FEEDING ACTIVITY, RATE OF CONSUMPTION, DAILY RATION AND PREY SELECTION OF MAJOR PREDATORS IN JOHN DAY RESERVOIR

ANNUAL REPORT

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ABSTRACT

This report summarizes activities in 1984, the third of a five year study to determine the extent of predation on juvenile salmonids in John Day Reservoir. Salmonids were the single most important food item by weight for northern squawfish (Ptychocheilus oregonensis) in the restricted zones at McNary tailrace and John Day forebay during all sampling periods. Salmonids accounted for 18.1% of the weight in the diet of walleyes (Stizostedion vitreum vitreum in 1984 which was at least twice that found in previous years. In smallmouth bass (Micropterus dolomieui) salmonids contributed little to their diet whereas for channel catfish (Ictalurus punctatus) fish accounted for 64.1% of the weight in their diet with salmonids responsible for approximately half of this weight.

The overall relative effectiveness of the beach seine was better than the boat electroshocker for capturing prey fishes. Right prey taxa comprised over 93% of the beach seine catch during 1984 with some taxa being concentrated in specific habitats within the reservoir. Digestion experiments were conducted at temperatures of 15 and 20 C on 106 northern squawfish fed juvenile salmonids.

An intensive search of the fisheries literature was conducted to review various fish capture and control techniques which might have Potential as predation control measures for the major predators of juvenile salmonids in the Columbia River system. Data from over 250 references were summarized and each measure was rated as having high, moderate, or low potential for reducing predation on juvenile salmonids.

Most prey protection measures were judged to have high potential (e.g. release strategies and predator avoidance conditioning) and direct predator control measures (e.g. netting, trapping, chemical control, electrofishing, and water level manipulation) were judged to have moderate or low potential. Certain measures could not be fully evaluated because there was insufficient knowledge of the feeding behavior, areas of concentrations, and reproductive requirements of the four predators under investigation. Recommendations were made on how to meet these data needs and to initiate several pilot studies which would test the feasibility of several predation control measures at minimal expense and without the delay of gathering additional data.

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PREFACE

The Seattle National Fishery Research Center of the U.S. Fish and Wildlife Service (USFWS) is working in cooperation with Oregon Department of Fish and Wildlife (ODFW) to determine the extent of predation by northern squawfish (Ptychocheilus oregonensis), walleyes (Stizostedion vitreum vitreum), smallmouth bass (**Micropterus dolomieui**), and channel catfish (**Ictalurus punctatus**) on juvenile anadromous salmonids in John Day Reservoir. Three primary objectives, to be completed by 1984, were identified in the original USFWS proposal:

1) Determine the food habits, rate of consumption, daily ration, and feeding activity of major predators.
2) Determine the pattern of prey selection of major predators as a function of time and reservoir habitat.
3) Estimate the rate of gastric evacuation of major predators.

Following consultation with ODFW and Bonneville Power Administration (BPA) personnel two new objectives were added in 1984:

4) Determine the feasibility of regulating predation on juvenile salmonids.
5) Develop conceptual and predictive models of the predator-juvenile salmonid relationship in John Day Reservoir.

Research under objectives four and five will be completed through a cooperative ODFW-USFWS effort. USFWS is responsible for reporting on Progress and results of activities covered under objective four and and ODFW objective five.

Information pertinent to objectives one, two, and three are presented in Section I of this report while that for objective four is presented in Section II.

SECTION I - OOD CONSUMPTION AND PREY A BUNDANCE

INTRODUCTION

During the third year of research on the feeding activity, rate of consumption, daily ration, and prey selection of northern squawfish, walleyes, smallmouth bass, and channel catfish the following subobjectives were delineated:

A. Obtain field data needed to estimate consumption and describe food habits of northern squawfish, walleyes, smallmouth bass, and channel catfish during the smolt outmigration.

B. Describe apparent abundance and distribution of northern squawfish, walleyes, and smallmouth bass.

C. Compare capture efficiency of beach seine and boat electroshocker for various length groups of the most common prey taxa.

D. Describe the composition, apparent abundance, and distribution of prey fishes in John Day Pool during the smolt outmigration in 1984.

E. Obtain data needed to describe statistical relationships between fork length of non-salmonid prey fishes and other body or bone measurements.

P. Complete single meal digestion experiments for northern sguawfish and develop the methodology for conducting multiple meal experiments.

Stomach content data (sub-objective A) will be used to estimate consumption for the average predator. The contribution of juvenile salmonids and other prey fishes to average daily consumption will be delineated.

Apparent abundance of predators (sub-objective B) will provide general information on predator density in areas sampled. Specific data on predator abundance and population dynamics are available through research being conducted by ODEW (Nigro et al. 1985).

Gear effectiveness (sub-objective C) will be evaluated for selecting gears to determine the apparent abundance of prey fishes in John Day Reservoir. Apparent abundance of prey (sub-objective D) and predator food habit data (sub-objective A) will be used to determine if a pattern of prey selection exists.

Body length versus bone length regressions (sub-objective E) are used to back-calculate original body length of partially digested prey fish found in stomachs of predators. Length measurements will be converted to weight and used to estimate food consumption.

Regression equations of northern squawfish digestion versus time (sub-objective F) will be used to estimate time of ingestion of each prey fish found in stomachs. These data will be used to calculate food consumption.

METHODS

Food Habits

Food consumption of predators was monitored by sampling three 24 hour periods at each of four stations during four Sampling periods (Table 1). Sampling stations at John Day forebay, Irrigon, and McNary tailrace remained unchanged (Gray et al. 1984). Sampling was discontinued at John Day tailrace and a new station was established at Arlington to more thoroughly sample John Day Reservoir (Fig. 1). Techniques used to collect and process predatory fish and to analyze stomach contents were similar to those used in 1983 (Gray et al. 1985). Percent occurrence and composition by weight of food items in the diet were calculated. For purposes of discussion, however, percent composition by weight was considered the best indicator of a prey item's relative importance and was the only index used in comparisons.

Apparent Abundance of Predators

Catch per transect (CPT) with the boat electroshocker was used as an index of apparent abundance for northern squawfish (> 250 mm), walleyes, and smallmouth bass. Collection and analysis techniques followed Gray et al. (1985).

Table 1. Sampling periods at each station, John Day Reservoir, 1984.

Sampling Period	McNary tailrace	Irrigon	John Day forebay	Arlington
I	Apr 4 - Apr 21	Apr 5 - Apr 22	Apr 19 - May 11	Apr 29 - May 12
II	May 5 - May 20	May 6 - May 24	May 23 - Jun 8	May 20 - May 30
III	Jun 4 - Jun 22	Jun 11 - Jun 17	Jun 21 - Jul 1	Jun 17 - Jun 26
IV	Aug 1 - Aug 25	Aug 3 - Aug 25	Aug 17 - Sep 2	Aug 19 - Aug 30

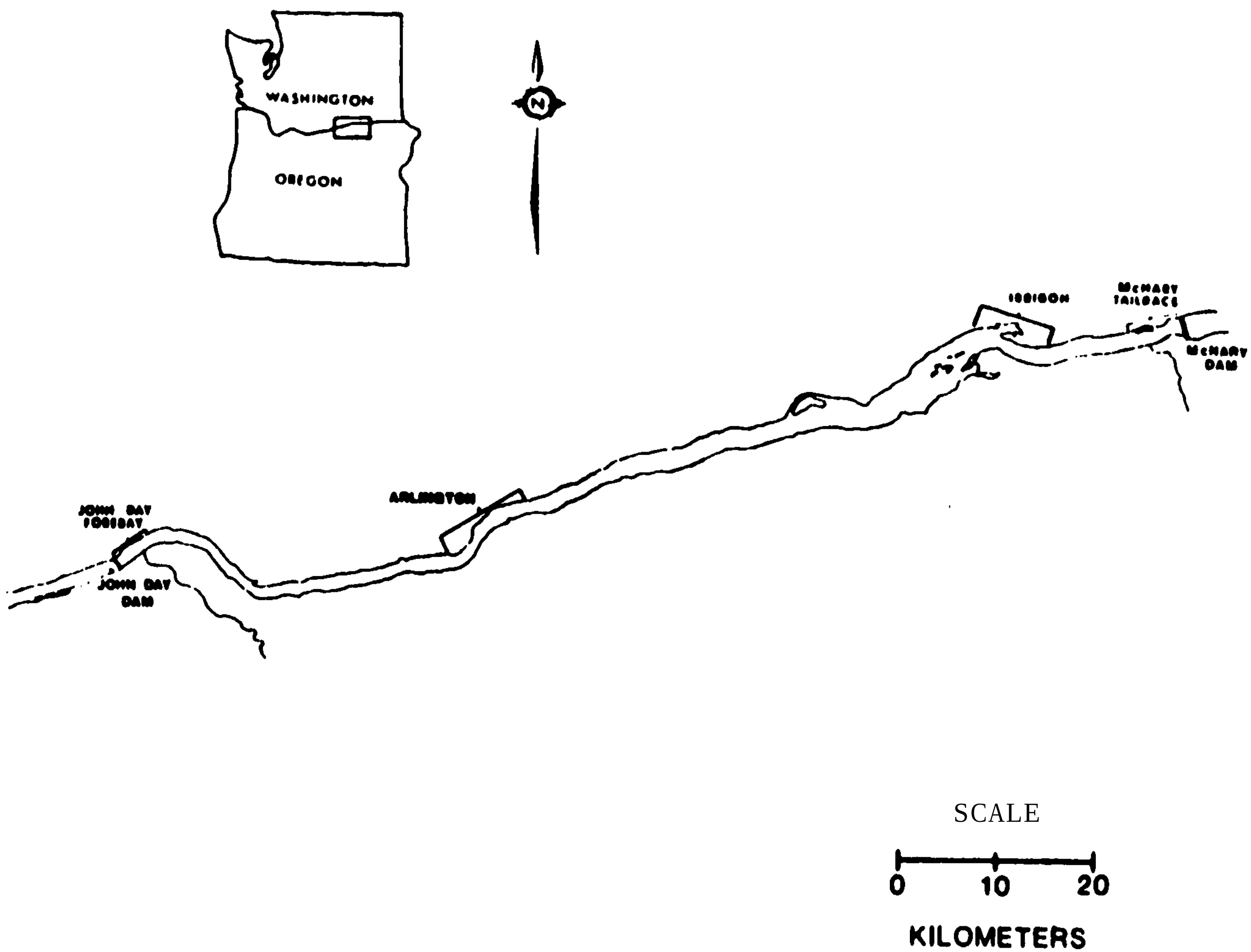

Figure 1. Location of four stations sampled in John Day Reservoir, April to September,1984.

Apparent Abundance and Distribution of Prey Fishes

Beach seine and boat electroshocker were used during each sampling period to collect prey fishes ($\leq$ 250 mm in fork length) at six sampling stations. Main channel habitats were sampled at McNary tailrace, Irrigon, Arlington, and John Day forebay. Backwater habitats were sampled at McNary tailrace (Plymouth slough) and Irrigon (Paterson slough). Sampling and enumeration techniques followed Gray et al. (1985) with two exceptions: 1) sampling effort was increased to four seine hauls and four electrofishing transects per station during each sampling period and 2) non-salmonid fish <150 mm in fork length were preserved in 10% formalin in the field and enumerated in the laboratory.

Catch data were analyzed to identify the most effective gear for sampling prey fishes and determine composition, apparent abundance, and distribution of prey taxa. Relative effectiveness of beach seine and boat electroshocker was compared for a prey taxon if it comprised more than 1% by occurrence and weight of the diet of any predator species (1% level was a mean based on 1982, 1983, and 1984 stomach contents data). To determine the most effective gear type, catches of each taxon were divided by gear into 25 mm length groups and the number of beach seine hauls or electroshocking transects in which each length group appeared was recorded. A chi-square analysis was performed on these data using a 2 x 2 contingency table of gear type versus presence or absence of each prey length group. In these comparisons, it was assumed that a gear was equally or more effective for a particular prey length group if the frequency of capture with that gear was equal to or significantly greater ($p \leq 0.05$) than the frequency of capture with the other. Mean catch with the most effective gear was used to describe apparent abundance and distribution of major prey taxa.

Body Length Regressions

Non-salmonid fishes were collected with a beach seine in John Day Reservoir to develop relationships between fork length and other morphological measurements (total length, standard length, nape to tail length, cleithrum, dentary, opercle, hypural plate, pharyngeal tooth, preopercle). Prey fish samples were processed in the same manner as juvenile chinook salmon in 1983 (Gray et al. 1985).

Body and bone lengths were measured on suckers, chiselmouth, peamouth, sculpins, northern squawfish, American shad, sand roller, smallmouth bass, largemouth bass, and crappies. All lengths of prey fishes found in stomachs of predators were not represented in prey fish samples, however, prohibiting development of complete regressions among weight, bone, and body lengths over the length range of prey consumed. Additional collections of prey fish during spring and summer of 1985 will provide data needed to complete these regressions.

Digestion Experiments

Single meal digestion experiments on northern squawfish were continued during 1984 using the methodology described in Gray et al. (1985). Experiments in 1984 utilized 106 northern squawfish and were conducted using various prey and predator sizes at water temperatures of 15 and 20 C.

Multiple meal experiments were initiated in 1984 and conducted in the same manner as single meals except that two to four juvenile salmonids were placed in each compartment of predators. To determine which fish a predator had eaten, each salmonid in the compartment was marked with a distinctively colored thread sewn below the dorsal fin and above the backbone. All multiple meals consisted of fish eaten within the same half hour interval.

RESULTS

Food habits of Northern Squawfish

Digestive tracts of 1,087 northern squawfish were analyzed. The number of empty digestive tracts was 301 (27.7%) and range in length was 30 to 562 mm ($\bar{x}$ = 360 mm).

Fish comprised 68.8% of the total weight of food consumed by northern squawfish (Table 2). Salmonids accounted for most of the fish weight (54.0%) and sculpins were second at 7.2%. The smallest northern squawfish that consumed a fish was 134 mm in length, and the smallest to eat a salmonid was 238 mm in length.

Percent weight of fish in the diet of northern squawfish generally increased with predator length (Pig. 2). Fish did not occur in the diet of northern squawfish less than 100 mm in length, but increased from 0.6% in northern squawfish 100 to 149 mm long to over 60% in those $\geq$350 mm in length. Similarly, salmonids contributed little to the diet of northern squawfish <350 mm in length, but accounted for more than 43% of the diet for those $\geq$350 mm in length.

Northern squawfish <100 mm in length were collected only at McNary tailrace and Irrigon (Fig. 3; Appendix Table 1). Insects accounted for 89.5% of the diet by weight at McNary tailrace and all of the diet at Irrigon.

At McNary tailrace, northern squawfish 100 to 249 mm in length did not eat fish (Fig. 4; Appendix Table 2). Crustaceans and/or insects

Table 2. Percent occurrence and weight of food items in digestive tracts of northern squawfish ranging in length from 30 to 562 mm ($\bar{X}$ = 360 mm), John Day Reservoir, April 4 to September 2, 1984. Sample size and number of empty digestive tracts were 1,087 and 301, respectively.

Food item	Percent occurrence	Percent weight
MOLLUSCA	4.6	1.1
Pelecypoda		
Corbicula manilensis	4.4	1.1
Gastropoda	0.3	<0.1
CRUSTACEA	44.3	23.3
Cladocerans	0.5	<0.1
Amphipoda	33.7	7.1
Anisogammarus spp.	4.2	to.1
Corophium	32.1	7.1
Unidentified Amphipoda	0.5	<0.1
Decapoda		
Pacifastacus leniusculus	16.9	16.2
INSECTA	37.3	2.4
Ephemeroptera	19.8	0.0
Odonata	0.0	to.1
Orthoptera	1.1	0.2
Dermaptera	0.1	to.1
Plecoptera	0.1	to.1
Thysanoptera	0.1	to.1
Hemiptera	1.3	to.1
Coleoptera	2.7	to.1
Trichoptera	6.7	0.3
Lepidoptera	1.1	to.1
Diptera	2.3	0.1
Homoptera	14.6	0.1
Hymenoptera	3.9	0.4
Unidentified	6.0	0.4
AGNATHA		
Petromyzontidae	0.5	0.1
OSTEICHTHYES	27.0	68.8
Clupeidae		
Alosa sapidissima	1.7	0.3
Salmonidae	15.6	54.0
Oncorhynchus tshawytscha	0.4	2.s
Salmo gairdneri	0.3	3.1
Unidentified Salmonidae	15.5	49.3
Cyprinidae	0.6	1.6
Acrocheilus alutaceus	0.3	1.0
Mylocheilus caurinus	0.2	0.4
Ptychocheilus oregonensis	0.2	0.2
Cyprinus carpio	0.1	to .1
Catostomidae		
Catostomus spp.	1.0	2.5
Percopsidae		
Percopsis transmontana	3.1	3.0
Centrarchidae	0.2	0.1
Cottidae		
Cottus spp.	4.0	7.2
Unidentified non-Salmonidae	0.5	<0.1
Unidentified Osteichthyes	0.0	0.1
OTHER FOOD	19.0	4.3

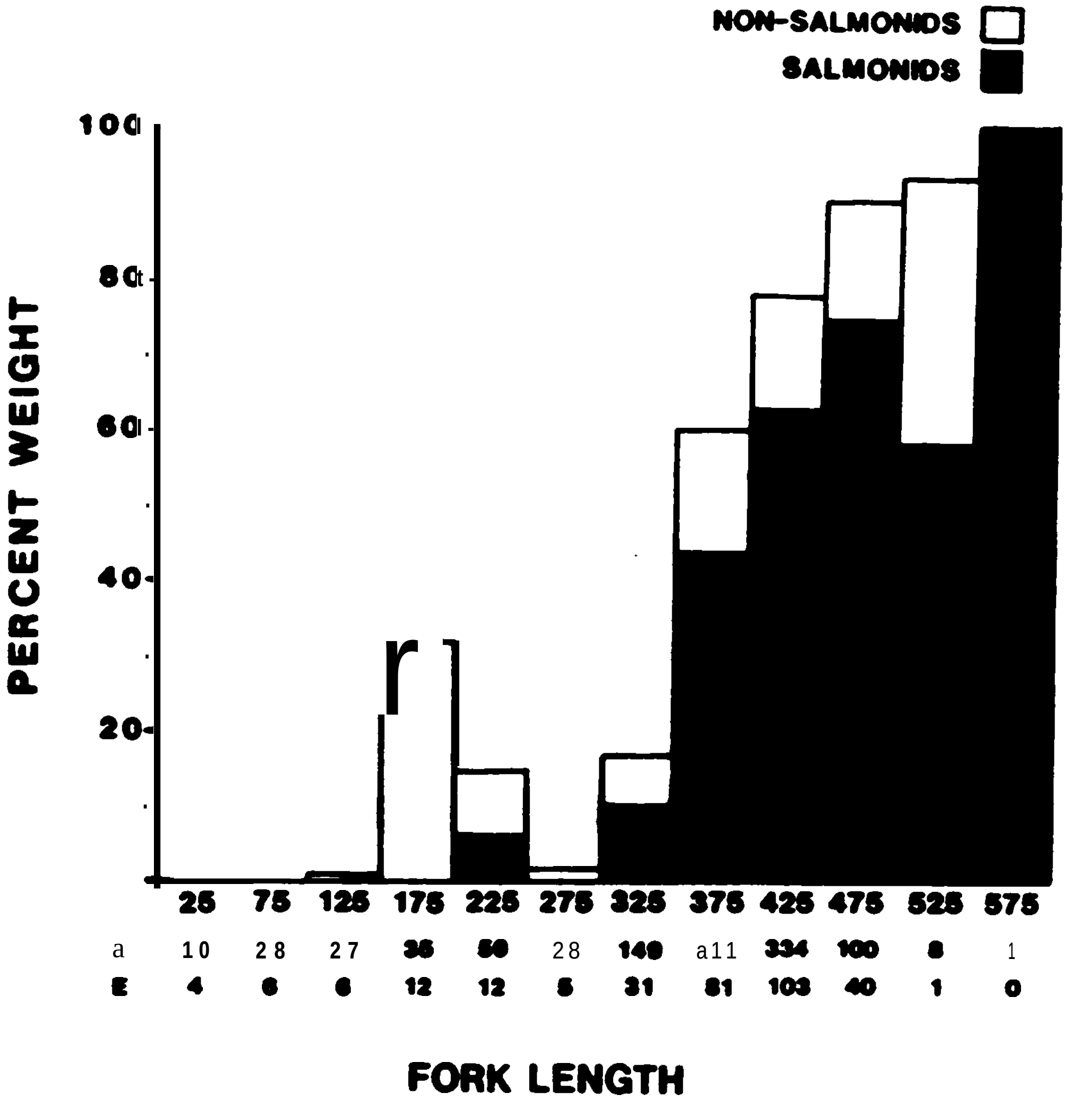

Figure 2. Percent weight of non-salmonid and salmonid fishes in the diet of northern squawfish by predator length, John Day Reservoir and tailrace, 1984. Lengths **are** midpoints of 50 mm intervals. N = number of digestive tracts analyzed; E = number of empty digestive tracts.

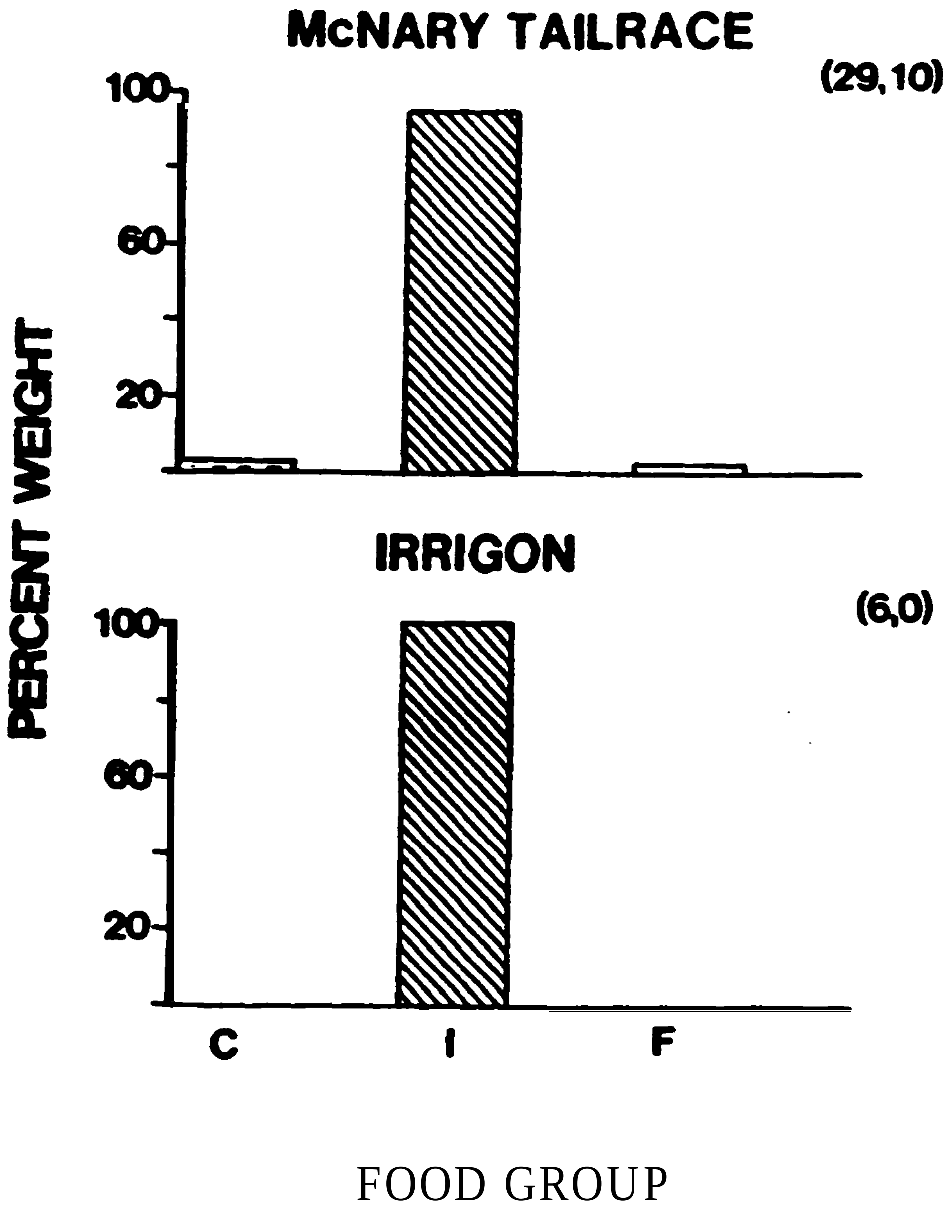

Figure 3. Percent veight of Crustacea (C), Insecta (I), and other food (F) in digestive tracts of small northern squawfish (<100 mm) at McNary tailrace and Irrigon, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses. Weights (4% are not included.

