DEVELOPMENT OF A SYSTEMWIDE PREDATOR CONTROL PROGRAM: STEPWISE IMPLEMENTATION OF A PREDATION INDEX, PREDATOR CONTROL FISHERIES, AND EVALUATION PLAN IN THE COLUMBIA RIVER BASIN (NORTHERN SQUAW-FISH MANAGEMENT PROGRAM)

SECTION II: EVALUATION

1995 ANNUAL REPORT

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SECTION II. EVALUATION

C o o p e r a t o r s

Columbia Basin Fish and Wildlife Authority

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Report F

Development of a Systemwide Predator Control Program: Indexing and Fisheries Evaluation

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1995 Annual Report

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ABSTRACT

We are reporting progress on evaluation of the Columbia River Northern Squawfish Management Program in 1995. Our objectives in 1995 were to (1) evaluate exploitation rate and size composition of northern squawfish *(Ptychocheilus* oregonensis) captured in various fisheries, compare incidental catch of non-target species among fisheries, and estimate reductions in predation on juvenile salmonids since implementation of the Northern Squawfish Management Program; and (2) evaluate changes through 1995 in relative abundance, consumption, size and age structure, growth, and fecundity of northen squawfish in lower Columbia and Snake River reservoirs and in the Columbia River downstream from Bonneville Dam.

Systemwide exploitation of northern squawfish in 1995 was 13.5% for sport-reward, 0.3% for dam-angling, and 1.9% for site-specific fisheries. Mean fork length of harvested northern squawfish was 327 mm in the sport-reward, 367 mm in the dam-angling and 411 mm in the site-specific gill-net fisheries. The dam-angling fishery had the lowest percentage (4.5%) of incidental catch relative to the total number of fish caught. Incidental catch was 29.8% in the sport-reward fishery and 57.3% in the site-specific fishery.

We estimate that potential predation by northern squawfish on juvenile salmonids in 1996 will be reduced 36% from pre-program levels. Eventual reductions in predation were dependent upon various levels of sustained exploitation. However, it appeared feasible to reduce overall northern squawfish predation by at least 40%.

Compared to previous years, relative abundance of northern squawfish in 1995 decreased downstream from Bonneville Dam, in John Day Reservoir, and in the Snake River. Relative abundance in Bonneville and The Dalles reservoirs was similar to previous years. Consumption indices of northern squawfish declined downstream from Bonneville Dam and increased in Lower Granite Reservoir relative to previous years. Consumption indices in the remain@ areas were generally similar to previous years. Predation indices in 1995 were lower than previous years in nearly all areas.

Proportional stock density (PSD) of northern squawfish was generally lower in 1995 than previous years. Estimates of PSD from 1991-1995 were generally below levels that would have been expected without northern squawfish fisheries. Variations in recruitment from 1989-91 and in exploitation in 1995 should result in decreased PSD estimates in 1996 for Bonneville Reservoir and the Columbia River downstream from Bonneville Dam, whereas PSD in John Day Reservoir should remain similar to 1995.

There is no evidence to date that northern squawfish have compensated in growth or fecundity in response to sustained harvest.

INTRODUCTION

The goal of the Columbia River Northern Squawfish Management Program is to reduce mainstem predation mortality on juvenile salmonids. From 1990 through 1992, we estimated the relative magnitude of northern squawfish *(Ptychocheilus* crew) abundance, consumption, and predation in the Columbia River impoundments (MM), Snake River impoundments (1991), and the unimpounded lower Columbia River downstream from Bonneville Dam (1992). Those results established baseline levels of predation and described northern squaw&h population characteristics throughout the lower basin before the implementation of sustained predator-control fisheries. In 1993, we again sampled Columbia River impoundments to evaluate changes from 1990. In 1994 and 1995, we sampled in areas where we felt we could obtain precise estimates of northern squaw&h predation that would facilitate comparisons among years. In this report we describe our activities and findings in 1995, and wherever possible, evaluate any changes from previous years.

Our objectives in 1995 were to (1) compare exploitation rate, size composition, and incidental catch among northern squawfish fisheries, and estimate reductions in predation on juvenile sahnonids since impkmentation of the management program; and (2) evaluate changes through 1995 in dative abundance, consumption, size and age structure, growth, and fecundity of northern squawfish in lower Columbia and Snake River reservoirs and in the Columbia River downstream from Bonneville Dam.

METHODS

Fishery Evaluation

Field Procedures

Three northern squawfish fisheries were conducted in 1995. The sport-reward fishery was impkmented by the Washington Department of Fish and Wildlife (WDPW) from May 1 through September 24 throughout the lower Columbia and Snake rivers. The dam-angling fishery was implemented by the Columbia River Inter-Tribal Fish Commission (CRITIC), the Confederated Tribes of the Warm Springs Reservation of Oregon, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes and Bands of the Yakama Indian Nation (YIN), and the Nez Perce Tribe (NPT) from May 8 through September 1 at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose and Lower Granite dams. A site-specific gill-net fishery was implemented by CRITFC, YIN, and NPT from March 24 through June 29 downstream from Bonneville Dam and in Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite reservoirs.

We estimated exploitation rates of northern squawfish for each fishery based on recovery of fish tagged primarily before implementation of 1995 fisheries. We used electrofishing boats and bottom gill nets to collect northern squawfish from March 1 to May 31. Sampling effort was randomly allocated in all river kilometers (RKm) from RKm 71 through Priest Rapids Dam tailrace (RKm 639) on the lower Columbia River, and on the Snake River from RKm 0 through RKm 229, excluding Ice Harbor Reservoir. Fish greater than 240 mm fork length were tagged with a serially numbered spaghetti tag and given a secondary mark (lower caudal tin hole punch). Tags were recovered from each fishery from April 8 through September 25.

Data Analysis

We used mark-and-recapture data to compare exploitation rates of northern squawfish among fisheries and memoirs. Exploitation rates were calculated for one-week periods and summed to yield total exploitation rates for each fishery (Beamesderfer et al. 1987). We adjusted exploitation rates for tag loss (4.8%) during the season.

We compared mean fork lengths and length frequencies of northern squawfish among fisheries, and incidental catches among fisheries. We compared mean fork lengths of fish harvested by sport-reward and dam-angling fisheries among years (1990-95) Information on size of northern squawfish harvested in the site-specific gill-net fishery was supplied to us by CRITFC.

We used the "Loss Estimate Spreadsheet Model" (Zimmerman et al. 1995) to estimate reductions in predation relative to predation prior to implementation of the management program. The model incorporates age-specific exploitation rates on northern squawfish and resulting changes in age structure to estimate changes in predation. We used a IO-year "average" age structure (based on catch curves) for a pre-exploitation base, and assumed constant recruitment. Age-specific consumption was incorporated, however, potential changes in consumption, growth, and fecundity due to removals were not considered likely. The model therefore estimates changes in potential predation related directly to removals. This in effect allows us to estimate what the effects of removals would be if we were able to hold all variables except exploitation constant.

We estimated both the potential predation reduction in 1996 based on observed exploitation rates, and the eventual maximum potential predation reduction assuming (1) continuing exploitation at 1995 levels, and (2) continuing exploitation at mean 1991-95 levels. In addition to reductions in overall predation, we estimated reductions in predation on juvenile salmonids originatiig in the Snake River upstream from Lower Granite Dam. We calculated 95% confidence intervals for all predation reduction estimates.

Biological Evaluation

Field Procedures

To evaluate changes in relative abundance and consumption for northern squawfish, we used boat electrofishing to collect northern squawfish in the following areas: upper Lower Granite Reservoir (RKm 22 l-229), Little Goose Reservoir tailrace, Lower Monumental Reservoir taihace, John Day Reservoir, The Dalles Reservoir forebay and tailrace, Bonneville Reservoir, Bonneville Dam taihace, and three sections in the Columbia River downstream from Bonneville Dam tailrace (RKm 117-121, RKm 171-177, and RKm 190-196). Sampling schedules, methods, and gear specifications were as descrii in previous reports (Vigg et al. 1990, Ward et al. 1991, Parker et al. 1994, Zimmerman et al. 1995, Knutsen et al. 1995). We collected digestive tracts of all northern squawfish ≥250 mm fork length and preserved them using methods descrii by Petersen et al. (1991).

To evaluate changes in population structure, growth, and reproduction, we collected biological data from all northern squawfish collected by electrofishing and from a subsample of northern squawfish caught in the sport-reward and dam-angling fisheries. We measured fork length (mm) and total body weight (g), determined sex (male, female, undetermined) and maturity (undeveloped or immature developing, ripe, or spent), and collected gonad (ripe females only) and scale samples.

Laboratory Procedures

We examined gut contents of northern squawfish collected by electrofishing to measure relative consumption rates of juvenile sahnonids by northern squawfish. Details of laboratory methods are given in Petersen et al. (1991). We used scale samples from northern squawfish collected primarily by electrofishing for age determinations. We used gravimetric quantification (Bagenal 1968) to estimate fecundity of northern squawfish. Details of aging and fecundity procedures are given in Parker et al. (1995).

Data Analysis

We used catch per unit effort of standardii electrofishing runs as an index of northern squawfish density and calculated indices of northern squawfish abundance as the product of the northern squawfish density index and reservoir or area-specific surface area (Ward et al. 1995). We compared density and abundance indices from 1990 through 1995 for all sampling areas.

The following formula was developed as a consumption index (CI) by Petersen et al. (1991).

$$CI = 0.0209 \cdot T^{1.60} \cdot MW^{0.27} \cdot (S \cdot GW^{-0.61})$$

Where

T = water temperature (°C),
MW = mean predator weight (g),
S = mean number of salmonids per predator, and
GW = mean gut weight (g) per predator.

The consumption index is not a rigorous estimate of the number of juvenile salmonids eaten per day by an average northern squawfish However, it is linearly related to the consumption rate of northern squawfish (Petersen et al. 1991). Spring (May-June) and summer (July-September) consumption indices were compared from 1990 to 1995 for all sampling areas. We plotted the daily juvenile salmonid passage index at lower Columbia and Snake River dams to compare timing of consumption index sampling with concentrations ofjuvenile salmonids present in each area. We used the product of abundance and consumption indices to calculate predation indices for spring and summer periods. We compared predation indices among years for reservoirs and areas where data had been collected each year.

Because fishery exploitation rates increase with increasing size of northern squawfish (Zimmerman et al. 1995), sustained fisheries should decrease the abundance of large fish relative to the abundance of smaller fish. We used proportional stock density [PSD = 100 •(number of fish at least quality length)/(number of fish at least stock length); Anderson 1980] to compare size structure of northern squawfish populations among years (1990-95) in the Columbia River downstream from Bonneville Dam, Bonneville Reservoir, and John Day Reservoir. Stock and quality sizes for northern squawfish have been defined as 250 mm and 380 mm fork length (Beamesderfer and Rieman 1988, Parker et al. 1995).

Comparisons of PSDs among years may be bii by (1) fluctuating year-class strengths that influence the number of stock-size fish (Mesa et al. 1990), and (2) size-selectivity of sampling gear (Beamesderf" and Rieman 1988). To reduce bias, we used information on relative year-class strengths and natural mortality rates of northern squawfish to estimate PSDs that would be expected with and without program implementation and used size-selectivity of our sampling gear to adjust observed PSD estimates (Knutsen et al. 1995). We then compared observed and expected PSDs.

To evaluate changes in growth rate after implementation of the management program, we used observed length-at-age data for female northern squafish from the Columbia River downstream from Bonneville Dam, and from Bonneville and John Day reservoirs We determined regression parameters (slope and y-intercept) for fork length on age using only those ages where growth rate was linear (ages 5 through 14 downstream from Bonneville Dam and Bonneville Reservoir, ages 5 through 13 in John Day Reservoir). We compared relationships among years (1990-95) using joint 95% family confidence regions for estimates of parameter pairs (Neter et al. 1985). Parameter pairs were considered significantly different if point estimates (center-point of ellipse) were outside the confidence region for another year.

We compared mean fecundity (number of developed eggs per female) and mean dative feaundity (number of developed eggs per gram of body weight) for the area downstream from Bonneville Dam and John Day Reservoir. We determined regression parameters for the regression of fecundity on fork length and compared relationships among years (1991-95) for each area using joint 95% family contidence regions for estimates of parameter pairs (Neter et al. 1985). Sample size for the fecundity-length relationship in Bonneville Reservoir (N=6) was inadequate in 1995 to make meaningful comparisons with previous years.

RESULTS

Fishery Evaluation

We tagged and released 1,427 northern squawfish throughout the lower Columbia and Snake rivers. A total of 188 tagged northern squawfish were recaptured in the three fisheries 164 in the sport-reward fishery, three in the dam-angling fishery, and 21 in the site-specific gill-net fishery.

Exploitation rates among reservoirs in which tagged fish were recaptured ranged from 4.6% in Lower Monumental Reservoir to 22.5% in McNary Reservoir (Table 1 and Figure 1; Appendii A). John Day Reservoir was the only area in which no tagged fish were recovered. The systemwide exploitation rate in 1995 was 13.5% in the sport-reward fishery, 0.3% in the dam-angliig fishery, and 1.9% in the site-specific fishery. Total exploitation rate (all fisheries combined) in 1995 was 15.6%, the highest annual rate observed to date (Table 2). Sport-reward exploitation rates have increased from 1991-95 downstream from Bonneville Dam, and in The Dalles and McNary reservoirs, and have declined in Snake River reservoirs (Appendii Table A-l). Dam-angling exploitation rates have declined from 1991-95 in nearly every area (Appendix Table A-2). Exploitation in the site-specific fishery in 1995 was similar to 1994 when the fishery was implemented.

The mean size of northern squawfish harvested systemwide in 1995 was 327 mm in the sport-reward fishery, 367 mm in the dam-angiing fishery, and 411 mm in the site-specific gill-net fishery (Figure 2). Mean size in 1995 was lower than 1994 for the sport-reward and dam-angling fisheries, and similar to 1994 for the site-specific fishery (Knutsen et al. 1995).

Mean size of northern squawfish harvested by dam angling in Bonneville Dam tailrace and Bonneville, The Dalles, and John Day reservoirs was lower in 1995 than any previous year (Table 3). Sample sizes for dam angling in McNary Reservoir and the Snake River reservoirs were too small (<5) to estimate mean fork length in 1995. Themeansizeof fish harvested in 1995 by sport-reward anglers was lower than 1994 in all locations except The Dalles Reservoir (Table 3). Sample sizes for sport reward in John Day, Ice Harbor, Lower Monumental, and Little Goose reservoirs were too small (≤5) to estimate mean size in 1995. The mean size of northern squawfish harvested in the site-specific fishery was similar between 1994 and 1995 in reservoirs where the fishery was conducted both years.

Table 1. Exploitation rates (%) of northern squawfish ≥250 mm among fisheries in 1995.

Area or reservoir	Sport reward	Dam angling	Site-specific	Total
Downstream from				
Bonneville Dam	16.2	0.2	0.2	16.6
Bonneville	3.5	0.0	5.9	9.4
The Dalles	15.0	0.0	1.1	16.1
John Day	0.0	0.0	0.0	0.0
McNary	22.5	0.0	0.0	22.5
Lower Monumental	0.0	4.6	0.0	4.6
LittleGoose	2.9	2.8	0.0	5.7
Lower Granite	6.4	0.0	0.0	6.4
Systemwide	13.5	6.3	1.9	15.6

Table 2. Total exploitation rates of northern squawfish ≥250 mm from 1991-95.

Area or reservoir	1991	1992	1993	1994	1995
Downsstream from					
Bonneville Dam	8.1	11.8	7.1	13.0	16.6
Bonneville	15.2	6.8	4.6	11.2	9.4
TheDalles	10.5	7.2	7.0	10.7	16.1
John Day	13.3	14.3	10.5	5.8	0.0
McNary	5.2	5.6	16.5	14.0	22.5
Ice Harbor	17.5				
Lower Momunental	27.0	7.7	3.1	0.8	4.6
LittleGoose	18.4	18.1	6.6	9.2	5.7
Lower Granite	16.8	14.6	12.6	8.1	6.4
Systemwide	11.3	12.2	8.5	13.1	15.1

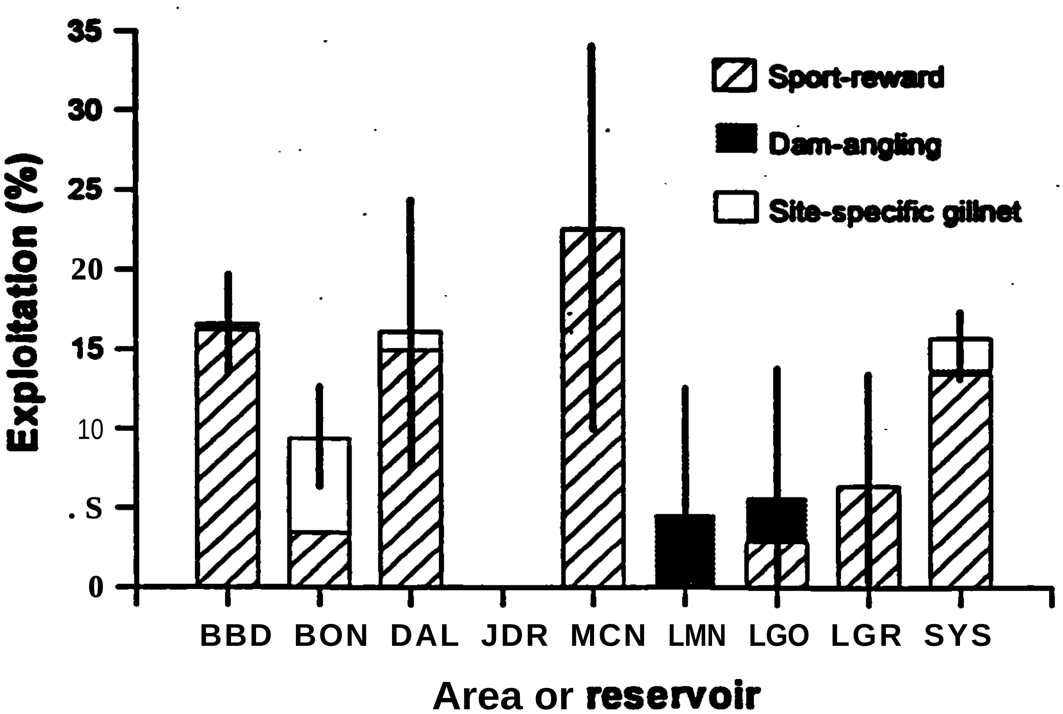


Figure 1. Exploitation rates of northern squawfish ≥250 mm by fishery during 1995. Vertical lines are 95% confideace intervals **for total exploitation rates (all fisheries combined). Areas are downstream from Bonneville Dam (BBD), systemwide (SYS), and resevoirs are Bonneville (BON), The Dalles (DAL), John Day (JDR), McNary (MCN), Lower Monnumental (LMN), Little Goose (LGO), and Lower Granite (LGR) reservoirs.**

In 1995 the various fishcries reported 93,177 incidentally caught fish including northern squawfish <250 mm (Table 4). The incidental catch rate was 4.5% in the dam-angling fishery, 29.8% in the sport-reward fishery, and 57.3% in the site-specitic fishery. Northern squawfish <250 mm, other cyprinids, smallmouth bass *(Micropterus tiblmieato, catostomids, and* **white sturgeon** *(Acijmiser transmontanus) were* **the most common incidentally caught fish. Sahnonids made up only 0.2% of the total catch and 0.7% of the incidental catch for all fisheries combined. The proportion of predator-sized (≥250 mm) northern squawfish relative to the total number of northern squawfish harvested was highest in the dam-angling fishery (100.0%) and lowest in the sport-reward fishery (83.8%).**

Results from the Loss Estimate Spreadsheet Model indicate that potential predation by northern squawfish on juvenile salmonids in 1996 may be reduced 36% from pre-program levels (Table 5). Predation on Snake River stocks will be similar to predation on other stocks. Eventual reductions in potential predation vary depending on estimates of sustained exploitation. However, it appears feasible to reduce potential northern squawfish predation by at least 40%.

