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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 SQUAWFISH MANAGEMENT PROGRAM)

SECTION II: EVALUATION

1995 ANNUAL REPORT

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In Cooperation With

Columbia Basin Fish and Wildlife Authority
Columbia River Inter-Tribal Fish Commission
Confederated Tribes of the Umatilla Indian Reservation
Confederated Tribes of the Warm Springs Reservation
National Marine Fisheries Service
Nez Perce Tribe
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Pacific States Marine Fisheries Commission
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SECTION II. EVALUATION

Cooperators

Columbia Basin Fish and Wildlife Authority
Oregon Department of Fish and Wildlife
Pacific States Marine Fisheries Commission

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 northern 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 remaining 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 oregonensis*) abundance, consumption, and predation in the Columbia River impoundments (1990), 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 squawfish 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 **squawfish** 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 (I) compare exploitation rate, size composition, and incidental catch among northern squawfish fisheries, and estimate reductions in

predation on juvenile salmonids since implementation of the management program; and (2) evaluate changes through 1995 in relative 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 implemented by the Washington Department of Fish and Wildlife (WDFW) 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 (CRITFC), 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** fin 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 reservoirs. 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 10-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 originating 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 221-229**), Little Goose Reservoir tailrace, Lower Monumental Reservoir tailrace, John Day Reservoir, The Dalles Reservoir **forebay** and tailrace, Bonneville Reservoir, Bonneville Dam tailrace, 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 described 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 described 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 salmonids 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 standardized 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).

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

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 of juvenile 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 [$PSD = 100 \cdot (\text{number of fish at least quality length}) / (\text{number of fish at least stock length})$; 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 biased 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 (Beamesderfer 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 squawfish 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 relative fecundity (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 confidence 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; Appendix 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-angling 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 (Appendix Table A-1). **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-angling 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. The mean size of 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 (5-5) 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 |
| Little Goose | 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 |
|-------------------|-------------|-------------|-------------|-------------|-------------|
| Downstream from | | | | | |
| Bonneville Dam | 8.1 | 11.8 | 7.1 | 13.0 | 16.6 |
| Bonneville | 15.2 | 6.8 | 4.6 | 11.2 | 9.4 |
| The Dalles | 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 Monumental | 27.0 | 7.7 | 3.1 | 0.8 | 4.6 |
| Little Goose | 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 |

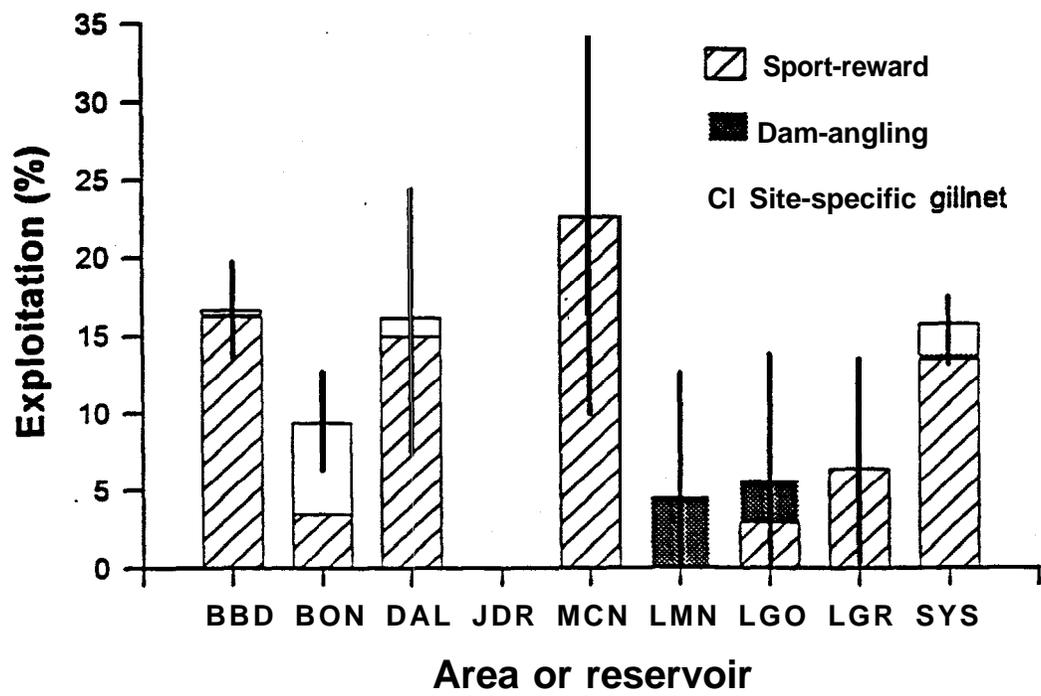


Figure 1. Exploitation rates of northern squawfish ≥ 250 mm by fishery during 1995. Vertical lines are 95% confidence intervals for total exploitation rates (all fisheries combined). Areas are downstream from Bonneville Dam (**BBD**), systemwide (**SYS**), and reservoirs are Bonneville (**BON**), The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

In 1995 the various fisheries 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-specific fishery. Northern squawfish <250 mm, other cyprinids, smallmouth bass (*Micropterus dolomieu*), catostomids, and white sturgeon (*Acipenser transmontanus*) were the most common incidentally caught fish. Salmonids 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%.

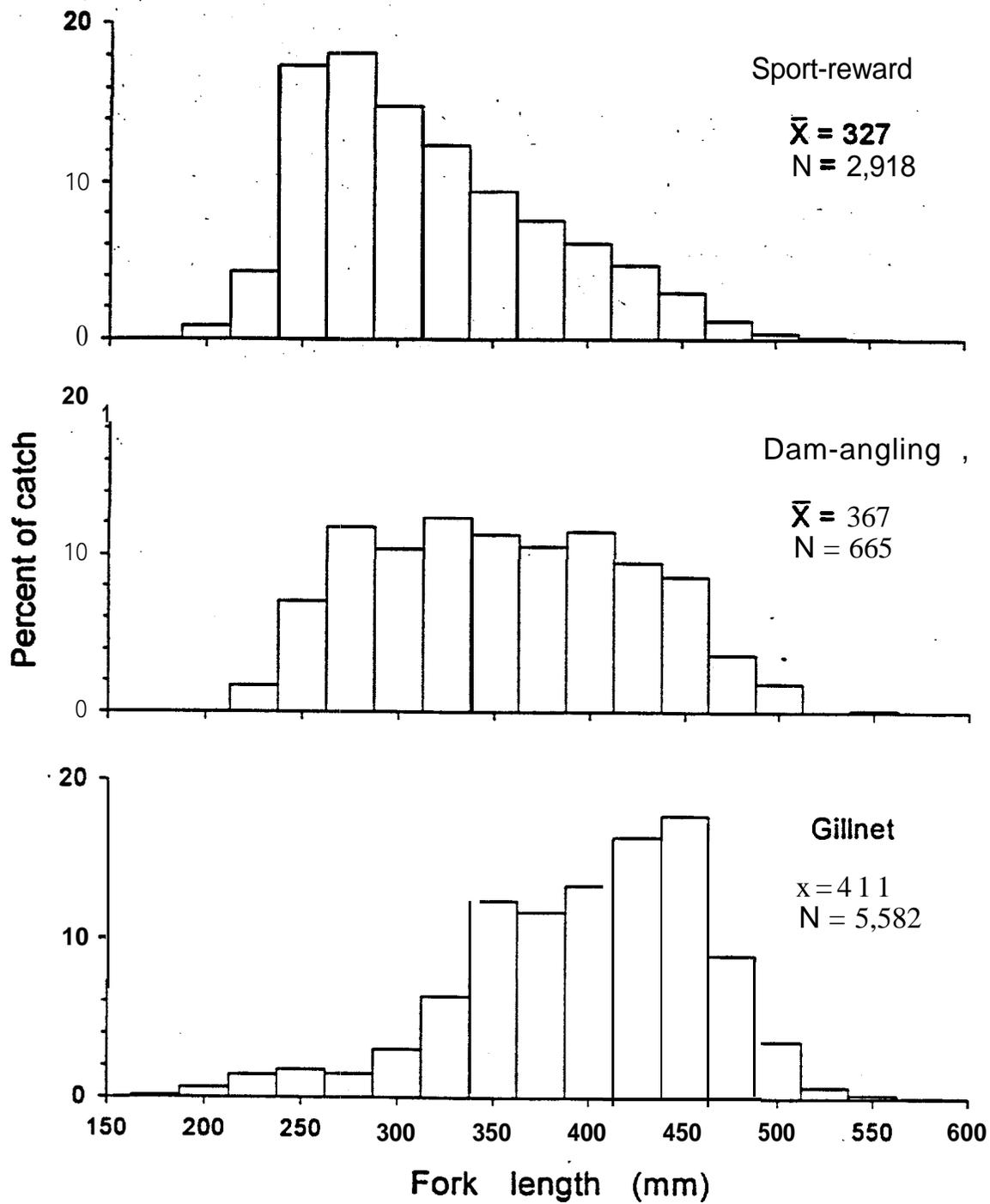


Figure 2. Size composition and mean fork length of northern squawfish in subsamples of fish harvested systemwide in sport-reward, dam-angling, and site-specific gill-net fisheries in 1995. N = subsample size.

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 rivers.

| 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 Reservoir | -- | 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 | a- | 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 Reservoir | -- | -- | -- | 371 | 411 | 416 |
| The Dalles Reservoir | -- | -- | -- | -- | 395 | 396 |
| John Day Reservoir | -- | -- | -- | -- | 366 | 370 |
| McNary Reservoir | -- | -- | -- | -- | 387 | 363 |
| Ice Harbor Reservoir | -- | -- | -- | -- | -- | 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 a 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 ^c | 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 Salmonids and non-game fish not identified to species.

