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NORTHERN SQUAWFISH HARVEST TECHNOLOGY: IMPLEMENTATION FEASIBILITY IN THE COLUMBIA RIVER

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Approved

Submitted____________________ ____
Director

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KEY WORDS

squawfish, Columbia River, juvenile salmonids, harvest methods, longline, gillnet, beach seine, purse seine, lake traps, Merwin trap, electrofishing, squoxin

LIST OF ACRONYMS AND ABBREVIATIONS

BPA	Bonneville Power Administration
CPUE	catch per unit effort
CRITFC	Columbia River Inter-Tribal Fisheries Commission
FPAC	Fish Passage Advisory Committee
NMFS	National Marine Fisheries Service
ODFW	Oregon Department of Fish and Wildlife
SOF	School of Fisheries
USFWS	United States Fish and Wildlife Service
UW	University of Washington
WDF	Washington Department of Fisheries

<	less than
>	greater than
≤	equal to or less than
≥	equal to or greater than
~	approximately
d	day(s)
ft	foot, feet
L	liter
h	hour(s)
in	inch(es)
m	meter(s)
mi	mile(s)
min	minute(s)
mo	month(s)
sec	second(s)
wk	week(s)
yr	year(s)

INTRODUCTION

The purpose of this report is as follows: (1) to review field results and literature pertinent to those potential methods of capturing or removing northern squawfish (*Ptychocheilus oregonensis*) from the Columbia River that have not yet been implemented or have been implemented unsuccessfully (longlines) in test fisheries under the Columbia River Northern Squawfish Management Program (Nigro 1990, 1991; Willis and Nigro 1991); (2) to summarize this knowledge in a manner that can be readily accessed by the management agencies in developing a system-wide implementation plan for removing an additional 200,000 squawfish per year; (3) to recommend methods for implementation; and (4) to discuss logistical, biological, and social problems anticipated in implementing the recommended technologies.

This report excludes analysis of the fully implemented hook-and-line programs—dam angling and sport reward fisheries. These fisheries together are currently removing about 200,000 squawfish per year in the target length range of ≥11", about a 9–14% annual exploitation rate according to tag returns (Parker et al. 1993). Implementation and evaluation of the angling fisheries is discussed in other reports (Nigro 1991, Willis and Nigro 1991). The angling fisheries have provided the largest harvests, but they are yielding only about one-half of the 15–20% annual exploitation identified as the program goal. We refer in the present report to the level of harvest achieved with angling fisheries as a benchmark for what may be achievable by implementing alternative technologies. Thus, in discussing potentially appropriate technologies, we have developed operating scenarios for the entire lower Snake and Columbia River system (eight reservoirs and the stretch of river below Bonneville Dam), indicating either our best assessment of the degree to which each method is capable of removing ~200,000 squawfish per year, or what level of effort might be required to reach this harvest objective, or both. Certain technologies, in our assessment, are not appropriate for implementation at any level. We discuss these and their problems but do not present operational scenarios. We also discuss other technologies that may have application but for which there is no test fishing or experimental experience from which to extrapolate implementation scenarios. Finally, there may be viable alternative harvest technologies that we are not aware of. In that sense, this report is not meant to provide any exhaustive treatment of the subject but simply to provide information on what we were able to identify as potentially promising technologies for harvesting northern squawfish in the mainstem Columbia and lower Snake River basins.

DATA SOURCES

Our major sources of data and other input are as follows:

1. Four years of experimental testing by the School of Fisheries (SOF) with floating and sunken traps, gillnets, purse seines, baited pots, beach seines, longlines, and electrofishing (1989–92). The 1989–91 results have been reported in Mathews and Iverson (1991); and Mathews et al. (1990, 1991). The 1992 SOF field results have been reported in weekly Field Activity Reports sent to Bonneville Power Administration (BPA), Fish Passage

Advisory Committee (FPAC), and National Marine Fisheries Service (NMFS) but not summarized or analyzed prior to the present report.

2. Reports on 1982–86 studies of abundance and distribution of squawfish, walleye (*Stizostedion vitreum*), and bass (*Micropterus* spp.) in John Day Reservoirs by the Oregon Department of Fish and Wildlife (ODFW) (Willis et al. 1982; Nigro et al. 1983, 1985; Beamesderfer and Rieman 1988; Beamesderfer et al. 1987).
3. Annotated bibliography on predation control methods for northern squawfish by UW (Mathews et al. 1990).
4. Report on feasibility of various predator control measures for the Columbia River by ODFW and United States Fish and Wildlife Service (USFWS) (Poe and Reiman 1988).
5. Earlier report on technologies for squawfish control in Columbia River reservoirs (LeMier and Mathews 1962).
6. NMFS reports presenting data on squawfish catches by Merwin traps and purse seines in various Columbia River reservoirs (Raymond et al. 1975; Sims et al. 1976, 1978).
7. NMFS report on feasibility of various squawfish harvest technologies at Bonneville Dam (Monk et al. 1991).
8. Weekly squawfish program field activity reports by ODFW, Columbia River Inter-Tribal Fish Commission (CRITFC), USFWS, NMFS, and UW for 1992 (see Willis and Nigro 1993).
9. Notes from discussions with commercial and tribal fishermen during 1989–92.

CRITERIA FOR EVALUATION

For clarity and comparability among alternative harvest technologies, we will discuss each separate technology, providing information relative to a standard set of criteria. These criteria were specifically developed at an ODFW, UW, and BPA conference held September 8, 1992, in Clackamas, Oregon. Input to these criteria was also provided by CRITFC (August 21 memo from R. Beaty and B. Parker to C. Willis). Criteria are listed in order of consideration in formulating recommendations for a harvest technology to implement in a test fishery on a system-wide scale.

SQUAWFISH CATCH

a. *Catch Consideration:* Does the gear catch or remove squawfish?
b. *Size Consideration:* What are the proportions of total squawfish catch under and over the 250 mm (11 in) length commonly accepted as the piscivorous size threshold?

CONTRIBUTION TO HARVEST

a. *CPUE Considerations:* What is the average number of squawfish caught per defined unit of effort? What is the variability of CPUE historically, temporally, and seasonally?

b. *Logistics Considerations:* How readily deployable and manageable is the gear? What are vessel and manpower requirements?

c. *Scale-of-Operation Considerations:* (1) What level of effort must be expended to achieve a harvest objective of 200,000 squawfish per year? (2) Is linear extrapolation of the catch rate appropriate or is the applied catch rate/effort function likely to be nonlinear? (3) What is the probability of being able to expend the required effort to achieve the harvest objective? (4) If it is impractical to attempt an annual harvest of 200,000 squawfish, what lesser harvest objective may be attainable, and how does it compare proportionately to the 200,000 squawfish objective?

INCIDENTAL CATCH

What are the catch rates (numbers per-unit-effort) on non-target species? What is the frequency distribution of condition of non-target species relative to likelihood of survival if released (Good, Poor, Dead)?

SOCIAL AND REGULATORY ISSUES

What conflicts with other river users are likely? What legal constraints might there be?

COST

a. What is the purchase cost for all of the equipment required to operate a standard unit of the gear?

b. What are the resources (personnel, supplies, etc.) and their costs to operate the gear for a time period (day, week, etc.)?

c. How does the seasonal cost of operation compare proportionately to the cost of implementing the combined sport reward and dam angling fisheries (~$4.2 million per year—$3 million for sport reward and $1.2 million for dam angling)?

Our rationale for the order in which the criteria were considered, selection of participants in evaluating information relative to the criteria, and actions resulting from evaluating harvest techniques relative to the criteria was as follows:

We sought technologies that can be used to successfully harvest northern squawfish, particularly from that portion of the population considered to be piscivorous (Criterion 1). Techniques failing to harvest squawfish that are primarily large enough to be considered piscivorous were not considered further. If a technique was able to target harvest on piscivorous-sized northern squawfish, then we assessed the rate at which, and the extent to which, squawfish could be harvested relative to program harvest objectives (Criterion 2). Techniques that could not contribute substantially, either alone or in combination with other harvest techniques, to program harvest objectives were dropped from further consideration. Next, we assessed the biological and environmental costs of implementing harvest techniques that could contribute substantially to squawfish harvest (Criterion 3). If these costs were acceptable, based on review and approval by fisheries management authorities, then we assessed potential social or regulatory conflicts that would inhibit or prohibit use of the technique (Criterion 4). Finally, the relative cost of implementation among alternative harvest technologies that are biologically feasible and socially acceptable were evaluated (Criterion 5). We determined that complete evaluation relative to Criteria 4 and 5 may require development of a detailed plan and subsequent broad review of that plan within the region.

HARVEST METHODS

Following are the fishery technologies we considered in this report.

I. HOOK AND LINE FISHERIES

A. UW Longlining System

Squawfish Catch

Catch Consideration

The UW longlining system was developed for use in a small boat fishery for removing northern squawfish on the Columbia River. The system uses light-weight monofilament groundline and custom-designed one-piece gangion snaps. Thirty-pound leaders are used with 3/0 Kahle horizontal hooks. A wide variety of baits can be used ranging from fresh salmon smolts to nightcrawlers (Mathews et al. 1990). The average length of groundline used is 660 ft with hooks spaced every 6–12 ft. Roughly 50–75 hooks were set on a standard unit of groundline by the UW.

This gear was developed and first tested in 1989 (Table 1). A total of 654 squawfish were captured that first summer in the tests done over 3 mo in the John Day Reservoir. During the summer of 1990, three tribal fishers removed 1,413 squawfish using the UW longline system in the John Day pool under a stringently controlled test program. In 1991, the fishery was fully implemented; nine tribal fishers operated UW longline systems from Bonneville Dam to McNary Dam and removed 1,071 squawfish. The tribal fisheries were operated under very stringent regulations; if a full-scale fishery was implemented with fewer restrictions and tailored to the fisher's needs, catch could be higher.

Size Consideration

The baited longline captures predominantly predacious-sized squawfish (>250 mm). Nearly 98% of the squawfish captured by the UW on the longlines in 1989 were >250 mm in length. Fishing within the McNary Dam boat-restricted zone (BRZ) yielded larger squawfish than elsewhere on the river, and a high proportion of the BRZ catches were gravid females.

Conclusion: Longlines catch squawfish, most of which are piscivorous size.

Contribution to Harvest

CPUE Considerations

Unit of Effort: A line set and retrieved with some given number of baited hooks attached could be a reasonable unit of effort; CPUE would thus be catch-per-baited-hook. However, in this report we use the reciprocal of this measure—number of hooks set for every squawfish caught—following common usage in commercial marine longline fisheries. The length and time a hook fishes is relatively immaterial in an efficiency analysis of a longline fishery, so we add no time dimension to our CPUE statistic for longlines. The more hooks set per fish, the less the efficiency.

Table 1 provides hooks set per squawfish for fishing both inside and outside of BRZs. One squawfish per 24.7 hooks set was the average catch rate for the UW longlining system in all areas in all years. The catch rate inside the BRZ was nearly double the catch rates outside of the BRZ, 14.5 and 26.2 hooks per squawfish, respectively. Bait type influences the overall catch rates of squawfish on the longline (see Mathews and Iverson 1991), with salmonid smolts 2.5–4 in long being the best bait.

Logistics Considerations

The UW longlining system can be safely operated out of any boat >16 ft long. Two people are needed to operate the gear, which can be manually or hydraulically deployed. Some training is required for the crew; however, it is not difficult to operate this gear. It is, however, necessary to be fastidious to achieve maximum efficiency. Hooks should be sharpened and straightened often, bait must be excellent quality, and constant attention must be given to depths fished because squawfish vary in their height within the water column. Best efficiency is achieved with systems of floats and anchors to suspend baits at various depths. Experience and practice are the only way to find how best to fish any given particular location and time.

The only limits as to where this gear can be fished are in very strong currents or heavy weeds. The optimal location for fishing is generally in 5 to 25 ft of water near a current shear close to a main channel; the longline should be set in slower water near faster moving currents. Baits should be pulled within 3 h because they lose their freshness after this time.