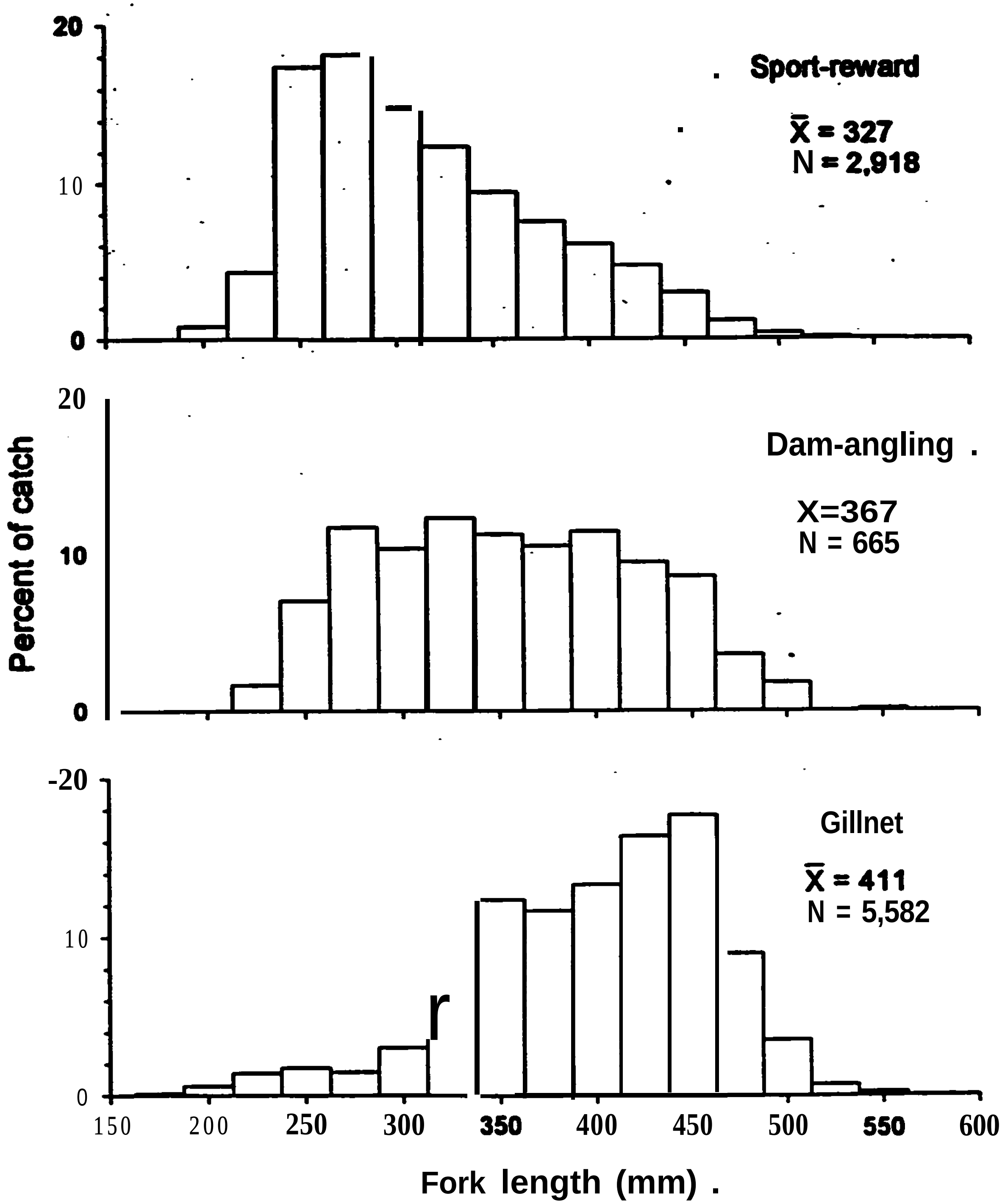


Figure 2. Size composition and mean fork length of northern squawfish in subsamples of fish harvested systemwide in sport-reward, dam-angling, and site-specific gill-net fisheries in 1995. N = subsample size.

Table 3. Mean fork length (mm) of northern squawfish harvested from 1990 through 1995 in the dam-angling, sport-reward, and site-specific gill-net fisheries in the lower Columbia and Snake livers.

Fishery: location	Mean fork length (mm)					
	1990	1991	1992	1993	1994	1995
Dam angling:						
Bonneville Dam Tailrace	414	417	388	390	376	364
Bonneville Reservoir	407	417	416	415	413	365
The Dalles Reservoir	421	404	380	420	390	343
John Day Reservoir	416	414	417	416	437	389
McNary Reservoir	393	393	356	358	366	323
Ice Harbor Reservoir		375	360	317	407	
Lower Monumental Reservoir		325	309	341		
Little Goose Resewoir		380	346	373	370	
Lower Granite Reservoir				377		
Sport reward:						
Downstream from Bonneville Dam		332	337	316	337	325
Bonneville Reservoir		343	347	312	323	305
The Dalles Reservoir		344	369	369	358	359
John Day Reservoir	377	370	367	370	329	
McNary Reservoir		354	356	358	366	323
Ice Harbor Reservoir		357	360	317	407	
Lower Monumental Reservoir		338	330	307	428	
Little Goose Reservoir		312	347	344	376	
Lower Granite Reservoir		343	345	362	348	322
Site specific:						
Downstream from Bonneville Dam						374
Bonneville Resewoir				371	411	416
The Dalles Reservoir					395	3 %
John Day Reservoir					366	370
McNary Reservoir					387	363
Ice Harbor Resewoir						386
Lower Monumental Reservoir						345
Little Goose Reservoir						379
Lower Granite Reservoir					377	370

Table 4. Number of northern squawfish and incidentally caught fish by species or family in each fishery in 1995. Northern squawfish <250 mm fork length are considered incidental catch. Incidental catch in the sport-reward fishery was estimated from 8 subsample of returning anglers, and the estimates do not include catches made by non-returning anglers (Scott Smith, WDFW, Pullman, November 1995, personal communication).

Species or family	Sport-reward	Dam-angling[a]	Gill-net[b]
Northern squawfish			
≥250 mm fork length	199,788	5,488	9,484
<250 mm fork length	38,712	0	150
smallmouth bass	13,364	0	228
White sturgeon[c]	4,945	200	1,288
Channel catfish[c]	1,762	0	481
Walleye[c]	1,948	0	184
American shad[c]	593	14	295
Salmonidae[c d]			
Chinook (adult)	20	--	104
Chinook (juvenile)	13		
Sockeye (adult)	0		1
Sockeye (juvenile)	0		
steelhead (adult)	80		71
Unknown salmon (adult)	18	3	0
Unknown salmon (juvenile)			18
Mountain whitefish[c]	7		34
other	241		8
Cyprinidae (minnows)	15,795		804
Catostomidae (suckers)	4,587		6,604
other	2,929	44	128
Total (all species)	284,802	5,749	19,882
Percent incidental catch	29.8	4.5	57.3

a Sahnonids and non-game fish not identified to species.
b Juvenile salmonids not identified to species.
c White sturgeon = *Acipnser transmontanus*, channel catfish = *Ictalurus punctatus*, walleye = *Stizostedion vitreum vitreurn*, American shad = *Alosa sapidissima*, Salmonidae = *Oncorhynchus*, *Salmo*, and *Salvelinius* spp., Mountain whitefish = *Prosopium williamsoni*.
d Estimates of salmonids caught by sport-reward anglers do not include fish caught in the Columbia River upstream from the mouth of the Snake River.

Table 5. Comparison of predicted reductions in potential predation of juvenile salmonids relative to predation prior to implementation of the northern squawfish management program. Snake River stocks are juvenile salmonids originating upstream from Lower Granite Dam. Numbers in parentheses represent 95% confidence intervals for estimates of potential predation.

	All Stocks		Snake River stocks	
	Reduction in predation	Year reached	Reduction in predation	Year reached
Potential predation reduction in 1996	36% (28-44%)	–	38% (30-45%)	–
Maximum potential predation reduction with 1995 exploitation levels continued	41% (3548%)	1998	41% (3 1-50%)	2003
Maximum potential predation reduction with mean 1991-95 exploitation levels continued	38%(30-45%)	1998	39% (3 1-46%)	1997

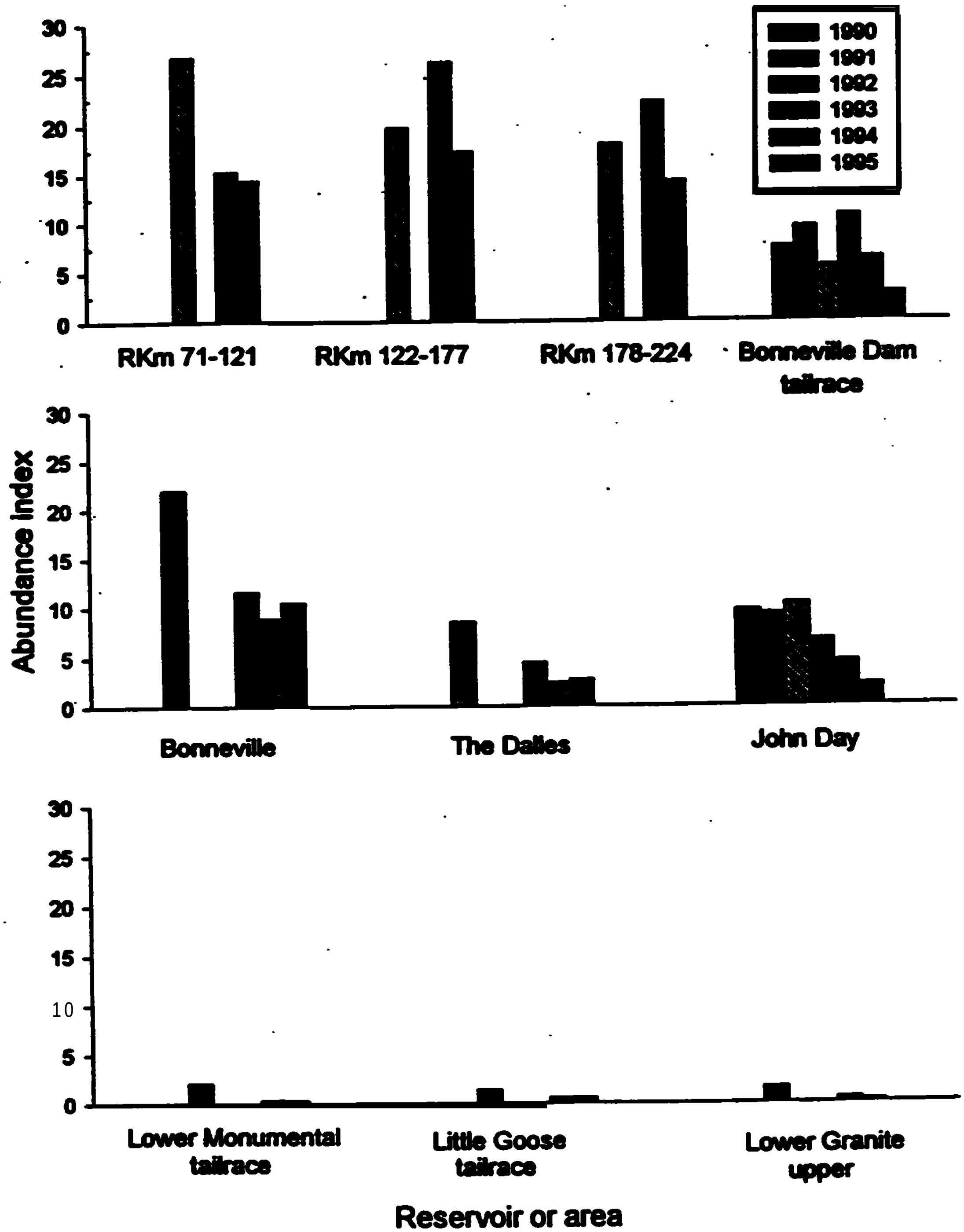
Biological Evaluation

Indices of density and relative abundance of northern squawfish ≥250 mm were lower in 1995 than any previous year in areas downstream from Bonneville Dam, and in John Day Reservoir, Lower Monumental Reservoir tailrace; and the upper reach of Lower Granite Reservoir (Figure 3; Appendix Tables B-l and B-2). Density and relative abundance in Bonneville and The Dalles reservoirs in 1995 was similar to 1994.

Northern squawfish consumption indices in 1995 during spring and summer were lower down&ream from Bonneville Dam than when the reach was previously sampled in 1992 and 1994 (Appendii Table B-3 and B-4). Consumption indices in other areas were generally similar to 1994, with the exception of the sping index for the upper reach of Lower Granite Reservoir where consumption doubled from 1994. Changes in relative abundance and consumption resulted in lower indices of predation during both spring and summer in nearly all areas sampled in 1995 relative to previous years (Figures 4 and 5). Predation indices in the tailraces of Bonneville and John Day reservoirs may be biased low because spill prohibited our sampling in the boat restricted zones of The Dalles and McNary Dam tailraces during 1995. Timing of our electrofishing sampling coincided with peaks in downstream passage ofjuvenile salmonids except during summer at Bonneville Dam (Appendix C).

Variations in year-class strength of northern squawfish downstream from Bonneville Dam and Bonneville Reservoir were similar until 1991, when a strong year class was produced in Bonneville Reservoir (Figure 6). The strongest year class in John Day Reservoir was produced in 1990. In general, year classes were stronger from 1988 through 1991 than in 1986 and 1987.

Proportional stock density (PSD) ofnorthern squawfish has decreased since implementation of the Northern Squawfish Management Program in 1990 (Figure 7). Observed PSDs initially remained stable or increased, as a relatively strong 1985 year class was recruited from stock to quality size. Observed PSDs then generally decreased as relatively weak 1986 and 1987 year classes were recruited to quality size, and relatively strong 1988-91 year classes were recruited to stock size. Observed PSDs were usually lower each year than would have been expected without implementation of the Northern Squawfish Management Program. Values for observed PSDs and PSDs expected with implementation of the management program often differed, however, trends were usually similar Direction of change between years was the same for 8 of 11 possible comparisons. Differences between observed and expected PSD values generally decreased over time.



Fiie 3. Index of northern squawfish abundance from 1990 through 1995 for sampling locations in the lower Columbia and Snake rivers.

Comparisons of confidence regions for joint estimates of parameters in northern squawfish length-age equations differed among years in some areas (Figure 8). The length-age relationship for northern squaw&h collected downstream form Bonneville Dam in 1995 was similar to the previous three years, but differnt from 1990 and 1991. The length-age relationship for northern squawfish collected in Bonneville Reservoir in 1995 was similar to growth in 1990 and 1994, but different than growth in 1993. In John Day Reservoir, the length-age relationship for 1995 was similar to previous years

The relationship between fecundity and length of northern squawfish in 1995 was significantly different than previous years downstream from Bonneville Dam and in John Day Reservoir (Figure 9). We did not analyze the fecundity-length relationship in Bonneville Reservoir in 1995 due to small sample size.

Mean fecundity of northern squawfish collected downstream from Bonneville Dam averaged 3 1.8% lower in 1995 relative to 1991-94 (Table 6). Mean relative fecundity downstream from Bonneville Dam averaged 11.5% lower than previous years. Mean fecundity and relative fecundity in Bonneville and John Day reservoirs was also much lower in 1995 relative to 1991-94. However, the number of northern squawfish collected in both reservoirs in 1995 (N=6 in Bonneville Reservoir, N=14 in John Day Reservoir) was too small to make meaningful comparisons with previous years.

