the site location number (Figures 1 and 2) refer to river mile in tenths. The last digit refers to river cross-sectional position: 1 thru 4 refer to main channel quarter from the Washington to Oregon shore, and zero and 5 refer to backwaters on the Washington and Oregon shores.

## Results

### Stomach Contents Analysis

Stomach contents were obtained from two hundred twenty-eight white sturgeon. Of these, one hundred seventy-one stomachs were dissected. The predominant prey item in stomachs of all age-classes from both pools was the amphipod *Corophium spp. (C. salmonis* and *C. spinecome)* (Tables 1 and 2). All but one stomach from a larval white sturgeon contained food items.

In 1989-1991, stomach contents were dissected from 149 subyearling white sturgeon from 20-267 mm total length (TL). Subyearlings consumed primarily *Corophium spp.* and also fed on *Neomysis mercedis*, Ramellogammarus *spp.*, Corbicula *spp.*, Chironomidae larvae, and other organisms in lower numbers (Table 1). Very small *Corbicula spp.* with shells intact were found in a few stomachs. Some subyearling white sturgeon less than 25 mm TL (larvae) began feeding about two weeks after hatching. The four smallest white sturgeon sampled were larvae collected from Bonneville Pool in 1991 which had recently absorbed their yolk sacs. One larva (22 mm TL) still contained a melanin plug in the spiral intestine and no food items were found; the three other larvae

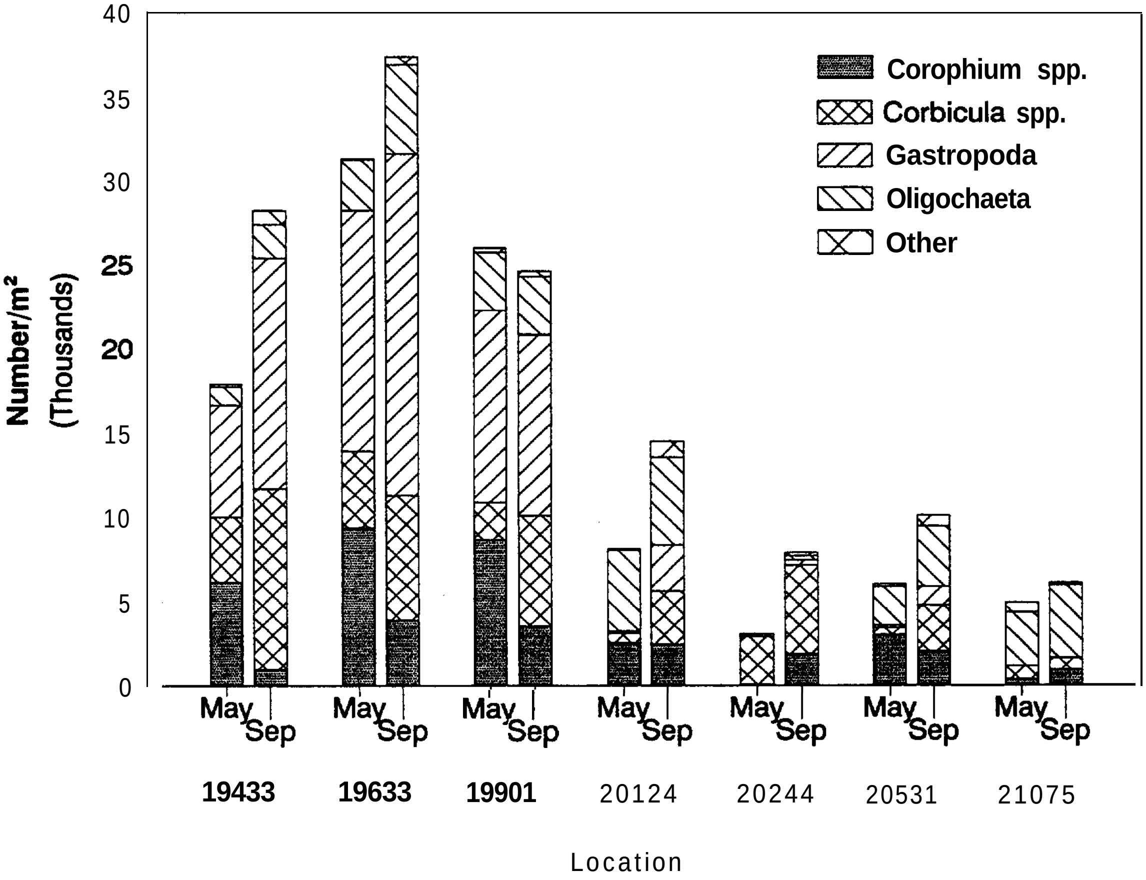

Figure 1. Estimated density of invertebrates by class or genus per $m^2$ at seven trawling locations in The Dalles Pool during May and September, 1988. "Other" category includes Nemertea, Insecta, and Chironomidae.

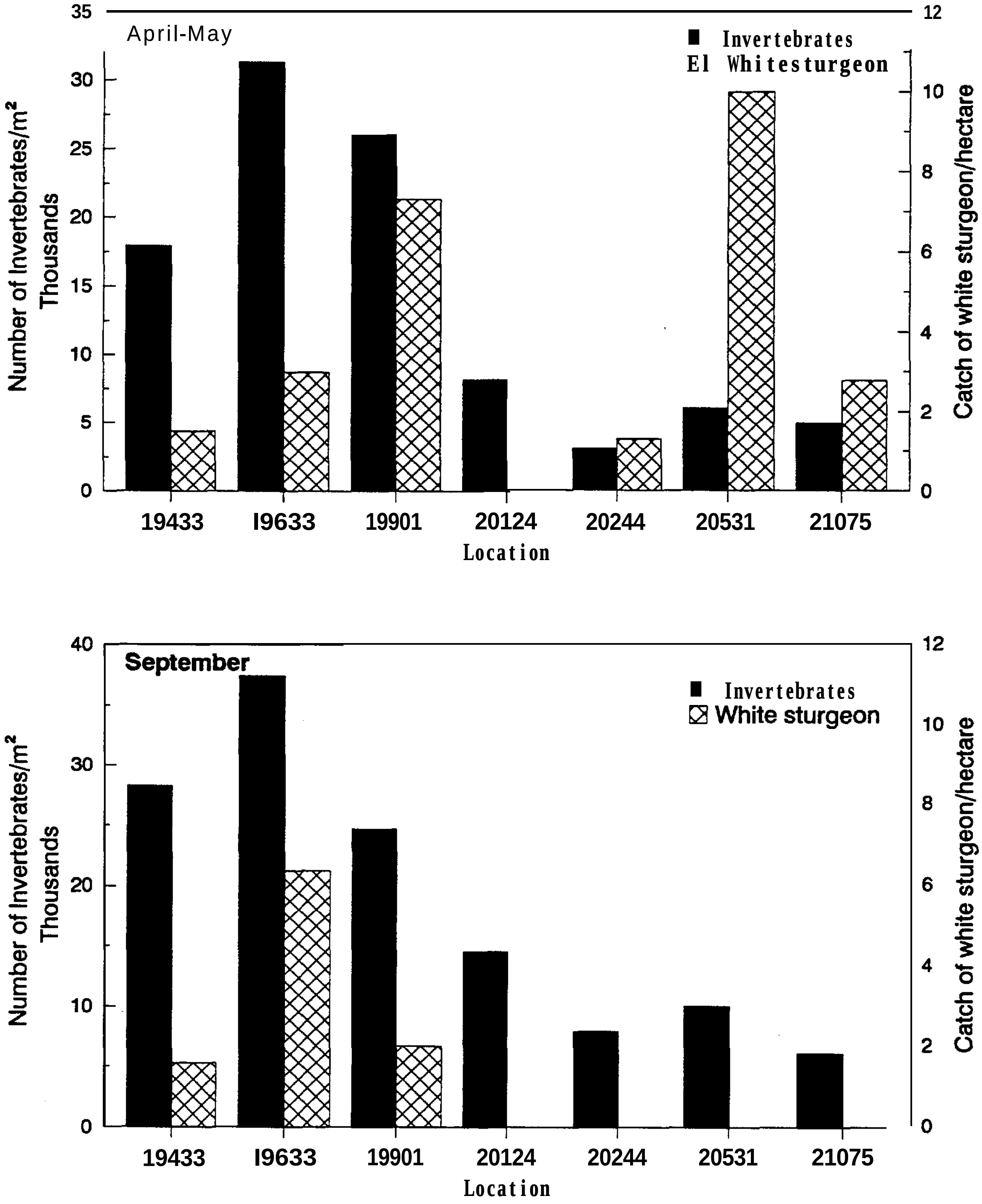

figure 2. Numbers of invertebrates per $m^2$ and catch of white sturgeon per hectare at seven trawling locations in The Dalles Pool, April-May and September, 1988.

Table 1. Percent occurrence, range and mean number of organisms per stomach, percent weight and relative abundance of food items recovered from 149 subyearling white sturgeon (20[1] to 267 mm TL) from Bonneville and The Dalles pools from 1989 thru 1991. Number of empty stomachs = 1.

| Food Item | Percent Occurrence | Number | | Percent Weight | Relative Abundance |
|---|---|---|---|---|---|
| | | Range | Mean | | |
| Annelida | | | | | |
| Oligochaeta | 0.7 | | 1.0 | 0.02 | 0.01 |
| Arthropoda | | | | | |
| Crustacea | | | | | |
| Copepoda | 1.3 | 1-21 | 11.0 | 0.00 | 0.25 |
| Calanoida | 0.7 | | 1.0 | 0.00 | 0.01 |
| Cyclopoida | 0.7 | - | | 0.00 | 0.01 |
| Cladocera | 9.4 | 1-2 | 1.0 | 0.06 | 0.18 |
| Daphnia | 0.7 | | 1.0 | 0.00 | 0.01 |
| Mysidacea | | | | | |
| *Neomysis mercedis* | *32.9* | 1-96 | 13.4 | 15.06 | 6.99 |
| Amphipoda | | | | | |
| *Ramellogammarus spp.* | *32.2* | 1-10 | 2.0 | 1.02 | 1.06 |
| *Corophium spp.* | *98.0* | 1-465 | 55.3 | 75.77 | 90.91 |
| Insecta | 4.3 | 1-1 | 1.0 | 0.00 | 0.09 |
| Diptera | | | | | |
| Chironomid larva | 17.5 | 1-4 | 2.2 | 0.13 | 0.45 |
| Ephemeroptera | 0.7 | | 1.0 | 0.00 | 0.01 |
| Mollusca | | | | | |
| Pelecypoda | | | | | |
| *Corbicula spp.* | *3.4* | 1-3 | 2.0 | 0.02 | 0.11 |
| digested material | 34.9 | | | 7.91 | |

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[1] White sturgeon shorter than 25 mm total length (TL) are designated larvae, and 25 mm TL or longer are young-of-the-year (YOY).

Table 2. Percent occurrence, range and mean number of organisms per stomach, percent weight and relative abundance of food items recovered from 22 yearling white sturgeon (199 to 340 mm FL) from Bonneville and The Dalles pools during 1991. Number of empty stomachs = 0.

| Food Item | Percent Occurrence | Number Range | Number Mean | Percent Weight | Relative Abundance |
|---|---|---|---|---|---|
| Arthropoda | | | | | |
| Crustacea | | | | | |
| Cladocera | 4.6 | | 1.0 | <.01 | 0.01 |
| Mysidacea | | | | | |
| *Neomysis mercedis* | 4.6 | | 3.0 | 0.16 | 0.04 |
| Amphipoda | | | | | |
| *Ramellogammarus* SPP* | 59.1 | 1-17 | 4.4 | 1.52 | 0.84 |
| *Corophium* SPP* | 95.5 | 1-1084 | 341.9 | 70.67 | 98.56 |
| Insecta | | | | | |
| Diptera | | | | | |
| Chironomid larva | 50.0 | 1-7 | 2.4 | 0.12 | 0.36 |
| Ephemeroptera | 13.6 | | 1.0 | 0.04 | 0.04 |
| Mollusca | | | | | |
| Pelecypoda | | | | | |
| *Corbicula* spp. | 4.6 | | 8.0 | 12.31 | 0.11 |
| Fish egg (uid)[1] | 4.6 | | 1.0 | 0.00 | 0.01 |
| digested material | 86.4 | | | 15.18 | |

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[1] Uid = unidentified

(20, 21, and 22 mm TL) contained no melanin plugs. We found one very small *Corophium spp.* in each stomach of two larvae, and a small amount of unidentifiable digested material in the third. The smallest YOY sampled was 28 mm TL. Stomachs of small, recently metamorphosed YOY contained mostly very small *Corophium spp.* and stomach contents of older, larger YOY were more diverse, consisting of various sizes of *Corophium spp.* and other organisms.

In 1991, stomach contents were dissected from 22 yearling white sturgeon from 199-340 mm fork length (FL). Yearlings consumed primarily *Corophium spp.* and also fed on *Neomysis mercedis*, *Ramellogammarus spp.*, and other organisms in lower numbers (Table 2). The stomach of one yearling from Bonneville Pool contained partly decomposed fleshy portions of the bivalve *Corbicula spp.*, exclusively.

In 1989, stomach contents were examined from 57 juvenile white sturgeon from 350 to 591 mm FL. Juveniles consumed *Corophium spp.*, *Neomysis mercedis*, *Ramellogammarus spp.*, *Corbicula spp.*, Chironomidae larvae/pupae, and a few fish bones. Organisms found in stomachs of juveniles collected from 1987-1989 were not quantified because of problems with stomach pumping and emetic sampling techniques. Though successful in removing some food items, stomach pumping was harmful to the fish and caused 33% mortality (4 of 12) within one week. Apparently, water pressure from flushing caused internal injuries; post mortem examination of two white sturgeon revealed ruptured swim bladders, and the other two fish were bleeding from the vent. The emetic hydrogen peroxide was useful in recovering some food items from white sturgeon, but the technique was not suitable for a quantitative analysis of prey items. For example, *C. salmonis* was present in all stomachs, but was detected in only 74% of all samples recovered with hydrogen peroxide.

Differences in prey item diversity were noted among age-classes and during different sampling periods. Juvenile white sturgeon had a more diverse diet than subyearlings and yearlings. More *Neomysis mercedis* were found in subyearling white sturgeon stomachs than in yearling stomachs, contributing almost 15% by weight of organisms sampled from subyearlings. Prey organism diversity was greater in stomachs of all age-classes in late summer than in spring when *Corophium spp.* were consumed almost exclusively.

Benthic Invertebrates

Benthic invertebrate samples collected in The Dalles Pool during May and September 1988 contained a wide variety of organisms (Table 3), and were dominated by four taxa (Figure 1). The dominant taxa included specimens of the class Oligochaeta, gastropods of the family Hydrobiidae, bivalves of the genus *Corbicula spp.*, and amphipods of the genus *Corophium*. Estimated densities of benthic invertebrates ranged from 3,698 to 31,833 per $m^2$ during May sampling and from 6,204 to 38,519 per $m^2$ during September sampling. Bivalves of the family Sphaeridae were also common in the benthos. Although both *Corbicula spp.* and *Corophium spp.* were commonly found in white sturgeon stomachs, Oligochaetes were rarely collected and gastropods (Hydrobiids or

Table 3. Benthic macroinvertebrates collected from seven locations in The Dalles Pool in May and September 1988.

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- Coelenterata
  - *Hydra spp.*
- Platyhelminthes
  - Tubellaria
- Nemertea
- Nematoda
- Annelida
  - Oligochaeta
  - Polychaeta
  - Hirudinea
- Arthropoda
  - Crustacea
    - *Bosmina longirostris*
    - *Daphnia spp.*
  - Ostracoda
  - Copepoda
    - Eucopepoda
      - Cyclopoida
  - Malacostracea
    - Mysidacea
      - Mysidae
        - *Neomysis* mercedis
    - Isopoda
    - Amphipoda
      - Gammaridae
        - *Ramellogammarus oregonensis*
      - Coophiidae
        - *Corophium salmonis*
        - Corophium spinicorne
    - Arachnida
      - Hydracarina
    - Insecta
      - Ephemeroptera
        - Ephemeridae
          - *Hexagenia spp.*
        - Tricoptera
        - Diptera
          - Chironomidae
- Mollusca
  - Gastropoda
    - Mesogastropoda
      - Hydrobiidae
        - *Fontellicella spp*[a] or Potamopyrgus antipodarum
      - Pleuroceridae
        - *Juga plicifera*
      - Ancylidae
        - Ferrissia rivularis

Table 3 (continued).

- Pelecypoda
  - Veneroida
    - Corbiculidae
      - *Corbicula* spp.
    - Sphaeriidae
      - *Sphaerium simile* or *Pisidium nitidum*[b]
  - Eulamellibranchia
    - Unionidae
      - *Anodonta oregonensis*
      - *Anodonta wahlametensis*[c]

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[a] Collected on 6 July 1988 at location 19902, identification not confirmed.

[b] Identification not confirmed for all collections, some specimens may be *Pisidium nitidum.*

[c] Identification not confirmed for all collections, some specimens may be *Anodonta walametensis.*

Sphaeriids were never found in white sturgeon stomachs. *Neomysis mercedis* numbers were very low in all benthic samples, although we found moderate numbers in some white sturgeon stomachs collected after 1988, especially in subyearling fish.

Based on this limited information, it appeared that catches of white sturgeon at the seven sampling locations during April were not related to densities of benthic invertebrates at those locations in early May (Figure 2).

## Discussion

As in other studies, we found that small benthic crustaceans were the dominant prey items of subyearling, yearling and juvenile white sturgeon. Schreiber (1962) reported that the primary food of 30 YOY white sturgeon sampled in the Sacramento-San Joaquin delta during late summer and fall was *Corophium spinicorne*. Small white sturgeon fed almost exclusively on *Corophium salmonis* in the Columbia River estuary (McCabe et al. 1983). The amphipod *Corophium salmonis* was the dominant food item for white sturgeon <80 cm TL in lower Columbia River studies (Muir et al. 1988; McCabe et al. 1992). All other prey organisms were found in far fewer numbers. Summaries of prey organisms found in juveniles and analyses of stomach pumping and emetic efficiency were reported in Palmer et al. (1988), Parsley et al. (1989), and Duke et al. (1990).

This research presents for the first time the presence and dominance of *Corophium spp.* in initial diets of some white sturgeon larvae and nearly all YOY in Columbia River impoundments. White sturgeon larvae initiated feeding after the intestinal melanin plug was absorbed. Analyses of additional larval white sturgeon stomachs is essential to gain a better understanding of diet composition following the onset of exogenous feeding.

More extensive benthic surveys are needed to document invertebrate abundance and distribution in Columbia River impoundments. It is necessary to study the ecology of *Corophium spp.* because of their importance in the diets of rearing white sturgeon in fresh water. *Corophium spp.* are primarily an estuarine species, and may only tolerate fresh water as less than optimum habitat (Higley et al., 1984). Abundant sand and silt substrate in both impoundments (Parsley et al. 1992) may provide habitat for *Corophium spp.* colonization upon introduction. Transfer of ballast water from commercial barge traffic may be responsible for *Corophium spp.* distribution in the Columbia River upstream of the estuary, as they have been found only as far upriver as commercial barges can navigate (B. Muir, NMFS, Cook, WA, personal communication).

Although limited in scope, the benthic surveys showed some important relationships between invertebrate abundance and white sturgeon prey selection. Several species were common in the benthos (Figure 1), but gastropods and Oligochaetes were rarely preyed upon by white sturgeon (Tables 1 and 2).

Several years of comparing benthic invertebrate abundance and distribution to rearing white sturgeon prey selection may reveal relationships among their feeding behavior, growth characteristics, and distribution. We noted very few *Neomysis mercedis* in benthos samples, but found them in moderate numbers in some stomachs in years subsequent to benthic sampling. *Neomysis mercedis* exhibit vertical die1 migration patterns (Davis 1978). Therefore, white sturgeon may be feeding on organisms suspended in the water column rather than exclusively on the substrate. Unknown factors such as differences in invertebrate densities between the impoundments and the free-flowing lower river may influence white sturgeon growth, since growth in the first seven years of life is greater in both impoundments than in the lower river (Miller and Beckman 1992). However, distribution of white sturgeon seems independant of invertebrate densities (Figure 2 and McCabe et al. 1989).

Resource managers need to implement long term benthic sampling and prey selection analyses and regulate activities such dredging operations that may affect prey organism populations to effectively manage rearing white sturgeon in Columbia River impoundments.

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## REPORT 0

# Feeding Ecology of Juvenile White Sturgeon *(Acipenser transmontanus)* in the Lower Columbia River

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## Abstract

The feeding ecology of juvenile white sturgeon (Acipenser transmontanus) in two areas of the lower Columbia River (Oregon and Washington) was studied from April through October 1988. Overall, the tube-dwelling amphipod Corophium salmonis was the most important prey for the two size classes of juvenile white sturgeon studied. However, during all sampling periods and at both areas (River Kilometers [RKm] 153 and 211), Size Class I white sturgeon (144-350 mm fork length) preyed more heavily on C. salmonis than did Size Class II white sturgeon (351 to 724 mm). Other temporally important prey for Size Class I white sturgeon included Corophium spinicorne, Neomysis sp., Chironomidae larvae, and eulachon (Thaleichthys pacificus) eggs; other temporally important prey for Size Class II white sturgeon included the bivalve Corbicula fluminea, Corophium spinicorne, Chironomidae larvae, and eulachon eggs. Index of Feeding analysis indicated that juvenile white sturgeon in both areas were feeding significantly less in September-October than in May-June or July-August. Benthic invertebrate sampling, in addition to white sturgeon sampling, was conducted at eight areas in the lower Columbia River, including RKm 153 and 211, in April and September 1988. Generally, the relationships between densities of specific benthic organisms and white sturgeon diets were poor at RKm 153 and 211. Although Coronhium salmonis was very important in the diets of juvenile white sturgeon, particularly for Size Class I fish, it was not abundant in the benthos (mean density, <185 organisms/m* in April and September). Regression analysis indicated that no more than 32% of the variation in white sturgeon abundance at the eight sampling areas could be explained by C. salmonis densities.

## Introduction

The white sturgeon A<u>cipernser transmontanus</u>), the largest North American sturgeon, is an anadromous species found along the west coast of North America from the Aleutian Islands, Alaska, to Monterey, California (Scott and Crossman 1973). Some populations in the Columbia River Basin are essentially landlocked due to dam construction (Cochnauer <u>et al</u>. 1985, Beamesderfer <u>et al</u>. 1990).

Historically, the population of white sturgeon in the Columbia River (Oregon and Washington) was large enough to support an intense commercial fishery, with catches peaking in 1892 at more than 2.4 million kg (Craig and Hacker 1940). However, due to overfishing, catches declined, and by 1899 the annual catch was less than 33,250 kg; during the early 1900s, annual catches were less than 104,930 kg (Craig and Hacker 1940).

Since the early 1900s, white sturgeon populations in the Columbia River, particularly the one downstream from Bonneville Dam (the lowermost dam), recovered sufficiently to support important recreational and commercial fisheries. Presently, the lower Columbia River (from the mouth to Bonneville Dam) supports one of the largest populations of white sturgeon. In 1989 the estimated recreational and commercial harvests in the lower Columbia River were 25,400 and 5,000 fish, respectively (Washington Department of Fisheries and Oregon Department of Fish and Wildlife 1990). Based on the number of recreational angler trips in 1989, the white sturgeon is second only to salmonid species as the most popular recreational fish in the lower Columbia River (Washington Department of Fisheries and Oregon Department of Fish and Wildlife 1990).

Little has been published about the ecology of the white sturgeon, and the feeding ecology of juveniles in particular has received only limited investigation. The diets of small juvenile white sturgeon (<800 mm total length) have been described in the Sacramento-San Joaquin River Basin, California (Schreiber 1962, Radtke 1966), and in the Columbia River and its estuary (Muir <u>et al</u>. 1988). However, most of the white sturgeon collected by Muir <u>et al</u>. (1988) were from the estuary; only a small number (N <54) were collected upstream from the estuary over a 3-month period.

A comprehensive food habit study of small juvenile white sturgeon was conducted in 1988. We examined the seasonal feeding characteristics of two size classes of juvenile white sturgeon (144-350 mm fork length and 351-724 mm fork length) in two areas of the lower Columbia River; we assessed both the importance of various prey eaten and the feeding intensity. Also, we examined the relationship between the feeding characteristics of juvenile white sturgeon and benthic invertebrate communities and the relationship between white sturgeon catches and benthic invertebrate abundance.

## Methods

Juvenile white sturgeon were collected with a 7.9-m (headrope length) semiballoon shrimp trawl, which was towed by a 12.2-m boat, in eight areas of the lower Columbia River between River Kilometer (RKm) 46 and RKm 211 (Fig. 1). Mesh size in the trawl net was 38 mm (stretched measure) in the

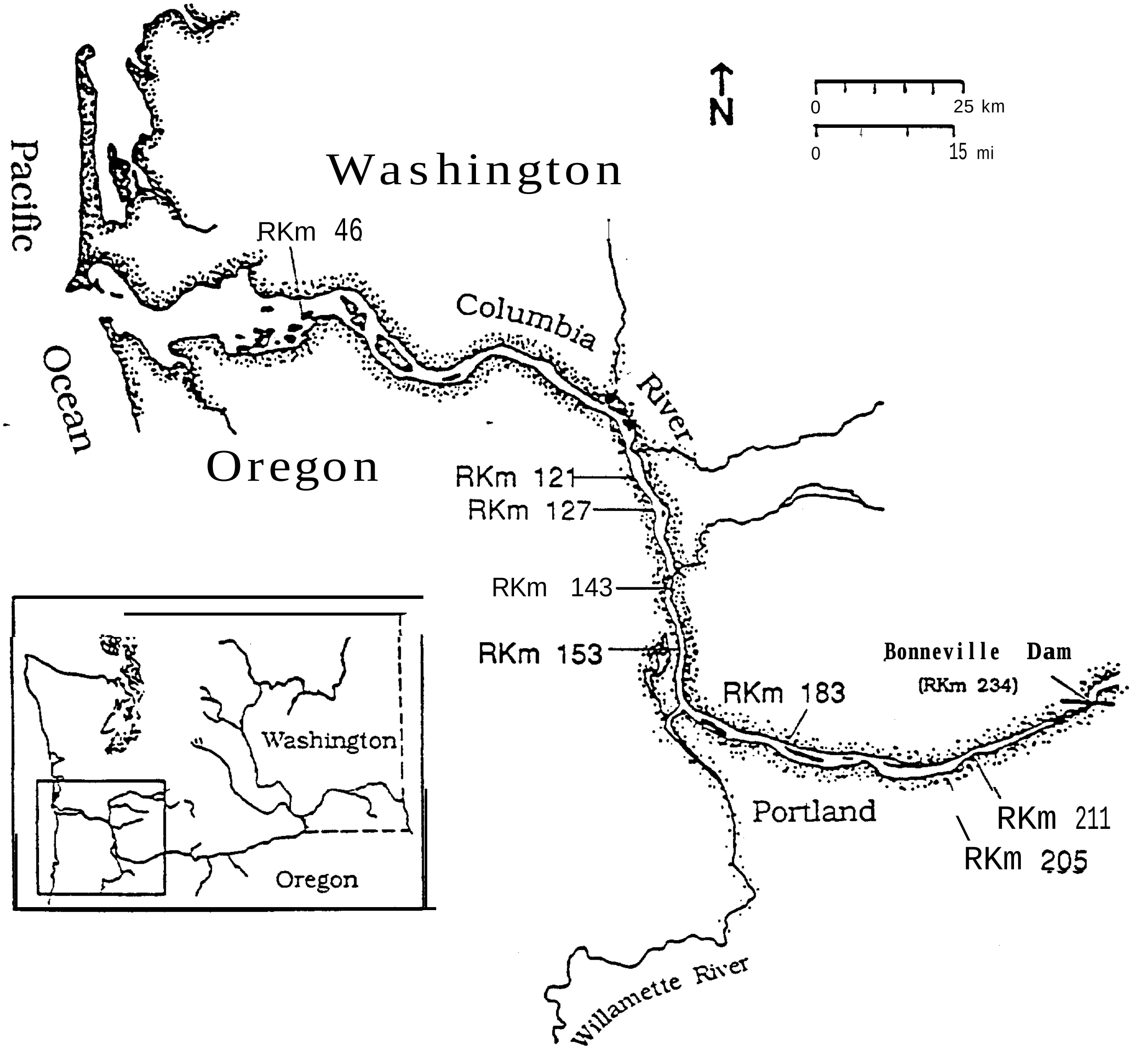

Figure 1. Map of the lower Columbia River showing the eight sampling areas where juvenile white sturgeon and benthic invertebrate samples were collected in 1988. Stomachs were collected from juvenile white sturgeon captured at River Kilometers (RKm) 153 and 211.

body; a 10-mm mesh liner was inserted in the codend of the net. Trawling efforts were normally 5 min in duration in an upstream direction; boat speed varied depending upon water velocity, wind, and bottom topography. Using a radar range-finder, we estimated the distance the net traveled during each sampling effort. Using the distance traveled and the estimated fishing width of the net (5.3 m), we calculated the area fished for each effort. Sturgeon density for each effort was then calculated (number of sturgeon caught/area fished) and expressed as number/hectare (ha).

Trawling was done from late March through October. At each of the eight sampling areas, trawling was done along two or three parallel transects; one trawl was done along each transect. Transect 1 was closest to the Washington shore, Transect 2 was the middle transect, and Transect 3 was closest to the Oregon shore. In river sections where only two transects were established, Transect 2 was closest to the Oregon shore.

All fishes captured in the trawl were identified and counted. Generally, all white sturgeon from a sampling effort were measured (fork length [mm]) and weighed (g). When a large number of white sturgeon was collected in a sampling effort, a subsample of at least 50 was measured and weighed.

Stomachs were taken from a subsample of white sturgeon captured at two sampling areas (RKm 153 and 211; Fig. 1) to determine their diet and its relationship to the benthic invertebrate community. White sturgeon stomachs were taken during three time periods: (1) May-June, (2) July-August, and (3) September-October. At each area, we tried to obtain 25 stomachs from each of two size classes of white sturgeon during each of the three time periods. The two size classes were (I) 144 to 350 mm fork length and (II) 351 to 724 mm fork length. Stomachs were removed from the white sturgeon on board the sampling vessel and placed in individual vials containing a 7% buffered formaldehyde solution. The stomachs were later transferred to vials containing a 70% ethyl alcohol solution. Individual food items in each stomach were identified to the lowest practical taxonomic level, sorted, counted, and weighed to the nearest 0.1 mg using a Mettler H-80 mechanical balance[1].

The diets of white sturgeon at RKm 153 and 211 during the three time periods were analyzed using two approaches. The importance of a prey taxon was determined using a modification of the Index of Relative Importance (IRI) described by Pinkas _et al_. (1971)

$$IRI = (N + W) F,$$

where N = percent number of a prey item, W = percent weight of a prey item, and F = percent frequency of occurrence of a prey item. Index of Relative Importance values for individual prey items were then converted to percentages. To determine feeding intensity in each area, an Index of Feeding (IF) was calculated using the equation

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[1] Reference to trade names does not imply endorsement by NMFS, NOAA.

$$IF = (Ws \div Wf) \times 100\%,$$

where Ws = weight of stomach contents of a fish and Wf = weight of a fish. Differences among IF values were statistically tested using the Mann-Whitney test (Ryan *et* al 1976).

Benthic invertebrate samples were collected at two stations along individual bottom trawling transects at the eight sampling areas. Benthic surveys were done in April and September 1988. During each survey, five benthic invertebrate samples were collected at each sampling station using a $0.1\text{-m}^2$ Van Veen grab sampler (Word 1976). When practical, each benthic invertebrate sample was sieved through a 0.5-mm screen and the residue preserved in a buffered formaldehyde solution (>4%) containing rose bengal. If it appeared that most of the material would not quickly wash through the sieve, then the entire sample was preserved and sieved at the laboratory. The samples were later washed with water and preserved in a 90% alcohol solution. Each benthic invertebrate sample was sorted and the invertebrates were identified to the lowest practical taxonomic level and counted. Eulachon (*Thaleichthys nacificus)* eggs, which were collected in April samples, were also counted. When large numbers of eulachon eggs occurred in samples, their numbers were estimated. Benthic data were analyzed both by individual transect and area.

The relationships between white sturgeon densities (April and October) and benthic invertebrate densities (April and September), specifically *Corbicula fluminea* and *Coroohium salmonis*, at the eight sampling areas were examined using simple and multiple regressions. Benthic invertebrate data collected in September were used to characterize the October period. White sturgeon densities were transformed to log,, of (density + 1) and benthic invertebrate densities were transformed (log,,) prior to analysis.

## Results

### Stomach Contents Analysis

A total of 292 stomachs were taken from white sturgeon collected at RKm 153 and 211 in 1988. Overall, the amphipod C. *salmonis* was the most important identifiable prey item at both areas (Table 1). During all three time periods in both areas, percent Index of Relative Importance (%IRI) for C. *salmonis* was higher for the smaller Size Class I white sturgeon than for the larger Size Class II white sturgeon, indicating that the smaller juveniles preyed more heavily on C. *salmonis*. The importance of c. *salmonis* for Size Class I white sturgeon at RKm 153 remained relatively consistent throughout the study, ranging from 75 to 82 %IRI during the three periods; whereas, at RKm 211, the %IRI of C. *salmonis* was more varied, ranging from 44 (September-October) to 75 %IRI (July-August).

Size Class II white sturgeon also preyed primarily on C. *salmonis*, but, on occasion, they also consumed large quantities of the bivalve *Corbicula fluminea*, Chironomidae larvae, and eulachon eggs. At both RKm 153 and 211, Size Class II white sturgeon fed on eulachon eggs only in

TABLE 1. Summary of white sturgeon diets from May through October 1988; numbers shown in the table are percents of total Index of Relative Importance (%IRI). Data are presented for two size classes--Size Class I (144-350 mm fork length) and Size Class II (351-724 mm fork length)--from two areas of the Columbia River, River Kilometers 153 and 211. Only prey items with %IRI values greater than 1 (for at least one size class and season) are shown.

River Kilometer 153

| Prey item | May-Jun | | Jul-Aug | | Sep-Oct | |
|---|---|---|---|---|---|---|
| | Size I | Size II | Size I | Size II | Size I | Size II |
| Corbicula fluminea | <1 | 11 | <1 | 19 | 0 | 3 |
| Neomysis mercedis | 0 | 0 | 4 | <1 | <1 | <1 |
| Corophium salmonis | 82 | 40 | 74 | 38 | 75 | 51 |
| Corophium spinicorne | 3 | 2 | 3 | 7 | 5 | 3 |
| Heleidae larvae | <1 | <1 | | 3 | <1 | <1 |
| Eulacho eggs | 2 | 12 | 0 | 0 | 0 | 0 |
| Digested material | 11 | 34 | 13 | 32 | 21 | 41 |

River Kilometer 211

| Prey item | May-Jun | | Jul-Aug | | Sep-Oct | |
|---|---|---|---|---|---|---|
| | Size I | Size II | Size I | Size II | Size I | Size II |
| Corbicula fluminea | <1 | 20 | <1 | 35 | <1 | <1 |
| Neomysis sp. | 0 | 0 | <1 | 0 | 20 | 2 |
| Neomysis mercedis | 0 | 0 | <1 | <1 | <1 | 1 |
| Corophium salmonis | 59 | 12 | 75 | 24 | 44 | 24 |
| Corophium spinicorne | <1 | <1 | 1 | <1 | <1 | <1 |
| Hemiptera | 0 | 0 | 0 | <1 | <1 | 1 |
| Chironomidae larvae | 0 | <1 | 4 | 2 | 11 | 18 |
| Chironomidae pupae | <1 | 0 | 0 | <1 | <1 | 4 |
| Heleidae larvae | <1 | <1 | 2 | 1 | 0 | 0 |
| Eulachon eggs | 25 | 51 | 0 | 0 | 0 | 0 |
| Fish (unidentified) | 0 | 3 | 0 | 0 | 0 | 0 |
| Digested material | 16 | 13 | 17 | 35 | 23 | 49 |

May. For Size Class II white sturgeon at RKm 153, %IRI for *Corophium salmonis* ranged from 38% in July-August to 51% in September-October. Additionally, eulachon eggs (12 %IRI) and *Corbicula fluminea* (11 %IRI) were important prey in May-June, and C. *fluminea* (19 %IRI) and *Corophium spinocorne* (7 %IRI) were important in July-August. For Size Class II white sturgeon at RKm 211, %IRI for C. *salmonis* ranged from 12% in May-June to 24% in July-October. Other important prey for this size class at RKm 211 included eulachon eggs (51 XIRI) and *Corbicula fluminea* (20 %IRI) in May-June, C. *fluminea* (35 XIRI) in July-August, and Chironomidae larvae (18 %IRI) in September-October.

The IF analysis indicated a reduction in feeding of juvenile white sturgeon at RKm 153 and 211 in September-October. At RKm 153, IF values for both size classes of white sturgeon were significantly lower (Mann-Whitney test, $P < 0.05$) in September-October than in either May-June or July-August (Table 2). At RKm 211, only Size Class II white sturgeon had significantly lower IF values in September-October than in May-June or July-August (Table 2). Besides lower IF values, the number of empty stomachs for both size classes in both areas was highest in September-October, further indicating reduced feeding.

## Benthic Invertebrates

Major benthic invertebrate taxa collected at RKm 153 included Oligochaeta, *Corbicula fluminea*, *Corophium salmonis*, Chironomidae larvae, and Heleidae larvae (Table 3). At RKm 2.11, the major benthic invertebrate taxa collected included Turbellaria, Oligochaeta, *Corbicula fluminea*, Ostracoda, *Corophium salmonis*, Chironomidae larvae, and Heleidae larvae (Table 4). Eulachon eggs are included in the tables because they were collected along with the benthic invertebrates and were important in the diet of white sturgeon. Densities of specific invertebrates often varied considerably among transects within each area.

Overall, the relationships between white sturgeon diets and specific benthic invertebrate densities were poor at RKm 153 and 211 (Figs. 2 and 3). No diet and benthic invertebrate data are presented for July-August because no benthic invertebrate sampling was done during this period. Although C. *salmonis* was by far the most important prey for both size classes of white sturgeon in May-June and September-October at RKm 153, it was not an abundant benthic invertebrate (mean density, <185 organisms/$m^2$ in both April and September). Eulachon eggs, which were the most abundant organisms in the benthos at RKm 153 during April, were an important food item for Size Class II white sturgeon during May-June. Heleidae larvae, although relatively abundant at RKm 153, particularly during April, were insignificant in white sturgeon diets. Likewise, oligochaetes were relatively abundant at RKm 153 during September, yet were not eaten by white sturgeon.

At RKm 211, *C. salmonis* was by far the most important prey in both May-June and September-October for Size Class I white sturgeon; however, it was not abundant in the benthos in either April or September (mean density, <120 organisms/$m^2$ in each month). *Corbicula fluminea* was the most abundant benthic invertebrate at RKm 211 in April and was also an

TABLE 2. Comparisons of Index of Feeding (IF) for two size classes of juvenile white sturgeon collected at River Kilometers 153 and 211 in the Columbia River, 1988. Size Class I white sturgeon were 144-350 mm fork length and Size Class II white sturgeon were 351-724 mm fork length. Mean IF was calculated using only stomachs that contained food. The total number of stomachs collected and the number of empty stomachs are shown for each class.

River Kilometer 153

| | Time period | | |
|---|---|---|---|
| Size Class | May-Jun | Jul -Aug | Sep-Oct |
| **Size I** | | | |
| a) mean IF | 0.39 | 0.44 | 0.22[a] |
| b) total number | 26 | 24 | 20 |
| c) number empty | 0 | 0 | 3 |
| **Size II** | | | |
| a) mean IF | 0.27 | 0.35 | 0.08[a] |
| b) total number | 25 | 25 | 24 |
| c) number empty | 1 | 0 | 10 |

River Kilometer 211

| | Time period | | |
|---|---|---|---|
| Size Class | May-Jun | Jul -Aug | Sep-Oct |
| **Size I** | | | |
| a) mean IF | 0.31 | 0.23 | 0.20 |
| b) total number | 27 | 25 | 24 |
| c) number empty | 2 | 0 | 6 |
| **Size II** | | | |
| a) mean IF | 0.38 | 0.41 | 0.03[a] |
| b) total number | 23 | 25 | 24 |
| c) number empty | 2 | 0 | 17 |

[a] Mean IF for Sep-Oct was significantly less than IF for both May-Jun and Jul-Aug; Mann-Whitney test, $P < 0.05$.