The UW longlining system is labor-intensive but simple to use. It takes ~20 min to bait and set 50 hooks on a 330-ft groundline. Another 20–30 min are required to pull and de-bait that same longline. Using groundline sets of this length, two people in an 8-h day could set and retrieve 500 hooks. But using longer groundline sets, 100 hooks per set, and after gaining experience, a crew could set and pull up to 1,000 hooks per d. The shorter sets would be recommended for use in the BRZs; consequently, 500 hooks per 8-h day should be used for projection in the BRZ. Outside of the BRZs, longer groundlines would be optimal, with 1,000 hooks per d being a reasonable projection.

Good bait is essential to longline catch success, and smolts are the best bait. There is no ready supply of smolts in quantities necessary at an implementation level. Perhaps this could be developed by using state or private hatchery facilities.

Scale-of-Operation Considerations

Considering that this gear can be set anywhere in the river, it is reasonable that longlining could remove the full 200,000 squawfish needed to compliment the sport reward and dam angling fisheries. It is simply a matter of setting enough hooks. The greatest obstacle in achieving this level of removal would be finding enough qualified and interested personnel to operate a sufficient number of longline boats. The 1991 tribal longline removal program was available to over 430 potential fishermen and only 9 participated.

We project that there is room within each BRZ for only one boat to operate. Each could set 500 hooks per d, and operate effectively for 100 d (5 mo at 20 d per mo). Outside the BRZs, there is effectively unlimited space for longlining, and we project potential catches on the basis of 1,000 hooks set per boat d and 100 d per boat per season. We base our projection on catch rates at 14.5 and 26.2 hooks per squawfish in and outside the BRZs.

Conclusion: Within the BRZs, eight longline operations (one at each dam) would remove 27,586 squawfish per year. Outside the BRZs, 46 additional boats would be required to take 175,573 more squawfish to yield the total of 203,159 per year.

The total amount of longlining effort needed to remove over 200,000 squawfish would then be 54 boats over a 5-mo period. This seems to be a reasonable extrapolation since this effort could easily be distributed over the full length of the Columbia and Snake rivers within the current squawfish program region, allowing each boat to fish roughly 10 mi of river outside the BRZs. The linear extrapolation also seems reasonable since 200,000 fish represents about 10% of the population. At this level of exploitation, the catch rate is nearly proportional to effort. It is only at substantially higher catch rates that the relationship becomes decidedly curvilinear.

Incidental Catch

The UW longlining system is relatively effective at targeting northern squawfish. A total of 70% of the fish caught on the UW longline system have been northern squawfish (Table 1). White sturgeon, *Acipenser transmontanus* (17%), and channel catfish, *Ictalurus punctatus* (9%) have been the predominant incidental species taken by this gear. The incidental catch is about the same inside and outside the BRZs. All of the white sturgeon captured on this longline are <4 ft (1,219 mm) in length, owing to the 30-lb breaking strength of the gangion leaders.

Conclusion: If a large-scale removal program were to occur with this longlining system, an anticipated catch of 49,338 white sturgeon and 26,120 channel catfish would occur. According to hooking mortality studies (Mathews et al. 1990, Mathews and Iverson 1991), 4% or 1,974 white sturgeon would be killed because of this fishery. Further confidence that the mortality rate of sturgeon released from longlines would be relatively low is the fact that longlining has been used frequently for sturgeon tagging studies, and we are unaware of any concern ever voiced or reported about significant hooking or handling mortality associated with such research.

Social and Regulatory Issues

For longlining within the BRZs, some coordination with the U.S. Army Corps of Engineers is required. Fishing can only occur in the spill basins of the hydroelectric projects when all spill gates at that particular dam are sealed.

When the tribal longline fishery was implemented in 1990–91, a 75–100% monitoring effort was considered necessary because of the potential for incidental catch injury and mortality. Yet, present commercial fisheries for salmon, shad (*Alosa sapidissima*), and sturgeon (tribal and non-tribal) on the river have little or no such monitoring, and incidental catch problems may exist with these. It would be economically impossible to monitor a fleet of 54 squawfish longline boats, and perhaps unnecessary.

Another important factor to consider is the established commercial fishing zones that have been developed on the river. Zone 6 is now restricted to only tribal members for salmon, sturgeon, and shad fishing. However, given the 1991 longlining implementation experience, it is likely that the projected fishery of 54 boats would require non-tribal participation in Zone 6.

Cost

A UW longlining system can be installed on any open boat 16 ft or longer. A safe and usable boat, including outboard motor and trailer, could be purchased for about $5,000. Equipment including a reel with replacement spools, groundline, gangion snaps, leader, hooks, and all necessary accessories would be roughly $2,500 per boat. Operation costs would be mainly for labor, including overhead and per diem; we project these at $200 per d per person. We project fuel and miscellaneous gear, boat, and travel expenses at $50 per d. Bait would be a major operating expense. Smolts would be needed; these, we project, would come from private trout and salmon aquaculturists, and could be as cheap as $0.05 per bait of 50 fish per lb size (roughly $3.00 per lb, which is close to the rainbow trout (*Oncorhynchus mykiss*)/coho (*O. kisutch*) salmon price for market-sized product).

Conclusion: Equipment costs for 54 units would total about $405,000. Annual operating costs, given the above data on boats needed, baited hooks required, manpower and fishing days per month, would be $2,025,000. These operating costs are 48% of the operating costs of the currently implemented hook and line test fisheries.

B. TRADITIONAL LONGLINING

Squawfish Catch

Catch Consideration

In 1992 a longline fishery was implemented by ODFW below Bonneville Dam on the Columbia River for removing northern squawfish (Mallette et al. 1993). The fishery was limited to three commercial fishers who were allowed to choose which type of longline gear they preferred to target northern squawfish. Two fishers chose to use their traditional black cod and halibut groundline (1/4-in braided rope) and metal gangion snaps. One fisher and the ODFW research vessel chose to use the UW longlining system with a few slight modifications. Restrictions were placed on the hook size (3/0) and gangion breaking strength (20-lb) of all gear owing to UW research efforts from 1989 through 1991 which showed that large sturgeon tended to break off 30-lb leaders and maximum hook size of 3/0 minimized hooking injury.

The two fishers that selected the traditional longline gear caught a total of 1,079 squawfish during 13 wk of fishing in 1993 (Table 2). The two vessels using the UW longlining system also caught 1,079 squawfish. A total of 850 sets were made with the traditional longline gear, averaging roughly 105 hooks per set.

Size Consideration

Of the 1,079 squawfish caught on the traditional longline gear, 818 (76%) had lengths of >11 in (Table 2). This compares with 916 squawfish out of 1,079 caught on the UW longlining system, or 85%.

Conclusion: Traditional longlining methods, using 3/0 hooks and 20-lb gangion material, capture squawfish of piscivorous size.

Contribution to Harvest

CPUE Considerations

Unit of Effort: The data are presented in terms of total sets, hooks set, and hours fished. We have summarized CPUE in two ways: Catch per set is recorded and, to maintain continuity with the preceding section on the UW longlining system, we also present hooks set per squawfish caught. In this way, the fewer hooks set per fish represents a higher catch per effort.

The traditional longlines captured 1,079 squawfish in 850 sets (1.27 squawfish per set). The alternate measure computes to 82.85 hooks set per squawfish caught. The UW longlining system averaged 67.08 hooks per squawfish during the same period.

Logistics Considerations

The traditional longline gear is set using hydraulic drums and davits. This gear requires a larger boat with sophisticated equipment on board for setting and retrieving lines. The advantage with this gear is that many more hooks can be set in a day of fishing. A disadvantage may be the cost of the longlining operation. Because of the requirement for mechanization, boats must be larger than with the UW system (>25 ft), and operational costs would probably be higher. With traditional longlining, the gear tends to sink to the bottom because of the weight of the groundline. Also, rapid setting of many hooks makes it difficult to manage the height of individual baits above the bottom, which we feel is essential for minimizing the ratio of squawfish/sturgeon caught.

Scale-of-Operation Considerations

Conclusion: We suggest that traditional longlining should not be used for large-scale removal for northern squawfish. The cost per vessel and the high degree of incidental harvest of white sturgeon are drawbacks too difficult to overcome. Thus, we present no scenario for operation.

Incidental Catch

Northern squawfish composed only 23% of the total catch for the traditional longlines while sturgeon composed 74% of the catch (Table 2). Virtually the reverse was encountered with the UW longlining system, not only above Bonneville Dam where all UW and tribal longlining was done, but also below. The two vessels that tested the UW longlining system in 1992 below Bonneville Dam caught roughly 81% squawfish, 15% sturgeon, and 4% other species.

Although sturgeon catch rate was high, the death and injury rates were low. Of 3,516 sturgeon caught, 97% (3,416) were released in good condition, 1.6% (55) were released in fair condition, 1.25% (44) were released in poor condition, and only 0.03% or 1 sturgeon was dead upon removal from the longline gear (Table 2).

Conclusion: Incidental catch of sturgeon is so high that traditional longlining is not a reasonable squawfish control technology for the Columbia and Snake rivers.

Social and Regulatory Issues

The high degree of incidental catch of white sturgeon would probably preclude this fishery from being allowed by the regulatory agencies.

Cost

We present no cost scenarios because this technology would probably not be allowed. We note only that the traditional longline fishermen were paid $250 per fishing d and also received a $3 per squawfish incentive payment in the 1992 ODFW test fishery.

C. SPORT REWARD LONGLINE

Squawfish Catch

Catch Consideration

An untested idea that may significantly supplement the sport reward angling program would be a licensed longline program for fishermen already participating in the sport reward program. A possible scenario would allow each sport fishermen to fish one longline of 30 or 50 hooks each. Fishermen might require a special license and probably a sticker on their boat to show that they were participating in the program. Assuming they would use basic gear (groundline, leaders, hooks, baits, anchors, and floats) similar to the UW system, the catch rate experienced for that gear can be used for projections.

A 50-hook longline set outside the BRZs will average two northern squawfish. To catch 200,000 per year would therefore require 100,000 such sets. There were 85,000 individual fishermen participating in the 1992 sport reward program. A large but unknown percentage of these would own a boat of sufficient size to handset a groundline with 50 baited hooks. It is quite likely that 100,000 such sets would be made, given the enthusiastic and intense participation by sport fishermen in the program.

Size Consideration

Most of the squawfish caught on UW and traditional longlines have been of piscivorous size. The use of smolts for bait practically guarantees that predaceous squawfish will be a high component of the catch.

Contribution to Harvest

Logistics Considerations

Longlines are relatively simple to operate. If fishermen were limited to a small number of hooks (50), and lines had to be hand set, an average fisherman could operate out of a very small boat with some level of success. This gear could be used to supplement their rod and reel catch. A boat would be mandatory for participating in this type of program. Vertical longlines (anchor on only one end, float on the other) might be preferable and have several advantages. One advantage is that most of the baits would be off the bottom, reducing sturgeon catch. Another is that many short lines could be set in this way, which would also create less of a navigational hazard than an equal number of hooks placed in standard form with anchors at each end of the groundline.

Owing to the small scale of this longlining effort, a fisherman could easily deploy 50 hooks before rod-and-reel fishing and retrieve them on the way to the check out station. The efficiency of the total effort would thereby be improved.

A longline can be made by tying monofilament gangions to a length of rope. Any heavy object such as a lead weight, a brick, or a piece of scrap iron can be used as an anchor, and floats can be made from old milk cartons. A 50-hook unit could be hand-coiled and set from a wash tub or large pail. Thus, costs would be very low to an angler.

Scale-of-Operation Considerations

Basically, the 50-hook sport reward longline allows the existing fishery to be considerably more effective. Fishermen would set their gear and then go rod-and-reel fishing; at the end of the outing, they would retrieve the longline.