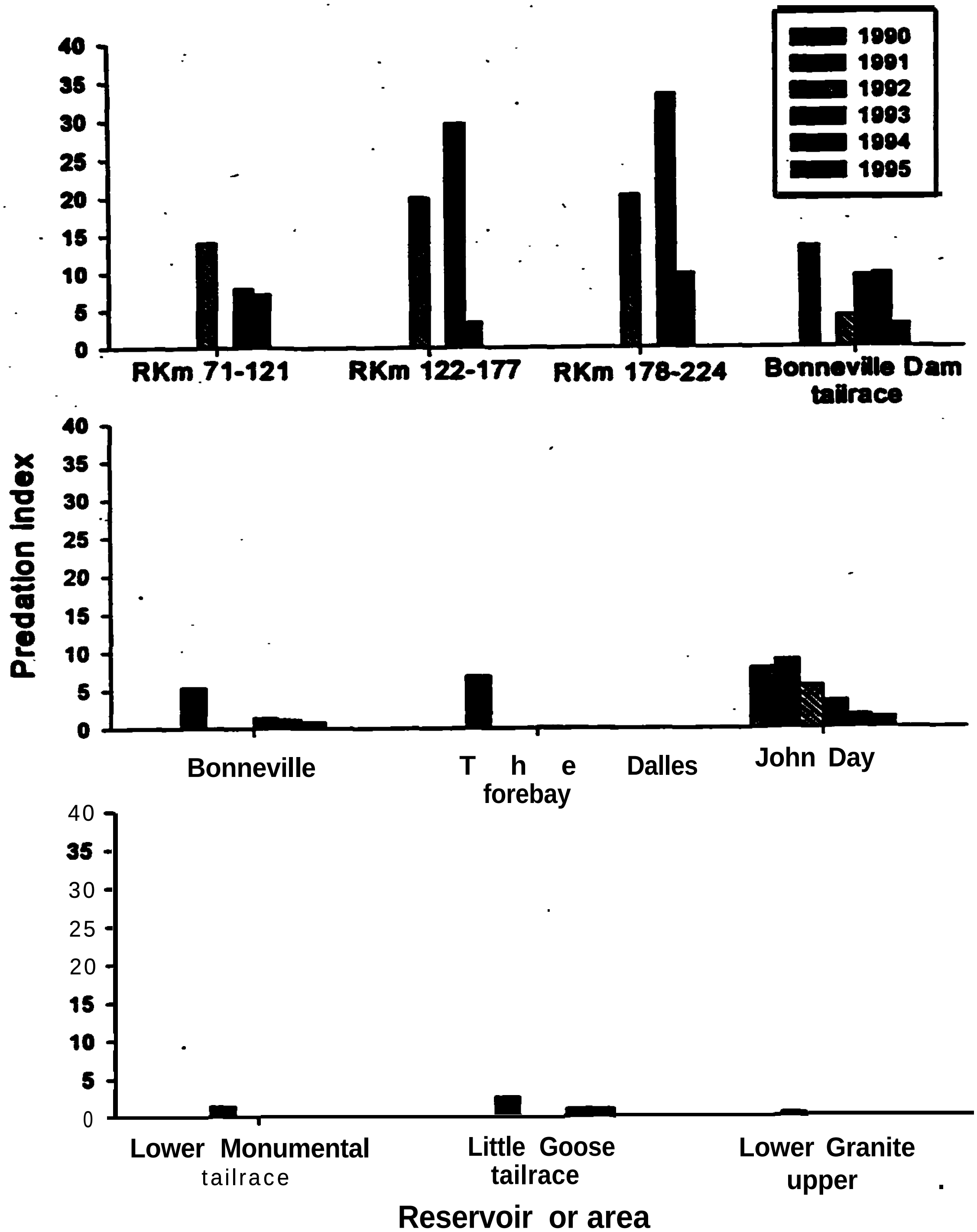


Figure 4. Index of predation by northern squawfish during spring from 1990 through 1995 for sampling loeations in the lower columbia and snakc rivers.

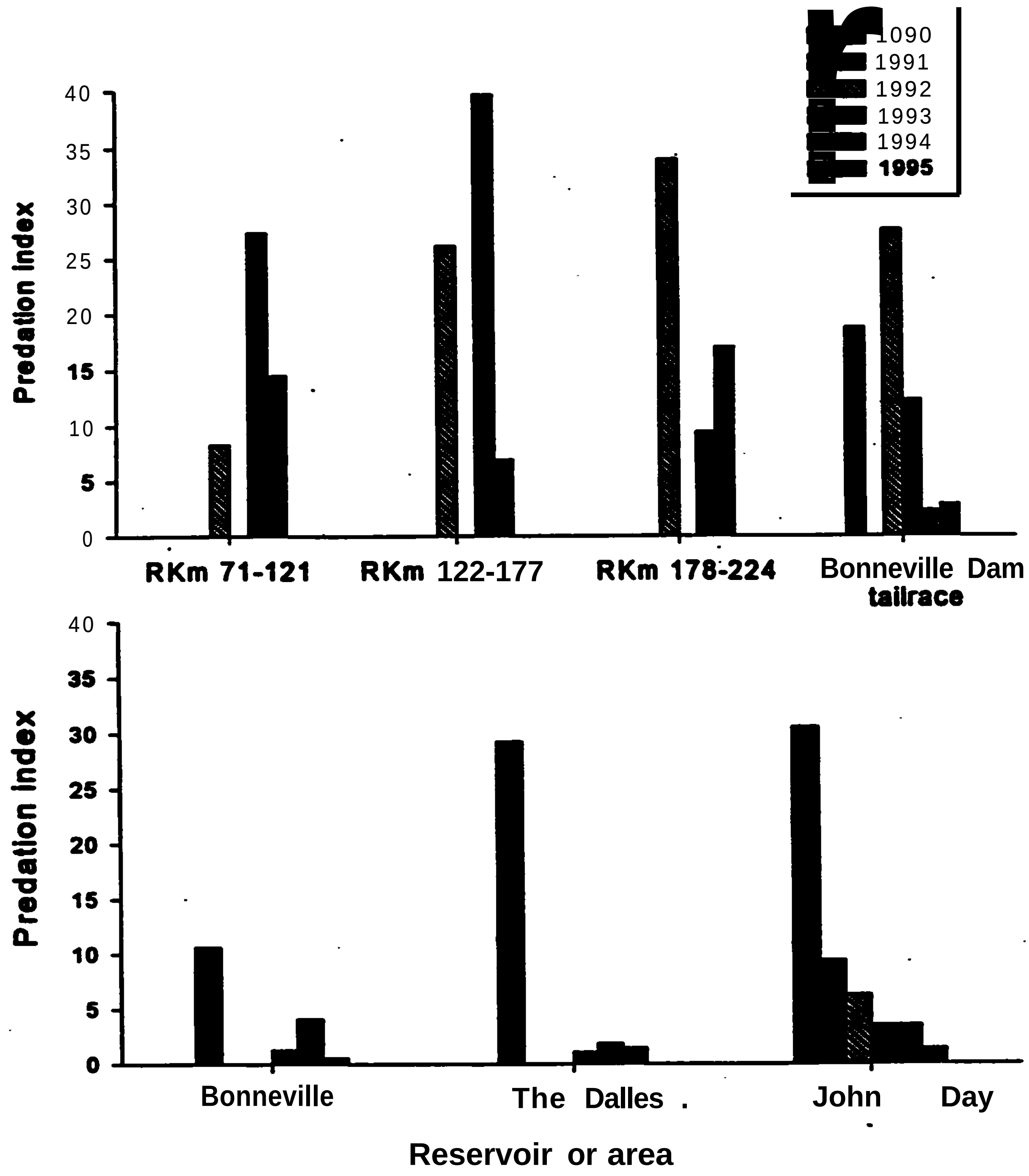


Figure 5. Index of predation by northern squawfish during summer from 1990 through 1995 for sampling locations in the lower Columbia and Snake rivers. Predation indices for The Dalles Reservoir excludes the mid-reservoir.

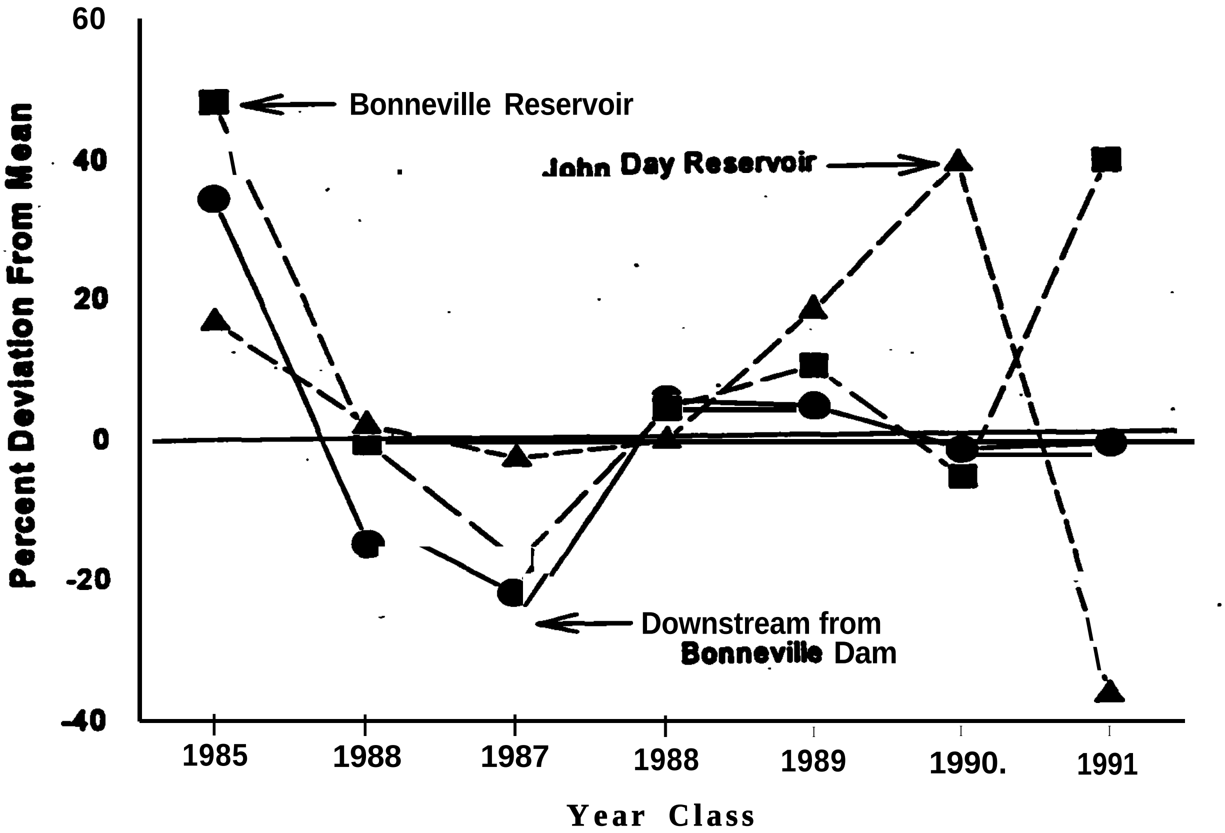


Figure 6. Index of relative year-class strength of northern squawfish in the Columbia River downstream from Bonneville Dam, Bonneville Reservoir, aud JohnDay Rcservoir.

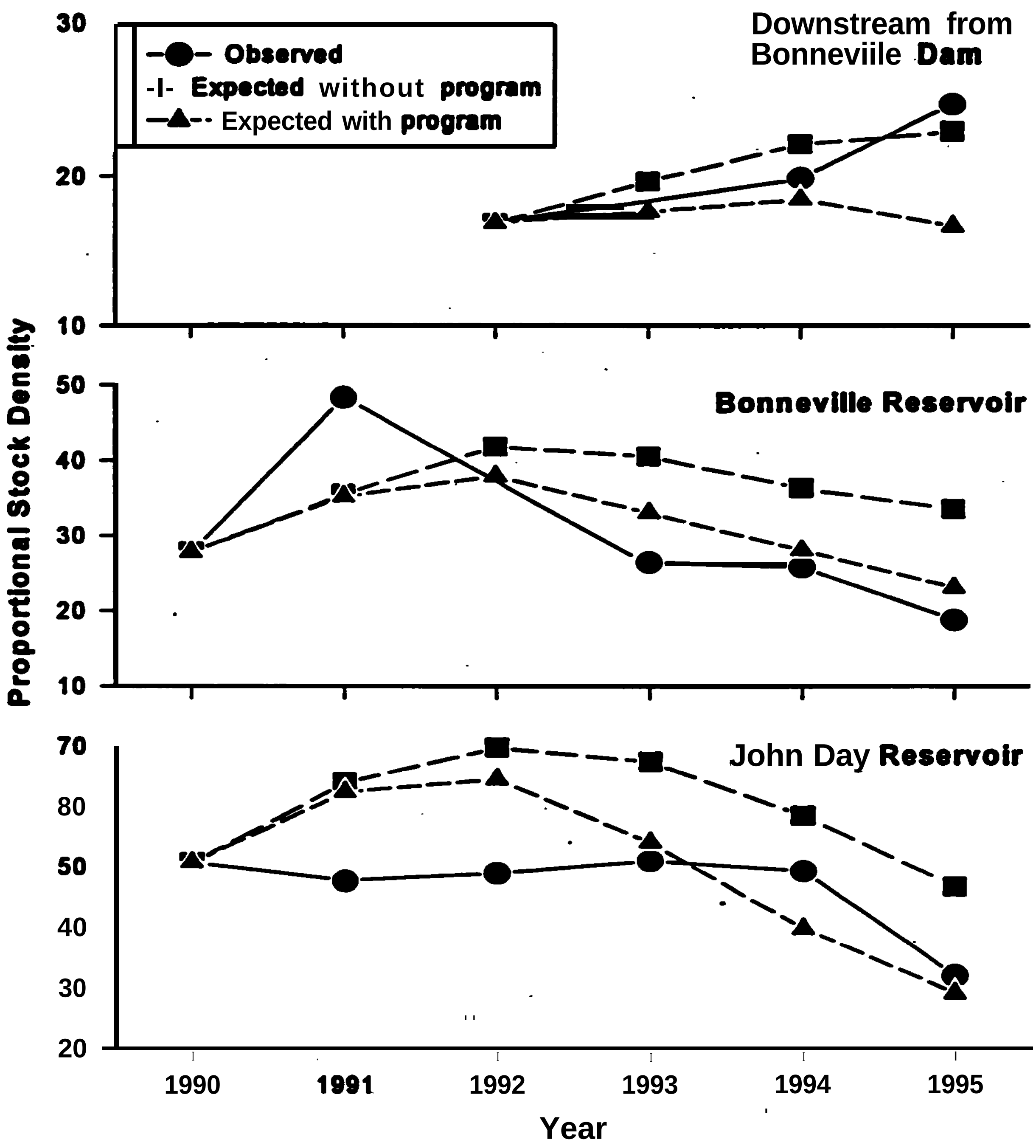


Figure 7. Observed and expected proportional stock density with and without implementation of the Northern Squawfish Management Program from 1990 through 1995 in the Columbia River downstream from Bonneville Dam, Bonneville Reservoir, and John **Day Reservoir.**

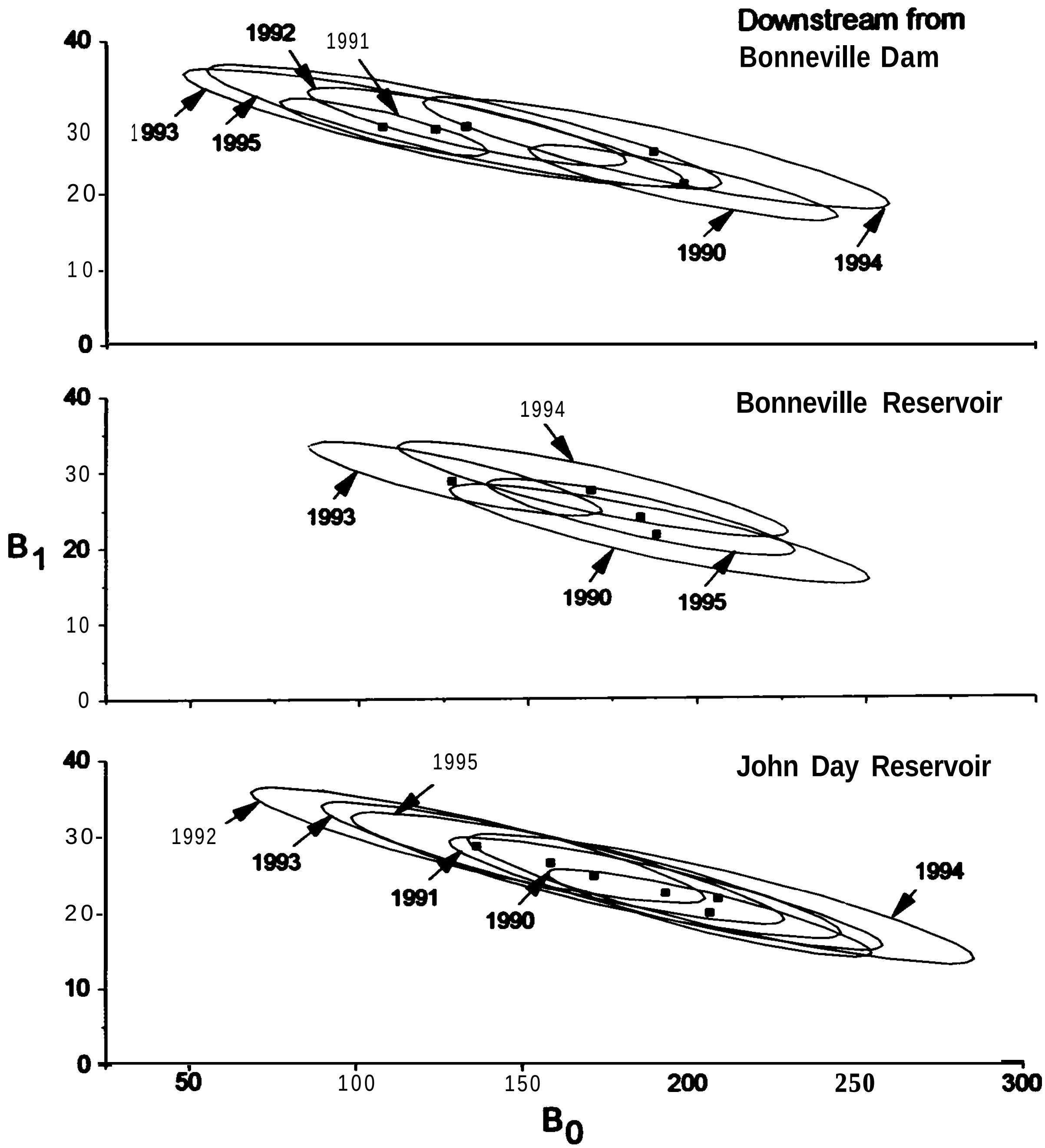


Figure 8. Joint 95% family confidence regions for estimates of length-age equation parameters (B_1 = slope and B_0 = y-intercept) for female northern squawfish in the Columbia River downstream from Bonneville Dam (ages 5-14), Bonneville Reservoir (ages 5-14), and John Day Reservoir (ages 5-13) from 1990-95. Data were not available for Bonneville Reservoir in 1991 and 1992. Parameter pairs are considered significantly different if point estimates (solid squares) are not within the confidence region for another year.