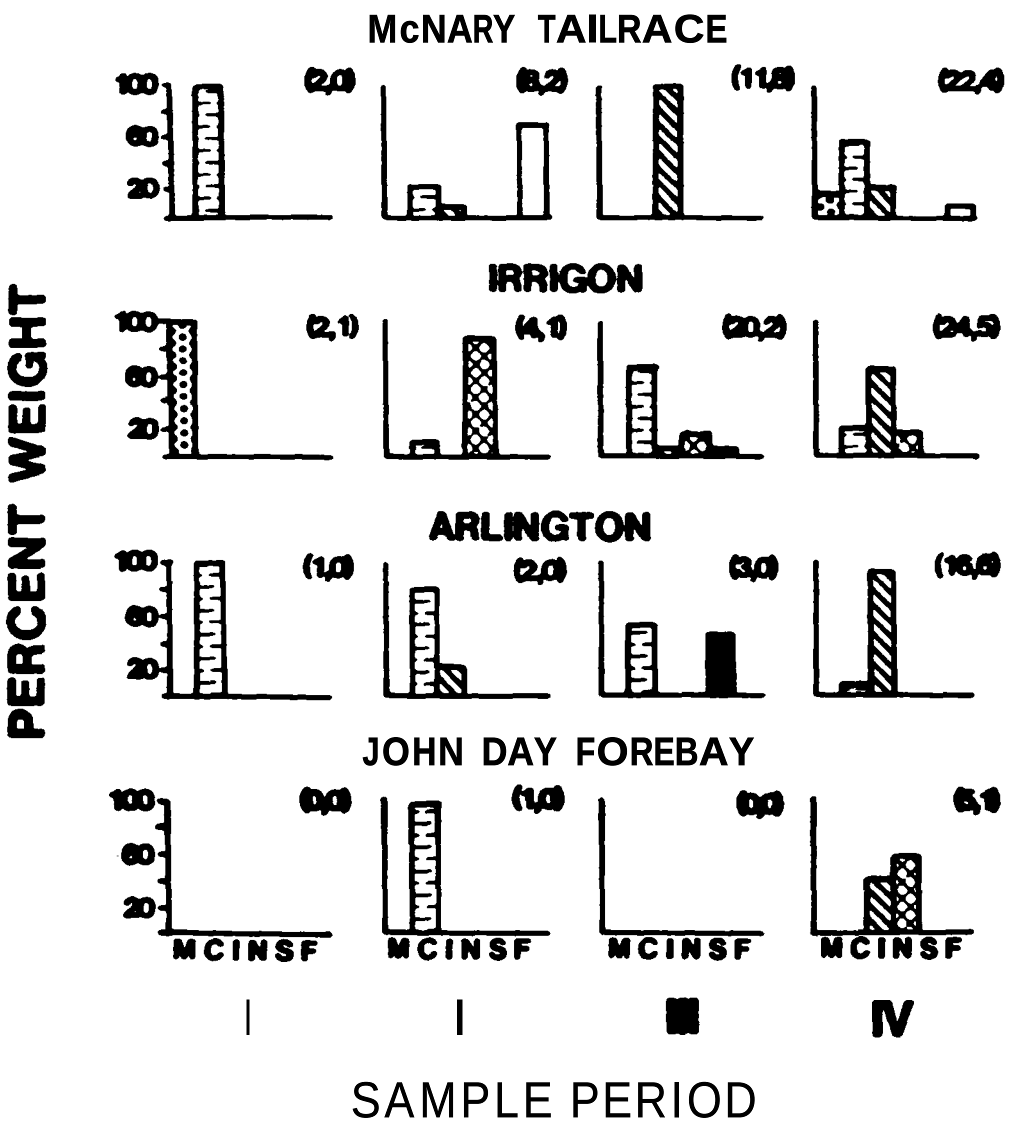

Figure 4. Percent weight of Mollusca (WI, Crustacea (C), Insecta (I), non-salmonids (N), salmonids (S), and other food (F) in digestive tracts of medium northern squawfish (l00-249 mm) by sample period at McNary tailrace, Irrigon, Arlington, and John Day forebay, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses. weights <4% are not included.

were the major contributors by weight in digestive tracts, excluding "other food" (primarily detritus) during all sample dates.

The primary food of northern squawfish between 100 to 249 mm in length at Irrigon varied with sample date (Fig. 4; Appendix Table 3). In April, only one northern squawfish with food was analyzed and the digestive tract contained only molluscs. Fish were most important by weight in May (87.1%) and of secondary importance in June (21.8%) and August (15.4%). Crustaceans accounted for the most weight (65.4%) in June, and insects accounted for the most weight (63.7%) in August. Salmonids were eaten only in June, accounting for 5.1% of the diet.

Crustaceans were the most important food item by weight for northern squawfish 100 to 249 mm in length at Arlington (Fig. 4; Appendix Table 4) in April (99.8%) May (78.8%) and June (52.7%), whereas insects accounted for the most weight in August (92.9%). Fish were present in the diet in June (44.0%) and August (1.9%). Salmonids accounted for all fish weight in June.

At John Day forebay, northern squawfish 100 to 249 mm in length were collected only in May-June and August-September samples (Fig. 4; Appendix Table 5). Crustaceans were the most important food item by weight during the earlier period (97.8%) and fish and insects were important by weight during the latter period (58.4 and 40.6%, respectively). No salmonids were found in these digestive tracts.

Fish was the major food item consumed by large northern squawfish (1 250 mm) at McNary tailrace during all sample dates (Fig. 5; Appendix Table 6). Salmonids comprised 49.8%, 74.2%, 44.1%, and 85.5% of the diet by weight in April, May, June, and August, respectively.

Figure 5. Percent weight of Mollusca (M), Crustacea (C), Insccta (I), non-salmonids (N), salmonids (S), and other food (F) in digestive tracts of large northern squawfish (≥250 mm) by sample period at McNary tailrace, Irrigon, Arlington, and John Day forebay, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses. Weights <4% are not included.

At Irrigon, large northern squawfish (Fig. 5; Appendix Table 7) fed primarily on fish in April (55.0%) and May (72.4%); salmonids occurred only in May and accounted for 30.6% of the diet. In June, the diet was more varied with a large percent of the diet accounted for by crustaceans (37.1%) and molluscs (20.3%) as well as fish (39.4%). Crustaceans were most important by weight in August (65.1%) while fish accounted for 24.2%.

The diet of large northern squawfish from Arlington was primarily fish (Fig. 5; Appendix Table 8) during April-early May (73.1%) and late May (60.9%). Salmonids were present in the diet during all sample periods, but were important by weight only during April-early May (61.1%) and late May (43.2%). Crustaceans became increasingly important with time and were the most important taxa by weight during June (53.9%) and August (69.1%).

Fish was the most important food item by weight in large northern squawfish at John Day forebay (Fig. 5; Appendix Table 9) during April-early May (73.4%) late May-early June (81.4%), and August-early September (83.5%). Salmonids were important by weight during all sample periods. During June-early July, crustaceans were the most important food by weight (69.2%).

Food Habits of Walleyes

Stomach contents of 339 walleyes, ranging in length from 176 to 801 mm ($\bar{x}$ = 559 mm), were analyzed. Over one-third (39.2%) of the walleyes collected had empty stomachs.

The diet of walleyes was composed primarily of fish, accounting for over 99% of the total weight of food consumed (Table 3). Suckers accounted for the highest percent by weight (36.9%) among six families of fish identified in the diet. Salmonids were the second highest at 18.1% with sculpins at 17.6%, sand roller at 13.49, and minnows at 12.0%.

Fish accounted for more than 95% of the diet by weight among walleyes in each 50 mm length group (Fig. 6). Among length groups with sample sizes >10, predation on salmonids was highest in walleyes between 550-599 mm (30.2%) and 600-649 mm (27.6%). A salmonid was found in the stomach of the smallest walleye analyzed (FL = 176 mm).

At McNary tailrace, fish comprised more than 99% of the diet by weight in all sampling periods (Fig. 7). Salmonids were more important to the diet in April (24.5%), May (37.6%), and August (58.101, than in June (6.9%) (Appendix Table 10).

Fish comprised greater than 98% of the diet by weight in all sample periods at Irrigon (Fig. 7). Salmonids accounted for 11.1, 25.0, <0.1, and 14.7% of the diet in April, May, June, and August, respectively (Appendix Table 11).

Five of the six walleyes captured at Arlington were caught in June. More than 99% of the food weight in June was fish with salmonids

Table 3. Percent occurrence and weight of food items in stomachs of walleyes ranging in length from 176 to 801 mm ($\bar{X}$ = 559 mm), John Day Reservoir, April 4 to September 2, 1984. Sample size and number of empty stomachs were 339 and 133, respectively.

Food item	Percent occurrence	Percent weight
MOLLUSCA	0.9	<0.1
Pelecypoda		
Corbicula manilensis	0.6	<0.1
Gastropoda	0.3	to.1
CRUSTACEA	7.1	<0.1
Copepoda	0.3	<0.1
Amphipoda	6.8	to.1
Anisogammarus spp.	0.6	<0.1
Corophium spp.	6.8	<0.1
INSECTA	5.6	to.1
Ephemeroptera	3.2	<0.1
Dermaptera	0.3	<0.1
Homoptera	0.3	<0.1
Coleoptera	0.3	<0.1
Trichoptera	0.9	<0.1
Diptera	1.2	<0.1
Unidentified Insecta	0.3	<0.1
OSTEICHTHYES	59.3	99.7
Salmonidae	15.0	18.1
Oncorhynchus tshawytscha	1.2	1.5
Salmo gairdneri	0.3	1.4
Unidentified Salmonidae	13.9	15.2
Cyprinidae	6.5	12.0
Acrocheilus alutaceus	1.8	7.8
Mylocheilus caurinus	3.5	2.4
Ptychocheilus oregonensis	1.8	1.9
Catostomidae		
Catostomus spp.	15.9	36.9
Ictaluridae		
Ictalurus spp.	0.3	0.1
Percopsidae		
Percopsis transmontana	15.6	13.4
Cottidae		
Cottus spp.	13.3	17.6
Unidentified non-Salmonidae	11.5	1.3
Unidentified Osteichthyes	2.9	0.1
OTHER FOOD	10.6	0.3

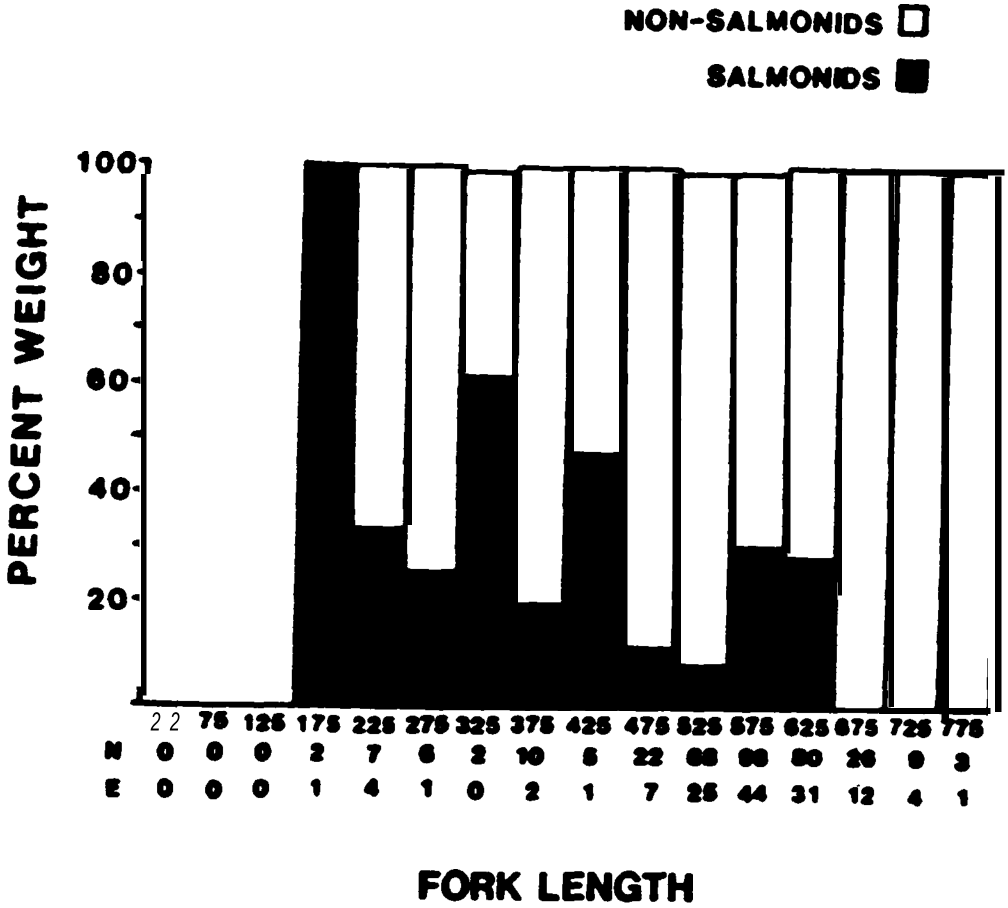

Figure 6. Percent weight of non-salronid and salmonid fishes in the diet of walleyes by predator length, John Day Reservoir, 1984. Lengths are midpoints of 50 mm intervals. N = number of stomachs analyzed; E = number of empty stomachs.

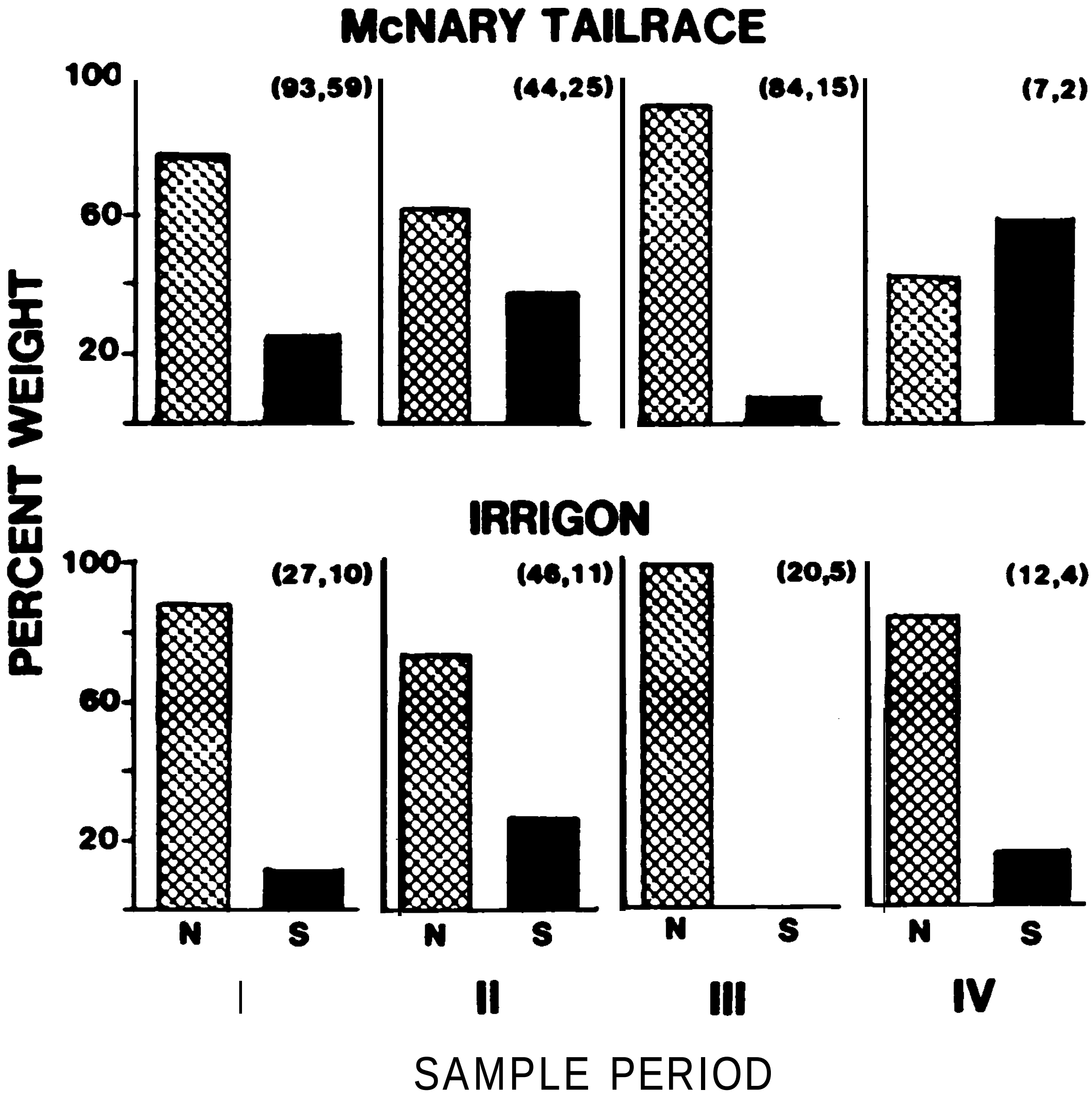

Figure 7. Percent weight of non-salmonids (N) and salmonids (S) in stomachs of walleyes by sample period at McNary tailrace and Irrigon, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses. Weights <4% are not included.

accounting for 40.5% (Appendix Table 12). No walleyes were taken from John Day forebay.

Food Habits of Smallmouth Bass

Stomach contents of 1,246 smallmouth bass, ranging in length from 53 to 582 mm ($\overline{x}$ = 240 mm), were examined. Nearly one quarter (21%) of the smallmouth bass examined had empty stomachs. In general, the diet of smallmouth bass consisted of fish and crayfish (Table 4). The primary fish taxa consumed were sculpins, suckers, and chiselmouth contributing 42, 15, and 9% to the total weight, respectively.

Fish comprised over 50% of the diet by weight for all lengths of smallmouth bass examined (Fig8). Salmonids occurred infrequently and contributed no more than 10% by weight in any length group. The smallest smallmouth bass to ingest a fish was 75 mm long and the smallest to ingest a salmonid was 98 mm in length.

Diets of smallmouth bass varied among sample stations. Fish accounted for more than 80% of the diet by weight in all sample periods at McNary tailrace and Irrigon (Fig. 9, Appendix Tables 13 and 14). Sculpins, sand roller, and suckers were the most common fish taxa in the diet at McNary tailrace but importance of individual taxa varied in each sample. At Irrigon, sculpins contributed most by weight in all samples, but decreased in importance from April (90%) to August (47%).

Crayfish and fish were the dominant prey groups consumed by smallmouth bass at Arlington (Fig. 9, Appendix Table 15) and John Day forebay (Fig. 9, Appendix Table 16), comprising 15.6 to 49.3% and

Table 4. Percent occurrence and weight of food items in stomachs of smallmouth **bass** ranging in length from 53 to 582 mm ($\bar{X}$ = 240 mm), John Day Reservoir, April 4 to September 2, 1984. Sample size and number of **empty** stomachs were 1,246 and 262, respectively.

Food item	Percent occurrence	Percent weight
MOLLUSCA	0.7	<0.1
Pelecypoda		
Corbicula manilensis	0.4	to.1
CRUSTACEA	48.1	2s.3
Cladocera	3.0	<0.1
Copepoda	1.6	<0.1
Isopoda	0.1	<0.1
Amphipoda	26.5	0.3
Anisogammarus spp.	12.9	0.1
Corophium spp.	17.5	0.1
Unidentified Amphipoda	2.4	<0.1
Decapoda		
Pacifastacus leniusculus	27.0	25.0
INSECTA	31 .o	0.1
Collembola	0.1	<0.1
Ephemeroptera	9.1	0.2
Odonata	0.6	0.1
Orthoptera	0.2	<0.1
Plecoptera	0.1	<0.1
Thysanoptera	0.3	<0.1
Hemiptera	2.1	to.1
Homoptera	1.1	<0.1
Coleoptera	1.1	<0.1
m l -	0.6	<0.1
	0.1	<0.1
% = -	17.8	0.1
Hymenoptera	3.0	0.1
Unidentified Insecta	4.3	to .l
OSTEICHTHYES	50.5	74.0
Clupeidae		
Alosa sapidissima	0.1	<0.1
Salmonidae	a.1	2.2
Oncorhynchus tshawytscha	0.2	0.0
Unidentified Salmonidae	2.1	1.3
Cyprinidae	7.5	10.3
Acrocheilus alutaceus	4.3	8.8
Mylocheilus caurinus	1.2	0.1
Ptychocheilus oregonensis	a.4	0.0
Richardsonius balteatus	0.2	to.1
Unidentified Cyprinidae	0.1	0.4
Catostomidae		
Catostomus spp.	11.1	0.0
Percopsidae		
Percopsis transmontana	2.6	3.5
Centrarchidae	0.9	0.2
Cottidae		
Cottus spp.	23.8	41.9
Unidentified non-Salmonidae	7.9	0.7
Unidentified Osteichthyes	5.9	0.2
OTHER FOOD	13.3	0.2

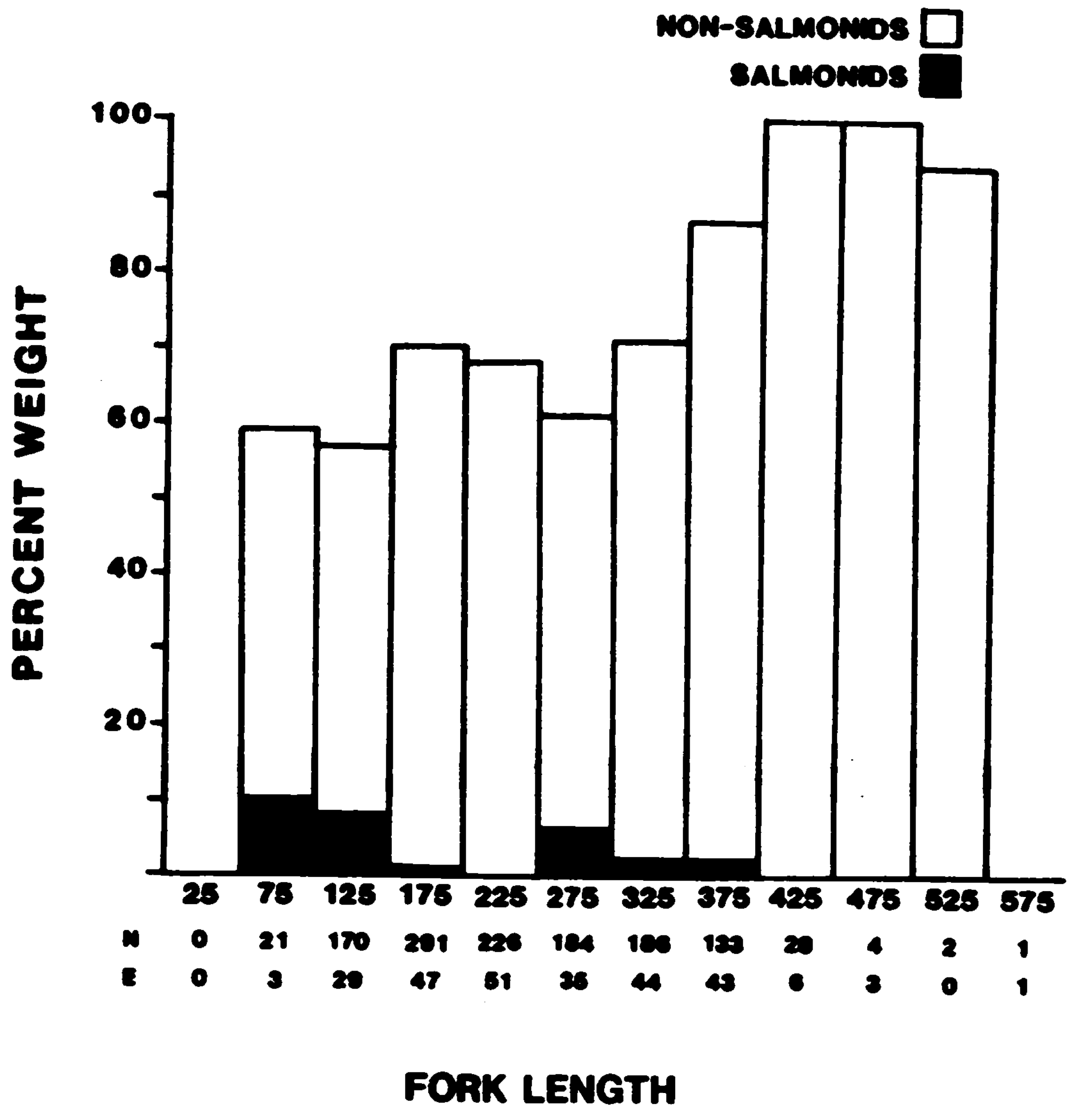

Figure 8. Percent weight of non-salmonid and salmonid fishes in the diet of smallmouth bass by predator length, John Day Reservoir, 1984. Lengths are midpoints of 50 mm intervals. N = number of stomachs analyzed; E = number of empty stomachs.