An additional 200,000 northern squawfish could probably be removed by this method. If fishermen were limited to 50 hooks each and 2,125 fishermen fished 12 d per mo for 4 mo, at two squawfish per 50 hooks, 204,000 squawfish would be removed. This participation level is only 2.5% of the number of participants in the 1992 sport reward program. We project that there would be this level of individual anglers with the time and enthusiasm to put forth such effort.

Incidental Catch

The numerical catch can be projected as equivalent to that of the full-scale UW longline scenario presented earlier. Thus, if 30-lb gangion breaking strength was specified, a 200,000 squawfish catch would result in a catch of 48,571 sturgeon and 25,714 channel catfish. We have no basis for projecting the mortality rate on these incidental catches because we cannot predict how carefully the individuals would handle and release these fish.

Social and Regulatory Issues

This operation would involve writing new regulations and issuing permits for the opportunity to fish longlines. A permit could be issued to a participant in the sport reward program to fish 50 fixed gear hooks. We have no basis for projecting enforcement needs or problems. If longlines were restricted to the vertical type, navigation hazards would be minimized.

Cost

This type of gear would not need a financial supplement from the removal project. Fishermen would pay their own costs as they are now doing for their angling gear. They would also pay to acquire their own bait. Even if they used smolts at $0.05 per bait, their projected return (two fish at $3 per fish) exceeds their bait cost for 50 hooks by more than double. The costs to the project would include writing regulations, creating a license and sticker for participants, and increasing program regulation enforcement. A license fee might remove all of these costs.

D. LURE TROLLING

Squawfish Catch

Catch Consideration

In 2 years of research, 1990–91, ODFW captured 1,396 northern squawfish on lures that were trolled behind a 28-ft aluminum motorboat (Vigg et al. 1990, Ward et al. 1991). Two down-riggers were used to hold 6 lures, 3 on each down-rigger, for trolling through the forebay and tailrace of Bonneville Dam. Many lures were evaluated during this study, with no one lure being more successful than all the others. During the summer of 1991, effort was limited to the 6 best lures from the 1990 experience.

Lure trolling is commonly used by sport reward fishery participants. In our field work we have met many clerks and participants in the sport reward program that informed us that many of the most productive fishermen in that fishery troll near hydroelectric projects and capture many squawfish.

Size Consideration

Of 1,381 northern squawfish that were measured, one fish was not of a predacious size (>250 mm). This gear definitely targets predacious-sized squawfish, almost exclusively.

Conclusion: Lure trolling captures northern squawfish of a piscivorous size.

Contribution to Harvest

CPUE Considerations

Unit of Effort: Catch-per-boat-hour is the unit used in the reports on this technology. This definition constitutes six lures trolling behind the boat for 1 h.

In 1991, squawfish catch per boat per h ranged from 0.35 (September) to 2.61 (July) averaging 1.09 squawfish per boat per h (Table 3). All of the fishing in 1991 occurred in the Bonneville Dam tailrace area. In 1990 it was discovered that trolling in the forebay never produced catch rates higher than 0.1 squawfish per boat/hour.

Logistics Considerations

Trolling can be performed from any sport or commercial motor boat of size suitable to safely navigate the Columbia River. One fishermen could tend several rods with a lure on each rod, or hand-operated guides (mounted reels) could handle multiple hooks.

Scale-of-Operation Considerations

Catch rates with multiple hook trollers were too low outside the BRZs to suggest that this would be a reasonable alternative. Even within the BRZs, trolling would not generate a very high fraction of the 200,000 squawfish target. For example, if there were eight boats, one at each dam working 8 h per d, 20 d per mo, and 3 mo per yr, 7,680 squawfish (less than 4% of the target) would be caught. There may not be enough fishing area within any BRZ to linearly extrapolate a two-boat fishing operation. Thus, this is our estimate of the maximum catch an aggressive multiple-hook trolling effort would achieve.

Conclusion: Lure trolling would not make a significant contribution to the squawfish control program.

Incidental Catch

In the 2 years that trolling was investigated at Bonneville Dam, three incidental fish were captured: one smallmouth bass (*Micropterus dolomieu*), one steelhead, and one sculpin. This gear effectively targets northern squawfish with little impact on incidental fish.

Social and Regulatory Issues

There would be no problems with a BRZ troll fishery. Sport fishermen can presently troll but cannot legally use multiple lures. Regulation changes to allow multiple rods, and/or multiple lures per rod, and/or fixed gurdies with multiple lures, could improve the efficiency of the sport reward program.

Cost

We project costs for BRZ trolling on a similar basis as costs for UW system longlining. A suitable used boat, fully geared for trolling, would cost $7,500. Trolling could be a one-person operation as opposed to longlining, which requires two people.

Conclusion: At $200 per d for labor, $50 for fuel and other operational expenses, 20 d per mo, 3 mo, and eight boats, total annual operating costs would be $120,000. This is about 3% of the annual cost of the implemented angling programs.

II. NET FISHERIES

A. GILLNETTING

Squawfish Catch

Catch Consideration

Gillnets have been used extensively for catching northern squawfish in the Columbia River. Since 1982, surface, bottom, and drift gillnets have been used as complementary gear to boat-based electrofishing for the ODFW predation indexing work. Also, the UW/ODFW experimented with gillnets in 1989 as potential small-boat commercial fishing gear for the squawfish removal program (Table 4). A total of 7,047 squawfish were taken from 1982–89 by all gillnetting efforts of the predator indexing and control programs (ODFW, USFWS, UW). Over 90% of these fish were taken by bottom gillnets in the John Day Reservoir.

Size Consideration

Only squawfish of predacious size are reported in 1982–86 ODFW reports; therefore, all of the 6,902 squawfish reportedly caught by gillnets were >250 mm in length, but according to the length frequency histograms in these reports, it appears that these catch figures may only represent 90–95% of all squawfish captured in these gillnets. In 1989, 99% of the squawfish captured by gillnets by the UW/ODFW were >250 mm.

Gillnets are a size selective gear; selectivity is determined by mesh size. Mesh sizes of 6.35 to 12.5 cm bar length proved to be the most effective at capturing predacious-sized squawfish.

Conclusions: Gillnets catch squawfish. If the correct mesh size is used, most of the catch will be fish of predaceous size.

Contribution to Harvest

CPUE Considerations

Unit of Effort: The commonly used gillnet in the ODFW studies was 100 ft long with mesh sizes varying from $2\frac{1}{2}$–$4\frac{1}{2}$" stretched mesh. Up to a point, gillnets catch more the longer they are allowed to fish, so soak time must be considered. The best unit of effort for gillnetting seems to be a 1-h soak.

The bottom gillnetting from 1982–86 yielded a CPUE ranging in annual mean from 1.29–1.85 squawfish per net h (Table 4). ODFW tested other modified gill nets (stationary surface, surface drift, and vertical gillnets) in dam tailraces. These have occasionally yielded a higher CPUE, with a range from 0.32 to 5.42 squawfish per net h. The 1989 UW/ODFW bottom gillnets averaged 0.3 squawfish per h. In projecting effectiveness of gillnetting in an implemented control program, we use an average catch rate of a 100-ft gillnet to be 1.5 squawfish per h.

Logistics Considerations

Bottom gillnets can be effectively fished only in areas of slow to medium current. Squawfish are found throughout the Columbia River but to date the largest concentrations have been found in the tailrace areas of boat-restricted zones, where the current is too strong to anchor and/or fish stationary gillnets.

Gillnets are relatively simple to fish; however, they can be hazardous to deploy since they can tangle or perhaps submerge an operator. Thus, some experience should be required of anyone working with them. A major problem with gillnets is the need to repair them frequently; gillnets accumulate woody debris drifting down with the current. As the nets fill with debris, they become less efficient and tend to tear. Gillnets seem to interfere with anglers, even when well-marked. Anglers tend to fish around the buoys, perhaps believing them to mark a good fishing spot, and get their hooks caught in the webbing. This tears the nets and also creates disharmony with the sport fishermen.

Scale-of-Operation Considerations

Although we do not recommend their use, gillnetting could theoretically take the 200,000 fish target. Thus, 66,667 2-h gillnet sets with a catch rate of 1.5 squawfish per net h would take this target. We project that one boat with a crew of two could set and retrieve eight 100-ft nets per d and do necessary repairs for this level of effort. Each set would be for 2 h. Since gillnetting can be done throughout the reservoirs and could be expected to yield a relatively constant (albeit low) catch rate, a linear projection is reasonable.

Conclusion: With 100-d fishing seasons per boat (20 d per mo and 5 mo), about 84 boats and crews would be needed.

Incidental Catch

Virtually everything big enough to get tangled in gill nets gets caught. In the 1989 UW/ODFW testing, we had a ratio of six incidental fish to every squawfish. The composition of this incidental catch is shown in Table 5. Of this catch 24% was game and food fish.

The rates of injury and mortality to incidental catch are also extremely high in gillnets. Five of nine steelhead adults captured during the summer were dead upon capture in the UW/ODFW 1989 gillnets. We found that many captured channel catfish had to have their pectoral or dorsal fin spines removed in order to facilitate release from gillnets. Most American shad appeared to be moribund after release from gillnets. In general, all species suffer significant injury or mortality after capture in a gillnet.

Conclusion: Salmonids composed 1.6% of the total bottom gillnet catch in 1989 (UW/ODFW). This would be a total of 21,622 caught in gillnets to capture the squawfish goal of 200,000. The projected levels of incidental harm and mortality to game and food fish alone should exclude the use of gillnetting from a full-scale removal effort. If 200,000 squawfish were to be caught by gillnets, 324,325 game and food species would also be caught; and most of these would be dead or moribund as a result of their encounter with the gear.

Social and Regulatory Issues

This gear could not be approved for use under the ESA, NMFS, and FPAC regulations because of the high incidental catch rate and the degree of harm imposed by this gear to other fish.

Cost

We project gillnetting costs on a similar basis as for the UW system longlining. A used outboard boat of suitable size and power equipped with 10 gillnets would cost $7,500. Operating costs would be $500 per d ($200 per d for each person, $50 for fuel and other boat operating costs, and $50 for new gillnet gear or repairs to old gear).

Conclusion: Operating 84 units would represent an equipment cost of $630,000 and an annual operating cost of $4,200,000. The latter figure is equal to the present annual cost of the two implemented angling programs.

B. BEACH SEINING

Squawfish Catch

Catch Consideration

Research done by USFWS in 1988 indicated that beach seines could be effective at capturing small squawfish in shallow areas of reservoirs having an unobstructed bottom. The beach seine was made of multifilament nylon and was 61 m long x 4.6 m deep with 5.1-cm bar mesh. Seine hauls were made with a boat and a three-person crew in areas along shores with depths of ≤4 m and smooth, gradually sloping bottoms. In undocumented tests in 1991, the UW beach-seined hundreds of squawfish <100 mm, averaging roughly 50–75 per seine haul.

Size Consideration

On the basis of the USFWS research and UW experimentation, the majority of squawfish vulnerable to beach seines would be <250 mm in length.

Conclusion: Beach seines can catch large numbers of squawfish; unfortunately, they are all less than predacious size.

Contribution to Harvest

CPUE Considerations

Unit of Effort: Catch per set of a 300-ft seine seems to be the most common reported statistic. A "set" is ~30 min and requires a small skiff with an outboard engine and 2–3 people.

Beach seines have been used sporadically, and for other purposes than to catch large squawfish. Thus, reported CPUE values are anecdotal to our present purpose.

Logistics Considerations

Beach seines were ranked by the SOF in 1989 as being relatively easy to handle and deploy with a limited crew (2–3) and a small boat. A beach seine's use is limited to specific bottom conditions such as smooth sand or gravel. In addition, beach seines are limited to areas of low to moderate current, further reducing potential fishing locations. There is relatively little suitable beach-seining habitat in the areas of large squawfish abundance. But for suitable areas, there would be no compelling disadvantages or problems using such gear. It is simple and safe to deploy.