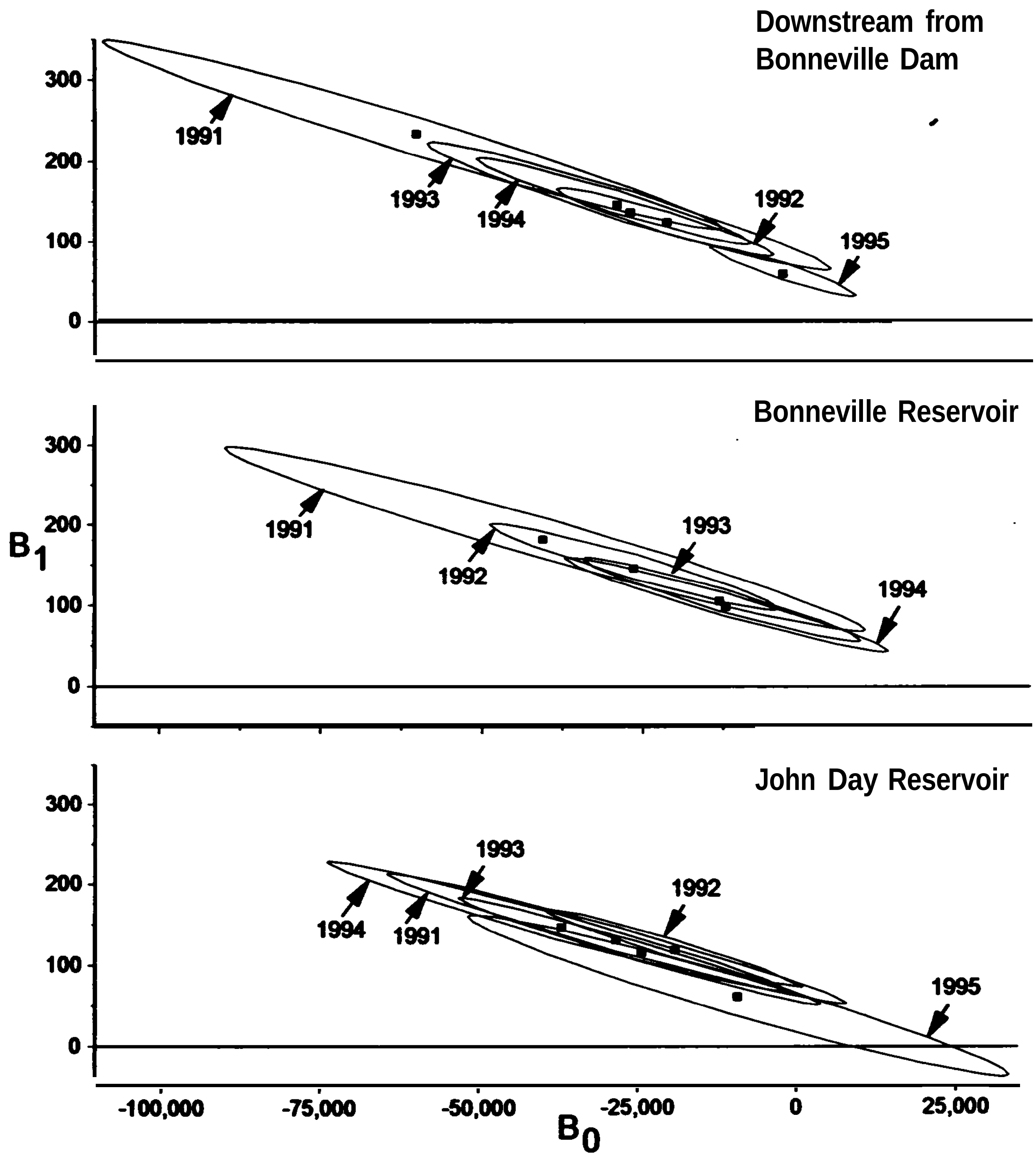


Figure 9. Joint 95% family confidence regions for estimates of fecundity-length equation parameters (B_1 = slope and B_0 = y-intercept) for northern squawfish in the Columbia River downstream from Bonneville Dam (1991-95), Bonneville Reservoir (1991-94), and John Day Reservoir (1991-95). Parameter pairs are considered significantly diffrent if point estimates (solid squares) are not within the confidence region for another year.

Table 6. Mean fecundity (number of developed eggs per female), mean relative fecundity (number of developed eggs per gram of body weight), and sample size (N) of northern squawfish in the Columbia River downstream from Bonneville Dam, and Bonneville and John Day reservoirs from 1991-95.

Location, parameter	1991	1992	1993	1994	1995
Downstream from Bonneville Dam					
Meanfecundity	34,806	23,437	24,288	27,812	18,363
Mean relative fecundity	36.58	30.59	34.41	36.47	30.37
N	52	77	33	75	126
Bonneville Reservoir					
Meanfecundity	35,796	33,338	30,405	28,688	18,550
Mean relative fecundity	43.52	34.94	31.86	31.91	22.27
N	45	110	103	101	6
John Day Reservoir					
Mean fecundity	30,619	31,504	26,088	27,638	16,840
Mean relative fecundity	28.11	31,62	24.83	24.93	18.97
N	81	119	96	60	14

DISCUSSION

High exploitation rates downstream from Bonneville Dam, and in The Dalles and McNary reservoirs in 1995 contrii to the highest systemwide exploitation rate since implementation of the Northern Squawfish Management Program. The sport-reward fisher accounted for the majority of systemwide exploitation, whereas exploitation in the dam-angling fishery in 1995 was an order of magnitude lower than all previous years. The site-specific fishery made a major contribution to exploitation in Bonneville Reservoir where gillnetting effort and harvest were greatest.

Reductions in potential predation on stocks of outmigrating Snake River salmonids may reach 38% in 1996 and could reach 41% ifexploitation remains at 1995 levels. The benefit of reduced predation on Snake River stocks is particularly important given their status under the Endangered Species Act. Efforts to reduce potential predation by increasing exploitation of northern squawfish in 1995 were at least somewhat succesful,and should be continued in 1996.

The indices of predation on spring-migrating juvenile salmonids by northern squawfish were lower in all sampling areas in 1995 relative to the previous five years. In Bonneville Reservoir, lower predation was attributable to lower consumption indices as abundance indices of northern squawfish from 1993-95 have not changed. In Lower Granite Reservoir, lower predation reflected lower abundance of northern squawfish as the consumption index for the upper reservoir was higher than previous years. This was the only sampling area in which our spring index of consumption was markedly higher than previous years. Low predation indices downstream from Bonneville Dam were attributable to lower abundance and consumption relative to previous years. We collected northern squawfish digestive tracts during times of peak juvenile salmonid abundance at most sampling areas in 1995. Therefore, we cannot attriiute lower consumption indices to mistimed sampling.

Decrees in PSD were greater than could be expplained by fluctuations in year-class strength, and indicate that sustained removals may be altering the size structure of predator-sized northern squawfish Although trends in observed PSD were usually similar to trends in expected PSD, observed and expected values often differed, especially in the early years of the management program. This is due in part to the fact that estimates of expected PSD incorporate estimates of annual mortality and age-specific lengths. Annual variations in natural mortality and growth are unpredictable; we therefore used estimates of annual mortality developed prior to sustained removals, and pooled 1990-95 growth data to estimate age-specific lengths. These data should be representative of long-term averages, but will not reflect annual variation around those averages. Differences between observed and expected values should therefore become smaller over a period of years, as annual variations "average out."

We found no evidence of increased growth among northern squawfish in *response* to sustained harvest. Although length-age relationships varied among years, no overall increase in growth was apparent in any area or reservoir. The magnitude of variation in growth estimates from 1990 through 1995 underscored the difficulty in detecting growth compensation by northern squawfish.

Northern squawfish have not compensated for sustained harvests by increasing fecundity. Our estimates of fecundity in 1995 were in fact lower than previous years. A decline in the mean size of northern squawfish collected for fecundity analysis in 1995 contributed to the observed differences in mean fecundity and the fecundity-length relationship between 1995 and previous years. This was particularly true of samples from Bonneville and John Day reservoirs where sample sizes were also very small. However, an adequate sample size was obtained downstream from Bonneville Dam in 1995 and the mean weight of northern squawfish was 14.8% lower than in previous years' samples. We observed an even greater decline (29.2%) in mean gonad weight of ripe females collected downstream from Bonneville Dam in 1995.

REFERENCES

Bagenal, T.B. 1968. Fecundity. Pages 160-169 *in* W.E. Ricker, editor. Methods for assessment of fish production in freshwater International Biological Programme Handbook 3, Blackwell Scientific Publications, oxford, England.

Beamesderfer, RC., and B.E. Rieman 1988. Size selectivity and bias in estimates of population statistics of smallmouth bass, walleye, and northern squawfish in a Columbia River reservoir- North American Journal of Fisheries Management 8:505-5 10.

Beamesderfer, RC., B.E. Rieman, J.C. Elliott, AA Nigro, and D.L. Ward. 1987. Distribution, abundance, and population dynamics of northern squawfish, walleye, smallmouth bass, and channel catfish in John Day Reservoir, 1986. Oregon Department of Fish and Wildlife, Contract DE-AI79-82BP35097. 1986 Annual Report to Bonneville Power Administration, Portland, Oregon.

Knutsen, C.J., D.L. Ward, T.A Friesen, and M.P. Zimmerman. 1995. Development of a systemwide predator control program: indexing and fisheries evaluation. Oregon Department of Fish and Wildlife Contract DE-AI799OBPO7084. 1994 Annual Report to the Bonneville Power Administration, Portland, Oregon.

Mesa, M.G., SD. Duke, and D.L. Ward. 1990. Spatial and temporal variation in proportional stock density and relative weight of smallmouth bass in a reservoir. Journal of Freshwater Ecology 5:323-339.

Neter, J., W. Wasserman and M.H. Kutner. 1985. Applied linear statistical models, 2nd ediion. Irwin Press, Homewood, Illinois.

Parker, RM., M.P. Zimmerman, and D.L. Ward. 1994. Development of a systemwide predator control program: indexing and fisheries evaluation. Oregon Department of Fish and Wildlife, Contract number DE-AI799OBPO7096. 1992 Annual Report to the Bonneville Power Administration, Portland, Oregon.

Parker, RM., M.P. Zimmerman, and D.L. Ward. 1995. Variability in biological characteristics of northern squawfish in the lower Columbia and Snake rivers. Transactions of the American Fisheries Society 124:335-346.

Petersen, J.H., D.B. Jepsen, R.D. Nelle, RS. Shively, R.A. Tabor, and T.P. Poe. 1991. Systemwide significance of predation on juvenile salmonids in Columbia and Snake River reservoirs. U.S. Fish and Wildlife Service, Contract DE-AI79-9OBPO7096. 1990 Annual Report to the Bonneville Power Administration, Portland, Oregon.

Vigg, S., CC. Burley, D.L. Ward, C. Mallette, S. Smith, and M. Zimmerman. 1990. Development of a systemwide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Oregon Department of Fish and Wildlife, Contract DE-BI79-9OBPO7084. 1990 Annual Report to the Bonneville Power Administration, Portland, Oregon.

Ward D.L., J.H. Petersen, and J. J. Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and in the lower Snake River. Transactions of the American fisheries Society 124:321-334.

Ward D.L., M.P. Zimmerman, RM. Parker, and S.S. Smith. 1991. Development of a systemwide predator control program: indexing, fisheries evaluation, and harvesting technology development. Oregon Department of Fish and Wildlife, Contract number DE-BI79-9OBPO7084. 1991 Annual Report to the Bonneville Power Administration, Portland, Oregon.

Zimmerman, M.P., C. Knutsen, D.L. Ward, and K. Anderson. 1995. Development of a systemwide predator control program: indexing and fisheries evaluation. Oregon Department of Fish and Wildlife, Contract DE-AI79-9OBPO7084. 1993 Annual Report to the Bonneville Power Administration, Portland, Oregon.

APPENDIX A

Exploitation of Northern Squawfish by Reservoir and Fishey from 1991-95

Appendix Table A-l. Exploitation rates (%) of northern squawfish ≥250 mm for the sport-reward fishery from 1991-95.

Area or reservoir	1991	1992	1993	1994	1995
Dowmtream from:					
Bonneville Dam	7.9	11.5	6.1	13.7	16.2
Bonneville	13.4	4.1	2.1	2.2	3.5
TheDalles	6.1	6.3	7.0	9.8	15.0
John Day	4.3	3.5	2.4	3.2	0.0[a]
McNary	3.3	5.6	16.0	14.0	22.5
Ice Harbor	3.9	--[b]	--[b]	--[b]	--[b]
Lower Monumental	10.0	1.8	3.1	0.8	0.0[a]
LittleGoose	5.0	12.0	3.3	6.1	2.9
Lower Granite	16.8	14.7	12.6	8.7	6.4
Systemwide	8.3	9.4	6.8	10.9	13.5

[a] Northern squawfish harvested, but no tags recovered.
[b] No northern squawfish were tagged.

Appendix Table A-2. Exploitation rates (%) of northern squawfish ≥250 mm for the dam-angling fishery from 1991-95.

Area or reservoir	1991	1992	1993	1994	1995
Downstream from:					
Bonneville Dam	0.2	0.2	0.0[a]	0.1	0.2
Bonneville	1.8	2.8	2.2	3.7	0.0[a]
The Dalles	4.4	1.0	0.0[a]	0.0’	0.0[a]
John Day	9.0	10.9	8.1	2.6	0.0[a]
McNary	1.9	0.0[a]	0.5	0.0’	0.0[a]
Ice Harbor	13.6	--[b]	--[b]	--[b]	--[b]
Lower Monumental	17.0	6.0	0.0[a]	0.0[a]	4.6
Little Goose	13.4	6.1	3.3	3.1	2.8
Lower Granite	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]
Systemwide	3.0	2.7	1.3	1.1	0.3

[a] Northern squawfish harvested, but no tags recovered.
[b] No northern squawfish were tagged.

Appendix Table A-3. Dates for each sampling period in 1995.

Period	Dates	Period	Dates
1	before April 2	14	June 26 - July 2
2	Apr 3-Apr 9	15	July 3-July 9
3	April IO-April 16	16	July 10 -July 16
4	April 17-April23	17	July 17 - July 23
5	April 24-April 30	18	July 24 - July 30
6	May l-May 7	19	July31 -August6
7	May 8-May 14	20	August 7-August 13
8	May l5-May 21	21	August 14 - August 20
9	May 22-May 28	22	August 21-August 27
10	May 29-June 4	23	August 28 - September 3
11	June 5-June 11	24	September 4 - september 10
12	June 12 -June 18	25	September 11 - September 17
13	June 19 - June 25	26	September 18 - September 24

Appendix Table A-4. Exploitation of northern squawfish downstream from Bonneville Dam in 1995. T = number marked. M = number marked at large. Misc. = marked fish recaptured outside the program area or fisheries.

Time period	T	Recaptures Sport	Recaptures Dam	Recaptures Net	Recaptures Misc.	M	Exploitation Sport	Exploitation Dam	Exploitation Net
1				--					
2	81			--					
3	125			--		81			
4	326			--		206			
5				--		532			
6		3		--	1	532	0.0056		
7	50			1	-	528			0.0019
8		4		--	-	577	0.0069		
9	14	4		--	1	573	0.0070		
10				--		582			
11		7		--		582	0.0120		
12		9		--		575	0.0157		
13		7		--		566	0.0124		
14		7		--		559	0.0125		
15		8		--		552	0.0145		
16		6		--		544	0.0110		
17		10	1	--	1	538	0.0186	0.0019	
18		3		--		526	0.0057		
19		4		--	1	523	0.0076		
20				--		518	--		
21		3		--	- -	518	0.0058		
22		3		--		515	0.0058		
23		2		--		512	0.0039		
24		5		--		510	0.0098		
25				--		505			
26				--		505			
Total	5 %	85	1	1	4		0.1549	0.0019	0.0019
Adjusted for tag loss							0.1623	0.0020	0.0020

Appendix Table A-5. Exploitation of northern squawfish in Bonneville Reservoir in 1995. T = number marked. M = number marked at huge. Misc. = marked fish recaptured outside the program area or fisheries.

Time period	Recaptures					M	Exploitation		
	T	Sport	Dam	Net	Misc.'		Sport	Dam	Net
1								--	--
2	350				1			--	--
3						349		--	--
4						349		--	--
5				1		349		--	0.0029
6				5	--	348		--	0.0144
7				2	--	343		--	0.0058
8		1		2	2	341	0.0029	--	0.0059
9		2		2	1	336	0.0060	--	0.0060
10		2		1	--	331	0.0060	--	0.0030
11		1		2	--	328	0.0030	--	0.0061
12		2		1	--	325	0.0062	--	0.003 1
13		1		3	2	322	0.003 1	--	0.0093
14	–	--			2	316		--	--
15		--			1	314		--	--
16		--			4	313		--	--
17		1			3	309	0.0032	--	--
18					--	305		--	--
19					--	305		--	
20	–				--	305		--	--
21	–				--	305		--	--
22	–				--	305		--	--
23	–				--	305		--	--
24	–	1			--	305	0.0033	--	--
25						304		--	--
26						304		--	--
Total	350	11	0	19	16		0.0338	0.0000	0.0564
Mjusted for tag loss							0.0354	0.0000	0.0591

Appendix Table A-6. Exploitation of northern squawfish in The Dalles Reservoir in 1995. T = number marked. M = number marked at large. Misc. = marked fish recaptured outside the program area or fisheries.

T i i period	Recaptures						Exploitation		
	T	Sport	Dam	Net	Misc.	M	Sport	Dam	Net
1	8			--	--			--	--
2	34			--	--	8		--	--
3				--	--	42		--	--
4				--	--	42		--	--
5				--	--	42		--	--
6	56			--	--	42		--	--
7				--	--	98		--	--
8				--	--	98		--	--
9				--	--	98		--	--
10		2		1	--	98	0.0204	--	0.0102
11				--	--	95		--	--
12		1		--	--	95	0.0105	--	--
13		2		--	--	94	0.0213	--	--
14		1		--	--	92	0.0109	--	
15				--	1	91		--	--
16		3		--	1	90	0.0333	--	--
17		3		--	--	86	0.9349	--	--
18				--	--	83		--	
19				--	--	83		--	--
20	–			--	--	83		--	--
21				--	--	83	--	--	
22	–			--	--	83		--	--
23				--	--	83		--	--
24		1		--	--	83	0.0120	--	--
25				--	--	82		--	--
26				--	--	82		--	--
Total	98	13	0	1	2		0.1433	0.0000	0.0102
Adjusted for tag loss							0.1502	0.0000	0.0107

Appendix Table A-7. Exploitation of northern squawfish in John Day Reservoir in 1995. T = number marked. M = number marked at large. Misc. = marked fish recaptured outside the program area or fisheries.