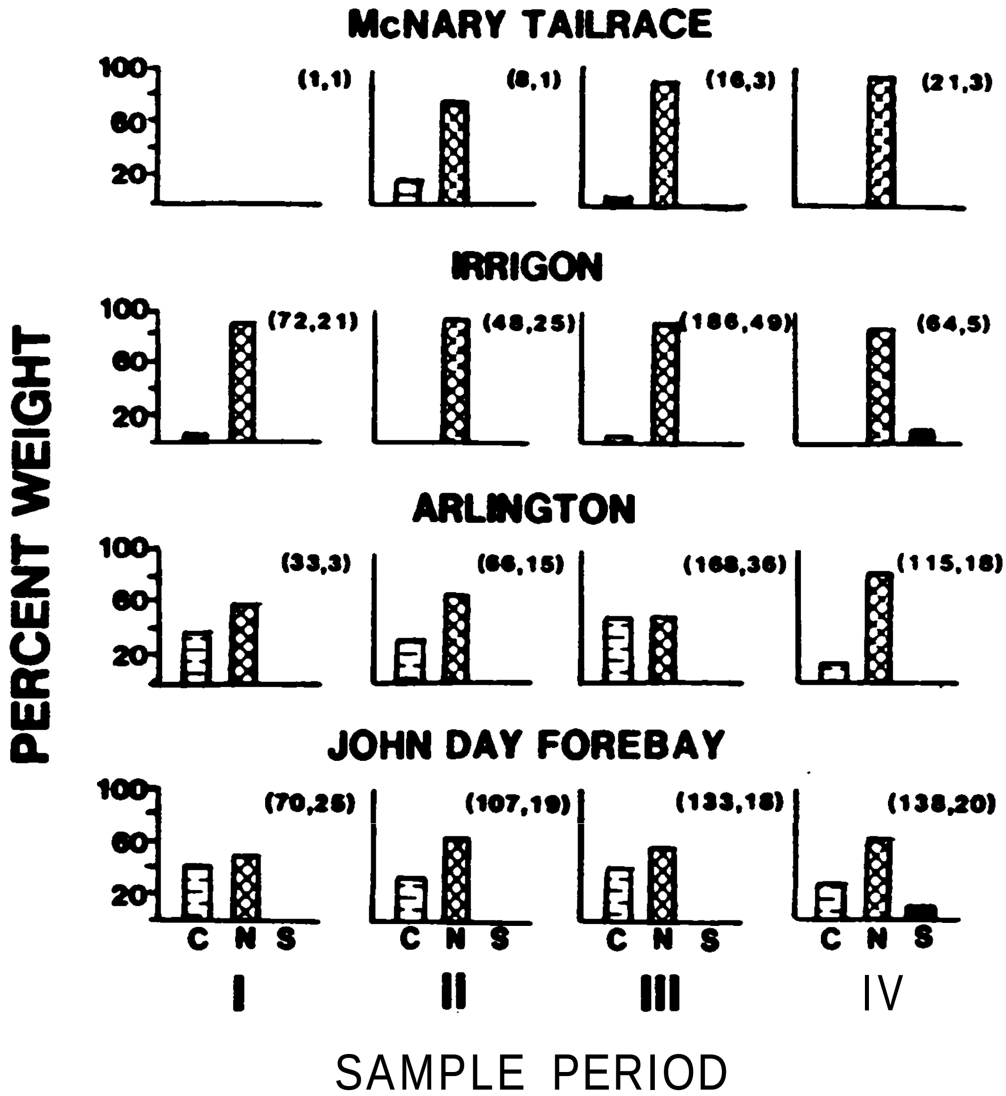

Figure 9. Percent weight of Crustacea (C), non-salmonids (N), and salmonids (S) in stomachs of smallmouth bass by sample period at McNary tailrace, Irrigon, Arlington, and John Day forebay, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses. Weights <4% are not included.

50.4 to 83.3% of the diet by weight, respectively, in all sample periods. The contribution of crayfish to the diet at both stations was greatest when fish contributed the least. Fish taxa primarily consumed at Arlington were sculpins in April, May, and June and suckers in August. At John Day forebay, sculpins contributed most by weight in April and August, and chiselmouth predominated in May and June.

Food Habits of Channel Catfish

Stomach contents of 161 channel catfish, ranging in length from 295 to 724 mm ($\bar{x}$ = 474 mm), were analyzed. Twenty-two (13.7%) of the stomachs were empty.

Fish accounted for 64.1% of the weight of prey items consumed by channel catfish (Table 5). Salmonids made up over 50% of the total fish weight. The smallest channel catfish to eat a fish was 352 mm and the smallest channel catfish to eat a salmonid was 399 mm. Crustaceans (primarily decapods) and molluscs accounted for 17.7 and 5.9% of the diet by weight, respectively.

The importance of fish in the diet of channel catfish generally increased with predator length and the contribution of salmonids to the diet generally decreased with length (Fig. 10).

At McNary tailrace, weight of fish in the diet of channel catfish increased with succeeding sample periods from 38.4% in April to 99.5% in August (Fig. 11, Appendix Table 17). Salmonids represented the major proportion of weight in the diet during April (31.1%),

Table 5. Percent occurrence and weight of food items in stomachs of channel catfish ranging in length from 295 to 724 mm ($\bar{X}$ = 474 mm), John Day Reservoir, April 4 to September 2, 1984. Sample size and number of empty stanachs were 161 and 22, respectively.

Food item	Percent occurrence	Percent weight
MOLLUSCA		
Pelecypoda		
Corbicula manilensis	9.9	5.9
CRUSTACEA	64.0	17.7
Isopoda	0.6	<0.1
Amphipoda	52.8	0.4
Anisogammarus spp.	5.6	to.1
Corophium spp.	49.7	0.4
Decapoda		
Pacifastacus leniusculus	22.4	17.3
INSECTA	31.1	0.8
Rphemeroptera	22.4	0.6
Coleoptera	0.6	<0.1
Trichoptera	0.6	<0.1
Diptera	8.7	0.2
Hymenoptera	0.6	<0.1
Unidentified Insecta	4.3	<0.1
OSTEICHTHYES	31.7	64.1
Salmonidae	12.4	34.3
Salmo gairdneri	0.6	6.4
Prosopium williamsoni	0.6	0.9
Unidentified Salmonidae	11.2	27.0
Cyprinidae	1.9	5.8
Hylocheilus caurinus	0.6	0.3
Ptychocheilus oregonensis	0.6	2.6
Cyprinus carpio	0.6	2.9
Catostomidae		
Catostomus spp.	2.5	2.6
Percopsidae		
Percopsis transmontana	1.9	0.8
Cottidae		
Cottus spp.	8.7	14.7
Unidentified non-Salmonidae	5.6	2.1
Unidentified Osteichthyes	6.2	3.8
OTHER FOOD	31.1	11.4

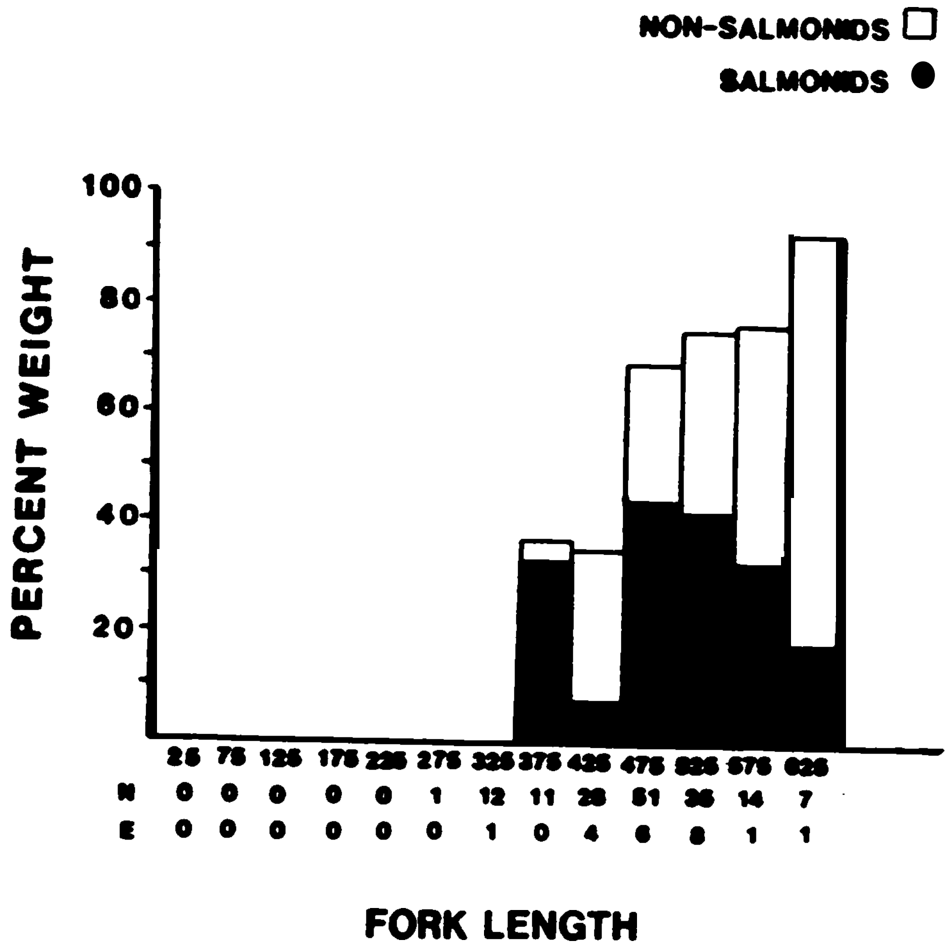

Figure 10. Percent weight of Don-salronid and salmonid fishes in the diet of channel catfish by predator length, John Day Reservoir, 1984. Lengths are midpoints of 50 mm intervals. N = nunber of stomachs analyzed; E = number of empty stomachs.

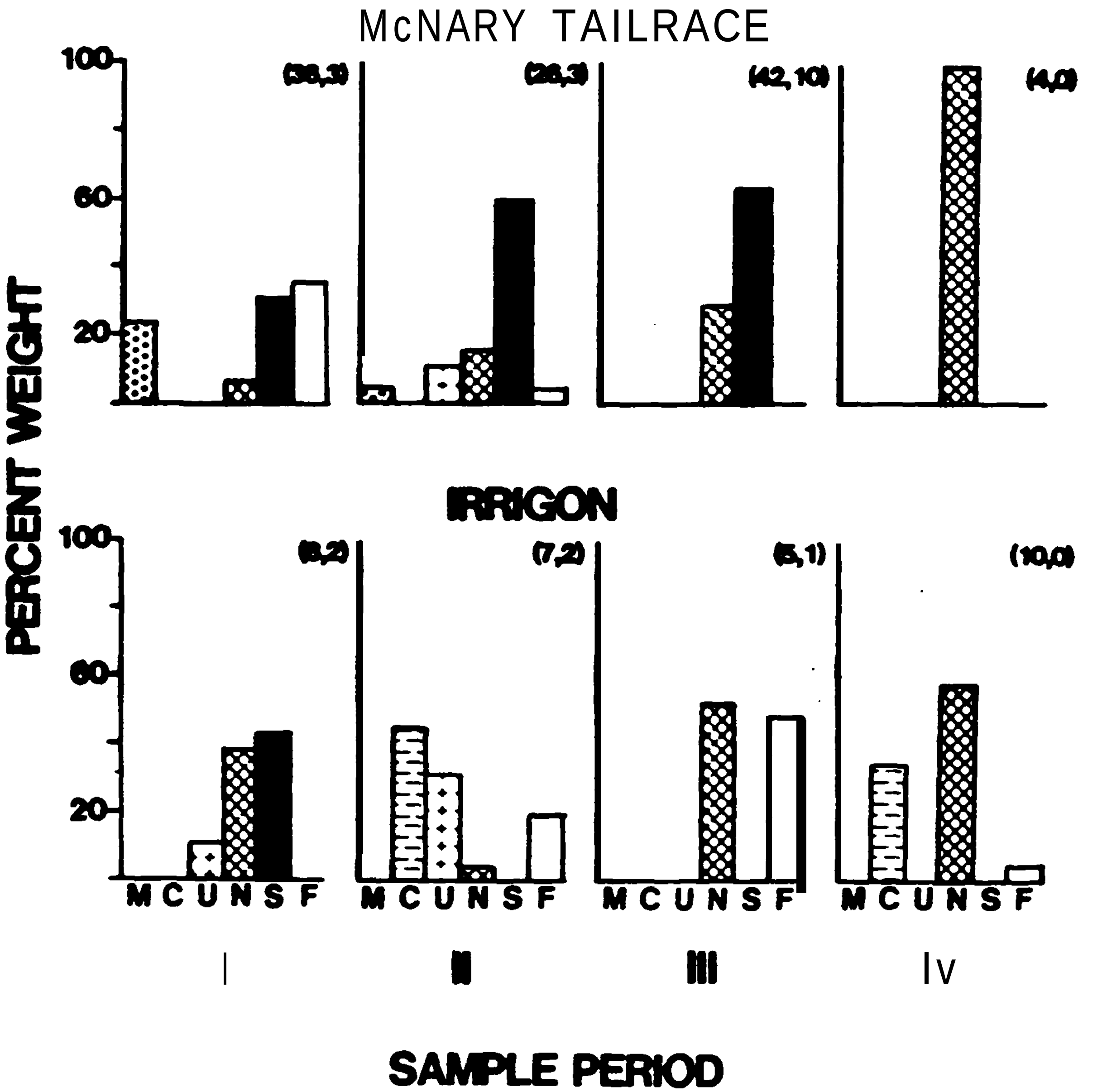

Figure 11. Percent weight of Uollusca (M), Crustacea (C), unidentified Osteichthyes (U), non-salmonids (N), salmonids (S), and other food (F) in stomachs of channel catfish by sample period at McNary tailrace and Irrigon, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses. Weights <4% are not included.

May (60.1%), and June (64.3%); no salmonids were found in the diet of channel catfish collected in August.

At Irrigon, fish was a major component in the diet of channel catfish during all sample periods (Fig. 11, Appendix Table 18). Salmonids comprised 42.8% of the diet by weight in April, but did not occur in the diet in May, June, and August. Crustaceans accounted for 45 and 34.2% of the diet by weight in August, respectively.

Channel catfish were collected at Arlington only in August. During that period, weight of crustaceans accounted for 94.4% of the diet (Appendix Table 19). Mean length of channel catfish collected at Arlington was substantially smaller ($\bar{x}$ = 354 mm) than mean length in the entire reservoir ($\bar{x}$ = 474 mm). No channel catfish were collected from John Day forebay.

Apparent Abundance of Predators

Mean catch per transect (CPT) of northern squawfish, walleyes, and smallmouth bass with boat electroshocker varied substantially among sampling stations (Table 6). Northern squawfish CPT were highest in restricted zones at McNary tailrace and John Day forebay with an overall CPT of 9.43 and 1.16, respectively. Overall CPT of northern squawfish out of restricted zones was less than 1.0 fish per transect. Catch rates of walleyes were highest at McNary tailrace and progressively decreased at stations downstream. Conversely, overall CPT of smallmouth bass was highest at John Day forebay and

Table 6. Mean catch per transect (CPT) of northern squawfish (≥250 mm), walleyes, and smallmouth bass collected with boat electroshocker by sample period at each station, John Day Reservoir, 1984.

Sampling station and period	northern squawfish ORZ[1]	northern squawfish RZ[2]	walleyes	smallmouth bass
McNary tailrace				
Apr 4 - Apr 21	0.36	6.44	0.45	0.09
May 5 - May 20	0.38	5.90	0.31	0.06
Jun 4 - Jun 22	1.13	14.11	1.50	0.13
Aug 1 - Aug 25	0.38	11.25		0.13
Overall CPT	0.56	9.43	0.57	0.10
Irrigon				
Apr 5 - Apr 22	0.50		0.25	0.31
May 6 - May 24	0.31		0.06	0.88
Jun 11 - Jun 17	0.44		0.19	4.06
Aug 3 - Aug 25	0.44			1.13
Overall CPT	0.42		0.13	1.60
Arlington				
Apr 19 - May 11	0.92			1.38
May 20 - May30	0.88			0.94
Jun 17 - Jun 26	0.31		0.19	3.31
Aug 19 - Aug 30	0.56			2.00
Overall CPT	0.67		0.05	1.91
John Day forebay				
Apr 19 - May 11	1.07	1.33	0.00	0.73
May 23 - Jun 8	0.50	1.45	0.00	4.56
Jun 21 - Jul 1	0.60	0.17	0.00	3.07
Aug 17 - Sep 2	0.69	1.67	0.00	1.63
Overall CPT	0.72	1.16	0.00	2.50

[1] Out of restricted zone
[2] Restricted zone

progressively decreased at stations upstream. Apparent abundance of predators fluctuated among sampling periods with no obvious trends discernable.

Apparent Abundance and Distribution of Prey Fishes

Chi-square analysis indicated that the beach seine was generally more effective than the boat electroshocker in capturing small prey fishes and usually equally effective in capturing larger prey fishes (Table 7). The beach seine was more effective in collecting smaller length groups of chinook salmon (< 75 mm), chiselmouth (5 75 mm), peamouth (≤75 mm), northern squawfish (< 100 mm), suckers (< 75 mm), sand roller (≤ 50 mm), and American shad (< 25 mm). No significant difference between gears was detected for larger length groups of chinook salmon (> 75 mm), peamouth (> 75 mm), northern squawfish (> 100 mm), sand roller (> 50 mm), and American shad (> 25 mm). The boat electroshocker was more effective than the beach seine in capturing chiselmouth and suckers >125 mm, but no significant difference between gears was detected for intermediate length groups of chiselmouth and suckers (76-125 mm) or any length group of sculpins.

Over 14,000 prey fish (< 250 mm) representing 10 families were collected by beach seine in John Day Reservoir from April to September, 1984 (Table 8). Prey fishes collected at main channel and backwater locations comprised 58.8 and 41.2% of the catch, respectively. Catch of prey fishes was highest at McNary backwater (Plymouth slough) and lowest at Arlington. Right prey taxa, including American shad, chinook

Table 7. Number of beach seine hauls[a] (BS) and boat electroshocking transects[b] (ES) in which prey fishes from various length groups were collected. Chi-square[c] values are given as a measure of heterogeneity between gears.

Length group (mm)	chinook salmon			chiselmouth			peamouth			northern squawfish		
	BS	ES	Chi-square	BS	ES	Chi-square	BS	ES	Chi-square	BS	ES	Chi-square
1 - 25	0	0		4	0	4.17[d]	4	0	4.17[d]	16	3	10.21
26 - 50	45	18	18.28	16	2	12.37	13	2	9.02	50	12	35.97
51 - 75	50	35	5.43	28	10	11.17	16	5	6.75	36	13	15.27
76 - 100	27	20	1.60	27	17	3.25	19	15	0.68	26	15	4.08
101 - 125	14	19	0.79	27	31	0.29	4	2	0.73[d]	46	41	0.75
126 - 150	18	24	0.95	13	25	4.44	3	4	0.13[d]	47	47	0.02
151 - 175	14	23	2.49	9	24	7.89	1	2	0.32[d]	16	18	0.10
176 - 200	8	15	2.26	8	24	9.24	3	1	1.07[d]	7	5	0.40
201 - 225	0	1	0.98[a]	3	10	3.89	0	1	0.98[d]	4	6	0.38[d]
226 - 250	0	0		1	3	0.98[d]	0	0		0	2	1.98[d]

[a] Total number of BS hauls = 93
[b] Total number of ES transects = 95
[c] Critical value of x^2 for X = 0.05 and df = 1 is 3.841
[d] Cannot he compared legitimately with table value because contingency table has expected frequency value(s) < 1 in a cell and/or < 5 in more than one-fifth of its cells.

Table 7. **(con't)**

Length group (mm)	suckers BS	suckers ES	suckers Chi-square	sand roller BS	sand roller ES	sand roller Chi-square	sculpins BS	sculpins ES	sculpins Chi-square	American shad BS	American shad ES	American shad Chi-square
1 - 25	12	1	10.25	4	0	4.17[d]	4	0	4.17[d]	8	1	5.88[d]
26 - 50	27	8	13.18	32	8	18.95	10	5	1.93	11	9	0.27
51 - 75	52	39	4.16	49	41	1.71	26	23	0.34	3	2	0.23[d]
76 - 100	64	55	4.08	25	34	1.73	25	35	2.15	0	1	0.98[d]
101 - 125	58	62	0.17	0	4	3.83[d]	22	30	1.47	0	0	
126 - 150	49	78	18.55	0	0		11	16	0.96	0	0	
151 - 175	53	81	18.35	0	0		6	5	0.12	0	0	
176 - 200	48	79	21.33	0	0		1	1	<0.01[d]	0	0	
201 - 225	25	65	32.49	0	0		0	0		0	0	
226 - 250	15	40	15.32	0	0		0	0		0	0	

[a] Total number of BS hauls = 93
[b] Total number of ES transects = 95
[c] Critical value of X^2 for X = 0.05 and df = 1 is 3.841
[d] Cannot be compared legitimately with table value because contingency table has expected frequency values(s) < 1 in a cell and/or < 5 in more than one-fifth of its cells.

Table 8. Catch and percent composition of preyfisher (≤250 mm) collected with beach seine, John Day Reservoir, April to September, 1984.

Common name	Scientific name	McNary tailrace	McNary backwater	Irrigon	Irrigon backwater	Arlington	Forebay	Total Catch	Percent Composition
American shad	*Alosa sapidissima*		17	4	284	20	269	574	3.9
coho salmon	*Oncorhynchus kisutch*	1						1	<0.1
sockeye salmon	*Oncorhynchus nerka*		1				1	2	<0.1
chinook salmon	*Oncorhynchus tshawytscha*	287	238	268	67	158	57	1075	1.4
rainbow trout	*Salmo gairdneri*		1	6	1		18	26	0.2
mountain whitefish	*Prosopium williamsoni*	9		2			6	17	0.1
chiselmouth	*Acrocheilus alutaceus*	26	69	27	5	28	1771	1926	13.2
goldfish	*Carassius auratus*	1		8				9	<0.1
carp	*Cyprinus carpio*		1		3	2		6	<0.1
peamouth	*Mylocheilus caurinus*	20	1101	59	6		1	1187	8.1
northern squawfish	*Ptychocheilus oregonensis*	87	1523	367	96	23	141	2237	15.3
dace[a]	*Rhinichthys* spp.					7	2	9	<0.1
redside shiner	*Richardsonius balteatus*	60	75	3	1	3	9	151	1.0
suckers[b]	*Catostomus* spp.	291	1823	1075	135	298	1367	4689	32.2
channel catfish	*Ictalurus punctatus*				1			1	<0.1
brown bullhead	*Ictalurus nebulosus*		9		1			10	<0.1
sand roller	*Percopsis transmontana*	560	68	847	25	69	6	1575	10.8
three spine stickleback	*Gasterosteus aculeatus*	6	21					27	0.2
sunfishes[c]	*Lepomis* spp.		40	1	34	5		80	0.5
smallmouth bass	*Micropterus dolomieui*	3	66	3	42	6	3	123	0.8
largemouth bass	*Micropterus salmoides*		61	3	18		1	83	0.6
crappies[d]	*Pomoxis* spp.	3	32	16	308	1		360	2.5
yellow perch	*Perca flavescens*		18	2	35	2		57	0.4
walleye	*Stizostedion vitreum vitreum*					1		1	<0.1
sculpins	*Cottus* spp.	40	34	21	41	59	160	355	2.1
Total catch		1394	4898	2712	1103	682	1792	14581	
Percent composition		9.6	33.6	18.6	1.6	4.7	26.0		

[a] Includes longnose dace (*Rhinichthys cataractae*) and speckled dace (*Rhinichthys osculus*).
[b] Includes largescale sucker (*Catostomus macrocheilus*) and bridgelip sucker (*Catostomus columbianus*).
[c] Includes pumpkinseed (*Lepomis gibbosus*) and bluegill (*Lepomis macrochirus*).
[d] Includes white crappie (*Pomoxis annularis*) and black crappie (*Pomoxis nigromaculatus*).

salmon, chiselmouth, peamouth, northern squawfish, suckers, sand roller, and sculpins comprised 93.4% of the total catch.

Mean catch per seine haul of major prey taxa varied among sampling stations for some taxa (Fig. 12 and 13). Catches of northern squawfish and peamouth were highest at McNary tailrace backwater, whereas, chiselmouth and sculpin catches were highest at John Day forebay. Catches of sand roller were highest at McNary and Irrigon main channel stations. Highest catches of chinook salmon were observed at main channel and backwater stations in the upper reservoir. Mean catch per seine haul of all prey taxa is sunmarized in Appendix Tables 20 and 21.

Temporal fluctuations in apparent abundance of prey taxa were most evident with anadromous forms (Fig. 12). Beach seine catch of chinook salmon was highest from April to June and lowest in August. American shad were collected with the beach seine only in August.

Temporal fluctuations in apparent abundance of resident prey taxa were highly variable and trends were usually not discernable except at stations where each taxon was most commonly found (Fig. 12 and 13). Mean catch of northern squawfish at McNary tailrace backwater was less than 60 fish per haul from April to June and increased to 234 fish per haul during August. Conversely, mean catch of sculpins at John Day forebay was highest during April, May, and June and lowest in August. Catches of chiselmouth at John Day forebay and peamouth at McNary tailrace backwater were substantially higher in May and June than catches observed in April and August. Mean catch of sand roller at McNary and Irrigon main channel stations was lower in April than during other time periods. No apparent pattern of temporal distribution was observed for suckers.