TABLE 3. Mean densities (number/m$^2$) and standard deviations (SD) of major benthic taxa collected in April and September 1988 at River Kilometer (RKm) 153 in the Columbia River. The total for each transect includes both major taxa and less important taxa not shown.

| RKm-transect | Taxon | April 1988 | | September 1988 | |
|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD |
| 153-1 | Oligochaeta | 405 | 444 | 1,849 | 697 |
| | *Corbicula fluminea* | 1,198 | 1,455 | 213 | 153 |
| | Heleidae larvae | 640 | 1,094 | 431 | 306 |
| | Eulachon eggs | 134,366 | 105,229 | 0 | 0 |
| | Total | 136,655 | 103,352 | 2,507 | 956 |
| 153-2 | *Corbicula fluminea* | 513 | 530 | 39 | 36 |
| | Heleidae larvae | 939 | 545 | 198 | 175 |
| | Total | 1,592 | 1,049 | 251 | 202 |
| 153-3 | *Corbicula fluminea* | 428 | 369 | 68 | 122 |
| | *Corophium salmonis* | 389 | 285 | 545 | 262 |
| | Chironomidae larvae | 78 | 90 | 0 | 0 |
| | Heleidae larvae | 146 | 156 | 8 | 15 |
| | Total | 1,144 | 798 | 625 | 377 |
| | Entire area[a] | 49,701 | 88,979 | 1,128 | 1,161 |

[a] The average of all samples taken at RKm 153; in April, only 28 samples were analyzed for the entire area.

TABLE 4. Mean densities (number/m$^2$) and standard deviations (SD) of major benthic taxa collected in April and September 1988 at River Kilometer (RKm) 211 in the Columbia River. The total for each transect includes both major taxa and less important taxa not shown.

| RKm-transect | Taxon | April 1988 | | September 1988 | |
|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD |
| 211-1 | Oligochaeta | 13 | 24 | 78 | 50 |
| | *Corbicula fluminea* | 1,210 | 860 | 478 | 370 |
| | Heleidae larvae | 772 | 509 | 500 | 284 |
| | Eulachon eggs | 8,874 | 14,262 | 0 | 0 |
| | Total | 10,930 | 14,028 | 1,110 | 558 |
| 211-2 | Turbellaria | 66 | 130 | 7 | 12 |
| | *Corbicula fluminea* | 544 | 908 | 248 | 253 |
| | Heleidae larvae | 301 | 467 | 440 | 386 |
| | Total | 982 | 1,212 | 739 | 582 |
| 211-3 | Oligochaeta | 406 | 214 | 627 | 645 |
| | *Corbicula fluminea* | 224 | 216 | 70 | 50 |
| | Ostracoda | 59 | 94 | 5 | 8 |
| | *Coronhium salmonis* | 309 | 143 | 221 | 84 |
| | Chironomidae larvae | 43 | 49 | 52 | 53 |
| | Eulachon eggs | 55 | 49 | 0 | 0 |
| | Total | 1,135 | 325 | 1,016 | 810 |
| | Entire area" | 4,122 | 8,850 | 955 | 657 |

a The average of all samples taken at RKm 211; in April, only 29 samples were analyzed for the entire area.

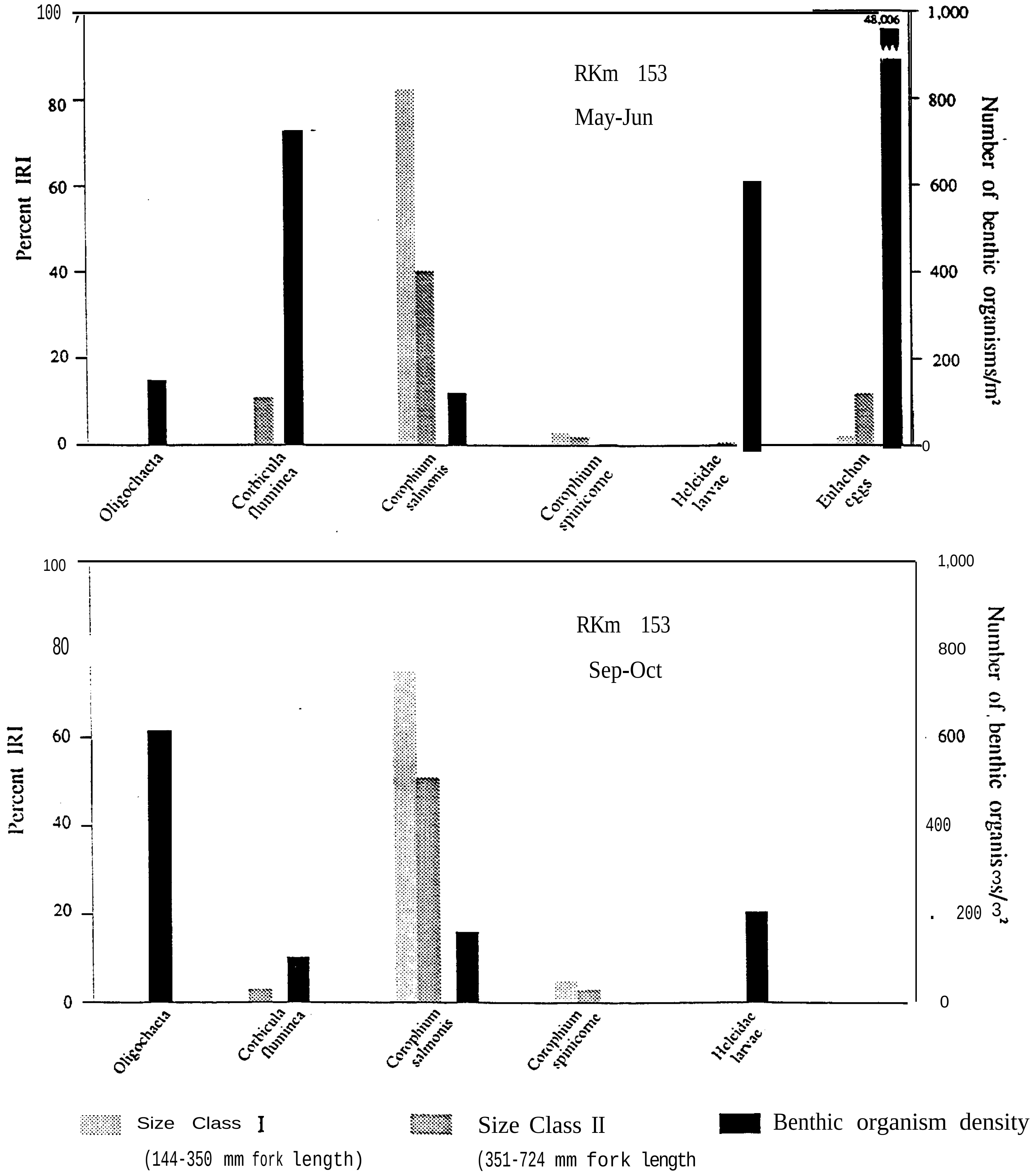

Figure 2. Percent Index of Relative Importance (%IRI) for prey of two size classes of juvenile white sturgeon collected during May-June and September-October 1988 at River Kilometer (RKm) 153 in the Columbia River. Also shown are densities of selected benthic organisms collected in April and September 1988; the April data are presented for the May-June period because no benthic sampling was done in May or June. Eulachon eggs are shown because they were collected along with the benthic invertebrates and were important white sturgeon prey.

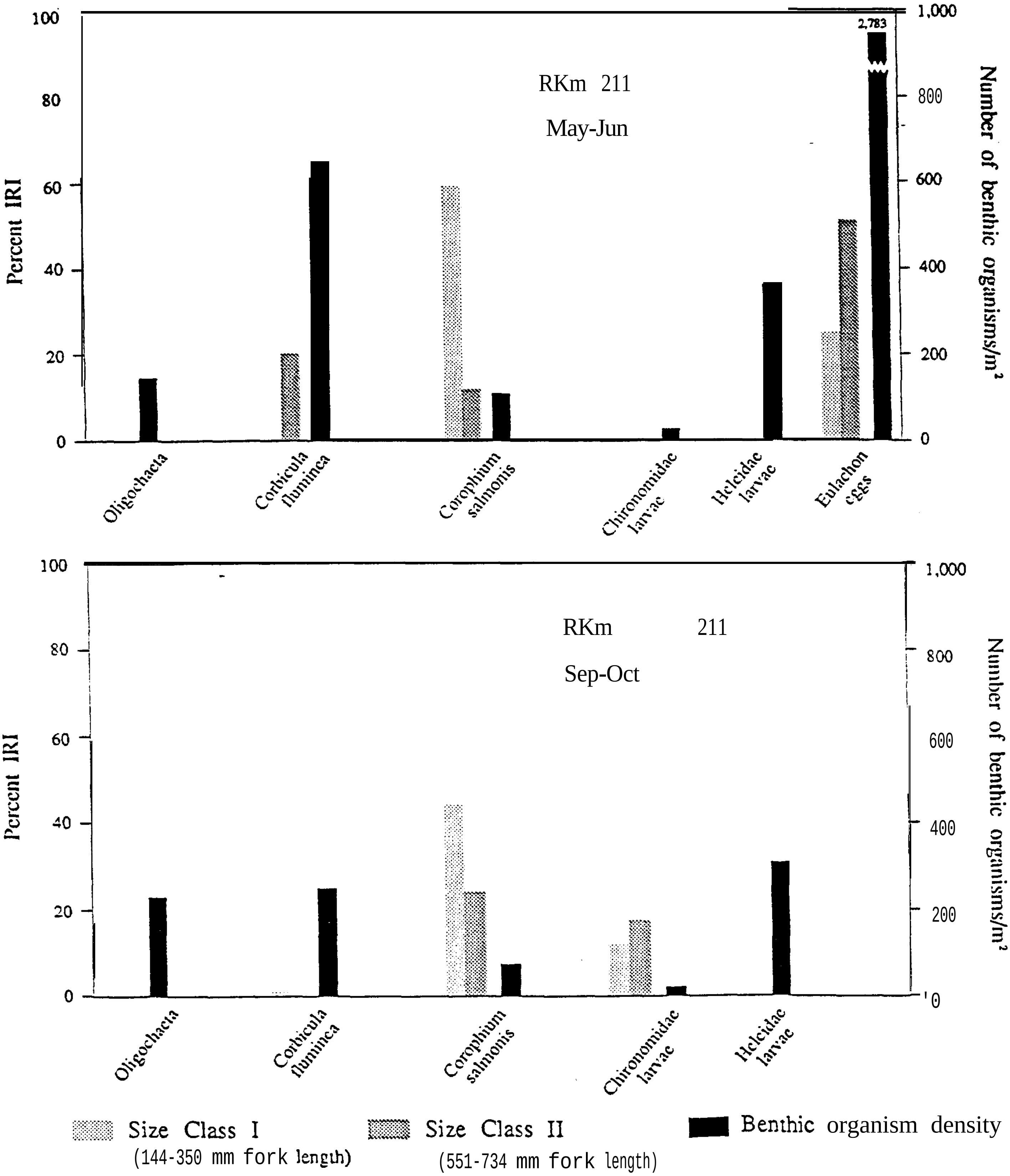

Figure 3. Percent Index of Relative Importance (%IRI) for prey of two size classes of juvenile white sturgeon collected during May-June and September-October 1988 at River Kilometer (RKm) 211 in the Columbia River. Also shown are densities of selected benthic organisms collected in April and September 1988; the April data are presented for the May-June period because no benthic sampling was done in May or June. Eulachon eggs are shown because they were collected along with the benthic invertebrates and were important white sturgeon prey.

important prey for Size Class II white sturgeon in May-June. Eulachon eggs were abundant at RKm 211 during April and were an important prey for both size classes of white sturgeon, particularly Size Class II fish, in May-June. In September, oligochaetes, C. fluminea, and Heleidae larvae were the most abundant benthic invertebrates at RKm 211, yet these taxa were unimportant in the diet of white sturgeon in September-October.

The relationships between white sturgeon densities and densities of Corbicula fluminea and Coroohium salrnonis at the eight sampling areas (data combined for all areas) were poor (Table 5). Simple regression analysis indicated that overall (combining the data for April and September-October), only 7% of the variation in white sturgeon densities was explained by Corbicula fluminea densities; 20% of the variation was explained by Corophium salmonis densities. Multiple regression analysis showed that 28% of the variation in white sturgeon densities was explained by using both Corbicula fluminea and Corophium salmonis densities as predictors. The data were also analyzed separately for the two time periods. For April, 12% of the variation in white sturgeon densities was explained by Corbicula fluminea densities, and 11% of the variation was explained by Corophium salmonis densities. Multiple regression analysis indicated that 26% of the variation in white sturgeon densities in April was explained by using both Corbicula fluminea and Corophium salmonis densities as predictors. For the September-October period, 3% and 32% of the variations in white sturgeon densities were explained by Corbicula fluminea and Corophium salmonis densities, respectively. Multiple regression analysis of the September-October data showed that 33% of the variation in white sturgeon densities was explained by using both Corbicula fluminea and Corophium salmonis densities as predictors.

## Discussion

The feeding ecology 'of juvenile white sturgeon in our study, in general, agrees with findings from the lower Columbia River feeding study of Muir et al. (1988). Although fewer white sturgeon stomachs were analyzed for content during their study, they also found that the predominant prey for white sturgeon less than 800 mm (total length) captured in the lower Columbia River and its estuary was Corophium salmonis. In Muir et al.'s (1988) study, neither Corbicula fluminea nor eulachon eggs were important prey for white sturgeon less than 800 mm long; this was in contrast to what we observed. Muir et al. (1988) sampled in the Columbia River only in July-September when eulachon eggs would not be present. This time period was well past the spawning migrations of eulachon.

The significant reduction in feeding by juvenile white sturgeon (i.e., lower IF values and a higher number of empty stomachs) at both RKm 153 and 211 in September-October indicates that prey abundance or availability may have limited feeding at this time of the year. At both locations, white sturgeon densities were higher in September-October than in May-June or July-August. For example, at RKm 153, the mean white sturgeon density in July-August was 38 fish/ha, whereas in September-October, it was 92 fish/ha (calculated from appendix data, McCabe et al. 1989). At RKm 211, the increase was even greater, going from a mean density of 79 fish/ha in July-August to 365 fish/ha in September-October (calculated from appendix data, McCabe et al. 1989). These increases in

TABLE 5. Summary of white sturgeon densities (number/ha) and benthic invertebrate densities (number/m*) at eight sampling areas (River Kilometer [RKm]-transect) in the lower Columbia River, 1988. Mean densities are shown for the invertebrates <u>Corbicula fluminea</u> (Cf) and <u>Corophium salmonis</u> (Cs), which are important prey for juvenile white sturgeon.

| RKm-transect | Apr | | | Sep-Oct | | |
|---|---|---|---|---|---|---|
| | Sturgeon density | Invertebrate density | | Sturgeon density" | Invertebrate density[b] | |
| | | Cf | Cs | | Cf | Cs |
| 46-1 | 0 | 29 | 55 | 0 | 171 | 604 |
| 46-2 | 6 | 88 | 6,574 | | 103 | 1,516 |
| 46-3 | 24 | 563 | 1,046 | 8 | 234 | 4,567 |
| 121-1 | 0 | 3 | 5 | 12 | 594 | 20 |
| 121-2 | 0 | 115 | 86 | 0 | 365 | 68 |
| 127-1 | 251 | 4 | 2 | 51 | 536 | 49 |
| 127-2 | 48 | 108 | 6 | 74 | 67 | 16 |
| 127-3 | 8 | 351 | 75 | 6 | 357 | 316 |
| 143-1 | 0 | 177 | 231 | 0 | 212 | 17 |
| 143-2 | 23 | 219 | 3 | 10 | 461 | 5 |
| 153-1 | 561 | 1,198 | 2 | 334 | 213 | 4 |
| 153-2 | | 513 | 29 | 18 | 39 | 5 |
| 153-3 | - | 428 | 389 | 3 | 68 | 545 |
| 183-1 | 0 | 201 | 1 | 0 | 292 | 18 |
| 183-2 | 0 | 176 | 9 | 8 | 661 | 68 |
| 205-2 | 0 | 42 | 33 | 2 | 56 | 6 |
| 205-3 | 54 | 572 | 12 | 7 | 686 | 3 |
| 211-1 | 78 | 1,210 | 26 | 198 | 478 | 9 |
| 211-2 | 531 | 544 | 5 | 763 | 248 | 8 |
| 211-3 | 0 | 224 | 309 | 0 | 70 | 221 |

a Sturgeon were collected in October 1988.

b Benthic invertebrates were collected in September 1988.

white sturgeon abundance could have reduced benthic invertebrate populations, particularly *Corophium salmonis*, to levels where juvenile white sturgeon were not able to feed as effectively.

Although RKm 153 and 211 are intensively used by juvenile white sturgeon, these areas do not have high standing crops of C. *salmonis*. In both areas, C. *salmonis* had mean densities less than $125/m^2$ (average of all samples taken in each area) during April 1988. For comparison, the mean density of C. *salmonis* at four stations (RKm 30-40) in Cathlamet Bay, which is primarily a freshwater bay in the Columbia River estuary, was $7,739/m^2$ in April 1984 (Emmett *et al*. 1986). At RKm 46 (upper estuary), the mean density of *C*. *salmonis* was $2,420/m^2$ in April 1988.

Considering the relatively low densities of C. *salmonis* in the benthos at RKm 153 and 211 and their importance in white sturgeon diets, it is possible that juvenile white sturgeon are (1) feeding on C. *salmonis* carried to them by the current drift, (2) moving to nearby areas with higher C. *salmonis* densities and feeding there, or (3) very efficiently feeding on *C*. *salmonis*, even when not abundant. *Corophium* spp. are often important river drift organisms and have been observed in white sturgeon egg and larval samples collected with plankton nets fished along the bottom at RKm 193 and 230 (Muir 1990). Davis (1978) observed that C. *salmonis* migrates vertically in the water column in the Columbia River estuary. *Corophium volutator*, a related Atlantic species, has also been found to swim above the bottom during part of its life cycle (Hughes 1988). If C. *salmonis* populations in freshwater sections of the lower Columbia River exhibit similar behavior, they could be dispersed by river, currents. During the early part of the 1988 field season, we tried to sample invertebrate drift just above the bottom using an epibenthic sled; however, we were unable to consistently collect good samples. Often the epibenthic sled would fill with sand when towed along the bottom.

To investigate the possibility that juvenile white sturgeon were moving into shallow water to feed, monthly benthic sampling (June through September) was done in 1990 at shallow-water stations (1-6 m deep) adjacent to the deeper water stations (11-21 m deep) at RKm 153 and 211 (McCabe and Hinton 1991). At RKm 153, monthly mean densities of &. *salmonis* at individual stations in shallow water often exceeded 1,200 organisms/m*, whereas monthly mean densities at the deeper water stations generally were less than 105 organisms/m*. However, at RKm 211, monthly mean densities of C. *salmonis* at the three shallow-water stations were low and usually did not exceed 76 organisms/m*. The populations of C. *salmonis* found at the shallow-water stations at RKm 153 may represent a good food source for juvenile white sturgeon in the area. Although juvenile white sturgeon in the lower Columbia River typically favor deeper water (29.1 m) during daylight (McCabe and Hinton 1990), they may move into shallower water at night to feed. Studies using juvenile white sturgeon that have been tagged with sonic or radio tags are needed to describe their diel movements.

Juvenile white sturgeon may not be selectively preying on *Corophium salmonis* and *Corbicula flurninea.* They may be preying primarily on *Corophium salmonis* and secondarily on *Corbicula fluminea* because these invertebrates are more available to them than other benthic invertebrates. *Corophium salmonis* is a tube-dwelling amphipod that migrates vertically in the water column in the Columbia River estuary (Davis 1978). Also this amphipod has been observed crawling over the bottom in the Columbia River estuary (G. T. McCabe, Jr., personal observation). *Corbicula fluminea* is primarily a filter feeder (Way et a. 1990) with short siphons and apparently lives in close proximity to the substrate surface. Eulachon eggs, which were an important white sturgeon prey during May-June, are found attached to the substrate surface. Oligochaetes and Heleidae larvae are not necessarily substrate surface dependent and may be found deeper in the substrate, and therefore be largely unavailable to juvenile white sturgeon.

Benthic invertebrate populations were not sampled monthly, and it is likely that some invertebrate densities were higher or lower in May-June than indicated by the April survey. Also, numbers of invertebrates in October may have differed from those during the September survey. However, based on benthic data collected monthly at RKm 153 and 211 in 1990 (McCabe and Hinton 1991), it is unlikely that *Corophium salmonis* densities at the deeper water stations (typically where white sturgeon are more abundant during daylight) ever reached moderate or high densities. McCabe and Hinton (1991) observed that densities of C. *salmonis* fluctuated from June through September but remained low; densities never exceeded 380 organisms/m* and were usually less than or equal to 101/m$^2$.

Results from our study highlight the importance of benthic invertebrates, particularly C. *salmonis*, in the diets of juvenile white sturgeon in the lower Columbia River. Considering the importance of C. *salmonis*, its habitat must be protected. Accordingly, additional studies are needed to describe the distribution, abundance, and life history of this prominent invertebrate in the Columbia River.

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## REPORT P

# Distribution, Abundance, and Community Structure of Benthic Invertebrates in the Lower Columbia River

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## Abstract

The benthic invertebrate communities in eight areas of the lower Columbia River, extending from River Kilometer (RKm) 46 to 211, were sampled in April and September 1988 and 1989. We compared benthic invertebrate densities and two community structure indices, diversity (Shannon-Wiener function [HI) and equitability (E), within each area; in addition, we made comparisons between similar months of 1988 and 1989. In 1988, mean densities of benthic invertebrates often exceeded 1,000 organisms/$m^2$, whereas in 1989, mean densities were generally less than 1,000 organisms/$m^2$. There were no significant differences ($P > 0.05$) in benthic invertebrate densities between April and September in any of the areas in 1988; however, in 1989, densities were significantly higher ($P < 0.05$) in September than in April at RKm 46, 127, and 205. A comparison of similar months in 1988 and 1989 showed that densities were usually not significantly different. Mean diversity (H) at individual areas was low, ranging from 0.89 to 1.81. Mean equitability (E) was moderate at individual areas, ranging from 0.32 to 0.70 during the 2 years. up to four or five taxa were numerically dominant in each area. Common taxa collected throughout the lower river included Turbellaria, Oligochaeta, Corbicula fluminea, Corophium salmonis, Chironomidae larvae, and Heleidae larvae. Although this study has increased the scientific knowledge of benthic invertebrates in the lower Columbia River, much more research is needed to adequately describe the distribution, abundance, and ecology of these organisms.

## Introduction

The Columbia River downstream from Bonneville Dam, the lowermost dam on the river, supports large populations of migrating juvenile salmonids (Oncorhynchus spp.) and one of the largest populations of white sturgeon (Acipenser transmontanus). Studies of fish diets in the Columbia River during the last 13 years indicated that benthic invertebrates were often primary food for these fishes. The tube-dwelling amphipod Corophium salmonis was a primary prey for juvenile chinook (0. tshawvtscha) and coho (0. kisutch) salmon and steelhead (0. mvkiss) in the lower 62 km of the Columbia River (McCabe et al. 1983, 1986). At Jones Beach, Oregon (River Kilometer [RKm] 75), Kirn et al. (1986) observed that benthic amphipods were a primary prey for subyearling chinook salmon prior to the 1980 eruption of Mount St. Helens. Migrating juvenile steelhead and sockeye (0. nerka), coho, and chinook salmon collected at Bonneville Dam during April-June 1984 preyed heavily on Corophium salmonis and Corophium spinicorne (Muir and Emmett 1988). Juvenile white sturgeon <80 cm long (total length) collected in the lower Columbia River also preyed heavily on Corophium salmonis (Muir et al 1988, McCabe and Hinton 1990a). The bivalve Corbicula fluminea (= C. manilensis) was at times an important food for juvenile white sturgeon (McCabe and Hinton 1990a).

Although benthic invertebrates are important dietary items for juvenile salmon and white sturgeon, relatively little is known about the benthos of the Columbia River upstream from RKm 75. The benthic invertebrate communities in the Columbia River estuary (RKm 0-75), which includes marine, brackish, and freshwater environments, have been studied more than upstream populations (e.g., Higley and Holton 1978; Durkin and Emmett 1980; Durkin et al. 1981, 1982; Emmett et al. 1986; Hinton et al. 1990; Jones et al. 1990). Upstream from the estuary, benthic invertebrate studies have been limited primarily to short-term or geographically limited studies (e.g., Blahm and McConnell 1979, Blahm et al. 1979, McCabe and Hinton 1990b, McCabe et al. 1990). Sanborn (1975) studied the benthos at four areas in the Columbia River between RKm 29 and 167 in 1973-1974.

To elucidate the ecological relationships between the benthos and feeding habits of juvenile salmon and white sturgeon and other fishes, it is necessary to conduct systematic and long-term benthic invertebrate research throughout the river. To help achieve this goal, we studied the benthic invertebrate populations in eight areas of the lower Columbia River. The objectives of this study were to describe the distribution, abundance, and community structure of benthic invertebrate populations in one estuarine and seven areas of the lower Columbia River (upstream from RKm 75) extending from RKm 46 to RKm 211.

## Methods

### Sampling

The study was conducted in eight areas of the lower Columbia River between RKm 46 and RKm 211 in April and September 1988 and 1989; the sampling area at RKm 46 is in the estuary (Figure 1). In each area (designated by RKm), samples were collected along either two or three transects that paralleled the shorelines. Transect 1 was closest to the

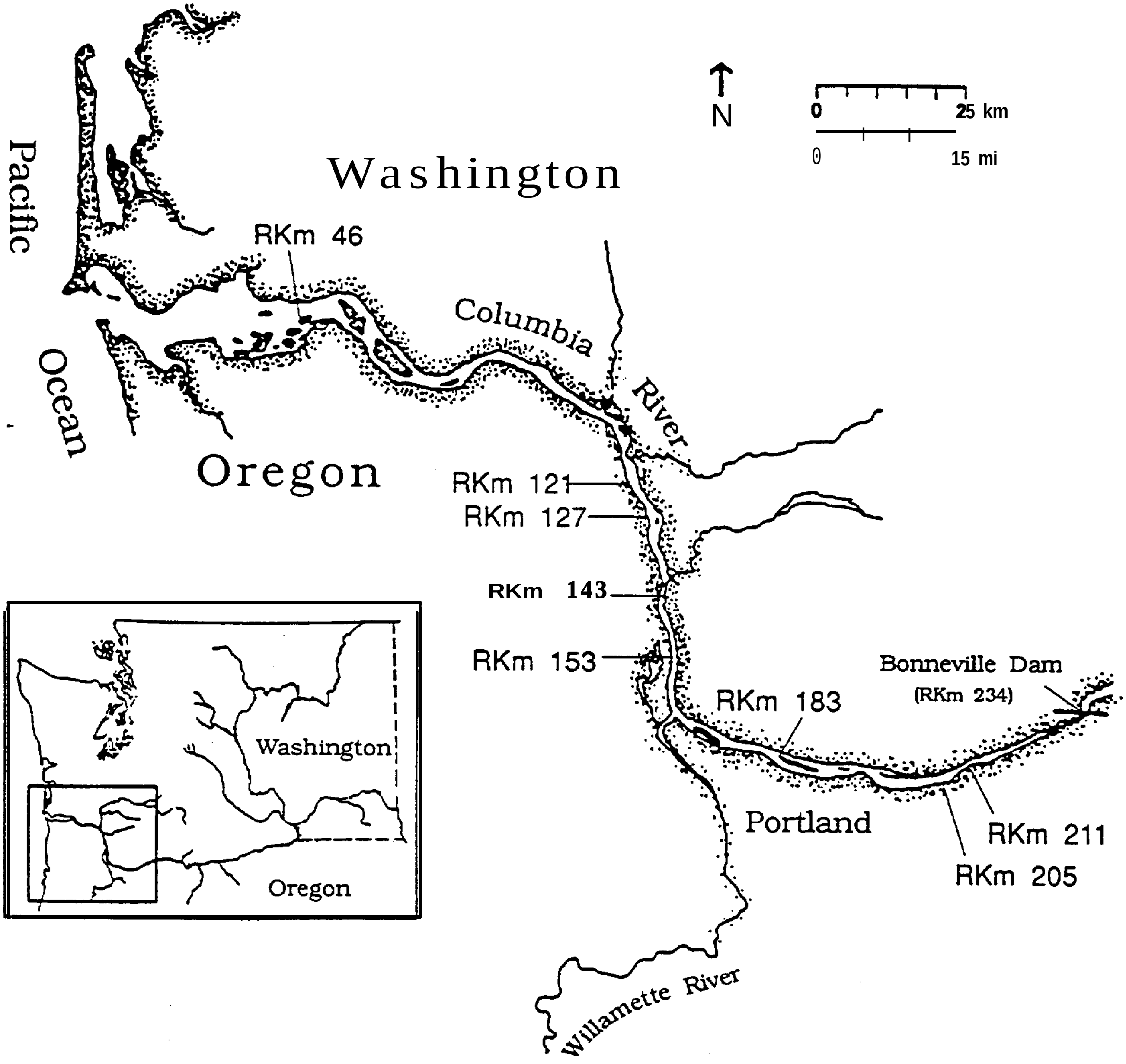

Figure 1. Map of the lower Columbia River showing the eight sampling areas.

Washington shore, Transect 2 was the middle transect, and Transect 3 was closest to the Oregon shore. In some river sections, only two transects were established.

During each survey, five benthic invertebrate samples and one sediment sample were collected at each sampling station with a $0.1\text{-m}^2$ Van Veen grab sampler (Word 1976). Two sampling stations about 185 m apart were established along each transect. When practical, each benthic invertebrate sample was sieved through a 0.5-mm screen in the field and the residue preserved in a buffered formaldehyde solution ($\geq$4%) containing rose bengal, an organic stain. If it appeared that most of the material would not wash through the sieve, the entire sample was preserved and sieved at a later time. Prior to sorting, all samples were washed with water and preserved in a 90% alcohol solution. Each benthic invertebrate sample was sorted and the invertebrates were identified to the lowest practical taxon and counted. Sediment samples were analyzed by the U.S. Army Corps of Engineers (North Pacific Division Materials Laboratory, Troutdale, Oregon) for sediment grain size and total volatile solids.

## Data Analysis

Benthic invertebrate data were analyzed by individual sampling station and by combining stations in an area. Information calculated for each station included the number of taxa, mean number/$\text{m}^2$ and standard deviation (SD) for each taxon and total mean number of invertebrates/$\text{m}^2$ and SD. Within a particular area, total benthic invertebrate densities were compared between months (April and September) for each year and between similar months of different years using a paired t-test (Ryan et al. 1985). The means from individual sampling stations provided the basic data entries for the statistical tests. Benthic invertebrate densities were transformed ($\log_{10}$) prior to analyses (Elliott 1977).

Two community structure indices (diversity and equitability) were calculated for each sampling station. Diversity was calculated using the Shannon-Wiener function (H) (Krebs 1978).

$$H = -\sum_{i=1}^{s} (p_i)(\log_2 p_i)$$

where $p_i$ = X,/n ($X_a$ is the number of individuals of a particular species in the sample, and n is the total number of all individuals in the sample) and s = number of species. Equitability (E) was the second community structure index; E measures the proportional abundances among the various species in a sample (Krebs 1978). E ranges from 0.00 to 1.00, with 1.00 indicating all species in the sample are numerically equal.

$$E = H/\log_2 s$$

where H = Shannon-Wiener function and s = number of species. H and E were calculated for each sampling station. For each area, individual comparisons for H and E were made between months using a paired t-test; comparisons were also made between similar months of 1988 and 1989.

## Results

Mean densities of benthic invertebrates (by area) in 1988 often exceeded 1,000 organisms/m$^2$; however, in 1989, mean densities were less than 1,000 organisms/m$^2$, except in September 1989 at RKm 46 (Tables 1 and 2). In 1988, benthic invertebrate densities at all individual areas were not significantly different between April and September (paired t-test, $P > 0.05$); however, in 1989, densities were significantly higher in September than in April at RKm 46, 127, and 205 ($P < 0.05$). Comparing similar months in 1988 and 1989 showed that the mean density was significantly higher in April 1988 than in April 1989 at RKm 143 (paired t-test, $P < 0.05$), and the mean density was significantly higher in September 1988 than in September 1989 at RKm 46.

The number of benthic invertebrate taxa collected in the lower Columbia River ranged from a low of 19 in September 1989 to a high of 25 in April 1988; in both September 1988 and April 1989, 21 taxa were collected (Table 3). The number of taxa collected at individual stations ranged from 4 to 13 in April 1988, from 4 to 13 in September 1988, from 3 to 13 in April 1989, and from 5 to 10 in September 1989. In each area, up to four or five taxa were numerically dominant. Common taxa collected throughout the lower river included Turbellaria, Oligochaeta, *Corbicula fluminea*, *Corophium salmonis*, Chironomidae larvae, and Heleidae larvae (Tables 4 and 5).

In 1988 and 1989, mean densities of *Corophium salmonis* were low throughout the study area upstream from RKm 46 (Tables 4 and 5). In 1988, mean densities of *Corophium salmonis* in this area never exceeded 184 organisms/m$^2$; and in 1989, mean densities never exceeded 651 organisms/m$^2$. There was no distinct monthly pattern in the abundance of *Corophium salmonis* (Tables 4 and 5). In some areas, mean densities of *Corophium salmonis* were similar in April and September, whereas in other areas they were considerably different.

Mean densities of the bivalve *Corbicula fluminea* were usually less than 500 organisms/m$^2$ in each area in 1988 and generally less than 300 organisms/m$^2$ in 1989 (Tables 4 and 5). Similar to *Corophium salmonis*, there was no distinct monthly pattern in the abundance of *Corbicula fluminea* (Tables 4 and 5).

Mean diversity (H) by area ranged from 0.89 to 1.81 in 1988 and from 0.92 to 1.80 in 1989 (Tables 1 and 2). The low diversity values were the result of the unequal proportional abundances of taxa or the small number of taxa at sampling stations. In 1988, H values were significantly different between April and September only at RKm 143 and 153 (paired t-test, $P < 0.05$), with the highest values occurring in April. In 1989, H was significantly higher in April than in September at RKm 46 ($P < 0.05$). H did not differ significantly for similar months in 1988 and 1989, except at RKm 46. H at RKm 46 was significantly higher in September 1988 than in September 1989 ($P < 0.05$).

Mean equitability (E) was moderate among areas, ranging from 0.35 to 0.7 in 198 and from 0.3 to 0.6 in 198 (Tables 1 and 2). The moderate

TABLE 1. Summary of benthic invertebrate densities (number/$m^2$) and community structure indices (H and E) at eight sampling areas (RKm-transect) of the lower Columbia River, 1988. The mean depth (m) for each transect is also indicated. The total benthic invertebrate density for each area (by season) was calculated by combining all samples taken in that area; an asterisk (*) indicates that less than five samples from a sampling station were analyzed. The totals for H and E represent means of the transect values.

| Area (depth) | April | | | | September | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | H | E | Mean | SD | H | E |
| 46-1 (12.9) | 344 | 275 | 1.80 | 0.74 | 2,754 | 1,794 | 1.18 | 0.40 |
| 46-2 (8.8) | 6,897* | 8,319 | 1.06 | 0.34 | 2,409 | 1,411 | 1.30 | 0.42 |
| 46-3 (12.3) | 2,263 | 1,214 | 2.08 | 0.58 | 5,859 | 1,149 | 1.20 | 0.36 |
| Total | 3,039 | 5,279 | 1.65 | 0.55 | 3,674 | 2,125 | 1.23 | 0.39 |
| 121-1 (14.8) | 353 | 215 | 1.48 | 0.60 | 2,042 | 1,601 | 1.44 | 0.52 |
| 121-3 (11.8) | 394 | 366 | 2.14 | 0.70 | 1,224 | 1,423 | 1.59 | 0.58 |
| Total | 374 | 293 | 1.81 | 0.65 | 1,633 | 1,533 | 1.52 | 0.55 |
| 127-1 (19.4) | 405 | 361 | 1.49 | 0.60 | 2,034 | 1,524 | 1.59 | 0.56 |
| 127-2 (12.3) | 343 | 262 | 1.21 | 0.49 | 451 | 500 | 1.16 | 0.44 |
| 127-3 (8.4) | 511 | 287 | 1.46 | 0.56 | 711 | 296 | 1.28 | 0.52 |
| Total | 420 | 304 | 1.39 | 0.55 | 1,065 | 1,150 | 1.34 | 0.51 |
| 143-1 (6.2) | 1,022 | 519 | 1.86 | 0.76 | 732 | 647 | 1.49 | 0.55 |
| 143-3 (15.2) | 1,412 | 825 | 1.46 | 0.64 | 712 | 415 | 1.13 | 0.46 |
| Total | 1,217 | 700 | 1.66 | 0.70 | 722 | 530 | 1.31 | 0.50 |
| 153-1 (19.3) | 2,289 | 2,174 | 1.59 | 0.65 | 2,507 | 956 | 1.04 | 0.36 |
| 153-2 (12.4) | 1,556 | 1,038 | 1.26 | 0.51 | 251 | 202 | 1.07 | 0.44 |
| 153-3 (6.3) | 1,125* | 794 | 1.94 | 0.62 | 625 | 377 | 0.56 | 0.24 |
| Total | 1,694 | 1,527 | 1.60 | 0.59 | 1,128 | 1,161 | 0.89 | 0.35 |
| 183-1 (7.7) | 454 | 204 | 1.16 | 0.50 | 1,417 | 1,219 | 1.42 | 0.48 |
| 183-3 (6.6) | 905 | 1,020 | 0.94 | 0.38 | 1,556 | 1,411 | 1.58 | 0.51 |
| Total | 680 | 753 | 1.05 | 0.44 | 1,486 | 1,285 | 1.50 | 0.50 |

Table 1.--Continued.

| Area (depth) | April | | | | September | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | H | E | Mean | SD | H | E |
| 205-1 (7.6) | 143 | 115 | 1.72 | 0.80 | 103 | 84 | 1.12 | 0.52 |
| 205-3 (15.8) | 758 | 618 | 1.17 | 0.48 | 1,797 | 1,379 | 1.10 | 0.49 |
| Total | 450 | 536 | 1.44 | 0.64 | 950 | 1,288 | 1.11 | 0.50 |
| 211-1 (14.2) | 2,056* | 1,182 | 1.19 | 0.44 | 1,110 | 558 | 1.59 | 0.51 |
| 211-2 (16.8) | 951 | 1,178 | 1.38 | 0.60 | 739 | 582 | 1.44 | 0.50 |
| 211-3 (6.2) | 1,080 | 285 | 1.87 | 0.56 | 1,016 | 810 | 1.70 | 0.51 |
| Total | 1,338 | 1,055 | 1.48 | 0.53 | 955 | 657 | 1.58 | 0.51 |

TABLE 2. Summary of benthic invertebrate densities (number/$m^2$) and community structure indices (H and E) at eight sampling areas (RKm-transect) of the lower Columbia River, 1989. The mean depth (m) for each transect is also indicated. The total benthic invertebrate density for each area (by season) was calculated by combining all samples taken in that area; an asterisk (*) indicates that less than five samples from a sampling station were analyzed. The totals for H and E represent means of the transect values.

| Area (depth) | April | | | | September | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | H | E | Mean | SD | H | E |
| 46-1 (13.2) | 222 | 71 | 1.94 | 0.70 | 1,697 | 1,670 | 1.06 | 0.40 |
| 46-2 (8.2) | 959 | 248 | 1.74 | 0.58 | 1,525 | 450 | 0.96 | 0.34 |
| 46-3 (13.7) | 1,360 | 964 | 1.64 | 0.52 | 3,222 | 1,172 | 0.74 | 0.22 |
| Total | 847 | 734 | 1.77 | 0.60 | 2,148 | 1,399 | 0.92 | 0.32 |
| 121-1 (14.9) | 572 | 302 | 1.27 | 0.48 | 477 | 359 | 1.54 | 0.56 |
| 121-3 (11.5) | 124 | 107 | 1.42 | 0.58 | 663 | 362 | 1.41 | 0.54 |
| Total | 348 | 318 | 1.34 | 0.53 | 570 | 364 | 1.48 | 0.55 |
| 127-1 (18.5) | 788 | 734 | 1.08 | 0.40 | 1,132 | 678 | 1.92 | 0.68 |
| 127-2 (12.0) | 227 | 186 | 0.97 | 0.48 | 678 | 393 | 1.44 | 0.56 |
| 127-3 (8.4) | 59 | 34 | 1.24 | 0.56 | 999 | 542 | 1.10 | 0.45 |
| Total | 358 | 528 | 1.10 | 0.48 | 936 | 565 | 1.49 | 0.56 |
| 143-1 (5.2) | 178 | 180 | 1.40 | 0.70 | 1,107 | 468 | 0.88 | 0.34 |
| 143-3 (15.5) | 325 | 321 | 1.34 | 0.52 | 553* | 421 | 1.58 | 0.58 |
| Total | 252 | 264 | 1.37 | 0.61 | 844 | 519 | 1.23 | 0.46 |
| 153-1 (19.9) | 1,544 | 1,297 | 1.50 | 0.58 | 859 | 650 | 1.24 | 0.46 |
| 153-2 (12.4) | 270 | 204 | 1.53 | 0.57 | 557 | 350 | 1.26 | 0.54 |
| 153-3 (5.3) | 524 | 290 | 1.59 | 0.64 | 1,325 | 627 | 1.08 | 0.42 |
| Total | 779 | 935 | 1.54 | 0.60 | 914 | 628 | 1.19 | 0.47 |
| 183-1 (7.4) | 433 | 223 | 1.49 | 0.55 | 351 | 167 | 1.45 | 0.54 |
| 183-3 (6.3) | 191 | 149 | 1.25 | 0.50 | 409 | 242 | 0.72 | 0.30 |
| Total | 312 | 223 | 1.37 | 0.52 | 380 | 205 | 1.08 | 0.42 |