Scale-of-Operation Considerations

Owing to the limited amount of seinable habitat, gear could not be expected to attain a catch rate anywhere near 200,000 squawfish, nor could it take a sufficient number of predaceous-sized individuals to be considered even as part of an implementation plan.

Conclusion: Beach seines would not be a productive means of removing predacious northern squawfish.

Incidental Catch

Beach seines capture a wide range of species, including salmonids, and a wide range of sizes, with varying degrees of effectiveness. In previous seining, large numbers of smolts were encountered. Condition of incidental captures appeared to be relatively good, but this method would tend to stress individuals.

Social and Regulatory Issues

Owing to the relatively high incidental catch of smolts by this gear, legal constraints under the ESA would be encountered.

Cost

Beach seining is a relatively inexpensive removal method (Mathews et al. 1990); however, the low catch rate of predaceous squawfish would make it an impractical removal method. We have not projected any costs.

C. PURSE SEINING

Squawfish Catch

Catch Consideration

Purse seines have been tested extensively for catching squawfish in the Columbia and Snake rivers mostly during summer months. The first major efforts were by NMFS during the years 1974–77 (Table 6). Most of that effort, in which 779 sets were initiated, was in the tailrace and forebay regions of John Day, McNary, Ice Harbor, Little Goose, and Lower Granite dams, using a 600-ft seine described in Sims et al. (1976). The UW tested purse seines during the years 1989–91. In 1989, 52 sets with a 350-ft seine and a 22-ft Boston Whaler were made in the vicinity of McNary

Dam; in 1990, 29 sets were made with this same gear near McNary Dam, and 45 sets were made at various other locations from the McNary forebay to the Bonneville tailrace by the chartered herring seiner *Bay Harvest* with a 600-ft seine. In 1991, 89 sets were made by the *Bay Harvest* with a 400-ft seine mostly in a region about 20 mi below to 20 mi above The Dalles Dam, and 21 sets were made by NMFS with a variable length net near Bonneville Dam.

A total of 9,373 squawfish were taken with all this effort (Table 6), indicating that squawfish can be taken by purse seining. Most of these fish were taken by NMFS in the early years, and most of that catch was in BRZs at the hydroelectric projects.

Size Consideration

More than 90% of the squawfish caught in the 1989–91 UW efforts were >250 mm in length; we used mesh sizes (2.5-in stretch measure in body of net and 2.0-in in the bunt) intended to pass salmonid smolts and, consequently, caught very few fish of any species <~250 mm. We have no data from the NMFS testing but presume that any purse seining done in the future, if it followed the minimum mesh criteria of our testing, would take mostly the large, target-sized squawfish.

Conclusion: Purse seining captures squawfish which are primarily large enough to be piscivorous.

Contribution to Harvest

CPUE Considerations

Unit of Effort: A convenient unit of effort for purse seining is a single set—the setting, pursing, and retrieving of the net one time. This requires from 15–60 min normally, depending on how long the net is held open before pursing, the length of the net, and occurrences of any physical problems.

For all purse seining tows, the catch per set has averaged 9.2 squawfish. CPUE has been about 3x higher in the tailraces (BRZs) than elsewhere, averaging 13.7 and 4.4 squawfish per set, respectively. It is our assessment that a purse-seine vessel could average about 8 sets per 8-h d. Sets can be made in <1 h, but counting travel time, downtime for repairs, etc., 1 set per h is a fair average. Thus, purse seining might yield about 110 squawfish per d on average in tailraces and 35 per d elsewhere. Most of the "elsewhere" areas of success would be in forebay areas inside dam BRZs. Fishing totally away from dams has produced <1 squawfish per set.

The UW attempted several techniques to improve purse seining catch success—nighttime fishing, use of lighting for attraction, and chumming with dead smolts. None of these techniques improved the catch rates.

Logistics Considerations

Purse seining is quite limited in its application. It requires a well-trained 3– or 4–person crew and two vessels to set and retrieve the net—the main vessel and a skiff to tow the other end of the net. The main vessel (which can be as small as a 22–ft open outboard boat) requires a high degree of specialized gear, a strong power source, and a heavy-duty hydraulics system. The skiff must be a well laid-out, efficient, smaller-sized, outboard or inboard open boat. The seine is also a relatively expensive piece of gear.

The number of places in the lower mainstem Snake and Columbia rivers that can be seined effectively for squawfish is severely limited. Seining is effective only in the BRZs at the dams. But around the dams, we have encountered numerous man-caused and natural hang-ups that do not always show on acoustic recorders. Hangups, requiring extensive time for net repair, plagued our efforts.

Wind and current turbulence cause additional problems. The Columbia River gorge, during summer months when squawfish concentrate at dams, is a notoriously windy environment. The norm is 15–35 knot westerly winds in the afternoons, which often persist all day and night. Seining close to dam structures in heavy wind, or near heavy currents, is hazardous not only to the gear but to the crew.

The tailrace regions are best for purse seining squawfish, but even these have serious limitations. First, you cannot seine in heavy current, so effective seining has to be coordinated with dam spillage and generation activities. This requires a lot of time, effort, and frustration in dealing with the hydropower operations because any flow regulation for squawfish removal is likely to be costly in terms of power generation. Second, even in the tailrace regions, the areas with optimum depth characteristics for any particular seine will be limited. It is likely that there will be only a few suitable sites, relative to the total available area that squawfish could access.

Scale-of-Operation Considerations

Purse seining could not be expected to approach the catch goal of 200,000 because of the logistical constraints described above. A principal limitation is that purse seining has a very low catch rate outside the BRZ. According to research on squawfish migration and distribution, perhaps 75% of the squawfish in the Columbia do not enter the BRZs at any time. Only in the BRZs, according to our experience, do squawfish exhibit sufficient schooling and pelagic behavior to make them vulnerable for seining. Elsewhere they are more benthic and structure-oriented, not a behavior suitable for purse seining. However, intense purse seining in BRZs could have a meaningful effect. One vessel could operate in the BRZs at each of the eight dams (total of eight operations). More than one operation per dam would be inefficient because of the limited sites. The tailraces would be fished when wind and water conditions were favorable, and forebays at other times. A high degree of coordination with hydropower operations would be necessary. Assuming 20 effective days per month (breakdowns and time off must be considered), 3-mo seasons, 8 sets per d, 9.2 squawfish per set, and 8 crews, a direct linear extrapolation gives a squawfish harvest estimate of 35,328 per year. Since squawfish tend to migrate to and from the BRZs over the course of the summer, a linear extrapolation (noncompetitive fishing) may be a reasonable assumption. The major caveat in this scenario is cooperation in spillage and generation flow by the dam operations. Also, the highest purse seine catch rates were from the 1970s. Our recent experience suggests that the linear extrapolation using the all-effort average should be viewed cautiously.

Conclusion: A maximum of ~35,000 squawfish could be harvested annually by purse seining in the BRZs of dam tailraces. (Effort expended elsewhere would be much less productive.) This is ~18% of the additional harvest objective of 200,000 squawfish.

Incidental Catch

Purse seines capture virtually the entire range of species that grow to a large enough size to be retained by the mesh (Table 5). Adult and juvenile salmonids and shad are the major potential problems. Juvenile salmonids are caught in the net folds or gilled in the mesh on occasion. In the recent (1989–91) UW and NMFS testing, the average adult salmonid, juvenile salmonid, and adult shad catches per seine set were 0.29, 0.44, and 43.3, respectively. The high average catch for shad was primarily a result of two sets below Bonneville Dam by NMFS in 1991 containing several thousand fish apiece.

Seines do capture fish alive, but there is potential for damage. This potential is highest for juvenile salmonids. They tend to be descaled from the web if they get caught between folds, and sometimes they are gilled. From our 1989–91 observations, we judge that all smolts retained in purse seines were in poor condition (on a good, poor, or dead scale). Adults fair better, but they also may be stressed by purse seine capture, particularly at high ambient water temperature. Of 60 seine-caught adult salmonids observed during August and September 1989–90, 40 were released in good condition, 15 were poor, and 5 were dead. Presuming all in poor condition died, then 20 of 60 or 33% is the mortality rate expected for adult salmonids released from purse seining at temperatures 65° or greater (when we did our seining). Shad also tend to be stressed from fighting to escape and would have, if anything, perhaps a higher mortality rate than salmon. However, depending on time of year, many of the shad we caught may have been spawned out, a condition adding to their stress.

Conclusion: A scenario was described under Scale-of-Operation Considerations that would remove 35,328 squawfish. This degree of effort, again linearly extrapolated from average CPUEs, would capture 1,114 adult salmon (330 would die), 1,690 juvenile salmon (most would die), and 166,656 shad. The shad situation could probably be improved but not eliminated by avoiding run peaks.

Social and Regulatory Issues

Other than the requirement for a high degree of coordination with the hydropower operators, there would be minimal expected conflict with other river users if the purse seining would occur only inside BRZs. The primary legal constraints would be encountered through the ESA because seining can harm adult salmonids. Seining in BRZs in the Snake River during the sockeye run, for example, might be too risky.

Conclusion: Identifiable social and regulatory issues appear resolvable and would be unlikely to prevent implementation of a purse seine fishery.

Cost

An efficient drum seining operation for squawfish removal can be utilized on a 22- to 24-ft open outboard boat. This can operate a net up to 500 ft, which is probably optimal. Approximately 200 hp would be required for the main drive engine. A 16-ft skiff with 40 hp motor would be a minimum safe size for the seine skiff. With trailers, trucks, a seine, and associated equipment, a unit cost would be about $110,000. The cost for a 500-ft seine is ~$2,000, and its useful life is ~2 seasons. Three well-trained people can efficiently operate such a unit. For a summer's season (the

3 mo when squawfish are concentrated near dams), operating costs would be ~$40,000 (wages, per diem, fuel, vessel maintenance, insurance).

Conclusion: Equipment costs would be ~$110,000 per unit, or $880,000, for operation at all mainstem dams. Operation and maintenance costs would be ~$40,000 per unit or $320,000 for operating at all mainstem dams. This cost is ~8% of the annual cost of operation of the combined sport reward ($3.0 million) and dam angling ($1.2 million) fisheries.

D. OTTER TRAWLING

We did not test the use of trawl gear to catch squawfish on the Columbia River, nor are we aware of any effort with such gear for squawfish elsewhere. We considered the use of a two-boat mid-water trawl system but did not test such because we felt that other gears had better potential. Bottom trawling, we felt, would be totally inappropriate because of irregular bottom configuration and underwater obstructions, particularly in the BRZs.

Either single-boat (fixed-frame or otter), or two-boat trawls could be physically operated in forebays; but in heavy current tailrace areas, two-boat systems would be most practical. We feel it would take enormous power to maneuver a single-boat otter or fixed-frame trawl at sufficient speed in tailrace currents. Even two-boat systems in such an environment would require considerable power and a great deal of operator skill and coordination. However, squawfish concentrations are high in tailraces, and trawl catches could also be high on occasion.

But trawling has likely drawbacks. First, we think that squawfish are pretty good at avoiding and escaping nets. On several occasions in our 1989 field tests, we fished purse seines and longlines concurrently, and on many occasions did so with gillnets and longlines (Mathews et al. 1990). The purse seine/longline test area was the McNary spill basin during non-spill, and the gillnet/longline test area consisted of many sites throughout the John Day Reservoir. We found both seines and gillnets surprisingly ineffective at times and places where longline catch rates indicated abundance of squawfish. Longlines set to fish at various depths between the surface and the bottom often indicated presence of squawfish in the depth range of the purse seine; yet our 30-ft-deep seine caught few to no fish. We think that squawfish are quite capable of spotting nets, interpreting them as trouble, and avoiding them. We think they would do the same with trawls towed at the speeds we could expect with any reasonable towing power and gear.