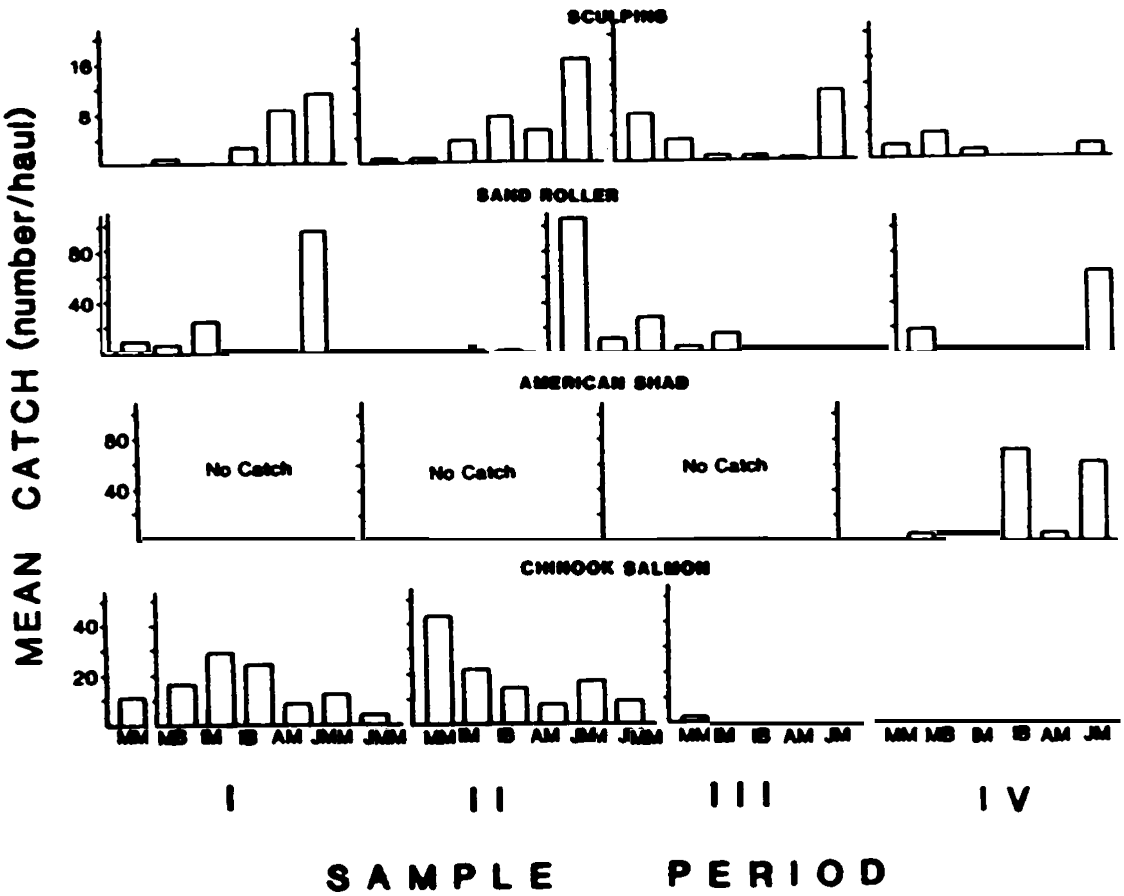

Figure 12. Mean catch per seine haul of sculpins, sand roller, American shad, and chinook salmon by sample period at McNary tailrace main channel (MM), McNary tailrace backwater (MB), Irrigon main channel (IM), Irrigon backwater (IB), Arlington main channel (AM), and John Day forebay main channel (JM), John Day Reservoir, 1984.

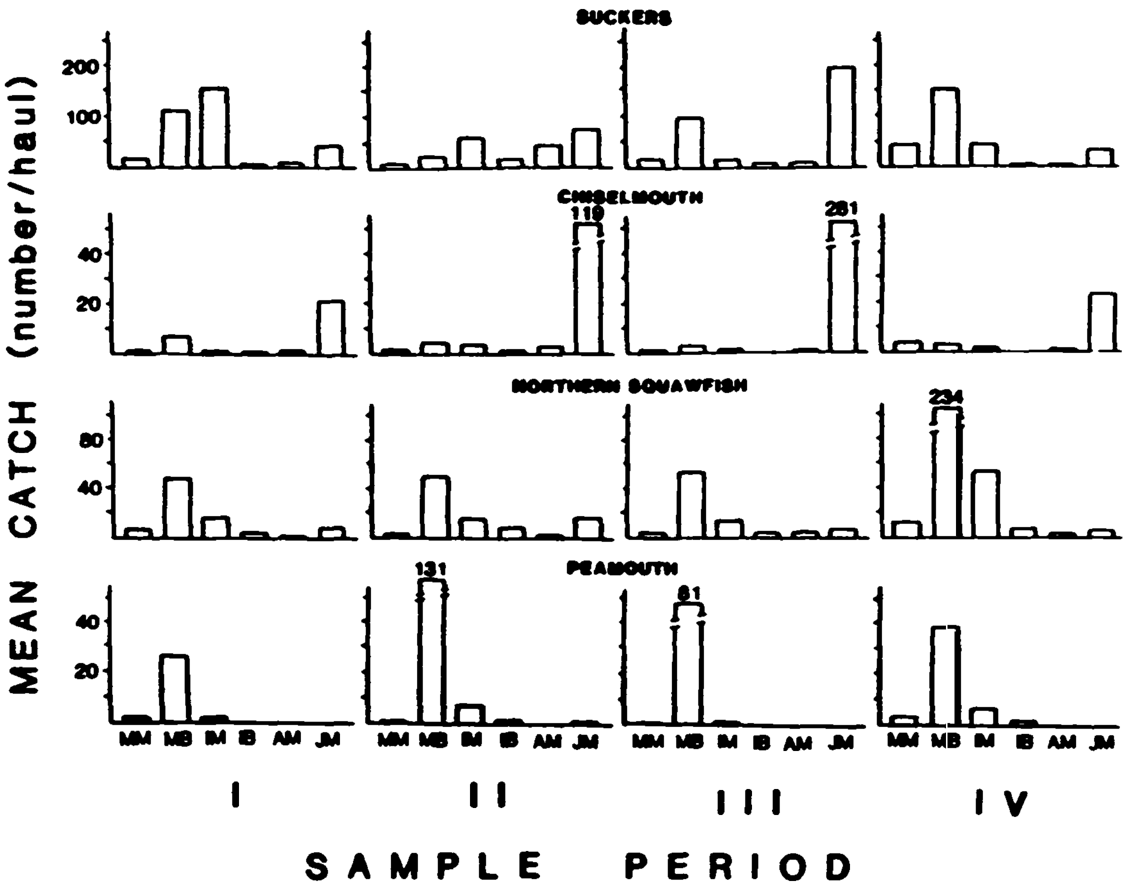

Figure 13. Mean catch per seine haul of suckers, chiselnouth, northern squawfish, and peamouth by sample period at McNary tailrace main channel (MM), McNary tailrace backwater (MB), Irrigon main channel (In), Irrigon backwater (IB), Arlington main channel (AM), and John Day forebay main channel (JM), John Day Reservoir, 1984.

DISCUSSION

The abundance and composition of prey items in the diets of northern squawfish, walleyes, smallmouth bass, and channel catfish, were generally similar to those of 1982 and 1983.

As in previous years, the highest concentrations of northern squawfish were in the restricted zones at McNary tailrace and John Day forebay. In these areas salmonids were the single most important food item by weight during April, May, June, and August. Similar to results in 1983, positive relationships between northern squawfish length and piscivory were also found as fish comprised a greater proportion of the weight of food items in the diet of larger predators. In 1984, as in previous years, no fish were found in the stomachs of northern squawfish less than 100 mm long.

As in 1982 and 1983, catches of walleyes were highest at McNary tailrace and Irrigon, and virtually nonexistent at John Day forebay. Catches were also low at the new Arlington station. Fish have accounted for almost all the weight of food consumed by walleyes in each year studied. In 1984, however, the percent weight of salmonids in the diet more than tripled that found in 1983 and doubled that found in 1982.

Salmonids were consumed by walleyes during all sampling periods at McNary tailrace and Irrigon in 1984. In 1983, this was true at McNary tailrace, but at Irrigon salmonids were not found in the diet during April or August. The increase in percent weight of salmonids in the diet at McNary tailrace from 1983 to 1984 was 8.7 to 24.5% in

April, 3.0 to 37.6% in May, 0.7 to 6.9% in June, and 22.4 to 58.1% in August. At Irrigon, the percent weight of salmonids in the diet during May increased from 13.2% in 1983 to 25.0% in 1984. As in 1983, a smaller percent weight of salmonids was consumed during June than in April, May or August at McNary tailrace.

As in previous years, smallmouth bass were widely distributed throughout the reservoir in 1984, but salmonids contributed little to their diet. Percent weight of salmonids in the diet was greatest in August, as was the case in 1983. As in the past, the contribution of fish to the diet decreased in the downstream portion of the reservoir (Arlington and John Day forebay) corresponding to increased predation on crayfish.

As in 1983, the majority of stomach samples from channel catfish were collected from McNary tailrace and Irrigon during 1984. At Arlington, channel catfish were collected only in August and none were collected at John Day forebay. Due to less gill net effort at Arlington and John Day forebay, however, these differences do not necessarily reflect the distribution of channel catfish throughout the reservoir. Fish was the major component in the diet of channel catfish during 1983 and 1984, accounting for 73.9 and 64.1% of the weight in the diet, respectively.

At McNary tailrace, salmonids comprised the largest proportion in the diet of channel catfish during April (3l.l%), May (60.191, and June (64.3%), but none were found during August. In 1983 the results at McNary tailrace were similar, but no salmonids were found in stomachs during April. At Irrigon, salmonids accounted for 42.8% of the weight in the diet during April 1984, but were not found in samples from May, June, or August. In 1983 at Irrigon, salmonids comprised over 42.5% of the weight in Hay, but were of little importance to the diet in other months.

In 1985, the 1984 sampling plan will be repeated to obtain additional food habits information at McNary tailrace, Irrigon, Arlington, and John Day forebay for the calculation of consumption estimates.

A comparison of beach seine and boat electroshocker catches in 1984 indicated the beach seine was generally more effective in capturing small prey fishes and usually equally as effective as the boat electroshocker in capturing larger prey fishes. Because the overall relative effectiveness of the beach seine for sampling prey fishes surpassed that of the boat electroshocker, catches with the beach seine were used to describe the composition, apparent abundance and distribution of prey taxa.

Composition of prey taxa in 1984 was similar to 1983 with American shad, chinook salmon, chiselmouth, peamouth, northern squawfish, suckers sand roller, and sculpins comprising over 93% of the beach seine catch during both years. As in 1983, differences in catch occurred among stations with concentrations of some taxa being found in distinct habitats within the reservoir.

In 1985, prey sampling will follow the same approach as 1984 except that only beach seining will be conducted. We will also evaluate beach seine efficiency for major prey taxa to obtain reliable estimates of prey abundance and reduce bias associated with gear selectivity. This will be accomplished by seining prey fishes within an enclosed area. Resulting information on beach seine efficiency will be used to adjust catch data to provide more accurate estimates of prey abundance. Accurate estimates of prey abundance are necessary for evaluating feeding selectivity of predators in John Day Reservoir.

In 1985, the results of single meal experiments for northern squawfish will be analyzed and equations and confidence intervals derived. The need for further experimentation will be assessed at that time. Effects of multiple meals will be evaluated for large predators eating medium prey (15-30 g) at 15 C with four hours digestion time. If multiple meals are found to have a significant effect on digestion time, further experiments will be conducted at other combinations of prey size, predators size, and temperature.

Experimentation to determine evacuation rates for smallmouth bass will begin in 1985, using water temperatures of 10, 15, and 20 C, prey less than 10 g, and smallmouth bass greater than 100 mm FL. Experimentation on walleyes will be conducted to evaluate the applicability of available evacuation rate formulas (Swenson and Smith 1972; Wahl and Nielsen 1985) to the range of water temperatures, prey sizes and size of walleyes found in John Day Reservoir.

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SECTION II - PREDATION CONTROL MEASURES

INTRODUCTION

The fourth project objective (see preface, page 1), to determine the feasibility of regulating predation on juvenile salmonids by major predators, was addressed by:

A) Identifying and describing potential predation control measures,

B) Preliminary evaluation of the biological feasibility of predation control measures and,

C) Identifying additional information needs.

Control measures considered include those that decrease the size of predator populations or reduce the susceptibility of juvenile salmonids to predation. Preliminary evaluation of control measures was limited to biological feasibility because the social and economic considerations, although exceedingly important, cannot be fully addressed until after the extent of juvenile salmonid losses has been more clearly delineated and the variety of potential control measures reduced to those most feasible. We emphasize that before a system-wide predation control program can be developed, the John Day Reservoir Predator/Prey Model (Project Objective No. 5) must be applied to other reservoirs in the Columbia River System to determine if serious predation problems exist elsewhere.

METHODS

Previously applied measures and strategies to regulate fish populations were identified from the literature. A computer literature search was conducted and searches of Sport Fishery Abstracts and Current References in Fish Research were also performed.

Criteria used to evaluate potential measures to reduce losses of juvenile salmonids by predation were: (1) demonstrated success, (2) applicability, (3) selectivity, (4) side effects, and (5) timeliness. To meet the first criterion, demonstrated success, a measure must have been used successfully in a majority of the fisheries field applications which we reviewed. To meet the second criterion, applicability, a measure must possess the attributes to be used effectively in a system of the type (i.e. cool water river with extensive network of dams) and size as the Columbia River; because many measures we reviewed were used in different types of systems and small bodies of water (e.g. warm water streams, farm ponds or small lakes) and could not be effectively applied in a system of the size of the Columbia River. To meet the third criterion, selectivity, a measure must be suitable for control of any of the four major predators in the system (northern squawfish, walleye, smallmouth bass, and channel) without having significant impact on other fish species in the Columbia River. To meet the fourth criterion, absence of side effects, a measure must not cause significant adverse environmental impacts (e.g. impacts on water quality, benthic invertebrates, etc.). To meet the fifth criterion, timeliness, a measure must be suitable for implementation within no more than two years and take no longer than four years to see a measurable effect (a six year maximum). A measure was considered to have high potential for reducing predation of juvenile salmonids if it met at least four of the five criteria, moderate potential if it met two or three of the above criteria, and low potential if it met fewer than two of the above criteria. We also rated a measure as having low potential if it had a side effect which was unacceptable even though it met all other criteria (e.g. a pathogen would not be acceptable to use even if it met all criteria but caused adverse effects on benthic invertebrates in the system).

Each of the measures rated as having high or moderate potential are discussed including summaries of past results, type of system where tested, and potential for use in the Columbia River. Those measures rated as having low potential are discussed in the Appendix II A-D.

RESULTS AND DISCUSSION

Measures to control predation were rated as having high, moderate, or low potential for reducing predation on juvenile salmonids in the Columbia River reservoirs (Table 1). As our ratings in Table 1 indicate, there were often insufficient data available to rate many of the measures for certain criteria, therefore additional research and testing of many of these measures would be needed before a final evaluation can be made.

Table 1. Preliminary evaluation of predation control measures based on their potential to reduce predation on juvenile salmonids in the Columbia River **reservoirs.**

Measure	Criteria					Potential[2]
	Demonstrated • ·□·♋	Applicability	Selectivity	Absence of side • ♦♂□□♦♋	Timeliness	
Predator Control						
Netting & trapping	+[1]	•	•	•	I	High
Electrofishing	0	♦		+	I	Moderate
Explosives	•	□	⧖	I	I	Low
Harvest regulations	□	•	+	+	I	Moderate
Water level manipulations	•	+	I	I	0	Moderate
Squoxin	•	+	•	I	I	Moderate
Antimycin	+	•	□	0	+	Low
Rotenone	+	□	□	0	•	Lou
Sterilization	♦	I	+	•	□	Moderate
Predator introduction	I	+	□	□	□	Low
Pathogen introduction	I	+	♦	□	♦	Low
Prey Protection						
Dam lighting	I	+	+	•	•	High
Release • •♦♦♋	I	+	+	+	+	High
Release times	I	+	+	+	+	High
Release number	I	•	+	+	♦	High
molt bypass location	I	+	+	•	+	High
Electrical barriers	I	+	0	I	I	Lou
Bubble barriers	0	•	□	I	♦	Low
Hydro-acoustics	0	+	0	I	1	Low
Predator • ttrooUnta	I	+	+	+	0	Moderate
Predator repellents	I	+	+	+	0	Moderate
Alternate prey introduction	I	+	0	0	I	Low
Predator-avoidance conditioning	I	+	•	+	♦	Low

[1] + = Met criterion
0 = Old ■□♦ • ·♦ criterion
I = Insufficient information to rate • wwro.

[2] High = Met 4 or 5 criteria
Moderate = Met 2 or 3 criteria
Low = Met 0 or 1 criteria or • oaourm would have • l4m • Ilwt(ob which is unacceptable even though all other criteria were met.

Predator Control Measures

Historically, when loss of prey fish to predators has been considered undesirable, recommendations have emphasized reducing the size of the predator population. Ihis may be accomplished by either direct kill of predators or reduction of reproduction and subsequent recruitment. There are many techniques which can be utilized as predator control measures but they can all be classified as either physical, chemical, or biological measures.

Physical Control Measures

Population manipulation by the physical removal of undesirable fish and habitat manipulation through control of water level fluctuations have played major roles in fishery management. The goals of removal efforts have been to reduce predation (Foerster and Ricker 1941; Meacham and Clark 1979; Moore et al. 1984) but removal efforts have also been used to reduce competition for food (Rawson and Elsey 1950; Byrd and Moss 1957; Byrd and Crance 1965; Priegel 1971; Johnson 1977; Hanson et al. 1983) and remove species that destroy habitat (Ricker and Gottschalk 1940; Rose and Moen 1952; McCrimmon 1968). Physical removal measures which were reviewed included: netting and trapping, electrofishing, water level manipulation, use of explosives, and change of harvest regulations. The feasibility of using explosives was considered to have a low potential for controlling predators and the discussion of this measure may be found in the Appendix II A.

Netting and Trapping Netting and trapping have been used to reduce predator populations and populations of fish that have individuals present in such numbers or condition (e.g. stunted) as to make them undesirable from a management viewpoint. Past efforts show varying degrees of success, but were often deemed effective (Table 2). Many studies, however, have failed to conduct post-removal evaluations to document effectiveness of removal efforts, in changing the long-term population structure of the targeted species. Thus, actual long-term benefits are difficult to assess.

Netting and trapping may be advantageous over chemical and biological treatments for some systems because it is relatively affordable, allows better control of size and species removed, mortality of non-target species is known, an improved fishery can often be obtained in a short time, and removal can be accomplished with non-technical assistance (Hanson et al. 1983). Removal by netting and trapping also has little or no impact on the abiotic environment.

The primary limitation of netting and trapping is that it depends largely upon vulnerability of the target species and effort expended. Except in backwaters and other protected areas, netting and trapping in the relatively swift-flowing Columbia River reservoirs would likely have limited application particularly in highly turbulent tailwaters below dams where predators often concentrate. Seasonal movements of walleye and northern squawfish out of areas accessible to nets and traps presently make these species difficult to locate at times. McCrimmon (1968) suggested that seines be used with caution because

Table 2. Summary data from studies on the effectiveness of netting and trapping as a control measure.

Measure	Duration of effort (yrs)	Type of system & size (ha)	Target species[1]	Results	Reference
Trapnets, hoopnets, and trawls	11	lake 55,730	freshwater drum	-decrease in the average age of drum -did not reduce gamefish populations -some gamefish populations increased	Priegel 1971
Seining and trapping (intensive)	12	lake 567	bigmouth buffalo, carp, freshwater drum	-decline in target fish -increase in game fish	Rose & Moen 1952
Fyke nets	5	ponds & lakes 9-109	mostly centrarchids, yellow perch white perch	-species removed showed increased growth rates -number of large gamefish did not increase	Grice 1958
Gillnetting, dynamiting, reservoir fluctuation, and rotenone	6	Hayden lake 1540	northern squawfish	-24,000 lbs. of northern squawfish removed -catches of predators declined 90% over the length of the experiment -improved fishing for salmonids	Jeppson & Platts 1959

Table 2. (con't.)

Measure	Duration of effort (yrd)	Type of system & size (ha)	Target species[1]	Results	Reference
Gillnetting and seining	6	Cultus Lake 626	northern squawfish & Arctic char	-decrease of northern squawfish and Arctic char to 10% previous levels -young sockeye salmon 2 1/2 to 4 1/2 times greater survival	Foerster & Ricker 1941
Confinement of fish	1	4 large lakes interconnected by swift streams, Wood River system	Arctic char	-estimated 900,000 smolts saved	Meacham & Clark 1979
Gillnets, trammel nets, hoop nets, angling, and poison chemicals	15	Heming Lake, <1	northern pike	-number of northern pike was reduced -main emphasis: disrupt life cycle of a parasite infecting lake whitefish -little angling done -initial chemical attempts considered futile	Lawler 1965
Fyke nets	1	English Lake 20	black crappie black bullhead	-removal of large numbers of small blackcrappie and black bullhead increased growth rates for these same species	Hanson et al. 1983

[1] Common names are used here and throughout the remainder of the report, and the scientific names for each species mentioned may be found in Appendix II E.

they scour the bottom fauna and could denude sport fish habitat, especially spawning areas.

Electrofishing Electrofishing normally involves the application of DC electricity to water to produce electronarcosis in fish. Since electrofishing is most effective in shallow water, fish that prefer littoral areas are collected most efficiently. One of the most effective electrofishing techniques used in small to medium-sized rivers involves electrofishing downstream to an alternating current electrical barrier. One or more electrofishing boats are used to "herd" fish into the barrier where they are stunned and captured. Studies where electroshocking was utilized in capturing large numbers of fish are summarized in Table 3.

Advantages of electrofishing are that it allows capture of fish in areas that are relatively inaccessible to other gears (e.g. flooded timber or dense aquatic vegetation), this method is highly selective as to which fish are removed since non-target fish can be released immediately without harm, and produces offers minimal impact on the environment. It would be effective on smallmouth bass that are found in littoral areas of the Columbia River and northern squawfish are also vulnerable especially in boat restricted areas near Columbia River dams. Channel catfish are infrequently collected with electroshocking equipment and would not be susceptible to control by this method whereas walleye may be vulnerable in some systems when they are spawning.

Table 3. Selected examples of studies where electroshocking was used as an effective measure for capturing large numbers of fish.

Habitat	Target species	Results	Reference
Small streams (Great Smokey Mountain National Park)	rainbow trout	-time-consuming and labor-intensive, but useful for small streams	Moore et al. 1904
Large river (Yellowstone River)	none specified	-with larger rivers, deeper areas and faster currents, efficiency decreased -small portion of river can be sampled -electrofishing effective to 3-4 meters -faster current, less exposure to the field and shallower response depth	Peterman 1978
Marshes, sloughs, lakes, and ponds	bullhead largemouth bass muskellunge walleye northern pike rainbow trout carp	-most effective for larger fish -not as efficient as netting (smaller CPUE) for smaller fish -population control not economically or technically feasible for bullheads nor carp compared to seining and trapping -limited use for other species	Newbury 1973
Large river (Pilica River)	miscellaneous fishes (18 species)	-capturing efficiencies for 18 different species ranged from 28 to 82%. -AC electrical barrier was effective in shallow areas	Mann & Penczak 1984

Water Level Manipulation Water level manipulation can be used to increase or decrease fish population size depending upon the timing and degree of fluctuation (Table 4). Stable or increasing water levels during spawning and embryo development usually benefits reproductive success, while fluctuating or decreasing water levels are detrimental (Hassler 1970; Nelson 1980; Martin et al. 1981). Water level manipulation can be used to expose spawning areas, dessicate nests or eggs, strand newly-hatched fry, and drive adults off nests, thereby exposing eggs and fry to predation. Manipulating water levels is most effective on species that spawn in shallow water, are reproductively stenothermal, and/or have fry stages that inhabit shallow water during development.

Temperature variations, as a consequence of water level manipulation, can also reduce reproductive success by inundating spawning and/or nursery areas with cool water. The resulting temperature shock can prevent or delay spawning and reduce survival of eggs and fry (Table 4).

Life history data on northern squawfish, walleye, smallmouth bass, and channel catfish (Table 5) indicate that water level manipulations might be used to reduce the reproductive success of several of these predators in the Columbia River.

Necessary conditions for spawning and embryo development of smallmouth bass (Table 5) make this species vulnerable to water level fluctuations. In the Hanford reach of the Columbia River, water level fluctuations resulted in cold water entering spawning areas. The temperature change retarded sexual maturation of adult smallmouth bass,

Table 4. Summary data from studies on the effects of water level manipulation on fish populations.