Table 2.--Continued.

| Area (depth) | April | | | | September | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | H | E | Mean | SD | H | E |
| | 51 | 34 | | | | | | |
| 205-1 (7.8) | 596 | 633 | 1.88 | 0.84 | 379 | 207 | 1.26 | 0.45 |
| 205-3 (16.1) | | | 1.06 | 0.46 | 1,434 | 1,197 | 1.40 | 0.46 |
| Total | 324 | 518 | 1.47 | 0.65 | 907 | 996 | 1.33 | 0.46 |
| 211-1 (14.8) | 166 | 69 | 1.30 | 0.57 | 843 | 346 | 1.84 | 0.64 |
| 211-2 (16.8) | 221 | 134 | 2.04 | 0.84 | 326 | 133 | 1.56 | 0.56 |
| 211-3 (5.2) | 1,869 | 954 | 1.66 | 0.47 | 555 | 227 | 2.00 | 0.67 |
| Total | 752 | 968 | 1.67 | 0.63 | 575 | 324 | 1.80 | 0.62 |

TABLE 3. Occurrence of benthic invertebrates in the lower Columbia River between RKm 46 and 211, 1988-1989. Presence is indicated by a "+" and absence by a "0."

| Taxon | 1988 | | 1989 | |
|---|---|---|---|---|
| | April | September | April | September |
| Turbellaria | + | t | t | t |
| Nemertea | 0 | t | t | t |
| Nematoda | + | 0 | 0 | 0 |
| Nematomorpha | t | + | + | t |
| Polychaeta | t | 0 | 0 | 0 |
| *Neanthes limnicola* | t | t | t | + |
| Oligochaeta | t | t | t | t |
| Hirudinea | 0 | 0 | t | 0 |
| *Anodonta* spp. | 0 | 0 | 0 | + |
| *Corbicula fluminea* | t | + | t | t |
| *Fluminicola* spp. | t | + | t | t |
| *Fluminicola virens* | + | 0 | 0 | 0 |
| *Juga* spp. | 0 | t | t | 0 |
| Ostracoda | t | + | t | t |
| Isopoda | t | 0 | + | 0 |
| *Gnorimosphaeroma oregonensis* | 0 | 0 | 0 | 0 |
| *Asellus occidentalis* | 0 | t | | 0 |
| *Porcellio scaber* | 0 | t | t | 0 |
| Gammaridae (Amphipoda) | + | 0 | 0 | t |
| *Corophium* spp. | 0 | t | t | t |
| *Corophium salmonis* | t | + | t | t |
| *Corophium spinicorne* | t | t | t | t |
| *Ramellogammarus oregonensis* | t | 0 | t | t |
| *Hyalella azteca* | 0 | t | + | |
| Phoxocephalidae (Amphipoda) | t | 0 | 0 | 0 |
| Arachnoidea (aquatic) | 0 | t | 0 | t |
| Ephemeroptera nymph | t | 0 | 0 | 0 |
| Odonata nymph | 0 | + | 0 | + |
| Plecoptera nymph | + | 0 | 0 | 0 |
| Trichoptera larvae | t | t | 0 | 0 |
| Diptera pupae | t | 0 | 0 | 0 |
| Tipulidae larvae | t | 0 | 0 | 0 |
| Chironomidae larvae | t | t | t | t |
| Chironomidae pupae | t | + | t | t |
| Heleidae larvae | t | t | t | t |
| Heleidae pupae | t | 0 | t | 0 |
| Total number | 25 | 21 | 21 | 19 |

TABLE 4. Mean densities (number/$m^2$) and standard deviations (SD) of benthic invertebrates collected in April and September 1988 between RKm 46 and 211 in the Columbia River. Less common taxa are included in the totals, but are not listed individually. Depending upon the number of transects, generally 20-30 samples were collected at each RKm.

| RKm | Taxon | April 1988 | | September 1988 | |
|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD |
| 46 | Turbellaria | 33 | 52 | 8 | 19 |
| | Neanthes limnicola | 9 | 23 | 43 | 72 |
| | Oligochaeta | 46 | 59 | 118 | 201 |
| | Corbicula fluminea | 232 | 381 | 169 | 215 |
| | Fluminicola spp. | 84 | 201 | 166 | 321 |
| | Coroohium salmonis | 2,420 | 5,337 | 2,229 | 1,873 |
| | Chironomidae larvae | 21 | 37 | 6 | 10 |
| | Heleidae larvae | 165 | 185 | 904 | 1,178 |
| | Total | 3,039 | 5,279 | 3,674 | 2,125 |
| 121 | Turbellaria | 41 | 68 | 2 | 7 |
| | Oligochaeta | 51 | 103 | 117 | 161 |
| | Corbicula fluminea | 59 | 112 | 480 | 490 |
| | CoroDhium salmonis | 46 | 86 | 44 | 71 |
| | Chironomidae larvae | 26 | 37 | 7 | 12 |
| | Heleidae larvae | 146 | 126 | 979 | 1,003 |
| | Total | 374 | 293 | 1,633 | 1,533 |
| 127 | Turbellaria | 33 | 82 | 2 | 6 |
| | Oligochaeta | 32 | 68 | 306 | 516 |
| | Corbicula fluminea | 154 | 218 | 320 | 528 |
| | Corophium salmonis | 27 | 39 | 127 | 158 |
| | Chironomidae larvae | 11 | 13 | 3 | 9 |
| | Heleidae larvae | 161 | 161 | 302 | 371 |
| | Total | 420 | 304 | 1,065 | 1,150 |
| 143 | Turbellaria | 105 | 144 | 1 | 3 |
| | Oligochaeta | 149 | 379 | 48 | 57 |
| | Corbicula fluminea | 198 | 129 | 336 | 378 |
| | Coronhium salmonis | 117 | 197 | 11 | 16 |
| | Chironomidae larvae | 14 | 18 | 2 | 4 |
| | Heleidae larvae | 635 | 563 | 323 | 266 |
| | Total | 1,217 | 700 | 722 | 530 |

TABLE 4 --Continued.

| RKm | Taxon | April 1988 |  | September 1988 |  |
|---|---|---|---|---|---|
|  |  | Mean | SD | Mean | SD |
| 153 | Turbellaria | 28 | 45 | 2 | 4 |
|  | Oligochaeta | 151 | 321 | 619 | 967 |
|  | Corbicula fluminea | 733 | 980 | 107 | 135 |
|  | CoroDhium salmonis | 122 | 226 | 184 | 298 |
|  | Chironomidae larvae | 36 | 67 | 2 | 5 |
|  | Heleidae larvae | 606 | 780 | 213 | 264 |
|  | Total | 1,694 | 1,527 | 1,128 | 1,161 |
| 183 | Turbellaria | 9 | 19 | 3 | 7 |
|  | Oligochaeta | 1 | 2 | 21 | 38 |
|  | Corbicula fluminea | 189 | 148 | 476 | 494 |
|  | Coroohium salmonis | 5 | 8 | 43 | 56 |
|  | Chironomidae larvae | 5 | 11 | 38 | 59 |
|  | Heleidae larvae | 472 | 643 | 886 | 941 |
|  | Total | 680 | 753 | 1,486 | 1,285 |
| 205 | Oligochaeta | 0 | 0 | 20 | 39 |
|  | Corbicula fluminea | 307 | 532 | 371 | 504 |
|  | Coroohium salmonis | 23 | 29 | 4 |  |
|  | Chironomidae larvae | 40 | 142 | 1 | 3 |
|  | Heleidae larvae | 73 | 45 | 553 | 818 |
|  | Total | 450 | 536 | 950 | 1,288 |
| 211 | Turbellaria | 31 | 80 | 10 | 20 |
|  | Oligochaeta | 144 | 228 | 238 | 457 |
|  | Corbicula fluminea | 640 | 813 | 266 | 303 |
|  | Ostracoda | 20 | 60 | 2 | 5 |
|  | Coroohium salmonis | 116 | 165 | 79 | 113 |
|  | Chironomidae larvae | 33 | 39 | 21 | 38 |
|  | Heleidae larvae | 349 | 492 | 314 | 349 |
|  | Total | 1,338 | 1,055 | 955 | 657 |

TABLE 5. Mean densities (number/m$^2$) and standard deviations (SD) of benthic invertebrates collected in April and September 1989 between RKm 46 and 211 in the Columbia River. Less common taxa are included in the totals, but are not listed individually. Depending upon the number of transects, generally 20-30 samples were collected at each RKm.

| RKm | Taxon | April 1989 | | September 1989 | |
|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD |
| 46 | Turbellaria | 40 | 51 | 5 | 25 |
| | *Neanthes limnicola* | 20 | 30 | 32 | 56 |
| | Oligochaeta | 40 | 68 | 11 | 19 |
| | *Corbicula fluminea* | 82 | 91 | 69 | 63 |
| | *Fluminicola* spp. | 201 | 475 | 44 | 99 |
| | *Coroohium salmonis* | 221 | 287 | 1,792 | 1,412 |
| | Chironomidae larvae | 17 | 21 | 2 | 4 |
| | Heleidae larvae | 220 | 287 | 185 | 204 |
| | Total | 847 | 734 | 2,148 | 1,399 |
| 121 | Turbellaria | 19 | 36 | 2 | 5 |
| | Oligochaeta | 27 | 44 | 28 | 49 |
| | *Corbicula fluminea* | 30 | 37 | 177 | 207 |
| | *Coroohium salmonis* | 4 | 7 | 39 | 48 |
| | Chironomidae larvae | 10 | 9 | 3 | 7 |
| | Heleidae larvae | 258 | 263 | 318 | 250 |
| | Total | 348 | 318 | 570 | 364 |
| 127 | Turbellaria | 27 | 61 | 12 | 24 |
| | Oligochaeta | 70 | 251 | 140 | 269 |
| | *Corbicula fluminea* | 15 | 18 | 318 | 350 |
| | *Coroohium salmonis* | 1 | 3 | 256 | 332 |
| | Chironomidae larvae | 7 | 8 | 4 | 8 |
| | Heleidae larvae | 238 | 383 | 205 | 201 |
| | Total | 358 | 528 | 936 | 565 |
| 143 | Turbellaria | 6 | 13 | 6 | 23 |
| | Oligochaeta | 13 | 18 | 15 | 22 |
| | *Corbicula fluminea* | 38 | 51 | 91 | 56 |
| | *CoroDhium salmonis* | 29 | 86 | 651 | 532 |
| | Chironomidae larvae | 1 | 3 | 8 | 13 |
| | Heleidae larvae | 164 | 228 | 48 | 43 |
| | Total | 251 | 264 | 844 | 519 |

TABLE 5.--Continued.

| RKm | Taxon | April 1989 | | September 1989 | |
|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD |
| 153 | Turbellaria | 2 | 6 | 1 | 2 |
| | Oligochaeta | 227 | 546 | 211 | 371 |
| | <u>Corbicula fluminea</u> | 263 | 489 | 138 | 181 |
| | <u>Coronhium salmonis</u> | 54 | 76 | 359 | 663 |
| | Chironomidae larvae | 5 | 7 | 14 | 23 |
| | Heleidae larvae | 228 | 232 | 190 | 196 |
| | Total | 779 | 935 | 914 | 628 |
| 183 | Turbellaria | 6 | 13 | 3 | 9 |
| | Oligochaeta | 1 | 3 | 7 | 14 |
| | <u>Corbicula fluminea</u> | 90 | 115 | 60 | 84 |
| | <u>CoroDhium salmonis</u> | 5 | 8 | 8 | 18 |
| | Chironomidae larvae | 21 | 29 | 7 | 23 |
| | Heleidae larvae | 189 | 144 | 291 | 195 |
| | Total | 312 | 223 | 380 | 205 |
| 205 | Oligochaeta | 129 | 291 | 195 | 436 |
| | <u>Corbicula fluminea</u> | 16 | 37 | 298 | 663 |
| | <u>Coroohium salmonis</u> | 13 | 16 | 12 | 20 |
| | Chironomidae larvae | 2 | 4 | 33 | 48 |
| | Heleidae larvae | 161 | 251 | 360 | 216 |
| | Total | 323 | 518 | 907 | 996 |
| 211 | Turbellaria | 2 | 7 | 1 | 2 |
| | Oligochaeta | 321 | 693 | 131 | 122 |
| | <u>Corbicula fluminea</u> | 70 | 50 | 106 | 164 |
| | Ostracoda | 2 | 7 | 14 | 39 |
| | <u>Coroohium salmonis</u> | 241 | 337 | 141 | 146 |
| | Chironomidae larvae | 33 | 47 | 32 | 41 |
| | Heleidae larvae | 65 | 74 | 143 | 189 |
| | Total | 752 | 968 | 574 | 324 |

values observed at most areas were caused by the numerical dominance of several taxa (Tables 4 and 5). In 1988, E values were significantly higher in April than in September at RKm 143 and 153 (paired t-test, $P < 0.05$). In 1989, E was significantly higher in April than in September at RKm 46 ($P < 0.05$). Comparing similar months in 1988 and 1989 showed one significant difference--E was higher in September 1989 than in September 1988 at RKm 211 ($P < 0.05$).

In areas that had both shallow (mean depth 57.0 m) and deep (>7.0 m) stations, there were no apparent relationships between depths and benthic invertebrate densities (Tables 1 and 2).

Sand (grain size 0.0625 to t2 mm diameter) frequently composed more than 80% of the substrate along individual transects in both 1988 and 1989 (see McCabe *et al*. 1989 and McCabe and Hinton 1990a for a more detailed description of the sediment analyses).

## Discussion

It is often difficult to compare data from benthic invertebrate studies done by different investigators. Frequently, there are differences in samplers, sieve sizes, sampling designs, and analyses used by researchers. Given this, we will compare findings from the present study to other large-river benthic invertebrate studies. In the lower Columbia River, we observed benthic invertebrate densities and number of taxa somewhat similar to those reported for the Fraser River, British Columbia, and the Hudson River, New York (Northcote *et al*. 1976, Ristich in *al*. 1977). In the mainstem of the Fraser River, Northcote et fl. (1976) found that annual densities of benthic organisms (including lamprey ammocoetes) usually averaged about 1,000 organisms/$m^2$, with seasonal averages generally the highest in the spring; the mean number of taxa per sample at each station was about 5 (range of 1 to 14). Dipteran larvae and oligochaetes were the dominant taxa in the mainstem of the Fraser River. Ristich et al. (1977) observed that densities of benthic invertebrates at freshwater stations in the lower Hudson River generally averaged less than 1,000 organisms/$m^2$ during the four sampling periods; the number of taxa at individual stations ranged from two to eight. Dominant taxa in freshwater areas of the Hudson River included oligochaetes, chironomids, and other insect species. In the lower Columbia River, annual benthic invertebrate densities at individual areas frequently exceeded 1,000/$m^2$ in 1988; however, in 1989, annual benthic invertebrate densities generally averaged less than 1,000 organisms/$m^2$. The number of taxa collected at individual stations in the lower Columbia River ranged from 4 to 13 in 1988 and from 3 to 13 in 1989. In contrast to the Fraser and Hudson rivers, bivalves (*Corbicula fluminea*) and amphipods (*Coroohium salmonis*) were much more dominant in the benthos of the lower Columbia River (Tables 4 and 5).

Diversity (H) at individual stations in the mainstem of the lower Fraser River usually ranged between 2.00 and 3.00 (Northcote *et al*. 1976), whereas in the lower Columbia River, H values generally ranged between 1.00 and 2.00 (Tables 1 and 2). Diversity values for the Fraser River were calculated by combining all samples from an individual station;

however, samples from individual stations in the lower Columbia River were combined only by transect (two stations per transect) for each survey. Combining of the Fraser River samples was probably one reason for the higher H values.

Benthic invertebrate densities in the present study were considerably less than those observed at four shallow subtidal stations (RKm 30 to 40) in Cathlamet Bay, a primarily freshwater bay in the Columbia River estuary. Densities at the four stations, which were sampled from April through September 1984, generally exceeded 20,000 organisms/m$^2$, and in some instances exceeded 200,000 organisms/m$^2$ (Emmett et al. 1986). Emmett et in. (1986) used coring devices which penetrated 15 cm into the substrate; their samples were then washed through a 0.25-mm mesh screen. The Van Veen grab sampler used in our study probably did not routinely penetrate 15 cm into the substrate; in addition, samples were washed through a 0.5-mm mesh screen. Some of the abundant taxa observed in the Cathlamet Bay study included Nematoda, Oligochaeta, Ostracoda, Scottolana canadensis (Copepoda), Corbicula fluminea, and Corophium salmonis. In tidal-fluvial areas of the Columbia River estuary, benthic invertebrate densities in main channel side (5.5-9.1 m deep) and main channel center (>9.1 m deep) habitats averaged 2,400 and 2,620 organisms/m$^2$, respectively, in September 1981 (Jones et al. 1990).

In The Dalles Reservoir (Columbia River), 74 to 113 km upstream from Bonneville Dam, benthic invertebrate densities were much higher than densities observed in the lower Columbia River. At the seven locations sampled in The Dalles Reservoir, benthic invertebrate densities exceeded 3,600 organisms/m$^2$ in May and September 1988; occasionally, densities exceeded 30,000 organisms/m$^2$ at individual stations (Parsley et al. 1989). During the same time period in our study, benthic invertebrate densities in the lower Columbia River never approached 3,600 organisms/m$^2$, with the exception of densities at RKm 46 (Table 1).

The lower Columbia River is a navigational channel for commercial ships and barges and requires periodic dredging to maintain adequate depths. Dredged material is often disposed at deep in-water areas in the lower river. Dredging or disposal operations could impact benthic invertebrate populations in channel areas downstream from RKm 205.

One of the most abundant organisms in the benthos of the lower Columbia River is the exotic bivalve Corbicula fluminea, introduced into North America in the late 1800s (McMahon 1982). This species has prospered since its introduction into the Columbia River.

Although the present study has increased the scientific knowledge of benthic invertebrates in the lower Columbia River, much more research is needed to adequately describe the distribution, abundance, and ecology of these organisms. Our sampling was limited to main channel areas of the lower Columbia River; sampling of shallow littoral areas, backwaters, and shallow side channels should be conducted, since there is some evidence to suggest that densities of Corophium salmonis, an important food for fishes, may be considerably higher in shallow littoral areas. McCabe and

Hinton (1991) observed that Corophium salmonis densities at shallow-water stations (2-5 m deep) at RKm 153 frequently exceeded 1,200 organisms/$m^2$. Besides sampling additional habitat types, it is also important to establish long-term studies of benthic invertebrate populations in the lower Columbia River to describe natural temporal variations. These studies are necessary to determine the effects of man-made and natural perturbations in the lower Columbia River. Within the last 15 years, there have been two major oil spills (1978 and 1984) and one natural disaster, the eruption of Mount St. Helens in 1980, that impacted the benthos of the lower Columbia River. Without long-term studies, it is impossible to determine the extent of the effects of such perturbations on the benthic invertebrate communities. Since benthic invertebrates, particularly Corophium salmonis, are primary prey for many fishes, the sustained health of benthic invertebrate populations in the lower Columbia River should be of concern.

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# Mortality and Pathology

# REPORT Q

# Recreational and Commercial Fisheries in the Columbia River Between Bonneville and McNary Dams, 1987-1991

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## Abstract

The Washington Department of Fisheries surveyed the recreational and commercial fisheries in Bonneville, The Dalles, and John Day reservoirs from 1987 to 1991. The recreational fisheries for sturgeon, salmonids, shad, walleye, smallmouth bass, and other resident fish were sampled during a significant portion of the year and throughout each reservoir. Angler surveys and aerial counts were used to estimate effort, harvest, and catch per effort (CPUE) for all species examined in the creel.

Recreational fisheries for sturgeon and salmonids were dominant in Bonneville and The Dalles reservoirs, while fisheries for walleye and smallmouth bass were most important in John Day Reservoir.

Anglers harvested an average of 2,148 white sturgeon, 1,322 salmonids (chinook, steelhead, and coho), 101 shad, 937 walleye and 1,185 smallmouth bass from Bonneville Reservoir each year from March-October, 1988-1990. Anglers averaged 25,700 trips each year, of which 47% were for sturgeon, 42% for salmonids, 5% for walleye, 6% for smallmouth bass and < 1% for shad.

Anglers harvested 1,990white sturgeon, 1,264 salmonids (chinook, coho and steelhead), 1,176 shad, 1,666 walleye, and 1,359 smallmouth bass from The Dalles Reservoir in 1987 (June-October). The March-October 1988-1989 harvest averaged 703 white sturgeon, 1,741 salmonids (chinook, coho, and steelhead), 3,477 shad, 5,518 walleye and 938 smallmouth bass. There was a total of 29,329 angler trips June-October in 1987. Anglers averaged 24,962 trips March-October, 1988-89. Thirty-five percent of angler trips were for sturgeon, 43% for salmonids, 3% for shad, 18% for walleye, and 1% for smallmouth bass during the three years.

The May-July 1989 harvest from John Day Reservoir included 283 white sturgeon, 8 steelhead, 1,303 shad, 1,718 walleye, and 4,776 smallmouth bass. The April-September 1990-1991 recreational fishery harvested an average of 203 white sturgeon, 77 salmonids (chinook, coho, and steelhead), 2,641 shad, 2,475 walleye, 5,888 smallmouth bass each year. There was a total of 19,784 angler trips May-July in 1989, 34,834 trips March-December in 1990, and 29,929 trips April-September in 1991. The 1989-1991 average distribution of these trips was 28% for white sturgeon, 4% for salmonids, 1% for shad, 33% for walleye, and 24% for smallmouth bass.

Estimated effort, harvest, and CPUE for white sturgeon in the recreational fisheries declined each year we surveyed The Dalles and John Day reservoirs. Sturgeon angling effort decreased from 71,078 hours in 1987 to 45,684 hours in 1989 for The Dalles Reservoir and from 51,824 hours in 1989 to 33,993 hours in 1991 for John Day Reservoir. Harvest estimates of legal size white sturgeon for these time periods also decreased from 1,990 to 499 in The Dalles Reservoir and from 283 to 143 in John Day Reservoir. Reduced catch rates and harvest correspond to both lower stock abundance and implementation of more restrictive harvest regulations recommended by the Sturgeon Management Task Force (SMTF) and adopted by the regulatory state fishery agencies. This same trend was not

observed during our survey of the white sturgeon recreational fishery in Bonneville Reservoir. Angling effort for sturgeon increased from 55,776 hours in 1988 to 83,924 hours in 1990. Harvest of white sturgeon also increased from 1,532 to 2,114 for the same years. Effort, harvest and CPUE in Bonneville Reservoir appeared stable relative to The Dalles and John Day reservoirs.

Tribal commercial fishery landings were sampled for white sturgeon harvest, mark and biological information from 1987 to 1991. The estimated harvest of white sturgeon peaked in 1987 when over 11,000 white sturgeon were harvested during the tribal commercial fisheries. Since then, conservative harvest guidelines have been recommended each year by the SMTF and adopted by the Columbia River Compact resulting in tribal commercial harvest reductions.

# INTRODUCTION

Recreational and commercial fisheries on the middle Columbia River (Bonneville to McNary dams) have changed significantly since the construction of hydroelectric dams (Craig and Hacker 1940; WDF and ODFW 1992). Studies indicate that anglers spend more time fishing for resident fish and less time fishing for salmonids (King 1981; Beamesderfer et al. 1990). New recreational fisheries have developed in recent years, including a sport fishery for walleye and a sport reward fishery for northern squawfish (Vigg et al. 1990). The recreational fishery for white sturgeon *Acipenser transmontanus* has continued to be one of the most important fisheries on the middle Columbia River despite habitat alterations and resulting changes in fisheries. However, recent increases in white sturgeon recreational and commercial harvest have fishery managers concerned about the status of this resource.

The Washington Department of Fisheries (WDF) was responsible for surveying the white sturgeon recreational fishery in Bonneville, The Dalles, and John Day reservoirs as part of a six year multi-agency study funded by the Bonneville Power Administration to determine the impacts of hydroelectric dams on white sturgeon populations downstream of McNary Dam. A comprehensive angler census was initiated in The Dalles Reservoir in 1987 and then expanded to Bonneville Reservoir in 1988 and John Day Reservoir in 1989. The census was conducted in each reservoir for three consecutive years. The objective of this survey was to estimate fishing effort, harvest, and catch rate for all species harvested during the census period and to provide Oregon Department of Fish and Wildlife (ODFW) with mark recovery information and biological samples from white sturgeon (North et al. 1992; Rien and Beamesderfer 1992; Rien et al. 1992).

Recreational fisheries that harvest other resident and anadromous fish from these reservoirs were also described in this report. Walleye *Stizostedion vitreum vitreum* and smallmouth bass *Micropterus dolomieui* were the resident species most frequently targeted by anglers. Other resident fish incidentally harvested include largemouth bass *Micropterus sa7moides*, white crappie Pomoxis *annulars*, black crappie P. *nigromaculatus* bluegill *Lepomis macrochirus*, yellow perch *Perca flavescens* carp *Cyprinus carpio*, northern squawfish *Ptychocheilus oregonensis*, peamouth *Mylocheilus caurinus*, tui chub *Gila bicolor* lake chub *Couesius plumbeus* and channel catfish *Ictalurus punctatus*. The anadromous fish harvested were chinook salmon *Onchorhynchus tshawytscha*, coho salmon *Onchorhynchus kisutch*, steelhead *Onchorhynchus mica*, and shad *Alosa sapidissima*.

Tribal commercial fisheries between Bonneville and McNary dams were sampled to provide ODFW with mark recovery data, biological data, and harvest estimates of white sturgeon. Commercial landings were randomly sampled from winter and fall setnet, sockeye setnet in 1987 and 1988, setline, hook and line, and dip-net fisheries.

# METHODS

## Study Area

The middle Columbia River is divided into a series of three impoundments between Bonneville and McNary dams. They are Bonneville Reservoir Rkm 235-309 (RM 146-192), The Dalles Reservoir Rkm 309-346 (RM 192-215), and John Day Reservoir Rkm 346-470 (RM 215-292) (Figures 1 and 2). Each reservoir provides a variety of recreational fishing opportunities and access areas for both Washington and Oregon anglers.

## Creel Census Periods

Initial creel surveys of The Dalles Reservoir were conducted during June-October in 1987. This reservoir was selected to initiate the study because of its small size and easy access. Additional surveys were conducted in The Dalles Reservoir during March-October of 1988 and 1989. Anglers were surveyed in Bonneville Reservoir during March-October, 1988-1990. The John Day Reservoir recreational fisheries were surveyed during May-July of 1989, March-December of 1990, and April-September of 1991. Sampling was confined to bank anglers within 22 Rkm (13 Rm) and boat anglers within 40 Rkm (24 Rm) of McNary dam during the extended census period (November-December) in 1990 on John Day Reservoir.

## Creel Survey Design

The methods used to estimate total angling effort (angler hours and angler trips) and harvest were similar for each year and reservoir. Sport fishing boats and bank anglers were counted in representative area indices within each reservoir (Appendix 1). Periodic aerial counts of boats and bank anglers were used to expand estimates of angling effort within index areas to account for angling effort throughout, the entire reservoir. Catch per effort data were collected by interviewing anglers and examining catches.

Index areas for angler counts were established at popular fishing locations and vantage points in Bonneville, The Dalles, and John Day reservoirs. Slight modifications were made in Bonneville Reservoir index areas in 1989 and John Day Reservoir index areas in 1990 to decrease the amount of time spent completing the index count.

Intensive counts of angling effort within index areas were conducted every three hours throughout the day on a twice weekly basis, beginning within three hours of sunrise and continuing until sunset. Bank rods were counted to determine bank effort and sport fishing boats were counted to determine boat angler effort. The average number of anglers per boat was determined through interviewing boat anglers at boat ramps. Rounds of index counts were considered instantaneous in catch and effort modeling. Curves describing average weekday and weekend day boat and bank effort were constructed from these counts. Effort curves were derived from a six week average of counts.

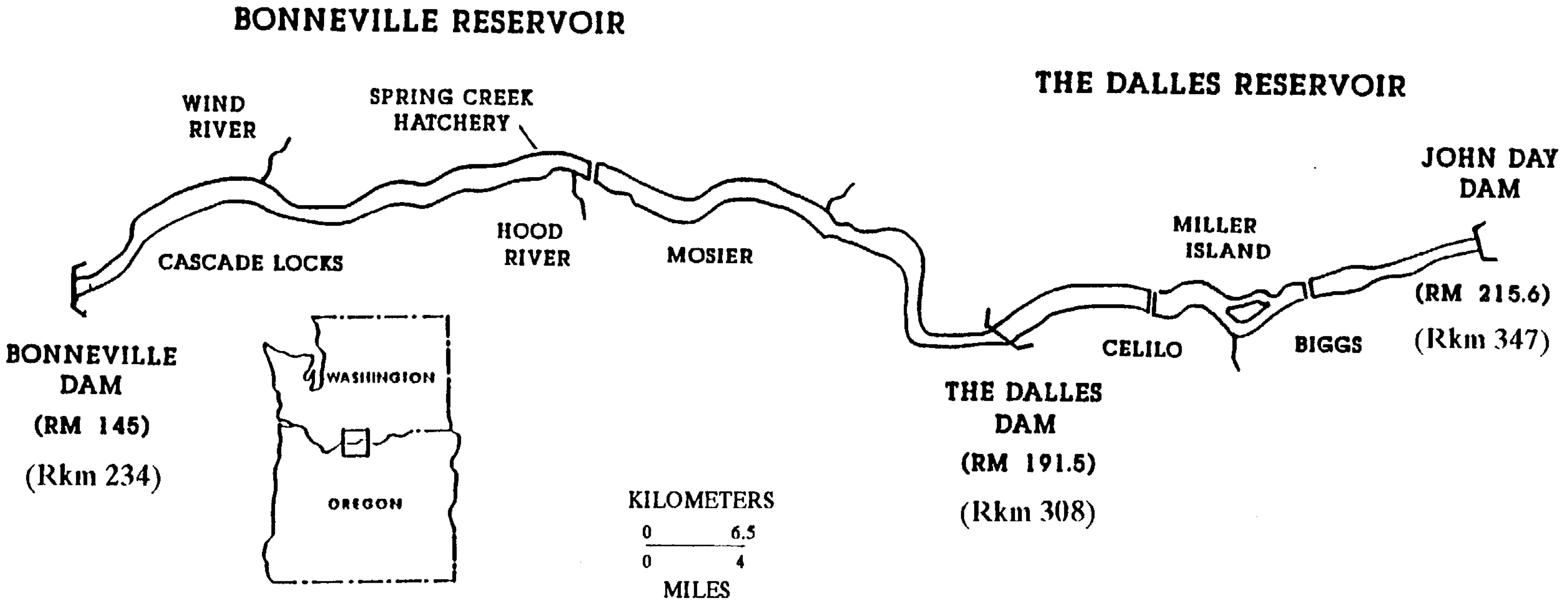

Figure 1. Location of Bonneville and The Dalles reservoirs on the Columbia River.

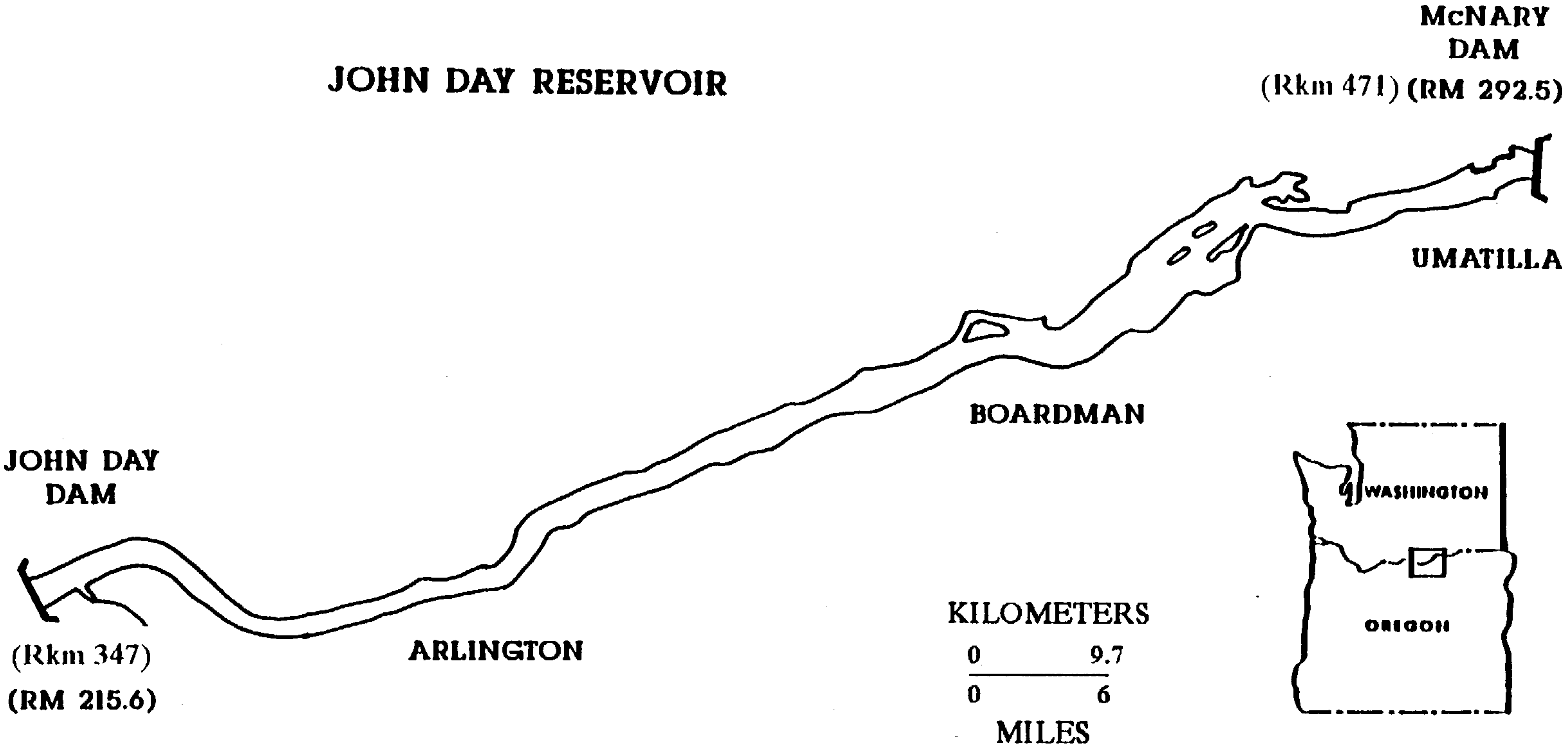

Figure 2. Location of John Day Reservoir on the Columbia River.

A single index count usually took place at peak effort hours during the remaining five days of each week. Index area angling effort on single count days was estimated by comparing that day's count to the corresponding average effort for that hour represented by the appropriate six week effort curve. Daily index area effort estimates were summed by two week periods.

Aerial counts of angling effort for the entire reservoir were made on four of every six intensive index area count days. The proportion of total effort represented by the index areas was determined by comparing counts from within and outside the index areas using aerial count data. Six weeks of aerial count data were averaged to derive this relationship which was applied to the two week index area effort counts to determine total reservoir angling effort for two week periods.

Samplers interviewed anglers at bank fishing sites and boat ramps to determine angler type (target species) and catch per hour of effort (CPUE) for each species in the creel. Interviews took place between index effort counts on intensive count days and during the entire day on non-intensive count days. Samplers collected data from both incomplete and complete angler trips. Interview data collected included angling method (boat or bank), target species, hours fished, number of anglers in the party, location, residence, species and numbers of fish caught and released, and mark sample data for sturgeon and salmonids. Anglers fishing for salmon and steelhead were recorded as the same angler type.

Effort and catch data were stratified by angling method, river subsection (Appendix l), as well as weekday and weekend day effort to account for differential catch rates. Harvest and effort estimates were made for two statistical week intervals (statistical weeks are Monday through Sunday numbered sequentially from the start of the year). If no anglers were interviewed in a subsection for a two week period when effort was counted, then data from preceding and successive two week periods were combined to derive a representative catch rate and applied to the effort estimate for that time period. Harvest estimates were calculated by multiplying the observed catch per hour for each angling method within a river subsection by the total estimated effort for each angler method for that period and subsection.

Total harvest of marked white sturgeon was estimated by dividing the number of marked fish observed in the creel by the mark sampling rate. The mark sampling rate was defined as the number of fish examined for marks divided by the estimated total harvest.

## Mark Recovery and Biological Sampling of the Creel

Sturgeon were examined for primary marks (spaghetti and monel tags) and secondary marks (clipped barbels, removed pectoral fin ray sections and scutes) (Rien et al. 1992). Marks observed during a routine interview were recorded as random or "in-sample". Information volunteered to samplers outside the random interview were recorded as non-random.

Signs informing anglers of the Columbia River sturgeon tagging program and encouraging anglers to volunteer tag recovery information were posted at bank fishing areas and boat ramps. Tag drop sites for volunteer tag returns were also established at popular tackle and convenience stores. Additionally, tag recovery information was routinely volunteered to creel samplers by anglers during census periods.

Biological data collected for sturgeon included fork length (FL in cm), total length (TL in cm), weight (lbs.), sex, and pectoral fin ray and ovary samples. Ovary samples were examined for stage of maturity and preserved in 10% formalin. Walleye, chinook, coho, and steelhead were measured to the fork of the tail (cm) and salmonids were mark sampled for coded wire tags. Scale samples were collected from fall chinook and walleye for analysis of age-growth composition.

### Commercial Landings of White Sturgeon

The number of white sturgeon harvested during tribal commercial fisheries was determined by applying an average weight per fish (determined by subsampling landings) to the number of pounds recorded on fish receiving tickets (Grimes 1992). These estimates did not include sturgeon harvested during treaty subsistence fisheries.

Sturgeon landed in tribal commercial fisheries were sampled at buying stations by WDF, Washington Department of Wildlife (WDW), and ODFW personnel. The same mark recovery and biological data collected from the recreational harvest were collected on a random sample of fish landed in tribal commercial fisheries.

Commercial landings by reservoir were estimated from the catch area reported on fish receiving tickets. Oregon buyers were not required to separate tribal landings by reservoir on their fish tickets until 1989. Therefore fish landed at Oregon buying stations prior to 1989 were recorded as reservoir "unknown". If the reservoir from which a fish was caught could not be identified by the sampler, it was recorded as pool "unknown". All "unknown" area landings were limited to harvests in Zone 6 (the tribal commercial fishing area between Bonneville and McNary dams). The legal commercial size limit for sturgeon was 48-72 inches TL during the study period.