Time Period	T	Recaptures			M	Exploitation	
		sport	Dam	Misc.		Sport	Dam
1	3	--		--		--	--
2	6	--		--	3	--	--
3	11	--		--	9	--	--
4	6	--		--	20	--	--
5		--		--	26	--	--
6	5	--		--	26	--	--
7	9	--		--	31	--	--
8	4	--		--	40	--	--
9		--		1	44	--	--
10		--		--	43	--	--
11		--		--	43	--	--
12		--		--	43	--	--
13		--		--	43	--	--
14				--	43	--	--
15	–	--		--	43	--	--
16		--		--	43	--	--
17		--		--	43	--	--
18		--		--	43	--	--
19		--		1	43	--	--
20		--		--	42	--	--
21		--		--	42	--	--
22		--		--	42	--	--
23		--		--	42	--	--
24				--	42	--	--
25				--	42	--	--
26				--	42	--	--
Total	44	0	0	2		0.0000	0.0000
Adjusted for tag loss						0.0000	0.0000

Appendix Table A-8. Exploitation of northern squawfish in McNary Reservoir in 1995. T = number marked. M = number marked at large. Misc. = marked fish recaptured outside the program area or fisheries.

Time Period	T	Recaptures			M	Exploitation	
		Sport	Dam	Misc.		Sport	Dam
1	2			--	--		
2				--	2		
3	20			--	2		
4				--	22		
5				--	22		
6		1		--	22	0.0455	
7				--	21		
8	6			--	21		
9	23			--	27		
10		1		--	50	0.0200	
11	174	1		--	49	0.0204	
12		3		--	222	0.0135	
13		5		--	219	0.0228	
14		5		--	214	0.0234	
15		3		--	209	0.0144	
16		4		1	206	0.0194	
17		1		--	201	0.0050	
18				--	200		
19				--	200		
20		1		--	200	0.0050	
21		3		--	199	0.0151	
22				--	1%		
23		1		--	1%	0.005 1	
24		1		--	195	0.005 1	
25				--	194		
26				--	194		
Total	225	30	0	1	--	0.2146	0.0000
Adjusted for tag loss						0.2249	0.0000

Appendix Table A-9. Exploitation of northern squawfish in Lower Monumental Reservoir in 1995. T = number marked. M = number marked at large. Misc. = marked fish recaptured outside the program area or fisheries.

Time Period	T	Recaptures			M	Exploitation	
		Sport	Dam	Misc.		snort	Dam
1		--	--	--		–	--
2	–	--	--	--			--
3	15	--	--	--		--	--
4		--	--	--	15	--	--
5		--	--	--	15	--	--
6		--	--	--	15	--	--
7		--	--	--	15	--	--
8		--	--	--	15	--	--
9	10	--	--		15	--	--
10		--	--	--	25	--	--
11		--	--	--	25	--	--
12		--	--	--	25	--	--
13		--	--	1	25	--	--
14		--	--	--	24	--	--
15		--	--	--	24	--	--
16		--	--	--	24	--	--
17		--	--	--	24	--	--
18		--	--	1	24	--	--
19		--	--	--	23	--	--
20			--	--	23	--	--
21			--	--	23	--	--
22			1	--	23	--	0.0435
23			--	--	22	--	--
24			--	--	22	--	--
25			--	--	22	--	--
26			--	--	22	--	--
Total	25	0	1	2	--	0.0000	0.0435
Adjusted for tag loss						0.0000	0.0456

Appendix Table A-10. Exploitation of northern squawfish in Little Goose Reservoir in 1995. T = number marked. M = number marked at large. Misc. = marked fish recaptured outside the program area or fisheries.

Time Period	T	Recaptures			M	Exploitation	
		Sport	Dam	Misc.		Sport	Dam
1		--	--				--
2		--	--				--
3	27	--	--				--
4		--	--		27		--
5		--	--	1	27		--
6		--	--		26		--
7		--	--		26		--
8		--	--		26		--
9		--	--		26		--
10	12	--	--		26		--
11		--	--		38		--
12		--	--		38		--
13		--	--		38		--
14		--	--		38		--
15		--	--		38		--
16		--	--		38		--
17		--	--		38		--
18		--	--		38		--
19		--	--	1	38		
20		--	--		37		
21		--	1		37		0.0270
22		--	--		36		
23		--	--		36		
24		1	--		36	0.0278	
25		--	--		35		
26		--	--		35		
Total	39	1	1	2		0.0278	0.0270
Adjusted fix tag loss						0.0291	0.0283

Appendix Table A-l 1. Exploitation of northern squawfish in Lower Granite Reservoir in 1995. T = number marked. M = number marked at large. Misc. = marked fish recaptured outside the program area or fisheries.

Time Period	T	Recaptures			M	Exploitation	
		Sport	Dam	Misc.		Sport	Dam
1		--				--	--
2		--				--	--
3	1	--					
4		--			1	--	--
5	49	--			1	--	--
6		1			50	0.0200	--
7		--			49	--	--
8		--			49	--	--
9		--			49	--	--
10		--			49	--	--
11		--			49	--	--
12		--			49	--	--
13		--			49	--	--
14		--			49	--	--
15		--			49	--	--
16		--			49	--	--
17		--			49	--	--
18		--			49	--	--
19		--			49	--	--
20		--			49	--	--
21		1	--		49	0.0204	--
22		1	--		48	0.0208	--
23					47	--	--
24					47	--	--
25					47	--	--
26					47	--	--
Total	50	3	0	0		0.0612	0.0000
Adjusted for tag loss						0.0642	0.0000

Appendii Table A-12. Exploitation of northern squawfish systemwide in 1995. T = number marked. M = number marked at large. Misc. = marked fish recaptured outside the program area or fisheries.

	Recaptures						Exploitation		
Tie period	T	Sport	Dam	Net	Misc.	M	Sport	Dam	Net
1	13				--			--	
2	471				--	13	–	--	
3	199				--	484	–	--	
4	332				--	683	–	--	
5	49			1	1	1015	–	--	0.0010
6	61	6		5	--	1062	0.0056	--	0.0047
7	59			3	--	1112	–	--	0.0027
8	10	6		2	1	1168	0.0051	--	0.0017
9	47	9		2	--	1169	0.0077	--	0.0017
10	12	5		2	--	1205	0.0041	--	0.0017
11	174	9		2	--	1210	0.0074	--	0.0017
12		15		1	--	1373	0.0109	--	0.0007
13		18		3	--	1357	0.0133	--	0.0022
14		15			--	1336	0.0112	--	
15		13			--	1321	0.0098	--	
16		17			2	1308	0.0130	--	
17		18	1		1	1289	0.0140	0.0008	
18		3			1	1269	0.0024	--	
19		6			1	1265	0.0047	--	
20	–	1			--	1258	0.0008	--	
21		7	1		--	1257	0.0056	0.0008	
22	–	4	1		--	1249	0.0032	0.0008	
23		3			--	1244	0.0024		
24		9			--	1241	0.0073	--	
25					--	1232		--	
26					--	1232	--	--	
Total	1427	164	3	21	7	--	0.1286	0.0024	0.0181
Adjusted for tag loss							0.1348	0.0025	0.0189

APPENDIX B

Density, Abundance, Consumption, and Predation Indices from 1990-95 for Sampling Locations in the Lower Columbii and Snake Rivers

Appendix Table B-l. Indices of northern squawfish density from 1990 through 1995 for sampling zones in the lower Cohunbia and Snake rivers. RKm = river kilometer. BRZ = boat restricted zone.

Location, zone	Density index					
	1990	1991	1992	1993	1994	1995
Below Bonneville Dam						
RKm 71-121			1.691		0.972	0.911
RKm 122-177			1.573		2.091	1.389
RKm 178-224			1.412		1.744	1.125
Tailrace	5.750	6.859	3.432	9.625	2.926	2.235
Tailrace BRZ	13.709	19.000	12.913	14.520	18.875	4.571
Bonneville Reservoir						
Forebay	5.711			2.229	2.371	2.354
Mid-reservoir	2.102			1.179	0.690	1.022
Tailrace	0.512			1.103	0.600	1.088
Tailrce BRZ	5.465			1.500	6.750	
The Dalles Reseroir						
Forebay	1.104			1.216	0.554	0.565
Tailrace	2.750			0.714	0.650	1.556
Tailrace BRZ	21.541			10.800	5.500	3.500 .
JohnDay Reservoir						
Forebay	0.715	0.656	1.252	0.634	0.692	0.267
Mid-reservoir	0.265	0.240	0.339	0.163	0.116	0.053
Tailrace	0.764	0.750	0.106	0.451	0.265	0.325
Tailrace BRZ	14.727	17.933	9.235	13.333	2.400	
Lower Monumental Res.						
Tailrace		1.524			0.331	0.105
Tailrace BRZ		16.312			1.200	3.875
Little Goose Reservoir						
Tailrace		1.625			0.484	0.063
Tailrace BRZ		28.294			6.418	10.250
Lower Granite Resevoir						
Upper-reseroir		1.855			0.541	0.225

Appendix Table B-2. Indices of northern squawfish abudance from 1990 through 1995 in the lower Columbia and Snake rivers. RKm = river kilometer. BRZ = boat restricted zone.

Location, zone	Abundance index					
	1990	1991	1992	1993	1994	1995
Below Bonneville Dam						
RKm 71-121			26.8		15.4	14.5
RKm 122-177			19.7		26.2	17.4
RKm 178-224			17.9		22.1	14.2
Tailrace	4.5	5.4	2.7	7.6	2.3	1.8
Tailrace BRZ	3.0	4.1	2.8	3.1	4.1	1.0
Bonneville Reservoir						
Forebay	5.5			2.1	2.3	2.3
Mid-reservoir	15.2			8.5	5.0	7.4
Tailrace	0.4			0.8	0.5	0.8
Tailrace BRZ	0.9			0.2	1.1	
The Dalles Reservoir						
Forebay	1.4			1.6	0.7	0.5
Tailrace	2.7			0.7	0.6	1.5
Tailrace BRZ	4.4			2.2	1.1	0.7
John Day Reservoir						
Forebay	1.4	1.3	2.5	1.2	1.4	0.5
Mid-reservoir	5.2	4.7	6.6	3.2	2.3	1.0
Tailrace	1.4	1.4	0.2	0.9	0.5	0.6
Tailrce BRZ	1.6	1.9	1.0	1.4	0.3	
Lower Monumental Res.						
Tailrace		1.3			0.3	0.1
Tailrace BRZ		0.8			0.1	0.2
Little Goose Reservoir						
Tailrace		0.7			0.2	<0.1
Tailrace BRZ		1.7			0.4	0.6
Lower Granite Reservoir						
upper-reservoir		1.6			0.5	0.2

Appendix Table B-3. Indices of northern squawfish consumption ofjuvenile salmonids from 1990 through 1995 during spring in the lower Columbia and Snake rivers. RKm = river kilometer. BRZ = boat restricted zone.

Location, zone	Consumption index					
	1990	1991	1992	1993	1994	1995
Below Bonneville Dam						
RKm 71-121			0.5		0.5	0.5
RKm 122-177			1.0		1.1	0.2
RKm 178-224			1.1		1.5	0.7
Tailrace	1.2		0.5	0.8	3.2	0.8
Tailrace BRZ	2.7		1.0	1.1	0.6	1.7
Bonneville Reservoir						
Forebay	0.6			0.7	0.2	0.3
Mid-reservoir	0.0			0.0	0.2	0.0
Tailrace	0.3			0.0	0.0	0.2
Taihce BRZ	2.3					
The Dalles Reservoir						
Forebay	0.8			0.1	0.1	0.0
Tailrace	0.7			0.0		
Tailrace BRZ	0.9			0.0		
John Day Reservoir						
Forebay	1.5	1.9	1.9	1.5	1.0	1.7
Mid-reservoir	0.0	0.5	0.0	0.0	0.0	0.0
Tailrace	1.5	0.9	0.0	2.0	0.3	0.8
Taihce BRZ	2.5	1.5	0.9		0.7	
Lower Monumental Res.						
Tailrace		0.6			0.7	0.0
Taihrace BRZ		0.7				1.3
Little Goose Reservoir						
Tailrace		0.7			1.9	1.4
Tailrace BRZ		1.2			1.5	1.6
Lower Granite Reservoir						
uppe resevoir		0.3			0.6	1.2

Appendix Table B-4. Indices of northern squawfish consumption of juvenile salmonids from 1990 through 1995 during summer in the lower Columbia and Snake rivers. RKm = river kilometer. BRZ = boat restricted zone.

Location, zone	Consumption index					
	1990	1991	1992	1993	1994	1995
Below Bonneville Dam						
RKm 71-121		--	0.3		1.8	1.5
RKm 122-177		--	1.3		1.5	0.4
RKm 178-224		--	1.9		0.4	1.2
Tailrace	0.5	--	2.1	1.2	0.4	0.9
Tailrace BRZ	5.5	--	7.8	1.0	2.1	1.3
Bonneville Reservoir						
Forebay	1.8	--	--	0.5	0.3	0.0
Mid-reservoir	0.0	--	--	0.0	0.0	0.0
Tailrace	0.0	--	--	0.0	0.0	0.8
Tailrace BRZ	0.8	--	--	1.0	3.2	
The Dalles Reservoir						
Forebay	1.0		--	0.0	0.0	0.0
Tailrace	0.0	- -	--	0.0	0.8	0.0
TailraceBRZ	6.4		--	0.5	1.2	2.2
John Day Reservoir						
Forebay	2.4	3.1	0.7	0.6	1.2	2.0
Mid-reservoir	0.9	0.0	.o.o	0.6	0.6	0.0
Tailrace	2.6	0.0	0.0	0.0	0.0	0.6
Tailrace BRZ	11.7	2.8	4.6	0.6	1.9	

Appendix Table B-5 Indices of northern squawfish predation of juvenile salmonids from 1990 through 1995 during spring in the lower Columbia and Snake rivers. RKm= river kilometer. BRZ = boat restricted zone.

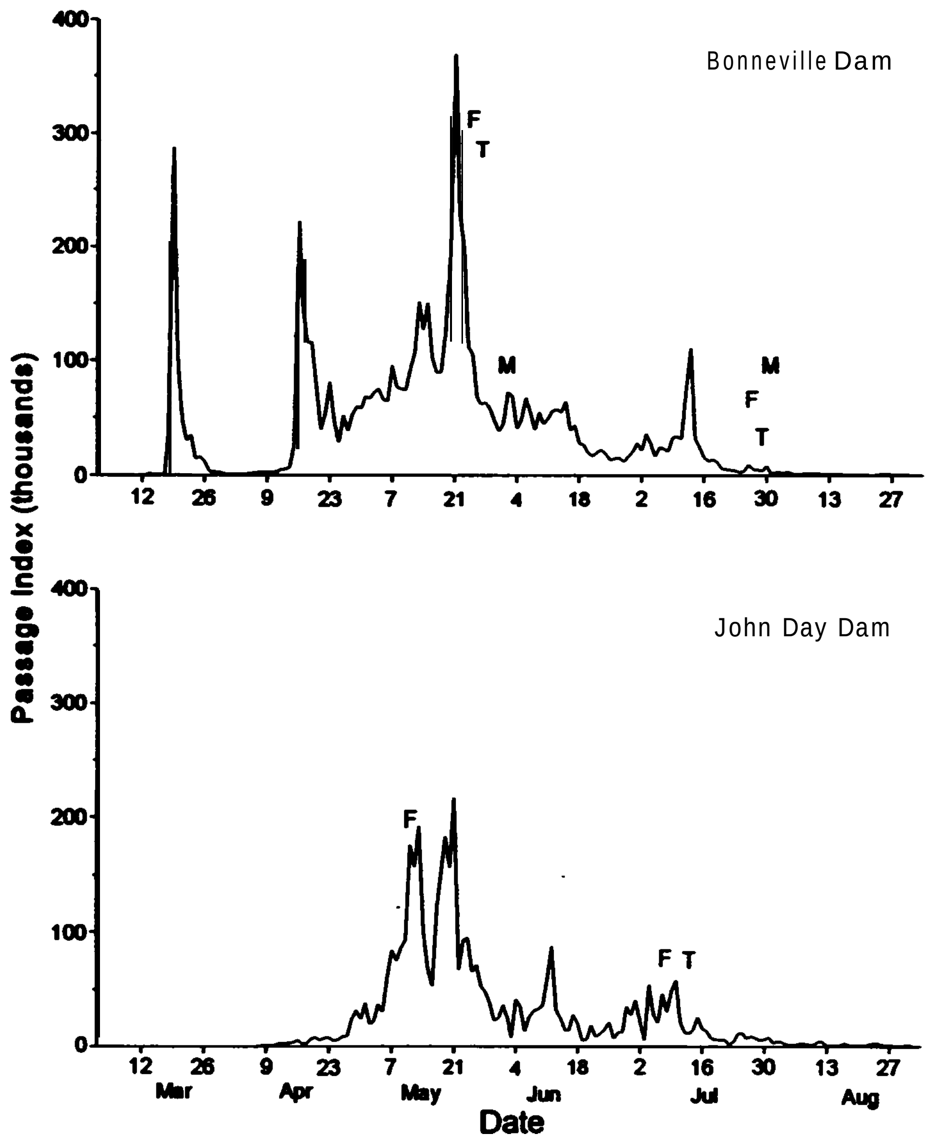
Location, zone	Predation index					
	1990	1991	1992	1993	1994	1995
Below Bonneville Dam						
RKm 71-121			14.0		8.0	7.3
RKm 122-177			20.0		29.7	3.5
RKm 178-224			20.2		33.3	9.9
Tailrace	5.5		1.4	6.1	7.4	1.4
TailraceBRZ	8.0		2.8	3.5	2.5	1.7
Bonneville Reservoir						
Forebay	3.3			1.5	0.3	0.7
Mid-reservoir	0.0			0.0	1.0	0.0
Tailrace	0.1	--		0.0	0.0	0.2
TailraceBRZ	2.0					
The Dalles Reservoir						
Forebay	1.1			0.2	0.1	0.0
Tailrace	1.9			0.0		
TailraceBRZ	3.9			0.0		
John Day Reservoir						
Forebay	2.1	2.4	4.7	1.9	1.3	0.9
Mid-reservoir	0.0	2.4	0.0	0.0	0.0	0.0
Tailrace	1.9	1.3	0.0	1.7	0.2	0.5
TailraceBRZ	3.9	2.9	0.9		0.2	
Lower Monumental Res.						
Tailrace		0.8			0.2	0.0
TailraceBRZ		0.6				0.3
Little Goose Reservoir						
Tailrace		0.5			0.4	<0.1
Tailrace BRZ		2.0			0.6	1.0
Lower Granite Reservoir						
upper-resewoir		0.5			0.3	0.2

Appendix Table B-6. Indices of northern squaw&h predation of juvenile salmonids from 1990 through 1995 during summer in the lower Columbia and Snake rivers. RKm = river kilometer. BRZ = boat restricted zone.