Size (ha)	Duration of study (yrs)	Species affected	Results	Reference
Lake Tohopekaligia	1	game & forage species	-increase in desirable plants and macroinvertebrates -enhanced population of game and forage species	Wagener & Williams 1974
Lake Oahe and Lake Sharper 126,800; 22,400		northern pike	-deterioration of ova with subsequent low year-class strength	June 1970
Lake Oahe 126,800		yellow perch	-newly inundated terrestrial vegetation associated with spawning success and year-class strength	Nelson & Walburg 1977
Lake Francis Case 27,700		young-of-year fishes	-flooded shoreline vegetation -enhanced reproductive success	Martin et al. 1981
West Point Reservoir 10,480		largemouth bass	-high water levels increased reproductive success -decreased young-of-the-year mortality -decreased growth of young-of-the-year largemouth bass	Miranda et al. 1984
Lake Oahe 126,800	4	larval fishes	-success of reservoir-spawning species dependent on above-average water levels	Nelson 1980

Table 4. (con't.)

Size (ha)	Duration of study (yrs)	Species affected	Results	Reference
Hayden Lake 1300	4	northern squawfish	-drawdowns of Scm/day Scm/day when water temperatures above 15.5°C would destroy eggs	Jeppson 1957
Fort Randall Reservoir 30,000	2	carp	-drawdowns of 0.5-0.6 meters lasting S to 9 days were successful in reducing reproductive success	Shields 1958
Cross Lake	2	lake whitefish cisco	-dewatering spawning areas -reduced hatching success	Gaboury & Potalas 1984
		northern pike walleye	-prevented from reaching preferred spawning areas	
Lake Oahe and Lake Sharpe, 126,800; 22,400	S	northern pike	-decline in temperature from 10.5°C to 7.5°C was associated with high mortality (75%) during early embryonic development	Hassler 1970
Western Lake Erie	11	walleye	-slow spring warming reduced year-class strength and lengthened egg incubation period -increased chance of exposure to low oxygen levels, siltation, disease, predation, currents and turbulence	Busch et al. 1975

Table 5. Pertinent life history information for smallmouth bass (SMB), walleye (WAL), northern squawfish (SQF) and channel catfish (CHC).

Species	Spawning time and temperature	Spawning substrate and depth	Temperature requirements	Behavior
SMB	-late May to July (19, 36)[a] -13 to 18°C (36)	-sand, gravel or rocky substrate near protection of logs, rocks or dense vegetation -depth of 0.3 to 1m (30)	-incubation 15°C - 10 days 25°C - 2 days (16, 31, 34)	-adult male guards eggs until hatching (36) -fry may remain near the nest for several days depending upon the temperature (7) -fry disperse among aquatic plants along the shoreline after emergence from the nest and move into grassy cover as water rises (24)
WAL	-late April to mid-May in John Day Reservoir (19) -6 to 11°C (30)	-rocks, gravel or rubble (36) -dense mats of vegetation (27) -rarely sand and silt (13) -depths of 0.1 m (9) to 4.6 m (3, 15) -typical depth about 1.5 m (2, 5, 13, 23)	-optimum fertilization 6-12°C -optimum incubation 9-15°C (17) -incubation 14°C - 7 days 4°C - 26 days (36)	-fry are pelagic and fingerlings demersal (8, 25) -benthic fry found at depths of 0.3-1.2 m (14, 29)

Table 5. (con't.)

Species	Spawning time and temperature	Spawning substrate and depth	Temperature requirements	Behavior
SQF	-late May to Aug (19, 33) -15 to 20°C	-clean gravel cobble with depths up to 3.6 m (28) -depths usually less than 0.3 m (10, 11, 32)	-15 to 20°C-7 days (10, 36)	-SQF was the dominant larval species occupying littoral microhabitats less than 0.15 m in John Day Reservoir (18) -fry school in shallow water for several weeks (11)
CHC	-late July and August -21°27°C (26, 30, 36)	-hollow logs, burrows, undercut banks or (in impoundments) rubble and boulders of protected shorelines at depth of 2-4 m (12)	-incubation optimum 27°C (4, 6) -hatching 16 to 18°C - 9 to 10 days 27°C - 6 to 7 days (6, 36) -growth of fry optimum 29-30°C (35) poor growth at less than 21°C (1, 20, 22)	-newly-hatched fry remain in the nest 7 to 8 days (21) then disperse to shallow areas with cover (9)

[a] Numbers in parentheses refer to following references:

1 Andrews et al. 1972
2 Arnold 1960
3 Baker 1964
4 Brown 1942
5 Clay 1962
6 Clemens & Sneed 1957
7 Coble 1975
8 Colby et al. 1979
9 Cross & Collins 1975
10 Jeppson 1957
11 Jeppson & Platts 1959
12 Jester 1971
13 Johnson 1961
14 Johnson 1969
15 Keller & Manz 1963
16 Kerr 1966
17 Koenst & Smith 1976
18 LaBolle & Li 1985
19 Li et al. 1981
20 Macklin & Soule 1964
21 Marzolf 1957
22 McCammon & LaFaunce 1961
23 McCrimmon & Skobe 1970
24 Montgomery et al. 1980
25 Moy 1978
26 Pflieger 1975
27 Priegel 1970
28 Reid 1971
29 Ryder 1977
30 Scott & Crossman 1973
31 Sigler 1959
32 Stewart 1966
33 Stober et al. 1978
34 Webster 1948
35 West 1966
36 Wydoski & Whitney 1979

increased nest abandonment, delayed spawning, and retarded or halted egg development (Montgomery et al. 1980). Declining water levels drove males off nests, permitting increased predation on eggs and reduced water circulation over the eggs. In addition, smallmouth bass **fry,** are vulnerable to trapping, dessication, thermal **stress,** malnutrition and predation when water levels recede (Montgomery et al* 1980; Becker et al. 1981).

Walleye are also vulnerable to water level fluctuations during spawning and embryonic development (Table 5). Chevalier (1977) found that low water levels during the spring may cause spawning in less that optimum locations, thereby reducing year-class strength. slow spring warming, cold weather fronts, rapidly fluctuating water levels and release of cold water into tailraces have all been associated with poor embryo survival (Pfitzer 1967; Busch et al. 1975; Groen and Schroeder 1978). Walleye recruitment from reproduction within John Day Reservoir has been low (Nigro et al. 1985) suggesting that something already has impacted reproductive success.

More research is needed to better understand the life history characteristics of northern squawfish (Brown and Moyle 1981), however, Several of the known life history characteristics do suggest they may be susceptible to water level manipulation (Table 5). Jeppson (1957) reported that a 1 meter **drawdown** at a mean rate of 0.1 m/week during June and July when water temperatures were above 15.5°C caused significant mortality of northern squawfish eggs in Hayden Lake, Idaho. Unfortunately little is known on the timing and location of northern squawfish spawning in Columbia River reservoirs. As with other target species, if a large portion of the population spawns in tributaries, drawdown of the reservoir will have little effect.

The spawning depths of channel catfish should make them invulnerable to water level fluctuations. However, the high thermal requirements for spawning and embryo development (Table 5) make them susceptible to temperature fluctuations. Inundation of spawning and nursery areas with cool water might delay spawning or retard development of channel catfish eggs and fry. Reduction of the water level may adversely impact channel catfish fry.

To effectively develop a program to reduce reproductive success of Columbia River predators using water level manipulation, it will be necessary to gain a better understanding of the reproductive requirements of the targeted predators in the Columbia River. Further research needs include: information on larval and juvenile fish abundance, distribution and subsequent recruitment data for target species. Finally, the logistics of water level manipulation in the reservoirs (i.e. magnitude, timing, duration, legalities) need to be analyzed before any recommendations are made.

Harvest Regulations The application of fishery regulations (sport and commercial) to reduce fish predators is not well documented. Fishing regulations have traditionally been employed for resource allocation and conservation. Harvest regulations usually include size limits, catch limits, and restricted fishing seasons. Since there are presently no closed seasons for sport fishery harvest of the target species, regulation by restricted fishing seasons will not be discussed.

None of the target predator species is currently being harvested commercially.

The application of size limits is a commonly employed technique in sport fisheries management. Size limits may be established to protect potential spawners, reduce the removal of fish until they reach a minimum size, maximize fishing yield, and prevent overharvest. The affect of minimum size limits is generally to reduce removal of younger fish (Table 6), therefore allowing a greater proportion of the population to grow to a larger size. Removal of size limits should cause a shift in age structure due to greater exploitation of smaller fish. This would severely impact the reproductive potential of the population by reducing the number of times the average fish spawns and the number of females that will survive to larger, more fecund egg producers.

Creel limits reduce the average daily harvest (Allen 1955) and are usually enacted to conserve potential spawning stock and equalize angler catches by reducing the catches of the more successful anglers and making more fish available to the less successful anglers. Unrestricted creel limits might also tend to increase fishing pressure because some fishermen who would have quit fishing after having caught the limit, will continue to do so as long as they are on the water. Removing creel restrictions may initially encourage people to fish more often, assuming they will be able to bring home more fish.

Liberalizing existing regulations for walleye in John Day Reservoir through increased creel limits and lifting of size restrictions would not likely increase harvest significantly. The

Table 6. Selected examples of studies where alteration of fishing regulations was used as a control measure.

Measure	Arab & Location	Target Species	Results	Reference
Minimum size limit (305 mm)	Pony Express Lake, Missouri	largemouth bass	accumulation of slow-growing ● ubloqol fish	Ming & McDannold 1975
Minimum size limit (381 mm)	Big Crooked Lake, Wisconsin	walleye	-four-Cold decrease in yield (kg/hectare) and ● n9l.r catch of legal fish first four years -number of sublegal walleyes increased -growth, condition factor, • ՁՁ■ length and weight of angled walleye declined	Serns 1979
Minimum ● lro limit (559 mm)	Escabana Lake, Wisconsin	northern pike	number of fish increased by 90% and growth rate decreased	Kempinger & Carline 1970
Minimum size limit	none ● pooiyld	walleye	● lmulrtlon modeling: lower or no minimum size limits are more likely to decrease total number of fish caught, population biomass, and reproductive potential of the population	Schneider 1978
Creel limits	none specified	smallmouth bass	-creel limits are usually considered unnecessary because few fishermen catch their limit -pressure from some individuals who consider the limit • ● 9oal' may increase	Coble 1975
Minimum size limit (406 mm) and or.01	Franklin Delano Roosevelt Reservoir	walleye	-regulations suggested in response to a decline in average ● 9b and size of fish -regulations initiated on 1 January, 1985. -initial observations: 50% decline in ● nplor effort, 60% of the fish caught are undersized	Beckman et al. 1985 and Hisata, pers. comm.

small size of the adult population coupled with an apparent low recruitment of juvenile walleye (Nigro et al. 1985) precludes sustained angling interest if catch per unit effort declined. Success on other reservoirs may differ, since the small average size of walleye on Roosevelt Reservoir was probably due to over fishing, and restrictions were suggested to prevent a collapse of the fishery (Beckman et al. 1985).

Estimated abundance of smallmouth bass in John Day Reservoir was low relative to walleye and northern squawfish (Nigro et al. 1985). Present liberalized regulations reflect light angling effort for smallmouth bass which are considered underutilized (Steven Williams, Oregon Department of Fish and Wildlife, personal communication). Increasing creel limits with unrestricted size limits would not reduce smallmouth bass populations in John Day Reservoir unless angler effort increased greatly.

There are currently no catch, size or possession limits on angling for channel catfish in John Day Reservoir. Channel catfish may not be common in the reservoir, and few anglers fish for them; most are caught incidentally. Increased channel catfish harvest is unlikely given existing fishing regulations.

The population of northern squawfish was estimated to be the most abundant of the predators under investigation in John Day Reservoir (Nigro et al. 1985). Northern squawfish are not classified as a game fish although, a related species, the Sacramento squawfish, once formed a substantial sport fishery in Clear Lake, California (Taft and Murphy 1950). Opportunities exist to exploit northern squawfish concentrations near Columbia River dams during periods of salmonid outmigrations. One option would be establishing squawfish tournaments (Tony Nigro, ODFW, personal communications) Similar to the annual series of "fishouts" to remove Sacramento squawfish at Red Bluff Diversion Dam, California (Vondacek and Hoyle 1983). A bounty on northern squawfish could also be implemented to provide ongoing predator control. Over $300,000 was spent in western Alaska from 1920 to 1941 for bounties on Dolly Varden in the belief they were serious predators on juvenile sockeye salmon (Norton 1982). Norton (1982) subsequently found that Dolly Varden are no more serious a predator than any other species of trout or char. Such a program should be adequately monitored because abuses have been observed in previous programs. Hubbs (1941) documented that during one Dolly Varden bounty program in Alaska, substantial numbers of rainbow trout and juvenile coho salmon were harvested for bounty.

The potential for significantly reducing fish predators through increased sport fishery effort appears to be minimal, except during certain times (spawning periods), in localized areas, or during species congregations. Angling pressure is influenced greatly by potential fishing success, density of nearby human population, and access to the water. The section of the John Day Reservoir closest to the Portland, Oregon metropoliton area is 170 km away. This distance coupled with minimum accessibility, current low annual success for target species and variable weather conditions likely preclude substantial increased angling effort and subsequent reduction in the size of predator populations.

Presently, three of the four target predators are classified as game fish, and cannot be harvest commercially. If these fish were reclassified, there would be a potential for a commercial fishery. The smallmouth bass population is considered small (Nigro et al. 1985) and would probably not support such a fishery, but walleye and channel catfish are fished commerically in other areas of the country (Tarzwell 1944; Carroll et al. 1961; Elsey and Thomson 1977; Hale et al. 1981) so these species have potential for supporting a commercial fishery in the Columbia River. Northern squawfish could be harvested for the fish meal, protein concentrate, or pet food markets, as it has been considered less palatable than the game species.

A combination of more intensive recreational and commercial harvest might produce the most reduction in population size. A commercial fishery on Lac Des Mille Lacs showed that angling was selectived for 4-6 year old walleye, while the commercial fishery mostly harvested fish 5 years and older, especially ages 8 to 11, with age 10 fish being predominant in the catch (Elsey and Thomson 1977). A large percentage of fish older than 6 years would probably not have been harvested without the commercial fishery and these fish represent a large proportion of the reproductive potential of the population. If recreational anglers generally take smaller channel catfish, or only a small portion of the populations a commercial fishery would have a much greater impact on the population than the recreational fishery. A modified recreational-commercial harvest might be developed so that sportsman would be allowed to sell their catches, thus creating an incentive for a more intense "recreational" fishery. Special licensing would be required to fund an ongoing monitoring program. There has been considerable commercial harvest of non-game species in the Columbia River for human consumption and other protein supplementation markets (Pruter 1966). Carp, steelhead, salmon, American shad, eulachon, white sturgeon and the Pacific lamprey are and have been harvested with success. Continuation of the fishery was dependent upon market conditions and consumer demand. The question of whether a commercial fishery designed to reduce predator populations could be profitable warrants further investigation. It has been demonstated that declining catches and fluctuating market prices may discourage commercial fishermen after an initial "boom' period during the opening of a fishery to commercial harvest (Carroll et al. 1961; Pruter 1966; Elsey and Thomson 1977).

Chemical Control Measures

Fish toxicants (piscicides) have been used extensively in the United States since the 1930's to manipulate fish communities through selective, partial, or total fish kills. A search for more selective piscicides during the 1950's resulted in the development of squoxin for use on squawfish and TFM (3-trifluoromethyl 4-nitrophenol) for use on sea lamprey. Current environmental policies and regulations require development of selective toxicants with little adverse effect on non-target species and the environment. Presently, only four piscicides are registered by the U.S. Food and Drug Administration and the U.S. Environmental Protection Agency: rotenone and antimycin for general piscicidal use, and two lampricides, TFM and Bayer 73.

Squoxin, antimycin, and rotenone were reviewed as potential piscicides for target predators in the Columbia River. Rotenone and antimycin are readily available in forms that facilitate handling and application, however, neither toxicant is specific. Therefore, we considered these piscicides as unlikely candidates for control and a discussion on their effectiveness and potential is in the Appendix II B. Although not yet registered for piscicide use, squoxin was evaluated because it is selective for northern squawfish (MacPhee and Ruelle 1969; Rulifson 1985).

Squoxin Squoxin, a stable white crystalline powder, is a phenol compound with industrial applications in rubber manufacture, epoxy resin hardening and extraction of metal chelates. Squoxin was found to be a selectively lethal toxicant to northern and Umpqua squawfish through a large-scale screening program (MacPhee and Ruelle 1969). Squoxin works on the nervous system as a vasoconstrictor, restricting blood vessel function and oxygen uptake (Lennon et al. 1970).

Several laboratory studies have been conducted to determine the effectiveness of squoxin as a piscicide. One of the most important attributes of squoxin is its selectivity for northern squawfish (Table 7). Selectivity indices are expressed as a ratio of LC_0/LC_{100} which compares the maximum concentration that will not kill any of the non-target species (LC_0) versus the LC_{100} for northern squawfish. Therefore, the higher the value the less likely a non-target species

Table 7. Selectivity Indices of squoxina for various salmonid species.

Non-target species	Temperature (°C)	Selectivity Indices	Reference
Coho salmon	10.0	87	MacPhee & Ruelle 1969
	12.8	100	
	15.6	100	
Chinook salmon	10.0	7	
	12.8	10	
	15.6	12	
Steelhead trout	10.0	87	
	12.8	100	
	15.6	100	
Sockeye salmon (newly-hatched)	4.4	0.9	Johnston 1972
	7.2	1.5	
	10.0	6	
	12.8	9	
Sockeye salmon (fry and fingerlings)	4.4	7[b]	
	7.2	3[c]	
		7[d]	
		11.7[b]	
		5.0[c]	
		11.7[a]	
	10.0	53.3	
	12.8	90	

[a] Selectivity Index: (LC_0/LC_{100}) is defined as the ratio of the highest concentration that will kill 0% the non-target organisms (LC_0) to the lowest concentration that kills 100% of the northern squawfish (LC^{100}) (MacPhee & Ruelle 1969).

[b] Before fish contracted disease (costiasis).

[c] With the disease.

d After treatment (1 week).

would be affected. These values varied with non-target species and temperature (Table 8), but indicate the relative non-toxicity Of squoxin to Columbia River salmonid species and their life stages. If trends of sockeye salmon are indicative of other salmonid Species, squoxin should be used with caution when disease is present or at low temperatures with early life stages (Table 9). Comparison of available LC_{50} values of various Columbia River fishes suggests that application of squoxin would probably cause little mortality to non-target fishes (Table 8).

Because water temperature is positively correlated with toxicant effectiveness and selectivity, timing of application is critical. The majority of juvenile salmonids in the Columbia River system have outmigrated by late summer when surface temperatures reach 20 C or higher, a temperature considered more effective with high kills and more rapid dissipation. The negative impact of late summer application on juvenile salmonids would be minimized and effect on predators maximized with application at that time.

Numerous field studies have demonstrated the ability of squoxin to kill northern squawfish (Table 10) and its relative non-toxicity to non-target species (Table 11). Results from these studies indicate that squoxin is an effective and selective fish toxicant. Everhart and Youngs (1981) list six criteria for the development and use of fish toxicants. Squoxin conforms to these criteria to a great degree because it is a relatively non-toxic to non-target organisms, is no more difficult to apply than other toxicants, and is relatively safe to

Table 8. Lethal concentrations (ppb) of squoxin for selected Columbia River fishes within 96 hours (LC_{50}).

Species	Temp (°C)	LC_{50}	Reference
northern squawfish	10.0	8	MacPhee & Ruelle 1969
	12.8	6	
	16.0	3	
rainbow trout	12.0	225	U.S. Department of the Interior 1969
coho salmon	12.0	189	
chinook salmon	10.0	375	MacPhee & Chenq 1974
	12.5	400	
gold fish	12.0	239	
carp	12.0	490	
chiselmouth	10.2	65	U.S. Department of the Interior 1969
redside shiner	10.2 - 10.6	180	MacPhee & Bailey 1973
	14.8 - 15.3	130	
torrent sculpin	10.2 - 10.6	900	MacPhee & Cheng 1974
	15.0 - 15.3	600	

Table 9. Toxicity of squoxin for various concentrations, duration and temperatures.

Species	Squoxin concentration (μg/liter)	Duration of test hours; temperature	Conclusions	Reference
northern squawfish	15 LC_{100}[a] 6 LC_{100} 15 15	96; 10°C 96; 18°C 96; 10°C 31.3 hours MST 96; 18°C 3.3 hours MST	Increased temperature increases squoxin toxicity lower concentrations needed to produce lethal dosages to 100% of the fish (LC_{100}) or shorter mean survival time (MST)	MacPhee & Ruelle 1969
sockeye salmon fingerlings	70 LCo 30 LCo 70 LCo	96; 4°C 96; 4°C 96; 4°C	Disease (Costia) lowers highest concentration tolerated before mortalities occur (LCo).	Johnston 1972
Various zooplankton species	8-100 LCo	168; 12.8°C	10 zooplankton species representing sockeye salmon prey exhibited no mortality	Johnston 1972

[a] Selectivity Index: (LCo/LC_{100}) is defined as the rate of the highest concentration that will kill 0% the non-target organisms (LCo) to the lowest concentration that kills 100% of the northern squawfish (LC_{100}) (MacPhee & Ruelle 1969).

Table 10. Summary data from studies on effects of squoxin on northern squawfish under field conditions.

Location, size	Squoxin concentration (µg/liter)	Results	Reference
St. Joe River, 35 km	75-130, usually 100	-several treatments -heavy reduction of northern squawfish numbers	MacPhee 1969; Reid 1970; MacPhee & Reid 1971
North Fork John Day River, 56 km	50	-complete kill of northern squawfish	Swan 1972
North Fork John Day River, 89 km	100	-estimated 30,000 northern squawfish killed	Claire 1973
Lower Smith River 24 km	100	-estimated 10,000 northern squawfish killed	Swan 1973a
Molalla River 32 km	100	-some northern squawfish killed	Whitworth & Collins 1973
Phillips Reservoir 5 km shoreline	100	-effective, but no enumeration	Swan 1973b
2 km shoreline	100	-ineffective, squoxin precipitated from solution	
Chehalis River System	100	-killed "tens of thousands" of northern squawfish	Watson 1972
Phinetta Lake, 27.5 ha	70	-apparent complete kill of northern squawfish	Cartwright 1973
Lagoon-Rochat Creek <1 ha	50	-almost a complete kill of all northern squawfish observed	MacPhee & Ruelle 1969

Table 11. Summary data from studies on effects of squoxin on non-target organisms under field conditions.

Location, size	Squoxin concentration (µg/liter)	Results	Reference
St. Joe River, 35 km	100	-72 hours of sampling revealed no change in drift patterns of Diptera, Ephemeroptera, Plecoptera, Trichoptera or Coleoptera	Brusven & MacPhee 1974
Chehalis River System	100	-a few minnows and sculpins killed -no adverse effects on aquatic indicator organisms	Watson 1972
Phinetta Lake, 27.5 ha	70	-no adverse effects noted on six fish species	Cartwright 1973
North Fork Clearwater River, 163 km	100	-large numbers of chiselmouth killed	Ball & Connor 1972
North Fork John Day River	100	-numbers of redside shiners, dace and chiselmouth were killed immediately below metering sites	Claire 1973
Lower Smith River, 24 km	100	-a few dace and sculpins killed	Swan 1973a
Molalla River 32 km	100	-a few dace killed	Whitworth & Collins 1973
Lagoon 4 ha	50	-no observed mortality of redside shiner, largescale sucker, brown bullhead, and yellow perch	MacPhee & Ruelle 1969

apply. No adverse effects were noted during field applications (Crowley 1974) and in the field squoxin degrades over 90% within seven hours (Burnard et al. 1974). Except for temperature, various water quality and chemistry differences do not significantly affect toxicity. Success in reducing predator population size in the Columbia River with toxicants would require development of specialized delivery equipment and techniques to insure proper dispersal of the toxicants. Studies have indicated that temperature affects the toxicity of squoxin with minimum lethal concentrations (ppb) required to kill 100% of the northern squawfish (LC_{100}) decreasing with increasing water temperature. Mortality of zooplankton also appears to be no problem.

There is no doubt that squoxin will kill northern squawfish in the Columbia River and could be used to effectively reduce the population in John Day Reservoir as demonstrated by the field trials summarized by Crowley (1974). The selectivity of squoxin makes its use for northern squawfish much more desirable than either antimycin or rotenone. It is the only toxicant available that is highly selective for any one of the four predators under investigation in this study.

The biggest obstacle to overcome before using squoxin as a piscicide will be registration which may take as long as 5 to 6 years. Further research needs to be conducted before squoxin can be registered and an economic evaluation of its merits must be completed before it can be applied (Rulifson 1985).

Biological Control Measures

In recent years there has been an increasing concern about the use of chemicals to control pests. In response, scientists have attempted to develop methods of biological control which accentuate natural methods of population regulation. Biological controls such as sterilization and introduction of predators and pathogens are generally much more species specific than other pest control measures. **That** is, their effects are most dramatic upon the target species, and have little or no effect on non-target organisms. The potential for the success of introduction of predators or pathogens was considered poor and a discussion of these measures may be found in the Appendix II C.