Incidental catch of salmonid smolts could also be a problem with trawls. Adult salmonids would probably avoid capture, but yearling smolts, particularly those fatigued by their passage through powerhouses, would be vulnerable. And we are not confident that this problem could be eliminated or sufficiently alleviated by use of large mesh codends. Mesh size regulation to avoid capture of small fish is not as effective with trawls as with stationary gear like traps and gillnets. Water pressure and the pressure of fish masses in codends forces retention of small fish otherwise perfectly capable of fitting through the codend mesh. Also, even the escaping smolts would be squeezed through the mesh under pressure, which would induce descaling.

Conclusion: Since two-boat trawling would be relatively expensive and could induce high incidental mortality, we recommend against consideration or testing of such gear.

III. TRAP FISHERIES

A. SUNKEN LAKE TRAPS

Squawfish Catch

Catch Consideration

Sunken traps were used early in the predator/prey investigations. ODFW fished sunken lake traps from 1982–86 and caught a total of 2,568 squawfish (Table 7). The UW fished a sunken trap for 2 d in 1989 and captured 8 squawfish.

The ODFW sunken trap nets had a 2.7-m deep x 1.8-m wide x 2.4-m long multi-filament nylon capture box of 1.9-cm bar mesh. Two 2.7-m deep x 7.6-m long wings and a 2.7-m deep x 60-m long lead of 5.1-cm bar mesh directed fish to 3.8-m long outer and inner hearts with 0.9-m wide fyked openings of 3.8-cm bar mesh. Fish were funneled from the inner heart to the capture box through a 17.8-cm opening. Trap nets were set with leads perpendicular to shore over substrates with gently sloping contours and in depths ranging from 2–5 m. Nets were checked and reset by two- or three-person crews at ~24-h intervals over periods of 2–6 d.

Size Consideration

During the ODFW sunken lake trapping efforts, 82% of the squawfish catches were of predaceous size.

Conclusion: Sunken lake traps catch predaceous sized squawfish.

Contribution to Harvest

CPUE Considerations

Unit of Effort: In the past, traps were fished for 24 h, and catch rates have been reported in terms of trap-days. If traps were to be used for squawfish control, shorter fishing periods would be recommended, but we have no CPUE data relative to lesser fishing times.

During 1982–86, ODFW reported that catch rates averaged annually 0.07–3.4 squawfish per trap per 24-h day.

Logistics Considerations

Lake traps are fairly cumbersome to deploy and cannot be operated in much of a current. In shallow water, they would represent a hazard to water navigation and angling. They would also have to be monitored continuously. It takes a well-organized work boat of ≥16 ft and a crew of two or three to set one of these. The traps accumulate woody debris and other trash drifting downstream, and to clean them, they must be removed from their site and brought to the beach.

Scale-of-Operation Considerations

To catch 200,000 squawfish at 2.0 squawfish per trap-day would require 100,000 trap days. There are probably enough sites where such gear could be deployed such that linear extrapolation might be mathematically correct; but nonetheless, this amount of effort is impractical from any reasonable economic projection. We have taken this scenario no further.

Incidental Catch

Incidental catch data was not reported in the 1982–86 reports used for evaluating this gear type. The limited effort by UW in 1989 gave no indication of which species might be captured in a large scale effort with this gear. Lake traps are hard to fish without stressing the incidental fish caught; they crowd the fish as the net is pulled to the surface for emptying. They are cumbersome and not easy to empty and the longer a fish is subjected to such disturbance, the greater it is stressed.

Conclusion: Handling problems would occur with incidental species in the sunken traps.

Social and Regulatory Issues

Potential incidental catch stress might preclude agency acceptance. Traps of any type need to be monitored frequently. They could be subject to theft or vandalism. Sunken traps create unseen hazards to other boaters.

Cost

Lake traps cost about $1,500 apiece. A two- to three-person crew with a suitable boat could effectively operate, monitor, clean, and repair four traps on a continuing basis. Thus, 25,000 boat-days would be required for 100,000 trap days. At $500 per boat d operating cost, this would represent an annual operating cost totaling $12.5 million. This is about 3x the annual cost of the implemented angling programs.

Conclusion: Due to low CPUE and a high cost of fishing, sunken lake traps are not recommended for use in a removal fishery.

B. BOX TRAPS

Box traps, or modified shrimp pots, have been used on the Columbia River for northern squawfish. The ODFW experimented with these traps in 1983, and the UW tried using them in 1989. The results from fishing these traps were dismal at best. For 2,734 h of effort, ODFW captured 13 northern squawfish >250 mm in length (Nigro et al. 1983). In 1989, Mathews et al. (1990) fished box traps for 10 pot nights and captured only 1 northern squawfish. This gear does not warrant a thorough critique.

The pots used in 1989 by Mathews et al. (1990) were commercially built shrimp pots. They consisted of a rectangular iron reinforcing bar framework (46 x 46 x 91 cm) covered with 2.54-cm stretch mesh knotless netting. There were in-facing conical tunnels at each end, which originally tapered to 2.54-cm diameter openings. The openings were modified to 7.6-, 10.2-, and 12.7-cm diameters to accommodate the entrance of squawfish. Pots were baited with smolts and fished singly with a separate buoyline on each. Usually, they were fished overnight.

The ODFW box traps had fykes in each end, were 1.2 m long x 0.9 m wide x 0.9 m deep with 2.5-cm bar nylon mesh, and were fished unbaited or baited with frozen juvenile salmon.

Conclusion: Box traps have proven to be ineffective for capturing northern squawfish.

C. MERWIN TRAPS

Squawfish Catch

Catch Consideration

Merwin traps were tested by several different agencies including WDF and NMFS in the late 1960s and early 1970s and, more recently, by the SOF in 1991 and 1992 (Table 8). Traps were fished primarily near dams along the Columbia River with the SOF concentrating its efforts in the cul-de-sac below The Dalles Dam. In this location, traps were fished a total of 165 d in 1991 and 1992, removing a total of 9,753 northern squawfish.

Previous studies utilizing Merwin traps have captured ~130,000 northern squawfish in the Columbia River watershed. The historical success demonstrated in previous studies indicates that significant numbers of squawfish can be captured with this type of gear.

Merwin traps fished by the SOF were similar in design to those fished in previous studies. Netting consisted of 1.25-in, knotless stretched mesh that had been treated with an algaecide. The lead portion of the trap consisted of three panels which, when sewn together, formed a continuous, 150-ft long by 35-ft deep panel. The heart section which included the wings and the last 17 ft of lead, consisted of panels 30 ft wide and 35 ft deep at the entrance, tapering down to a width of 2 ft wide and 12 ft deep at its conclusion, 7.5 ft inside the pot. The pot and spiller, both 16 ft^2 and 16 ft deep, were connected by a tunnel measuring 7 ft long. The entrance to the tunnel was 4 ft^2 with the last 2.5 ft tapering down to an exit 12 in^2.

The system of nets was supported by various means: either by flotation provided by a wooden frame containing styrofoam or by aluminum pontoons specifically constructed for trapping.

Size Consideration

Approximately 80% of the squawfish caught in 1991–92 by the SOF were >250 mm in length (Table 9). Previous studies concluded that 71% of the squawfish captured were >250 mm in length. From these data it can be surmised that ~75% of squawfish captured with this gear would be >250 mm in length in a large-scale removal program.

Conclusion: Merwin traps capture significant numbers of predacious sized squawfish.

Contribution to Harvest

CPUE Considerations

Unit of Effort: A meaningful unit of effort for this gear is a nightly fishing period—from dusk until dawn. This period was found to be successful at targeting squawfish while reducing incidental salmon catch significantly (Lynch 1993). We project an average catch rate (weighted by days fished) of 54 squawfish per night for the trap based on previous studies. Recent studies done by the SOF have indicated a more conservative estimate of squawfish catch rate for this gear: an average of 33 squawfish per trap-night (Table 8).

Historical CPUE estimates are based on effort carried out near dams where large concentrations of squawfish were known to exist. For this reason, SOF estimates of CPUE may be more realistic for a river-wide estimate of CPUE since mid-reservoir fishing with this gear was carried out by the SOF.

Logistics Considerations

Merwin trapping is a relatively simple operation in terms of gear and crew requirements. A trap itself can be designed to be light and maneuverable, both in and out of water. Webbing requires limited handling and is easily deployed by a single vessel (a 16-ft jet boat would be ideal) with a crew of 2–3 individuals. Crews must be responsible, but they require no elaborate training or qualifications in order to fish this gear.

The main limitation of Merwin trapping is its need for suitable river conditions. An area of low (<1.5 mph) current and proper bottom topography is required. Depth for the standard-sized Merwin trap should be ≥30 ft, though the lead can be in shallower water. Modifications in design could produce an effective Merwin-style trap that could fish in depths of about 15 ft.

A system-wide survey of the mainstem Columbia and Snake rivers carried out in 1992 by SOF identified 11 highly suitable trapping locations in 32 river miles above McNary Dam. On the basis of this survey, it can be estimated that ~100 to 150 ideal trapping sights would exist in the 425 miles of Columbia and Snake rivers included in the predator control program (Puget Island, Columbia River mile 40, to the Snake River confluence, Columbia River mile 325, and on up to Lewiston, Idaho, Snake River mile 140), with another 100 sites deemed suitable but not ideal.

Scale-of-Operation Considerations

On the basis of past and recent CPUE estimates using the Merwin trap, it is reasonable to assume that large-scale application of this gear could attain the removal goal of 200,000 squawfish annually. Assuming an effective season of 100 d (5 mo, 20 d per mo) and using the conservative catch estimate of 33 fish per night, 61 traps would be required to meet the removal goal (Table 8). If a higher catch rate of 54 fish per night is considered using the same fishing parameters, only 37 traps would be needed to theoretically remove 200,000 squawfish per year. A linear extrapolation of catch assumes that traps are independent of one another. There may be some point at which this does not hold true in a large-scale removal effort, particularly since the highest catch rates would occur near dams, where traps might be fished close together. Gear competition effects in these areas (non-linear catch per effort function) seem likely, though difficult to quantitatively predict.

Conclusion: Merwin trapping operations could be used to remove 200,000 additional squawfish.

Incidental Catch

Merwin traps are a non-selective gear that will capture the entire range of species residing in a fished area. As previously mentioned, steps can be taken to reduce incidental catch by following diurnal and seasonal trends regarding salmonids (Lynch 1993). In recent studies (1991–92) it was found that traps exhibited incidental catch rates of 7.72 salmonids per night (Table 8). Previous studies indicated a lower catch rate of 1.49 salmonids per night. With the high rate, it can be expected that in order to meet squawfish removal goals, ~47,092 salmonids would be trapped.

Studies have found that during 24–h periods, salmon tend to be most vulnerable to this gear during periods of daylight (6 am to 6 pm), whereas squawfish tend to be most vulnerable to this gear during periods of darkness (6 pm to 6 am) (Lynch 1993). Research carried out near The Dalles Dam in 1991 and 1992 indicates that by fishing during periods of darkness it is possible to significantly reduce incidental catches of salmonids while maintaining a squawfish removal effort (Lynch 1993).

Merwin traps capture and hold fish in good condition, but mortalities due to handling and/or holding will occur. Estimates based on SOF research carried out in 1991–92 indicated a mortality rate of 0.27% for trap-caught salmonids (Mathews et al. 1992). On the basis of this rate, a salmonid catch of 47,092 would cause ~127 mortalities (Table 8). If salmonid catches averaged the lower 1–2 per night, then a total catch of 9,089 would be expected with a mortality of 25.

In addition to squawfish and salmonids, a variety of other incidental species would be encountered in traps such as shad, peamouth (*Mylocheilus caurinus*), bass and lamprey (*Entosphenus tridentus*) (Table 10).

Conclusion: Because of the low mortality rate of this gear, trapping is thought to have minimal effect on incidentally captured species.

Social and Regulatory Issues

Problems could arise in implementing a fishery such as this owing to the high visibility and accessibility of traps to other river users. Operation of traps would require that personnel be highly visible and vigilant in order to ensure no loss of equipment or fish. Legal constraints due to the handling of large numbers of salmonids would be encountered through the ESA, a problem which may be overcome because of this gear's low mortality estimates. Fishing in restricted areas near dams would require coordination with the U.S. Army Corp of Engineers, a process which has not proven difficult in past efforts. Traps would have to be monitored continuously to avoid vandalism and theft. In addition, special permits would be needed to fish traps in certain areas owing to potentially hazardous navigational considerations.