## RESULTS

### Recreational Fisheries

#### Bonneville Reservoir

Anglers averaged 153,479 hours of effort (25,700 trips) while fishing in Bonneville Reservoir between March-October each year from 1988-1990 (Tables 1,2,10 and 11). Oregon anglers outnumbered Washington anglers 5 to 1. Forty-seven percent of the average hourly effort was for sturgeon, 42% for salmonids (steelhead and salmon), 5% for walleye, and 6% for smallmouth bass and other resident fish. There was minimal effort in the

Table 1. Combined Washington and Oregon angling effort and harvest on the middle Columbia River, 1987-1991.

| Reservoir<br>Year | Census period | Angler trips | Harvest | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sturgeon | Chinook | Coho | Steelhead | Shad | Walleye | Smallmouth bass | Other resident fish[a] | Northens squawfish |
| **Bonneville** | | | | | | | | | | | |
| 1988 | Mar-Oct | 22,344 | 1,532 | 620 | 0 | 776 | 0 | 394 | 1,336 | 313 | -- |
| 1989 | Mar-Oct | 26,595 | 2,798 | 307 | 0 | 922 | 0 | 1,066 | 953 | 159 | -- |
| 1990 | Mar-Oct | 28,160 | 2,114 | 627 | 23 | 691 | 202 | 1,351 | 1,265 | 254 | 586 |
| **The Dalles** | | | | | | | | | | | |
| 1987 | Jun-Oct | 29,329 | 1,990 | 1,021 | 0 | 243 | 1,176 | 1,660 | 1,359 | 884 | -- |
| 1988 | Mar-Oct | 23,257 | 907 | 1,178 | 0 | 655 | 1,645 | 3,480 | 780 | 461 | -- |
| 1989 | Mar-Oct | 26,666 | 499 | 884 | 0 | 765 | 5,296 | 7,556 | 1,096 | 115 | -- |
| **John Day** | | | | | | | | | | | |
| 1989 | May-Jul | 19,784 | 283 | 0 | 0 | 8 | 1,303 | 1,718 | 4,776 | 321 | |
| 1990 | Mar-Dec | 34,834 | 314 | 126 | 27 | 114 | 3,675 | 3,088 | 6,821 | 1,707 | 2,390 |
| 1991 | Apr-Sep | 29,929 | 143 | 29 | 22 | 61 | 1,607 | 2,207 | 5,630 | 1,334 | 3,453 |

*a Resident fish other than walleye, smallmouth bass and squawfish.*

*b Catch estimates for squawfish began in 1990 after initiation of the sport reward program.*

Table 2. Estimated recreational fishery effort, harvest, and CPUE for sturgeon, salmonids, and shad by Oregon and Washington anglers on the middle Columbia River, 1987-1991.

| Reservoir | | Bank | | | Boat | | |
|---|---|---|---|---|---|---|---|
| Year | Census period | Effort (Hrs) | Harvest | CPUE | Effort (Hrs) | Harvest | CPUE |
| | | | | Sturgeon | | | |
| Bonneville | | | | | | | |
| 1988 | Mar-Oct | 31,696 | 668 | 0.021 | 24,080 | 864 | 0.036 |
| 1989 | Mar-Oct | 46,029 | 1,525 | 0.033 | 30,287 | 1,273 | 0.042 |
| 1990 | Mar-Oct | 45,671 | 857 | 0.019 | 38,253 | 1,257 | 0.033 |
| The Dalles | | | | | | | |
| 1987 | Jun-Oct | 50,292 | 1,151 | 0.023 | 20,786 | 839 | 0.040 |
| 1988 | Mar-Oct | 50,551 | 546 | 0.011 | 14,716 | 361 | 0.025 |
| 1989 | Mar-Oct | 35,047 | 273 | 0.008 | 10,637 | 226 | 0.021 |
| John Day | | | | | | | |
| 1989 | May-Jul | 29,830 | 111 | 0.004 | 21,994 | 172 | 0.008 |
| 1990 | Mar-Dec | 24,833 | 90 | 0.004 | 18,335 | 224 | 0.012 |
| 1991 | Apr-Sep | 19,860 | 47 | 0.002 | 14,133 | 96 | 0.007 |
| | | | | Chinook, Steelhead, Coho | | | |
| Bonneville | | | | | | | |
| 1988 | Mar-Oct | 57,094 | 852 | 0.015 | 10,809 | 544 | 0.050 |
| 1989 | Mar-Oct | 55,424 | 864 | 0.016 | 14,435 | 365 | 0.025 |
| 1990 | Mar-Oct | 36,027 | 630 | 0.017 | 16,971 | 711 | 0.042 |
| The Dalles | | | | | | | |
| 1987 | Jun-Oct | 23,232 | 325 | 0.014 | 67,925 | 939 | 0.014 |
| 1988 | Mar-Oct | 16,851 | 282 | 0.017 | 38,725 | 1,551 | 0.040 |
| 1989 | Mar-Oct | 17,094 | 401 | 0.023 | 65,228 | 1,248 | 0.019 |
| John Day | | | | | | | |
| 1989 | May-Jul | 391 | 8 | 0.020 | 0 | 0 | 0.000 |
| 1990 | Mar-Dec | 7,059 | 153 | 0.022 | 3,702 | 114 | 0.031 |
| 1991 | Apr-Sep | 4,692 | 105 | 0.022 | 788 | 7 | 0.009 |
| | | | | Shad | | | |
| Bonneville | | | | | | | |
| 1988 | Mar-Oct | 0 | 0 | 0.000 | 0 | 0 | 0.000 |
| 1989 | Mar-Oct | 21 | 0 | 0.000 | 0 | 0 | 0.000 |
| 1990 | Mar-Oct | 505 | 202 | 0.400 | 125 | 0 | 0.000 |
| The Dalles | | | | | | | |
| 1987 | Jun-Oct | 3,058 | 1,155 | 0.378 | 224 | 21 | 0.094 |
| 1988 | Mar-Oct | 3,561 | 1,612 | 0.453 | 54 | 33 | 0.611 |
| 1989 | Mar-Oct | 5,148 | 5,296 | 1.029 | 0 | 0 | 0.000 |
| John Day | | | | | | | |
| 1989 | May-Jul | 1,921 | 1,148 | 0.598 | 446 | 155 | 0.348 |
| 1990 | Mar-Dec | 6,432 | 3,638 | 0.566 | 144 | 37 | 0.257 |
| 1991 | Apr-Sep | 4,076 | 1,546 | 0.379 | 441 | 61 | 0.138 |

shad fishery until 1990. We interviewed a total of 6,216 boat anglers (16% average sampling rate) and 9,803 bank anglers (25% average sampling rate) during the study years (APPENDIX 2, Table 1). Angler effort was counted 91% of the days during the census period on Bonneville Reservoir from 1988-1990 (APPENDIX 2, Table 2). Tables 3, 4, 12 and 13 provide further detail of effort and harvest by angler type, state, and boat and bank fisheries.

### The Dalles Reservoir

Recreational effort averaged 160,352 angler hours (24,962 trips) in The Dalles Reservoir from March-October of 1988 and 1989 (Tables 1,2,10 and 11). Oregon anglers outnumbered Washington anglers 3 to 1. Forty-three percent of the average hourly effort targeted salmonids, 35% sturgeon, 18% walleye, 3% shad and 1% smallmouth bass and other resident fish. We interviewed a total of 9,187 boat anglers (17% average sampling rate) and 13,330 bank anglers (53% average sampling rate) during the study years (APPENDIX 2, Table 1). Angler effort was counted 87% of the days during the census period on The Dalles Reservoir from 1987-1989 (APPENDIX 2, Table 2).

### John Day Reservoir

Anglers in John Day Reservoir averaged 152,227 hours of effort (28,872 trips) from April-September of 1990 and 1991 (Tables 1,2,10 and 11). Fifty-eight percent of the anglers were Oregon residents and 42% were Washington residents. The distribution of effort was 33% for walleye, 28% for sturgeon, 24% for smallmouth bass, 7% for other resident fish, 4% for salmonids, 3% for squawfish and 1% for shad. We interviewed a total of 6,690 boat anglers (11% average sampling rate) and 6,339 bank anglers (23% average sampling rate) during the study years (APPENDIX 2, Table 1). Angler effort was counted 90% of the days during the census period on John Day Reservoir from 1989-1991 (APPENDIX 2, Table 2).

## Recreational Sturgeon Fisheries

### Bonneville Reservoir

The sturgeon fishery in Bonneville Reservoir occurred year round and throughout the entire reservoir. Anglers averaged 72,005 hours of effort (12,937 trips) for sturgeon March-October each year from 1988-1990 (Tables 2, 3 and 4). Sturgeon effort increased 37% from 1988 to 1989 and 10% from 1989 to 1990. Catch per effort (CPUE) averaged 0.03 fish per hour (0.17 fish per trip) and the estimated mean harvest of sturgeon was 2,148 fish each year. Boat and bank CPUE averaged 0.04 fish/hour and 0.02 fish/hour respectively. Harvest and CPUE were highest in 1989.

Sturgeon angler effort varied seasonally throughout the census period (Figure 3). A higher level of effort was estimated from May through September than in spring and late fall. Catch per effort peaked in June

Table 3. Effort and harvest for sturgeon, chinook, coho, steelhead, and shad by Washington bank and boat anglers by reservoir, 1987-1991.

| Reservoir<br>Year<br>Period | Angler trips | | | Harvest | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sturgeon | Salmonid | Shad | Sturgeon | Chinook | Coho | Steelhead | Shad |
| **Bank** | | | | | | | | |
| Bonneville | | | | | | | | |
| 1988 Mar-Oct | 2,262 | 1 | 0 | 277 | 0 | 0 | 0 | 0 |
| 1989 Mar-Oct | 3,667 | 1 | 0 | 698 | 0 | 0 | 0 | 0 |
| 1990 Mar-Oct | 3,193 | 61 | 0 | 618 | 6 | 0 | 0 | 0 |
| The Dalles | | | | | | | | |
| 1987 Jun-Oct | 2,049 | 1,997 | 264 | 394 | 60 | 0 | 36 | 70 |
| 1988 Mar-Oct | 1,376 | 1,336 | 228 | 217 | 58 | 0 | 33 | 213 |
| 1989 Mar-Oct | 1,008 | 975 | 542 | 71 | 26 | 0 | 18 | 2,427 |
| John Day | | | | | | | | |
| 1989 May-Jul | 1,316 | 0 | 27 | 58 | 0 | 0 | 0 | 0 |
| 1990 Mar-Dec | 938 | 57 | 44 | 0 | 0 | 0 | 0 | 33 |
| 1991 Apr-Sep | 629 | 9 | 35 | 17 | 0 | 0 | 0 | 25 |
| **Boat** | | | | | | | | |
| Bonneville | | | | | | | | |
| 1988 Mar-Oct | 682 | 672 | 0 | 110 | 64 | 0 | 15 | 0 |
| 1989 Mar-Oct | 302 | 399 | 0 | 52 | 13 | 0 | 22 | 0 |
| 1990 Mar-Oct | 625 | 397 | 0 | 97 | 60 | 9 | 15 | 0 |
| The Dalles | | | | | | | | |
| 1987 Jun-Oct | 2,055 | 783 | 69 | 448 | 32 | 0 | 27 | 21 |
| 1988 Mar-Oct | 1,319 | 629 | 0 | 126 | 56 | 0 | 30 | 0 |
| 1989 Mar-Oct | 470 | 1,516 | 0 | 59 | 103 | 0 | 69 | 0 |
| John Day | | | | | | | | |
| 1989 May-Jul | 919 | 0 | 0 | 42 | 0 | 0 | 0 | 0 |
| 1990 Mar-Dec | 1,319 | 194 | 25 | 83 | 10 | 1 | 19 | 15 |
| 1991 Apr-Sep | 1,096 | 62 | 125 | 42 | 0 | 0 | 3 | 29 |

**Table 4. Effort and harvest for sturgeon, chinook, coho, steelhead and shad by Oregon bank and boat anglers by reservoir, 1987-1991.**

| Reservoir<br>Year<br>Period | Angler trips | | | Catch | | | | |
|---|---|---|---|---|---|---|---|---|
| | Sturgeon | Salmonid | Shad | Sturgeon | Chinook | Coho | Steelhead | Shad |
| **Bank** | | | | | | | | |
| **Bonneville** | | | | | | | | |
| 1988 Mar-Oct | 3,391 | 6,227 | 6 | 391 | 167 | 0 | 685 | 114 |
| 1989 Mar-Oct | 4,361 | 5,818 | | 827 | 62 | 0 | 802 | 0 |
| 1990 Mar-Oct | 4,020 | 3,804 | 12: | 239 | 34 | 14 | 576 | 202 |
| **The Dalles** | | | | | | | | |
| 1987 Jun-Oct | 2,970 | 938 | 298 | 757 | 151 | 0 | 50 | 1,085 |
| 1988 Mar-Oct | 3,667 | 792 | 430 | 329 | 141 | 0 | 204 | 1,399 |
| 1989 Mar-Oct | 2,651 | 916 | 505 | 202 | 153 | | | 2,869 |
| John Day | | | | | | | | |
| 1989 May-Jul | 2,256 | 70 | 393 | 53 | 0 | 0 | 8 | 1,148 |
| 1990 Mar-Dec | 2,868 | 1,200 | 1,513 | 90 | 66 | 19 | 68 | 3,605 |
| 1991 Apr-Sep | 1,348 | 589 | 714 | 30 | 29 | 22 | 54 | 1,521 |
| **Boat** | | | | | | | | |
| **Bonneville** | | | | | | | | |
| 1988 Mar-Oct | 4,094 | 2,510 | 0 | 754 | 389 | 0 | 76 | 0 |
| 1989 Mar-Oct | 5,490 | 2,794 | 0 | 1,221 | 232 | 0 | 98 | 0 |
| 1990 Mar-Oct | 6,724 | 3,357 | 35 | 1,160 | 527 | 0 | 100 | 0 |
| **The Dalles** | | | | | | | | |
| 1987 Jun-Oct | 1,563 | 13,245 | 63 | 391 | 778 | 0 | 102 | 0 |
| 1988 Mar-Oct | 1,247 | 7,371 | 32 | 235 | 923 | 0 | 542 | 33 |
| 1989 Mar-Oct | 1,290 | 9,855 | 0 | 167 | 602 | | 474 | 12 |
| John Day | | | | | | | | |
| 1989 May-Jul | 2,482 | 0 | 144 | 130 | 0 | | 0 | |
| 1990 Mar-Dec | 1,744 | 612 | 33 | 141 | 50 | 07 | 27 | 155 22 |
| 1991 Apr-Sep | 1,367 | 100 | 134 | 54 | 0 | 0 | 4 | 32 |

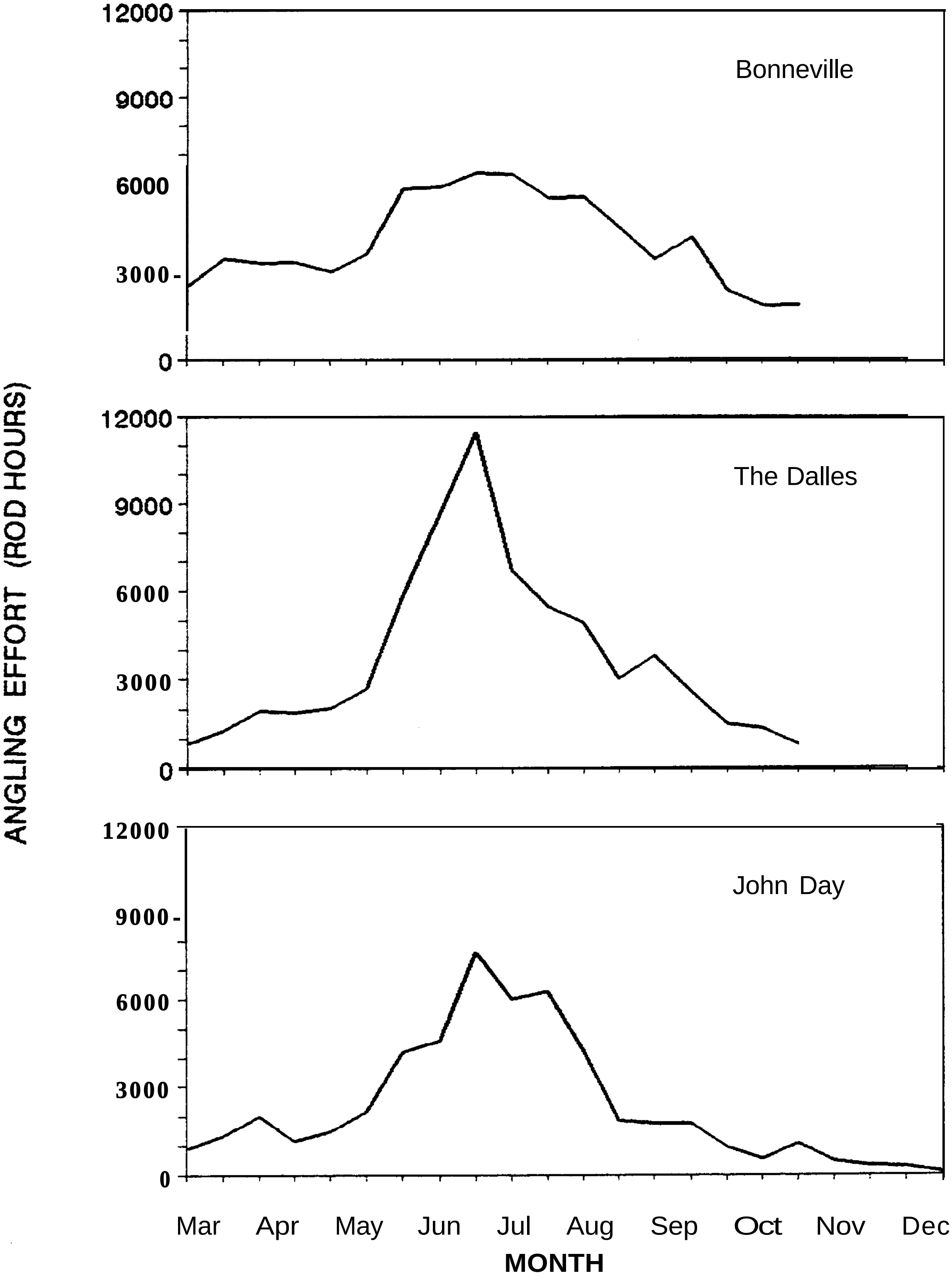

Figure 3. Average recreational fishery effort (angler hours) by two week period for white sturgeon in Bonneville Reservoir (March-October, 1988-90), The Dalles Reservoir (June-October, 1987, and March-October, 1988-89), and John Day Reservoir (May-July, 1989, March-December, 1990, and April-September, 1991).

for boat anglers and in March for bank anglers (Figure 4). Harvest peaked in June for both boat and bank anglers.

We examined 1,027 sturgeon (18% sampling rate) for primary and secondary marks and recovered 9 marked sturgeon during our random sampling of Bonneville Reservoir sport fisheries from 1988 to 1990 (Table 5).

The mean fork length of sturgeon harvested was 103 cm (41 in) (n=963) from 1988 to 1990 (Table 6). There was only a slight variation in mean fork length of sturgeon harvested annually. The ratio of sublegal (<40 in, <102 cm TL), to legal (40-72 in, 102-183 cm TL), to oversized (>72 in, >183 cm TL) in the catch was 235:35:1 (Table 7).

## The Dalles Reservoir

Sturgeon anglers were sampled throughout the entire reservoir, although most of the bank and boat effort was concentrated within 8 km (5 miles) downstream of John Day Dam. Sturgeon anglers spent an estimated 71,078 hours of effort (8,637 trips) from June-October in 1987 and averaged 55,476 hours of effort (6,514 trips) between March-October of 1988 and 1989 (Tables 2, 3, and 4). Annual catch per effort averaged 0.02 fish per hour (0.15 fish/trip) from 1987 to 1989. Catch .per effort was higher for boat anglers than for bank anglers. Anglers harvested 1,990 sturgeon in June-October of 1987. Harvest averaged 340 sturgeon during March-October of 1988 and 1989. Effort, harvest, and CPUE decreased annually from 1987 to 1989.

Boat and bank angling effort, harvest, and CPUE peaked in June (Figure 3). Catch per effort for both angler methods peaked again in late September (Figure 4).

We examined 792 sturgeon (23% sampling rate) for marks and recovered 34 marked sturgeon during our creel survey from 1987 to 1989 in The Dalles Reservoir (Table 5).

The mean fork length of sturgeon harvested was 110 cm (43 in) in 1987 (n=317) and increased to 117 cm (46 in) from 1988 to 1989 (n=427) after the 40" minimum size regulation became effective (Table 6). The ratio of sublegal (~36 in, 91 cm TL) to legal (36-72 in, 91-183 cm TL) to oversized (>72 in, 183 cm TL) was 55:18:1 in 1987 (Table 7). The ratio of sublegal (<40 in, 102 cm TL) to legal (40-72 in, 102-183 cm TL) to oversize (>72 in, 183 cm TL) was 48:7:1 from 1988-1989 (Table 7).

## John Day Reservoir

The sturgeon fishery in John Day Reservoir was concentrated in the upper 48 km (29 miles) of the reservoir, with most of the effort immediately downstream from McNary Dam. Anglers spent an estimated 51,824 hours of effort (6,973 trips) fishing for sturgeon from May-July in 1989, compared to an average 35,526 hours of effort (5,165 trips) between April-September of 1990 and 1991 (Tables 2, 3, and 4). Sturgeon anglers averaged 0.01 fish per hour (0.04 fish/trip) from 1989 to 1991, with boat

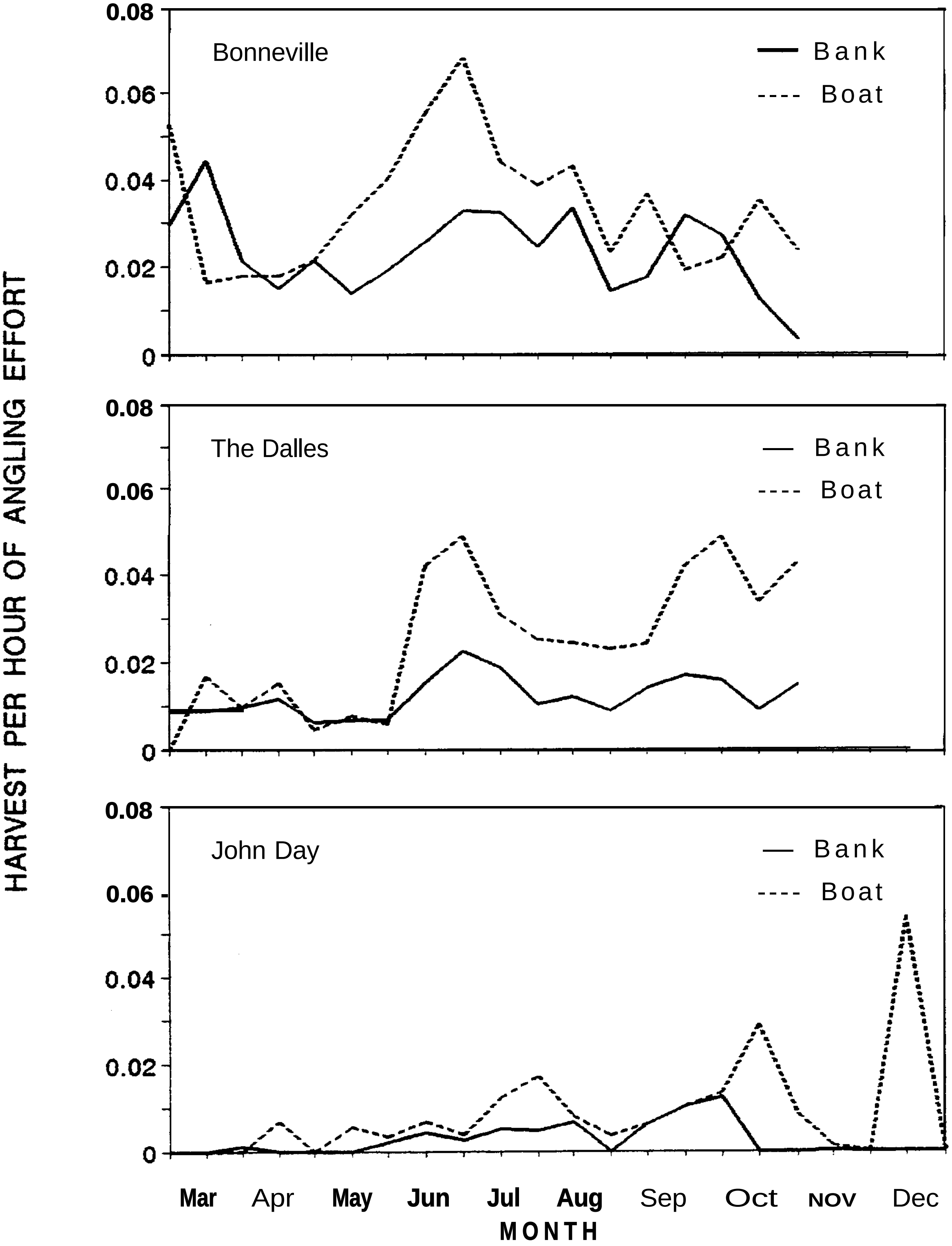

Figure 4. Average harvest per angler hour of white sturgeon by target sturgeon anglers, by two week period, in Bonneville (March-October, 1988-90), The Dalles (June-October, 1987, and March-October, 1988-89), and John Day reservoirs (May-July, 1989, March-December, 1990, and April-September, 1991).

Table 5. Estimated number of marked white sturgeon harvested in the recreational fisheries in Bonneville, The Dalles, and John Day reservoirs, 1987-1991.

| Reservoir<br>Year | Period | Estimated Harvest | Number examined for marks | Observed marks | Estimated marked fish harvested |
|---|---|---|---|---|---|
| **Bonneville** | | | | | |
| 1988 | Mar-Oct | 1,532 | 255 | 0 | 0 |
| 1989 | Mar-Oct | 2,798 | 507 | 2 | 11 |
| 1990 | Mar-Oct | 2,114 | 265 | 7 | 56 |
| **The Dalles** | | | | | |
| 1987 | Jun-Oct | 1,991 | 365 | 5 | 27 |
| 1988 | Mar-Oct | 907 | 241 | 19 | 72 |
| 1989 | Mar-Oct | 499 | 186 | 10 | 27 |
| **John Day** | | | | | |
| 1989 | May-Jul | 283 | 27 | 0 | 0 |
| 1990 | Mar-Dec | 314 | 53 | 1 | 6 |
| 1991 | Apr-Sep | 143 | 27 | 2 | 11 |

**Table 6. Length frequencies of white sturgeon harvested during recreational fisheries in Bonneville, The Dalles, and John Day reservoirs,** 1987-1991.

| Length interval (cm FL) | Bonneville | | | The Dalles | | | John Day | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1988 | 1989 | 1990 | 1987 | 1988 | 1989 | 1989 | 1990 | 1991 |
| 56 - 65 | | | | | | | | | |
| 66 - 75 | | | | | | | | | |
| 76 - 85 | 2 | | | 11 | 2 | 1 | | | |
| 86 - 95 | 59 | 65 | 54 | 78 | 24 | 24 | 5 | 12 | |
| 96 - 105 | 108 | 232 | 109 | 67 | 64 | 48 | 13 | 14 | 4 |
| 106 - 115 | 38 | 148 | 60 | 62 | 45 | 31 | 4 | 12 | 8 |
| 116 - 125 | 9 | 26 | 21 | 38 | 30 | 21 | 3 | 5 | 8 |
| 126 - 135 | 6 | 7 | 7 | 27 | 26 | 23 | | 2 | 9 |
| 136 - 145 | 4 | 3 | 1 | 16 | 19 | 11 | | | 1 |
| 146 - 155 | | | 3 | 11 | 18 | 14 | | 6 | |
| 156 - 165 | | | | 5 | 10 | 7 | | 1 | 1 |
| 166 - 175 | | 1 | | 2 | 5 | 3 | | | |
| 176 - 185 | | | | | | | | | |
| **Total** | 226 | 482 | 255 | 317 | 243 | 184 | 25 | 52 | 31 |

Table 7. Numbers of sturgeon anglers interviewed and white sturgeon sampled by size group in the middle Columbia River recreational fisheries, 1987-1991.

| Reservoir |  | Bank |  |  |  |  | Boat |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Period | Anglers checked | Sublegal | Legal released | Legal kept | Oversized | Anglers checked | Sublegal | Legal released | Legal kept | Oversized |
| **Bonneville** |  |  |  |  |  |  |  |  |  |  |  |
| 1988 | Mar-Oct[a] | 1,464 | 645 | 9 | 127 | 0 | 653 | 866 | 22 | 152 | 15 |
| 1989 | Mar-Oct[a] | 1,981 | 1,590 | 7 | 240 | 1 | 1,062 | 1,920 | 11 | 295 | 12 |
| 1990 | Mar-Oct[a] | 1,895 | 1,341 | 6 | 150 | 1 | 765 | 1,151 | 11 | 164 | 3 |
| **The Dalles** |  |  |  |  |  |  |  |  |  |  |  |
| 1987 | Jun-Oct[b] | 2,277 | 772 | 93 | 283 | 20 | 592 | 593 | 27 | 156 | 5 |
| 1988 | Mar-Oct[a] | 2,969 | 680 | 16 | 195 | 43 | 412 | 487 | 2 | 57 | 3 |
| 1989 | Mar-Oct[a] | 2,515 | 921 | 2 | 115 | 11 | 477 | 799 | 8 | 82 | 3 |
| **John Day** |  |  |  |  |  |  |  |  |  |  |  |
| 1989 | May-Jul[a] | 593 | 139 | 1 | 14 | 6 | 273 | 288 | 8 | 16 | 2 |
| 1990 | Mar-Dec[a] | 794 | 50 | 4 | 16 | 8 | 467 | 499 | 5 | 39 | 13 |
| 1991 | Apr-Sep[c] | 1,239 | 279 | 7 | 12 | 14 | 468 | 714 | 1 | 20 | 14 |

[a] *Minimum size limit 40 inches (TL).*

[b] *Mininum-maximum size limit 36-72 inches (TL).*

[c] *Minimum-maximum size limit 48-66 inches (TL).*

and bank anglers harvesting at about the same rate. Anglers harvested 283 sturgeon during May-July of 1989. The mean harvest of sturgeon during April-September of 1990 and 1991 was 203 fish. Effort and harvest decreased annually from 1989 to 1991.

Angling effort varied seasonally, although effort was highest June through July for both bank and boat anglers (Figure 3). Sturgeon CPUE and harvest remained low relative to the other reservoir fisheries throughout the census period (Figure 4). Catch per effort was highest in early winter during the extended sampling period in 1990 (Figure 4).

We examined 107 sturgeon (14% sampling rate) for marks and recovered 3 marked sturgeon during our random sampling of John Day Reservoir sport fisheries from 1989 to 1991 (Table 5).

The mean fork length of sturgeon in the catch was 111 cm (44 in) (n=108) from 1989 to 1991 (Table 6). Average fork length of sturgeon in the harvest increased annually from 101 cm in 1989, to 111 cm in 1990 and to 120 cm in 1991. The ratio of sublegal (<40 in, 102 cm TL) to legal (40-72 in, 102-183 cm TL) to oversize (>72 in, 183 cm TL) was 32:3:1 from 1989-1990 (Tabl e 7). The ratio of sublegal (<40 in, 102 cm TL) to legal (40-66 in, 102-168 cm TL) to oversize (>66 in, 168 cm TL) was 35:1:1 in 1991 (Table 7).

## Recreational Salmonid Fisheries

### Bonneville Reservoir

Salmonid anglers in Bonneville Reservoir harvested winter and summer steelhead, fall chinook, and coho. The steelhead fishery was predominantly a bank fishery located at Cascade Locks, Oregon (Rkm 238, RM 148). Boat anglers were usually concentrated outside the mouths of tributaries (Eagle Creek Rkm 235, RM 146, White Salmon Rkm 270, RM 168, and Klickitat rivers Rkm 291, RM 180.5). Detailed summaries of stock composition and mark sampling results for these fisheries are available in WDF Columbia River Progress Reports ( Fiscus 1988, 1989, 1990, 1991).

Salmonid anglers averaged 63,602 hours of effort (8,681 trips) with an average CPUE of 0.02 fish per hour (0.15 fish/trip) during March-October each year from 1988 to 1990 (Tables 2,3,and 4). Average CPUE was higher for boat anglers than bank anglers. Annual harvest averaged 1,322 fish of which 60% were steelhead, 39% were fall chinook, and 1% were coho.

Seasonal trends in salmonid effort were associated with run timing and angling closures. Salmonid effort was greatest from July through September, peaking the end of August (Figure 5). Catch per effort peaked in September for boat and bank anglers (Figure 6).

Fork lengths of fall chinook in the catch ranged from 28-114 cm (n=115) and averaged 63 cm for adult salmon, and 43 cm for jack salmon (Table 8). Coho salmon averaged 63 cm (adults) and 43 cm (jacks) based on

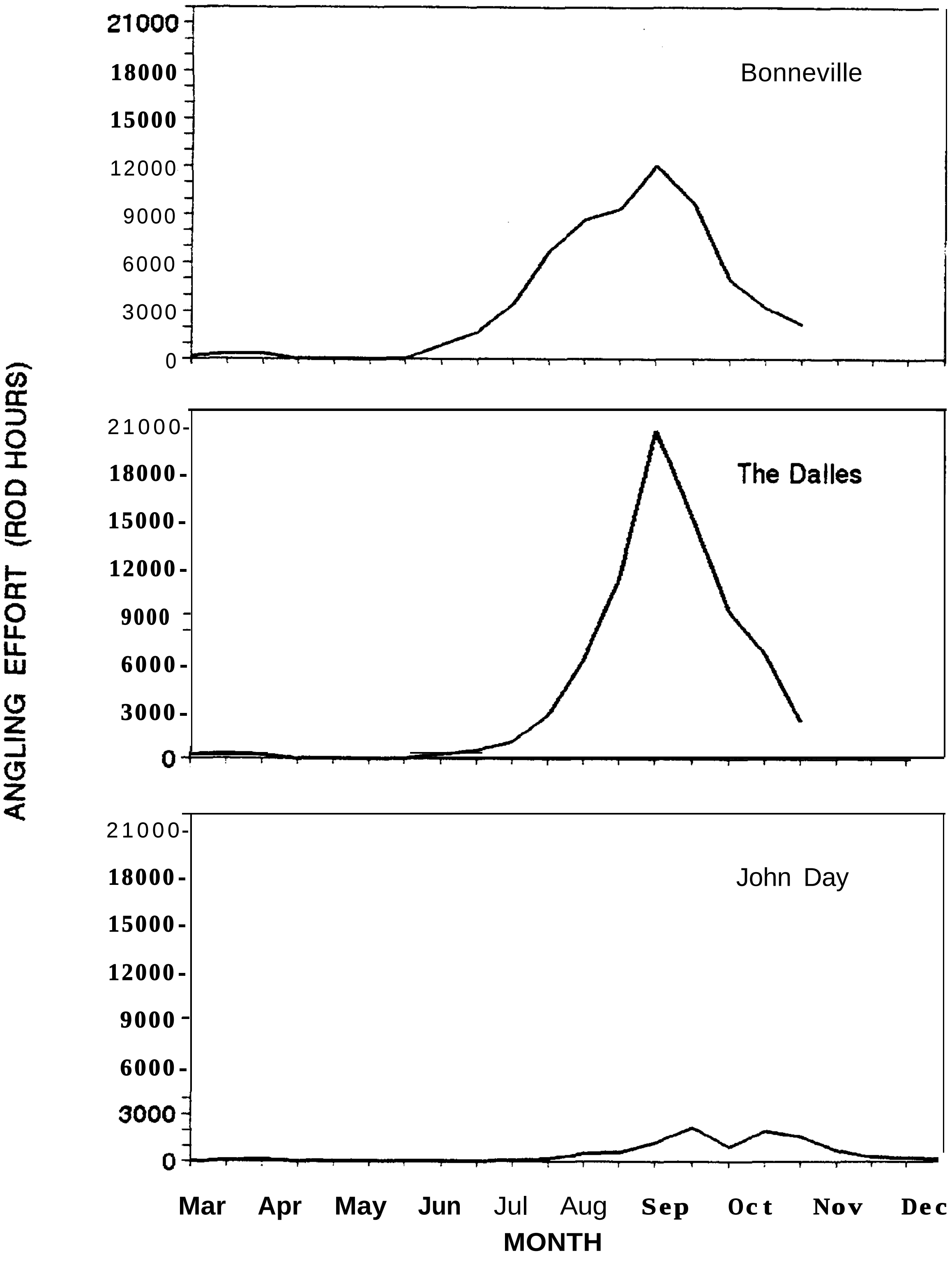

Figure 5. Average recreational fishery effort (anglers hours) by two week period for chinook, coho, and steelhead in Bonneville Reservoir (March-October, 1988-90), The Dalles Reservoir (June-October, 1987, and March-October, 1988-89), and John Day Reservoir (May-July, 1989, March-December, 1990, and April-September, 1991).

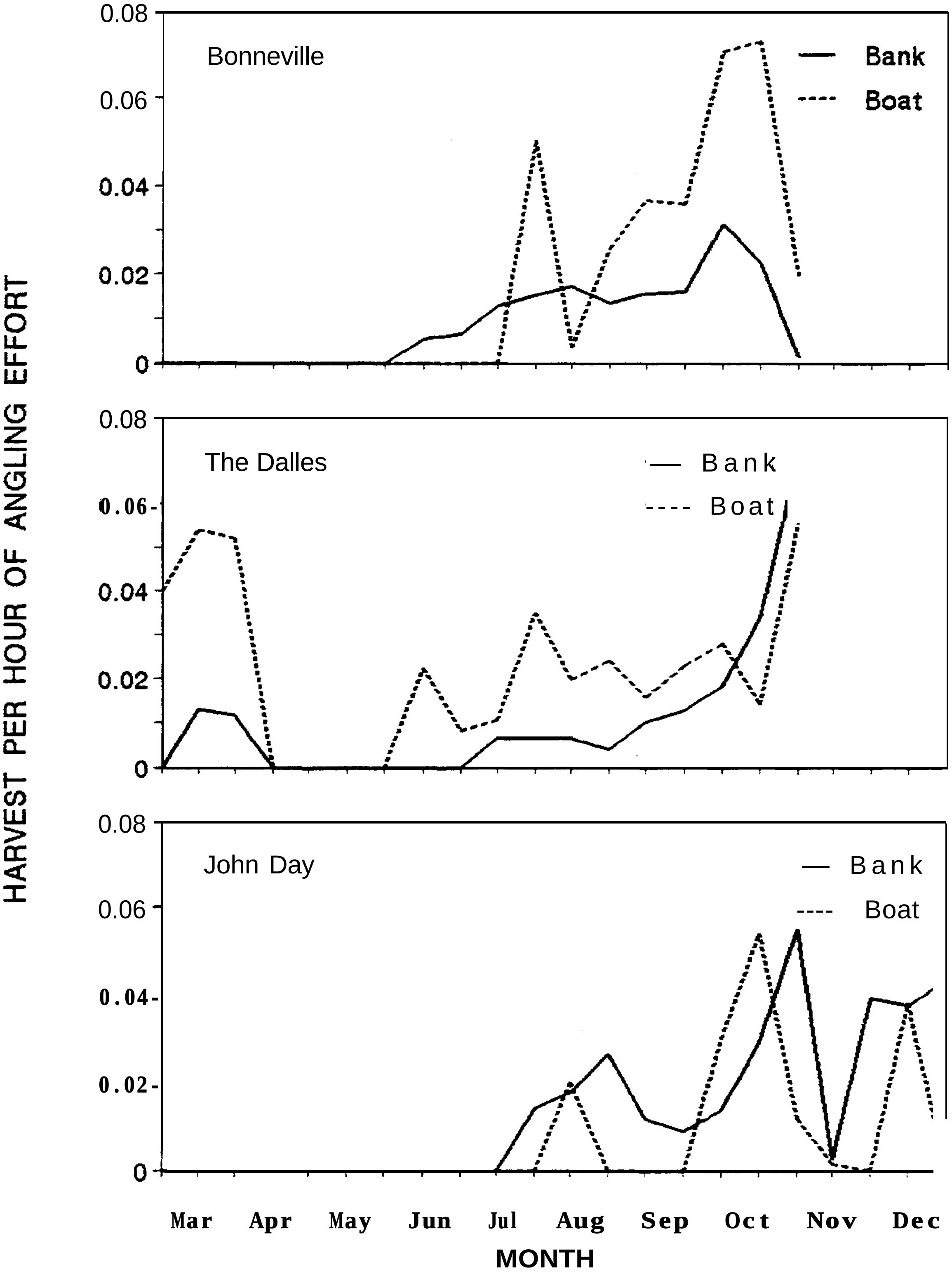

Figure 6. Average combined harvest per angler hour of chinook, coho, and steelhead by target salmonid anglers, by two period, in Bonneville (March-October, 1988-90), The Dalles (June-October, 1987 and March-October, 1988-89), and John Day reservoirs (May-July, 1989, March-December, 1990, and April-September, 1991).

Table 8. Length frequencies of fall chinook salmon harvested during recreational fisheries in Bonneville, The Dalles, and John Day reservoirs, 1987-1991.

| Length interval (cm FL) | Bonneville | | | The Dalles | | | John Day | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1988 | 1989 | 1990 | 1987 | 1988 | 1989 | 1989 | 1990 | 1991 |
| 26 | | | | | 1 | | | | |
| 36 - 435 | 8 | 33 | 1 | 2 | 22 | | | 1 | |
| 46 - 55 | | 1 | 1 | 8 | 3 | 2 | | | |
| 56 - 65 | | 3 | 2 | 18 | 3 | 5 | | 1 | |
| | | 8 | | | 6 | 8 | 1 | | |
| 76 - 85 | 1 | 6 | 7 | 5 | 13 | 9 | 1 | 3 | |
| | | 9 | 12 | 5 | | 31 | | 3 | |
| 96 - 105 | 5 | 5 | 20 | 2 | 26 | 33 | 1 | 1 | |
| 106 - 115 | 1 | 2 | 3 | | 9 | 14 | 1 | | 1 |
| 116 - 125 | | | | | | 1 | | | |
| Total | 29 | 40 | 46 | 44 | 110 | 103 | 4 | 9 | 1 |

7 fish sampled in the creel. Steelhead averaged 76 cm FL (n=239), ranging from 47 cm to 97 cm (Table 9).

## The Dalles Reservoir

Most of the salmonid effort in The Dalles Reservoir was concentrated in a boat fishery outside the mouth of the Deschutes River (Rkm 332, RM 206). Significant bank angler effort for salmonids occurred immediately downstream from John Day Dam. Salmonid anglers fished 91,157 hours (16,963 trips) during June-October in 1987 and averaged 68,945 hours of effort (11,695 trips) during March-October of 1988 and 1989 (Tables 2, 3, and 4). Catch per effort averaged 0.02 fish per hour (0.13 fish/trip) from 1987 to 1989. Harvest averaged 1,741 fish during March-October each year of 1988 and 1989, of which 59% were chinook salmon and 41% were steelhead.