Sterilization Sterilization was the only biological control measure we considered feasible. Sterilization of a proportion of one sex (usually the males) of a species and the subsequent release of these individuals into a natural population has led to population suppression in insects **(Knipling** 19681, mammalian predators **(Balser** 19641, and parasitic sea lampreys (Hanson and **Manion** 19801. Most efforts at chemical and physical control of populations are usually discontinued after the target population has been reduced because the results per unit of effort are reduced. However, the reproductive potential of the target species may result in a rapid population expansion which negates the efforts of removal. The sterility method of pest control, on the other hand, becomes more effective as population size declines and the ratio of sterile to fertile individuals increases.

The mechanism of population reduction through sterilization entails releasing individuals into the environment that do not produce viable gametes and therefore cannot reproduce; pairing and mating of a sterile individual with a fertile one will produce no young. Therefore, those gametes that might have produced young had the fertile individual mated with another fertile individual are 'wasted".

Sterilization is most effective when there is a large parental investment in finding a mate, courting, nest building, and other such energetically and temporally "costly' behaviors. Sterilization works best when mating is monogamous because all of the female's reproductive effort is wasted. The presence of only a small proportion of sterile males will have little effect on a population of polygenous (one female mating with several males) breeders.

Hanson and Manion (1980) discussed the basic requirements and type of data needed to evaluate the feasibility of a sterilization program- Those factors were:

1) a method of inducing sterility without serious adverse effects on mating behavior and competitiveness of the males,
2) quantitative information on the density and rate of population increase as a guide for determining the necessary rate of overflooding with sterile males,
3) a method for and cost evaluation of capturing and sterilizing a portion of the natural population or rearing and releasing the required number of sterile males,
4) the cost of maintaining control by continuing sterile male releases compared to other methods,

5) hazards to humans and the environment when other methods are employed must be evaluated,

6) the release of sterile males must not outweigh the benefits of population control.

Sterilization of large numbers of animals can be achieved by feeding (Balsar 19641, injection of chemicals (Hanson and Manion 1980), or by artificial propagation of genetically sterile individuals (Stanley 1976). Ultrasonic exposure has also been reported to cause destruction of the reproductive organs in herring (Rumyantsey 1960).

Population control through sterilization should pose no threats to the environment, provided the method of sterilization was carried out carefully. The potential exists for almost complete eradication of a population, though the control efforts must be extended through several generations of the target organisms lifespan (Knipling 1968). Cessation of a control program would allow the target population to recover, should population control become undesirable. The time-lag for recovery would depend upon the ratio of sterile males to non-sterile males present and the reproductive potential of the species.

The sterility technique may be most useful for controlling populations of smallmouth bass and channel catfish in the John Day Reservoir because both species mate in single pairs. Control of northern squawfish and walleye with this method would be more difficult because several males usually spawn with a single female. However, if the permanent sterilization of young male fish with a long life expectancy could be achieved, the continued release of these fish could eventually result in "swamping" the natural population with sterile males, thus achieving population control.

Prey Protection Measures

Alternatives to controlling salmonid predation by reducing predator populations are to reduce predator-prey encounters or to improve predator avoidance by juvenile salmonids. Prey protection techniques are designed to reduce predation without altering predator population size. Prey protection measures which we considered include: (1) changing the location and pattern of juvenile salmonid releases, (2) development of predator restricted zones, attractants, and repellents, (3) predator avoidance conditioning and (4) use of alternate prey species. The use of alternate prey was not considered to have much potential for reducing predation and a review of this measure may be found in the Appendix II D.

Juvenile Salmonid Releases

The migratory behavior patterns of juvenile salmonids reflect evolutionary adaptations that could be useful in devising strategies to reduce predatory losses. Researchers have shown the timing of salmonid alevin activity, emergence, and migration is set early in development (Dill 1970; Dill and Northcote 1970; Carey and Noakes 1981) to take advantage of reduced light levels which decrease the probability of detection and capture by predators (Ali 1959; Brett and Groot 1963;

Ginetz and Larken 1976). Light sensitivity is so acute among some salmonid species that moonlight can reduce nocturnal migrations (Pritchard 1944; Kobayashi 1964). Predation on coho salmon fry by sculpins has been shown to increase during moonlit nights (Patten 1971). Changes in light intensity, as well as other conditions such as turbidity, current and depth which are presumed to affect hunting efficiency of predators, have been shown to affect the magnitude of migration of juvenile salmonids (Bakshtanskiy et al. 1980).

Change of release sites Changing hatchery release sites may be an effective prey protection measure. A study on Lake wenatchee in Washington compared sockeye salmon fingerling in diets of Dolly Varden trout and northern squawfish directly before, during, and after hatchery releases (Thompson and Tufts 19671. The mean number of salmon in predator stomachs and the percentage of the predator population that had eaten salmon increased during hatchery releases. Size ranges and presence of fin clipped salmon in predator stomachs confirmed that most were of hatchery origin. The mean number of salmon eaten, percentage of the predator population eating salmon, and number of predators collected all decreased after releases were completed. Evidently congregation of predators, and concentration and disorientation of prey led to increased vulnerability in areas of hatchery release, which in turn increased the number of juvenile salmonids being eaten.

Northern squawfish are known to congregate near hatchery outlets and fishery personnel have observed predation on juvenile salmonids in those locations (Thompson and Tufts 1967). Hatchery release sites could be moved during fish releases to reduce prey concentration and predator congregation although this may cause problems with imprinting. Releases should be avoided when large populations of predators are residing nearby unless predation can be thwarted by deterring or removing predators.

Sites where transported fish are released could also be relocated to increase survival of juvenile salmonids. Predators, especially northern squawfish, are known to congregate in slack waters near at least two dams on the Columbia River (Gray et al. 1983; Nigro et al. 1985). Similar problems have been observed at the Red Bluff Diversion Dam in California (Vogel and Smith 1984). Salmonids that are released in these areas may be safe as long as they stay within turbulent zones, but may be preyed upon more heavily when they seek out slower water where predators are more prevalent.

At certain locations along the Columbia River a change of release sites may reduce predation on juvenile salmonids, however, whether predator congregation actually occurs needs to be documented. The impact of changing release sites may cause a change in the distribution of predators, especially a reduction in the number of predators at "traditional* release stations. Some increased localized competition with resident fishes may occur at new release sites as predators immigrate into the area; however, these populations have coevolved with competing salmonids, and the impact would probably be minimal.

Changing smolt bypass locations may also be an effective prey protection measure. Smolt bypass structures are designed to guide fish away from the hydroelectric powerhouse intake through an alternate pathway to reduce turbine-related injury and mortality (Long and Krcma 1969). The upper portion of the water column is diverted and fish move into a collection area where they may be sorted, counted, marked, and released below the dam via the bypass structure. This structure is often a modified sluiceway that releases fish relatively close to the dam (Krcma et al. 1982). The terminal end of the bypass extends into the river a short distance and water pressure expels juvenile salmonids across the upper part of the water column.

Upon exiting a bypass release structure prey fish are often disoriented and may not be able to effectively avoid predation. Observations of Sacramento squawfish behavior at RBDD bypass outlet by SCUBA divers suggested that release of juvenile salmonids higher in the water column resulted in increased visibility of prey and higher rates of predation (Vogel and Smith 1984). The number and success rates of attacks by Sacramento squawfish were fewer after juvenile salmonids had found cover nearer to the substrate and had begun to school.

There appears to be potential for increasing the survival of juvenile salmonids by changing the design or location of the bypass outlet. A one-time alteration of existing bypass outlets would probably require no more maintenance than the existing outlets, and environmental impacts would be negligible. Locating the terminal end of the release structure nearer to the river bed would reduce the silhouetting effect that has been suggested to increase predation (Keenleyside 1979). Any alteration of existing bypass facilities should consider design strategies to help control predation, including:

1) a smooth flow pattern without eddies, flow shears or abrupt changes in velocity.
2) positive, unidirectional downstream flow under all flow conditions.
3) a multiple outlet bypass system.
4) a bottom release bypass outlet.
5) artificial turbidity.
6) an environment that is not structurally complex since it can result in increased predation by providing locations for waiting predators (Cooper and Crowder 1979 and Delta Fish Facilities Technical Coordinating Committee 1980).

Die1 release patterns Crepuscular periods may be particularly hazardous times for prey. Visually-oriented predators often hunt during these times (Keenleyside 1979) when prey may be less successful at detecting and avoiding predators. The lights illuminating dams may create an extended artificial crepuscular period, thus exposing juvenile salmonids to increased risk of predation over a longer period of time. At RBDD, evidence from Vogel and Smith (1984) suggests that predation on juvenile salmonids by Sacramento squawfish during day releases was greater than at night with the dam lights turned off.

Release procedures at dams may also produce unnecessary losses of juvenile salmonids. Although migration of these fish occurs during a 24-hour period throughout the reservoir, passage through dam facilities occurs mainly at night, peaking between 2200 and 0200 hours

(Simms et al. 1981). However, because passage can take anywhere from a few to twenty-four hours (Brad Eby, U.S. Army Corps of Engineers, personal communication; Umatilla, OR) fish may not exit the bypass at night which may increase the probability of being eaten by predators.

The releases of hatchery fish and those that are transported may not always be at times that are beneficial to survival. Currently all barged fish are released about midnight. Release of fish from trucks generally occurs at night, although this depends largely upon scheduling conflicts and competing priorities (Donn Park, National Marine Fisheries Service, personal communication). Release times at hatcheries may occur at anytime of the day.

The potential to increase survival of juvenile salmonids through changes in timing of release and alteration of lighting conditions at dams has potential. Evaluation of night releases and comparisons of mortality of juvenile salmonids during the night with the dam lights off versus mortality with the dam lights on are needed to determine strategies that increase survival of juvenile salmondis. we also need to increase our basic knowledge of the feeding behavior of northern squawfish under different conditions of light, current, and depth.

Number of fish released The migration behavior of juvenile salmonids has several characteristic patterns, one of which is synchronized migration with distinct peaks in abundance being noted (Basham et al. 1983; Delarm et al. 1984; Koski et al. 1985). Predator population size stays essentially fixed during prey population peaks. Prey behave so as to "swamp" predators over a short period of time and many more prey are encountered than predators could possibly eat. Prey in excess of the limited number eaten by predators will survive. This swamping effect has been shown to reduce the percentage of the population eaten (Table 12). Results of these studies suggest that swamping was at least part of the juvenile salmonid survival strategy. Releasing juvenile salmonids in large numbers should be given high priority for hatchery, barge, and truck release sites because this would reduce predation by creating a swamping effect. At bypass facilities, the temporal distribution of releases could be changed by holding the fish for a longer time. Instead of fewer fish continually trickling out of a bypass over 24 hours, if they could be held and released at night, swamping would occur.

Predator-restricted zones, attractants and repellents

Reduction of the number of predators in the areas surrounding release sites would decrease predation due to predator congregation. Low survival of juvenile salmonids at RBDD on the Sacramento River has been attributed to congregations of Sacramento squawfish below the dam. Vondracek and Moyle (1983) point out that the congregation of Sacramento squawfish at the RBDD may be due in part to available food below the dam, but, also to the poor passage facilities that exist. Sacramento squawfish migrate toward RBDD before spawning, which occurs during April and June, producing an overlap with releases of hatchery salmon. A similar situation may occur along the Columbia River.

Table 12. Studies on the "swamping" effects of high numbers of prey on predation efficiency.

System location	Prey species	Results	References
Little Togiok River, Alaska	sockeye salmon	-high smolt abundance (20,000 smolts/day) overwhelmed overwhelmed Arctic char, reducing risk of predation	Ruggerone & Rogers 1984
Hooknose Creek, British Columbia	pink and chum salmon	-predators remove relatively fixed number of prey with fluctuating fry abundance affecting the percentage of fry being eaten	Hunter 1959
McClinton Creek, British Columbia	pink salmon	-because predator levels are fairly fixed, prey mortality becomes depensatory at low population levels	Neave 1953

Establishment of a zone with fewer predators could be achieved in a number of ways such as by using electrical barriers, turbulence, acoustics, and chemical methods to repel or attract predators. The use of turbulence and acoustical apparatus were rated as having low potential for creation of a predator-restricted zone and are discussed in the Appendix II D.

Electrical barriers originally built to guide salmon fingerlings to collection areas have been shown to be successful in the laboratory in blocking passage of adult northern squawfish (Maxfield et al. 1970). Field research suggests that northern squawfish in the area of the electrical barrier can be diverted (Maxfield et al. 1969), although effectiveness for other predators has not been documented. Production of the electrical barrier in the field did not create a predator-free zone, but rather an area with a reduced number of predators when the power was turned on (Maxfield et al. 1969). An electrical barrier was installed at RBDD but has not been in operation long enough to evaluate effectiveness (Dave Vogel, personal communication).

Olfactory attractants could be used to create a zone with a reduced number of predators by luring them away from areas of prey concentration. Attractants might also be used to concentrate predators to increase the efficiency of some of the predator control techniques. Olfactory organs of most fishes are well developed and fish can detect odors at very low concentrations. Pheromones (chemical substances produced by animals to communicate with individuals of the same species) may act as either an attractant or repellent. Pheromone attractants have been identified for female poeciliid fish (Crow and Liley 1979;

Brett and Grosse 1982) and are known to exist in female ictalurids. Timms and Kleerekoper (1972) note that commercial fishermen along the Mississippi River bait traps with ripe female channel catfish to increase catches of male catfish. It is not known if pheromones play a role in the sexual behavior of smallmouth bass, walleye, or northern squawfish.

Pheremones may be useful in repelling fish as well. Pheromones which induce fright or alarm type behavior are present in fishes of the superorder Ostatiophysii which includes the family Cyprinidae (Heczko and Sghers 1981). Minute amounts of the substance, termed "Schreckstoff", are released from the epidermis of injured minnows and related species and cause an almost immediate fright reaction and retreat in members of the same species (Bond 1979). Pfeiffer (1963) described the fright reaction of northern squawfish that fed cannibalistically. The author noted, however, that after repeated cannibalistic episodes the fright reaction subsided. Pfeiffer (1963) assumed that large squawfish become indifferent to the alarm substance in nature as they become cannibalistic and feed on other cyprinids. Alarm substances have not been identified for smallmouth bass, walleye, or channel catfish. Investigations into the actions of pheromones may prove fruitful in aiding the removal of undesirable fish predators, especially channel catfish. The development of alarm substances for northern squawfish may allow fishery managers to create predator-restricted zones in areas of juvenile salmonid concentrations.

Predator-avoidance Conditioning

Conditioning hatchery-reared salmonids to the hazards of predation may reduce losses after release. Artificial propogation does not expose juvenile salmonids to predators and young fish may become habitualized to the presence of hatchery workers (Vincent 1960). They may not be as wary of avian, terrestrial, or aquatic predators as naturally-spawned fish. Therefore, hatchery fish may be more susceptible to predation than naturally-spawned fish. A number of studies have shown that fish which have survived exposure to predators are less likely to be eaten upon the second exposure, with mortality rates decreasing with successive encounters with predators (Table 13). These experiments term "trained" or "experienced" fry as those that have been exposed to predators and have survived. It may be that there is actually a continuum of predator avoidance ability ranging from very poor to very good. Those with inadequate avoidance ability will be eaten, leaving those with adequate avoidance behavior. What is termed learning may actually be a simple cropping of individuals lacking adequate avoidance responses. Two factors associated with previous experiments are important: 1) learning may or may not be taking place; and 2) adoption of this training technique would require losses of fish that may not be necessary to elicit an adequate avoidance response,

Several experiments have shown that sight plays an important role in conditioning fish to avoid predators (Popov 1953; Bogomolova et al. 1956; Girsa 1962; Gerasimov 1965; Rekubratskiy 1965). According to

Table 13. Results of experiments exposing prey to predators.

Prey species	Results of experiments	Reference
sockeye salmon	-hatchery vs. naturally-spawned fry -6 to 20% higher mortality rate (12% overall)	Rams 1967
chum salmon	-hatchery vs. naturally-spawned fingerlings -more hatchery fish consumed: 14-30% initially 12-18% after contact with predators and release from hatchery no difference after 2-4 weeks	**Kanid'yev** 1966
Vimba **sp.**	-two days of "training", few fish eaten -untrained fish, 50% mortality from predation	Veselov 1962
sockeye salmon	-"experienced" fry defined as those exposed to predators overnight -predation was higher with younger fish, higher night light intensity, less turbidity and lower water velocity -experienced fry less vulnerable to predation than "naive" fry -successive exposure to predators further decreased losses to predators -experienced fry formed more compact schools in response to stimuli	Ginetz hi **Larkin** 1976
sockeye salmon	-conditioned responses to predators were retained for several months	**Tarrant** 1964

Gerasimov (1965) a conditioning of a defense response is usually stronger in an onlooking fish rather than the fish actually attacked. Therefore, observation of predator pursuit and evasive action of a conspecific prey fish may produce the desired response. Of special interest is acquisition of defense reflexes in roach (*Rutilus sp.*) to a model of a pike (*Esox sp.*) (Popov 1953). In this instance, loss of fish was not necessary to elicit a predator avoidance response. After exposure to the pike model, death of larvae and fingerlings was one-third that of "uninstructed" fish over the same time period. Because the difference between trained and untrained fish did not require that prey fish be individuals with inadequate response patterns. learned response. Learning of a conditioned response may be persistent over a long period of time. Juvenile salmon conditioned over 16 days retained their conditioned response for months without additional reinforcing stimuli (Tarrant 1964). Upon release, fish would be likely to encounter the eliciting stimuli of predator sight and pursuit much more often and reinforcement should be stronger.

RECOMMENDATIONS

The highest rated measures for potentially reducing juvenile salmonid losses to predation primarily involved prey protection by changing juvenile salmonid release strategies and altering lighting at the dams (Table 1). These measures are designed to interfere with the feeding behavior of the predators by temporally and spatially separating predators and prey. The predation control measure of netting and trapping was also highly rated but most other measures involving direct control of predators, such as electrofishing, limiting reproductive success, or poisoning were rated as having moderate potential. Utilization of predator attractants and repellents to protect prey were also moderately rated measures and are designed to exploit concentrations of predators or attack vulnerable aspects of their reproductive behavior. Unfortunately, for most species of predators in John Day Reservoir, our present level of knowledge of their feeding behavior, areas of high concentrations, or reproductive requirements is insufficient to allow us to effectively evaluate the true potential of many of these measures for reducing juvenile salmonid losses to predation. Therefore, we recommend the following steps need to be taken before final recommendations can be made for a system-wide predation control program:

1. Feeding Behavior: To evaluate measures to protect juvenile salmonids at the dams from predation by northern squawfish we must better understand their feeding behavior. The effects of light

intensity, current velocity, water depth, prey selection, and striking characteristics are required to efficiently design systems to decrease the feeding success of northern squawfish and minimize the frequency of juvenile salmonid/squawfish encounters.

2. Life History Characteristics: The reproductive requirements and areas of high predator concentrations in Columbia River basin reservoirs must be better understood if measures to manipulate water levels or to physically remove predators are to be effectively implemented. The depths and locations where predators deposit their eggs must be determined to evaluate whether they would be vulnerable to exposure by lowering water levels. Whether walleye or northern squawfish populations presently congregate in specific areas during spawning or at other times of the year so their vulnerability to physical removal would be increased is also unknown. Northern squawfish concentrations in McNary tailrace have been documented but whether similiar situations occur below other dams in the system with different designs is unknown.

3. Squoxin Registration: Initial results of the predator/prey studies indicate that northern squawfish have the highest juvenile salmonid consumption rates and highest population levels of the piscivorous species in John Day Reservoir. Therefore, it is logical to proceed with efforts to obtain registration of squoxin so it may at least be used in spot treatments to reduce northern

squawfish concentration in areas such as juvenile salmonid release sites and tailrace areas.

4. Pilot Studies: Several measures were identified which can be tested with minimal expense and without the delay of gathering background data. Lights can be turned off at dams and bypassed juvenile salmonids which were not going to be transported could be retained in holding facilities for a single daily release. Distribution of northern squawfish in tailraces with different juvenile salmonid bypass outlets should be compared to estimate which system maximizes spatial separation between juvenile salmonids and northern squawfish. Rxamination of consumption rates of juvenile salmonids by predators before and after the above tests were conducted would allow more effective evaluation of the feasibility of each measure.

Once these additional data requirements are met and the pilot studies are completed the control measures can be thoroughly evaluated. Before a comprehensive predation control program can be developed, the system-wide extent of the predation problem must be determined by: (1) conducting site specific studies to compare known problem areas in John Day Reservoir with similar potential problem areas in other reservoirs and (2) application and validation of the John Day Reservoir predator/prey model in other parts of the system to help us predict if serious predation problems exist in other reservoirs which have different species and sizes of predator and prey (juvenile salmonids) populations. A compilation of all this information will form the biological basis for a system-wide predation control strategy. Incorporating economic and **socio-political** considerations with the biological information will then form the base upon which a sound control program can be initiated and evaluated. Unquestionably, any control program will require a combination of measures because of the variety of predators and diversity of habitats present in the Columbia River system.

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APPENDIX

Section I

Appendix Table 1. Percent occurrence and weight of food items in digestive tracts of small northern squawfish (<100 mm) by station from John Day Reservoir, April 4 to September 2, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses.

Station	Food item	Percent occurrence	Percent weight
McNary tailrace (29, 10)	Mollusca	0.0	0.0
	Crustacea	20.7	5.1
	Insecta	58.6	89.5
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	10.3	5.4
Irrigon (6, 0)	Mollusca	0.0	0.0
	Crustacea	0.0	0.0
	Insecta	100.0	100.0
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	0.0	0.0
Arlington (0, 0)	Mollusca		
	Crustacea		
	Insecta	NS[a]	NS
	Osteichthyes		
	Salmonidae		
	Other food		
John Day forebay (0, 0)	Mollusca		
	Crustacea		
	Insecta	NS	NS
	Osteichthyes		
	Salmonidae		
	Other food		

a NS = no sample.

Appendix Table 2. Percent occurrence and weight of food items in digestive tracts of medium northern squawfish (100-249 mm) by sample period from McNary tailrace, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 4 - Apr 21	Mollusca	0.0	0.0
(2, 0)	Crustacea	100.0	99.7
	Insecta	50.0	0.2
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	50.0	<0.1
May 5 - May 20	Mollusca	0.0	0.0
(8, 2)	Crustacea	62.5	23.3
	Insecta	75.0	8.2
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	12.5	68.5
Jun 4 - Jun 22	Mollusca	0.0	0.0
(11, 8)	Crustacea	18.2	0.4
	Insecta	27.3	99.6
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	0.0	0.0
Aug 1 - Aug 25	Mollusca	22.7	14.1
(22, 4)	Crustacea	45.5	56.1
	Insecta	54.5	21.6
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	31.8	8.2

Appendix Table 3. Percent occurrence and weight of food items in digestive tracts of medium northern squawfish (100-249 mm) by sample period from Irrigon, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 5 - Apr 22	Mollusca	50.0	100.0
(2, 1)	Crustacea	0.0	0.o
	Insecta	0.0	0.0
	Osteichthyes	0.0	0.o
	Salmonidae	0.0	0.0
	Other food	0.0	0.0
May 6 - May 24	Mollusca	0.0	0.0
(4, 1)	Crustacea	50.0	10.7
	Insecta	50.0	2.1
	Osteichthyes	25.0	87.1
	Salmonidae	0.0	0.0
	Other food	0.0	0.0
Jun 11 - Jun 17	Mollusca	10.0	3.4
(20, 2)	Crustacea	75.0	65.4
	Insecta	70.0	6.2
	Osteichthyes	15.0	21.8
	Salmonidae	5.0	5.1
	Other food	15.0	3.2
Aug 3 - Aug 25	Mollusca	4.2	0.2
(24, 5)	Crustacea	37.5	20.6
	Insecta	66.7	63.7
	Osteichthyes	4.2	15.4
	Salmonidae	0.0	0.0
	Other food	8.3	0.1

Appendix Table 4. Percent occurrence and weight of food items in digestive tracts of medium northern squawfish (100-249 mm) by sample period from Arlington, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 29 - May 12	Mollusca	0.0	0.0
(1, 0)	Crustacea	100.0	99.8
	Insecta	0.0	0.0
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	100.0	0.2
May 20 - May 30	Mollusca	0.0	0.0
(2, 0)	Crustacea	100.0	78.8
	Insecta	100.0	21.2
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	0.0	0.0
Jun 17 - Jun 26	Mollusca	0.0	0.0
(3, 0)	Crustacea	100.0	52.7
	Insecta	100.0	3.2
	Osteichthyes	33.3	44.0
	Salmonidae	33.3	44.0
	Other food	33.3	<0.1
Aug 19 - Aug 30	Mollusca	0.0	0.0
(16, 6)	Crustacea	25.0	5.1
	Insecta	50.0	92.9
	Osteichthyes	12.5	1.9
	Salmonidae	0.0	0.0
	Other food	6.3	<0.1

Appendix Table 5. Percent occurrence and weight of food items in digestive tracts of medium northern squawfish (100-249 mm) by sample period from John Day forebay, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 19 - May 11	Mollusca		
(0, 0)	Crustacea		
	Insecta	NS[a]	NS
	osteichthyes		
	Salmonidae		
	Other food		
May 23 - Jun 8	Mollusca	0.0	0.0
(1, 0)	Crustacea	100.0	97.8
	Insecta	100.0	2.2
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	0.0	0.0
Jun 21 - Jul 1	Mollusca		
(0, 0)	Crustacea		
	Insecta	NS	NS
	Osteichthyes		
	Salmonidae		
	Other food		
Aug 17 - Sep 2	Mollusca	0.0	0.0
(5, 1)	Crustacea	60.0	0.9
	Insecta	60.0	40.6
	osteichthyes	20.0	58.4
	Salmonidae	0.0	0.0
	Other food	20.0	<0.1

[a] NS = no sample.