^b Juvenile salmonids not identified to species.

^c White sturgeon = *Acipenser transmontanus*, channel catfish = *Ictalurus punctatus*, walleye = *Stizostedion vitreum vitreum*, 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% (35-48%) | 1998 | 41% (31-50%) | 2003 |
| Maximum potential predation reduction with mean 1991-95 exploitation levels continued | 38% (30-45%) | 1998 | 39% (31-46%) | 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- 1 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 downstream **from** Bonneville Dam than when the reach was previously sampled in 1992 and 1994 (Appendix Tables B-3 and B-4). Consumption indices in other areas were generally similar to 1994, with the exception of the spring 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 of juvenile 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**) of northern 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.

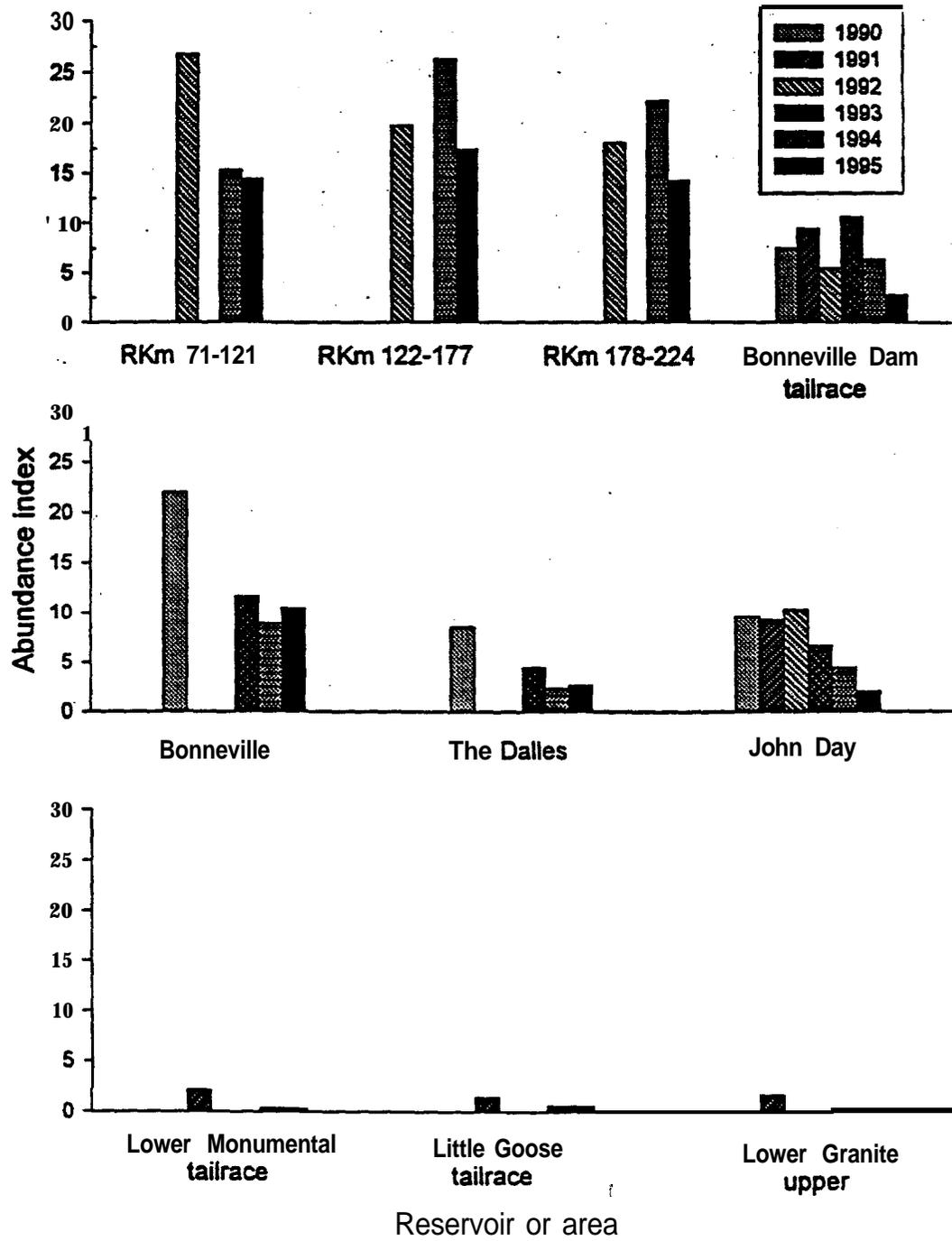


Figure 3. Index of northern squawfish abundance from 1990 through 1995 for sampling locations in the lower Columbia and Snake rivers.

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 **squawfish** collected downstream from Bonneville Dam in **1995** was similar to the previous three years, but differed **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 31.8% 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.

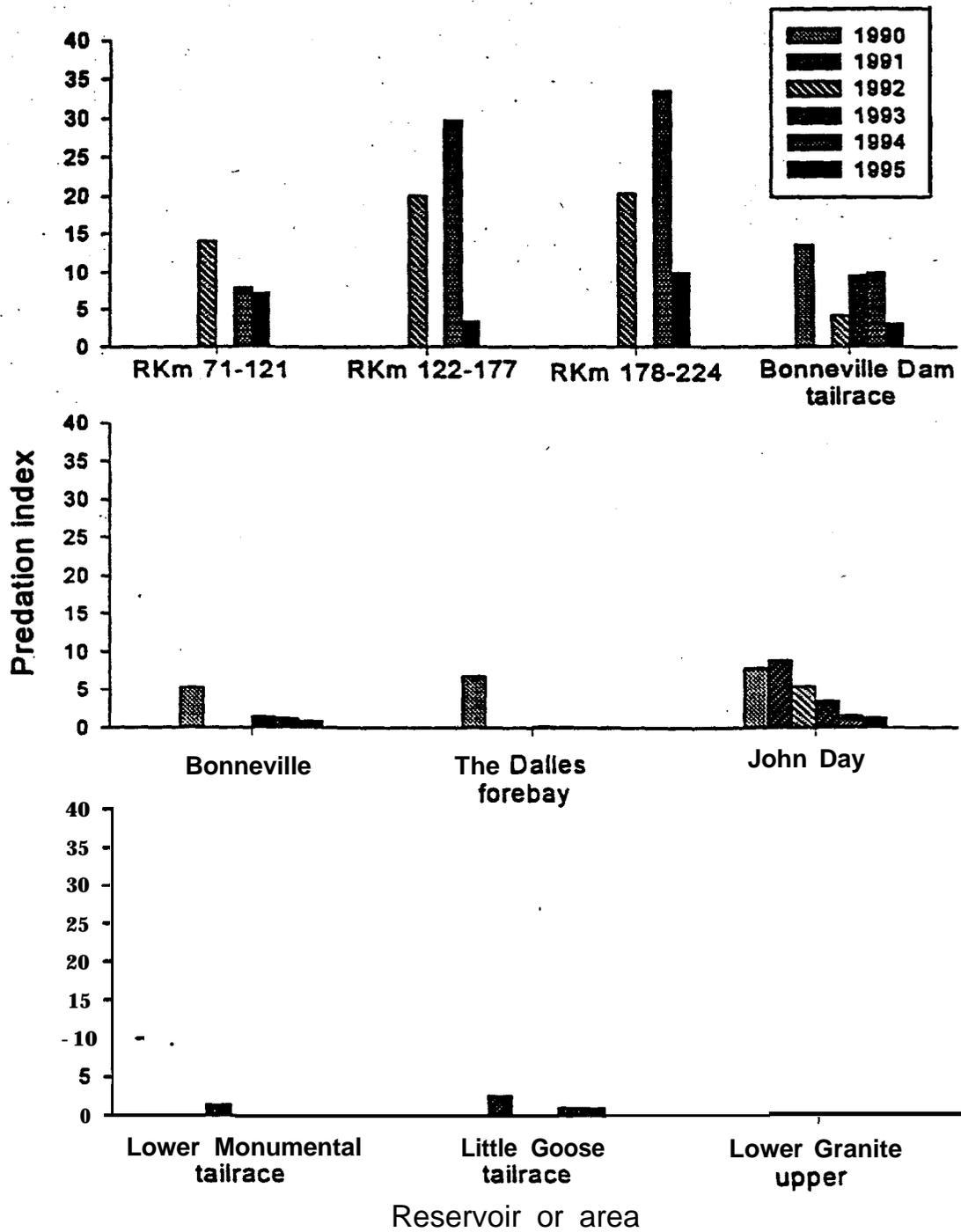


Figure 4. Index of predation by northern squawfish during spring from 1990 through 1995 for sampling locations in the lower Columbia and Snake rivers.