Salmonid effort peaked in late August (Figure 5). Catch per effort varied throughout the season for boat and bank anglers, but peaked in October (Figure 6).

Fork lengths of fall chinook in the harvest ranged from 36-124 cm (n=257) and averaged 89 cm for adult salmon and 52 cm for jack salmon (Table 8). Steelhead averaged 73 cm FL (n=127), ranging from 48-124 cm in length (Table 9).

## John Day Reservoir

Fishing effort for salmonids in John Day Reservoir was minimal compared to Bonneville and The Dalles reservoirs. Very little effort was observed in the spring and summer, therefore our estimates of angler effort were lower in 1989 than for the 1990 and 1991 census periods. Angler effort averaged 5,416 hours (878 trips) during April-September of 1990 and 1991 (Tables 2,3, and 4). In 1990, the census period extended through December, accounting for another 5,413 hours of salmonid effort (1,064 trips). Catch per effort averaged 0.02 fish per hour (0.13 fish/trip) from 1989 to 1991, with average CPUE being similar for boat and bank anglers. The total harvest of salmonids from March-December in 1990 was 267 fish, comprised of 126 fall chinook, 114 steelhead, and 27 coho salmon.

Salmonid effort peaked in mid-September and again in October (Figure 5). Catch per effort was highest in late fall (Figure 6).

Fall chinook ranged from 57-107 cm FL (n=14) and averaged 82 cm (Table 8) : Steelhead harvested ranged 52 to 101 cm FL (n=26) and averaged 69 cm (Table 9).

Table 9. Length frequencies of steelhead harvested during recreational fisheries in Bonneville, The Dalles, and John Day reservoirs, 1987-1991.

| Length interval (cm FL) | Bonneville | | | The Dalles | | | John Day | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1988 | 1989 | 1990 | 1987 | 1988 | 1989 | 1989 | 1990 | 1991 |
| 26 - 35 | | | | | | | | | |
| 36 45 | | | | | | | | | |
| 46 I 55 | 2 | 4 | 8 | | 7 | | | | |
| 66 - 65 | 7 | 19 | 15 | | 22 | 13 | 3 | 82 | 1 |
| 76 - 75 | | | | 2 | | | | 5 | |
| | | 56 | 25 | 3 | 13 | 14 | | 4 | |
| 86 - 95 | 2 | 42 | 12 | f | 8 | 11 | | | |
| 96 - 105 | | | 1 | | | 2 | 1 | 2 | |
| 106 - 115 | | | | | | | | | |
| 116 - 125 | | | | 1 | | | | | |
| Total | 11 | 144 | 84 | 15 | --a | 47 | 4 | -- 21 | 1 |

## Recreational Shad Fisheries

### Bonneville Reservoir

The shad fishery in Bonneville Reservoir was not as popular as it was in The Dalles and John Day reservoirs, primarily due to the lack of bank access areas on either shore downstream from The Dalles Dam. Effort, catch, and harvest rates were minimal during the census periods in 1988 to 1990 (Tables 2, 3, and 4, Figures 7 and 8). However, effort did increase significantly from 1989 to 1990, when a bank fishery developed in Cascade Locks, Oregon (Rkm 238, RM 148).

### The Dalles Reservoir

Shad angling occurred primarily from the bank immediately downstream from John Day Dam. Shad anglers averaged 4,015 hours of effort (810 trips) annually during the census period from 1987 to 1989 (Tables 2, 3, and 4, Figures 7 and 8). Catch per effort averaged 0.62 fish per hour (3.05 fish/trip) and harvest averaged 2,710 fish each year. Harvest and CPUE more than doubled from 1988 to 1989.

### John Day Reservoir

The anadromous shad run attracted many anglers in John Day Reservoir. A concentrated bank fishery developed on the Oregon shore immediately downstream from McNary Dam, coinciding with the large shad runs. Shad were also incidentally harvested by boat anglers fishing for steelhead and walleye. Shad angler effort averaged 4,487 hours (1,062 trips) annually and catch per effort averaged 0.49 fish per hour (2.06 fish/trip) during May-July from 1989 to 1991 (Tables 2, 3, and 4, Figures 7 and 8). Shad anglers harvested an average of 2,195 fish annually during this three month fishery. Effort and harvest were greatest in 1990.

## Recreational Walleye Fisheries

### Bonneville Reservoir

Walleye were harvested primarily by boat anglers and incidentally by bank anglers. Walleye anglers averaged 8,375 hours of effort (1,786 trips) and total harvest averaged 937 walleye during March-October each year from 1988-1990 (Tables 10, 11, and 12). Effort increased 49% from 1988 to 1989 and 50% from 1989 to 1990. Catch per effort changed little from 1988 to 1990, averaging 0.10 fish per hour (0.46 fish/trip).

A bimodal distribution of effort occurred in the boat fishery with peaks in late March and mid-August (Figure 9). Catch per effort varied seasonally but peaked in May (Figure 10). Harvest was greatest in late February and early March.

Length of walleye in the harvest ranged from 25-69 cm FL (n=326) and averaged 50 cm from 1988 to 1990 (Table 13).

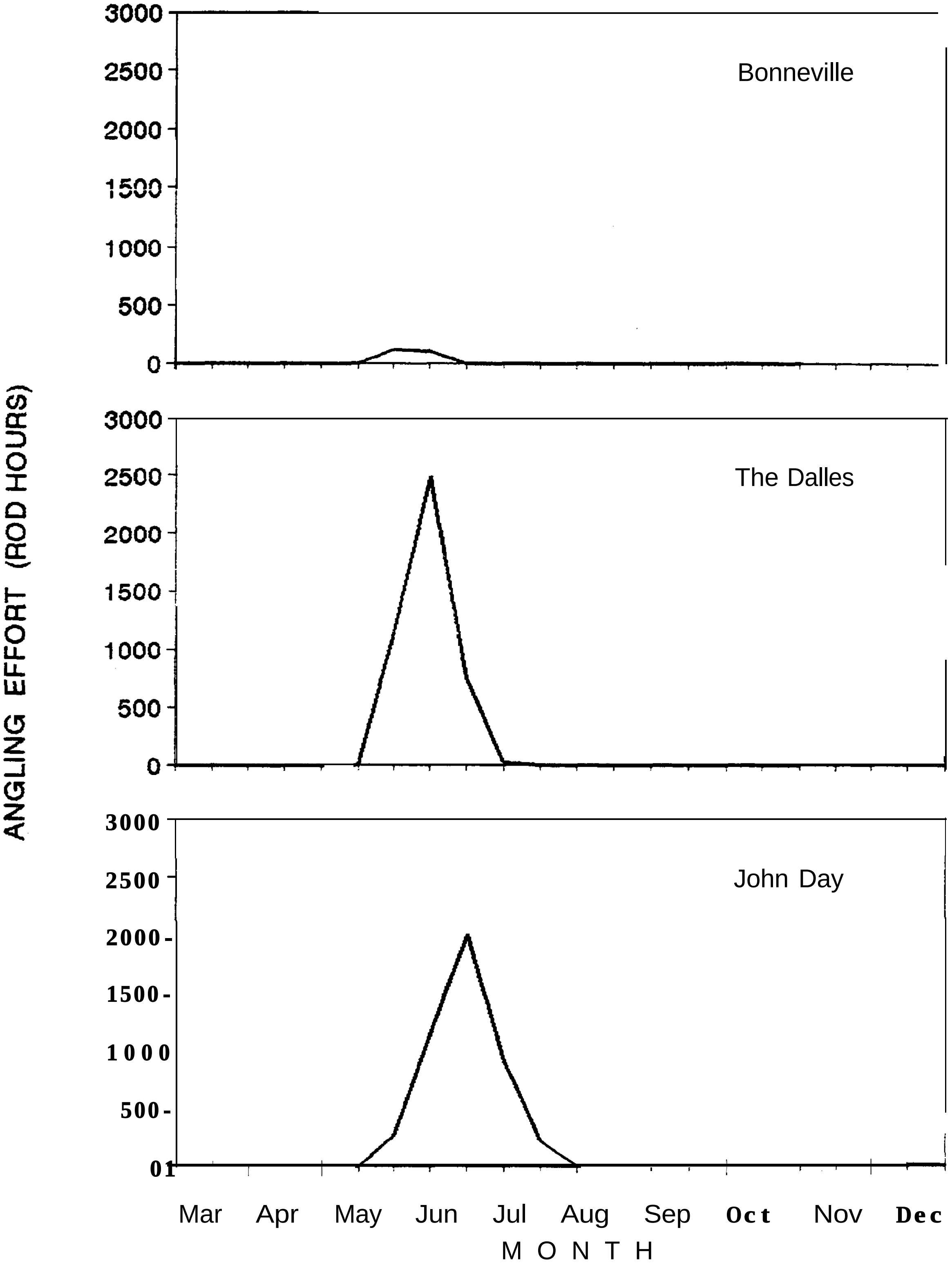

Figure 7. Average recreational fishery effort (anglers hours) by two week period for shad in Bonneville Reservoir (March-October, 1988-90), The Dalles Reservoir (June-October, 1987, and March-October, 1988-89), and John Day Reservoir (May-July, 1989, March-December, 1990, and April-September, 1991).

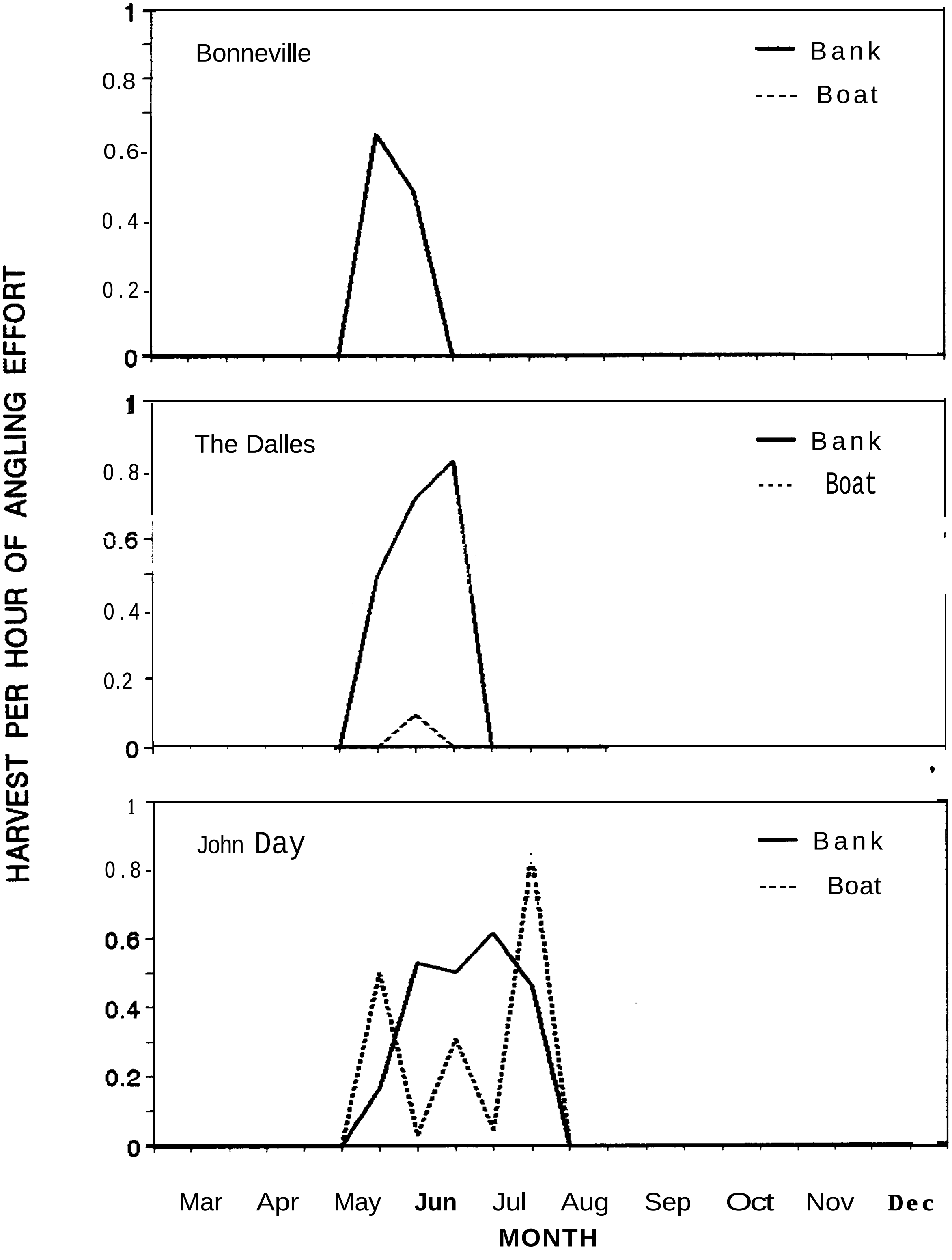

Figure 8. Average harvest per angler hour of shad by target shad anglers, by two week period, in Bonneville (March-October, 1988-90), The Dalles (June-October, 1987 and March-October, 1988-89), and John Day reservoirs (May-July, 1989, March-December, 1990, and April-September, 1991).

Table 10. Estimated recreational fishery effort, harvest, and CPUE for walleye and smallmouth bass on the middle Columbia River, 1987-1991.

| Reservoir Year | Period | Bank Effort (Hrs) | Bank Harvest* | Bank CPUE | Boat Effort (Hrs) | Boat Harvest* | Boat CPUE |
|---|---|---|---|---|---|---|---|
| | | | | Walleye | | | |
| **Bonneville** | | | | | | | |
| 1988 | Mar-Oct | 3 | 0 (0) | 0.000 | 3,647 | 341 (394) | 0.094 |
| 1989 | Mar-Oct | 3 | 0 (16) | 0.000 | 7,143 | 872 (1,050) | 0.122 |
| 1990 | Mar-Oct | 31 | 0 (0) | 0.000 | 14,298 | 1,343 (1,351) | 0.094 |
| **The Dalles** | | | | | | | |
| 1987 | Jun-Oct | 559 | 13 (13) | 0.023 | 9,805 | 1,647 (1,647) | 0.168 |
| 1988 | Mar-Oct | 212 | 15 (53) | 0.071 | 20,805 | 3,112 (3,427) | 0.150 |
| 1989 | Mar-Oct | 275 | 16 (82) | 0.058 | 35,354 | 7,389 (7,474) | 0.209 |
| **John Day** | | | | | | | |
| 1989 | May-Jul | 38 | 2 (3) | 0.053 | 34,489 | 1,715 (1,715) | 0.050 |
| 1990 | Mar-Dec | 128 | 0 (13) | 0.000 | 72,779 | 3,035 (3,075) | 0.042 |
| 1991 | Apr-Sep | 688 | 3 (18) | 0.004 | 43,061 | 1,985 (2,189) | 0.046 |
| | | | | Smallmouth Bass | | | |
| **Bonneville** | | | | | | | |
| 1988 | Mar-Oct | 841 | 298 (312) | 0.354 | 3,073 | 739 (1,024) | 0.240 |
| 1989 | Mar-Oct | 479 | 80 (80) | 0.167 | 6,275 | 654 (873) | 0.104 |
| 1990 | Mar-Oct | 870 | 109 (154) | 0.125 | 8,593 | 953 (1,111) | 0.111 |
| **The Dalles** | | | | | | | |
| 1987 | Jun-Oct | 1,067 | 553 (625) | 0.518 | 633 | 362 (734) | 0.572 |
| 1988 | Mar-Oct | 1,189 | 436 (508) | 0.367 | 468 | 62 (272) | 0.132 |
| 1989 | Mar-Oct | 1,148 | 391 (431) | 0.341 | 1,786 | 377 (665) | 0.211 |
| **John Day** | | | | | | | |
| 1989 | May-Jul | 2,498 | 104 (117) | 0.042 | 26,246 | 4,461 (4,659) | 0.170 |
| 1990 | Mar-Dec | 4,866 | 1,214 (1,242) | 0.249 | 39,169 | 5,101 (5,579) | 0.130 |
| 1991 | Apr-Sep | 10,212 | 1,112 (1,197) | 0.109 | 26,399 | 4,121 (4,433) | 0.156 |

*a Harvest by anglers targetting on other species in parenthesis.*

Table 11. Effort and harvest for walleye, smallmouth bass, squawfish, and other resident fish by Washington bank and boat anglers by reservoir, 1987-1991.

| Reservoir<br>Year<br>Period | Angler trips | | | | Harvest | | | |
|---|---|---|---|---|---|---|---|---|
| | Walleye | Bass | Squawfish | Other | Walleye | Bass | Squawfish | Other |
| | | | | | Bank | | | |
| Bonneville | | | | | | | | |
| 1988 Mar-Oct | 0 | 108 | --- | 176 | 0 | 192 | --- | 93 |
| 1989 Mar-Oct | 0 | 50 | --- | 285 | 9 | 15 | --- | 29 |
| 1990 Mar-Oct | 8 | 21 | 12 | 199 | 0 | 11 | 28 | 10 |
| The Dalles | | | | | | | | |
| 1987 Jun-Oct | 182 | 153 | --- | 133 | 0 | 348 | --- | 320 |
| 1988 Mar-Oct | 68 | 126 | --- | 146 | 17 | 122 | --- | 171 |
| 1989 Mar-Oct | 26 | 95 | --- | 61 | 52 | 75 | --- | 14 |
| John Day | | | | | | | | |
| 1989 May-Jul | 3 | 328 | --- | 80 | 3 | 101 | --- | 38 |
| 1990 Mar-Dec | 3 | 833 | 0 | 1,379 | 0 | 1,059 | 52 | 492 |
| 1991 Apr-Sep | 247 | 2,625 | 383 | 1,376 | 0 | 1,038 | 454 | 434 |
| | | | | | Boat | | | |
| Bonneville | | | | | | | | |
| 1988 Mar-Oct | 33 | 0 | --- | 3 | 3 | 1 | --- | 5 |
| 1989 Mar-Oct | 0 | 55 | --- | 10 | 28 | 28 | --- | 0 |
| 1990 Mar-Oct | 68 | 385 | 0 | 10 | 8 | 0 | 1 | 43 |
| The Dalles | | | | | | | | |
| 1987 Jun-Oct | 242 | 101 | --- | 108 | 140 | 154 | --- | 87 |
| 1988 Mar-Oct | 865 | 42 | --- | 31 | 571 | 43 | --- | 23 |
| 1989 Mar-Oct | 1,285 | 137 | --- | 10 | 1,489 | 156 | --- | 16 |
| John Day | | | | | | | | |
| 1989 May-Jul | 2,289 | 3,542 | --- | 118 | 177 | 3,198 | --- | 104 |
| 1990 Mar-Dec | 5,494 | 4,417 | 219 | 505 | 1,119 | 3,821 | 1,021 | 329 |
| 1991 Apr-Sep | 3,344 | 3,042 | 716 | 437 | 991 | 2,429 | 541 | 263 |

Table 12. Effort and harvest for walleye, smallmouth bass, squawfish, and other resident fish by Oregon bank and boat anglers by reservoir, 1987-1991.

| Reservoir<br>Year<br>Period | Angler trips | | | | Harvest | | | |
|---|---|---|---|---|---|---|---|---|
| | Walleye | Bass | Squawfish | Other | Walleye | Bass | Squawfish | Other |
| | | | | **Bank** | | | | |
| **Bonneville** | | | | | | | | |
| | | | | | 0 | | | |
| 1988 Mar-Oct | 3 | 141 | --- | 243 | 7 | 120 | --- | 112 |
| 1989 Mar-Oct | 3 | 89 | --- | 183 | | 65 | --- | 73 |
| 1990 Mar-Oct | 5 | 205 | 1 | 493 | 0 | 143 | 44 | 96 |
| **The Dalles** | | | | | | | | |
| 1987 Jun-Oct | 165 | 187 | --- | 68 | 36 | 277 | --- | 105 |
| 1988 Mar-Oct | 65 | 250 | --- | ;: | 30 | 386 | --- | 138 |
| 1989 Mar-Oct | 1 | 192 | --- | | | 356 | --- | 46 |
| **John Day** | | | | | | | | |
| | | | | | | 16 | | |
| 1989 May-Jul | 0 | 58 | --- | 231 | 0 | 183 | --- | 22 |
| 1990 Mar-Dec | 36 | 158 | 97 | 1,007 | 13 | | 800 | 686 |
| 1991 Apr-Sep | 180 | 617 | 465 | 1,602 | 18 | 159 | 1,844 | 362 |
| | | | | **Boat** | | | | |
| **Bonneville** | | | | | | | | |
| 1988 Mar-Oct | 856 | 802 | --- | 134 | 391 | 1,023 | --- | 103 |
| 1989 Mar-Oct | 1,648 | 1,332 | --- | 101 | 1,022 | 845 | --- | 57 |
| 1990 Mar-Oct | 2,732 | 1,487 | 23 | 209 | 1,343 | 1,111 | 513 | 105 |
| **The Dalles** | | | | | | | | |
| 1987 Jun-Oct | 1,600 | 39 | --- | 2: | 1,513 | 580 | --- | 372 |
| 1988 Mar-Oct | 3,040 | 63 | --- | | 2,856 | 229 | --- | 129 |
| 1989 Mar-Oct | 4,765 | 253 | --- | 18 | 5,985 | 509 | --- | 39 |
| **John Day** | | | | | | | | |
| 1989 May-Jul | 3,769 | 1,597 | --- | 162 | 1,538 | 1,461 | --- | 157 |
| 1990 Mar-Dee | 7,514 | 2,207 | 152 | 266 | 1,970 | 1,758 | 517 | 200 |
| 1991 Apr-Sep | 4,734 | 2,768 | 774 | 415 | 1,200 | 2,004 | 614 | 275 |

Figure 9. Average recreational fishery effort (anglers hours) by two week period for walleye in Bonneville Reservoir (March-October, 1988-90), The Dalles Reservoir (June-October, 1987, and March-October, 1988-89), and John Day Reservoir (May-July, 1989, March-December, 1990, and April-September, 1991).

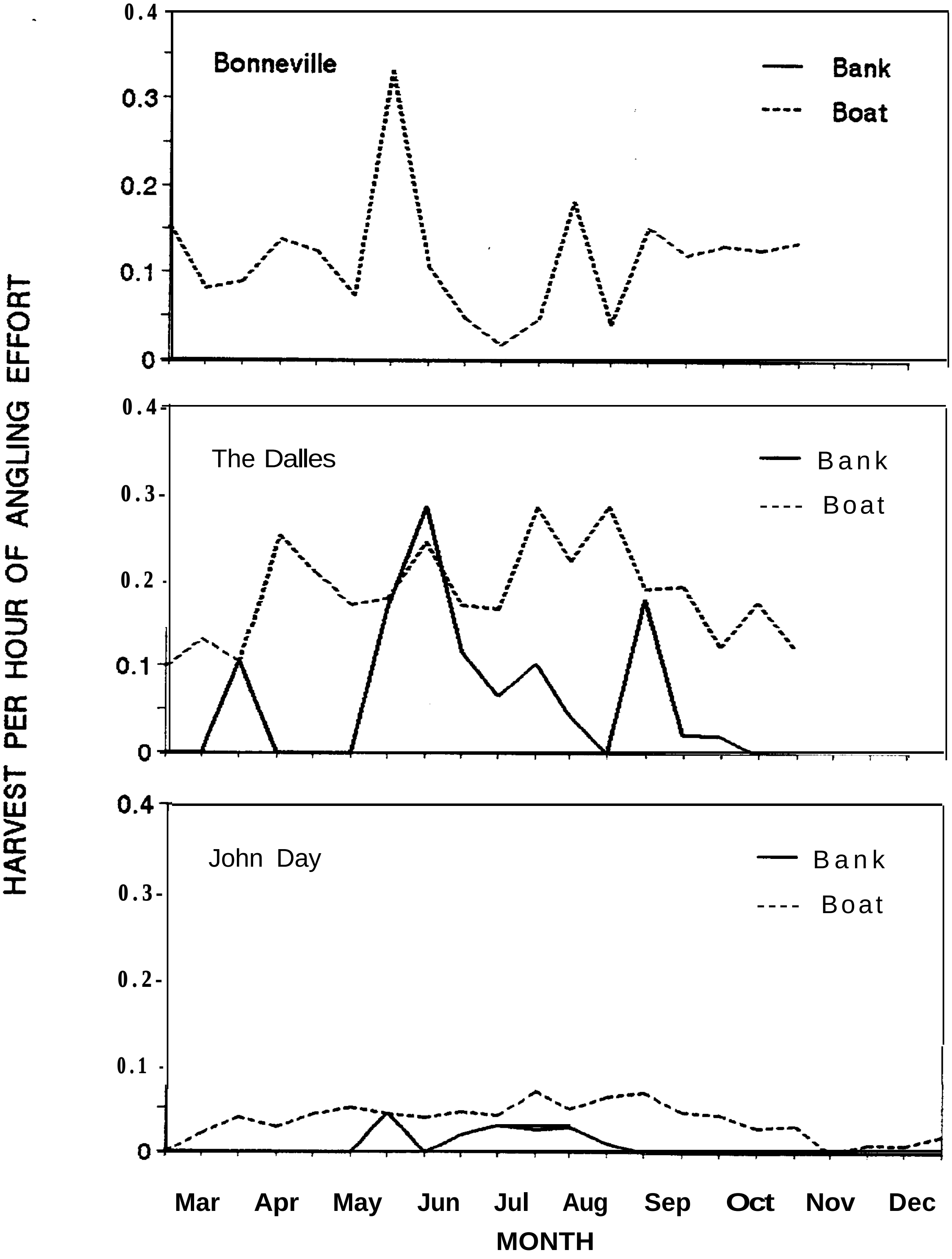

Figure 10. Average harvest per angler hour of walleye by target walleye anglers, by two week period, in Bonneville (March-October, 1988-90), The Dalles (June-October, 1987 and March-October, 1988-89), and John Day reservoirs (May-July, 1989, March-December, 1990, and April-September, 1991).

Table 13. Length frequencies of walleye harvested during recreational fisheries in Bonneville, The Dalles, and John Day reservoirs, 1987-1991.

| Length interval (cm FL) | Bonneville | | | The Dalles | | | John Day | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1988 | 1989 | 1990 | 1987 | 1988 | 1989 | 1989 | 1990 | 1991 |
| 21 - 25 | | 1 | | | | | | | |
| 26 - 30 | | | | 4 | 3 | 1 | | | |
| 31 - 35 | | 5 | | 9 | 63 | 125 | | | 1 |
| 36 - 40 | 1 | 7 | 1 | | | | | 1 | |
| | 1 | 31 | 12 | 41 | 73 | 101 | 5 | 19 | 14 |
| 46 - 50 | 2 | 30 | 128 | 43 | 181 | 83 | 10 | 52 | 28 |
| 51 - 55 | 2 | 11 | 40 | 10 | 31 | 36 | 11 | 59 | 66 |
| 56 - 60 | 3 | 12 | 17 | 9 | 9 | 21 | 11 | 35 | 61 |
| 61 - 65 | 1 | 5 | 9 | 14 | 4 | 10 | 7 | 28 | 25 |
| 66 - 70 | 1 | 2 | 4 | | | | 4 | 25 | 22 |
| 71 - 75 | | | | 2 | 5 | 5 | 5 | 10 | 14 |
| 76 | | | | 1 | 2 | 1 | 4 | 6 | 5 |
| 81 - 85 | | | | | 1 | | 1 | 7 | 6 |
| 86 - 90 | | | | | | | | 2 | 1 |
| 91 - 95 | | | | | | | 1 | | |
| Total | 11 | 104 | 211 | 135 | 394 | 396 | 59 | 242 | 243 |

### The Dalles Reservoir

Walleye fishing was observed throughout the reservoir, with most of the effort concentrated within 8 km (5 miles) of John Day Dam. Walleye anglers fished 10,364 hours (2,189 trips) during June-October in 1987 and averaged 28,323 hours of effort (5,058 trips) during March-October of 1988 and 1989 (Tables 10, 11 and 12). Catch per effort averaged 0.17 fish per hour (0.92 fish/trip) from 1987 to 1989. The mean harvest of walleye during March-October of 1988 and 1989 was 5,266 fish. Effort, harvest and CPUE increased annually during the study period.

The seasonal distribution of effort was variable instead of bimodal as observed in Bonneville and John Day reservoirs (Figure 9). Walleye CPUE also varied throughout the sample periods (Figure 10). Harvest peaked the end of July and early August.

Fork lengths of walleye in the harvest ranged from 28-81 cm (n=925) and averaged 46 cm from 1987 to 1989 (Table 13).

### John Day Reservoir

Anglers spent more time fishing for walleye in John Day Reservoir than for any other fish. Annual trends were difficult to discern, mainly because our sampling periods changed each year. Walleye anglers spent 34,527 hours of effort (6,061 trips) from May-July in 1989 compared to an averaged 49,280 hours of effort (9,159 trips) during April-September of 1990 and 1991 (Tables 10, 11,and 12). Catch per effort remained consistent from 1989 to 1991, averaging 0.05 fish per hour (0.25 fish/trip). Total mean harvest was 2,475 walleye between April-September each year of 1990 and 1991.

A bimodal distribution of effort similar to Bonneville Reservoir displayed two distinct peaks of effort in March and July (Figure 9). Catch per effort was highest July through August and harvest was greatest in July (Figure 10).

Walleye harvested ranged from 34 to 91 cm FL (n=546) and averaged 58 cm from 1989 to 1991 (Table 13).

## Recreational Smallmouth Bass Fisheries

### Bonneville Reservoir

Smallmouth bass anglers averaged 6,710 hours of effort (1,558 trips) during March-October each year from 1988 to 1990 (Tables 10, 11, and 12, and Figure 11). Bass anglers averaged 0.16 fish per hour (0.66 fish/trip) and harvest averaged 1,185 smallmouth bass each year during the census period (Figure 12).

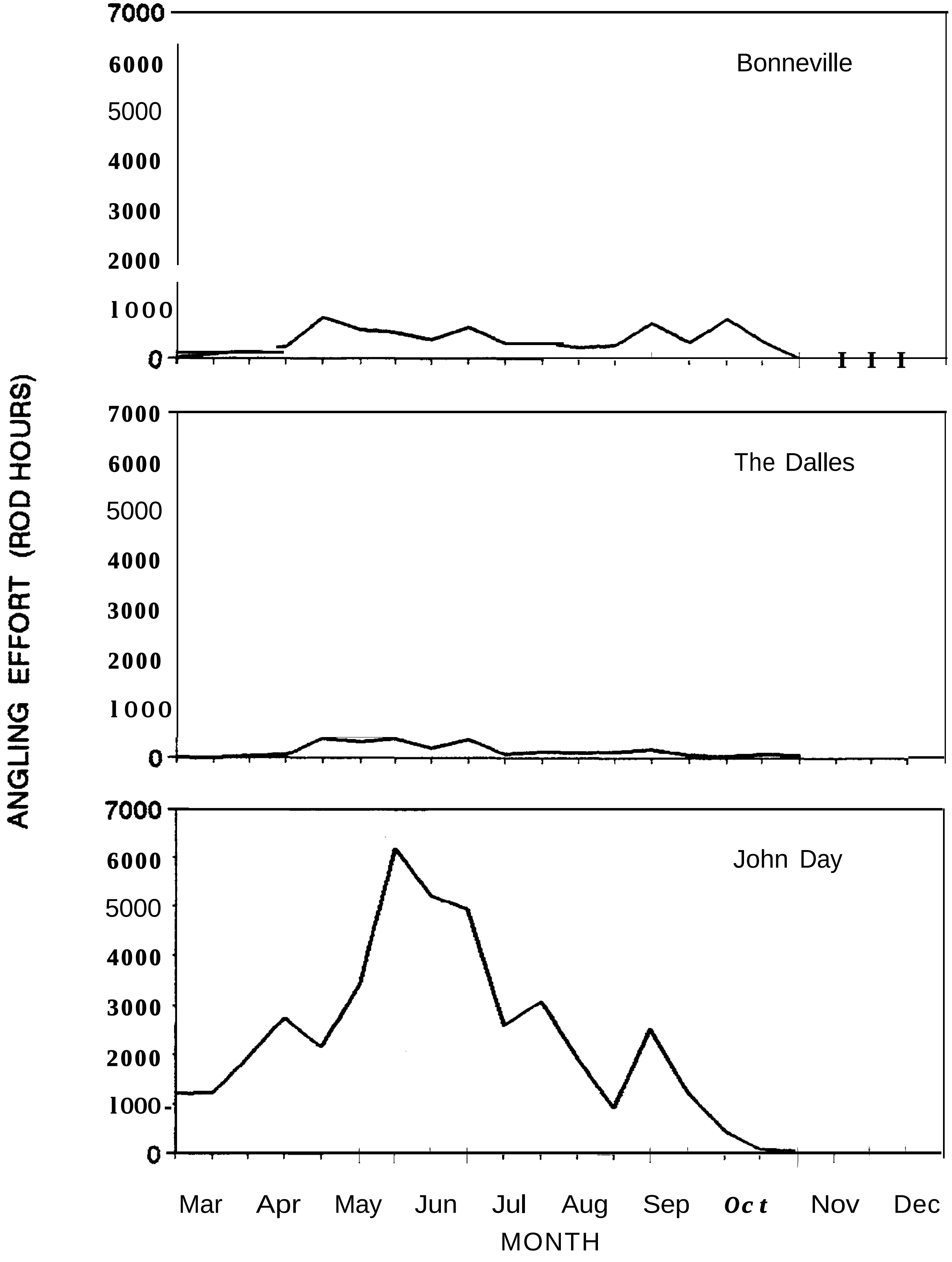

**Figure 11.** Average recreational fishery effort (anglers hours) by two week period for smallmouth bass in Bonneville Reservoir (March-October, 1988-90), The Dalles Reservoir (June-October, 1987, and March-October, 1988-89), and John Day Reservoir (May-July, 1989, March-December, 1990, and April-September, 1991).

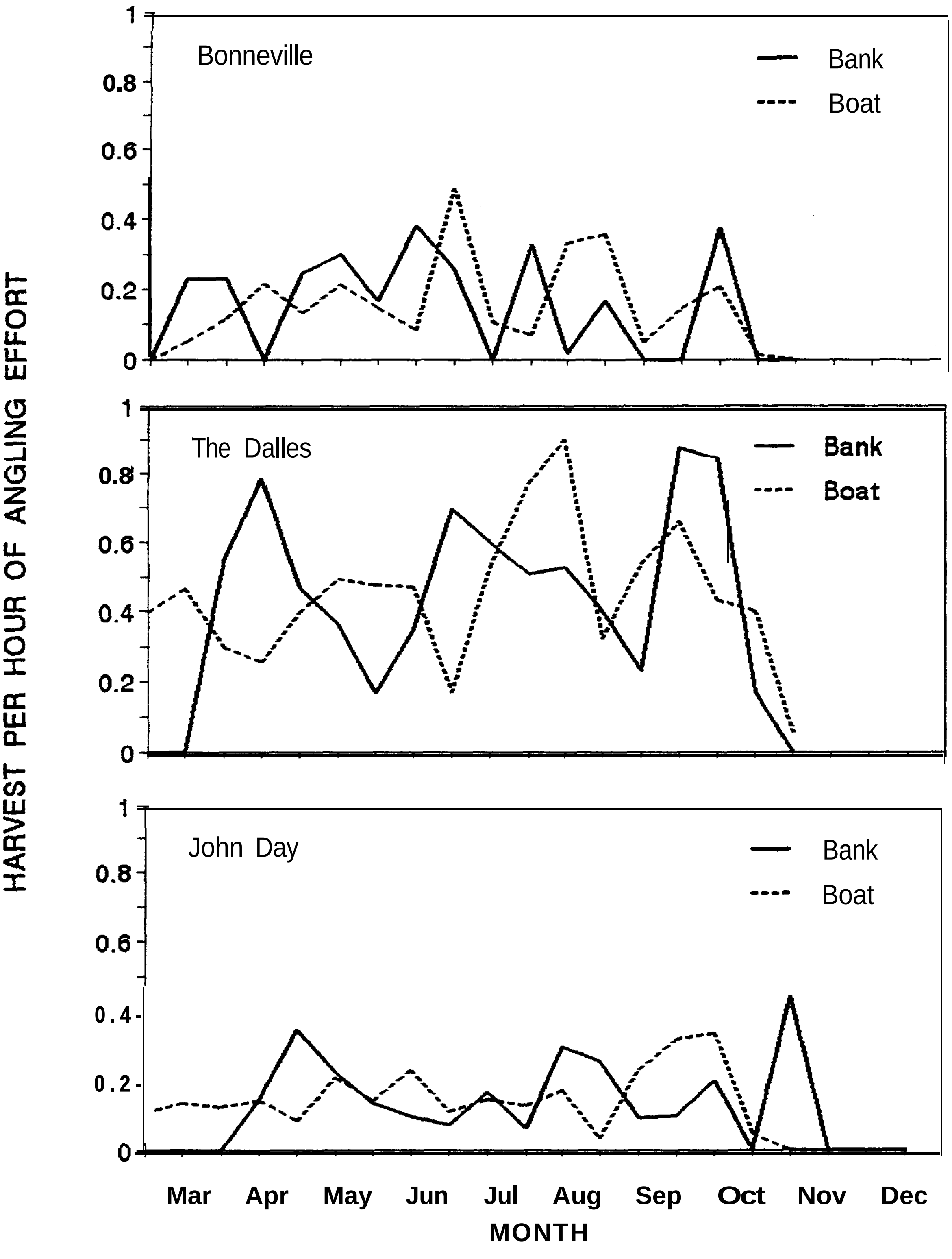

Figure 12. Average harvest per angler hour of smallmouth bass by target bass anglers, by two week period, in Bonneville (March-October, 1988-90), The Dalles (June-October, 1987 and March-October, 1988-89), and John Day reservoirs (May-July, 1989, March-December, 1990, and April-September, 1991).

### The Dalles Reservoir

Smallmouth bass anglers fished 1,700 hours (480 trips) during June - October in 1987 and averaged 2,296 hours of effort (579 trips) during March-October of 1988 and 1989 (Tables 10, 11, and 12, and Figure 11). Anglers averaged 0.37 fish per hour (1.36 fish/trip) fishing for smallmouth bass during the study years (Figure 12). A total of 1,359 smallmouth bass were harvested in 1987, compared to an average 938 smallmouth bass harvested during March-October of 1988 and 1989.

### John Day Reservoir

Anglers spent 28,744 hours of effort (5,525 trips) fishing for smallmouth bass from May-July in 1989 and averaged 39,340 hours of effort (6,818 trips) during April-September of 1990 and 1991 (Tables 10, 11, and 12, and Figure 11). Smallmouth bass anglers averaged 0.15 fish per hour (0.74 fish/trip) from 1989 to 1991 (Figure 12). A total of 4,776 smallmouth bass were harvested during May-July of 1989, compared to an average 5,888 fish harvested during April-September of 1990 and 1991.

## Recreational Northern Squawfish Fisheries

### Bonneville Reservoir

Northern squawfish were occasionally harvested by anglers in Bonneville Reservoir. We estimate anglers harvested 586 northern squawfish during March-September in 1990 (Tables 11, 12,and 14).

### The Dalles Reservoir

Effort and harvest for northern squawfish were not estimated for the years we surveyed this reservoir.

### John Day Reservoir

The Bonneville Power Administration initiated a pilot sport reward fishery in John Day Reservoir in 1990 to decrease the numbers of northern squawfish in the Columbia River. Angler check stations were established at Plymouth, Umatilla, Arlington, and Le Page boat ramps during 1990. In 1991, Arlington was dropped as a check station. A bounty of $1-3 per squawfish greater than or equal to 11 inches was given to anglers who registered and returned fish to check stations.

We periodically interviewed registered bounty anglers during our random sampling of fisheries. We estimated 2,034 hours of bounty angler effort (468 trips) in 1990 and 10,443 hours (1,795 trips) in 1991 (Tables 11, 12, and 14). Catch per effort decreased from 0.74 fish per hour (3.10 fish/ trip) in 1990 to 0.19 fish per hour (0.85 fish/ trip) in 1991, although total harvest increased from 2,390 fish to 3,453 fish, respectively.