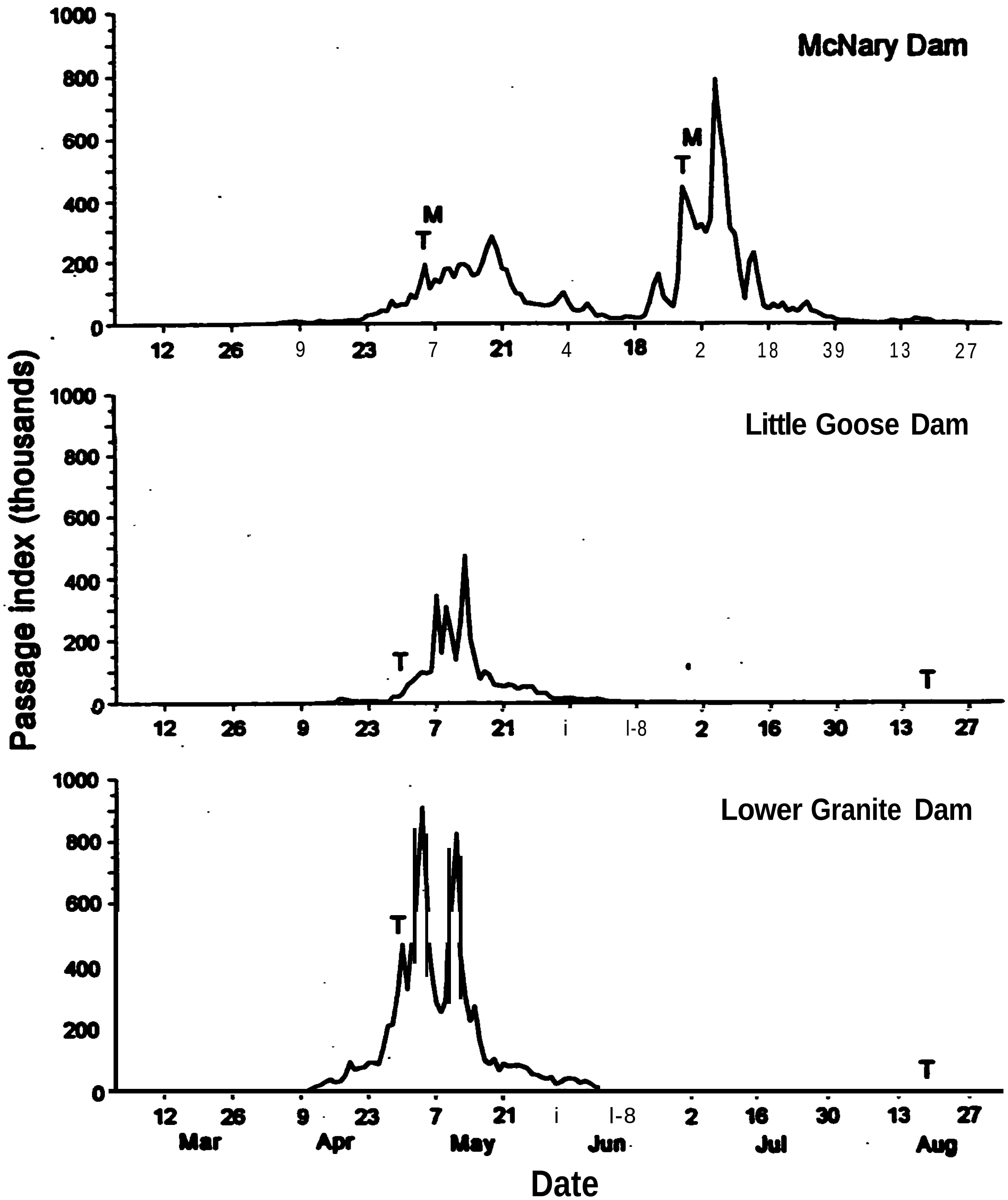
Location, zone	Density index					
	1990	1991	1992	1993	1994	1995
Below Bonneville Dam						
RKm 71-121		--	8.3		27.3	14.5
RKm 122-177		--	26.1		39.6	7.0
RKm 178-224		--	33.9		9.5	17.0
Tailrace	2.3	--	5.7	9.1	1.0	1.6
Tailrace BRZ	16.4	--	21.8	3.2	1.3	1.3
Bonneville Reservoir						
Forebay	9.9	--	--	1.1	0.6	0.0
Mid-reservoir	0.0	--	--	0.0	0.0	0.0
Tailrace	0.0	--	--	0.0	0.0	0.6
Tailrace BRZ	0.7	--	--	0.2	3.5	--
The Dalles Reservoir						
Forebay	1.4	--	--	0.0	0.0	0.0
Tailrace	0.0	--	--	0.0	0.5	0.0
Tailrace BRZ	27.8	--		1.1	1.4	1.5
John Day Reservoir						
Forebay	3.4	4.0	1.7	0.7	1.6	1.0
Mid-reservoir	4.7	--	0.0	1.9	1.4	0.0
Tailrace	3.8	--	0.0	0.0	0.0	0.4
TailraceBRZ	18.6	5.4	4.6	0.9	0.5	--

APPENDIX C

Timing of Consumption Index Sampling witb Passage Indices at Lower Columbia and Snake River Dams in 1995



Appendix Figure! C-l. Timing of consumption index sampling with respect to juvenile salmonid passage indices at Bonneville and John Day dams in 1995 Sample times for forebay (F), tailrace (T), and areas downstream from Bonneville Dam tailrace (M) are shown.



Appendix Figure C-2. Timing of consumption index sampling with respect to juvenile salmonid passage indices at McNary, Little Goose, and Lower Granite dams in 1995. Sample times for tailrace (T) and the mid-reservoir of John Day Reservoir (M) are shown.

APPENDIX D

Response of Smallmouth Bass to Sustained Removals of Nortbem Squawfish

Introduction

A large-scale management program for northern squawfish (Ptychocheilus oregonensis)began in l990 to increase survival ofjuvenile salmonids in the Columbia River Basin (Parker et al. 1995; Beamesderfer et al., in press). The program consists of both public and agency-operated fisheries that target northern squawfish exceeding 275 mm in fork length approximately the size at which northern squawfish become important predators on juvenile salmonids (Poe et al. 1991). The goal of the program is to sustain annual exploitation of "predator-sized" northern squawfish at lO-20%, which may reduce losses of juvenile salmonids by as much as 50% (Rieman and Beamesderfer 1990). Approximately 950,000 northern squawfish were removed by this program from 1990 through 1995. Estimates of annual exploitation in the lower Columbia and Snake rivers ranged from 8.5% to 15.6%.

Ahhough predation by native northern squawfish has been well documented throughout the lower Columbia River Basin (Rieman et al. 1991; Ward et al. 1995), other predators such as introduced smalhnouth bass *(Micropterus dolomieui) are also* present. Smalhnouth bass are distributed throughout the lower Columbia and Snake rivers, with densities highest in Snake River reservoirs (Zimmerman and Parker 1995). Smallmouth bass abundance ranged from under 40% of northern squawfish abundance in John Day Reservoir (Beamesderfer and Rieman 1991) to more than 100% of northern squawfish abundance in Lower Granite Reservoir (Curet 1993). Smalhnouth bass were responsible for only 7% of the total predation on juvenile salmonids in John Day Reservoir (Rieman et al. 1991). However, in some areas and times of year, smallmouth bass may be more important predators than northern squawfish (Tabor et al. 1993).

The effects of large-scale removals of northern squawfish on predation by smallmoutb bass are unknown and difficult to predict. Johnson (1977) and Hayes et al. (1 992) found that populations of yellow perch *(Perca flavscens) were enhanced* by intensive removals of white sucker (Catostomus commersoni), however, removals were far more intensive (80-85% of adult white suckers), and competition between yellow perch and white sucker was strongly indicated. Although diets of smallmouth bass and northern squawfish overlap (Poe et al. 1991), differences in distriiution between the two species may limit competition. Densities of smallmouth bass are generally greatest in forebays immediately upstream from dams and in midreservoir areas (Zimmerman and Parker 1995), whereas northern squawfish densities are generally greatest in tailraces immediately downstream from dams, and lowest in midreservoir areas (Ward et al. 1995).

Our objective was to describe the response of smalhnouth bass to sustained removals of northern squawlish. We examined smallmouth bass density, consumption ofjuvenile salmonids, population structure, and growth and mortality over a period of years coinciding with the Northern Squaw&h Management program. Information comparing smalhnouth bass populations before and after sustained removals of northern squawfish will help assess the effectiveness of the removal program in reducing predation on juvenile sahnonids.

Methods

Data Collection and Summary

We sampled from 1990 through 1995 to collect information on smalhnouth bass in the lower Columbia and Snake rivers. We sampled each year in the forebay (immediately upstream from the dam), midreservoir, and taihace (immediately downstream from the next dam) of John Day Reservoir, and in the taihace immediately downstream from Bonneville Dam. We sampled in the forebay, midreservoir, and tailrace of Bonneville Reservoir each year except 1992. We sampled the taihace of Lower Monumental and Little Goose reservoirs, and the upper reach of Lower Granite Reservoir in 1991,1994 and 1995. Fiiy, we sampled three reaches of the Columbia River downstream from Bonneville Dam tailrace in 1992,1994 and 1995. Each sampling reach was 6 km long, and was subdivided into 24 nearshore sampling sites of equal length. .

We used boat electrofishing, and sampled 4-8 boat-days in each reach between early April and mid-September to collect smallmouth bass. Sampling was stratified so that efforts in spring (April-June) and summer (July-September) were approximately equal to accommodate differences in water temperature and in species ofjuvenile sahnonids present (Ward et al. 1995). We sampled at least six randomly selected sites each boat-day between 3 am. and 11 am. Effort at each site consisted of a 15-minute electrofishing run with continuous output of approximately 4 A

We measured fork length (mm) and weight (g), and collected scales from all smallmouth bass captured. Stomach contents from smallmouth bass that were 200 mm fork length or longer were pumped with a modiied Seaburg stomach sampler (Seaburg 1957). All stomach samples were kept on ice and later frozen until subsequent laboratory analysis.

Jn the laboratory, stomach contents were thawed, and weighed to the nearest 0.01 g. To speed processing of samples, we first digested them with a solution of lukewarm tapwater, 2'% (wet weight) pancreatin (8x porcine digestive enzyme), and

1% (wet weight) sodium sulfide. The solution was poured into sample bags until contents were submersed, and the bags were sealed and contents mixed to ensure all food was in contact with the solution. Samples were placed in a desiccating oven at 40°C for 24 hours. Digested samples were poured through a 425-µm sieve and rinsed with tap water. Diagnostic bones of prey fish were examined under a dissecting microscope and identified to the lowest possible taxon (Hansel et al. 1988). We enumerated prey fish consumed by adding the number of paired diagnostic bones to remaining unpaired bones.

We used standard methods to determine ages of smallmouth bass from scales (Jearld 1983). Data were pooled so that for each reservoir and the Columbia River downstream from Bonneville Dam, fish were grouped by 25-mm fork length intervals, and scales from 20 individuals were selected randomly from each group to be aged.

Although we sampled all reaches in both spring and summer, data were often pooled to achieve adequate sample sizes or to simplify data analyses. We pooled catch and effort data to produce yearly estimates of density for each reach, however, differences in water temperatures between seasons precluded pooling of consumption data. Population structure data were pooled to produce yearly estimates for each reservoir and for the Columbia River downstream from Bonneville Dam. Growth and mortality data were pooled similarly, except that we obtained sufficient sample sizes only for Bonneville, John Day, and Lower Granite reservoirs, and for the Columbia River downstream from Bonneville Dam.

Density

We used catch per 15-minute electrofishing run (CPUE) as an index of smallmouth bass density for each reach. Beamesderfer and Rieman (1988) found that electrofishing captured the widest size range of smallmouth bass; Zimmerman and Parker (1995) concluded that electrofishing CPUE was a good indicator of smallmouth bass density. We calculated mean CPUE and 95% confidence intervals for eachreacheachyear.

Consumption *of Juvenile salmonids*

We developed an index to compare consumption ofjuvenile salmonids by smallmouth bass among years. Our consumption index was analogous to the consumption index for northern squawfish developed by Ward et al. (1995), which was highly correlated with direct estimates of consumption, and was easily obtained so that laboratory effort was minimized.

Beyer et al. (1988) calculated the days to 99% digestion ($T90_i$) for northern squafish as

$$T90_i = 47.792 \bullet M_i^{0.61} \bullet T^{-1.60} \bullet W^{-0.27};$$

where

M_i = meal size (g) at time of ingestion of sahnonid prey item i,
T = water temperature (°C), and
W = predator weight (g).

From this equation, Ward et al. (1995) determined that daily consumption rate (C) of juvenile salmonids by northern 4uawfish could be expressed as

$$C = 0.0209 \bullet T^{1.60} \bullet W^{0.27} \bullet \sum_{i=1}^{n} M_i^{-0.61}.$$

However, this requires measurement of meal size M,which is time consuming and difficult Ward et al. (1995) tested several potential indices by substituting some easily measured parameters for meal size, and found a consumption index (CI) that was highly correlated with direct estimates of consumption:

$$CI =- 0.0209 . T^{1.60} \bullet W^{0.27} \bullet$$ [illegible]

where

S = mean number of sahnonids per sample of northern squawfish, and
GW = meantotalgutweight.

Rogers and Burley (1990) determined the $T90_i$ for smallmouth bass to be

$$T90_i = 24.542 \bullet M_i^{0.29} \bullet e^{-0.15T} \bullet W^{-0.23}.$$

Following the method of Ward et al. (1995), a potential index ofjuvenile salmonid consumption for smalhnouth bass would therefore be

$$CI = 0.0407 \bullet e^{0.15T} \bullet W^{0.23} \bullet (S \bullet GW^{-0.29}).$$

We tested how well ditfference in consumption indices related to differences in direct estimates of consumption rate. Consumption indices and consumption rates were both computed for reaches sampled in 1995, and the correlation between the index and the direct estimate was examined.

We used the simple meal turnover-time method of Tabor et al. (1993) -to estimate smalhnouth bass consumption rate ofjuvenile sahnonids in 1995:

$$C = (R \bullet P \bullet W) / SW;$$

where

R	=	daily ration (% body weight/day),
P	=	proportion of diet (by weight) that is sahnonid prey, and
SW	=	mean sahnonid prey weight (g) before digestion.

Daily ration (R) was estimated as

$$R = (M \bullet n) / (T90_i \bullet N);$$

where

M	=	average size of ingested meal (% body tight),
n	=	number of fish that contain food in the stomach and
N	=	total Mmber of fish examined.

An estimate of original meal weight of fishes was based on lengths of prey fishes. Identity and original fork lengths of prey fishes were determined from diagnostic bones (Hansel et al. 1988), then original weights were estimated from length-wtight regressions (Vigg et al. 1991). Original weights of other prey items were estimated by adjusting the observed non-fish weight with the same ratio used for fish weight.

We adjusted estimates of consumption rate for diel feeding periodicity. Vigg et al. (1991) found that smallmouth bass consumed 32% of their daily ration during the hours we sampled.

Population Structure

We used proportional stock density (PSD) to compare size structure of smallmouth bass population among years (PSD= 100 • number of fish of at least quality length/number of fish of at least stock length; Anderson 1980). Stock and quality sizes were defined as 180 mm and 280 mm total length, respectively (Anderson and Gutreuter 1983), where total length = 1.04 • fork length (Carlander 1977). We computed 95% confidence intervals for each PSD estimate (Gustafson 1988) and used chi-square analyses to compare PSD among years.

We used mean relative weight (Wr) to compare fish condition among years (Wr= 100 • weight/Ws; ws is the length-specific standard weight of smallmouth bass). The standard weight equation defined by Kolander et al. (1993) for smallmouth bass at least 150 mm total length is

$$\log_{10}(Ws) = -5.239 + 3.200 \bullet \log_{,,} (\text{total length}).$$

We computed 95% confidence intervals for each estimate of mean Wr.

Growth and Mortality

We used length-at-age data to compare growth rate among years and reservoirs. We plotted observed length at ages for each reservoir and visually inspected each plot for trends in growth over time.

To evaluate total instantaneous mortality and annual mortality rates, we developed catch curves for each reservoir (Richer 1975). We tested the descendii limb of the catch curves (estimates of total instantaneous mortality) for homogeneity of slopes among years.

Results

Density

Catch rate of smallmouth bass varied considerably among reaches and years (Appendix Figure D-l), with catch generally highest in John Day Reservoir and in the Snake River. Catch rate consistently increased over time at one of four reaches downstream from Bonneville Dam, however, we found no evidence of an increase in catch rate at any of the nine reaches upstream from Bonneville Dam. Catch rate consistently decreased at two of three reaches in the Snake River.