Cost

The initial cost of implementing a removal effort such as this would be quite high because of the large amount of gear needed. After an initial investment was made for gear, yearly costs would drop significantly. Traps would cost ~$12,000 each and would be reusable for several seasons with minimal upkeep. In addition to traps, approximately thirty-five 16-ft aluminum jet boats would be required at a cost of ~$10,000 each. To operate 70 traps, 75–80 personnel would be required. With vehicle rentals and other overhead (fuel, insurance, maintenance), the approximate cost of an operation such as this would be $750 per d per crew, over a 100-d season, for 35 crews, equaling $2,625,000. This cost is equivalent to 62.5% of the cost of the fully implemented hook and line test fisheries (dam angling and sport reward).

IV. ELECTROFISHING

A. BOAT-BASED ELECTROFISHING

Squawfish Catch

Catch Consideration

Since the early 1980s, boat-based electrofishing has been extensively used by ODFW, NMFS, and USFWS for sampling northern squawfish in the Columbia River. The principal electrofishing unit in use is the Smith Root SR-18E* heavy-duty electrofishing boat. Electrical output is supplied via a gas-powered pulsator (Model 5.0 GPP), which provides an output capacity of 5,000 watts, 0–750 RMS volts AC or 0–1,000 volts pulsed DC at frequencies of 7.5 up to 120 Hz (pulses per second).

Since 1983, ODFW and USFWS have been using gear similar to that described above in their ongoing work on predation by resident fish on juvenile salmonids in the Columbia River (Poe and Reiman 1988). From 1983 to 1986, electrofishing efforts were restricted to the John Day Reservoir. Presently, the effort has been fully expanded to cover the area from below Bonneville Dam up to the Lower Granite Dam tailrace on the Snake River. Although the fishing effort has been applied reservoir-wide, the highest catch rates for squawfish >250 mm have consistently come from the project tailrace and BRZs. From 1984 to 1986, 55% of all electrofished squawfish were captured in the McNary Dam BRZ, resulting from only 8% of the total fishing effort (hours of electrofishing unit power-on time) in the John Day Reservoir (Table 11). In 1992, the UW operated a 28-ft electrofishing jet boat with the purpose of determining how effective electrofishing would be as a squawfish control removal gear. This boat was equipped with a new Smith-Root Model 5.0 GPP* electrofishing unit, the output parameters being the same as those listed above. Electrical output was delivered into the water via two Model UAA-6* dropper anode arrays. These boom anodes were bow-mounted at 20° and 90° off the starboard beam. The boat's aluminum hull was utilized as one large cathode.

During ODFW predator indexing, 1984–1986, a total of 4,813 squawfish were taken. From 1990 to 1992, ODFW, NMFS, USFWS, and SOF took a total of 22,980 squawfish (Table 12). In 1992, UW caught 4,076 squawfish during a 12-wk test removal fishery (Table 13). Historically, squawfish electrofishing efforts have emphasized dam tailrace and BRZs. All SOF electrofishing was restricted to mid-reservoir areas, well away from project BRZs.

Size Consideration

Of the 4,813 squawfish reported by ODFW from 1984 to 1986, all were >250 mm; squawfish <250 mm were not included in their data set. Roughly 80% of the 4,076 squawfish taken by UW electrofishing operations were <250 mm. The factors that skewed length-frequency to the smaller sizes in the UW operation were as follows:

1. Electrofishing away from project BRZs tends to yield smaller resident squawfish.
2. Most UW fishing effort occurred early in the season. Most of the 50-d effort coincided with high CRITFC dam-angling catch rates, indicating that the larger squawfish were

concentrated in the BRZ which, therefore, effectively removed them from the mid-reservoir fishing regions.

3. Inclement spring weather, persistent strong winds, and heavy wake resulted in inconsistent boat-handling and a low water visibility in the spring. These environmental constraints resulted in significant numbers of stunned fish being missed by the dipnetters when fishing in waters deeper than 4 ft.

The UW electrofishing season ran from May 4 to July 30. During the last 2 wk, July 13 to July 30, we saw an increase in the percentage of squawfish >250 mm taken in the nightly catch. Thus, we felt larger squawfish would be taken by electrofishing if some portion of the fishing occurred in the BRZs, and the mid-reservoir fishing occurred later in the season, from June 1 to September 30.

Conclusion: Boat-based electrofishing captures a significant number of squawfish of all size classes.

Contribution to Harvest

CPUE Considerations

Unit of Effort: The standard unit of effort for electrofishing is given as 1 h of electrofishing unit on-time. Generally, a fishing run has a duration of 900 sec, 15 min of on-time. There are two electrofishing techniques: steady on and power pulsing. The difference between the methods is related to power unit on/off output power time ratio. With steady on, output remains on as much as possible. With power pulsing, generally a 1:3 time ratio is maintained. A power-pulsing, 900-second fishing run often takes up to 1 h to complete. Power pulsing tends to catch more fish. It effectively reduces an electrofishing units-applied perception zone, resulting in fewer fish being frightened out of an area before the electrofishing boat can get into an effective catch range.

Typically, 18- to 22-ft shallow draft, aluminum outboard Jon boats are outfitted as electrofishers. The crew usually consists of one boat driver and one dipnetter. The UW 28-ft, jet-powered electrofisher carried a crew of four—one driver and three dipnetters.

For all electrofishing efforts from 1990 to 1992 (Table 12), CPUE averaged 27.95 squawfish per h of on-time. The SOF 1992 CPUE was 94.44 for all squawfish and 18.9 for squawfish >250 mm. For ODFW from 1984 to 1986, CPUE averaged 28.27 in the McNary BRZ and 1.9 throughout the John Day Reservoir, excluding the BRZ (Table 11).

Electrofishing is clearly effective for capturing squawfish; however, it is possible that these CPUE figures are conservative in assessing what an implemented control effort might yield. The ODFW efforts were research projects, not direct attempts to maximize squawfish catch. If an electrofishing boat were to be charged with the sole task of squawfish removal, total catch and CPUE would probably be higher. The UW efforts were restricted in two regards—no fishing was conducted in the BRZs, and the operations were strictly governed by occurrence of individual salmonid observations.

A typical electrofishing boat can average 2 h of unit on-time a night, eight electrofishing runs per night, 4 d per wk. Thus, using the average CPUE of 27.95, electrofishing might yield 55.9

squawfish per d by fishing mid-reservoir and project tailrace areas. Successful squawfish electrofishing would spend 1 d (2 h on-time) in project BRZs, 1 d in the tailrace areas just outside of BRZs, and the remaining 2 d fishing mid-reservoir locations. This distribution of effort counters electrofishing's propensity towards diminishing returns of repetitive fishing runs; once a mid-reservoir area has been electrofished, ensuing catch rates will remain low for ≥1–2 wk.

The reasons the SOF mid-reservoir CPUE of squawfish was relatively high were as follows:

- we fished only at night;
- we sought out squawfish habitat (i.e., submerged rip-rap, moderate current, good visibility, steep slope, and associated prey holding areas);
- we used three dipnetters in the boat instead of just one;
- we placed both anodes to one side of the boat (20° and 90° of the beam), which enables the boat to remain in more consistent contact with the shoreline;
- we increased dipnet mesh and head size to as large as practical;
- we employed the power-pulsing technique when fishing; and
- we stopped fishing during inclement weather or when the crew was fatigued.

Future ways to increase CPUE would include the following:

- fishing later in the season in order to take advantage of calmer midsummer weather while intercepting larger squawfish as they disperse from the dams,
- reducing operating noise by either mounting the generator below deck or by insulating it,
- improving the outboard lighting system with stronger dispersal lights,
- using four anode arrays (two retractable anodes on each side of the boat) which would allow more downstream fishing, and
- occasionally using a second catcher boat and experimenting with the throwable anode/beach seine technique.

Logistics Considerations

Electrofishing requires a minimum crew of two well-trained persons per boat or four per boat if three dipnetters are used. This unique gear requires highly specialized equipment, safety systems, and a large power supply. Daily operations require a high degree of boat-handling skill, along with electrofishing and safety skills.

The number of places open to electrofishing are primarily limited by environment (wind and current) and safety considerations. There is a dramatic decrease in CPUE in winds >15 knots. In mid-reservoir electrofishing, the anodes are fished parallel to the bank 2–6 ft from the shore. When winds are in the 15- to 25-knot range, the combination of inconsistent boat-handling, wake, and reduced visibility makes dipnetting difficult. Continued fishing under such conditions is counterproductive; most of the affected fish are missed by the netters and the operators become quickly fatigued. It is better to rest during these conditions and put forth maximum energy in calm conditions. Fish that are stunned but not netted experience spatial displacement and may acquire a hypersensitivity to induced electric fields. These fish are temporarily lost to the sample population. A 2- to 3-wk gap between repeated electrofishing efforts is recommended.

Safety to boat crew, other river uses, and wildlife should be a prime directive. It would be inappropriate and dangerous to electrofish through either a group of bank fishermen or a beaver den. Dipnetting 8–9 h a night is very strenuous; once a crew is fatigued, CPUE decreases, stunned fish are lost, and the risk of serious injury increases. It is important to recognize and accept the limitations of equipment and crew.

Electrofishing is productive for squawfish in both mid-reservoir and tailrace areas. The BRZs seasonally hold large concentrations of predacious squawfish, making these areas of special concern. The limitations presented by the strong currents in the BRZ could be overcome by coordination with project hydropower operations and choice of selective fishing times. Squawfish production of mid-reservoir areas approaches that of tailrace areas when fishing effort is concentrated at times and areas of strong squawfish potential. In 1992, the SOF found that a typical mid-reservoir pool possessed enough likely squawfish habitat for 4–6 nights of non-repetitive effort.

Scale-of-Operations Considerations

Full implementation of electrofishing could be expected to catch 200,000 squawfish in a 5-mo season (May–September) if 36 electrofishing boats were to fish throughout every reservoir, every BRZ, and below Bonneville Dam. Assuming 20 effective d per mo (allowing for days off, severe weather, and breakdowns), eight runs per d (2 h of unit on-time), 27.95 squawfish per h, and 55.9 squawfish per d, the 36 boat crews would yield 201,240 squawfish.

In 1992, the UW electrofished only at night, in preferred squawfish habitat, using the power-pulsing technique; we effectively fished 8 mi of riverbank per night. Thirty-six crews would cover 288 river mi per night. Electrofishing CPUE decreases with multiple attempts. With the above scenario, there exists strong potential that fishing effort would quickly become redundant, resulting in perpetually declining average CPUE.

For a variety of reasons (cost, CPUE, incidental catch, gear conflicts), 36 electrofishing boats may not be a feasible scenario. A compromise solution of multiple removal methods (Merwin trap, dam angling, sport bounty) and a fleet of 18 electrofishing boats may prove to be more reasonable. Using the same extrapolation as above, 18 electrofishing boats would take 100,620 squawfish in a 5-mo season.

It is probably more reasonable to linearly extrapolate the test catch rates to a fleet of 18 boats than to a fleet of 36 boats owing to observed declining CPUE with repeat fishing of an area too close in shore to the initial fishing.

Conclusion: Boat-based electrofishing operations could remove an additional 200,000 squawfish.

Incidental Catch

The potential incidental catch of electrofishing is significant. The electric field of an operation will have some affect on any fish that encounters it. The short- and long-term effects of pulsed direct current electrofishing on fish from the Columbia River is not well-documented. Of special concern are the effects on salmonids. Reports on electrofishing-induced harm have yielded a tremendously wide range of results. Studies on rainbow trout alone have reported electrofishing injury rates ranging from 0 to 96%.