Table 14. Estimated recreational fishery effort, harvest, and CPUE for northern squawfish and other resident fish on the middle Columbia River, 1987-1991.

| Reservoir | | Bank | | | Boat | | |
|---|---|---|---|---|---|---|---|
| Year | Period | Effort (Hrs) | Harvest' | CPUE | Effort (Hrs) | Harvest[a] | CPUE |
| | | | | Squawfish | | | |
| **Bonneville** | | | | | | | |
| 1990 | Mar-Ott | ---- | 16 (72) | ---- | ---- | 0 (514) | |
| **John Day** | | | | | | | |
| 1990 | Mar-Dee | 312 | 539 (852) | 1.73 | 1,722 | 913 (1,538) | 0.53 |
| 1991 | Apr-Sep | 3,875 | 1680 (2,298) | 0.43 | 6,568 | 303 (1,155) | 0.05 |
| | | | | Other Fish | | | |
| **Bonneville** | | | | | | | |
| 1988 | Mar-Ott | 1,394 | 158 (205) | 0.11 | 519 | 44 (108) | 0.08 |
| 1989 | Mar-Ott | 1,603 | 58 (102) | 0.04 | 511 | 53 (57) | 0.10 |
| 1990 | Mar-Ott | 2,674 | 52 (106) | 0.02 | 997 | 126 (148) | 0.13 |
| **The Dalles** | | | | | | | |
| 1987 | Jun-Oct | 638 | 280 (425) | 0.44 | 755 | 95 (459) | 0.13 |
| 1988 | Mar-Ott | 747 | 119 (309) | 0.16 | 343 | 28 (152) | 0.08 |
| 1989 | Mar-Ott | 638 | 54 (60) | 0.08 | 136 | 21 (55) | 0.15 |
| **John Day** | | | | | | | |
| 1989 | May-Jul | 1,995 | 44 (60) | 0.02 | 1,435 | 222 (260) | 0.15 |
| 1990 | Mar-Dec | 11,742 | 993 (1,178) | 0.08 | 4,548 | 468 (529) | 0.10 |
| 1991 | Apr-Sep | 9,382 | 716 (796) | 0.08 | 3,875 | 488 (538) | 0.13 |

[a] *Harvest by anglers targetting on other species in parenthesis*

## Tribal Commercial White Sturgeon Fisheries

A total of 6,066 sturgeon from Bonneville Reservoir, 6,664 sturgeon from The Dalles Reservoir, and 2,929 sturgeon from John Day Reservoir were harvested in Zone 6 tribal commercial fisheries from 1987 to 1991 (Table 15). An additional 8,183 sturgeon from unidentified reservoirs were harvested from 1987 to 1988.

We examined 863 sturgeon from Bonneville Reservoir, 1,572 sturgeon from The Dalles Reservoir, 540 sturgeon from John Day Reservoir, and 596 sturgeon from unidentified reservoirs for marks from 1987 to 1991 (Table 15), resulting in an average mark sample rate of 15 percent for all three reservoirs. Five marked fish from Bonneville Reservoir, 46 marked fish from The Dalles Reservoir, and 4 marked fish from unidentified reservoirs were recovered during random sampling of commercial fisheries. No marked white sturgeon were recovered from John Day Reservoir during the same period.

A detailed summary of treaty commercial landing statistics by fishery and year are available in WDF Columbia River Progress Reports: Tracy 1988; Wright 1989; Grimes 1990, 1991, 1992.

## DISCUSSION

The methods used to estimate total angling effort and harvest were designed after a similar survey conducted on the Cowlitz River in 1983 (DeVore 1984). A roving creel survey was effective for sampling the majority of access points within these large reservoirs. We were able to sample all the recreational fisheries represented in each reservoir during a significant portion of the year. Most of our efforts were directed towards sampling between March and October when fishing effort was greatest, although during spot checks conducted in the late fall and winter months we observed low levels of effort for sturgeon, salmonids, and walleye. We would have preferred to interview more boat anglers in each reservoir for a better sampling rate, but this would have required more personnel.

The distribution of anglers varied within and between reservoirs. Sturgeon anglers were primarily concentrated below the dams in The Dalles and John. Day reservoirs, whereas in Bonneville Reservoir anglers were found throughout the reservoir. The distribution of sturgeon anglers may be associated with the abundance and distribution of sturgeon. According to recent studies, higher densities of sturgeon were observed in the tailrace areas and boat restricted zones immediately downstream from mid-Columbia hydroelectric projects (Beamesderfer et al. 1990; Rien et al., 1991), although sturgeon moved widely within the reservoirs (North et al. 1992). Walleye anglers usually congregated below the dams, but we noticed an expansion of the fishery further downstream in each of the reservoirs through the course of the study. Similar trends were observed in John Day Reservoir from 1983 to 1986 (Beamesderfer et al. 1990). Beamesderfer and Rieman (1988) reported smallmouth bass were most abundant in sloughs and embayment areas adjacent to the mainstem Columbia River and their

Table 15. Estimated harvest of marked white sturgeon landed during tribal commercial fisheries in Bonneville, The Dalles, and John Day reservoirs, 1987-1991.

| Reservoir Year | Number landed[a] | Number examined for marks[b] | Observed marks | Estimated mark harvest |
|---|---|---|---|---|
| **Bonneville** | | | | |
| 1987 | 618 | 96 | 0 | 0 |
| 1988 | 985 | 267 | 0 | 0 |
| 1989 | 1,410 | 185 | 2 | 15 |
| 1990 | 1,890 | 207 | 2 | 18 |
| 1991 | 1,163 | 108 | 1 | 11 |
| **The Dalles** | | | | |
| 1987 | 2,376 | 494 | 12 | 58 |
| 1988 | 808 | 106 | 2 | |
| 1989 | 1,932 | 663 | 22 | 6 |
| 1990 | 1,206 | 237 | 7 | 36 |
| 1991 | 342 | 72 | 3 | 14 |
| **John Day** | | | | |
| 1987 | 1,861 | 320 | 0 | 0 |
| 1988 | 466 | 175 | 0 | 0 |
| 1989 | 165 | 1 | 0 | 0 |
| 1990 | 405 | 32 | 0 | 0 |
| 1991 | 32 | 12 | 0 | 0 |
| Unidentified[c] | | | | |
| 1987 | 6,297 | 483 | 2 | 26 |
| 1988 | 1,886 | 89 | 2 | 42 |
| 1989 | | 5 | 0 | 0 |
| 1990 | | 11 | 0 | 0 |
| 1991 | | 8 | 0 | 0 |

---

[a] *Combined total of setline, setnet, and hook and line landings reported by Washington and Oregon buyers.*

[b] *Fish were not always separated by pool at the buying stations.*

[c] *Prior to 1989, Oregon buyers were not required to document landings by reservoir.*

distribution varied monthly. Smallmouth bass anglers were observed fishing in these areas during our survey.

The importance of each fishery, in terms of effort and catch rate, varied between reservoir depending on the area and time of year. Sturgeon and salmonid fisheries were most important in Bonneville and The Dalles reservoirs whereas walleye, smallmouth bass, and other resident fish were more frequently targeted in John Day Reservoir. King (1985) reported that in 1983 sturgeon anglers comprised 67% and 44% of the total estimated angling effort in John Day and The Dalles reservoirs, suggesting that either interest and success in this fishery has declined or interest in other species has increased.

Effort, harvest, and CPUE for walleye increased each year we surveyed The Dalles Reservoir from 1987 to 1989 and Bonneville Reservoir from 1988 to 1990. The discovery of new recreational opportunity may explain this recent increase in effort. Walleye harvest increased because of good spawning success from 1985-1988 and successful recruitment to the fishery during 1988-1990 (WDF and ODFW 1992). Compared to Bonneville and John Day reservoirs, CPUE was higher in The Dalles Reservoir, although the mean length of walleye in the catch was smaller. Catch per effort of walleye in John Day Reservoir was slightly higher than the CPUE (0.019 fish per hour) reported in the same reservoir from 1983 to 1986 (Beamesderfer et al . 1990) . In 1990, CPUE (0.48 fish /trip) in Bonneville Reservoir was higher than the 0.26 fish/trip reported in the lower Columbia River (Melcher and King 1991) and was similar to the CPUE observed in John Day Reservoir during the same year. Some fluctuations in effort and harvest were observed in John Day Reservoir from 1990 to 1991, but not enough to suggest that this fishery was unstable or depressed.

During the final two years of our study in John Day Reservoir, we interviewed anglers registered in the sport-reward fishery for northern squawfish. Estimates of effort and harvest on squawfish were provided in this report because these anglers were part of our random sample. Most of our efforts were concentrated on sampling the upper John Day Reservoir during'the study years and excluded sampling the John Day arm portion, therefore our squawfish harvest estimates should be considered minimal compared to estimates calculated from sport-reward vouchers. Bonneville Reservoir squawfish harvest for 1990 was also included to provide a background level estimate of squawfish harvest. For a more complete analysis of the predator control fisheries, results are currently available for the 1990 fisheries in BPA annual reports (Vigg et al. 1990) and will be published for the 1991 fisheries in 1992 (Craig Burley, WDW personal communication).

We observed several changes in effort, harvest, and CPUE in recreational sturgeon fisheries during the study years. Estimated annual effort, harvest, and CPUE declined each year in The Dalles Reservoir from 1987 to 1989 and in John Day Reservoir from 1989 to 1991. This was due in part to enactment of more restrictive recreational fishery regulations, but also may indicate a decline in abundance of white sturgeon in these reservoirs. This same annual trend was not observed in Bonneville Reservoir from 1988 to 1990. Sturgeon angler effort increased annually, although CPUE decreased slightly from 1989 to 1990. Effort, harvest, and

CPUE in Bonneville Reservoir appeared stable relative to The Dalles and John Day reservoirs.

Catch per effort of sturgeon varied between reservoirs. Catch per effort was highest in Bonneville Reservoir (0.17 fish/trip) from 1988 to 1990, second highest in The Dalles reservoir (0.15 fish/trip) from 1987 to 1989, and lowest in John Day Reservoir( 0.04 fish/trip) from 1989 to 1991. Catch per effort for all reservoirs combined (0.12 fish/trip) was lower than the CPUE (0.20 fish/trip) estimated in 1983 for the middle Columbia River (King 1985). However, sampling was confined to the areas immediately downstream from the dams in 1983, which might account for some of this difference. Catch per effort in John Day Reservoir from 1989 to 1991 was substantially lower than the CPUE of 0.023 fish per hour (0.11 fish/trip) reported by Beamesderfer et al.(1990) for the same reservoir from 1983 to 1986. Although some declines in CPUE could be attributed to regulation changes (Appendix 2, Table 3), our estimates showed that while CPUE declined in The Dalles and John Day reservoirs, effort and CPUE increased in Bonneville Reservoir as anglers sought better fishing opportunities.

Catch per effort for sturgeon in The Dalles and John Day reservoirs was poor compared to annual CPUE reported for the lower Columbia River (downstream from Bonneville Dam) from 1987 to 1990 (Melcher and King 1991). Catch per effort for Bonneville Reservoir in 1990 was higher than the 0.13 fish per trip reported in the white sturgeon recreational fishery on the lower Columbia River for the same year (Melcher and King 1991).

The number of sublegals in the catch increased from Bonneville to John Day reservoirs during the study years. The ratio of sublegal to legal-size sturgeon in the catch was also different between reservoirs. This ratio was higher in each of the reservoirs we surveyed than the two to one sublegal to legal-size sturgeon ratio reported by King (1985) on the middle Columbia River in the 1983, indicating that the number of legal-size sturgeon relative to the number of undersized fish in the catch had declined. This change was attributed to both regulation changes implemented in 1988, increasing the allowable minimum size from 36 to 40 inches, and a decline in the abundance of legal size fish.

The ratio of legal-size to oversize sturgeon also varied among reservoirs. This ratio averaged 36:1 in Bonneville Reservoir from 1988 to 1990, 10:1 in The Dalles Reservoir from 1987 to 1989 and 2:1 in John Day Reservoir from 1989 to 1991. The number of legal-size to oversize sturgeon in the catch doubled from 1990 to 1991 in John Day Reservoir. This increase was partially attributed to more restrictive regulations enacted in 1991, lowering the maximum size from 72 to 66 inches.

Our results further confirm that white sturgeon populations between Bonneville and McNary dams have been overexploited in recent years as a result of overfishing by treaty commercial and non-treaty recreational fishermen (Rieman and Beamesderfer 1990; WDF and ODFW 1992). Current research has also suggested that the development of hydroelectric dams on the Columbia River have adversely affected the potential productivity and critical habitat of these landlocked populations (Beamesderfer and Rien 1992; Parsley and Beckman 1992). However, significant progress has been made towards more conservative management of these less productive populations. Beginning in 1987, the SMTF was organized by the WDF, ODFW and the Columbia River treaty tribes to address harvest management of Columbia River sturgeon populations (WDF and ODFW 1992). Beginning in 1988, Washington and Oregon adopted regulations to reduce sport harvest on sturgeon in the middle Columbia River (Appendix 2 Table 3).

Harvest guidelines on white sturgeon were also established for treaty commercial fisheries in 1988. Annual sturgeon harvest in Zone 6 had increased steadily from 1983 to 1987, warranting concern for the population status (ODFW and WDF 1991). Based on the 1987 harvest of 11,152 sturgeon, a recommendation was made by the SMTF to reduce the 1988 treaty commercial harvest by 40 percent. Efforts were made by the tribes to reduce harvests to the SMTF guidelines by prohibiting the sale of sturgeon during certain seasons.

Beginning in 1991, reservoir specific harvest rates were adopted as management goals for recreational, tribal commercial, and tribal subsistence fisheries. The SMTF recommended a reduction in harvest rates of 3-6 foot sturgeon in all fisheries to 15% in Bonneville Reservoir and 10% in The Dalles and John Day reservoirs. The tribes agreed to provide harvest data by reservoir from the subsistence fishery and to limit the sale of sturgeon from the commercial fisheries to maintain recommended harvest rates (ODFW and WDF 1991).

Monitoring of the recreational and commercial fisheries is an important management and research tool for determining the health of the white sturgeon populations and should be continued. Annual harvest and exploitation data should be used by fishery managers to determine the effectiveness of regulations towards achieving sustainable exploitation rates and preserving the resource.

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# APPENDIX 1

## Angler Effort Count Index Areas and Catch Per Effort Analysis River Subsections

## INDEX AREAS

### Bonneville Reservoir

#### Boat

Bridge of the Gods at Cascade Locks, OR [Rkm 239.0 (RM 148.4)] upstream past Stevenson, WA [Rkm 244.3 (RM 151.7)].

West of Spring Creek Hatchery [Rkm 267.3 (RM 166.0)] upstream to Mosier, OR (Rkm 282.6 [RM 175.51).

West end of The Dalles, OR [Rkm 303.7 (RM 188.6)] upstream to Hwy. 197 bridge at The Dalles [Rkm 308.4 (RM 191.5)].

#### Bank

The old lock structure on the Oregon shore at Cascade Locks [Rkm 239.9 (RM 149.0)].

Three access points along the Washington shore between Thirteenmile Point and Spring Creek Hatchery [Rkm 258.5 (RM 160.5), Rkm 266.0 (RM 165.2), and Rkm 268.4 (RM 166.7)].

The Highway pullout on the Oregon shore just west of Mosier [Rkm 280.0 (RM 173.9)].

The Washington shore across from Mosier [Rkm 282.0 to Rkm 283.4 (RM 175.1 to RM 176-0)].

The Oregon and Washington shore at The Dalles [Rkm 303.7 to Rkm 305.2 (RM 188.6 to RM 189.5)].

### The Dalles Reservoir

#### Boat

The lower end of Miller Island [Rkm 327.2 (RM 203.2)] upstream to John Day Dam [Rkm 347.2 (RM 215.6)].

#### Bank

The Washington shore east of Maryhill, WA [Rkm 340.7 (RM 211.6)] upstream to the base of John Day Dam [Rkm 347.0 (RM 215.5)].

The Oregon shore east of Rufus, OR [Rkm 344.9 (RM 214.2)] upstream to John Day Dam [Rkm 347.2 (RM 215.6)].

John Day Reservoir

Boat

West of Boardman, OR [Rkm 431.6 (RM 268.0)] upstream past Glade Creek on the Washington shore [Rkm 439.6 (RM 273.0)].

Irrigon, OR [Rkm 455.7 (RM 283.0)] upstream to McNary Dam [Rkm 471.0 (RM 292.5)].

Bank

The Oregon shore just west of Irrigon, OR [Rkm 449.4 to Rkm 449.8 (RM 279.1 to RM 279.3)].

The Washington shore west of Plymouth, WA [Rkm 461.2 (RM 286.4)].

The Oregon shore just upstream of Hwy. 82 bridge at Umatilla, OR [Rkm 468.6 (RM 291.0)].

The Oregon shore just downstream of McNary Dam [Rkm 470.4 (RM 292-1)].

## RIVER SUBSECTIONS

Bonneville Reservoir

Boat

Bonneville Dam [Rkm 233.5 (RM 145.0)] upstream past Spring Creek Hatchery [Rkm 268.9 (RM 167.0)].

East of Spring Creek Hatchery [Rkm 268.9 (RM 167.0)] upstream to Hwy. 35 bridge at Hood River [Rkm 273.1 (RM I69.6)].

Hwy. 35 bridge at Hood River [Rkm 273.1 (RM 169.6)] upstream to The Dalles Dam [Rkm 308.4 (RM 191.5)].

Bank

The Oregon shore from Bonneville Dam [Rkm 233.5 (RM 145.0)] upstream past Cascade Locks [Rkm 239.9 (RM 149.0)].

The Oregon shore upstream of Cascade Locks [Rkm 239.9 (RM 149.0)] to Hwy. 35 bridge [Rkm 273.1 (RM 169.6)].

The Washington shore from Bonneville Dam [Rkm 233.5 (RM 145.0)] upstream to Hwy. 35 bridge [Rkm 273.1 (RM 169.6)].

Both the Oregon and Washington shore from Hwy. 35 bridge [Rkm 273.1 (RM 169.6)] upstream to The Dalles Dam [Rkm 308.4 (RM 191.5)].

## The Dalles Reservoir

### Boat and Bank

The Dalles Dam [Rkm 308.4 (RM 191.5)] upstream to the railroad bridge at Celilo, OR [Rkm 323.8 (RM 201.1)].

The railroad bridge [Rkm 323.8 (RM 201.1)] upstream to Hwy. 97 bridge at Biggs, OR [Rkm 336.7 (RM 209.1)].

Hwy. 97 bridge at Biggs [Rkm 336.7 (RM 209.1)] upstream to John Day Dam [Rkm 347.2 (RM 215.6)].

## John Day Reservoir

### Boat

John Day Dam [Rkm 347.2 (RM 215.6)] upstream to Boardman [Rkm 431.6 (RM 268-0)].

Boardman [Rkm 431.6 (RM 268.0)] upstream past Patterson, WA [Rkm 449.3 (RM 279.0)].

East of Patterson [Rkm 449.3 (RM 279.0)] upstream to McNary Dam [Rkm 471.0 (RM 292.5)].

### Bank

Both the Oregon and Washington shore from John Day Dam [Rkm 347.2 (RM 215.6)] upstream past Patterson [Rkm 449.3 (RM 279.0)].

Both the Oregon and Washington shore east of Patterson [Rkm 449.3 (RM 279.0)] upstream to Hwy. 82 bridge [Rkm 468.4 (RM 290.9)].

Both the Oregon and Washington shore from Hwy. 82 bridge [Rkm 468.4 (RM 290.9)] upstream to McNary Dam [Rkm 471.0 (RM 292.5)].

# APPENDIX 2

## Proportion of Angler Effort Sampled, Angler Effort Counts, and Recreational Fishery Regulations

**Appendix 2 Table 1.** Number and proportion of anglers and angler effort sampled annually in the middle Columbia River recreational fisheries, 1987-1991.

| Reservoir | | Angler trips | | | Angler effort (Hrs) | | |
|---|---|---|---|---|---|---|---|
| Year | Period | Total | Sampled | Proportion sampled | Total | Sampled | Proportion sampled |
| | | | | | **Bank** | | |
| **Bonneville** | | | | | | | |
| 1988 | Mar-Oct | 12,558 | 3,145 | 0.25 | 91,037 | 13,913 | 0.15 |
| 1989 | Mar-Oct | 14,464 | 3,641 | 0.25 | 105,104 | 16,399 | 0.16 |
| 1990 | Mar-Oct | 12,131 | 3,017 | 0.25 | 85,778 | 12,867 | 0.15 |
| **The Dalles** | | | | | | | |
| 1987 | Jun-Oct | 9,404 | 4,061 | 0.43 | 78,846 | 19,742 | 0.25 |
| 1988 | Mar-Oct | 8,574 | 4,861 | 0.57 | 73,111 | 29,019 | 0.40 |
| 1989 | Mar-Oct | 7,067 | 4,408 | 0.62 | 58,341 | 23,041 | 0.39 |
| **John Day** | | | | | | | |
| 1989 | May-Jul | 6,033 | 955 | 0.16 | 36,673 | 3,813 | 0.10 |
| 1990 | Mar-Dec | 10,135 | 1,946 | 0.19 | 55,372 | 6,168 | 0.11 |
| 1991 | Apr-Sep | 10,815 | 3,438 | 0.32 | 52,785 | 9,486 | 0.18 |
| | | | | | **Boat** | | |
| **Bonneville** | | | | | | | |
| 1988 | Mar-Oct | 9,786 | 2,337 | 0.24 | 42,490 | 6,876 | 0.16 |
| 1989 | Mar-Oct | 12,131 | 2,042 | 0.17 | 58,651 | 9,775 | 0.17 |
| 1990 | Mar-Oct | 16,029 | 1,837 | 0.11 | 79,237 | 9,013 | 0.11 |
| **The Dalles** | | | | | | | |
| 1987 | Jun-Oct | 19,925 | 2,955 | 0.15 | 100,128 | 15,039 | 0.15 |
| 1988 | Mar-Oct | 14,683 | 2,883 | 0.20 | 75,111 | 13,553 | 0.18 |
| 1989 | Mar-Oct | 19,599 | 3,349 | 0.17 | 113,141 | 18,777 | 0.17 |
| **John Day** | | | | | | | |
| 1989 | May-Jul | 14,693 | 912 | 0.06 | 84,610 | 5,064 | 0.06 |
| 1990 | Mar-Dec | 24,700 | 2,983 | 0.12 | 140,399 | 16,660 | 0.12 |
| 1991 | Apr-Sep | 19,114 | 2,795 | 0.15 | 95,268 | 17,055 | 0.18 |

Appendix 2 Table 2. Number of days angler effort was counted on Bonneville, The Dalles and John Day reservoirs, 1987-1991.

| Reservoir/ Year | Census period | Flights | Sunrise-Sunset index | Once through index |
|---|---|---|---|---|
| Bonneville | | | | |
| 1988 | Mar-Oct | 71 | 72 | 139 |
| 1989 | Mar-Oct | 45 | 68 | 148 |
| 1990 | Mar-Oct | 44 | 69 | 163 |
| The Dalles | | | | |
| 1987 | Jun-Oct | 36 | 36 | 90 |
| 1988 | Mar-Oct | 71 | 72 | 158 |
| 1989 | Mar-Oct | 45 | 68 | 137 |
| John Day | | | | |
| 1989 | May-Jul | 15 | 24 | 57 |
| 1990 | Mar-Dec | 52 | 81 | 178 |
| 1991 | Apr-Sep | 34 | 52 | 128 |

Appendix 2 Table 3. History of recreational sturgeon fishery regulations for the middle Columbia River, 1987-1991.

| Year | Daily Bag Limit | Size Limit | Other |
|---|---|---|---|
| 1987 | 2 | 36" minimum<br>72" maximum | No gaffing of sturgeon in Washington. Sturgeon catch record and 30 fish annual limit required of Oregon anglers since 1986. |
| 1988 | 2 | 40" minimum<br>72" maximum | Sturgeon catch record required of Washington anglers. |
| 1989 | 2 | 40" minimum<br>72" maximum | 15 fish annual limit in Washington. |
| 1990 | 2 | 40" minimum<br>72" maximum | 15 fish annual limit in Oregon. No gaffing of sturgeon in Oregon. Single point barbless hooks. |
| 1991 | 2 | 40" minimum<br>72" maximum | Bag limit changed to 1 fish less than 48 " and 1 fish greater than or equal to 48". |
| 1991 | 1 | 48" minimum<br>66" maximum | Effective April 16, 1991 for waters upstream of The Dalles Dam. |

# REPORT R

# Predation on White Sturgeon Eggs by Sympatric Fish Species in Columbia River Impoundments

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*U.S. Fish and Wildlife Service*

## Abstract

Three endemic fish species, prickly sculpin Cottus *asper*, largescale sucker *Catostomus macrocheilos*, and northern squawfish *Ptychocheilus oregonensis*, and one introduced species, common carp *Cyprinos carpio*, prey on white sturgeon *Acipenser transmontanus eggs* in Columbia River impoundments; the four species are among the most abundant species in the impoundments. Predation on viable white sturgeon eggs occurs throughout the egg incubation period. Seventy white sturgeon eggs were collected from one largescale sucker and nine were collected from one prickly sculpin. Predation on white sturgeon eggs may be more intense now than historically, due to changes in abundance and distribution of predators brought about by impoundment, and by the introduction of species such as common carp.

## Introduction

White sturgeon broadcast adhesive eggs (Conte et al. 1988) and since no parental care is provided, eggs may be vulnerable to predation. Predation on white sturgeon eggs has not been reported in the literature, but at least four abundant fish species in the Columbia River, prickly sculpin *Cottus asper*, largescale sucker *Catostomus macrocheilus*, northern squawfish *Ptychocheilus oregonensis*, and common carp *Cyprinus carpio*, are known to feed on fish eggs. Adult prickly sculpin feed primarily on aquatic insect larvae, planktonic crustaceans, and small fish (Lee et al. 1980) but consume fish eggs when they are available (Scott and Crossman 1973; Wydoski and Whitney 1979). Largescale suckers are opportunistic feeders, ingesting a variety of benthic organisms (Wydoski and Whitney 1979). Carl (1936) reported that 58% of stomachs examined from lake dwelling largescale suckers contained fish eggs during fall spawning activity of anadromous salmonids. Fish are the primary food item of large northern squawfish *Ptychocheilus oregonensis* in the Columbia River (Wydoski and Whitney 1979), however, Patton and Rodman (1969) reported cannibalism of eggs by male northern squawfish. Kempinger (1988) observed common carp feeding on lake sturgeon *Acipenser fulvescens* eggs. Crayfish *Orconectes spp.* have also been observed feeding on lake sturgeon eggs (Kempinger 1988) and are abundant in white sturgeon spawning areas in the Columbia River.

White sturgeon populations in the Columbia River have declined relative to historic conditions (Rieman and Beamesderfer 1990). Increased predation related to habitat changes may have contributed to declines in white sturgeon populations in Columbia River impoundments. Factors reported to have contributed to the decline in white sturgeon numbers include: obstruction of migration by dams (Bajkov 1951; Lukens 1981), altered food availability (Bajkov 1951), altered flow regime (Coon et al. 1977)) altered temperature regime (Haynes et al. 1978)) altered predator/prey relationships (Bosley and Gately 1981), and overharvest (Rieman and Beamesderfer 1990). This paper documents predation on white sturgeon eggs by four fish species and discusses the effects on recruitment.

## Methods

White sturgeon eggs were collected from the drift in single or paired plankton nets and with a single 3-m wide by 0.5-m high beam trawl net to determine location, timing, and extent of white sturgeon spawning activity in the three furthest downriver pools (Bonneville, The Dalles, and John Day) of the Columbia River (Figure 1). Both types of gear were fished on the substrate, usually for 30 min. The plankton nets were constructed of 1.59-mm knotless nylon mesh attached to a "D" shaped frame constructed of 1.3-cm diameter stainless steel (0.76 m wide and 0.54 m high). Two to six lead weights (4.5 or 9.1 kg each) were attached to the two corners of the frame to hold the flat side of the frame stationary on the substrate. The beam trawl liner was also constructed of 1.59-mm knotless nylon mesh, but was attached to a three-sided 3-m wide by 1.0-m high aluminum frame with weighted skids and was fished in a stationary

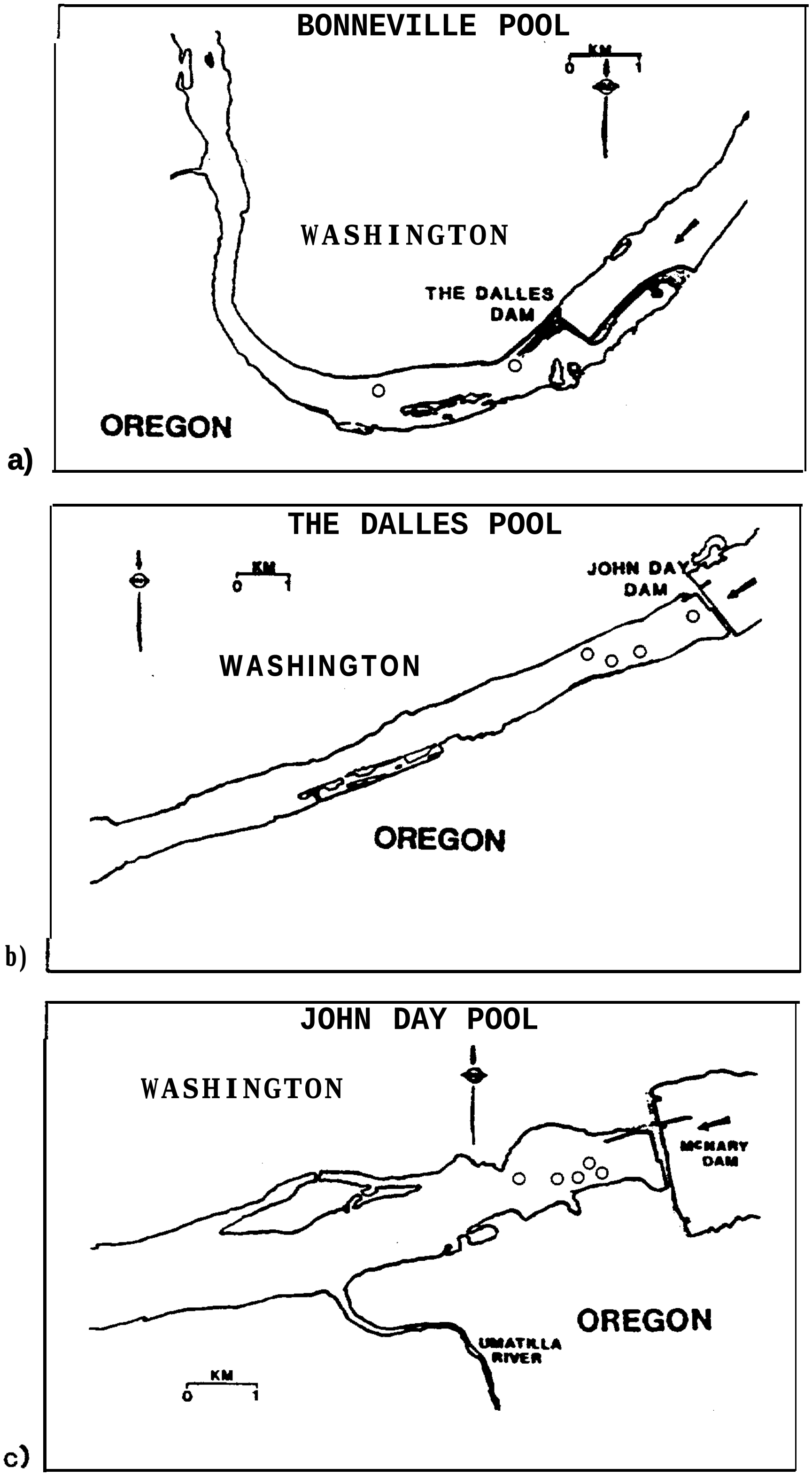

Figure 1, Location of tailrace sites (circles) where fish were collected for stomach examination, to determine if white sturgeon eggs were ingested, in Bonneville (a), The Dalles (b), and John Day (c) pools.

position or towed slowly upstream. Plankton nets and the beam trawl were fished in the upstream portion of each pool. Sites were sampled weekly from early April or May through July of each year.

Juvenile white sturgeon were collected with a 6.2-m high-rise trawl towed upstream for 10 minutes (about 0.3 miles) on the substrate to determine abundance and distribution. The high-rise trawl was‘ fished throughout each pool .in April and August through September during 1987 through 1991 in The Dalles Pool, 1988 through 1991 in Bonneville Pool, and 1989 through 1991 in John Day Pool, at the same sites each year. Catch per hectare was calculated for all 23 fish species collected.

Some non-sturgeon adult fishes captured with the beam and high-rise trawls during the white sturgeon spawning period were measured and digestive tracts were retained (Figure 1). White sturgeon eggs were separated from other digestive tract contents, counted, and developmental stages were determined, when possible, using criteria from Beer (1981).

Fish examined were separated into three groups: those collected during a sampling effort which collected white sturgeon eggs, those collected at a site where white sturgeon eggs had been collected previously, and those collected at a site where white sturgeon eggs had not been collected previously.

## Results

Digestive tracts of 40 fish were examined; 30 largescale sucker, 4 northern squawfish, 3 common carp, and 3 prickly sculpin (Table 1). Twenty-one of these fish were from John Day Pool, 12 were from The Dalles Pool, and 7 were from Bonneville Pool.

A total of 80 white sturgeon eggs were'found in the digestive tracts of the three fish collected during efforts which collected white sturgeon eggs, five white sturgeon eggs were found in the digestive tracts of one of the two fish collected at sites where white sturgeon eggs had been collected previously, and a total of 13 white sturgeon eggs were found in the digestive tracts of 3 of the 35 fish collected at sites where white sturgeon eggs had not been collected (Table 1).

Prickly sculpin was the most abundant of the 23 fish species collected in the three pools with high-rise trawls; largescale sucker, northern squawfish, and common carp were also among the most abundant species collected (Table 2). These four species accounted for 48% of the total number of fish caught with high-rise trawls in Bonneville Pool, 53% in The Dalles Pool, and 70% in John Day Pool. High-rise trawl catch per hectare for the four species combined was 10.0 for Bonneville Pool, 7.7 for The Dalles Pool, and 97.1 for John Day Pool (Table 2). Consumed eggs were at various stages of development, indicating that predation was not limited to eggs recently expelled into the water column, but that some eggs were ingested by scavenging on top of the substrate or by feeding on drifting or dislodged eggs.

Table 1. Number and range in total length of fish examined, number of white sturgeon eggs collected in digestive tracts, and percent of examined fish with white sturgeon eggs in the digestive tract, for samples collected during efforts which collected white sturgeon eggs, for samples collected at sites where white sturgeon eggs have been collected in the past, and for samples collected at sites where white sturgeon eggs have not been collected.

| Species | Number of fish examined | Range in Total length (mm) | Number of white sturgeon eggs consumed | Percent of fish with eggs consumed |
|---|---|---|---|---|
| Samples collected during efforts which collected white sturgeon eggs. | | | | |
| Prickly sculpin | 1 | 120 | 9 | |
| Prickly sculpin | 1 | - | 1 | |
| Largescale sucker | 1 | 534 | 70 | |
| Totals | 3 | | 80 | 100 |
| Samples collected at sites where white sturgeon eggs had been collected previously | | | | |
| Largescale sucker | 1 | 477 | 0 | |
| Largescale sucker | 1 | 485 | 5 | |
| Totals | 2 | | 5 | 50 |
| Samples collected at sites where white sturgeon eggs had not been collected previously | | | | |
| Samples containing eggs | | | | |
| Northern squawfish | 1 | 324 | 2 | |
| Common carp | 1 | | 6 | |
| Common carp | 1 | | 5 | |
| Samples Containing no eggs | | | | |
| | | - | 0 | |
| 1 Prickly sculpin | 27 | 385-550 | 0 | |
| Northern squawfish | 3 | 274-328 | 0 | |
| Common carp | 1 | | 0 | |
| Totals | 35 | | 13 | 12 |

Table 2. Number collected for the 8 most abundant of 23 resident fish species collected with high-rise trawls in Bonneville, The Dalles, and John Day pools during 1990 and catch per hectare for the four species observed to prey on white sturgeon eggs.

| | | Catch per hectare | | |
|---|---|---|---|---|
| Species | Number collected | Bonneville Pool | The Dalles Pool | John Day Pool |
| Prickly sculpina | 3097 | 8.40 | 2.49 | 80.00 |
| Sand roller | 948 | | | |
| Peamouth | 538 | | | |
| Common carp[a,b] | 224 | 0.02 | 0.67 | 11.24 |
| Smallmouth bass[b] | 199 | | | |
| Largescale sucker[a] | 154 | 0.50 | 1.82 | 4.68 |
| Northern squawfish[a] | 125 | 1.07 | 2.69 | 0.37 |
| Walleye[b] | 37 | | | |
| Combined species catch per hectare | | 9.99 | 7.67 | 97.09 |

[a] Known predators of white sturgeon eggs.
[b] Introduced.

## Discussion

A number of conditions exist in Columbia River impoundments which could intensify predation on white sturgeon eggs by the four species examined or intensify the effect of that predation on recruitment: only a small percent of adult white sturgeon spawn in any given year (Conte et al. 1988; Apperson and Anders 1990; Rien et al. 1991), broodstock numbers are low (Beamesderfer and Rien 1992)) potential predators of white sturgeon eggs are abundant, and potential predators overlap spatially and temporally with white sturgeon spawning (Miller et al. 1991).

Predation on eggs by the four species probably affects recruitment more in John Day Pool than in Bonneville or The Dalles pools. John Day Pool has higher densities of fish known to prey on white sturgeon eggs and the lowest white sturgeon broodstock (Beamesderfer and Rien 1992). Also, densities of prickly sculpin are highest in the upriver one-third of the pool where white sturgeon spawning occurs. The incubation period for white sturgeon eggs during this study, estimated using criteria from Wang et al. (1985), ranged from 6 to 11 days; predation probably occurs during the entire incubation period since the eggs receive no parental care.

Predation on white sturgeon eggs by prickly sculpin and crayfish may be more intense where substrates have large interstitial spaces which provide cover or velocity refugia for these predators. Predation on white sturgeon eggs by largescale sucker, northern squawfish, and common carp may be more intense where substrates have few interstitial spaces large enough for-white sturgeon eggs to fall into. Substrates in white sturgeon spawning areas in Columbia River impoundments are predominantly gravel, cobble, boulder, and bedrock (Parsley et al. 1992). Egg vulnerability to predators could be assessed in laboratories.

Predation on white sturgeon eggs in the three impoundments may be more intense now than historically, due to changes in abundance or distribution of fish caused by impoundment, modification of the hydrograph, or by the introduction of species such as common carp. Impoundment has reduced water velocities in white sturgeon spawning areas; high water velocities could provide protection from predators by exclusion. It is unknown if high water velocities exclude some predators of white sturgeon eggs from spawning areas. However, Faler et al. (1988) reported that northern squawfish in' the McNary Dam Tailrace (John Day Pool) avoided surface water velocities > 70 cm/s. Mesa and Olson (1992) estimated from laboratory swimming performance tests, that northern squawfish could not maintain position in the water column in water velocities > 150 cm/s. Water velocities > 70 cm/s were common in the tailrace areas in average and low water years; velocities > 150 cm/s were common only in average water years (U.S. Fish and Wildlife Service, unpublished data). No high water years occurred during the study. All four species known to prey on white sturgeon eggs prefer areas of low to moderate water velocities (Wydoski and Whitney 1979). Recruitment of white sturgeon in the three impoundments was greater in average water years than in low water years (Miller and Beckman 1992); increased predation on white sturgeon eggs in low water years could be a contributing factor.

## Conclusions

At least three endemic fish species (prickly sculpin, largescale sucker, and northern squawfish) and one introduced species (common carp) prey on white sturgeon eggs in Columbia River impoundments; the four species are among the most abundant species in the impoundments. Predation on viable white sturgeon eggs occurs throughout the egg incubation period. Predation can be intense (70 white sturgeon eggs were collected from one largescale sucker and 9 were collected from one prickly sculpin). More work is needed to determine the significance to sturgeon populations of predation on eggs by resident fishes and possible relations between water velocity and predation intensity.

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# REPORT S

# Comparisons of White Sturgeon
# Egg Mortality and Juvenile Deformity among Four Areas of the Columbia River

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# Abstract

This paper compares the number of dead white sturgeon eggs, and the incidence of juvenile pectoral fin deformity among Bonneville, The Dalles, and John Day pools, and the free flowing river section downstream from Bonneville Dam. White sturgeon eggs, larvae, YOY, and juveniles (<800 mm TL) were sampled from April or May through October, from 1987 through 1991 downstream from Bonneville Dam and in The Dalles Pool, from 1988 through 1991 in Bonneville Pool, and from 1989 through 1991 in John Day Pool. The percent of dead white sturgeon eggs in The Dalles Pool samples from 1987 through 1991 was at least twice as high as from samples in Bonneville and John Day pools, and more than 20 times higher than white sturgeon egg mortality from samples collected downstream from Bonneville Dam. High egg mortality in The Dalles Pool may have been caused by high (lethal) water temperatures during spawning, or by water borne contaminants.

A greater percentage of juvenile and YOY white sturgeon captured in The Dalles Pool were physically deformed compared to white sturgeon captured in Bonneville or John Day pools.