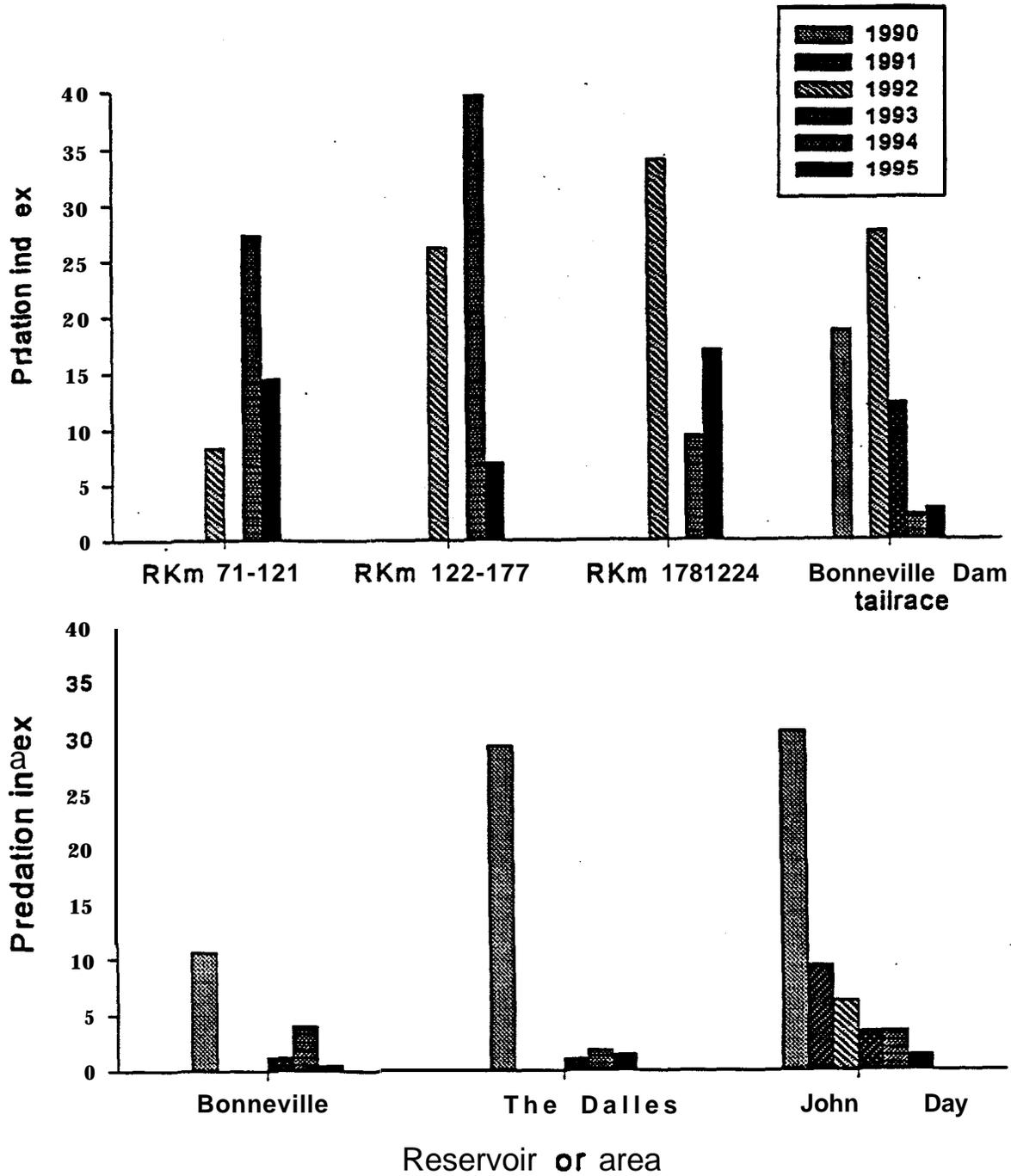


Figure 5. Index of predation by northern **squawfish** during summer from 1990 **through 1995** for sampling locations in the lower Columbia and Snake rivers. Predation indices for **The Dalles** Reservoir excludes the mid-reservoir.

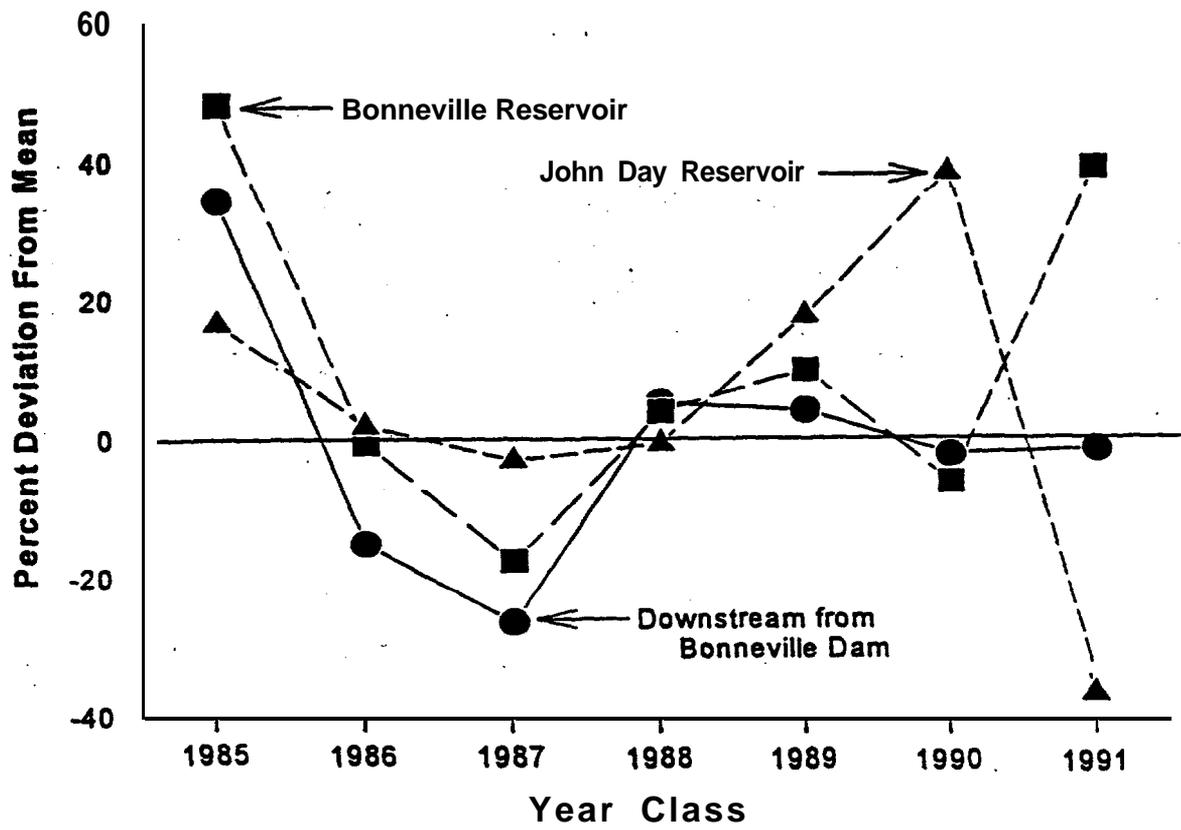


Figure 6. Index of relative year-class strength of northern squawfish in the Columbia River downstream from Bonneville Dam, Bonneville Reservoir, and John Day Reservoir.

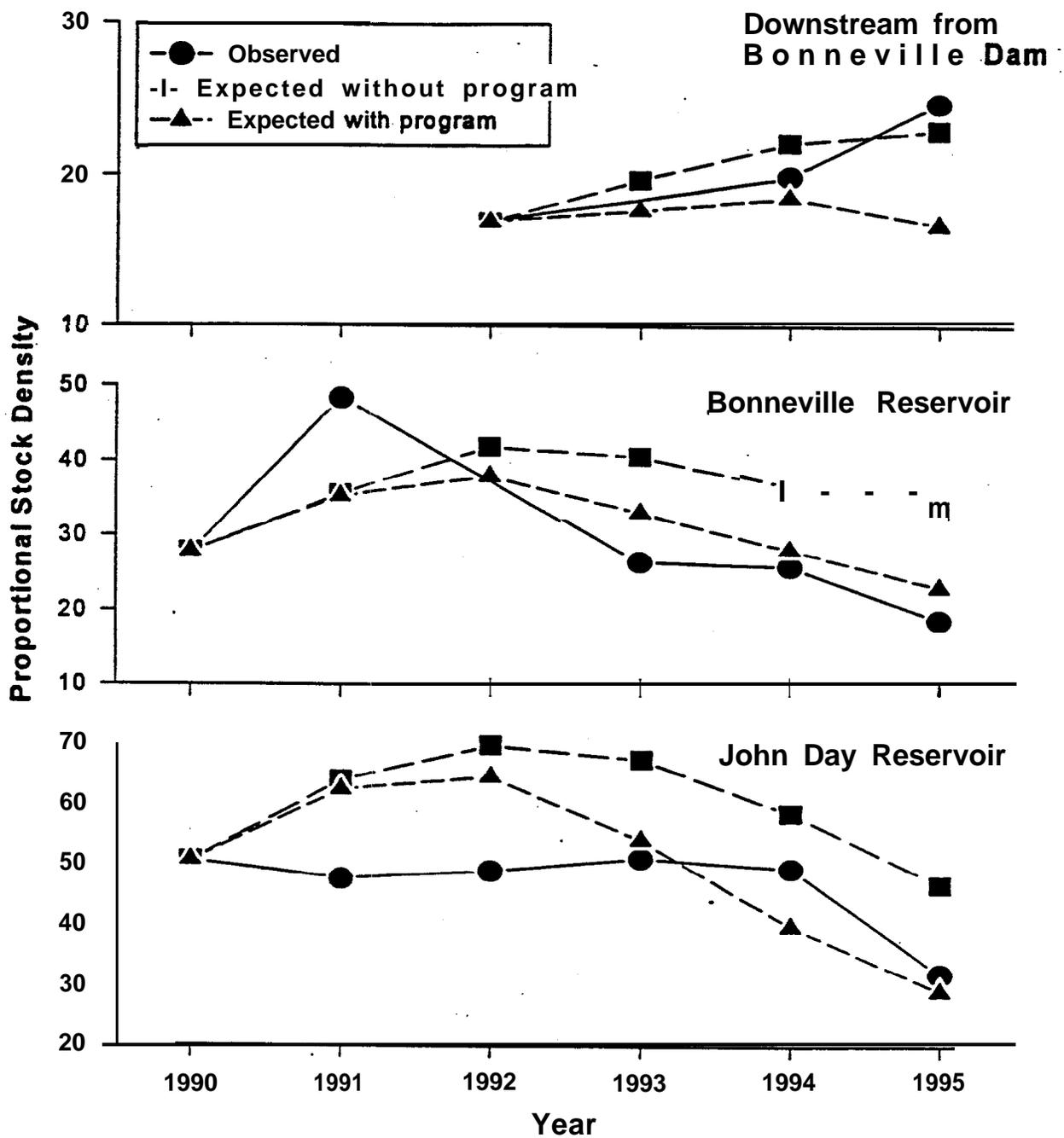


Figure 7. Observed and expected: proportional stock density with and without implementation of the Northern Squawfish Management Program from 1990 through 1995 in the Columbia River downstream from Bonneville Dam, Bonneville Reservoir, and John Day Reservoir.