Appendix Table 6. Percent occurrence and weight of food items in digestive tracts of large northern squawfish (≥250 mm) by sample period from McNary tailrace, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 4 - Apr 21	Mollusca	1.4	0.1
(69, 6)	Crustacea	71.0	22.3
	Insecta	42.0	0.4
	Osteichthyes	29.0	69.7
	Salmonidae	14.5	49.8
	Other food	44.9	7.5
May 5 - May 20	Mollusca	1.1	<0.1
(90, 13)	Crustacea	53.3	9.6
	Insecta	44.4	0.2
	Osteichthyes	60.0	88.3
	Salmonidae	45.6	74.2
	Other food	33.3	1.9
Jun 4 - Jun 22	Mollusca	6.7	0.3
(134, 31)	Crustacea	59.7	19.7
	Insecta	38.1	1.3
	Osteichthyes	31.3	74.8
	Salmonidae	15.7	44.1
	Other food	20.1	3.4
Aug 1 - Aug 25	Mollusca	3.4	2.2
(149, 81)	Crustacea	8.1	3.1
	Insecta	16.1	0.5
	Osteichthyes	34.9	93.0
	Salmonidae	24.2	85.5
	Other food	8.1	1.2

Appendix Table 7. Percent occurrence and weight of food items in digestive tracts of large northern squawfish (≥250 mm) by sample period from Irrigon, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 5 - Apr 22	Mollusca	10.5	2.4
(19, 5)	Crustacea	31.6	14.6
	Insecta	15.8	0.2
	Osteichthyes	21.1	55.0
	Salmonidae	0.0	0.0
	Other food	36.8	27.7
May 6 - May 24	Mollusca	5.9	1.3
(17, 6)	Crustacea	35.3	25.9
	Insecta	23.5	0.3
	Osteichthyes	41.2	72.4
	Salmonidae	17.6	30.6
	Other food	5.9	0.1
Jun 11 - Jun 17	Mollusca	25.9	20.3
(27, 10)	Crustacea	40.7	37.1
	Insecta	22.2	0.2
	Osteichthyes	14.8	39.4
	Salmonidae	0.0	0.0
	Other food	11.1	3.0
Aug 3 - Aug 25	Mollusca	0.0	0.0
(19, 8)	Crustacea	42.1	65.1
	Insecta	21.1	8.1
	Osteichthyes	10.5	24.2
	Salmonidae	0.0	0.0
	Other food	10.5	2.6

Appendix Table 8. Percent occurrence and weight of food items in digestive tracts of large northern squawfish (≥250 mm) by sample period from Arlington, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 29 - May 12	Mollusca	0.0	0.0
(22, 1)	Crustacea	86.4	20.6
	Insecta	77.3	2.2
	Osteichthyes	31.8	73.1
	Salmonidae	18.2	61.1
	Other food	59.1	4.1
May 20 - May 30	Mollusca	2.9	0.3
(70, 9)	Crustacea	67.1	33.5
	Insecta	40.0	2.6
	Osteichthyes	18.6	60.9
	Salmonidae	8.6	43.2
	Other food	22.9	2.3
Jun 17 - Jun 26	Mollusca	14.3	3.4
(42, 4)	Crustacea	78.6	53.9
	Insecta	47.6	3.4
	Osteichthyes	19.0	17.6
	Salmonidae	4.8	0.1
	Other food	14.3	21.8
Aug 19 - Aug 30	Mollusca	6.5	2.7
(62, 18)	Crustacea	43.5	69.1
	Insecta	40.3	17.4
	Osteichthyes	11.3	6.6
	Salmonidae	1.6	1.3
	Other food	12.9	4.1

Appendix Table 9. Percent occurrence and weight of food items in digestive tracts of large northern squawfish (≥250 mm) by sample period from John Day forebay, John Day Reservoir, 1984. Sample sizes and numbers of empty digestive tracts are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 19 - May 11 (61, 9)	Mollusca	0.0	0.0
	Crustacea	62.3	24.9
	Insecta	26.2	0.2
	Osteichthyes	37.7	73.4
	Salmonidae	32.8	71.5
	Other food	29.5	1.6
May 23 - Jun 8 (58, 20)	Mollusca	3.4	0.6
	Crustacea	39.7	15.0
	Insecta	25.9	1.5
	Osteichthyes	22.4	81.4
	Salmonidae	17.2	65.9
	Other food	12.1	1.5
Jun 21 - Jul 1 (20, 13)	Mollusca	5.0	0.7
	Crustacea	20.0	69.2
	Insecta	15.0	<0.1
	Osteichthyes	5.0	30.1
	Salmonidae	5.0	30.1
	Other food	0.0	0.0
Aug 17 - Sep 2 (72, 27)	Mollusca	0.0	0.0
	Crustacea	6.9	3.6
	Insecta	36.1	11.3
	Osteichthyes	37.5	83.5
	Salmonidae	16.7	71.6
	Other food	6.9	1.5

Appendix Table 10. Percent occurrence and weight of food items in stomachs of walleyes by sample period from McNary tailrace, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 4 - Apr 21	Mollusca	1.1	<0.1
(93, 59)	Crustacea	1.1	<0.1
	Insecta	3.2	0.1
	Osteichthyes	33.3	99.8
	Salmonidae	17.2	24.5
	Other food	6.5	0.1
May 5 - May 20	Mollusca	0.0	0.0
(44, 25)	Crustacea	2.3	to.1
	Insecta	2.3	to.1
	Osteichthyes	43.2	>99.9
	Salmonidae	13.6	37.6
	Other food	13.6	<0.1
Jun 4 - Jun22	Mollusca	1.2	to.1
(84, 15)	Crustacea	7.1	<0.1
	Insecta	2.4	<0.1
	Osteichthyes	82.1	99.9
	Salmonidae	10.7	6.9
	Other food	15.5	<0.1
Aug 1 - Aug 25	Mollusca	0.0	0.0
(7, 2)	Crustacea	0.0	0.0
	Insecta	0.0	0.0
	Osteichthyes	71.4	>99.9
	Salmonidae	28.6	58.1
	Other food	14.3	<0.1

Appendix Table 11. Percent occurrence and weight of food items in stomachs of walleyes by sample period from Irrigon, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 5 - Apr 22	Mollusca	0.0	0.0
(27, 10)	Crustacea	7.4	<0.1
	Insecta	14.8	0.2
	Osteichthyes	59.3	99.0
	Salmonidae	14.8	11.1
	Other food	11.1	0.8
May 6 - May 24	Mollusca	2.2	<0.1
(46, 11)	Crustacea	15.2	0.1
	Insecta	15.2	0.1
	Osteichthyes	73.9	98.7
	Salmonidae	17.4	25.0
	Other food	10.9	1.1
Jun 11 - Jun 17	Mollusca	0.0	0.0
(20, 5)	Crustacea	10.0	<0.1
	Insecta	0.0	0.0
	Osteichthyes	75.0	>99.9
	Salmonidae	5.0	<0.1
	Other food	0.0	0.0
Aug 3 - Aug 25	Mollusca	0.0	0.0
(12, 4)	Crustacea	16.7	<0.1
	Insecta	8.3	<0.1
	Osteichthyes	66.7	99.7
	Salmonidae	16.7	14.7
	Other food	16.7	0.2

Appendix Table 12. Percent occurrence and weight of food items in stomachs of walleyes by sample period from Arlington, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 29 - May 12	Mollusca		
(0, 0)	Crustacea		
	Insecta	NS[a]	NS
	Osteichthyes		
	Salmonidae		
	Other food		
May 20 - May 30	Mollusca	0.0	0.0
(1, 1)	Crustacea	0.0	0.0
	Insecta	0.0	0.0
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	0.0	0.0
Jun 17 - Jun 26	Mollusca	0.0	0.0
(5, 1)	Crustacea	60.0	0.1
	Insecta	20.0	0.1
	Osteichthyes	80.0	99.9
	Salmonidae	60.0	40.5
	Other food	0.0	0.0
Aug 19 - Aug 30	Mollusca		
(0, 0)	Crustacea		
	Insecta	NS	NS
	Osteichthyes		
	Salmonidae		
	Other food		

[a] NS = no sample.

Appendix Table 13. Percent occurrence and weight of food items in stomachs of smallmouth bass by sample period from McNary tailrace, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 4 - Apr 21	Mollusca	0.0	0.0
(1, 1)	Crustacea	0.0	0.0
	Insecta	0.0	0.0
	Osteichthyes	0.0	0.0
	Salmonidae	0.0	0.0
	Other food	0.0	0.0
May 5 - May 20	Mollusca	0.0	0.0
(8, 1)	Crustacea	37.5	19.0
	Insecta	12.5	<0.1
	Osteichthyes	62.5	80.6
	Salmonidae	0.0	0.0
	Other food	25.0	0.4
Jun 4 - Jun 22	Mollusca	0.0	0.0
(16, 3)	Crustacea	31.3	4.2
	Insecta	6.3	0.3
	Osteichthyes	56.3	95.5
	Salmonidae	0.0	0.0
	Other food	25.0	0.1
Aug 1 - Aug 25	Mollusca	9.5	<0.1
(21, 3)	Crustacea	23.8	2.0
	Insecta	52.4	0.9
	Osteichthyes	71.4	97.0
	Salmonidae	9.5	1.2
	Other food	19.0	0.1

Appendix Table 14. Percent occurrence and weight of food items in stomachs of smallmouth bass by sample period from Irrigon, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 5 - Apr 22	Mollusca	0.0	0.0
(72, 21)	Crustacea	27.8	5.7
	Insecta	16.7	0.2
	Osteichthyes	58.3	93.9
	Salmonidae	0.0	0.0
	Other food	12.5	0.3
May 6 - Hay 24	Mollusca	0.0	0.0
(48, 25)	Crustacea	16.7	2.0
	Insecta	8.3	0.3
	Osteichthyes	27.1	97.5
	Salmonidae	0.0	0.0
	Other food	25.0	0.1
Jun 11 - Jun 17	Mollusca	0.5	0.3
(186, 49)	Crustacea	24.2	5.3
	Insecta	23.1	0.3
	Osteichthyes	59.1	93.9
	Salmonidae	4.3	2.5
	Other food	12.4	0.3
Aug 3 - Aug 25	Mollusca	4.7	<0.1
(64, 5)	Crustacea	29.7	1.8
	Insecta	75.0	0.5
	Osteichthyes	82.8	97.6
	Salmonidae	4.7	9.2
	Other food	21.9	0.1

Appendix Table 15. Percent occurrence and weight of food items in stomachs of smallmouth bass by sample period from Arlington, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 29 - May 12	Mollusca	0.0	0.0
(33, 3)	Crustacea	63.6	39.8
	Insecta	24.2	0.4
	Osteichthyes	51.5	59.7
	Salmonidae	9.1	2.6
	Other food	15.2	to.1
May 20 - May 30	Mollusca	0.0	0.0
(66, 15)	Crustacea	50.0	33.4
	Insecta	19.7	0.5
	Osteichthyes	48.5	66.1
	Salmonidae	1.5	0.1
	Other food	1.5	<0.1
Jun 17 - Jul 26	Mollusca	0.0	0.0
(168, 36)	Crustacea	63.1	49.3
	Insecta	22.6	0.2
	Osteichthyes	43.5	50.4
	Salmonidae	2.4	1.8
	Other food	7.7	0.1
Aug 19 - Aug 30	Mollusca	0.0	0.0
(115, 18)	Crustacea	50.4	15.6
	Insecta	42.6	1.0
	Osteichthyes	63.5	83.3
	Salmonidae	2.6	3.8
	Other food	16.5	0.1

Appendix Table 16. Percent occurrence and weight of food items in stomachs of smallmouth bass by sample period from John Day forebay, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 19 - May 11	Mollusca	0.0	0.0
(70, 25)	Crustacea	48.6	43.8
	Insecta	14.3	0.2
	Osteichthyes	38.6	55.6
	Salmonidae	1.4	0.4
	Other food	5.7	0.5
May 23 -Jun 8	Mollusca	0.0	0.0
(107, 19)	Crustacea	56.1	35.2
	Insecta	29.9	0.4
	Osteichthyes	54.2	64.1
	Salmonidae	0.0	0.0
	Other food	17.8	0.3
Jun 21 - Jul 1	Mollusca	0.8	<0.1
(133, 18)	Crustacea	66.9	43.9
	Insecta	42.9	1.0
	Osteichthyes	33.8	55.1
	Salmonidae	0.8	0.4
	Other food	10.5	<0.1
Aug 17 -Sep 2	Mollusca	1.4	<0.1
(138, 20)	Crustacea	67.4	28.2
	Insecta	42.8	0.7
	Osteichthyes	41.3	70.6
	Salmonidae	2.2	6.1
	Other food	16.7	0.5

Appendix Table 17. Percent occurrence and weight of food items in stomachs of channel catfish by sample period from McNary tailrace, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 4 - Apr 21	Mollusca	5.6	23.6
(36, 3)	Crustacea	88.9	1.7
	Insecta	16.7	0.2
	Osteichthyes	16.7	38.4
	Salmonidae	13.9	31.1
	Other food	33.3	36.1
May 5 - May 20	Mollusca	7.7	5.0
(26, 3)	Crustacea	65.4	1.8
	Insecta	23.1	0.2
	Osteichthyes	38.5	88.9
	Salmonidae	19.2	60.1
	Other food	23.1	4.2
Jun 4 - Jun 22	Mollusca	2.4	0.8
(42, 10)	Crustacea	45.2	2.9
	Insecta	35.7	1.5
	Osteichthyes	35.7	93.8
	Salmonidae	19.0	64.3
	Other food	33.3	1.0
Aug 1 - Aug 25	Mollusca	0.0	0.0
(4, 0)	Crustacea	25.0	0.1
	Insecta	25.0	0.1
	Osteichthyes	25.0	99.5
	Salmonidae	0.0	0.0
	Other food	50.0	0.3

Appendix Table 18. Percent occurrence and weight of food items in stomachs of channel catfish by sample period from Irrigon, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 5 - Apr 22	Mollusca	25.0	1.9
(8, 2)	Crustacea	25.0	<0.1
	Insecta	37.5	1.4
	Osteichthyes	62.5	92.8
	Salmonidae	25.0	42.8
	Other food	25.0	3.8
May 6 - May 24	Mollusca	0.0	0.0
(7, 2)	Crustacea	57.1	45.0
	Insecta	28.6	2.6
	Osteichthyes	28.6	33.1
	Salmonidae	0.0	0.0
	Other food	57.1	19.3
Jun 11 - Jun 17	Mollusca	0.0	0.0
(5, 1)	Crustacea	0.0	0.0
	Insecta	20.0	<0.1
	Osteichthyes	80.0	51.5
	Salmonidae	0.0	0.0
	Other food	20.0	48.5
Aug 3 - Aug 25	Mollusca	60.0	2.8
(10, 0)	Crustacea	80.0	34.2
	Insecta	30.0	to.1
	Osteichthyes	50.0	57.9
	Salmonidae	0.0	0.0
	Other food	70.0	5.1

Appendix Table 19. Percent occurrence and weight of food items in stomachs of channel catfish by sample period from Arlington, John Day Reservoir, 1984. Sample sizes and numbers of empty stomachs are in parentheses.

Date	Food item	Percent occurrence	Percent weight
Apr 29 - May 12	Mollusca		
(0, 0)	Crustacea		
	Insecta	NS[a]	NS
	Osteichthyes		
	Salmonidae		
	Other food		
May 20 - May 30	Mollusca		
(0, 0)	Crustacea	NS	NS
	Insecta		
	Osteichthyes		
	Salmonidae		
	Other food		
Jun 17 - Jun 26	Mollusca		
(0, 0)	Crustacea		
	Insecta	NS	NS
	Osteichthyes		
	Salmonidae		
	Other food		
Aug 19 - Aug 30	Mollusca	13.0	0.5
(23, 1)	Crustacea	87.0	94.4
	Insecta	56.5	2.1
	Osteichthyes	13.0	2.0
	Salmonidae	0.0	0.0
	Other food	8.7	1.0

a NS = no sample.

Appendix Table 20. Mean catch per seine haul of prey fishes (≤250 mm) collected at McNary tailrace main channel, McNary tailrace backwater, and Irrigon main channel, John Day Reservoir, April to August, 1984.

Common name	McNary tailrace main channel					McNary tailrace backwater					Irrigon main channel				
	Apr 4 Apr 21	May 5 May 20	Jun 4 Jun 22	Aug 1 Aug 25	Mean	Apr 4 Apr 21	May 5 May 20	Jun 4 Jun 22	Aug 1 Aug 25	Mean	Apr 5 Apr 22	May 6 May 24	Jun 11 Jun 17	Aug 3 Aug 25	Mean
American shad									4.25	1.06				1.00	0.28
coho salmon	0.17				0.04										
sockeye salmon							0.25			0.06					
chinook salmon	10.75	16.00	43.25	1.75	17.54	10.25	28.00	21.25		14.50	28.50	IJ.75	14.15		18.75
rainbow trout						0.33				0.0.	1.00	0.50			0.18
mountain whitefish			0.25	2.00	0.54									0.50	0.13
chiselmouth	0.15	1.75	0.50	4.00	1.61	6.50	4.50	3.25	3.00	4.31	0.50	J.75	1.00	1.50	1.69
goldfish				0.25	0.08							1.00			0.58
carp									0.15	0.06					
peamouth	1.00	0.15	0.25	3.50	1.25	25.25	01.00	81.00	30.00	68.03	1.50	4.50	0.25	6.50	J.68
northern squawfish	6.00	2.00	2.25	11.50	5.44	47.75	48.50	50.50	234.00	95.21	15.00	13.25	12.25	51.25	22.94
redside shiner	3.33	3.00		0.75	J.77	7.00	10.75	1.00		4.45		0.50	0.25		0.15
suckers	14.75	5.50	14.50	38.00	18.17	110.50	23.50	57.75	1145.00	55.15	151.00	57.15	18.25	42.25	b7.15
brown bullhead									1.15	0.54					
sand roller	4.25	5.75	106.25	15.75	J4.H	6.25	0.25	10.25	0.15	4.23	23.00	96.25	28.00	64.50	0.54
three-spine stickleback	0.17	0.75	0.15	0.15	0.36	1.00	2.25	1.00		1.31					
sunfishes[b]						0.33		7.25	1.50	2.52				0.15	0.08
smallmouth bass				0.75	0.15				16.50	4.13			0.25	0.58	0.15
largemouth bass									15.25	3.81		0.25		0.50	0.18
crappies[c]				0.75	0.15				8.00	1.00		1.00	1.25	1.75	1.00
yellow perch						0.83		3.50	0.25	1.15			0.10		0.11
sculpins		0.50	7.50	a.00	1.50	0.75	0.50	3.25	4.00	a.15		3.50	0.50	1.25	1.31

[a] Includes largescale sucker (*Catostomus macrocheilus*) and bridgelip sucker (*Catostomus columbianus*).
[b] Includes pumpkinseed (*Lepomis gibbosus*) and bluegill (*Lepomis macrochirus*).
[c] Includes white crappie (*Pomoxis annularis*) and black crappie (*Pomoxis nigromaculatus*).

Appendix Table 21. Mean catch per seine haul of prey fishes (≤250 mm) collected at Irrigon backwater, Arlington main channel, and John Day forebay main channel, John Day Reservoir, April to September, 1984.

Common name	Irrigon backwater					Arlington main channel					John Day forebay main channel				
	Apr 5 Apr 22	May 6 May 14	Jun 11 Jun 17	Aug 3 Aug 25	Mean	Apr 29 May 12	May 20 May 30	Jun 17 Jun 26	Aug 19 Aug 30	Mean	Apr 19 May 11	May 23 Jun 8	Jun 21 Jul 1	Aug 17 Sep 2	Mean
American shad				71.00	17.75				5.00	1.25				62.25	15.56
sockeye salmon												0.25			0.06
chinook salmon		9.00	7.75		4.19	6.50	12.60	17.00	0.25	9.09		4.50	9.75		3.56
rainbow trout		0.25			0.06						4.50				1.13
mountain whitefish											0.50		0.25	0.75	0.3.
chiselmouth	0.50	0.75			0.31	1.50	3.20	0.75	0.75	1.55	21.00	116.75	260.75	22.25	110.69
carp	0.50			0.25	0.19		0.20	0.25		0.11					
peamouth		0.75		0.75	0.30							0.25			0.06
northern squawfish	4.00	9.50	1.75	8.75	6.00	0.50	0.40	2.29	2.50	1.41	8.50	15.50	6.75	4.50	8.81
dace[a]						0.50	1.00			0.38		0.50			0.13
redside shiner		0.25			0.06	0.50		0.25		0.19	0.10	1.00	0.25	0.50	0.56
suckers[b]	4.50	16.25	8.75	2.25	8.44	9.00	41.60	0.00	5.25	16.01	42.50	75.00	194.06	30.25	85.44
channel catfish				0.25	0.06										
brown bullhead				0.25	0.06										
sand roller	1.00	2.25	2.75	0.25	1.56	1.00	1.20	13.25	1.50	4.24	0.50	0.50		0.50	0.36
sunfishes[c]		0.25	2.00	6.25	2.13		1.00			0.25					
smallmouth bass		0.25	0.25	10.00	2.63				1.50	0.36				0.75	0.19
largemouth bass				4.50	1.13									0.25	0.06
crappies[d]		2.50	3.75	70.75	19.25				0.25	0.06					
yellow perch	1.50	1.00	6.25		2.19		0.40			0.10					
walleye							0.20			0.05					
sculpins	2.50	7.25	0.50		2.56	8.50	4.60	0.25		3.39	11.00	16.25	10.75	2.00	10.00

a Includes longnose dace (Rhinichthys cataractae) and speckled dace (Rhinichthys osculus).
b Includes largescale sucker (Catostomus macrocheilus) and bridgelip sucker (Catostomus columbianus).
c Includes pumpkinseed (Lmacrochirus) aus) and bluegill (Lepomis
d Includes white crappie (Pomoxis annularis) and black crappie (Pomoxis nigromaculatus).

APPENDIX

Section II

Explosives

Explosives have been used to control fish populations by disrupting spawning activities (Jeppson 1957; Jeppson and Platts 1959) and eradicating localized concentrations of fish (Johnston 1961). Hubbs and Rechnitzer (1952) reported that mortality of fishes using explosives was caused by "hemorrhaging, burst air bladders, and general disruption of the viscera". Jeppson and Platts (1959) used dynamite to disrupt spawning and kill large numbers of northern squawfish in Hayden Lake, Idaho. Johnston (1961) used dynamite to eradicate a large number of longnose gar while killing few gamefish. The small kill of game fish probably reflects low abundance of these fish prior to dynamiting, as death by concussion is generally not species or size selective (Coker and Hollis 1950; Hubbs and Rechnitzer 1952). However, Alpin (1947) reported that fish with air bladders are much more susceptible to concussion than those without air bladders.

Other than the obvious safety factors involved (especially potential damage to dams) the use of dynamite to control fish in localized areas should pose no threat to the environment or to water quality of the Columbia River. However, the non-selective nature of explosive material limits its use.

Part B. Chemical control methods: antimycin and rotenone.

Antimycin

The potential use of antimycin as a piscicide was discovered when scientists were testing the antibiotic against fungi that destroys crops (Lennon and Berger 1970). Initial registration as a fish toxicant in the United States and Canada occurred in 1966 as Fintrol-5, an antimycin-coated sand formulation which releases the toxicant within 1.5 m (5 feet) of the water surface (Lennon et al. 1970; Cumming 1975). Two additional formulations were registered in 1968 and 1969: Fintrol-15, a coated-sand formulation which releases toxicant in the upper 4.6 m (15 feet) of the water column, and Fintrol-Concentrate, a liquid form for stream and shallow water application. Fintrol-Concentrate is the only form of antimycin presently available. Antimycin is non-repellent to fish, compatible with rotenone, for multi-toxicant treatment, and fluorescent dyes, for tracing movement of the toxicant (Lennon et al. 1970). Antimycin acts as an irreversible inhibitor of cellular respiration for all fish life stages, including incubating eggs. A toxic antimycin solution can be readily neutralized by introduction of potassium permanganate. Berger et al. (19691 reported that in initial tests a 0.3 μg/l potassium permanganate solution detoxified 5 μg/l of antimycin within 6 hours and Gilderhus et al. (1969) reported using a l-2 μg/l application of potassium permanganate to detoxify antimycin in two field trials.