## Introduction

White sturgeon *Acipenser transmontanus* eggs, larvae, YOY, and juveniles (<800 mm TL) were sampled for up to five years (1987-1991) in Bonneville, The Dalles, and John Day pools (RKm 234-470)(Miller et al. 1991; Duke et al 1990; Parsley et al. '1989; Palmer et al. 1988)) and downstream from Bonneville Dam (McCabe and Hinton 1990; McCabe et al. 1989; McCabe and McConnell 1988) (Figure 1) to investigate spawning biology and early life history. White sturgeon egg samples from The Dalles Pool had consistently higher percentages of non-viable or dead eggs than comparable samples from the other pools and downstream from Bonneville Dam. Field observation also suggested an increased incidence of juvenile white sturgeon pectoral fin deformities in The Dalles Pool compared to the adjacent Bonneville and John Day pools.

Conte et al. (1988) reported bacterial and fungal diseases, and environmental stress to cause white sturgeon egg mortality. In experiments by Wang et al. (1985), elevated white sturgeon egg mortality occurred at 18°C and exposure to 20°C water was lethal to all white sturgeon eggs. Sediment deposition, water level fluctuations, and fungal infection also caused lake sturgeon *Acipenser fulvescens* egg mortality (Kempinger 1988). Increased shortnose sturgeon *Acipenser brevirostrum* egg mortality was caused by excess water velocity which kept eggs suspended in the water column until they lost adhesiveness, and insufficient water velocity, which allowed egg clumping, respiratory stress, and fungal growth (Buckley and Kynard 1982, 1985).

This paper compares the number of dead white sturgeon eggs, and the incidence of juvenile pectoral fin deformity among Bonneville, The Dalles, and John Day pools, and the free flowing river section downstream from Bonneville Dam.

## Methods

White sturgeon eggs, larvae, YOY, and juveniles (<800 mm TL) were sampled from April or May through October, from 1987 through 1991 in The Dalles Pool and downstream from Bonneville Dam, 1988 through 1991 in Bonneville Pool, and 1989 through 1991 in John Day Pool. Eggs and larvae were sampled with a D-shaped plankton net (0.78 m max. width, 0.54 m high, 1.59 mm knotless mesh) and a beam trawl net (2.7 m X 0.5 m, 1.59 mm knotless mesh) weekly for 30 minute sets at 6 or 7 sites in Bonneville, The Dalles, and John Day pools from April or May through July. Plankton nets were fished in pairs (port and starboard) in an upright stationary position on the substrate. Downstream from Bonneville Dam, D-shaped plankton nets were fished either weekly or bi-weekly from April or May through July.

Young-of-the-year and juvenile sturgeon were also sampled with the beam trawl net and a high-rise trawl (6.2 m max. width, 0.78 mm mesh cod liner). The high-rise trawl net was fished weekly for 10 minute sets at 11 sites in The Dalles Pool, 19 sites in John Day Pool, and 22 sites in Bonneville Pool from May through October. Less rigorous recording of juvenile white sturgeon deformity occurred in 1987 and 1990 which

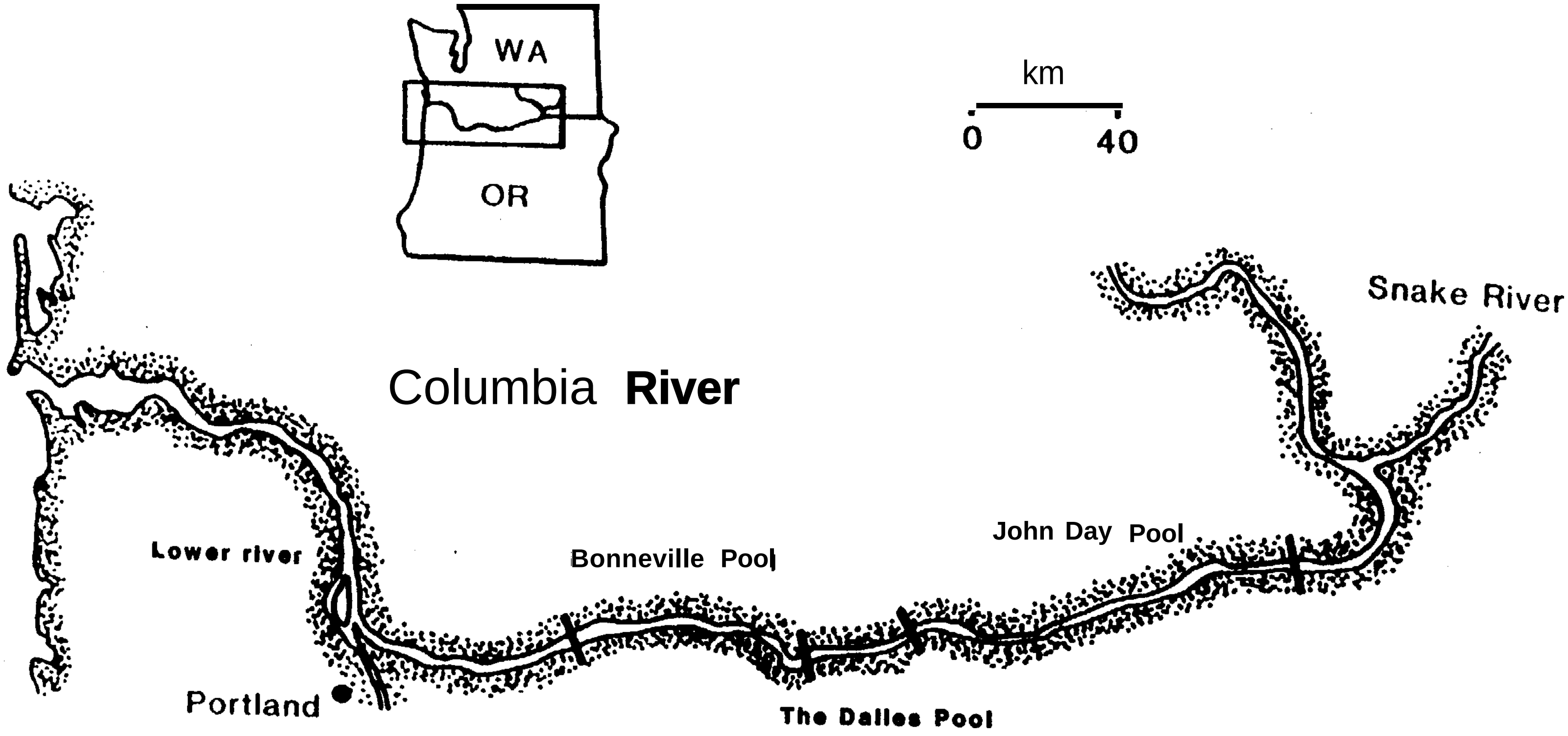

Figure 1. Location of the three furthest downstream impoundments of the Columbia River and the unimpounded lower river.

invalidated comparisons of juvenile deformity among pools. No juveniles were examined downstream from Bonneville Dam.

Dead white sturgeon eggs were characterized by abnormal embryological development and coloration, and may have been covered with fungus; dead eggs often exhibited more than one of these characteristics simultaneously. White sturgeon larvae were defined as post-hatch fish < 25 mm TL, and YOY were determined by reading pectoral fin ray cross sections with a dissection microscope. Juveniles were older than one year of age and < 800 mm TL.

## Results

The percent of dead white sturgeon eggs collected from 1987 through 1991 was at least twice as high in samples from The Dalles Pool than from samples from Bonneville and John Day pools, and more than 20 times higher than from samples collected downstream from Bonneville Dam. Forty-five percent (373 of 826) of white sturgeon eggs collected in The Dalles Pool were non-viable), compared with 21% (303 of 1,444) in Bonneville Pool, 17% .(31 of 181) in John Day Pool, and 2% (140 of 6,567) downstream from Bonneville Dam (Table 1). Percent egg mortality in annual collections ranged from 0.7 to 5.5 downstream from Bonneville Pool, from 9.6 to 34.6 in Bonneville Pool, from 20 to 87 in The Dalles Pool, and from 8.7 to 36.5 in John Day Pool (Table 1).

A greater percentage of juvenile and YOY white sturgeon captured in The Dalles Pool were physically deformed compared to fish captured in Bonneville or John Day pools from 1987 through 1991. Eighteen percent (9 of 49) of juveniles captured in The Dalles Pool during 1991 had some form of physical deformity, compared with 0.5% (3 of 640) deformity in Bonneville Pool; none of the five juveniles captured in John Day pool in 1991 were physically deformed. Observed deformities were primarily flared or deformed pectoral fins, while deformed caudal and dorsal fins and a crooked notochord were also observed. In 1989 four percent (11 of 257) of juvenile white sturgeon captured in The Dalles Pool were physically deformed, compared with no deformities of 611 and 67 juveniles in Bonneville and John Day pools.

In 1991 nearly 5% (2 of 42) of YOY white sturgeon captured in The Dalles Pool had deformed pectoral fins, while none of the 220 white sturgeon YOY captured in Bonneville Pool were deformed. No other deformed YOY white sturgeon were captured in any of the study areas from 1987 through 1991.

## Discussion

The unusually high percentage of dead white sturgeon eggs (45%) in The Dalles Pool compared to adjacent impoundments (17% and 21%), and downstream from Bonneville Dam (2%) during the study may be a symptom of unfavorable environmental conditions for white sturgeon reproduction. While limited white sturgeon recruitment to YOY was documented in The Dalles Pool in 1990 and 1991, (Miller and Beckman 1992), this high incidence of dead eggs in collections from The Dalles Pool may be cause

Table 1. White sturgeon egg mortality in samples collected in the Columbia River downstream from McNary Dam.

| Year | Total # eggs collected | # Non-viable eggs | % non-viable eggs |
|---|---|---|---|
| | **Downstream from Bonneville Dam** | | |
| **1987** | 18 | 1 | 5.5 |
| 1988 | 719 | 17 | 2.4 |
| 1989 | 2,018 | 34 | 1.7 |
| 1990 | 1,804 | 73 | 4.0 |
| 1991 | 2,008 | 15 | 0.7 |
| Total | 6,567 | 140 | mean 2.1 |
| | **Bonneville Pool** | | |
| **1988** | 156 | 15 | **9.6** |
| **1989** | 104 | 36 | 34.6 |
| **1990** | 772 | 167 | 21.6 |
| 1991 | 412 | 85 | 20.6 |
| Total | 1444 | 303 | mean 20.9 |
| | **The Dalles Pool** | | |
| 1987 | 132 | 115 | 87.1 |
| 1988 | 25 | 11 | 44.0 |
| 1989 | 25 | 5 | 20.0 |
| 1990 | 310 | 165 | 53.2 |
| 1991 | 334 | 77 | 23.1 |
| Total | 826 | 373 | mean 45.2 |
| | **John Day Pool** | | |
| 1989 | **69** | 6 | 8.7 |
| 1990 | 71 | 10 | 14.1 |
| 1991 | 41 | 15 | 36.5 |
| Total | 181 | 31 | mean 17.1 |

for concern.

Physical, biological, or chemical conditions unique to The Dalles Pool may have accounted for the unusually high mortality of white sturgeon eggs. High water temperature during spawning may have contributed to egg mortality in The Dalles Pool. Wang et al. (1985) reported that some white sturgeon embryos died when exposed to 18°C water, while 20°C water was lethal all exposed embryos. The majority of egg mortality during 1987 in the Dalles Pool may have been caused by lethal water temperature, since nearly 98% (129 of 132) of all eggs were collected from water 18°C or warmer. High water temperature undoubtedly resulted in additional egg mortality in other pools during other years. While dead egg collection was associated with water temperature above 18°C, dead eggs were also collected in each pool in 13 to 17°C water, indicating that additional factors caused egg mortality.

Studies in the white sturgeon spawning area in the upstream end of The Dalles Pool found that high levels of industrial water borne pollutants (heavy metals) modified and delayed adult salmonid migrations from 1979 through 1986 (Damkaer 1983, Damkaer and Dey 1984, 1985, 1986). If reductions of water borne pollutants have occurred since the mid-1980s, accumulation of heavy metals and organic pollutants in sediments in this area may still pose a threat to white sturgeon egg viability (D. B. Dey, pers. comm. 1992). In addition, bioaccmulation of pollutants may have occurred in reproducing white sturgeon, effecting egg viability prior to spawning. If pollutant levels similar to those reported in the mid 1980s existed from 1987 through 1991 in this area, they may have been responsible, at least in part, for high white sturgeon egg mortality documented in this study.

Dissolved oxygen was probably not limiting in the egg incubation areas immediately downstream from each dam in the study area. Sampling gear and techniques were consistent among years and pools, and were similar downstream from Bonneville Dam, suggesting that high egg mortality in The Dalles Pool was not an artifact of sampling. No evidence was found to suggest that fungal infection was responsible for egg mortality since numerous dead eggs without fungus were collected. Substrates in the tailraces where white sturgeon spawned were somewhat varied, but, probably not different enough to explain the high egg mortality in The Dalles Pool compared with other spawning areas, especially if high egg mortality occurs in non-lethal water temperatures.

Rieman and Beamesderfer (1990) reported that white sturgeon in the Lower Columbia River are being overharvested and that current (1988-1990) harvest cannot be sustained without risking eventual collapse of the fishery. Overharvest, coupled with poor egg survival in The Dalles Pool, should not be overlooked in future management of this species. Physical, biological, and chemical conditions unique to The Dalles Pool must be identified if causal factors of high egg mortality and juvenile white sturgeon deformity are to be identified.

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## REPORT T

# Frequency of Occurence of the Parasite *Cystoopsis acipenseri* in Juvenile White Sturgeon *Acipenser transmontanus* in the Lower Columbia River

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## Abstract

Juvenile white sturgeon Acipenser transmontanus in the lower Columbia River (downstream from the lowermost dam) of Oregon and Washington, were examined for the nematode parasite Cystoopsis acipenseri from 1987 through 1991. Incidence of the parasite in juvenile white sturgeon varied annually, ranging from 1% in 1989 to 14% in 1987. Infested white sturgeon ranged in size from 240 mm to 452 mm fork length.

## Introduction

The white sturgeon *Acipenser transmontanus* is the largest species of North American sturgeon. Considered to be an anadromous species. the white sturgeon is distributed from the Aleutian Islands of Alaska to Monterey, California (Scott and Crossman 1973). In the Columbia River system, some white sturgeon populations have become essentially landlocked due to dam construction (Cochnauer et al. 1985; Beamesderfer et al. 1990).

From 1987 through 1991, spawning characteristics, early life history, and habitat use of white sturgeon were studied in the lower Columbia River. Numerous juvenile white sturgeon were collected during the 5-year study and incidentally examined for the nematode parasite *Cystoopsis acipenseri*. The parasite is contained in blister-like cysts located just under the skin of affected fish (Wagner 1867 as cited in Bauer 1959; Chitwood and McIntosh 1950; Markevich 1951; Figure 1).

*Cystoopsis acipenseri* was first observed in *Acipenser ruthenus* in the former Soviet Union (Wagner 1867 as cited in Bauer 1959) and for a long time was thought to be a specific parasite of A. *ruthenus*. In the mid 1900s, the parasite was found in A. *ouldenstadti* (Nechaeva 1953 as cited in Bauer 1959) and A. *stellatus* and A. *schrencki* (Saidov 1954 as cited in Bauer 1959). In North America, *Cvstoonsis acinenseri* was first reported in white sturgeon in the Columbia River, Oregon (Chitwood and McIntosh 1950), and later in the Fraser River, British Columbia (Margolis and McDonald 1986; McDonald et al. 1989).

Little is known about C. *acinenseri* in wild populations of white sturgeon. This paper describes the frequency of occurrence of C. *acipenseri* in juvenile white sturgeon in the lower Columbia River (downstream from Bonneville Dam, Figure 2), and the size range of white sturgeon infested with C. *acipenseri*.

## Methods

Five bottom trawls were used to sample the lower Columbia River for juvenile white sturgeon: a 3.1-m plumb staff beam trawl, a 3.0-m beam trawl, a standard 4.9-m semiballoon shrimp trawl, a modified 4.9-m semiballoon shrimp trawl, and a 7.9-m shrimp trawl (see McCabe and McConnell 1988; McCabe and Hinton 1991 for more detailed descriptions of the trawls). The 7.9-m shrimp trawl was the principal trawl used in the study. Mesh size in the 7.9-m trawl was 38 mm (stretched measure) in the body; a lo-mm mesh liner was inserted in the cod end of the net. Trawl efforts with the 7.9-m trawl were usually 5 min in duration inan upstream direction.

Bottom trawling was conducted from late March or early April through September or October of each year at selected locations extending from River Kilometer (RKm) 29 to 231 (range for the entire study, not necessarily the range for each year). In the Columbia River, RKm 0 is located at the mouth of the river. In 1987 and 1989, some sampling was conducted in November. Trawling effort and geographic range of sampling varied among the years. In 1987-1989, more trawling occurred in the river upstream from RKm 120 than in the river downstream from RKm 120. However,

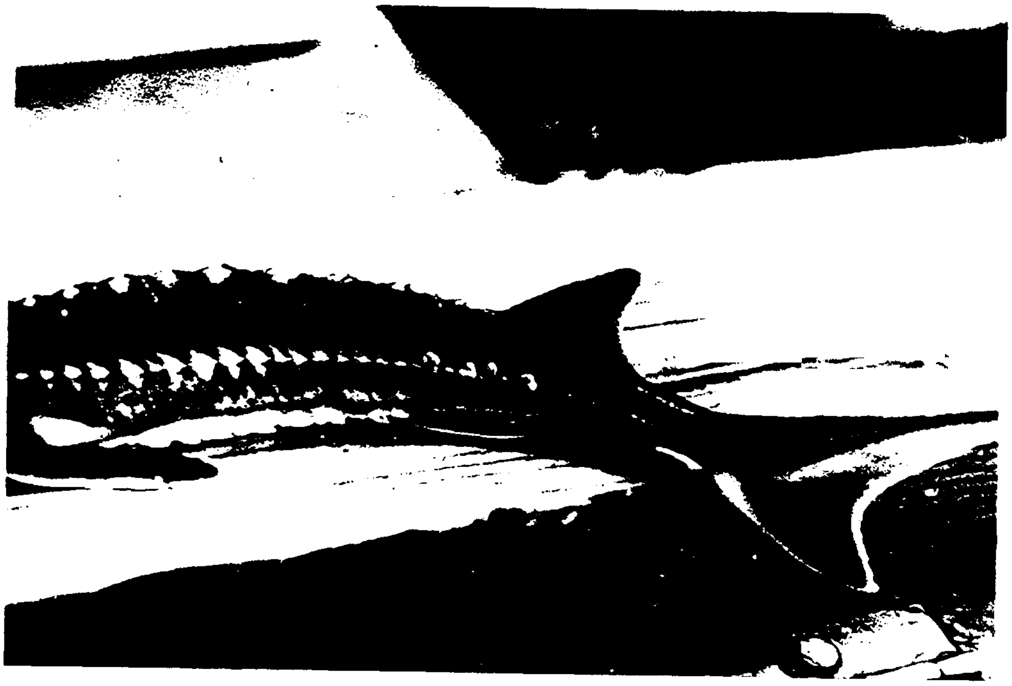

Figure 1. A juvenile white sturgeon infested with the nematode parasite *Cystoopsis acipenseri*; the sturgeon was collected in the lower Columbia River.

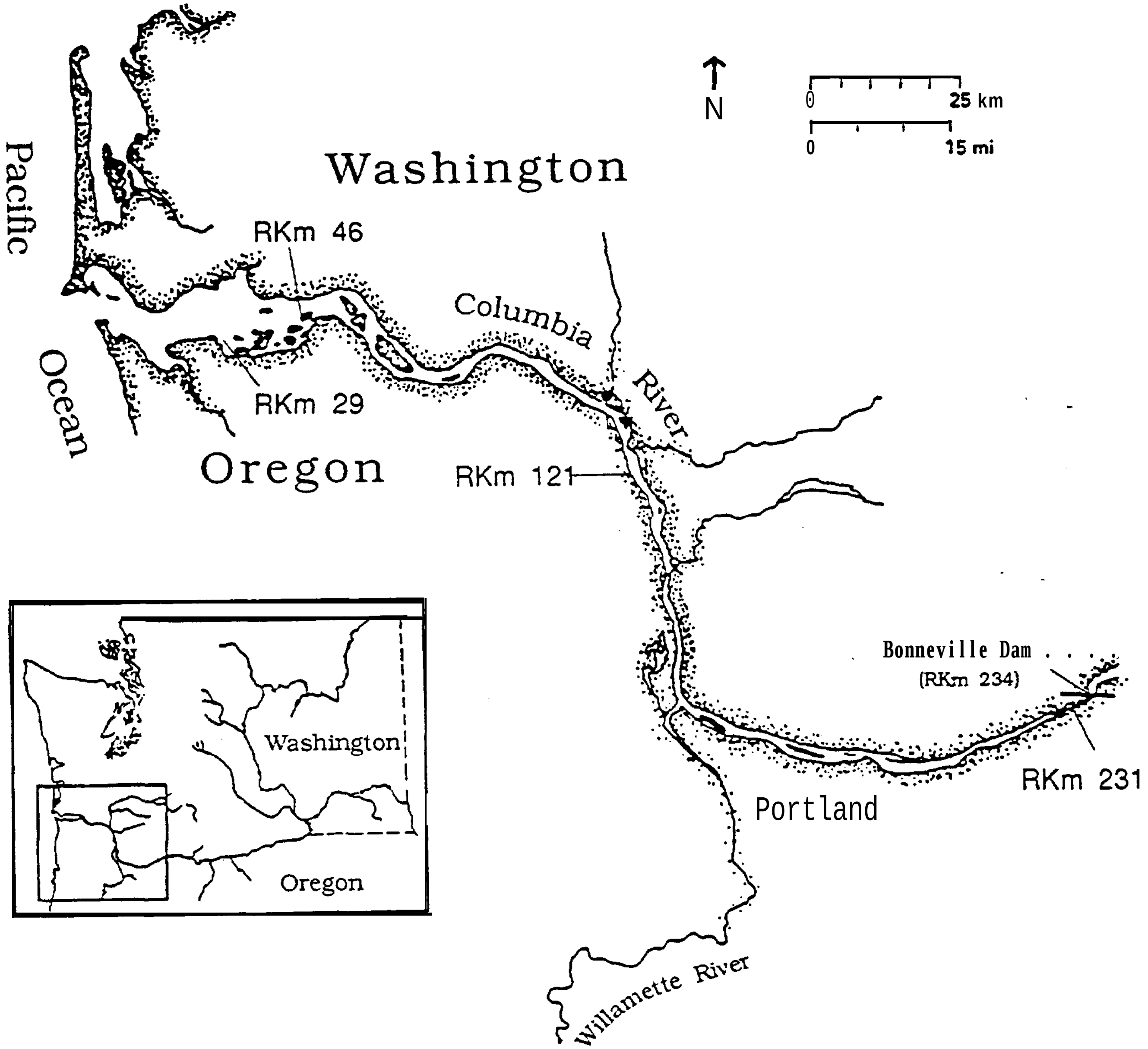

Figure 2. Map of the lower Columbia River.

in 1990 and 1991, much more trawling occurred in the river between RKm 46 and 120 than in previous years.

White sturgeon captured in the bottom trawls were measured (fork length [FL] in mm) and examined for the blister-like cysts typical of C. acipenseri (Chitwood and McIntosh 1950). Examination of parasites contained in the cysts (taken from white sturgeon collected in the lower Columbia River prior to this study) identified them as C. acipenseri (T. C. Coley, U.S. Fish and Wildlife Service, personal communication). White sturgeon shorter than 175 mm were not routinely examined for C. acipenseri. No attempt was made to quantify the number of blister-like cysts on infested white sturgeon.

## Results

The incidence of C. acipenseri in juvenile white sturgeon in the lower Columbia River dufing the S-year study ranged from 1% in 1989 to 14% in 1987 (Table 1). The length range of infested white sturgeon was similar throughout the study. Combining data from the 5 yr, I observed that the smallest infested sturgeon was 240 mm FL and the largest was 452 mm FL. White sturgeon longer than 452 mm FL were routinely examined; however, no parasites were observed on these longer white sturgeon. In all years except 1988, infested white sturgeon were collected in a similar geographic range in the lower Columbia River (Table 1).

## Discussion

Cystoopsis acipenseri is not confined to white sturgeon in the lower Columbia River. The parasite has also been observed in white sturgeon collected in the lower Fraser River, British Columbia (Margolis and McDonald 1986; McDonald et al. 1989). In 1986, McDonald et al. (1989) examined 189 white sturgeon collected in the lower Fraser River and found that 11% of the sturgeon were infested with C. acipenseri. Cystoopsis acipenseri has also been observed in juvenile white sturgeon collected in three impoundments immediately upstream from Bonneville Dam (Duke et al. 1990). In 1989, frequencies of occurrence of C. acipenseri in white sturgeon in the three impoundments ranged from 1 to lo%, whereas in the lower Columbia River the frequency of occurrence was 1%. The incidence of C. acipenseri in yearling and two-year-old A. ruthenus collected in the former Soviet Union was 27.4% (Skorikov 1903 as cited in Bauer 1959).

It is not known how white sturgeon in the Columbia River are infected by C. acipenseri, but it is likely that the parasite enters the sturgeon's digestive tract via an intermediate host. In experiments with A. ruthenus, Janicki and Rasin (1929 as cited in Bauer 1959) determined that amphipods were the intermediate hosts for C. acioenseri. After entry into the sturgeon's intestine, the larval parasite burrows through the intestine and surrounding tissues until it reaches the subcutaneous fatty tissue where it encysts and grows to sexual maturity (Bauer 1959; Cheng 1986). If amphipods are the intermediate hosts for C. acioenseri in the lower Columbia River, juvenile white sturgeon could be exposed to the parasite frequently. McCabe and Hinton (1990) found that the amphipod Coroohium salmonis was a very important prey for juvenile white sturgeon

Table 1. Frequencies of occurrence, length ranges, and areas of capture of juvenile white sturgeon infested with *Cystoopsis acipenseri* in the lower Columbia River, 1987-1991. Length is fork length (mm); the area of capture is the geographic range in River Kilometers (RKm).

| Year | Total no. examined | No. infested (% infested) | Length range of infested fish (mm) | Area of capture of infested fish (RKm) |
|---|---|---|---|---|
| 1987 | 1,534 | 217 (14%) | 240-442 | 49-217 |
| 1988 | 1,824 | 148 (8%) | 252-433 | 121-212 |
| 1989 | 1,822 | 24 (1%) | 294-405 | 46-212 |
| 1990 | 903 | 31 (3%) | 291-379 | 50-212 |
| 1991 | 726 | 60 (8%) | 252-452 | 45-212 |

shorter than 726 mm FL. Additional research should be conducted to determine if *Corophium salmonis* is an intermediate host for C. *acipenseri*.

*Cystoopsis acipenseri* appears to affect only smaller sturgeon. In this study, the maximum length of an infested white sturgeon was 452 mm FL. The length range of infested white sturgeon in the lower Fraser River study was 243 to 798 mm FL (McDonald et al. 1989). The length range of infested white sturgeon collected in the three impoundments immediately upstream from Bonneville Dam was 317 to 765 mm FL (Duke et al. 1990). Skorikov (1903 as cited in Bauer 1959) reported that for 4. *ruthenus*, infested individuals ranged in length from 100 to 250 mm, with highest infestation in 140 to 180 mm fish (i.e., mainly two-year-old fish). Apparently, the parasite is rare in older sturgeon (Bauer 1959). No C. *acipenseri* were found in marketable acipenserids in the Volga delta (Dogel' and Bykhovskii 1939 as cited in Bauer 1959).

If white sturgeon in the lower Columbia River are infested by C. *acipenseri* at a size as small as reported for A. *ruthenus* by Skorikov (1903), it is possible that the frequency of infestation in Columbia River white sturgeon is somewhat higher than reported here. White sturgeon shorter than 175 mm FL were not routinely examined for C. *acipenseri* during this study.

If white sturgeon responds to C. *acipenseri* in a fashion similar to 4. *ruthenus*, it probably does not kill the fish. Skorikov (1903 as cited in Bauer 1959) concluded that infested A. *ruthenus* were not killed by the parasite. Bauer (1959) also suggests that A. *ruthenus* develops post-invasion immunity due to previous infestation. No information was available on how the parasite affected the growth rate of A. *ruthenus* (Bauer 1959).

## Acknowledgments

I thank Lawrence Davis, Maurice Laird, Roy Pettit, and Susan Hinton for assisting in the collection of juvenile white sturgeon. Also, I thank Lee Harrell for reviewing the manuscript and providing important references that had been translated from Russian. This research was funded primarily by the Bonneville Power Administration.

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# Data Documentation

## REPORT U

# White Sturgeon Data Set Documentation
# National Marine Fisheries Service

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Coastal Zone and Estuarine Studies Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration

# WHITE STURGEON DATA SET DOCUMENTATION

## NATIONAL MARINE FISHERIES SERVICE

From 1987 through 1991, the National Marine Fisheries Service (NMFS) conducted white sturgeon research in the Columbia River downstream from Bonneville Dam. Data collected during this study and past NMFS studies (sturgeon related) were entered into ASCII computer files. Five types of data were entered into computer files--physical, biological, food habit, benthic invertebrate, and sediment. A list of the data formats and codes used in these files are listed below.

There are a few items about the data that need clarification. If a measurement (for example, temperature, velocity, or weight) was not taken, then a blank space(s) is shown in the data file. For NMFS's locations across the river (column 19 in the Physical Data), we did not break the river into two separate channels when islands are present; the island is considered a part of the total width of the river. Hamilton Island is no longer an island, so its shore was considered a part of the Washington mainland. Sauvie Island presented a unique problem because of Multnomah Channel, which originates from the Willamette River. In NMFS's location codes (column 19), the shore of Sauvie Island was considered a part of the Oregon mainland; therefore, if a sample was collected within a quarter mile of the shore of Sauvie Island, the code 4 was entered in column 19.

Physical data collected in former years and from 1987 through 1991 are contained in the following computer files: STUPHYS.FOR, STUPHYS.87, STUPHYS.88, STUPHYS.89, STUPHYS.90, and STUPHYS.91.

Biological data (catches of white sturgeon and other fishes) collected in former years and from 1987 through 1991 are contained in the following computer files: STUBIO.FOR, STUB10.87, STUB10.88, STUB10.89, STUB10.90, and STUB10.91. Also, we have included a file named STUSPEC.LI, which is a list of fish species codes and the appropriate common and scientific names.

Food habit data are contained in the computer file STUGUTS.88. Benthic invertebrate data collected from 1988 through 1991 are contained in the following computer files: STUBEN.88, STUBEN.89, STUBEN.90, and STUBEN.91. The computer file BENTHCDS.89 contains a list of benthic invertebrate and prey item codes along with the accompanying names.

Sediment (substrate) analyses from 1988 through 1991 are contained in the following computer files: STUSED.88, STUSED.89, STUSED.90, and STUSED.91.

Copies of these files are archived with the National Marine Fisheries Service, Hammond, Oregon. If anyone has any questions about these files, please contact George T. McCabe, Jr. (Phone 503-861-1818).

## DATA DOCUMENTATION - PHYSICAL DATA

| Variable | Field | Codes and remarks |
|---|---|---|
| Record type | 1-2 | l=physical, 2=biological, 6=food habit, 7=benthic invertebrate, 15=sediment |
| Agency | 3 | O=ODFW, W=WDF, F=USFWS, N=NMFS |
| Sample number | 4-7 | 4 digits; unique number for each sampling effort |
| Date | 8-13 | 6 digits; year, month, day |
| Reservoir | 14 | L=below Bonneville Dam, B=Bonneville Res., D=Dalles Res., J=John Day Res., U=Unknown |
| Location | 15-19 | Expressed as river mile to the nearest 0.1; 4th digit is 0.1 mile; 5th digit is section of the river from bank to bank (north to south). Approximately l/4 mile from WA shore is 1; approximately l/4 mile from OR shore is 4; 2 and 3 are used for the appropriate sections of the river more than a l/4 mile from the shore. |
| Gear | 20-21 | 7.9-m shrimp trawl= 10<br>4.9-m shrimp trawl= 11<br>4.9-m shrimp trawl (mod.)= 12<br>3.1-m staff beam trawl= 13<br>3.0-m beam trawl= 18<br>U.S. FWS 6.2-m trawl= 19<br>WDF plankton net= 30<br>Epibenthic sled= 39<br>Artificial substrate= 60<br>O.l-m2 Van Veen grab= 80<br>50-m beach seine= 90<br>200-m purse seine= 92 |
| Start time | 22-25 | 4 digits; military time |
| Stop time | 26-29 | 4 digits; military time |
| Effort (time) | 30-33 | 4 digits to nearest 0.01 hour |
| Effort (volume) | 34-39 | 6 digits to nearest $m^3$ |
| Effort (area) | 40-44 | 5 digits to nearest $m^2$ |

| | | |
|---|---|---|
| Depth (minimum) | 45-47 | 3 digits to nearest foot |
| Depth (maximum) | 48-50 | 3 digits to nearest foot |
| Temperature (bot.) | 51-52 | 2 digits to nearest degree (C) |
| Turbidity (bot.) | 53-56 | 4 digits to nearest 0.1 NTU |
| Velocity (bot.) | 57-59 | 3 digits to nearest 0.1 m/sec |
| Velocity (mean column) | 65-67 | 3 digits to nearest 0.1 m/sec |
| Station no. | 68-71 | 4 digits |

## DATA DOCUMENTATION - BIOLOGICAL DATA

| Variable | Field | Codes and remarks |
|---|---|---|
| Record type | 1-2 | 1=physical, 2=biological, 6=food habit, 7=benthic invertebrate, 15=sediment |
| Agency | 3 | O=ODFW, W=WDF, F=USFWS, N=NMFS |
| Sample number | 4-7 | 4 digits; unique number for each sampling effort |
| Line number (fish number) | 8-10 | 3 digits |
| Species code | 11-13 | 3 digits; see file STUSPEC.LI for codes |
| Maturity stage | 14-15 | 99= general unknown for sturgeon |
| Number collected | 16-18 | 3 digits; enter at least "1" for each entry; does not necessarily represent a total number |
| Fork length | 19-22 | 4 digits to nearest mm |
| Total length | 23-26 | 4 digits to nearest mm |
| Weight | 27-33 | 7 digits to nearest 0.1 g |
| Parasites (C. *acipenseri*) | 38 | 0= no parasites; 1= parasites; 9= not checked |
| Tag status | 52 | 0= not tagged; 1= tagged; 2= recapture |
| Tag code | 57-58 | 2 digits; 9=monel type tag |
| Tag number | 60-66 | alphanumeric; left justified |

## DATA DOCUMENTATION - BENTHIC INVERTEBRATE DATA

| Variable | Field | Codes and remarks |
|---|---|---|
| Record type | 1-2 | 1=physical, 2=biological, 6=food habit, 7=benthic invertebrate, 15=sediment |
| Agency | 3 | O=ODFW, W=WDF, F=USFWS, N=NMFS |
| Sample number | 4-7 | 4 digits; unique number for each sampling effort |
| Date | 8-13 | 6 digits; year, month, day |
| Survey number | 14-15 | 2 digits |
| Station number | 16-19 | 4 digits |
| Replicate number | 20-21 | 2 digits |
| Benthic invert. species code | 36-39 | 4 digits; see file BENTHCDS.89 for codes |
| Total number | 40-44 | 5 digits |

## DATA DOCUMENTATION - FOOD HABIT DATA

| Variable | Field | Codes and remarks |
|---|---|---|
| Record type | 1-2 | 1=physical, E=biological, 6=food habit, 7=benthic invertebrate, 15=sediment |
| Agency | 3 | O=ODFW, W=WDF, F=USFWS, N=NMFS |
| Sample number | 4-7 | 4 digits; unique number for each sampling effort |
| Date | 8-13 | 6 digits; year, month, day |
| Station number | 16-19 | 4 digits |
| Fish species code | 20-22 | 3 digits; always 036 for white sturgeon |
| Sturgeon fork length | 23-26 | 4 digits to nearest mm |
| Sturgeon weight | 27-31 | 5 digits to nearest g |
| Specimen number (sturgeon) | 32-33 | 2 digits |
| Fullness index of stomach | 34 | 1 digit; codes range from 1 (empty) to 7 (distended) |
| Digestive state of food for entire stomach | 35 | 1 digit; codes range from 1 (all prey unidentifiable) to 6 (no digestion) |
| Prey species code | 36-39 | 4 digits; see file BENTHCDS.89 for codes |
| Total number of a prey | 40-45 | 6 digits |
| Total weight of a prey | 46-53 | 8 digits to nearest 0.0001 g |

## DATA DOCUMENTATION - SEDIMENT DATA

| Variable | Field | Codes and remarks |
|---|---|---|
| Record type | 1-2 | 1=physical, E=biological, 6=food habit, 7=benthic invertebrate, 15=sediment |
| Agency | 3 | O=ODFW, W=WDF, F=USFWS, N=NMFS |
| Sample number | 4-7 | 4 digits; unique number for each sampling effort |
| Date | 8-13 | 6 digits; year, month, day |
| Survey number | 14-15 | 2 digits |
| Station number | 16-19 | 4 digits |
| Percent material passing 5 in. sieve | 20-24 | 4 digits and decimal point (0.1) |
| Percent material passing 2.5 in. sieve | 25-29 | 4 digits and decimal point (0-1) |
| Percent material passing 1.25 in. sieve | 30-34 | 4 digits and decimal point (0.1) |
| Percent material passing 5/8 in. sieve | 35-39 | 4 digits and decimal point (0.1) |
| Percent material passing 5/16 sieve | 40-44 | 4 digits and decimal point (0.1) |
| Percent material passing No. 5 pan | 45-49 | 4 digits and decimal point (0.1) |
| Percent material passing No. 10 pan | 50-54 | 4 digits and decimal point (0-1) |
| Percent material passing No. 18 pan | 55-59 | 4 digits and decimal point (0.1) |
| Percent material passing No. 35 pan | 60-64 | 4 digits and decimal point (0.1) |
| Percent material passing No. 60 pan | 65-69 | 4 digits and decimal point (0.1) |
| Percent material passing No. 120 pan | 70-74 | 4 digits and decimal point (0.1) |

| | | |
|---|---|---|
| Percent material passing No. 230 pan | 75-79 | 4 digits and decimal point (0.1) |
| Percent organic content | 80-84 | 4 digits and decimal point (0.1) |

# REPORT V

## White Sturgeon Data Set Documentation
## Oregon Department of Fish and Wildlife

**Thomas A. Rien**

**Oregon *Department of Fish and Wildlife***

## WHITE STURGEON DATASET DOCUMENTATION

## OREGON DEPARTMENT OF FISH AND WILDLIFE

Data collected during field sampling, from analysis of pectoral fin-rays for age determination, and from analysis of gonad samples for maturity and fecundity are stored as ASCII (American Standard Code for Information Interchange) files on IBM (International Business Machines Corporation) compatible magnetic disks. The sections of this report contain descriptions of variables in each data set.

Field sampling data sets contain information collected on white sturgeon we caught, and on the field conditions at the time. Additionally these data sets have information on recaptured fish collected by Washington Department of Fisheries creel personnel and reported by sport and commercial anglers. The data sets consist of five files corresponding to the year field data was collected: STGWRK87.DAT, STGWRK88.DAT, STGWRK89.DAT, STGWRKgO.DAT, and STGWRK91.DAT.

The aging data set (STGAGE.DAT) contains estimated age determinations from white sturgeon pectoral fin-rays.

The gonad data set (STGGONAD.DAT) contains egg counts, gonad weights, and estimated maturities determined from gonad samples collected from fish we caught and whole gonads collected by creel personnel or from illegally harvested fish.

Copies of these files are archived with Oregon Department of Fish and Wildlife (ODFW), Research and Development Section, Clackamas, Oregon. ODFW personnel familiar with data storage and coding include: Thomas Rien and Raymond Beamesderfer (Phone: 657-2035).