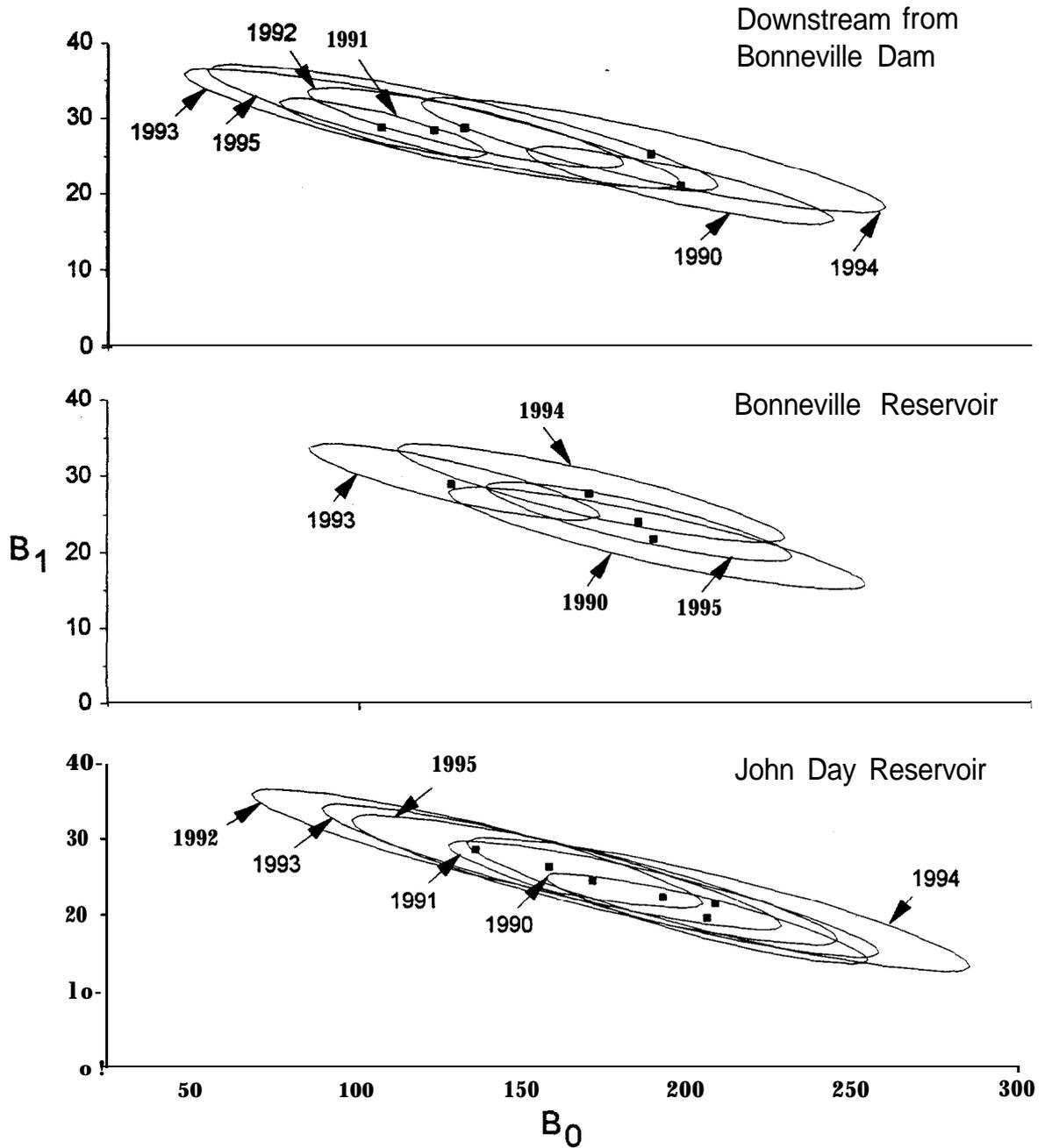


Figure 8. Joint 95% family confidence regions for estimates of length-age equation parameters (B_1 = slope and B_0 = y-intercept) for female northern squawfish in the Columbia River downstream from Bonneville Dam (ages 5-14), Bonneville Reservoir (ages 5-14), and John Day Reservoir (ages 5-13) from 1990-95. 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.

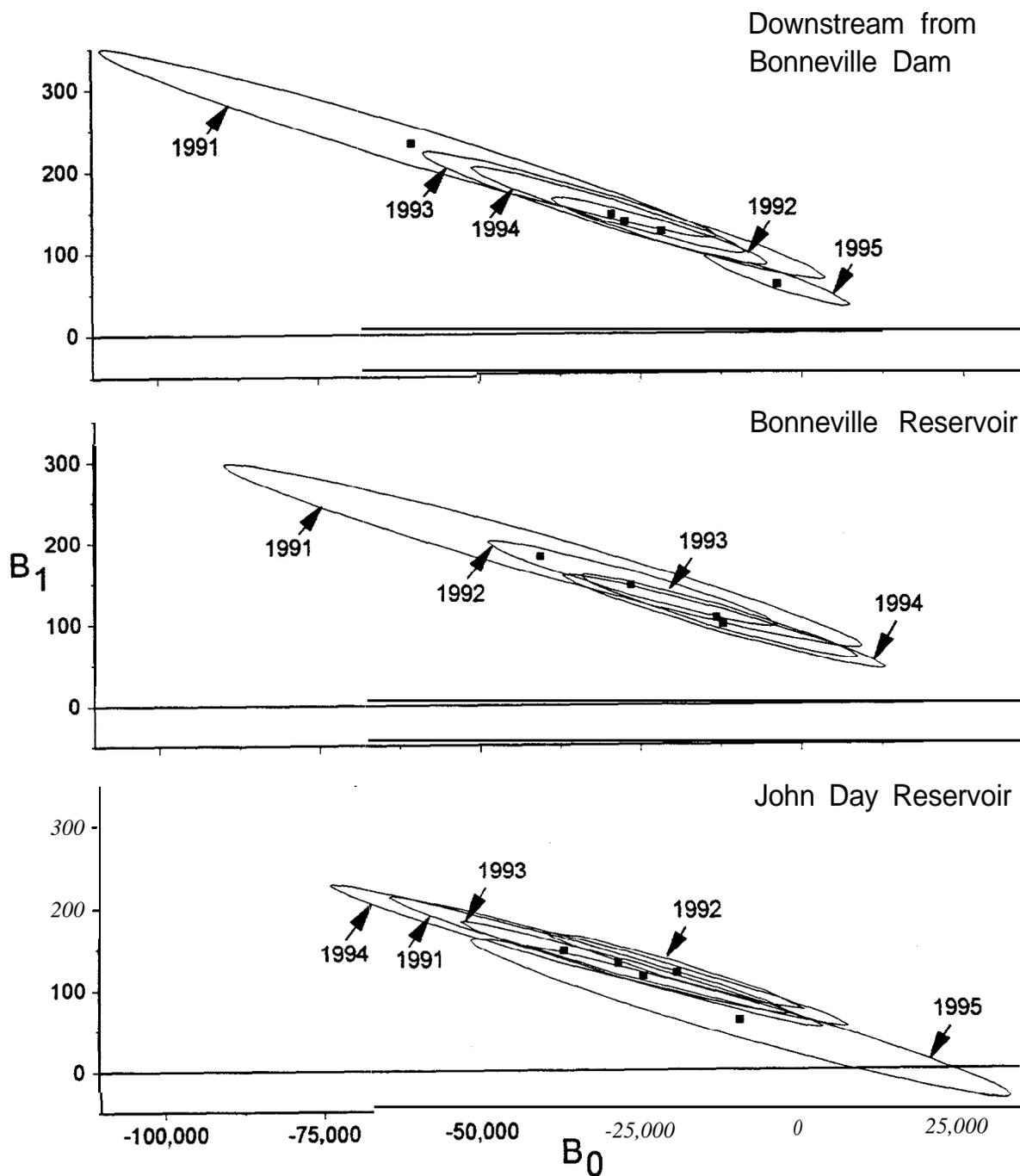


Figure 9. Joint 95% family confidence regions for estimates of fecundity-length equation parameters (B_1 = slope and B_0 = y-intercept) for northern squawfish in the Columbia River downstream from Bonneville Dam (1991-1995), Bonneville Reservoir (1991-94), and John Day Reservoir (1991-95). Parameter pairs are considered significantly different 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 | | | | | |
| Mean fecundity | 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 | | | | | |
| Mean fecundity | 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 contributed to the highest systemwide exploitation rate since implementation of the Northern Squawfish Management Program. The **sport-reward** fishery 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% if exploitation 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 successful, 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 attribute lower consumption indices to mistimed sampling.