Consumption of juenile salmonids

Our proposed consumption index for smalhnouth bass,

$$CI = 0.0407 \cdot e^{0.15T} \cdot W^{0.23} \cdot (S \cdot GW^{-0.29}),$$

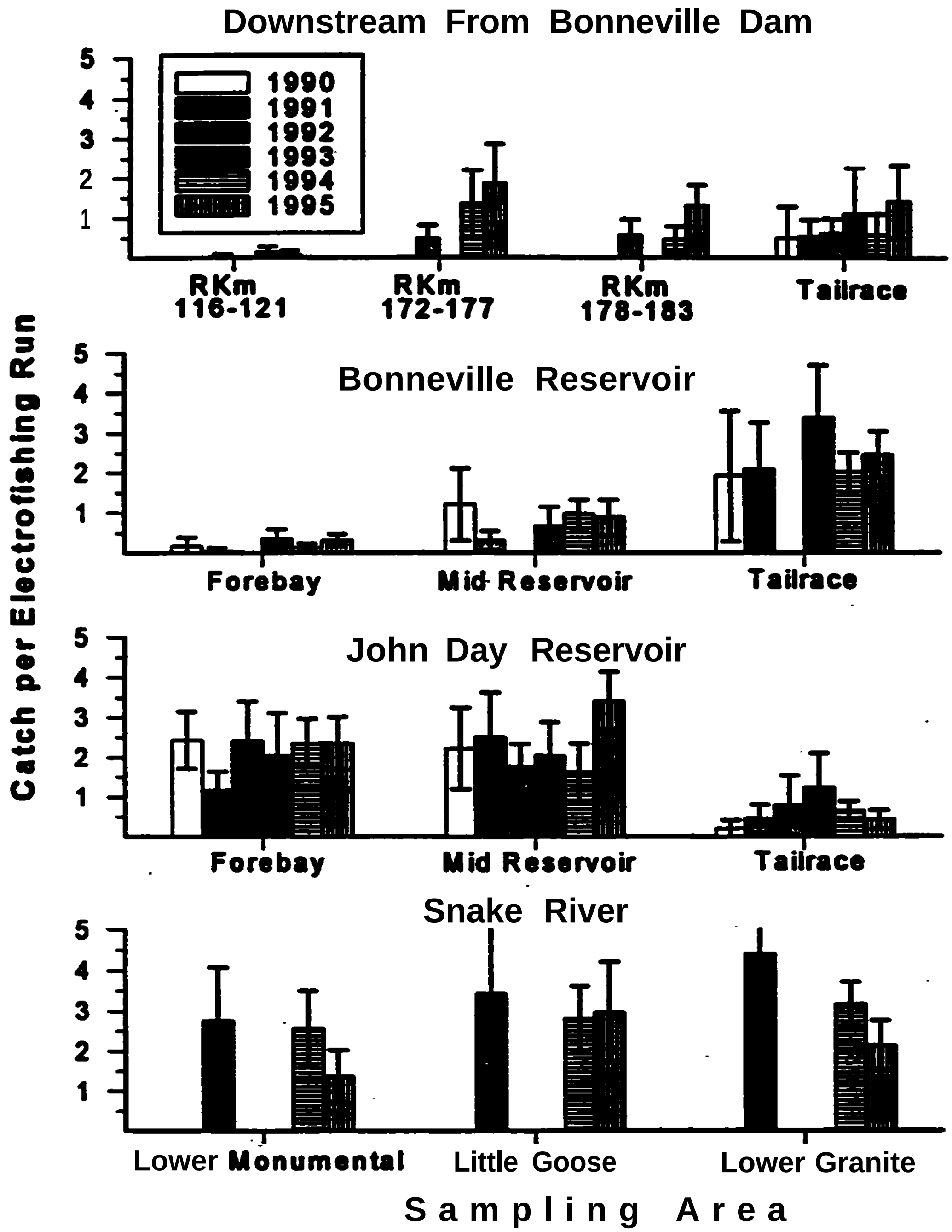
was highly correlated with the direct estimate of consumption (Appendix Figure D-2). We therefore used this index to evaluate consumption of juvenile salmonids by smallmouth bass.

Consumption of juvenile salmonids was highly variable among reaches and seasons, but was generally low (Appendix Tables D-l and D-2). Although consumption indices for spring were especially low, we found consistent evidence of predation on juvenile salmonids in Snake River reservoirs, and to a lesser extent in the forebay of John Day Reservoir. In summer, consumption was highest in the forebay of John Day Reservoir, and in the reach from RKm 178- 183, downstream from Bonneville Dam. We found no trend of increasing consumption by smallmouth bass over time.

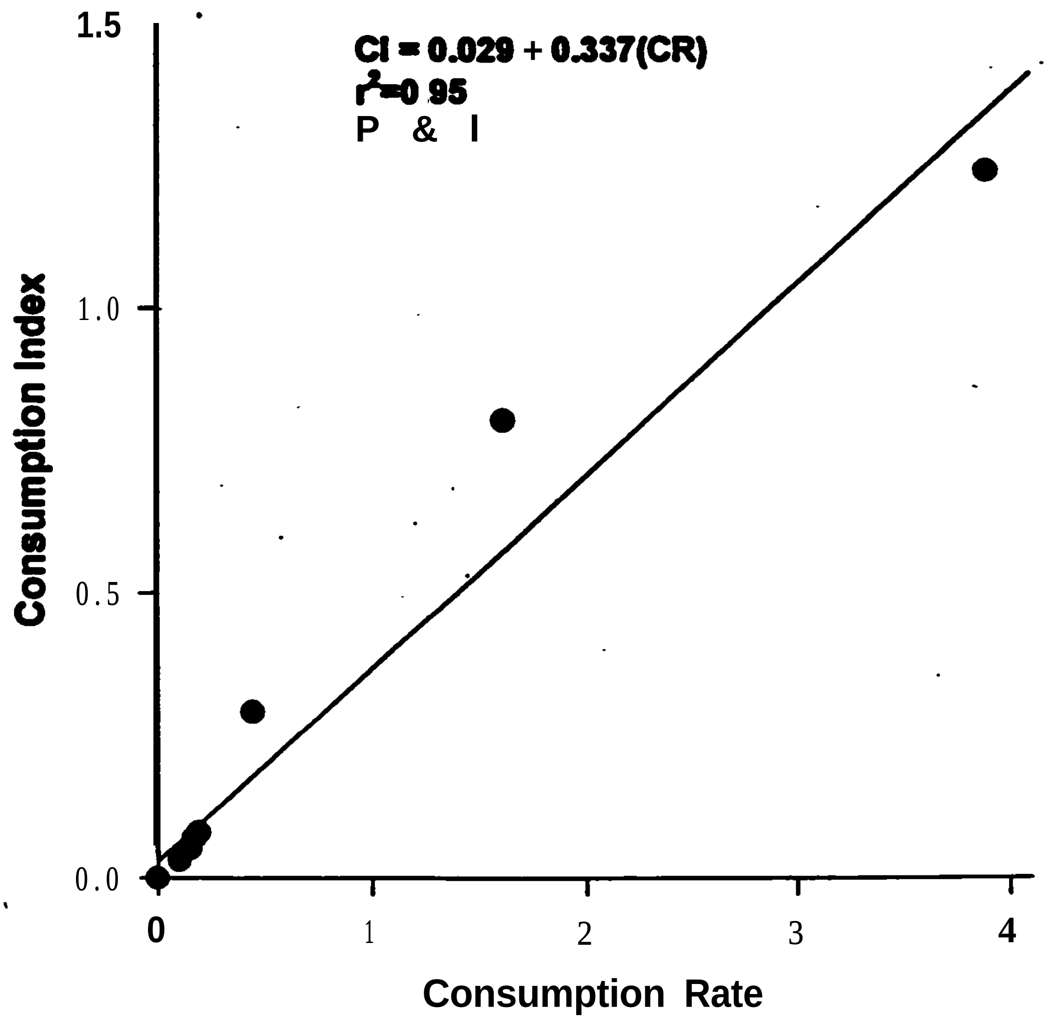
Population Structure

Proportional stock density of smallmouth bass varied considerably among *reservoirs and years (Appendix Figure D-3)*, **but was generally higher in the Columbia River than in the Snake River. In John Day Reservoir, PSD was relatively stable except for a one-year increase in 1991. Annual variation in PSD was generally grater in other resevoirs. We found no trend of increasing or decreasing PSD over time for any reservoir.**

Relative weight of smallmouth bass was also highly variable, but was generally higher in the Columbia River than in the Snake River (Appendix Figure D-4). Relative weight was usually highest in Bonneville Reservoir or in the Columbia River downstream from Bonneville Dam. We found no trend of increasing or decreasing relative weight over time for any reservoir.



Appendix Figure D-1. Relative density of smallmouth bass 200 mm fork length and larger in the lower Columbia and Snake rivers, 1990-95, as determined by catch per 15-minute electrofishing run. Vertical bars represent 95% confidence intervals.



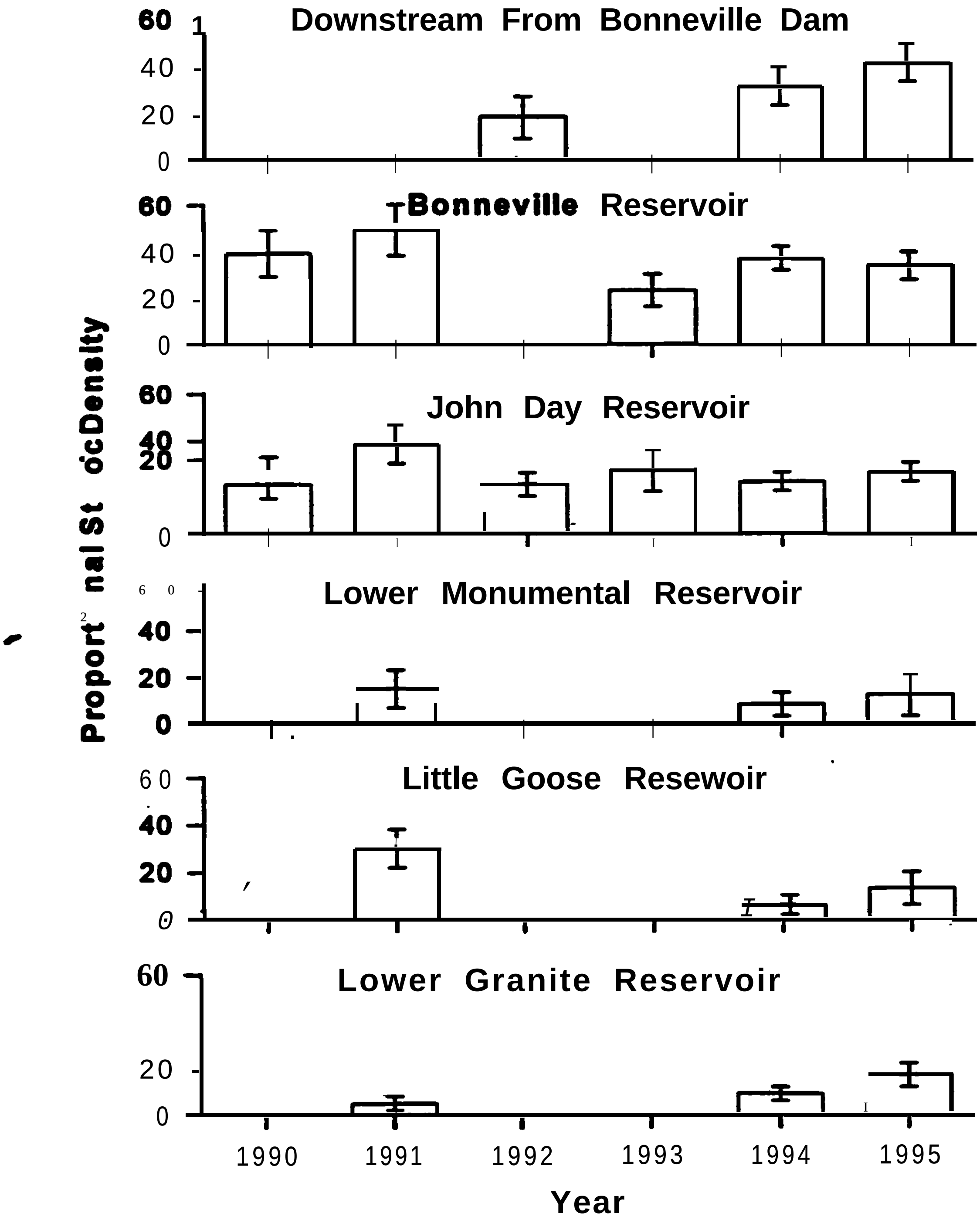
Appendix Figure D-2. Relationship bctween proposed consumption index for smallmouth **bass (CI) and direct estimate of consumption rate (CR); CR = number of juvenile** salmonids per smallmoutb bass per day.

Appendix Table D-l. Index of salmonid consumption by smallmouth bass in the lower Columbia and Snake rivers during spring, 1990-95. CI = consumption index, N = sample size.

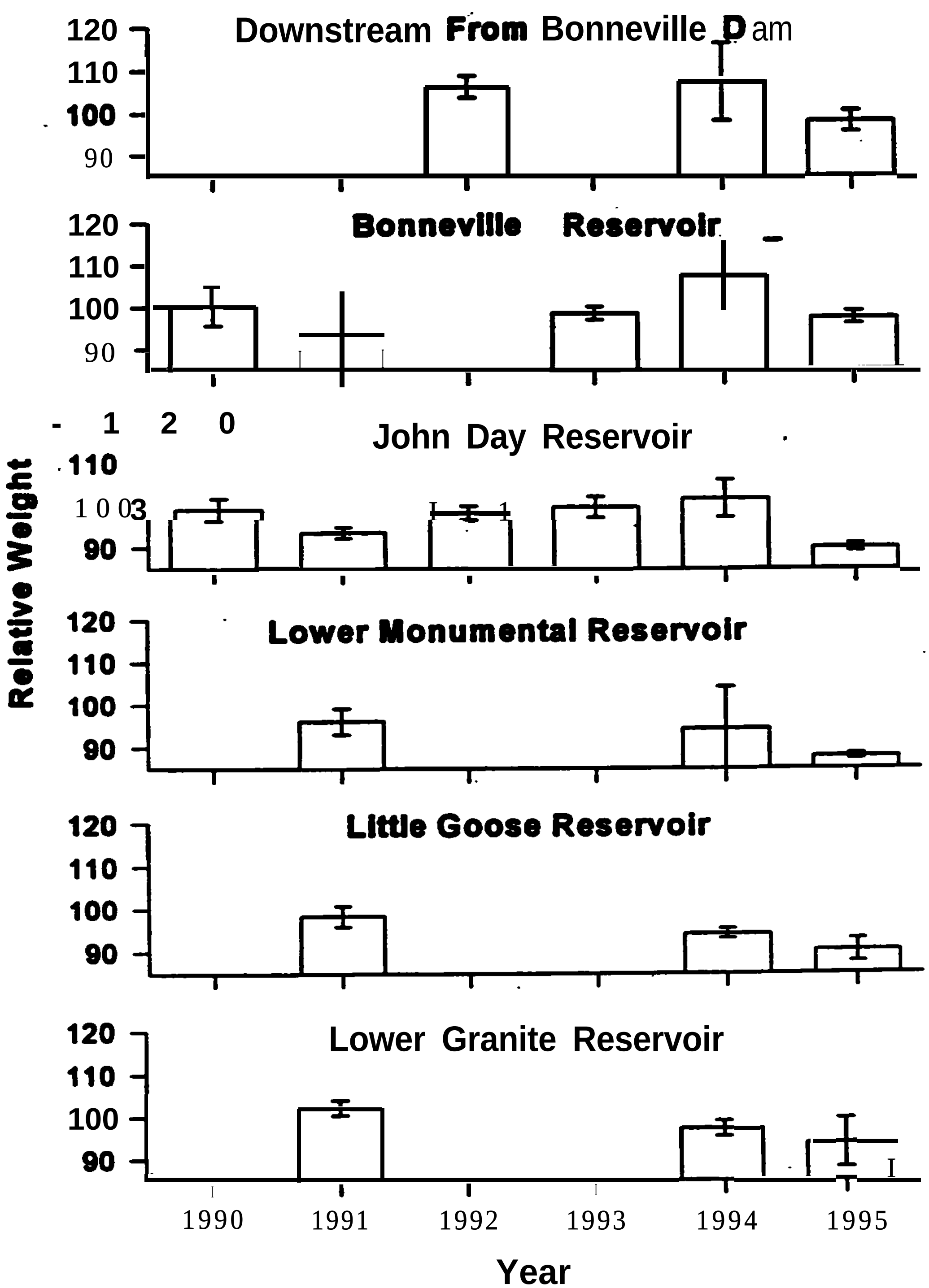
Reservoir, reach	1990		1991		1992		1993		1994		1995	
	CI	N	CI	N	CI	N	CI	N	CI	N	CI	N
Downstream from Bonneville Dam												
RKm 116121	–	–	–	–	0.0	1	–	–	0.0	0	0.0	2
RKm 172-177	–	–	–	–	0.1	12	–	–	0.0	23	0.1	47
RKm 178-183	–	–	–	–	0.0	5	–	–	0.3	10	0.0	33
Tailrace	0.5	5	–	–	0.0	4	0.0	4	0.0	7	0.0	26
Bonneville												
Forebay	0.0	0	-	–	–	–	0.0	2	0.0	5	0.1	12
Mid-reservoir	0.0	0	–	–	–	–	0.0	1	0.0	47	<0.1	3 0
Tailrace	0.0	10	–	–	–	–	0.0	21	0.0	58	0.0	99
John Day												
Forebay	0.1	6	0.0	41	0.1	39	0.0	37	0.1	75	0.0	76
Mid-reservoir	0.0	17	0.0	33	0.0	14	0.0	27	0.0	45	0.0	127
Tailrace	0.0	0	0.0	4	0.0	1	0.0	3	0.0	27	0.0	11
Lower Monumental												
Tailrace	–	–	0.0	74	–	–	–	–	0.1	23	0.0	25
LittleGoose												
Tailrace	–	–	<0.1	6 3	–	–	–	–	0.1	9	<0.1	7 8
Lower Granite												
upper reservoir	–	–	0.1	57	–	–	–	–	0.2	48	0.1	94

Appendix Table D-2. Index of salmonid consumption by smallmouth bass in the lower Columbia and Snake rivers during summer, 1990-95. CI = consumption index, N = sample size.

Reservoir, reach	1990		1991		1992		1993		1994		1995	
	CI	N	CI	N	CI	N	CI	N	CI	N	CI	N
Downstream from Bonneville Dam												
RKm 116-121	–	–	–	–	0.0	0	–	–	0.0	6	0.0	2
RKm 172-177	–	–	–	–	0.0	7	–	-	0.2	22	0.3	18
RKm 178-183	–	–	–	–	0.4	13	–	–	0.3	9	0.8	17
Tailrace	0.0	2	–	–	0.0	2	0.2	10	0.0	14	0.0	8
Bonneville												
Forebay	0.0	0	–	–	–	–	0.0	2	0.4	8	0.0	13
Mid-reservoir	0.0	3	–	a	–	–	0.0	14	0.0	32	0.0	9
Tailrace	0.0	3	–	–	–	–	0.0	36	0.1	77	<0.1	97
John Day												
Forebay	0.3	10	0.5	43	0.2	35	0.7	55	0.2	137	0.3	92
Mid-reservoir	0.3	13	0.0	40	0.0	4	0.1	65	0.0	35	0.0	182
Tailtace	0.0	10	0.1	13	0.0	6	0.0	23	0.0	19	0.0	22
LOWER Monumental												
Tailrace	–	–	–	–	–	–	–	–	–	–	0.0	34
LittleGoose												
Tailrace	–	–	–	–	–	–	–	–	–	–	0.0	38
Lower Granite												
Upper reservoir	–	–	–	–	–	–	–	–	–	–	0.0	81



Appendix Figure D-3. Proportional stock dcnsity of smallmouth bass in the lower Colmbia and Snake rivers, 1990%. Vertical bars represent 95% confidentce intervals.