In 1992, the UW observed 25,643 incidentally affected fish in 43.16 h of electrofishing unit on-time (Table 13). Of these, 316 were smolts and 54 were unidentified adult salmonids. Only squawfish were intentionally netted from the water. To reduce the effects of UW electrofishing on salmon, output was turned off whenever a salmon was encountered. This allowed the salmon to leave the area; fishing would then be restarted some distance downstream. Catastomids and cyprinids made up more than 80% of the incidental catch.

Electrofishing has the potential to harm or kill fish. When electrofishing in tailrace areas, some interaction with salmonids is unavoidable. Two issues that demand attention before any large-scale electrofishing operation can begin are (1) to what degree resident fish are being affected (i.e., short-term effects, mortality) and (2) how much incidental catch is acceptable.

Conclusion: Applying the UW 1992 incidental catch rates of 1,171 miscellaneous fish, 2.5 adult salmonids, and 14.6 smolts per 2 h of unit one-time to the 200,000 squawfish benchmark, the 36-boat operation yields 4,215,600 miscellaneous fish, 9,000 adult salmon, and 52,560 smolts over the 5-mo season. Presently, there are no sufficient data that could be used to determine the expected rates of harm and mortality to these fish.

Social and Regulatory Issues

Because of the potential harm that electrofishing presents to salmonids, it can be anticipated that any large-scale operation would have to meet stringent requirements as established by the ESA, NMFS, and FPAC. In 1992, the UW electrofishing operation was strictly regulated by the following FPAC guidelines: (1) no fishing in any hydroelectric project BRZ, (2) immediately stop fishing whenever a smolt or adult salmon was encountered, (3) move to a new fishing area upon encountering salmon, (4) cease electrofishing for the night whenever a total of more than two adult salmon were encountered.

The negative social impact of 36 electrofishing boats working 4–5 nights per wk throughout the Columbia River would be immense. Such a large operation would directly compete for squawfish with sport bounty and dam-angling fishermen, and physically disturb recreational game fishermen, other river users, and campers. Such an effort would have an unknown impact on resident fish populations.

Cost

There are two main suppliers of electrofishing equipment in the United States: Coffelt Electronics and Smith Root. Both companies can properly outfit any single-boat electrofishing operation. A 36-boat approach would require using both firms to supply all needed equipment. Even with both companies, it would be a long-term effort to outfit this number of boats.

Electrofishing requires very specialized and therefore expensive equipment. A Smith Boat SR-18E* heavy-duty electrofishing boat and associated equipment will run about $29,000. This figure does not include boat trailer, truck, insurance, fuel, wages, per diem, and maintenance. We suggest a 22– to 24–ft boat as being the optimal size; this would be large enough to carry a crew of four and have steering stations on both sides of the boat. Such a vessel, fully outfitted, would cost about $60,000. Each unit would need a four-wheel drive, heavy duty pickup truck and a trailer at $25,000. Thus 36 units would cost $3,060,000. Daily operating costs, including $200 per man a day for labor, overhead and per diem, $200 for operation and miscellaneous supplies, would be $1,000 per boat per d.

Conclusion: At 100 d per season 36 electrofishing boats would have an operating cost of $3.6 million. This is 86% of the operating costs for the implemented angling programs.

B. FIXED LOCATION ELECTROFISHING

Squawfish Catch

Catch Consideration

Research carried out by NMFS in 1991 at Bonneville Dam indicated that fixed location electrofishing was not successful in removing northern squawfish near hydroelectric projects (Monk et al. 1991). A total of 116 squawfish were captured in ~2 mo of experimental shocking near Bonneville Dam.

Numerous problems associated with permanently installed gear became evident in its short time of operation. Fish were dispersed by repeated shocking efforts, indicating the need for a more mobile piece of gear. Collection of shocked fish was inefficient owing to high currents and low visibility in the area of shocking. As a result of inefficient collection techniques, many stunned individuals were able to escape.

Size Consideration

No size distribution data is available for northern squawfish captured using this method.

Contribution to Harvest

CPUE Considerations

Efforts carried out by NMFS with a fixed-location shocker in 1991 had a CPUE of 8.9 fish per operating d or 5.1 fish per operating h. Fishing was carried out in 2–3 h intervals at dusk or dawn. Duration of actual shock time was 2–3 min unless salmonids were encountered. Available voltages were 208, 240 and 480 AC (variable 0–500 volts), supplied in a three-phase configuration. Individual phase currents were variable from 0–500 amps (Monk et al. 1991).

Logistics Considerations

This gear's design and purpose limits its application to dams or other fixed locations. It is not easily manageable.

Scale-of-Operation Considerations

Research indicates that this method would be incapable of approaching the 200,000 squawfish removal goal, or taking a sufficiently large fraction of this goal to warrant usage. Boat-based electrofishing is far more efficient.

Incidental Catch

This gear exhibited a rather significant effect on American shad, stunning ~7,000 to 10,000 adults during the course of the NMFS study. The majority of salmonids that were affected included subyearling chinook (0–72 per d) and smolts (6–9 per d). Most fish appeared to have recovered, although no major efforts were made to assess the injury that may have been done to the fish incidentally stunned (Monk et al. 1991).

Social and Regulatory Issues

Because of the unknown number and condition of salmonids effected by this gear, serious conflicts would be experienced under the ESA.

Cost

This does not appear to be a cost-effective method of removing northern squawfish. We present no projection or analysis.

V. CHEMICALS AND EXPLOSIVES

A. SQUOXIN

Squawfish Catch

Fish toxicants have been used extensively in the United States since the 1930s as a means of manipulating fish communities both through selective, partial, or total fish kills. Compounds such as Rotenone and Antimycin have been widely used in fisheries management in the past, but the non-selectivity of these compounds limits their usefulness for squawfish removal. In the early 1970s, a compound commonly known as "squoxin" (1,1'-methylene-di-2-napthnol) was found to be highly selective for northern squawfish (USFWS 1984).

Catch Consideration

Various studies have shown Squoxin to be highly effective in killing squawfish. One particular study carried out in the North Fork of the Payette River, Idaho, estimated that 200,000 squawfish were killed following the application of 25 gal of squoxin (Irizarry 1970). On the basis of available research, there is little doubt that Squoxin would be highly successful at removing squawfish.

Size Consideration

Squoxin is non-size selective; therefore, a broad range of individuals would be affected.

Conclusion: Squoxin could remove squawfish; selective harvest of only large predaceous size fish would be difficult.

Contribution to Harvest

CPUE Considerations

Unit of Effort: It is difficult to define a unit of effort for squoxin owing to the nature of this chemical and its application technology. Research indicates that squawfish do not detect the presence of this compound, therefore, large concentrations of fish in limited areas could be removed. CPUE would then depend mainly on the number of squawfish in a given area, since this chemical could be applied in such a manner to attain the lethal 0.1 mg per L concentration in a specific area.

CPUE for squoxin would vary seasonally since this chemical is more toxic to squawfish at elevated water temperatures. In addition, sunlight breaks this compound down quickly; therefore, application would occur during the night to maximize effectiveness.

Logistics Considerations

Squoxin is available in forms that are highly soluble and easy to apply. The application of squoxin would require very small crews, simple outboard motor boats and limited amounts of gear. The chemical could be sprayed into propeller turbulence from portable pumps mounted on boats. A crew of 2 or 3 per boat could accomplish this task with ease.

Scale-of-Operation Considerations

Previous research indicates that squoxin would be highly successful at killing squawfish, making a removal goal of 200,000 fish easily attainable (USFWS 1984).

Conclusion: Removal rates on squawfish would rely on the available population and access to that population.

Incidental Catch

Research compiled by USFWS in 1984 found that squoxin was relatively nontoxic to non-target species; however, sockeye salmon alevins were found to be adversely affected by squoxin at water temperatures <4.4°C.

Research carried out in laboratory and field settings indicates that this chemical is relatively safe in terms of its toxicity to organisms other than squawfish. But large-scale application of this compound contains many risks due to the stochastic nature of the environment. Laboratory studies on fish can only scratch the surface of the countless interactions that would occur between this chemical and the biota. As a result of past experience with chemical contaminants and the present prevailing ecological climate, the risks associated with the use of this chemical may prove to be unacceptable.

Social and Regulatory Issues

As it stands now, squoxin is not a legal piscicide. The greatest obstacle to using squoxin is obtaining certification from proper authorities (USFWS 1984). Recent attempts to obtain experimental permits for this chemical have not been successful, thus diminishing the probability of registration (Tom Poe, USFWS, Cook, Washington, pers. comm.). Overall, the likelihood of this chemical being approved for large-scale use in the Columbia River is not good.

Cost

The cost of getting this chemical registered with the EPA for use has been estimated by USFWS to be between 6 and 7 million dollars. This is simply the cost of getting the chemical registered, not for application. The company that developed this chemical, American Cyanimide, has deemed this chemical not profitable to license owing to the large amount of research yet needed (Tom Poe, USFWS, Cook, Washington, pers. comm.). The substantial investment needed before this chemical could be used would probably make this removal method less cost-effective than other removal methods currently available. BPA has funded an in-depth analysis of procedures for developing this chemical for use as a control method (Rulifson 1985).

Conclusion: The legal problems associated with this chemical and size of the Columbia River make it unlikely that Squoxin would be an effective removal method for northern squawfish.

B. DYNAMITE

Squawfish Catch

Catch Consideration

Previous studies have shown that explosives are effective at disrupting spawning activities and eradicating localized concentrations of squawfish (USFWS 1984). If significant concentrations of squawfish could be identified, this method of removal could be effective.

Size Consideration

Owing to the non selectivity of this removal method, all sizes of squawfish residing in schools would be effected.

Conclusion: Dynamite could be used to remove squawfish, but selective harvest would be difficult.

Contribution to Harvest

CPUE Considerations

Unit of Effort: A unit of effort is difficult to determine since effectiveness will vary tremendously depending on the application. CPUE would depend on the number of individuals contained in a treatment area. If localized concentrations of squawfish could be identified, the CPUE for this method would be extremely high.

CPUE would vary seasonally since this method requires concentrations of fish to be effective. As a result, this method would be mainly limited to periods during the season when spawning and feeding concentrations are available.

Logistics Considerations

In order to utilize this method of removal, surveys would be needed to locate and identify areas where squawfish spawn. Efforts have been made in the past by UW and NMFS to identify such locations with quite limited success.

After spawning locations have been identified where use of explosives would be feasible, crew requirements would be minimal; however, individuals would require special training in the use of explosives in order to ensure safety.

The most effective location for treatment with explosives would be at hydroelectric projects. Huge schools of squawfish are known to occupy the turbine outflow areas at most of the dams. Use of explosives near dams would have to be intensively investigated since there could be damage to structures from the blasts.

Scale-of-Operation Considerations

Previous research indicates that if localized concentrations of squawfish could be identified, this method would have the potential to meet the removal goal of 200,000 squawfish (Jeppson and Platts 1959).

Squawfish spawning concentrations observed by NMFS have been estimated to contain 3,000 to 15,000 individuals. In order to approach the removal goal, 100 to 150 of such sites would have to identified in order for this method to be successful.

Conclusion: Dynamite could be used to make a significant impact on squawfish populations; however, a harvest goal of 200,000 would be difficult to achieve.

Social and Regulatory Issues

This method of removal is highly non-selective in nature; therefore, its applications would be limited under ESA. Permits would have to be acquired from agencies regulating use of explosives in addition to basic collection permits.

Public opinion regarding the use of explosives would have to be taken into consideration in addition to other legal criteria. The non-selective nature of this method of removal may cause a significant public outcry if implemented.

Cost

This method of removal would be inexpensive as far as equipment and personnel costs are concerned. A crew of two to three with a boat and acoustic equipment could target localized concentrations of squawfish quite easily. Five to 10 of these crews could easily cover available areas.

Hidden costs such as additional impact studies and possible litigation from user groups may serve to make this removal method undesirable for use.