Decreases in PSD were greater than could be explained 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.

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APPENDIX A

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

Appendix Table A-1. Exploitation rates (%) of northern squawfish ≥ 250 mm for the sport-reward fishery from 1991-95.

| Area or reservoir | 1991 | 1992 | 1993 | 1994 | 1995 |
|-------------------|-------------|-----------------|-----------------|-----------------|------------------------|
| Downstream from: | | | | | |
| Bonneville Dam | 7.9 | 11.5 | 6.1 | 13.7 | 16.2 |
| Bonneville | 13.4 | 4.1 | 2.1 | 2.2 | 3.5 |
| The Dalles | 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 |
| Little Goose | 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 ^a | 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 ^a | 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 | April 3 - April 9 | 15 | July 3 - July 9 |
| 3 | April 10 - April 16 | 16 | July 10 - July 16 |
| 4 | April 17 - April 23 | 17 | July 17 - July 23 |
| 5 | April 24 - April 30 | 18 | July 24 - July 30 |
| 6 | May 1 - May 7 | 19 | July 31 - August 6 |
| 7 | May 8 - May 14 | 20 | August 7 - August 13 |
| 8 | May 15 - 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 | Recaptures | | | | | M | Exploitation | | |
|-----------------------|------------|-------|-----|-----|-------|-----|--------------|--------|--------|
| | T | sport | Dam | Net | Misc. | | sport | Dam | 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 | 596 | 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 large. 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 | -- | 0.0031 |
| 13 | -- | 1 | -- | 3 | 2 | 322 | 0.0031 | -- | 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 |
| Adjusted 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.

| Time 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 | 0.0349 | -- | -- |
| 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 | |
|-----------------------|------------|------------|-----|-------|------------|----------------|---------------|
| | | Snort | 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 | -- | -- | -- | -- | 196 | -- | -- |
| 23 | -- | 1 | -- | -- | 196 | 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. | | sport | 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 for tag loss | | | | | | 0.0291 | 0.0283 |

Appendix Table A-1 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 | <i>0.0000</i> |
| Adjusted for tag loss | | | | | | 0.0642 | 0.0000 |

Appendix 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.

| Time period | Recaptures | | | | | M | Exploitation | | |
|-----------------------|------------|------------|----------|-----------|----------|-------------|---------------|---------------|---------------|
| | T | sport | Dam | Net | Misc. | | 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 Columbia and Snake Rivers**

Appendix Table B-I. Indices of northern **squawfish** density from 1990 through 1995 for sampling zones 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 | -- | -- | 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 |
| Tailrace BRZ | 5.465 | -- | -- | 1.500 | 6.750 | -- |
| The Dalles Reservoir | | | | | | |
| 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 |
| John Day 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 | 0.45 1 | 0.265 | 0.325 |
| Tailrace BRZ | 14.727 | 17.933 | 9.235 | 13.333 | 2.400 | -- |
| Lower Monumental Res. | | | | | | |
| Tailrace | -- | 1.524 | -- | -- | 0.33 1 | 0.105 |
| Tailrace BRZ | -- | 16.3 12 | -- | -- | 1.200 | 3.875 |
| Little Goose Reservoir | | | | | | |
| Tailrace | -- | 1.625 | -- | -- | 0.484 | 0.063 |
| Tailrace BRZ | -- | 28.294 | -- | -- | 6.418 | 10.250 |
| Lower Granite Reservoir | | | | | | |
| Upper-reservoir | -- | 1.855 | -- | -- | 0.541 | 0.225 |

Appendix Table B-2. Indices of **northern** squawfish abundance **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 |
| Tailrace 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 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 | Consumption index | | | | | |
|-------------------------|-------------------|------|------|------------|------------|------|
| | 990 | 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 |
| Tailrace 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 |
| Tailrace BRZ | 2.5 | 1.5 | 0.9 | -- | 0.7 | -- |
| Lower Monumental Res. | | | | | | |
| Tailrace | -- | 0.6 | -- | -- | 0.7 | 0.0 |
| Tailrace 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 | | | | | | |
| Upper-reservoir | -- | 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 |
| Tailrace BRZ | 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 | 0.0 | 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.

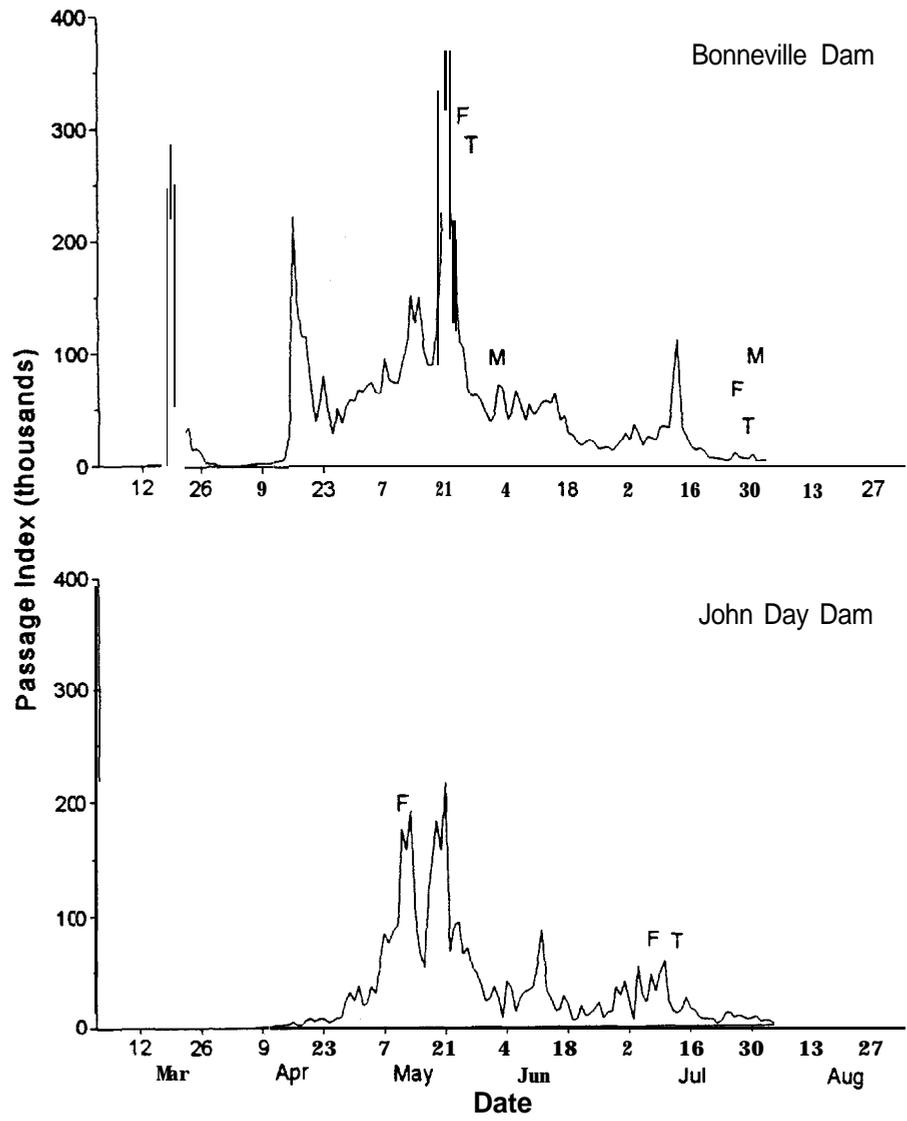
| Location, zone | Predation index | | | | | |
|-------------------------|-----------------|------------|-------------|------------|-------------|------------|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
| Below | | | | | | |
| Bonneville Dam | | | | | | |
| RKm 71-121 | -- | -- | 14.0 | -- | 8.0 | 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 |
| Tailrace BRZ | 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 |
| Tailrace BRZ | 2.0 | -- | -- | -- | -- | -- |
| The Dalles Reservoir | | | | | | |
| Forebay | 1.1 | -- | -- | 0.2 | 0.1 | 0.0 |
| Tailrace | 1.9 | -- | -- | 0.0 | -- | -- |
| Tailrace BRZ | 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 |
| Tailrace BRZ | 3.9 | 2.9 | 0.9 | -- | 0.2 | -- |
| Lower Monumental Res. | | | | | | |
| Tailrace | -- | 0.8 | -- | -- | 0.2 | 0.0 |
| Tailrace BRZ | -- | 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-reservoir | -- | 0.5 | -- | -- | 0.3 | 0.2 |