Appendix Figure D-4 Relative weigh of smallmouth bass in the lower Columbia and Snake rivers, 1990-95. Vertical bars represent 95% confidence intenvals.

Growth and Mortality

observed fork lengths at ages varied more among reservoirs than among years within reservoirs (Appendix Figure D-5). Lengths at age were generally highest downstream from Bonneville Dam and in Bonneville Reservoir, and lowest in Lower Granite Reservoir. We found no evidence of faster growth over time.

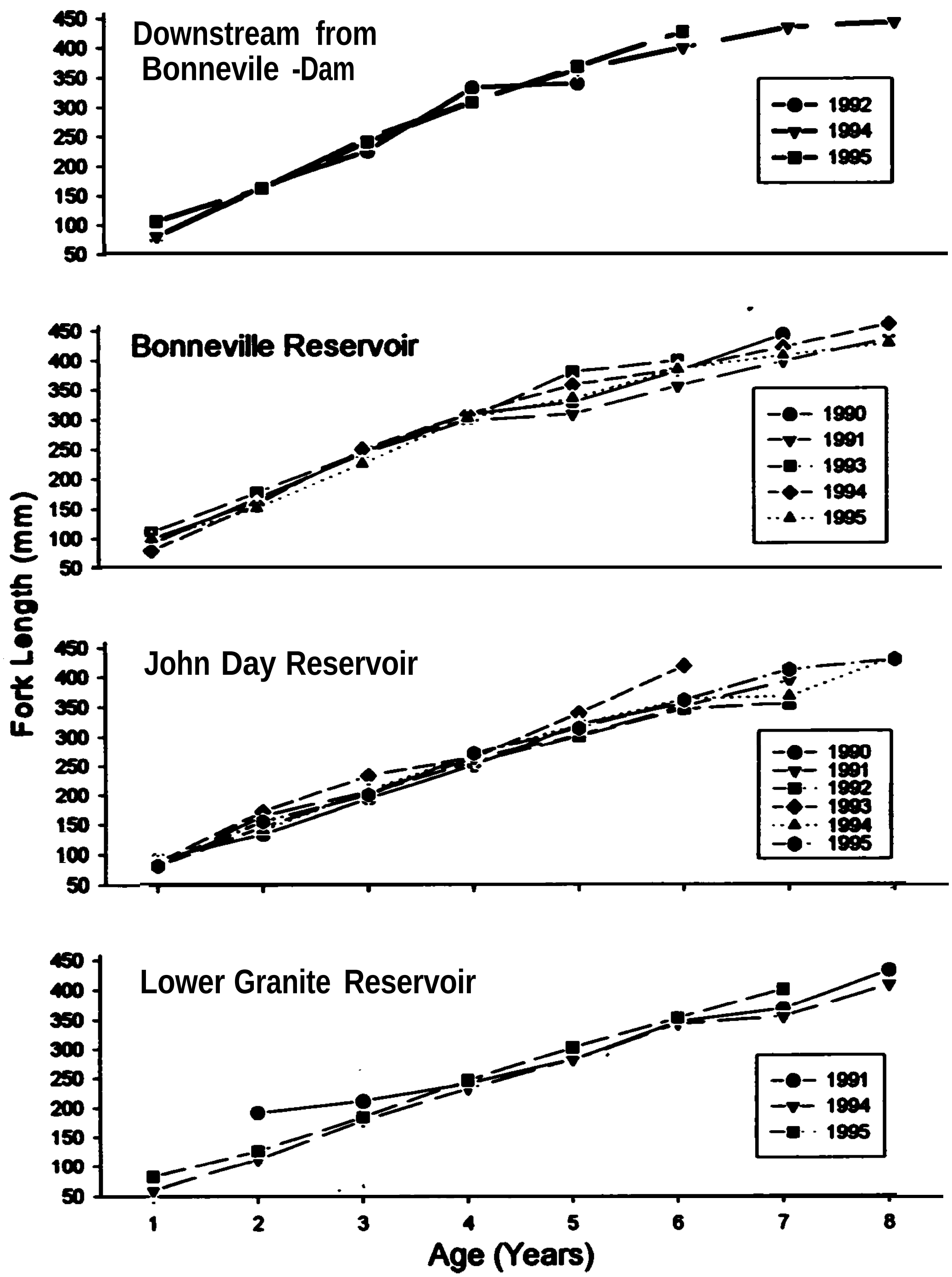
Estimates of annual mortality of smallmouth bass consistently exceeded 50% throughout the Columbia River basin (Appendix Table D-3). We found no evidence of decreased mortality over time. Differences among years in slopes of the descending limbs of catch curves (estimates of total instantaneous mortality) were not significant for the Columbia River downstream from Bonneville Dam (P=O,38), Bonneville Reservoir (P =0.85), John Day Reservoir (P =0.79), or Lower Granite Reservoir (P =0.93).

Discussion

We have found no evidence of any smallmouth bass response to sustained removals of northern squawfish No trends in smallmouth bass density, consumption ofjuvenile salmonids, population structure, or growth and mortality have been realized since implementation of the Northern Squawfish Management Program.

The first evidence of any response by smalhnouth bass would likely be changes in diet, which could then lead to changes in growth (Johnson 1977,Hayes et al. 1992). Data from John Day Reservoir (ODFW, unpublished data) indicate that the diet of smalhnouthbassremains similar to that prior to northern squawfish removals (Poe et al. 1991). Sculpins (Cottus spp.) remain the most common fish in the diet, and *crustaceans (pimarily crayfish Pasifisticus* spp.) remain the most common non-fish prey item.

of the population characteristics we examined, size structure may be the most likely to exhibit measurable change within the period studied. Small changes in growth, survival, and recruitment may all contribute to and, therefore, be more apparent as changes in size structure. After a single-year removal of 80% of a white sucker population, Hayes et al. (1992) reported small changes in size structure of yellow perch for three years, and a much larger change in the fourth year Although annual exploitation rates of northern squawfish were much lower, removals have been sustained for five years in most areas, with little evidence of changing size structure of smalhnouth bass. However, the highest levels of sustained exploitation have occurred downstream from Bonneville Dam and in Lower Granite Reservoir, the only two areas where smalhnouth bass PSD has increased Further research is needed to determine if these trends in PSD continue, or if they result from variations in year-class strength prior to sustained removals of northern squawfish.



Appendix Figure D-5. Observed fork length at age for smallmouth bass downstream from Bonneville Dam, and in Bonneville, John Day, and Lower Granite reservoirs.

Appendix Table D-3. Estimates of annual mortality (%) for smallmouth bass in the Lower Columbia and Snake rivers. Estimates are for ages 3-6 unless otherwise noted.

Reservoir	Year					
	1990	1991	1992	1993	1994	1995
Downstream from Bonneville Dam	–		62'		63	57
Bonneville	69	57		62	62[a]	69
John Day	64	55[b]	57[a]	60[a]	68	58
Lower Granite	–	57[a]			72	58

[a] Ages 3-5.
[b] Ages 4-6.

E&&mess of the Northern Squawfish Management Program relies partially on the response of other predators to sustained removals of northern squawfish. Smallmouth bass are the most abudant and widespread predator other than northern squawfish in the lower Columbii and Snake rivers, and theretfore have the highest potential for reducing benefits of the management program. The lack of response to date by smalhnouth bass increse confidence in the hypothesis that sustained removals of northern squawfish increases survival ofjuvenile salmonids.

References

Anderson, RO. 1980. Proportional stock density (PSD) and relative weight (W,): interpretive indices for fish populations and communlties. Pages 27-33 in S. Gloss and B. Shupp, editors. Practical fisheries management: more with less in the 1980%. American Fisheries society, New York Chapter, Ithaca, New York.

Anderson, RO., and S.J. Gumuter 1983. Length, weight, and associated structural i&ices. Pages 283-300 in L.A Nielsen and D.L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Beamesdefer, RC., and B.E. Rieman. 1988. Sii selectivity and bias in estimates of population statistics of smalhnouth bass, walleye, and northern squafish in a Columbia River reservoir. North American Journal of Fisheries Management 8:505-5 10.

Beamesderfer, RC., and B.E. Rieman. 1991. Abundance and distribution of northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Tmnsactions of the American Fisheries Society 120:439-447.

Beamesderfer, RCP., D.L. Ward, and AA Nigro. In press. A unique predator control program on northern squawfish in the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences.

Beyer, J.M., M.G. Lucchetti, and G. Gray. 1988. Digestive tract evacuation in northern squawfish (*Ptychocheilus oregonensis)* Canadian Journal of Fisheries and Aquatic Sciences 45:548-553.

Carlander, K.D. 1977. Handbook of freshwater fishery biology, volume 2. Iowa State University Press, Ames.

Curet, T.S. 1993. Habitat use, food habits and the influence of predation on subyearling chinook salmon in Lower Granite and Little Goose Reservoirs, Washington. Master thesis, University of Idaho, Moscow.

Gustafson, K-A 1988. Approximating confidence intervals for indices of fish population size structure. North American Journal of Fisheries Management 8:139-141.

Hansel, H.C., SD. Duke, P.T. Lofy,, and G.A Gray. 1988. Use of diagnostic bones to identify and estimate original lengths of prey species. Tmnsactions of the American Fisheries Society 117:55-62.

Hayes, D-B., W. W. Taylor, and J.C. Schneider. 1992. Response of yellow perch and the benthic invertebrate community to a reduction in the abundance of white suckers. Transactions of the American Fisheries Society 121:36-53.

Jearld, W.E. 1983. Age determination. Pages 301-323 *in* L.A Nielsen and D.L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Johnson, F.H. 1977. Responses of walleye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavescens*) to removal of white sucker (*Catostomus commersoni*) from a Minnesota Lake, 1966. Journal of the Fisheries Research Board of Canada 34: 1633-1642.

Kolander, T.D., D.W. Willis, and B.R Murphy. 1993. Proposed revision of the standad weight (W,) equation for smalhnouth bass. North American Journal of Fisheries Management 13:398-400.

Neter, J., W. Wasserman and M.H. Kutner. 1985. Applied linear statistical models, 2nd edition. Irwin Press, Homewood, Illinois.

Parker, RM., M.P. Zimmerman, and D.L. Ward. 1995. Variability in biological characteristics of northern squawfish in the lower Columbia and Snake rivers. Transactions of the American Fisheries Society 124:335-346.

Poe, T.P., H.C. Hansel, S. Vigg, D.E. Palmer, and L.A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:405-420.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Rieman, B.E., and RC. Beamesderfer. 1990. Dynamics of a northern squawfish population and the potential to reduce predation on juvenile salmonids in a Columbia River reservoir. North American Journal of Fisheries Management 10:228-241.

Rieman, B.E., R. C. Beamesderfer, S. Vigg, and T.P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120448-458.

Rogers, J.B., and C.C. Burley. 1990. A sigmoid model to predict gastric evacuation rates of smallmouth bass *(Micropterus dolomieui)* fed juvenile salmon. Canadian Journal of Fisheries and Aquatic Sciences 48:933-937.

Seaburg, K.G. 1957. A stomach sampler for live fish. Progressive Fish Culturist 19: 137-139.

Tabor, RA, R.S. Shively, and T.P. Poe. 1993. Predation on juvenile sahnonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. North American Journal of Fisheries Management 13:83 l-838.

Vigg, S., T.P. Poe, L.A Prendergast, and H.C. Hansel. 1991. Rates of consumption ofjuvenile salmonids and alternative prey fish by northern squaw&h, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Ward, D.L., J. H. Petersen, and J.J. Loch. 1995. Index of predation on juvenile sahnonids by northern squawfish in the lower and middle Columbia River and in the lower Snake River. Transactions of the American Fisheries Society 124:321-334.

Zimmerman, M.P., and RM. Parker. 1995. Relative density and distribution of smallmouth bass, channel catish, and walleye in the lower Columbia and Snake rivers. Northwest Science 69: 19-28.

APPENDIX E

Digestive Tract Contents of Northern Squawfisb and Smallmouth Bass in 1995 and Comparison of Fish Diets between Northern Squawfisb and Smallmouth Bass in 1994-95

We examined digestive tract contents of 8 17 northern squawfish and 1,485 smallmouth bass collcted during standardized electrofishing in 1995 (Appendix Table E. 1). The systemwide occurrence of salmonids in digestive tracts was 15.3% for northern squawfish and 2.4% for smallmouth bass, which was nearly identical to results from 1993-94 (Knutsen et al. 1995). The occurrence of ingested juvenile sahnonids during spring was highest for northern squawfish caught in Little Goose Reservoir (90.8%) and smalhnouth bass caught in Lower Granite Reservoir (11.7%), whereas during summer it was highest for northern squawfish in Bonneville Reservoir (22.2%) and smallmouth bass downstream from Bonneville Dam tailrace (13.5%).

We pooled data from 1994 and 1995 to compare fish diets of northern squawfish and smalhnouth bass. To increase sample sizes, data from individual reservoirs were pooled to compare diets among three areas — downstream from Bonneville Dam, Columbia River reservoirs, and Snake River reservoirs. Salmonids comprised at least 80% of the fish in northern squawfish digestive tracts, and salmonids and sculpins together accounted for at least 94% of all northern squawfish prey in all areas (Appendix Table E-2). In contrast, salmonids comprised 24% of fish in smalhnouth bass digestive tracts in Snake River sampling sites, and 11% downstream from Bonneville Dam and in lower Columbia River reservoirs. Sculpins were the most common fish in smalhnouth bass digestive tracts. Fish other than salmonids and sculpins were far more prevalent in smalhnouth bass than northern squawfish and comprised over 40% of the fish eaten by smallmouth bass downstream from Bonneville Dam and in the Snake River. Excluding salmonids and sculpins, cyprinids were the most common fish in smallmouth bass digestive tracts in all areas. The increase in the percentage of centrarchids (including smallmouth bass) and catfish in smallmouth bass from below Bonneville Dam to the Snake River was consistent with the increase in relative abundance of smallmouth bass and catfish in the lower Columbia and Snake rivers (Zimmerman and Parker 1995).

Appendix Table E-l. Number of northern squawfish and smallmouth bass digestive tracts examined from the lower Columbia and Snake rivers in 1995 (N) and the percent of digestive tracts that contained food, fish, and juvenile salmonids. Sampling periods were spring (April 25 - June 1) and summer (June 27 - August 18).

Period:	Northern squawfish				smallmouth bass			
Resevoir or area	N	% Food	% Fish	% Sal.	N	% Food	% Fish	% Sal.
spring:								
Below Bonneville								
Dam tailrace 7	8	50.0	18.0	9.0	82	76.2	32.9	2.4
Bonneville Dam								
tailrace	42	45.2	31.0	31.0	26	61.5	23.1	0
Bonneville	136	54.4	10.3	5.2	141	62.4	27.7	1.4
TheDalles	22	31.8	4.6	4.6	101	41.6	15.8	1.0
John Day	21	52.4	28.6	28.6	214	53.3	12.2	0
Lower Monumental	7	57.1	57.1	2.9	25	28.0	8.0	0
Little Goose	65	96.9	90.8	90.8	78	52.6	21.8	1.3
Lower Granite	16	75.0	56.3	56.3	94	64.9	36.2	11.7
summer:								
Below Bonneville								
Dam tailrace 5	6	41.1	14.3	7.1	37	62.2	40.5	13.5
Bonneville Dam								
tailrce	27	44.4	29.6	22.2	8	87.5	62.5	0
Bonneville	182	39.6	1.7	1.7	119	73.1	26.1	0.8
TheDalles	84	19.1	4.8	3.6	111	82.9	17.1	0
John Day	30	26.7	13.3	10.0	296	71.0	16.9	4.1
Lower Monumental	28	25.0	0	0	34	50.0	20.6	0
Little Goose	19	36.8	10.5	5.3	38	76.3	7.9	0
Lower Granite	4	50.0	0	0	81	77.8	17.3	0

Appendix Table E-2. Sample size and percentage of salmonids, cottids, and other fish families in northern squawfish and smallmouth bass digestive tracts containing identifiable fish in three reaches of the lower Columbia and Snake rivers from 1994-95. Reaches are downstream from Bonneville Dam (DBD), lower Columbia River reservoirs (COL), and lower Snake River reservoirs(SNK).

sample size, family	Northern squawfish			Smallmouth bass		
	DBD	COL	SNK	DBD	COL	SNK
N (digestive tracts)	611	1,099	261	224	1,710	430
N (fish)	243	220	227	156	475	164
N (identifiable fish)	227	201	214	126	353	126
% Salmonidae	85.0	82.6	98.1	11.1	10.8	23.8
% cottidae	9.7	11.4	0	47.6	66.9	30.2
% other taxa	5.3	6.0	1.9	41.3	22.3	46.0
% cyplinidae	2.2	3.0	0.5	16.7	15.3	15.1
% catostomidae	0	5.5	0	15.8	1.7	8.7
% Ictaluridae	0	0	0	0	0.2	11.9
% Percopsidae	0.4	0.5	0	3.2	1.4	0
% Gastelosteidae	2.2	1.5	0	4.8	0.6	0
% Centrarchidae	0	0	1.4	0.8	1.7	10.3
% other	0.5	0.5	0	0	1.4	0

References

Knutsen, C.J., D.L. Ward, T.A Friesen, and M.P. Zimmerman. 1995. Development of a systemwide predator control program: Indexing and fisheries evaluation. Oregon Department of Fish and Wildlife, Contract DE-AI79-9OBPO7084. 1994 Annual Report to the Bonneville Power Administration, Portland, Oregon.

Zimmerman, M.P., and RM. Parker. 1995. Relative density and distribution of smallmouth bass, channel catfish, and walleye in the lower Columbia and Snake rivers. Northwest Science 69: 19-28.