## DATA DOCUMENTATION - FIELD SAMPLING DATA

| Variable | Field | Codes |
|---|---|---|
| Record Type | 1- 2 | 1 Physical data |
| | | 2 Biological data |
| | | C Angler counts |
| | | D Angler interviews |
| | | E Age data |
| | | F Stomach contents |
| | | G Benthic data |
| | | H Physical & biological data |
| Agency | 3 | 0 ODFW |
| | | N NMFS |
| | | F USFWS |
| | | W WDF |
| Sample Number | 4- 8 | Note: columns 6-8 are ODFW sample number |
| Date | 9-14 | YYMMDD 1987-88 = date pulled<br>1989-91 = date set |
| Location | 15-19 | River Mile XXX-X, 1/4 miles from WA shore X |
| Gear | 20-21 | 1 Angling from boat |
| | | 2 Angling from bank |
| | | 21 Gill net (10' X 150'; 4”, 6.75”, 9”) |
| | | 22 Gill net (small mesh) |
| | | 23 Gill net (large mesh) |
| | | 30 Commercial insample |
| | | 31 Commercial selected |
| | | 32 Commercial voluntary |
| | | 33 Commercial tag sampled |
| | | 35 Commercial weight sampled |
| | | 40 Setline (40 hooks; 12/0, 14/0, 16/0) |
| | | 47 Setline (40; 11/0, 12/0, 14/0, 16/0) |
| | | 90 Angler survey insample |
| | | 91 Angler survey selected |
| | | 92 Angler survey voluntary |
| | | 93 Angler survey tag sampled |
| | | 95 Angler survey weight sampled |
| | | 99 Indian fishery unknown |
| Effort | 22-25 | 1/100 Hours |
| Line Number | 27-28 | |

Continued

## DATA DOCUMENTATION - FIELD SAMPLING DATA

| Variable | Field | Codes |
|---|---|---|
| Species | 30-31 | 36 White sturgeon |
| Life Stage | 32-33 | 00 Unknown adult<br>01 Maturing<br>02 Mature<br>03 Ripe<br>04 Spent<br>05 Pre vit w/ attritic oocytes<br>06 Pre vit<br>70 Immature<br>99 General unknown<br>Note that WDF has other data codes |
| Fork Length | 34-36 | Nearest cm. |
| Total Length | 38-40 | Nearest cm. |
| Weight | 42-48 | Nearest 0.1 g. |
| Pectoral Girth | 49-52 | Nearest cm. |
| Pelvic Girth | 53-56 | Nearest cm. |
| Sex | 57 | M Male<br>F Female<br>U Unknown<br>0 Not examined |
| Disposition 1 | 58 | 1 Regular sampling (ODFW all code 1)<br>2 Oxytetracycline injection<br>3 Blood chemistry<br>4 Surgery sample |
| Disposition 2 | 59 | 0 Unknown<br>1 Alive & released (undersized)<br>2 Alive & released (3-6 ft)<br>3 Alive & released (oversized)<br>4 Alive, kept or sacrificed (undersized)<br>5 Alive, kept or sacrificed (3-6 ft)<br>6 Alive, kept or sacrificed (oversized)<br>7 Dead (undersized)<br>8 Dead (legal)<br>9 Dead (oversized) |

Continued

## DATA DOCUMENTATION - FIELD SAMPLING DATA

| Variable | | Field | Codes | |
|---|---|---|---|---|
| Tags at Capture | Tag | 60 | 0 | Unknown |
| | | | 1 | Never tagged |
| | | | 2 | Anterior & posterior present |
| | | | 3 | Anterior present, posterior never tagged |
| | | | 4 | Anterior present, posterior missing |
| | | | 5 | Anterior missing, posterior never tagged |
| | | | 6 | Anterior missing, posterior present |
| | | | 7 | Anterior & posterior missing |
| | | | 8 | Another tag present |
| | | | 9 | Monel tag present |
| | Tattoo | 61 | 0 | Unknown |
| | | | 1 | No tattoo or evidence thereof |
| | | | 2 | Tattoo present, legible |
| | | | 3 | Tattoo present, illegible |
| | | | 4 | No tattoo present, evidence of tagging |
| Tags Applied | Tag | 62 | 0 | Unknown |
| | | | 1 | No tag applied |
| | | | 2 | Anterior & posterior applied |
| | | | 3 | Anterior only applied |
| | | | 4 | Posterior only applied |
| | Others | 63 | 0 | Unknown |
| | | | 1 | None |
| | | | 2 | Other tag applied (note type) |
| Marks at Capture | Fin | 64 | 0 | Unknown |
| | | | 1 | No fin mark |
| | | | 2 | Left pect section |
| | | | 3 | Left fin removed |
| | | | 4 | Right pect section |
| | | | 5 | Right fin removed |
| | | | 6 | Both fins removed |
| | | | 7 | Both pect sectioned |
| | | | 9 | Unusual combination |
| | Barbel | 65 | 0 | Unknown |
| | | | 1 | No barbel clip |
| | | | 2 | Left barbel clip |
| | | | 3 | Left center barbel clip |
| | | | 4 | Right center barbel clip |
| | | | 5 | Right barbel clip |

Continued

## DATA DOCUMENTATION - FIELD SAMPLING DATA

| Variable | | Field | Codes |
|---|---|---|---|
| Marks at Capture Scute | | 66 | 0 Unknown |
| | | | 1 No lateral scutes removed |
| | | | 2 R 3rd scute removed (1988 mark) |
| | | | 3 R 2nd & 3rd scutes removed |
| | | | 4 L 3rd scute removed (1989 mark) |
| | | | 5 L 3rd & R 2nd scutes removed |
| | | | 6 R 4th scute removed (1990 mark) |
| | | | 7 R 4th & R 2nd scutes removed |
| | | | 8 L 4th scute removed (1991 mark) |
| | | | 9 L 4th & R 2nd scutes removed |
| Marks Applied Fin | | 68 | 0 Unknown |
| | | | 1 No fin mark |
| | | | 2 Left pect section |
| | | | 3 Left fin removed |
| | | | 4 Right pect section |
| | | | 5 -Right fin removed |
| | | | 6 Both fins removed |
| | | | 7 Both pects sectioned |
| | Barbel | 69 | 0 Unknown |
| | | | 1 No barbel clip |
| | | | 2 Left barbel clip |
| | | | 3 Left center barbel clip |
| | | | 4 Right center barbel clip |
| | | | 5 Right barbel clip |
| | Scute | 70 | 0 Unknown |
| | | | 1 No lateral scutes removed |
| | | | 2 R 3rd scute removed (1988 mark) |
| | | | 3 2nd & 3rd scutes removed |
| | | | 4 L 3rd scute removed (1989 mark) |
| | | | 5 L 3rd & R 2nd scutes removed |
| | | | 6 R 4th scute removed (1990 mark) |
| | | | 7 R 4th & R 2nd scutes removed |
| | | | 8 L 4th scute removed (1991 mark) |
| | | | 9 L 4th & R 2nd scutes removed |
| Tag | Color | 72 | Y Yellow |
| | | | 0 Orange |
| | Prefix | 73-74 | BO Bonnevile |
| | | | JD John Day |
| | | | TD The Dalles |
| | Number | 75-79 | xxxxx |

Continued

## DATA DOCUMENTATION - FIELD SAMPLING DATA

| Variable | Field | Codes |
|---|---|---|
| Hook Size | 80-81 | 10, 11, 12, 14, 16 |
| Bait Type | 82 | 0 Unknown<br>1 Lamprey<br>2 Coho<br>3 Smelt<br>4 Smolt |
| Document Number | 83-86 | |
| Start Time Hour | 87-88 | 00-24 Midnight is 00. |
| Minute | 89-90 | 00-60 |
| Stop Time Hour | 91-92 | 00-24 Midnight is 00. |
| Minute | 93-94 | 00-60 |
| Reservoir | 95 | L Below Bonneville<br>B Bonneville<br>D The Dalles<br>J John Day<br>U Unknown -- above Bonneville |
| Oxytet | 96 | 0 No<br>1 Yes |
| Surgery | 97 | 0 No<br>1 Yes |
| Blood | 98 | 0 No<br>1 Yes |
| Minimum depth of set | 99-101 | XXX feet |
| Maximum depth of set | 102-104 | XX feet |
| Second tag -- Color | 105 | Y Yellow<br>0 Orange |
| Prefix | 106-107 | BO Bonnevile<br>JD John Day<br>TD The Dalles |
| Number | 108-112 | xxxxx |
| Comments | 113-132 | 20 spaces |

End

## DATA DOCUMENTATION - AGING DATA FILE

| Variable | Field | Codes |
|---|---|---|
| Ageing data sheet page # | 1- 4 | XXXX |
| Slide box # | 5- 6 | XX |
| Ageing data sheet line # (also slide box slot #) | 7- 9 | XXX |
| Gear type | 10-11 | 1 = ODFW in sample<br>32 = WDF commercial<br>42 = WDF sport |
| Agency | 12 | 0 = ODFW<br>N = NMFS<br>F = USFWS<br>U = USFWS<br>W = WDF<br>H = UWF |
| Other agency year code | 13 | 0, 8, 9, C |
| Sample # (from original data sheet) | 14-16 | XXX |
| Line # (from original data sheet) | 17-19 | XXX |
| Date | 20-25 | YYMMDD |
| Reservoir | 26 | L = Below Bonneville Dam<br>B = Bonneville Pool<br>D = The Dalles Pool<br>J = John Day Pool<br>U = Unknown-above Bonneville Dam |
| Fork length group | 27-29 | Upper limit 10 cm fork length intervals 0.0-9.0=9, 9.1-19.0 = 19, 19.1-29.0 = 29 etc. (Ex. 990mm = 99, 991mm = 109, 1089mm = 109) |
| Reader #1 ID # | 30 | D = Ruth Farr<br>E = John North<br>F = Amber Ashenfelter<br>G = Tom Rien<br>H = Ray Beamesderfer |
| Reader #l initial age | 31-33 | Number of annuli counted |
| Reader #l Plus | 34 | 0 or ' ' sample taken after July 1<br>P sample taken before June 31 |
| Banding | 35 | Number of banding areas observed |

Continued

## DATA DOCUMENTATION - AGING DATA FILE

| Variable | Field | Codes |
|---|---|---|
| Years young | 36-37 | Number of years age is overestimated if banding pattern is only one annulus |
| Edge | 38 | 0 = Stacked annuli not present<br>1 = Stacked annuli present |
| Years older | 39-40 | Number of years age is underestimated if marks not counted at the edge are in fact annuli |
| Reader #2 ID # | 41 | D  Ruth Farr<br>E = John North<br>F = Amber Ashenfelter<br>G = Tom Rien<br>H = Ray Beamesderfer |
| Reader #2 initial age | 42-44 | Number of annuli counted |
| Reader #2 Plus | 45 | 0 or ' ' = Sample taken after July 1<br>P = Sample taken before June 31 |
| Final age assigned | 46-48 | Number of annuli counted |
| Final age Plus | 49 | Oar' ' = Sample taken after July 1<br>P = Sample taken before June 31 |
| Decision | 50 | A = Exact match<br>B = Compromise<br>C = Sample thrown out<br>D-H = reader whose age was assigned as final |
| Reader #1 first reading | 51-53 | Age assigned at first reading |
| First Reading Plus | 54 | 0 or ' ' = Sample taken after July 1<br>P = Sample taken before June 31 |
| Reader #1 second reading | 55-57 | Age assigned at second reading |
| Second Reading Plus | 48 | 0 or ' ' = Sample taken after July 1<br>P = Sample taken before June 31 |
| Reader #2 first reading | 59-61 | Age assigned at first reading |
| First Reading Plus | 62 | 0 or ' ' = Sample taken after July 1<br>P = Sample taken before June 31 |
| Reader #2 second reading | 63-65 | Age assigned at second reading |
| Second Reading Plus | 66 | 0 or ' ' = Sample taken after July 1<br>P = Sample taken before June 31 |

Continued

## DATA DOCUMENTATION - AGING DATA FILE

| Variable | Field | Codes |
|---|---|---|
| Fork length | 67-70 | Fork length in mm |
| Sex | 71 | M = Male<br>F = Female<br>U = Unknown<br>0 = Not examined |
| Maturity | 72 | Needs to be deleted from data set, invalid early assignments |
| Record type | 73-74 | 1 = Physical data<br>2 = Biological data<br>5 = ODFW ageing data<br>C = Angler counts<br>D = Angler interview<br>E = Age data<br>F = Stomach contents<br>G = Benthic data<br>H = Both 1 & 2 |
| Frequency type | 75-76 | 0 |
| Document # | 77-80 | Original data sheet # |
| Third reader ID (pre 1990) | 81 | 3 |
| Third reader age | 82-84 | Age assigned by third reader |
| Third reader plus | 85 | 0 or " = Sample believed to have formed an annulus in the calendar year<br>P = Sample blieved not to have formed an annulus in the calendar year |
| Record # (pre 1990) | 86-89 | Unique sequential record # |
| Fourth reader ID (pre 1990) | 90 | 4 |
| Fourth reader age | 91-93 | Age assigned by fourth reader |
| Fourth reader plus | 94 | 0 or " = Sample believed to have formed an annulus in the calendar year<br>P = Sample blieved not to have formed an annulus in the calendar year |
| End of data line | 95 | 0 |

End

## DATA DOCUMENTATION - GONAD DATA FILE

| Variable | Field | Codes |
|---|---|---|
| Date | 1-6 | MMDDYY |
| Pool | 9 | B Bonneville<br>D The Dalles<br>J John Day<br>U Unknown pool above Bonneville |
| Fork Length | 13-15 | Nearest centimeter, (X.) |
| Egg Diameter | 21-24 | Millimeters, (X.Xx) |
| Stage of Maturity | 29 | 1 Early Vitellogenic<br>2 Late Vitellogenic<br>3 Ripe<br>4 Spent<br>5 Previtellogenic with atritic oocytes<br>6 Previtellogenic |
| Stage Comments | 30 | R Being reabsorbed in the stage specified<br>A Atritic oocytes found in sample |
| Source | 33 | C Commercial<br>S Sport<br>R Research |
| Sample Number | 36-39 | XXXX |
| Line Number | 42-43 | XX |
| Gonad Weight | 44-53 | Grams |
| Fish Weight | 54-64 | Grams |
| GSI | 65-73 | Gonadal Somatic Index = Gonad Weight/Fish Weight x 100, (XX.XXXX) |
| Fecundity | 76-81 | X |
| Alkaline-labile phosphoproteins | 82-88 | Micrograms/ml, (XX-XX) |
| Total Estrogen | 89-95 | Nanograms(lxlO-9)/mm, (XX.XX) |

End

# REPORT W

# White Sturgeon Data Set Documentation
# U.S. Fish and Wildlife Service

**Paul J. Anders**

*U.S. Fish and Wildlife Service*

# WHITE STURGEON DATASET DOCUMENTATION

## U.S. FISH AND WILDLIFE SERVICE

Data collected during field sampling or generated through laboratory procedures are stored as ASCII (American Standard Code for Information Interchange) files on IBM compatible high density double sided magnetic discs. These data are stored in five databases (WST87, WST88, WST89, WST90, and WST91), according to the years of collection.

Within each of the five annual "WST" databases listed above, data are stored in three files. The first file is titled "Sample" and contains only physical or non-biological field data. The second file is titled "Catch", and contains mostly biological data. When necessary, for analytical purposes, these two files were combined, forming a third new file titled "Samcat"; the first half of" Samcat" is identical to the file "sample", and the second half is identical to the file "catch".

The following pages explain what the files "Sample" and "Catch" specifically contain.

## DATA DOCUMENTATION FIELD SAMPLING DATA

1) **Filename: Sample**

| Variable | Field | Codes |
|---|---|---|
| Sample | 1 | Up to 4 digits,assigned in lab after field collection |
| Day | 8 | 6 digits: YYMMDD |
| Reser | 15 | B, 0, or J, for Bonneville, The Dalles, or John Day pools |
| Lot. | 22 | five digit number: 1st four digits are river mileage to the tenth of a mile, the fifth digit is 0 through five, indicating cross-sectional position (quarters) in river channel. Starting at north shore: 0 = WA backwater, WA shore, 1 = northern 1/4 of river 2=second quarter, 3= third quarter, 4=fourth quarter, 5 = Oregon backwater |
| Gear | 29 | 14 = High-rise trawl<br>17 = Beam trawl<br>31 = D-shaped plankton net |
| Deploy | 36 | Start time for net tows (24 hour military time) |
| stop | 42 | Stop time, end of tow (24 hour military time) |
| Hrs | 49 | To nearest 1/100 of an hour |
| Volume | 56 | Volume sampled by nets to nearest $m^3$ |
| Area | 63 | Area sampled by nets to the nearest $m^3$ |
| Mindepth | 70 | Minimum depth during a tow to the nearest foot |

Continued

## DATA DOCUMENTATION FIELD SAMPLING DATA

| Variable | Field | Codes |
|---|---|---|
| Maxdepth | 77 | Maximum depth during a tow to the nearest foot |
| Temp | 84 | Surface water temperature; either to nearest degree with lab thermometer or l/10 degree Celsius with digital thermometer |
| Turb | 91 | Water turbidity (NTU), to the nearest l/10 turbidity unit |
| Vel2d | 98 | Water velocity at 2/10 maximum site depth, to nearest l/10 meter per second |
| vel8d | 105 | Water velocity at 8/10 maximum site depth, to nearest l/10 meter per second |
| Velbot | 112 | Water velocity at substrate, to nearest l/10 meter per second |
| Totime | 119 | Tow duration, to nearest l/100 hour |
| Meanvel | 126 | Mean of Vel2d and Vel8d |
| Substrate | 133 | Code for substrate type:<br>1 Islands<br>10 Organic material<br>20 Mud/soft clay<br>30 Silt<br>40 Sand<br>50 Gravel<br>60 Cobble/rubble<br>70 Boulder<br>80 Bedrock<br>90 Hard clay<br>Combinations are often used, with higher of two numbers first: for example 42 is sand and mud, 43 is sand and silt |

End

## DATA DOCUMENTATION FIELD SAMPLING DATA

1) Filename: Catch

| Variable | Field | Codes | |
|---|---|---|---|
| Sample | 1 | Up to 4 digits,assigned in lab after field collection; these sample numbers correspond to those in the "Sample" file | |
| Line# | 8 | Identifies individual or group of fish in net catches | |
| Species | 15 | LAM | Pacific lamprey |
| | | WST | White sturgeon |
| | | ASH | American Shad |
| | | COH | Coho |
| | | sot | Sockeye |
| | | CHN | Chinook |
| | | MWF | Mountain whitefish |
| | | RBT | Rainbow trout |
| | | CHM | Chiselmouth |
| | | CRP | Common carp |
| | | GDF | Goldfish |
| | | PEM | Peamouth |
| | | SQF | Squawfish |
| | | LND | Longnose Dace |
| | | SPD | Speckled Dace |
| | | RSS | Redside shiner |
| | | sue | Sucker spp. |
| | | BLS | Bridgelip sucker |
| | | LSS | Largescale sucker |
| | | BRB | Brown bullhead |
| | | BUL | Bullhead spp. |
| | | CHC | Channel catfish |
| | | TRP | Sand Roller |
| | | STB | Threespine stickleback |
| | | PSS | Pumpkinseed sunfish |
| | | CYP | Cyprinid see. |
| | | LEP | Lepomis spp. |
| | | BLG | Bluegill sunfish |
| | | SMB | Smallmouth bass |
| | | LMB | Largemouth bass |
| | | WCR | White crappie |
| | | BCR | Black crappie |
| | | CRA | Pomoxis spp. |
| | | YLP | Yellow perch |
| | | WAL | Walleye |
| | | COT | Prickly sculpin |

## DATA DOCUMENTATION FIELD SAMPLING DATA

1) Filename: Catch (Cont'd)

| Variable | Field | Codes |
|---|---|---|
| Life-St | 22 | Fish lifestage:<br>10 Eggs (general)<br>11-29 Embryonic stages of white sturgeon eggs<br>29 Dead eggs<br>30 Larvae<br>30-40 White sturgeon larval stages.<br>50<br>60 Young of the year<br>99 Juvenile or older |
| NoColl | 29 | Number of fish of collected |
| Spawndate | 36 | Date (month and day) of white sturgeon spawning |
| Spawnhour | 42 | Hour (0-2300) of the day or night when white sturgeon spawning was estimated to have occurred |
| Flength | 49 | Fork length of fish collected |
| Tlength | 56 | Total length fo fish collected |
| Weight | 63 | Weight (nearest gram or 1/10 gram) of fish or larvae collected |
| Age | 70 | Age (years) of white sturgeon collected |
| Cond | 77 | Genral condition of white sturgeon collected: 0=unknown, l=alive and undersized (<800 mm FL), 4=alive, undersized and sacrificed, 7=dead and undersized |
| Status | 84 | Tag status: 0=untagged, l=taged with Monel tag on right' pectoral fin ray, 2=recapture |

Continued

## DATA DOCUMENTATION FIELD SAMPLING DATA

1) Filename Catch (Cont'd)

| Variable | Field | Codes |
|---|---|---|
| TagNo | 91 | Number on tag:first digit B, D, or 3 for pool designation, last 4 digits specific numerical tag code |
| Mark | 98 | Pelvic fin hole punch:1 if fin is punched |
| Spine | 105 | Pectoral fin ray section (spine) removed for ageing: X if spine taken |
| OTC | 112 | OTC (oxytetracycline) injected as mark and antiseptic: X if injected |
| OTCmark | 119 | Pattern of lateral scutes removed from side of collected white sturgeon |
| Remarks | 126 | Any comments needed to clarify data in "Catch" file |

End

For specific analyses requiring data subsets, various smaller files were created. Computer generated habitat data are also stored in separate files; information concerning these files is available from the contacts listed in the next paragraph.

Copies of these files are archived with the U.S. Fish and Wildlife Service (FWS), National Fishery Research Center, Columbia River Field Station, in Cook Washington. FWS personnel familiar with data storage and coding include: Paul Anders, Allen Miller, and Mike Parsley (Phone (509) 538-2299, FAX (509) 538-2843).

# REPORT X

# White Sturgeon Data Set Documentation
# Washington Department of Fisheries

**Brad W. James**

*Washington Department of Fisheries*

# White Sturgeon Dataset Documentation
# Washington Department of Fisheries
## Ageing Data File

| Variable | Field | Codes |
|---|---|---|
| Sample number | l- 8 | XXXXXXXX |
| Month | 15-16 | MM |
| Day | 24-25 | DD |
| Year | 33-34 | YY |
| Fork length | 41-43 | Nearest cm |
| Annuli | 48-50 | Number of annuli visible |
| Plus | 55 | 0 or ' ' translucent ring on edge<br>1 opaque ring on edge |
| Final Age | 60-62 | # annuli if plus=0 or month >6<br># annuli + 1 if plus=1 and month 26 |
| Decision | 70 | 0 or ' ' = one reader undisputed<br>1 = two readers agreed<br>2 = two readers compromised |
| Sex | 88 | 0 or ' ' = unknown<br>= male<br>: = female |
| Source | 94 | B = Broodstock monitoring<br>C = Commercial sampling<br>M = Mortality<br>S = Sport sampling<br>T = Tagging research<br>U = NMFS |

End

# White Sturgeon Dataset Documentation
## Washington Department of Fisheries
## Commercial and Recreational Fishery Sampling - Biological Data

| Variable | No of char. | Alf/ Num | Data Set columns | Variable limits | A G |
|---|---|---|---|---|---|
| record type | 1 | A | 1 - 2 | 02 | C |
| agency | 4 | N | 3 - 3 | W | C |
| sample number |  |  | 4 - 7 | 0-9,001-999 | C |
| line number | 3 | N | 8 - 10 | 001-999 | C |
| species code | 3 | N | 11 - 13 | 036 | C |
| life stage/maturity code |  | N | 14 | 00-99 | C |
| number collected | 5 | N | 16 - 18 | 001 | C |
| fork length | 4 | N | 19 - 22 | CI000-9990(mm) | U |
| total length | 4 | N | 23 - 26 | 0000-9990(mm) | C |
| weight | 7 | N | 27 - 33 | 0.00-999999.9(grams) | C |
| pectoral girth | 4 | N |  | 0000-9999(mm) | U |
| pelvic girth | 4 | N | 38 - 41 | 0000-9999(mm) | U |
| sex code | 1 | A | 42 - 42 | M,F,U | C |
| gonad sample weight | 3 | N | 43 - 45 | 00.0-99.9(grams) | U |
| gonad total weight | 4 | N | 46 - 49 | 0000-999(grams) | U |
| fish disposition code | 1 | N | 50 - 50 | o-9 | C |
| tag status at capture code | 2 | N | 51 | 0-8,0-4 | C |
| tag status at proces. code | 2 | N | 53 - 54 | 00 | C |
| secondary mark code | 2 | N | 55 - 56 | o-5,0-5 | U |
| tag 1 type | 2 | N | 57 - 58 | 0-1 ,0-8 | C |
| tag 1 color | 1 | A/N | 59 - 59 | Y,O,R,W,G,B,Z,1,2 | C |
| tag 1 number | 7 | A/N | 60 - 66 | A-Z,A-Z,00001-99999 | C |
| tag 2 type | 2 | N | 67 - 68 | 0-1,0-8 | U |
| tag 2 color | 1 | A/N | 69 - 69 | Y,O,R,W,G,B,Z,1,2 | U |
| tag 2 number | 7 | A/N | 70 - 76 | A-Z,A-Z,00001-99999 | U |
| sample category | 1 | N | 77 - 78 | 00-05 | W |
| fin ray collected | 1 | N | 79 - 79 | 0,1,2,3 | W |
| gonad sample collected |  |  |  | 0,1 | W |
| mark status at capture | 4 | N | 81 - 84 |  | W |
| gear type code or angler survey C/E line No. | 2 | N | 85 - 86 | 00-15 | W |
| reservoir |  | A | 87 - 87 | L,B,D,J,A,U | W |
| sample number two |  | A | 88 - 88 | C,S,I,N,T,E | W |
| date (YY,MM,DD | 6 | N | 89 - 94 | 87-91,01-12,01-31 | W |
| Comments |  | A | 95- |  | W |

White Sturgeon Dataset Documentation

Washington Department of Fisheries

Variable descriptions for commercial and recreational biological data.

## Record Type (1-2)

01 - Physical sampling information.

02 - Fish biological information. We will distinguish between sampling method (egg/larvae sampling, tagging operations, sport and commercial fishery sampling) by sample number (see Sample Number and Sample Number 2).

03 - Angler survey fishing effort counts.

04 - Angler survey catch and effort (interview) information.

05 - Age data and annuli measurements.

06 - Stomach contents.

07 - Benthic information

08 - Reproductive information

## Agency (3)

| | |
|---|---|
| O | Oregon Department of Fish and Wildlife |
| N | National Marine Fisheries Service |
| F | U.S. Fish and Wildlife Service |
| W | Washington Department of Fisheries |

## Sample Number (4-7)

Four digit code, a unique identification number corresponding to each unit of sampling effort or document.

First digit - We will use the first digit to help match biological samples to a particular sampling source.

O- 1987/88 Commercial fisheries.
1- 1989 Commercial fisheries.
2 - 1990 Commercial fisheries.
3 - 1991 Commercial fisheries.
4- Below Bonneville Dam tagging operations.

5 - Below Bonneville Dam egg/larvae sampling.

6 - 1990 Bonneville - McNary Dam sport fisheries.
7 - 1991 Bonneville - McNary Dam sport fisheries.
8 - 1988 Bonneville and The Dalles Reservoirs sport fishery.
9 - 1989 Bonneville - McNary Dam sport fisheries.
C - 1987 The Dalles Reservoir sport fishery.

Second-Fourth digit - unique three digit number.

Line Number (8-10)

Line number of data sheet corresponding to an individual or group of fish from a particular sample.

Species (11-13)

See attached NMFS codes for species.

Life Stage/Maturity (14-15)

Sub-adult and adult female codes:

Egg maturity based on a visual examination of sturgeon ovaries in the field for samples collected from the sport and commercial fisheries above Bonneville Dam. Egg maturity for fish from below Bonneville Dam determined from either microscopic examination of ovary tissue (1988 samples) or visual examination in the field (pre-1988 samples).

00 - Unknown, adult size fish.

01 - Early vitellogenic (previously classified as 'maturing'). Ovary has obvious egg development. Eggs are clear/white to gray in color and have a diameter ranging from 0.6mm to 2.2mm.

02 - Late vitellogenic (old classification - mature). Ovary has eggs that are fully pigmented and are attached securely to the ovarian tissue. Eggs have a diameter ranging from 2.2mm to 2.9mm.

03 - Ripe (old classification - ripe). Ovary has fully pigmented eggs which are completely separated form the ovarian tissue. Eggs have a diameter ranging from 3.1mm to 3.3mm.

04 - Spent (old classification - ripe). Ovaries are flaccid with some loose fully pigmented eggs remaining.

05 - Pre-vitellogenic with attritic oocytes (no former classification). Ovaries do not show any visual signs of vitellogenesis but there are dark pigment spots present which are believed to be remnants of reabsorbed eggs.

06 - Pre-vitellogenic (no former classification). Ovaries do not show any visual signs of vitellogenesis. When the tissue is sample there will be oocytes present that have an average diameter less than 0.5mm.

70 - Immature. No oocytes can be distinguished in the examined tissue. Pre-vitellogenic ovaries and previtellogenic ovaries with attritic oocytes examined only in the field would also fall under this classification.

99 - General unknown.

Sub-adult and adult males classified as either immature, ripe (milting) or spent (flaccid) based on visual examination of gonads int he field (same codes as above).

Spawned egg and larvae codes:

- See attached code listing.

Number collected (16-18)

- Number of fish this line represents (1 = one fish).

Fork Length (19-22)

- Length from tip of snout to point where upper and lower caudal lobes meet (in mm). Measured as the fish lays on its side and tail is picked up and dropped into a natural position. Sub-adult and adult fish measured to nearest cm.

Total Length (23-26)

- Length from tip of snout to the end of the upper caudal lobe (in mm). Measured as in fork length. Sub-adult and adult fish measure to nearest cm.

Weight (27-33)

- Wet weight of fish in grams (to nearest 0.1 gram). Sub-Adult and adult fish weighted in field to nearest 0.1 pound, then weight converted to grams.

Girth 1 (34-37)

- Measured around the fish immediately behind the pectoral finds (in mm). Sub-adult adult fish measured to nearest cm.

Girth 2 (38-41)

- Measured around the fish immediately behind the pelvic fins (in mm). Sub-adult and adult fish measured to nearest cm.

Sex (42)

Determined by examination of gonads.

M- Male
F - Female
U - Unknown

Gonad Sample Weight (43-45)

- Wet weight of sub-sample(s) taken from the ovary (to nearest 0.1 gram). Normally weighted prior to preserving in formalin.

Gonad Total Weight (46-49)

- Wet weight of entire egg mass (in grams). Normally weighted in the field to nearest 0.1 pound.

Fish Disposition (50)

O- Unknown
1- Alive and released undersized (relative to the appropriate sport or commercial minimum size limit).
2 - Alive and released legal sized (year dependent for sport - 91-183cm 'in 1987, 102-183cm in 1988).
3 - Alive and released oversized.
4 - Alive and kept undersized.
5 - Alive and kept legal sized.
6 - Alive and kept oversized.
7 - Dead undersized.
8 - Dead legal sized.
9 - Dead oversized.

Tag Status at Capture (51-52)

First digit

O- Unknown, no information (fish not examined by WDF sampler for tags or secondary marks).

1- Never before tagged (no sign of tag scars or secondary marks).

2- Anterior and posterior dorsal ODFW tags present.

3 - Anterior dorsal ODFW tag present, posterior never tagged (no sign of posterior tag scar).

4 - Anterior dorsal ODFW tag present, posterior tag missing (posterior tag scar visible).

5 - Anterior dorsal never tagged (no sign of anterior tag scar), posterior dorsal ODFW tag present.

6 - Anterior dorsal tag missing (anterior tag scar visible), posterior dorsal ODFW tag present.

7 - Both anterior and posterior dorsal tags missing (both anterior and posterior tag scars visible).

8 - A non-ODFW tag present (usually a USFWS-FAO tag).

9 - Monet tag present.

Second digit

0 - Unknown, no information (fish not examined by WDF sampler for secondary marks).

1 - Never tattooed (tattoo not visible).

2 - Tattoo present, legible.

3 - Tattoo present, illegible.

4 - Fish tattooed, tattoo missing (this code not used by WDF).

### Tag Status at Processing (53-54)

Not applicable for WDF on fish sampled from the Bonneville to McNary Dam sport and commercial fisheries. Filled with '00' for no information available.

### Hark Code (55-56)

00 - Unknown, no information (fish not examined by WDF samplers for tags and secondary marks) or no tags, tag scars or secondary marks visible.
01 - 1987 ODFW tag and mark combination.
02 - 1988 ODFW tag and mark combination.
03 - 1989 ODFW tag and mark combination.
04 - 1990 ODFW tag and mark combination.
05 - 1991 ODFW tag and mark combination.
09 - A non-ODFW tag or mark.
90 - Unknown mark combination with an OTC mark.
92 - 1988 mark combination with an OTC mark.
93 - 1989 mark combination with an OTC mark.

94 - 1990 mark combination with an OTC mark.
95 - 1991 mark combination with an OTC mark.

## Tag 1 Type (57-58), Tag 2 Type (67-68)

- Two digit code. The first digit indicates the presence or absence of a non-ODFW tag on the fish. The second digit specifies the ODFW tag and tattoo combination found on the fish (tag scars are ignored for this).

First digit

O- No non-ODFW tag(s) or tag scars minus an ODFW mark combination were found on the fish (or the fish was not examined by WDF samplers for tags and marks).

1 - A non-ODFW tag or a tag scar minus an ODFW mark combination was found on the fish.

Second digit

0 - No ODFW tag visible (or fish was not examined by WDF samplers for tags and secondary marks).
1 - Only an anterior dorsal ODFW tag present.
2 - Both an anterior and posterior dorsal ODFW tag present.
3 - Just an anterior dorsal ODFW tag and a tattoo present.
4- Both an anterior and posterior dorsal ODFW tag plus a tattoo present.
5- Only a posterior dorsal ODFW tag present.
6 - Just a posterior dorsal ODFW tag and a tattoo present.
7 - Only a tattoo present.
8 - A non-ODFW tag present.
9 - A monel tag present.

## Tag 1 Color (59) and Tag 2 color (69)

- Color of spaghetti tag(s).

0 - Orange
R- Red
W - White
Y- Yellow
G- Green
B- Black
Z- Other
1 - Orange Spaghetti and black tattoo
2 - Yellow Spaghetti and black tattoo

## Tag 1 Number (60-66) and Tag 2 Number (70-76)

- Number of ODFW spaghetti tag(s) and/or tattoo USFWS-FAO spaghetti tag, and USFWS monel tag (monel tag number left justified).

Sampling Category (77-78)

- Denotes whether fish sampled from sport and commercial fisheries was randomly sampled, selectively sampled (for instance biological information taken only because fish was tagged or particularly large or fish was checked by a creel sampler after his routine random interview process was completed), or fish or information was voluntarily reported to samplers by an angler or fish buyer.

O- In random sample for both biological and mark information.

1 - Selected sample (commercial samples - not random for biological information, part of random sample for mark information, sport samples - not random for either biological or mark information).

2 - Volunteer sample (non-random for biological and mark information).

3- Tag and mark sampled only, no biological data collected. Not used in 1987 and 1988. Instead these fish were recorded as category '0' (random) and the biological data columns were zero filled.

5 - Biased weight sample (gutted fish for instance). In random sample for other biological and mark information.

Fin Ray Sample Collected (79)

0 - Fin ray sample not collected.
1 - Leading left pectoral fin ray collected.
2 - Leading right pectoral fin ray collected.
3- Leading ray from both pectoral fins collected.

Gonad Sample Collected (80)

0 - Gonad sample not collected.
1 - Gonad sample collected.

Mark Status at Capture (81-84)

- Four digit code identifying ODFW secondary marks observed on fish sampled from sport and commercial fisheries.

First digit (pectoral fin marks)

| | |
|---|---|
| O- Unknown, no information. | |
| 1 - No fin marked. | 1987-89 |
| 2 - Left pectoral fin ray section missing. | 1987/89 |
| 3 - Entire left pectoral ray missing. | 1987/89 |
| 4 - Right pectoral fin ray section missing. | 1988 |

|  |  |
|---|---|
| 5 - Entire right pectoral ray missing. | 1988 |

Second digit (barbel clips)

|  |  |
|---|---|
| 0 - Unknown, no information. |  |
| 1 - No barbel clip. | 1987-89 |
| 2 - Left barbel clip. | 1987 |
| 3 - Right barbel clip. | 1988 |

Third digit (scute marks)

|  |  |
|---|---|
| 0 - Unknown, no information. |  |
| 1 - No scute marks. | 1987 |
| 2 - Third right lateral scute missing. | 1988 |
| 3 - Second and third right lateral scute missing | 1988 |
| 4 - Third left lateral scute missing. | 1989 |
| 5 - Third left and second right lateral scute missing. | 1989 |
| 6 - Fourth right lateral scute missing. | 1990 |
| 7 - Fourth right and second right lateral scute missing. | 1990 |
| 8 - Fourth left lateral scute missing. | 1991 |
| 9 - Fourth left and second right lateral scute missing. | 1991 |

Fourth digit (dye marks)

|  |  |
|---|---|
| O- Unknown, no information |  |
| 1 - No dye mark. | 1987-89 |
| 2 - Right pectoral girdle dye mark. | 1988 |

Angler Survey Catch/Effort Line Number (85-86)

- Specific to biological data collected through the angler survey. Biological data for a sampled fish is recorded on one field form, the catch and effort data corresponding to that fish is recorded on a separate field form with its own line numbers. Both forms share the same sample number.

Commercial Gear Type or Angler Survey C/E Line Number (85-86)

- Specific to biological data collected from commercial fisheries.

00 - Unknown, no information.
02 - Hook and line treaty subsistence.
23 - Treaty set net.
45 - Treaty setline.

Reservoir (87)

U- Unknown.

L - Below Bonneville Dam.
A - Above Bonneville Dam, pool unknown.
B - Bonneville Reservoir.
D - The Dalles Reservoir.
J - John Day Reservoir.

**Sample Number 2 (88)**

- An alphabetic code used in conjunction with Sample Number to help associate biological samples with the source of sampling used to collect them.

C - Bonneville Dam to McNary Dam angler creel survey.
S - Below Bonneville Dam angler creel survey.
I - Bonneville Dam to McNary Dam Indian commercial and subsistence fishery sampling.
N - Below Bonneville Dam non-Indian commercial fishery sampling.
T - Below Bonneville Dam tagging operations.
E - Below Bonneville Dam egg/larvae sampling.

**Date (89-94)**

- Six digit code (format YY,MM,DD) for year, month and day used for quick reference without linking the physical data file.

**Comments (95- )**

- General comments.

## White Sturgeon Dataset Documentation
## Washington Department of Fisheries
## Recreational Fishery Sampling - Catch and Effort Data

| Variable | No of Char. | Alf/ Num | Data Set Columns | Variable limits | |
|---|---|---|---|---|---|
| record type code | 2 | N | 1 - 2 | 04 | W |
| agency code | 1 | A | 3 - 3 | W | W |
| sample number | 4 | N | 4 - 7 | C or 8-9, 001-999 | C |
| line number | 3 | N | 8 - 10 | 001-999 | C |
| date | 6 | N | 11 - 16 | 87-91,01-12, 01-31 | C |
| reservoir code | 1 | A | 17 - 17 | L,B,D,J,A,U | C |
| gear code | 2 | N | 18 - 19 | 01 | W |
| day type code | 1 | N | 20 - 20 | 1,2 | W |
| location | 5 | N | 21 - 25 | 0010-9990(0.0), 0-3(side) | C |
| ramp code | 2 | N | 26 - 27 | 01-99 | W |
| state of residence | 1 | A | 28 - 28 | W,0,3(other) | W |
| angle type code | 1 | N | 29 - 29 | 1-6 | W |
| boat/bank type code | 1 | N | 30 - 30 | 1,2 | W |
| number of anglers | 2 | N | 31 - 32 | 01-99 | W |
| trip completion code | 1 | N | 33 - 33 | 192 | W |
| angler start time | 3 | N | 34 - 36 | 001-239 | W |
| interview time | 3 | N | 37 - 39 | 001-239 | W |
| angler expected quit time | 3 | N | 40 - 42 | 001-239 | W |
| expended effort per angler | 3 | N | 43 - 45 | 001-999 | W |
| stgn sublegal catch | 2 | N | 46 - 47 | 00-99 | W |
| mark sample type | 1 | N | 48 - 48 | 0,1,2 | W |
| number tagged fish reported | 1 | N | 49 - 49 | o-9 | W |
| stgn released legal catch | 1 | N | 50 - 50 | 0-9 | W |
| mark sampler type | 1 | N | 51 - 51 | 0,1,2 | W |
| number tagged fish reported | 1 | N | 52 - 52 | 0-9 | W |
| stgn oversize catch | 1 | N | 53 - 53 | o-9 | W |
| mark sample type | 1 | N | 54 - 54 | 0,1,2 | W |
| number tagged fish reported | 1 | N | 55 - 55 | o-9 | W |
| stgn kept legal catch | 2 | N | 56 - 57 | 00-99 | W |
| mark sample type | 1 | N | 58 - 58 | 0,1,2 | W |
| number marked fish observed | 1 | N | 59 - 59 | o-9 | W |
| kept chinook catch | 2 | N | 60 - 61 | 00-99 | W |
| kept coho catch | 1 | N | 62 - 62 | 00-99 | W |
| kept steelhead catch | 1 | N | 63 - 63 | 00-99 | W |
| kept shad catch | 2 | N | 64 - 65 | 00-99 | W |

continued

## White Sturgeon Dataset Documentation
## Washington Department of Fisheries
## Recreational Fishery Sampling - Catch and Effort Data

| Variable | No of Char. | Alf/ Num | Data Set Columns | Variable limits | |
|---|---|---|---|---|---|
| kept walleye catch | 2 | N | 66 - 67 | 00-99 | W |
| kept squawfish catch | 2 | N | 68 - 69 | 00-99 | W |
| kept other catch | 2 | N | 70 - 71 | 00-99 | W |
| sample number two | 1 | A | 72 - 72 | C | W |
| comments | | A | 73 - | | W |

end