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

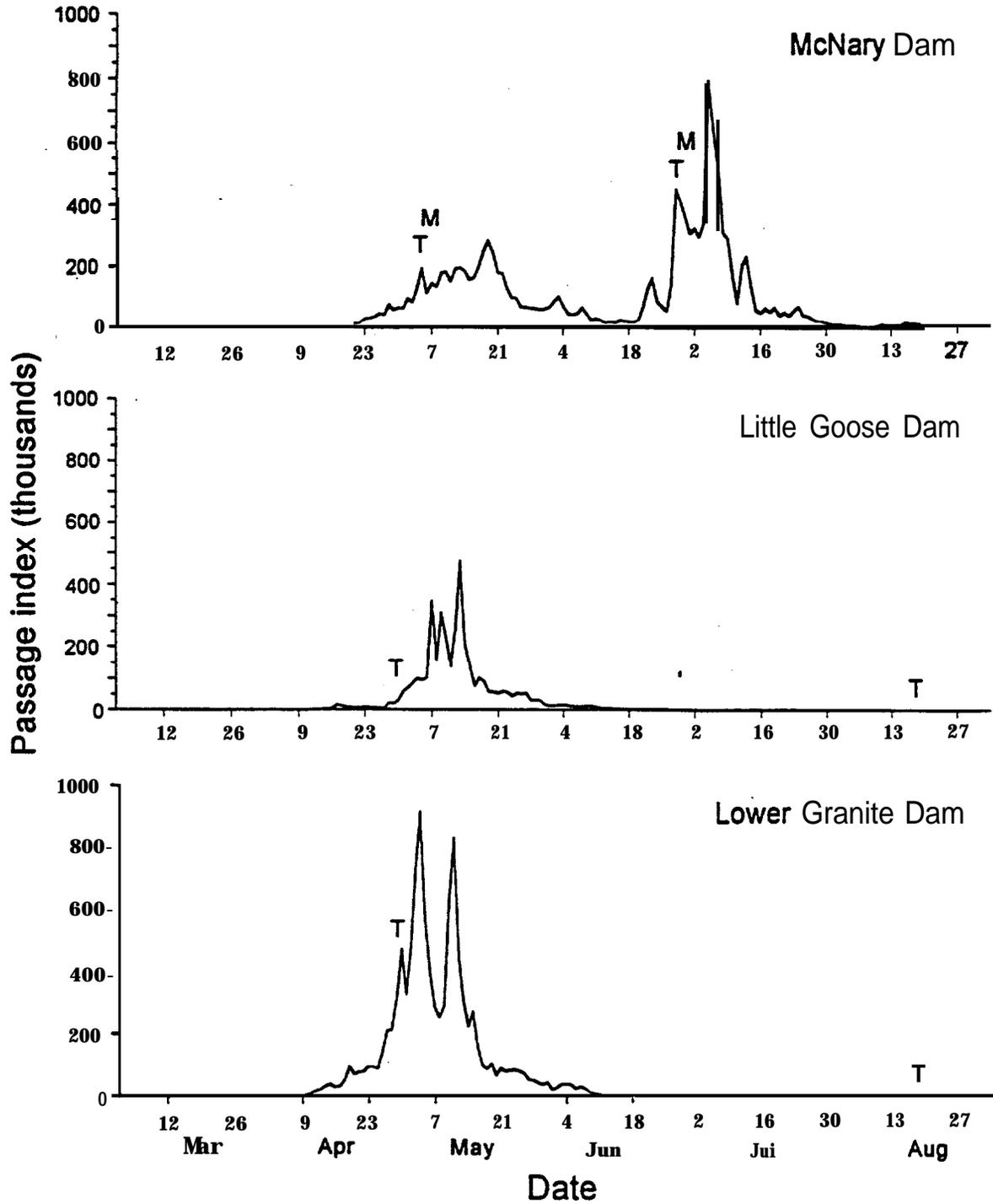
| Location, zone | Density index | | | | | |
|----------------------|---------------|------|------|------|------|------|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
| Below | | | | | | |
| Bonneville Dam | | | | | | |
| RKm 71-121 | -- | -- | 8.3 | -- | 27.3 | 14.5 |
| RKm 122-177 | -- | -- | 26.1 | -- | 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 | 01.7 | -- | -- | 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 |
| Tailrace BRZ | 18.6 | 5.4 | 4.6 | 0.9 | 0.5 | -- |

APPENDIX C

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



Appendix Figure **C-1**. 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 Northern Squawfish

Introduction

A large-scale management program for northern squawfish (*Ptychocheilus oregonensis*) began in 1990 to increase survival of juvenile 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 10-20%, 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%.

Although 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 smallmouth bass (*Micropterus dolomieu*) are also present. Smallmouth 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). Smallmouth 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 smallmouth bass are unknown and difficult to predict. Johnson (1977) and Hayes et al. (1992) found that populations of yellow perch (*Perca flavescens*) 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 distribution 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 smallmouth bass to sustained removals of northern squawfish. We examined smallmouth bass density, consumption of juvenile salmonids, population structure, and growth and mortality over a period of years coinciding with the Northern Squawfish Management Program. Information comparing smallmouth bass populations before and after sustained removals of northern squawfish will help assess the effectiveness of the removal program in reducing predation on juvenile salmonids.

Methods

Data Collection and Summary

We sampled from 1990 through 1995 to collect information on smallmouth bass in the lower Columbia and Snake rivers. We sampled each year in the **forebay** (immediately upstream from the dam), **midreservoir**, and **tailrace** (immediately downstream from the next dam) of John Day Reservoir, and in the **tailrace** immediately downstream from Bonneville Dam. We sampled in the **forebay**, **midreservoir**, and **tailrace** of Bonneville Reservoir each year except 1992. We sampled the **tailrace** of Lower Monumental and Little Goose reservoirs, and the upper reach of Lower Granite Reservoir in 1991, 1994 and 1995. Finally, 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 of juvenile salmonids present (Ward et al. 1995). We sampled at least six randomly selected sites each boat-day between 3 a.m. and 11 a.m. 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 modified **Seaburg** stomach sampler (**Seaburg** 1957). All stomach samples were kept on ice and later frozen until subsequent laboratory analysis.

In 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 Da.m, 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 each reach each year.

Consumption of Juvenile Salmonids

We developed an index to compare consumption of juvenile salmonids by smallmouth bass among years. Our consumption index was analogous to the consumption index for not-them 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 90% digestion (**T90**) for northern squaw-fish as

$$T90_i = 47.792 \cdot M_i^{0.61} \cdot T^{-1.60} \cdot W^{-0.27},$$

where

M_i = meal size (g) at time of ingestion of salmonid 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 squawfish could be expressed as

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

However, this requires measurement of meal size M_i , 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:

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

where

S = mean number of salmonids per sample of northern squawfish, and
 GW = mean total gut weight.

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

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

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

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

We tested how well differences 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 smallmouth bass consumption rate of juvenile salmonids in 1995:

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

where

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

Daily ration (**R**) was estimated as

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

where

M = average size of ingested meal (% body weight),
n = number of fish that contain food in the stomach, and
N = total number 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-weight 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 populations 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

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

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 (**Ricker** 1975). We tested the descending 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-1), 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 Juvenile Salmonids

Our proposed consumption index for smallmouth bass,

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

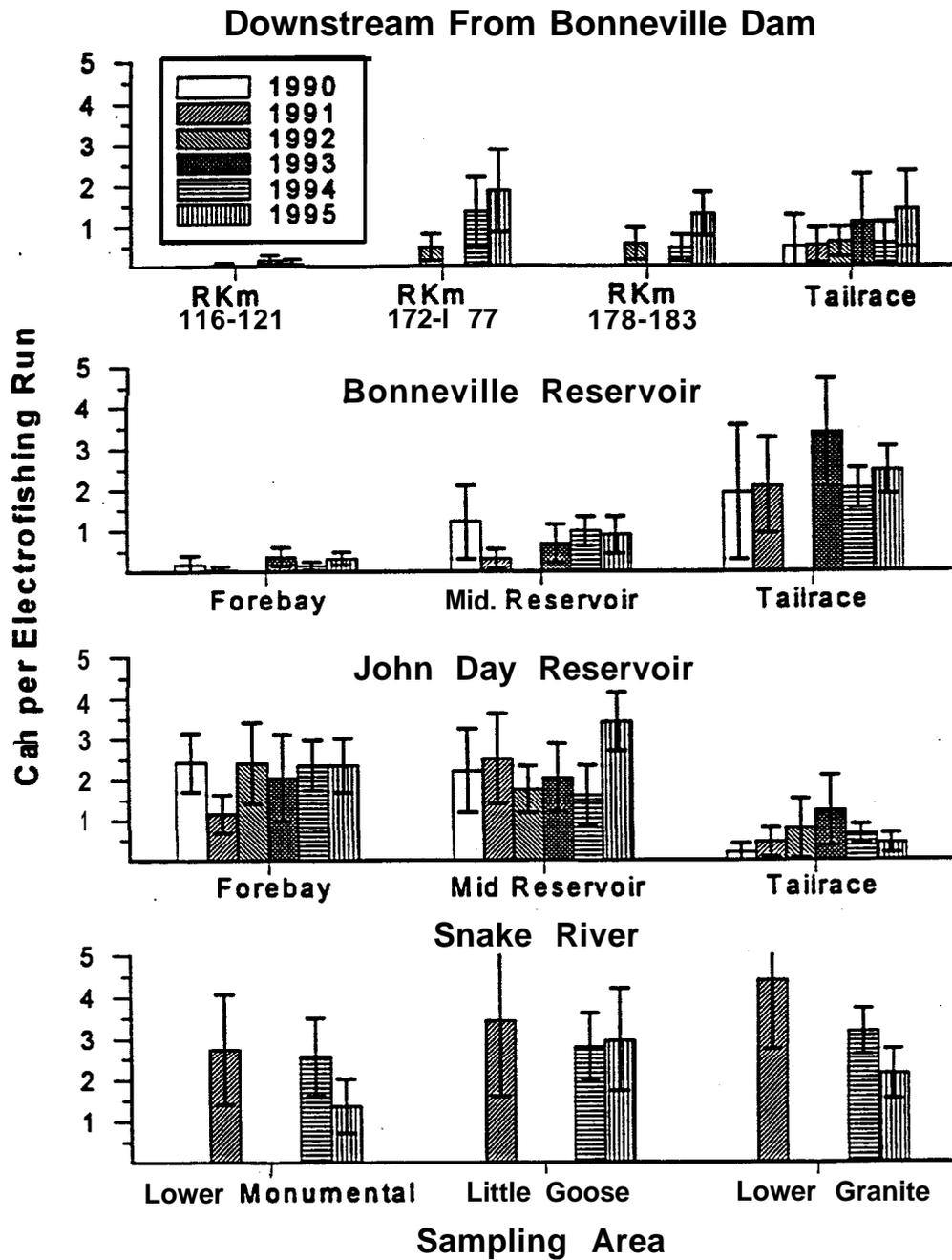
was highly correlated with the direct estimate of consumption (Appendix Figure D-2). We therefore used this index to evaluate consumption of juvenile salmonids by smallmouth bass.