Laboratory and field experiments have shown that antimycin toxicity is influenced by pH, water temperature, turbidity, and hardness of water. With application of antimycin at pH values from 5 to 10, increasing in one unit intervals, 96-hour LC_{100} values (concentration lethal to 100% of the organisms) at 12 C for goldfish were 200, 300, 400, 1100, 6000 and 60,000 µg/l respectively (Berger et al. 1969). he magnitude of increasing toxicants required to produce total mortality increased with higher pH values, especially between 8 and 10. One field trial with a pH of 10 and concentration of 10 µg/l detoxified so quickly that few fish were killed, with no species having a complete kill within 96 hours (Walker et al. 1964). In contrast, application of 12 mg/liter of antimycin in a soft water pond with pH 7.2 remained toxic for more than two weeks (Gilderhus et al. 1969). Higher water temperature generally results in a lower concentration of antimycin required to produce a kill. Two to five-fold differences between 96-h LC_{100} values are noted for various species at 7 and 22 C. Increased turbidity through the addition of 1000 µg/l of clay suspension only slightly increased the concentration necessary to kill 50% of the rainbow trout tested at 12 C during 24, 48 and 96-hour bioassay tests. Similar tests with 5000 µg/l clay suspension had LC_{50} values from about 1.5 to 2.5 times higher than controls. Harder water does reduce the effectiveness of antimycin, as evidenced by slightly higher 96-h LC_{100} values for trout, goldfish and bluegill at 20 and 400 µg/l total hardness (Berger et al. 1969).

Toxicity also varies widely among species of fish, with salmonids, centrarchids, and percids among the more sensitive and ictalurids one of the least sensitive. Minimum lethal concentrations (LC_{100}) for 96-h bioassays of three of the proposed target predators at temperatures of 12 and 17 C are as follows: smallmouth bass 0.1 and 0.08 µg/l; walleye 0.08 and 0.03 µg/l, and channel catfish 16 and 10 µg/l. In contrast, rainbow trout LC_{100} values at 12 and 17 C are 0.6 and 0.04 µg/l, respectively (Berger et al. 1969).

Effective contact time (ECT) is important in field application because water quality parameters such as high pH and low temperatures greatly decrease the toxicity of antimycin. Exposure to antimycin before substantial loss of toxicity can take place is a major concern. Differences in exposure time necessary to produce a kill can also be used to achieve selective poisoning for more sensitive species. The effective contact time is relatively short. A concentration of 10 µg/l at 12 C killed rainbow trout (Gilderhus 1972) and green sunfish (Berger et al. 1969) in 1 hour, northern redbelly dace and yellow perch within 2 hours, and largemouth bass and carp within 6 hours (Berger et al. 1969; Gilderhus 1972). In contrast, application of antimycin 25 times more concentrated required more than 8 hours to produce a 100% mortality of black bullhead (Berger et al. 1969).

Laboratory and field tests suggest that antimycin is not toxic to non-target organisms at piscicidal levels. Laboratory tests of antimycin toxicity to aquatic invertebrates and non-fish vertebrates was first investigated by Walker et al. (1964) who reported that a 100 µg/l exposure for 24 hours at 12 C was toxic to cladocerans. Gilderhus et al. (1969) reported that frogs, salamanders, water snakes, turtles, waterfowl, and wading birds were exposed to 10 µg/l antimycin during the field trials with no adverse effects observed. Use of antimycin evidently does not affect the reproduction of fish surviving treatment. Burress and Luhning (1969) used antimycin to reduce numbers of smaller-sized bluegill, largemouth bass, and redear sunfish. Sunfish which survived multiple exposures up to 1 µg/l were able to successfully reproduce. Consumption of fish affected by the toxicant did not appear to harm any of the vertebrate predators (Gilderhus et al. 1969). Treatments of 3 and 10 µg/l antimycin resulted in high mortalities of rotifers, cladocerans, and copepods. nayflies, damselflies, water boatmen, backswimmers, midges and seed shrimp were not affected at the higher concentration. However, researchers felt that the occurrence of the first fall frost during the treatment may have amplified the zooplankton mortality. A partial kill of freshwater shrimp occurred during a 10 µg/l treatment of a spring-fed lake in Wyoming. Mortality was confined to the spring area where toxicant concentrations were temporarily higher. Walker et al. (1964) also reported no significant effect upon plankton, filamentous algae, or aquatic plants exposed to antimycin.

Rotenone

Rotenone, a chemical compound found in the roots of many plants in the family Leguminosae, is the most widely used piscicide. It is not as selective as antimycin. Rotenone inhibits cellular respiration to induce death. It is registered for fishery use in three formulations: 5% wettable powder, 5% liquid and 2.5% liquid compound with synergists added (Lennon et al. 1970; Gumming 1975). The liquid formulations are easier to use than the wettable powder but contain solvents or carriers which repel fish. Post (1955) refined a colorimetric test for measuring rotenone concentration in water. The test was adopted for field use by the Wyoming Game and Fish Commission and provides a means of field monitoring rotenone concentrations during treatment and subsequent toxicant degradation. Dawson et al. (1983) described a simple, rapid, high-performance liquid chromatography procedure for determining rotenone concentrations in water at piscicidal levels.

Rotenone can be detoxified with potassim permanganate or chlorine (Lawrence 1956; Lennon et al. 1970; Everhart and Youngs 1981). The action of rotenone has been reversed in warmwater species by methyl blue (Lennon et al. 1970). The concentration of detoxicant required increases with higher rotenone concentrations and background demand for the detoxifying agent. Low alkalinities and faster detoxification times also require higher concentrations of detoxifiers. From 2.0 to 2.5 µ g/l solutions of potassium permanganate have been used to neutralize pond, stream and large river applications of 0.05 ug/l rotenone (Lawrence 1956; Hocutt et al. 1973). It is possible to create toxic conditions due to the addition of potassium permanganate or chlorine if high concentrations of the detoxifying agent are used. Addition of sodium thiosulfate will neutralize potassium permanganate and chlorine (Dawson 1975).

Rotenone degradation can be influenced by water quality and temperature. Clemens and Martin (1953) compared different combinations of turbidity, alkalinity and rotenone concentrations in Oklahoma ponds with various water chemistries and concluded that increased turbidity, decreased alkalinity and higher desired rotenone concentrations all lengthened the time required for degradation. A change in temperature from 9 C to 26 C reduced the degradation time from 9 or 10 days to about 3 days.

Toxicity of rotenone is influenced by water quality and temperature. Gilderhus (1972) investigated exposure times necessary to eliminate fishes at various water temperatures and rotenone concentrations. He determined that the exposure time needed to produce a kill was influenced more by water temperature than rotenone concentration. Black bullhead, for example, were eliminated 3 to 8 times faster at 17 C than 12 C with 1 µg/l of rotenone. Low pH (Leonard 19391, high alkalinity, and high organic content all increase the toxicity of rotenone (Bennett 1971). Gilderhus (1982) used bentonite clay suspensions to examine the effect of clay turbity on rotenone toxicity to fathead minnows. Bentonite concentrations of 0.5 and 1.0 µg/l increased the lethal rotenone concentrations required to kill fathead minnows 7 to 9 times respectively in 24-hour tests.

Rotenone toxicity varies, with goldfish and black bullhead being highly resistant with 96-h LC_{50} values at 12 C greater than 350 µg/l (Marking and Bills 1976). values for fathead minnows and channel catfish were 164 mg/liter and 142 mg/liter respectively. Toxicity of rotenone to smallmouth bass (79 µg/l) was only slightly higher than that of the most tolerant salmonid, coho salmon (62 mg/liter). Chinook salmon and rainbow trout had LC_{50} values of 37 ug/liter and 46 µg/l respectively. Toxicity of rotenone to walleye was very high, as the

LC_{50} value was less than 17 µg/l (Marking and Bills 1976). Differences in species sensitivity to rotenone has been used to effectively reduce gizzard shad populations in southern reservoirs without causing substantial mortality among game fishes (Bowers 1955; Zeller and Wyatt 1967).

The response of invertebrate populations to rotenone application differs, with insects usually considered to be less sensitive than zooplankton with shorter recovery periods (Cushing and Olive 1956; Almquist 1959; Kiser et al. 1963; Cook and Moore 1969; Anderson 1970). Insects within an order and even within a family do not necessarily exhibit similar reactions to toxicants at piscicidal levels (Engstrom-Heg et al. 1978). Application of rotenone to two lakes caused moderate mortality to chironomid and oligochaete populations, but their populations rebounded in a short period of time (Cushing and Olive 1956). Cook and Moore (1969) described rotenone poisoning and subsequent recovery of insect fauna in a California stream. There was a rapid explosion of the insect fauna, most likely due to elimination of insectivorous fish and other predators in the treated zone. During the winter, however, insect population levels in the treated zone were comparable to population levels in the untreated zone. Almsquist (1959) noted heavy mortality of zooplankton after rotenone application. Some species showed effects of the toxicant within 15 minutes and had 100% mortality in 3 hours. Application of rotenone to Washington Lake eliminated adult cladocerans and copepods for over three months (Kiser et al. 1963). Anderson (1970) noted that crustacean zooplankton remained absent over 6 months after rotenone treatment in two mountain lakes in Canada. Partial poisoning of selected areas on a water body may not require such a long recovery period. Treatment of a lake cove with about 0.6 µg/l of rotenone produced a drastic decline (97% less) in plankton volume within 24 hours. Copepods and cladocerans were nearly eliminated after two days, with some species being eradicated. Species composition and plankton volume approached that of the control cove in less than a week (Neves 1975).

Rotenone treatment to control undesirable fish populations is now an established management technique. Rotenone has been used to thin or completely eradicate existing fish populations. The high sensitivity of gizzard shad to rotenone allows for partial removal of overabundant shad populations using dilute (0.1 to 0.2 mg/liter) concentrations of rotenone (Rowers 1955; Seller and Wyatt 1967). Seller and Wyatt (1967) found control effective for three to five years before treatment was necessary. Jenkins (1959) reported reduction of fish populations resulted in improved fishing in three of the four Oklahoma lakes. The fourth produced an explosive carp population that reportedly hindered centrarchid reproduction.

The first large-scale watershed renovation program with rotenone was on the Russian River drainage in California (Pintler and Johnson 1958). A total of 461 stream km were treated with rotenone from 1952 to 1954. Targeted species were the western sucker, roach, carp and Sacramento squawfish; stream flows ranged from less than 1-17 m^3/s 1 m^3/s to over 17 m^3/s. Surveys conducted in 1955 indicated an initial benefit as indicated by a thirteen-fold increase in the number of juvenile steelhead trout, while non-game fish populations were reduced to about one-seventh their former abundance. Hudson (1975) also reported the successful renovation of Cagles Hill, a 567-hectare reservoir in Indiana, and 650 stream km of associated watershed. This effort targeted carp and bigmouth buffalo to enhance establishment of warmwater fishes. Sport fish were held and restocked. The reported increase in fishing success followed a previous attempt eight years earlier to control these fishes using a special commercial fishery and rotenone treatment of 82 hectares of reservoir shallows where carp were concentrated. These earlier efforts provided only two years of improved fishing.

Renovation of J.C. Murphy Lake in Indiana with rotenone resulted in improved fishing during a six-year period following treatment. Primary target species were carp and gizzard shad. Overall, the treatment was considered successful (Robertson 1975).

In contrast, Moyle et al. (1983) concluded that rotenone treatments in the North Fork of the Feather River in California (1.6 to 4.0 m^3/second), did not significantly improve the rainbow trout fishery in either of the two treatment areas based upon long-term populations trends. The two river reaches were treated twice, with ten years between treatments.

Considerations for use of antimycin or rotenone in the Columbia River

If antimycin or rotenone are considered for predator control in the Columbia River, the selection of which toxicant to use will depend upon the species targeted. Antimycin will effectively kill three of the four target predators in John Day Reservoir. Laboratory and field trials indicate antimycin is highly toxic to walleye with intermediate toxicity to smallmouth bass. Toxicity to northern squawfish will probably be intermediate based on toxicity to other minnow species. Channel catfish are not readily affected by antimycin. Concentrations necessary to kill channel catfish are too toxic to other non-target species to consider antimycin an effective toxicant for control of this species. Differences in the toxicity of antimycin to target species may affect mortality to non-target organisms. The high toxicity of antimycin to walleye would allow selective treatment with minimal loss of non-target species. However, concentrations toxic to walleye would also be toxic to salmonids. Smallmouth bass would be very susceptible to antimycin treatment in John Day Reservoir. Treatment of the littoral zone would be relatively easy if the sand formulations were available. Antimycin concentrations required for smallmouth bass would cause non-target mortality among salmonids, percids, catostomids, centrarchids, and cyprinids within the treatment zone. Northern squawfish control with antimycin would require treatment concentrations about equal to those used for smallmouth bass. Mortality of non-target organisms should be similar.

Toxicity of rotenone is also rather non-specific. As with antimycin, rotenone toxicity to walleye is very high, and losses of non-target species will be less than treatment for other predators. Lethal concentrations for all other target species are higher than for the most tolerant salmonid species, indicating heavy potential losses of non-target fishes in the treatment zones. Rotenone is much more toxic to channel catfish than is antimycin, although population distribution and concentration of toxicant **necessary to kill channel** catfish make control with rotenone unlikely.

The low toxicity of antimycin to invertebrates is definitely important for juvenile salmonids of the Columbia River, as zooplankton and aquatic insects make up a major portion of their diet (Craddock et al. 1976; Dauble et al. 19801. A decrease in zooplankton abundance that could accompany treatment with rotenone however and might decrease the carrying capacity of John Day Reservoir for juvenile salmonids. Bioassay tests on zooplankton and aquatic insects should be completed to evaluate potential reduction of fish food organisms before use of any toxicant.

The non-repellent nature of antimycin is especially important when only part of a water body is being treated. Fish exposed to rotenone often flee from the application area and it would be difficult to expose fish to a lethal dose of rotenone without poisoning the whole river. Chemical application during predator population congregations would produce the most effective results and would cause the smallest loss of non-target organisms. Congregation of walleye during spawning is probably the best time to apply chemicals. Most of the rest of the year these fish are scattered and in deeper water. Smallmouth bass are readily accessible during spawning, which occurs in relatively shallow water. In general, smallmouth bass spend a great deal of time in the littoral zone, especially during feeding therefore, this predator would be vulnerable to toxicants over a longer period of time than walleye.

Northern squawfish often form large spawning congregations. On the Columbia River northern squawfish also seem to congregate just above and especially below dams for a large part of the year (Gray et al. 1985). Application of a toxicant would probably be very effective in these areas.

Because water temperatures are positively correlated with toxicant effectiveness, timing of application is also very critical. The majority of juvenile salmonids in the Columbia River system have outmigrated by late summer when surface temperatures reach 20 C or higher, a temperature considered more effective with high kills and more rapid dissipation. The negative impact of late summer application on juvenile salmonids would be minimized and effect on predators maximized with application at that time.

Part C. Biological control methods: predation and pathogens.

Predation

Theoretically, a population of predators could be reduced if an additional predator (one which preys upon the first) is introduced into the system. Of the four main predators in the Columbia River system, only the northern squawfish is consumed by the other predators to a large extent. Juveniles of the other three species are not abundant enough to be important prey.

Predator introductions to control overabundant prey populations have resulted in mixed success. Control of the overabundant alewife in Lake Michigan was achieved by introducing predatory salmonids (Stewart et al. 1981). However, at the time of introduction, there were virtually no other predators present within the lake. Snow (1968, 1974) reported that the stocking of muskellunge, walleye and northern pike did not effectively control bluegill populations in Wisconsin lakes. Pritchard et al. (1978) found that 16 different predators had been tested for forage fish control in southern reservoirs with little success. Jenkins and Morais (1978) determined that diversification of predators in a system did not achieve control of prey fish.

Some introductions of predators have led to disasterous results. Largemouth bass introductions into Cuba resulted in a drastic decline of native cyprinodontid fishes, causing an increase in the malaria-carrying Anopheles mosquito (Rivero 1936). Striped bass have caused severe depletions of forage fish in reservoirs in which they were stocked (Morris and Follis 1979). The inadvertent introduction of the highly predaceous peacock bass into Gatun Lake, Panama resulted in a reduction of more than 99% of the total numbers of the 12 native species and the local extermination of all but one (Zaret 1979).

The removal of a top predator can also have a powerful impact on fish community structure. Paine (1969) demonstrated that removal of the major (keystone) predator, the starfish (Pisaster sp.), from an intertidal invertebrate community resulted in a reduction in the species diversity. The starfish removed mussels and barnacles, thus clearing substrate where "less competitive" species could colonize.

The disadvantages from introduction of predators in the Columbia River appear to outweight any benefits that might be anticipated. The Columbia River already supports sizable populations of piscivorous predators. It is unlikely that introduction of another predator could reduce predation upon juvenile salmonids and it may compound the problem since most piscivorous predators are opportunistic in their feeding habits. Currently there are regulations governing the introduction of non-native fishes into the Columbia River Basin which would need to be addressed before attempting this control measure.

Pathogens

There is a paucity of information in the literature concerning the use of pathogens (an organism which causes disease) for fish control. Most pathogen research is directed toward prevention and treatment of fish diseases rather than promotion. Biological control of noxious populations using pathogens has been well documented for insects (Sweetman 1958; DeBach 1965; Huffaker 1971; DeBach 1974; Delucchi 1976; Ridgeway and Vinson 1977; van den Bosch et al. 1982) and has been used with temporary success to control rabbits in Australia (Penner and Ratcliffe 1965). Control of the European spruce sawfly is an example of how pathogens can reduce the size of a population. The larvae of the sawfly were causing extensive damage to spruce trees in Canada and the United States after introduction of this pest about 1930. A virus proved to be the most effective method of control (Neilson and Morris 1964). By 1940 the population size was reduced to less than 1% of the 1938 level.

Pathogens of fish are poorly understood (Coutenay and Robins 1973). Extensive information about the host is important to pinpoint time periods, life history stages and areas where the host is most vulnerable to attack. One of the most important requirements for using pathogens to control animal populations is host specificity. A pathogen can detrimentally affect non-target organisms if it is not host specific. There are very few known fish pathogens that are host specific. Golden shiner virus is host specific, although introduction of the virus to control golden shiner populations is probably not effective (Plumb et al. 1979). Relatively low mortality rates are associated with the disease under normal culture conditions but crowding may increase the incidence of the virus, although it does not affect the mortality rate (Schwedler and Plumb 1982). Channel catfish virus is also a relatively specific pathogen. The only hatchery-reared species from which the virus has been isolated is channel catfish (Plumb and Chappell 1979), although white catfish and blue catfish have been experimentally infected (Plumb 1971). The disease usually only affects fry and fingerlings and mortality up to 100% has been recorded (Plumb 1974). The disease is highly contagious and is usually spread through the water or by contact with susceptible fish (Wellborn et al. 1969; Fijan et al. 1970). Vertical transmission through eggs of brood fish may also occur (Plumb 1978).

There are numerous drawbacks to use of pathogens including: irreversibility of pathogen introduction; potential damage of the spread of disease to areas where the target predator is not considered a problem; once a pathogen is established in the environment it is essentially impossible to eradicate. Members of the family salmonidae can be hosts to most known fish diseases; lack of host specificity for known pathogens; and there is no known pathogen specific to walleye, smallmouth bass or northern squawfish (Eric Pelton, personal communication).

Part D. Prey protection measures: attractants, repellents and alternate prey.

Attractants and Repellents

Predators around dams seek out slack water where currents are reduced and tend to shun turbulent areas. Use of a bubbler or series of air jets might eliminate feeding or resting areas for predators but should not affect juvenile salmonid passage because tests of air jets to deter juvenile salmon from entering a tributary were a failure (Warner 1956). However, it is unknown how effective a turbulent zone would be in deterring predators.

Investigations into the use of underwater acoustics to attract or repel fish have met with mixed results. Most studies aimed at attracting fish have used recordings of the fish under natural conditions. Sound detection is well developed in most fish, with sensitivity greatest in the lower frequencies (Bond 19701. Burkett (1977) recorded feeding and spawning sounds of carp, river carpsucker, smallmouth buffalo, and white crappie and observed that the fish showed no reaction to the playback of the sounds. Bullheads showed no response to playback of their recorded sounds (Wallace 1969) and two species of squirrelfish showed no reaction to a sound source over 3 m away (Popper et al. 1973). Gerald (19701, however, attracted several species of sunfishes to a playback of their recorded spawning sounds at a distance of 3.

Higher sound intensities have been shown to repel or frighten fish. Hashimoto and Maniwa (1967) stated that carp swam away as if frightened when the intensity of the playback of their sounds was increased. Smith and Anderson (1984) used broad-band and low frequency transducers in an unsuccessful attempt to drive reservoir fishes from dam sluiceways. Most research to date indicates that underwater acoustical stimulus would have little value in attracting or repelling fish.

Alternate Prey

An introduction or an increase in the abundance of alternate prey in the Columbia River Basin could benefit juvenile salmonids by decreasing the relative frequency of juvenile salmonid encounters with predators or predators may switch prey to take advantage of shifts in the relative abundance of prey species (Campbell 1979). The influence of increased prey abundance on the functional response of predators has been well documented (Beers and McConnel 1966; Parsons 1971; Hartman and Burgner 1972; Forney 1974). Conversely, it is also suggested that intensity of predation is not solely proportional to predator food supply, but involves a myriad of other factors including environmental complexity, prey exposure, and average area searched by the predator (Ware 1972; Jenkins 1979; Paloheimo 1979).

Enhancement of an endemic prey species would require increasing the abundance of the species to such a level that predator switching to the alternate prey would occur, thereby reducing the impact of predation on juvenile salmonids. Prey enhancement could be achieved by increasing natural production or through stocking. The potential impacts to the environment resulting from prey enhancement must be considered. Overpopulation of a prey species could result in severe competition for food and rearing habitat between that species and other endemic species, particularly migrating juvenile salmonids.

Although there have been reports of improved fisheries due to the introduction of exotic prey (particularly threadfin shad) any introduction should be viewed with the utmost caution (Beers and McConnell 1966; Jenkins 1970; McHugh 1983). Larken and Smith (1953) reported the widespread decline of the Kamloops trout fishery in many British Columbia lakes was due to increased competition for food between juvenile trout and the introduced redside shiner. Campbell (1979) states that research tends to indicate that species introductions are ventures into the unknown; we do not know if the new species will succeed or what effects it will have if it does succeed. Successful introductions are usually irreversible and if the consequences of introduction are undesirable, mismanagement will have brought about a permanent problem. It is the relative uncertainty of this technique which renders it of little potential use in the Columbia River system.

Part E. List of common and scientific names of fishes used in Section II.

Family	Scientific name	Common name
Lepisosteridae	Lepisosteus osseus	longnose gar
Amiidae	Amia calva	bowfin
Clupeidae	Alosa pseudoharengus	alewife
	Dorosoma cepedianum	gizzard shad
Salmonidae	Coregonus artedii	cisco
	C. clupeaformis	lake whitefish
	Salmo clarki	cutthroat trout
	S. gairdneri	rainbow trout
	S. gairdneri kamloops	Kamloops trout
	S. trutta	brown trout
	Oncorhynchus keta	chum salmon
	O. kisutch	coho salmon
	O. nerka	sockeye salmon
	O. tschawytscha	chinook salmon
	Salvelinus alpinus	Arctic char
	S. fontinalis	brook trout
	S. malma	Dolly Varden
Esocidae	Esox lucius	northern pike
	E. masquinongy	muskellunge
Holocentridae	Myripristic spp.	squirrel fishes
cyprinidae	Acrocheilus alutaceus	chiselmouth
	Carassius auratus	goldfish
	Catostomus occidentalis	western sucker
	Hesperoleucus venustus	roach
	Mylocheilus caurinus	peamouth
	Phoxinus eos	northern redbelly dace
	Pimephales promelas	fathead minnow
	Ptychocheilus grandis	Sacramento squawfish
	P. oregonensis	northern squawfish
	P. umpquae	Umpqua squawfish
	Richardsonius balteatus	redside shiner
	Rutulis spp.	European roach
Catostomidae	Carpiodes carpio	river carpsucker
	Catostomus macrocheilus	largescale sucker
	C. occidentalis	western sucker

(Appendix Part E Continued)

Family	Scientific name	Common name
Catostomidae (con't.)	Ictiobus babulus	smallmouth buffalo
	I. cyprinellus	bigmouth buffalo
Ictaluridae	Ictalurus catus	white catfish
	I. furcatus	blue catfish
	I. punctatus	channel catfish
	I. nebulosus	brown bullhead
Percichthyidae	Morone saxatilis	striped bass
Centrarchidae	Lepomis microlophys	redear sunfish
	Lepomis spp.	sunfish spp.
	Micropterus dolomieui	smallmouth bass
	M. salmoides	largemouth bass
	Pomoxis annularis	white crappie
Perchidae	Perca flavescens	yellow perch
	Stizostedion vitreum vitreum	walleye
Sciaenidae	Aplodinotus grunniens	freshwater drum
Cottidae	Cottus spp.	freshwater sculpins
Cichlidae	Cichla ocellaris	peacock bass