Consumption of juvenile salmonids was highly variable among reaches and seasons, but was generally low (Appendix Tables D-1 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 **RKm178- 183**, downstream from Bonneville Dam. We found no trend of increasing consumption by smallmouth bass over time.

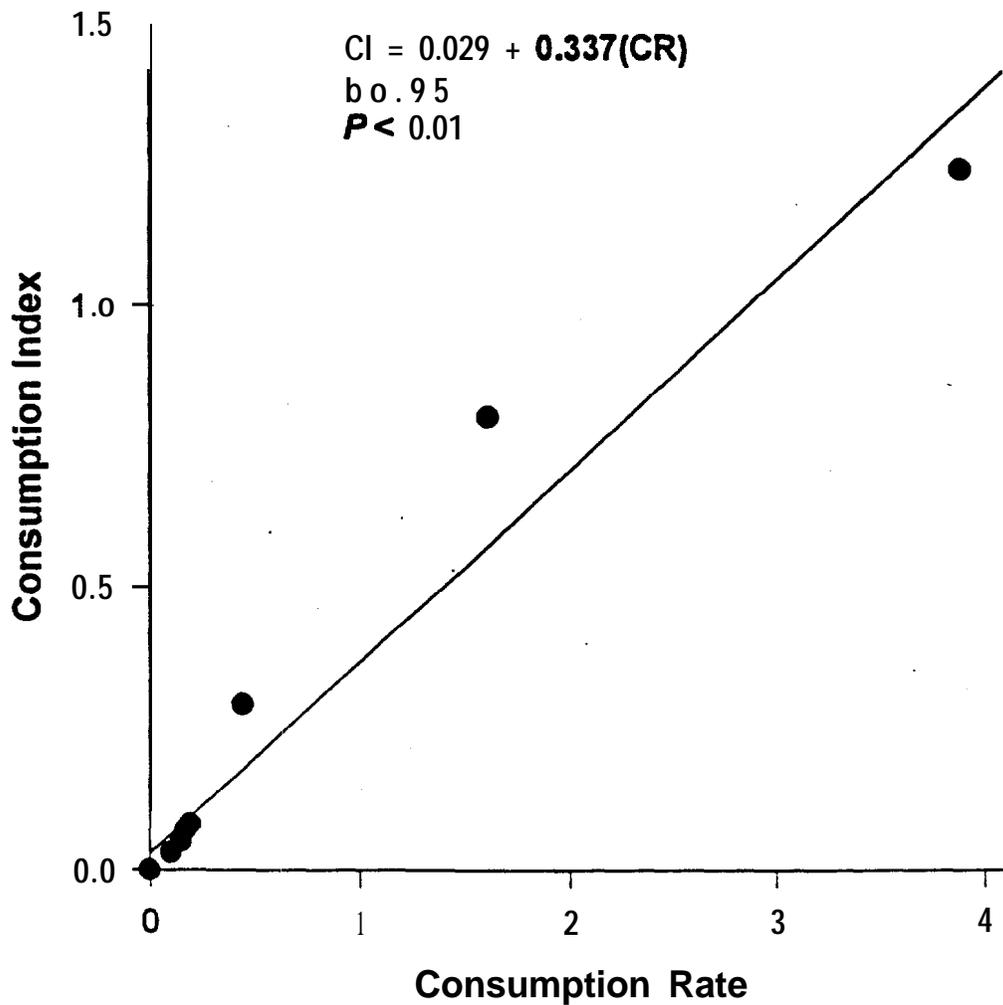
Population Structure

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 greater in other reservoirs. 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.



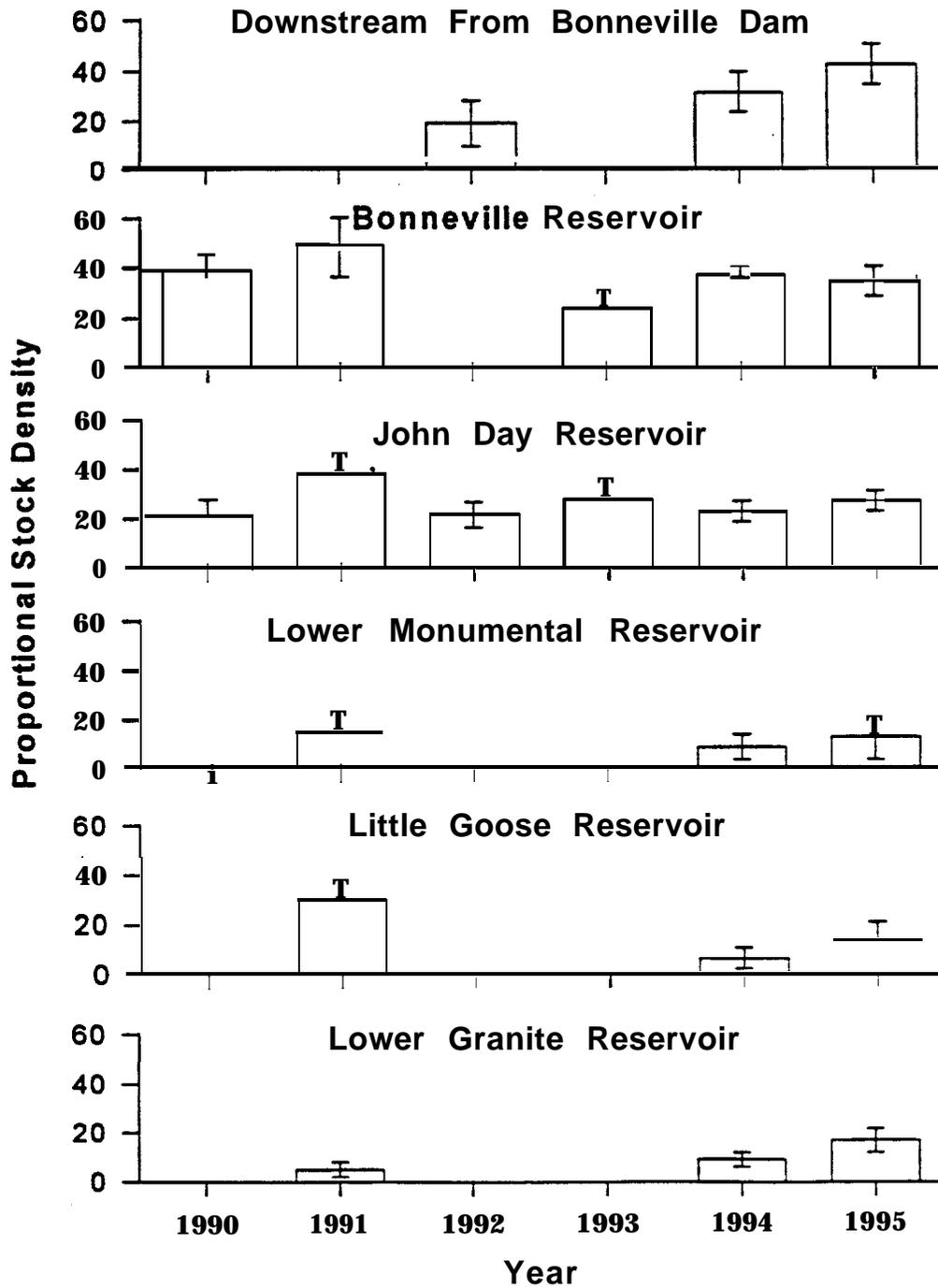
Appendix Figure D-2. Relationship between proposed consumption index for smallmouth bass (CI) and direct estimate of consumption rate (CR); CR = number of juvenile salmonids per smallmouth bass per day.

Appendix Table D- 1. Index of **salmonid** consumption by smallmouth bass in the lower Columbia and Snake rivers during spring, 1990-95. CI = consumption index, N = sample size.

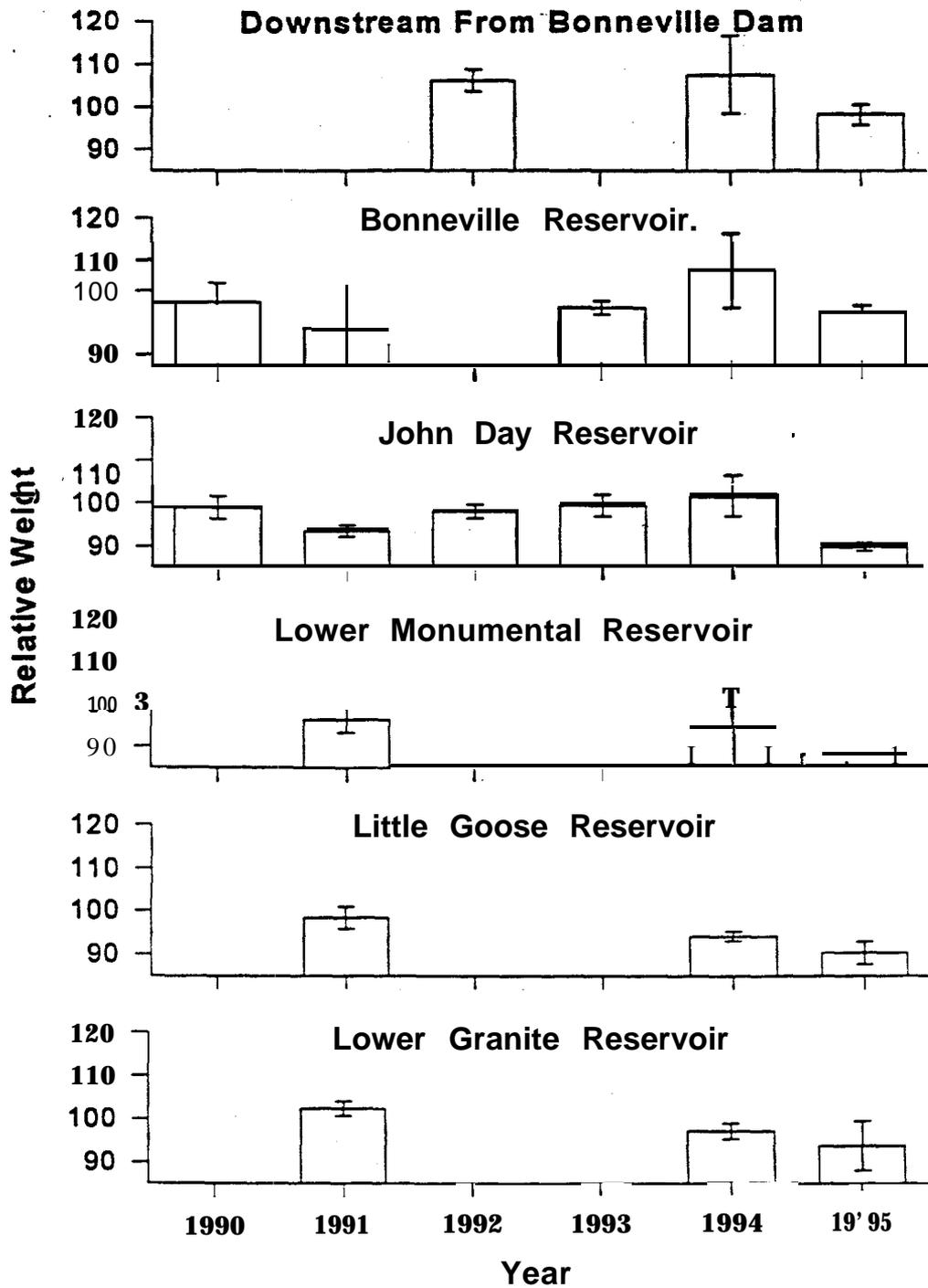
| Reservoir, reach | 1990 | | 1991 | | 1992 | | 1993 | | 1994 | | 1995 | |
|-----------------------------------|------|----|------|----|------|----|------|----|------|----|------|-----|
| | CI | N |
| Downstream from Bonneville Dam | | | | | | | | | | | | |
| RKm 116-121 | -- | -- | -- | -- | 0.0 | 1 | -- | -- | 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 | 30 |
| 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 |
| Little Goose | | | | | | | | | | | | |
| Tailrace | -- | -- | <0.1 | 63 | -- | -- | -- | -- | 0.1 | 9 | <0.1 | 78 |
| 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 |
| 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 | -- | -- | -- | -- | 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 |
| Tailrace | 0.0 | 10 | 0.1 | 13 | 0.0 | 6 | 0.0 | 23 | 0.0 | 19 | 0.0 | 22 |
| Lower | | | | | | | | | | | | |
| Monumental | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0.0 | 34 |
| Tailrace | | | | | | | | | | | | |
| Little Goose | | | | | | | | | | | | |
| Tailrace | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0.0 | 38 |
| Lower Granite | | | | | | | | | | | | |
| Upper reservoir | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0.0 | 81 |



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



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

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.

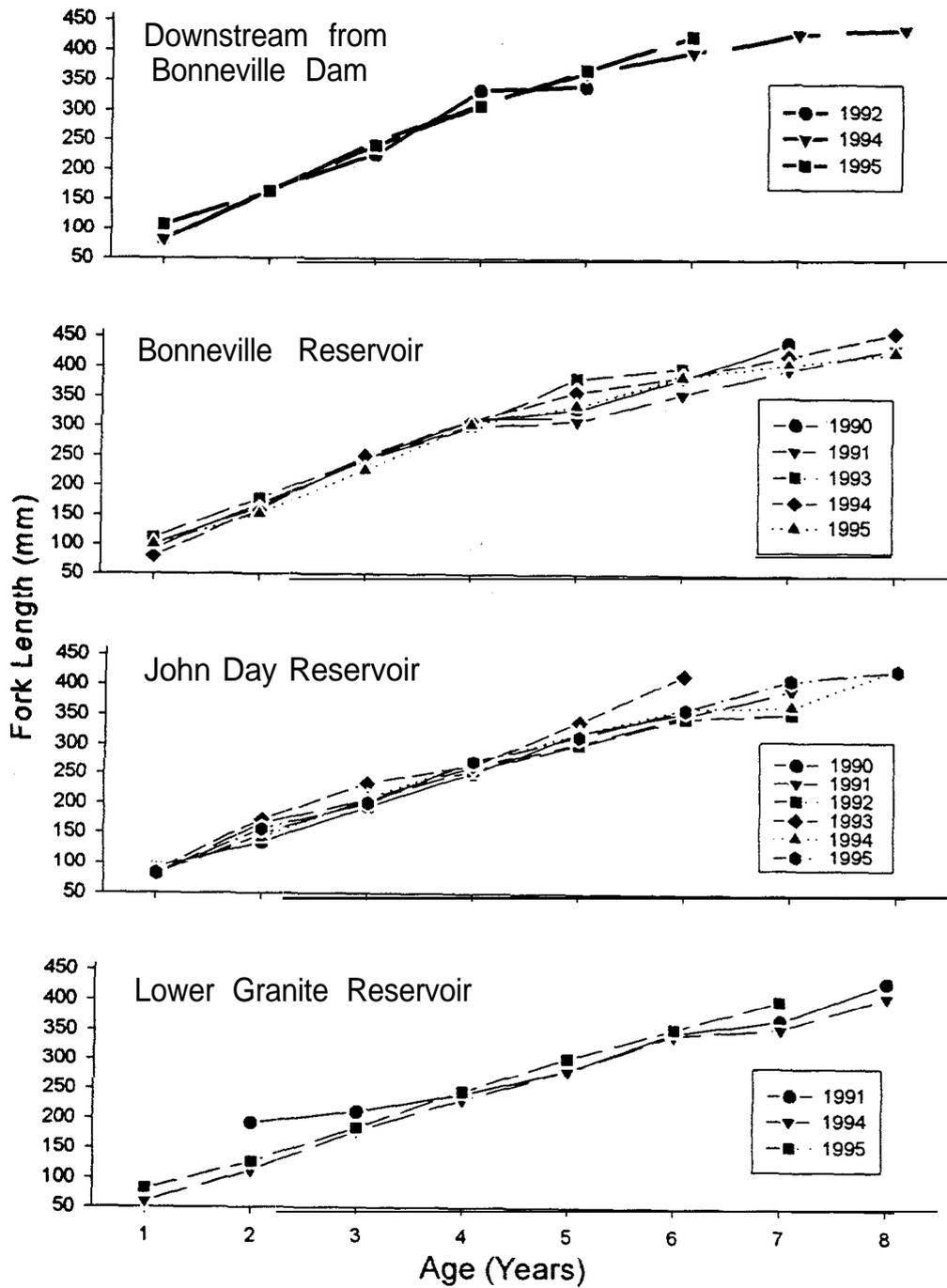
Estimates of annual mortality of smallmouth bass consistently exceeded 50% throughout the Columbia River basin (Appendix Table D-3). We found no evidence of decreased mortality over time. Differences among years in slopes of the descending limbs of catch curves (estimates of total instantaneous mortality) were not significant for the Columbia River downstream from Bonneville Dam ($P=0.38$), 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 of juvenile 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 smallmouth 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 smallmouth bass remains 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 (primarily 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 smallmouth bass. However, the highest levels of sustained exploitation have occurred downstream from Bonneville Dam and in Lower Granite Reservoir, the only two areas where smallmouth 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" | 69 |
| John Day | 64 | 55 ^b | 57" | 60" | 68 | 58 |
| Lower Granite | -- | 57" | -- | -- | 72 | 58 |

^a Ages 3-5.

^b Ages 4-6.

Effectiveness 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 abundant and widespread predator other than northern squawfish in the lower Columbia and Snake rivers, and therefore have the highest potential for reducing benefits of the management program. The lack of response to date by smallmouth bass increases confidence in the hypothesis that sustained removals of northern squawfish increases survival of juvenile salmonids.

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APPENDIX E

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

We examined digestive tract contents of 817 northern squawfish and 1,485 smallmouth bass collected 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 (Knutson et al. 1995). The occurrence of ingested juvenile salmonids during spring was highest for northern squawfish caught in Little Goose Reservoir (90.8%) and smallmouth 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 smallmouth 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 smallmouth 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 smallmouth bass digestive tracts. Fish other than salmonids and sculpins were far more prevalent in smallmouth **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-I. 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: Reservoir or area | Northern squawfish | | | | Smallmouth bass | | | |
|------------------------------|--------------------|--------|--------|--------|-----------------|--------|--------|--------|
| | N | % Food | % Fish | % Sal. | N | % Food | % Fish | % Sal. |
| Spring: | | | | | | | | |
| Below Bonneville | | | | | | | | |
| D a m 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 |
| The Dalles | 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 | | | | | | | | |
| D a m tailrace | 5 6 | 41.1 | 14.3 | 7.1 | 37 | 62.2 | 40.5 | 13.5 |
| Bonneville Dam | | | | | | | | |
| tailrace | 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 |
| The Dalles | 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 |
| % Cyprinidae | 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 |
| % Gasterosteidae | 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 |

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