SUMMARY

Many gear types have been evaluated in this report as to their application in large-scale removal of northern squawfish from the Columbia River. Each gear was considered in the context of implementation that would equal the current sport reward and dam-angling removal efforts. Although several of the gears (UW longlining system, Merwin trapping, and boat based electrofishing) show potential for removing the benchmark of 200,000 squawfish while maintaining reasonably low harm to other species, no one gear could be expected to complete the Squawfish Management Program's portfolio of terminal gears needed for achieving a 15–20% removal rate on squawfish under the least-cost criteria.

Each of the gear types examined in this report tends to target different populations of squawfish, either by fishing different locations within the river or by taking advantage of different stages in squawfish life history. For example, the Merwin traps tend to catch squawfish that migrate seasonally from one area to another, be it for spawning or feeding, while the electrofishing vessels seem to target resident fish that have moved inshore in a diurnal migration to feed. When selecting fishing gear to be used in this program, a wide range of methods should be employed.

We recommend a diverse program utilizing several of the removal methods discussed. A longline fishery within the BRZs would remove 27,500 squawfish without interfering with sport fishermen. Allowing sport fishermen to use a limited length of longline could increase the sport reward catch by as much as 200,000 squawfish. A combined Merwin trapping and electrofishing program could round out the removal efforts with nearly 200,000 more squawfish removed (100,620 by electrofishing and 100,000 using Merwin traps). A plan such as this could achieve a 15–20% removal of northern squawfish. Interference among participants would be limited and squawfish would be targeted throughout the Columbia and Snake river systems.

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TABLES

Table 1. UW longlining system catch and effort for 1989–1991.

	Hook set	Hooks/ sq. f	Squawfish		Catfish		Sturgeon	
			Catch	%	Catch	%	Catch	%
1989								
UW								
McNary BRZ	463	12.5	37	0.84	5	0.11	2	0.05
Mid river	9,925	16.1	617	0.68	119	0.14	97	0.11
All (UW)	10,388	15.9	654	0.69	124	0.13	99	0.1
1990								
UW								
McNary BRZ	4,953	15.4	322	0.80	30	0.07	50	0.12
Mid river	4,641	43.8	106	0.74	10	0.07	25	0.17
All (UW)	9,594	22.4	428	0.78	40	0.07	75	0.14
Tribal	31,842	22.5	1,413	0.73	194	0.10	294	0.15
1991								
UW								
McNary BRZ	1,370	12.6	109	0.64	18	0.11	41	0.24
Mid river	1,320	37.7	35	0.51	2	0.03	24	0.35
All (UW)	2,690	18.7	144	0.60	20	0.08	65	0.27
Tribal	37,112	34.7	1,071	0.66	96	0.06	359	0.22
Total								
McNary BRZ	6,786	14.5	468	0.76	53	0.09	93	0.15
Mid river	84,840	26.2	3,242	0.69	421	0.09	799	0.17
All	91,626	24.7	3,710	0.70	474	0.09	892	0.17

Source: Mallette and Willis (1991), Mathews and Iverson (1991), Mathews et al. (1990)

Table 2. Results of the 1992 ODFW-implemented longline fishery using traditional longline gear.

	Traditional longline		UW longline system		Total	
EFFORT						
# sets	850		908		1,758	
# hooks	89,393		72,382		161,775	
# hours	11,298		10,699		21,997	
	Number	% of total	Number	% of total	Number	% of total
CATCH						
Squawfish	1,079	23	1,079	81	2,158	36
>250 mm	818 (76%)		916 (85%)		1,734 (80%)	
<250 mm	261 (24%)		163 (15%)	4	24 (20%)	
Sturgeon	3,460	74	200	15	3,660	61
Other	165	4	52	4	217	4
CPUE						
Catch per set						
Squawfish	1.27		1.19		1.23	
Sturgeon	4.07		0.22		2.08	
Hooks set per fish						
Squawfish	82.85		67.08		74.97	
Sturgeon	25.84		361.91		44.20	

Disposition of sturgeon

	Number	Percent
Good	3,416	97.16
Fair	55	1.56
Poor	44	1.25
Dead	1	0.03
Total	3516	

Source: Mallette et al. (1993)

Table 3. Catch of northern squawfish in the troll fishery in Bonneville Dam tailrace and forebay, 1990–91.

Year	Month	Effort	Catch	CPUE
1990	August	77.60	9	0.12
	September	193.80	104	0.54
	October	143.13	115	0.80
	Total	414.53	228	0.55
1991	May	115.00	62	0.54
	June	161.00	239	1.48
	July	263.00	686	2.61
	August	239.00	151	0.63
	September	86.00	30	0.35
	Total	864.00	1,168	1.35
	TOTAL	1,278.53	1,396	1.09

Source: Vigg et al. (1990), Ward et al. (1991)

Table 4. Total gillnetting efforts by ODFW, USFWS, and UW in the Columbia River, 1982–89.

Year	Agency	Location	Squawfish catch	CPUE
1982	ODFW	Bottom	396	1.85
1983	ODFW	Bottom	1,330	1.58
		Surface	78	2.29
		Drift	5	0.36
1984	ODFW	Bottom	1,417	1.75
		Surface	96	5.42
		Vertical	15	0.01
	USFW	Bottom	89	0.17
1985	ODFW	Bottom	1,809	1.34
		*Bottom	118	0.17
		Surface	10	0.32
		Vertical	5	0.05
1986	ODFW	Bottom	1,266	1.29
		*Bottom	268	0.56
1989	UW	Bottom	136	0.33
		Surface	9	0.13
		Total	7,047	

*Note: Gillnets with large mesh used in this study.

Source: Beamsderfer et al. (1987); Mathews et al. (1990); Nigro et al. (1983, 1984, 1985); Willis et al. (1982)

Table 5. Total catch by species from bottom gillnetting in the John Day Reservoir, April–October, 1989.

Species	Catch	Percent
Catastomids	542	58.8
Northern squawfish, *Ptychocheilus oregonensis*	136	14.8
American shad, *Alosa sapidissima*	76	8.2
White sturgeon, *Acipenser transmontanus*	56	6.1
Channel catfish, *Ictalurus punctatus*	45	4.9
Chiselmouth chub, *Acrocheilus alutaceus*	14	1.5
Walleye, *Stizostedion vitreum*	14	1.5
Smallmouth bass, *Micropterus dolomieu*	11	1.2
Steelhead, *Oncorhynchus mykiss*	10	1.1
Carp, *Cyprinus* spp.	4	0.4
Bullhead, *Ictalurus* spp.	3	0.3
Yellow perch, *Perca flavescens*	3	0.3
Crappie, *Pomoxis* spp.	3	0.3
Coho salmon, *O. kisutch*	2	0.2
Sockeye salmon, *O. nerka*	2	0.2
Chinook salmon, *O. tshawytscha*	1	0.1
Total	922	

Source: Mathews et al. (1990)

Table 6. Purse seining in the Columbia River for northern squawfish. NA = not available.

Agency	NMFS	UW	UW	UW	UW	NMFS	
Year	1974-77	1989	1990	1990	1991	1991	
Length of seine	600'	350'	350'	600'	400'	450'-600'	
Boat used	NA	Boston Whaler	Boston Whaler	Bay Harvest	Bay Harvest	NA	Total
Total Sets	779	52	29	45	89	21	1,015
Total squawfish	9,061	88	1	26	63	134	9,373
Squawfish/set	11.6	1.7	Tr	0.6	0.7	6.4	9.2
Other species:							
Adult chinook	NA	9	1	9	1	4	24
Adult steelhead	NA	11	1	25	-	-	37
Adult coho	NA	-	-	1	-	-	1
Adult sockeye	NA	3	-	-	3	-	6
Juvenile salmon	NA	-	-	12	-	92	104
American shad	NA	51	2	-	688	9,465	10,206
White sturgeon	NA	-	-	-	23	-	23
Suckers	NA	29	2	19	22	-	72
Peamouth	NA	-	-	-	59	18	77
Chiselmouth	NA	3	2	-	23	-	28
Carp	NA	13	2	14	20	-	49
Shiner	NA	-	-	-	-	20	20
Bass	NA	1	1	1	7	-	10
Crappie	NA	-	-	-	3	-	3
Walleye	NA	1	-	-	4	-	5
Sunfish	NA	-	-	3	1	-	4
Channel catfish	NA	-	-	-	1	-	1
Tailrace Sets	451	22	21	12	12	10	528
Squawfish	7,093	88	1	2	8	52	7,244
Squawfish/set	15.7	4.0	Tr	0.2	0.7	5.2	13.7
Sets in other areas	328	30	8	33	77	11	487
Squawfish	1,968	0	0	24	55	82	2,129
Squawfish/set	6.0	Tr	Tr	0.7	0.7	7.5	4.4

Source: Mathews and Iverson (1991); Mathews et al. (1990, 1991); Raymond et al. (1975); Sims et al. (1976, 1977, 1978)

Table 7. Catch-per-unit-effort (CPUE) in experimental sunken lake traps fishing Columbia River reservoirs, 1982–1989 (effort units are trap day).

Location	Year	Period fished	Trap days	CPUE	Data source*
McNary tailrace	82	7/17 to 12/31	16.10	1.40	a
John Day pool	82	5/24 to 7/16	15.70	1.80	a
John Day tailrace	82	7/17 to 12/31	22.50	0.80	a
John Day forebay	83	7/17 to 9/24	10.00	3.40	b
John Day tailrace	83	4/24 to 9/24	124.60	1.90	b
John Day, Irrigon	83	7/17 to 9/24	49.90	1.70	b
McNary tailrace	83	4/24 to 9/24	154.00	2.40	b
John Day forebay	84	4/8 to 10/1	102.60	2.60	c
John Day, Arlington	84	4/8 to 10/1	88.80	3.10	c
John Day, Irrigon	84	4/8 to 10/1	100.00	1.40	c
McNary tailrace	84	3/25 to 10/1	94.30	1.90	c
John Day, forebay	85	3/24 to 9/2	64.10	1.90	d
John Day, Arlington	85	4/7 to 9/2	113.90	0.70	d
John Day, Irrigon	85	4/7 to 9/2	104.80	1.70	d
McNary tailrace	85	4/7 to 9/2	87.50	1.00	d
John Day forebay	86	4/6 to 9/1	54.20	2.40	e
John Day, Arlington	86	4/6 to 9/1	84.00	1.40	e
John Day, Irrigon	86	3/23 to 9/1	90.30	0.70	e
McNary tailrace	86	3/23 to 9/1	68.00	0.70	c
McNary tailrace	89	11/1 to 11/3	2.00	4.00	f

Source: a = Willis et al. 1982, b = Nigro et al. (1983), c = Nigro et al. (1984), d = Nigro et al. (1985), e = Beamsderfer et al. (1987), f = Mathews et al. (1990)

Table 8. Results of the Merwin trapping in the Columbia River for northern squawfish.

Location	Year	Approximate days fished	Total squawfish	Total salmonids	Squawfish per day	Salmonids per day	Squawfish night catches*	Salmonid night catches*
The Dalles Dam, Drano Lake, McNary Dam (LeMier and Mathews 1962)	1961-62	188	17,347	1,460	92	8	83	3
Lake Merwin, Washington (Hamilton et al. 1970)	1960-64	600	34,951	-	58	-	52	-
Lyons Ferry, Levy Landing, John Day Forebay, The Dalles Dam Forebay (Bentley et al. 1975)	1973-75	884	32,240	701	36	1	33	0.27
Palouse Arm, Lyons Ferry (Sims et al. 1977, 1978)	1976	165	30,017	-	182	-	164	-
The Dalles Dam (Mathews et al. 1991, 1993)	1991-92	165	9,753	6,369	59	39	53	13
The Dalles Dam, various other locations (Mathews et al. 1993)	1992	79	1,108	536	14	7	13	2
						Weighted Average:	54	1.49
						UW Simple Average:	33	7.72

*Adjusted catches are based upon data obtained in 1991-1992 which indicates that 66% fewer salmonids are caught when a trap is fished exclusively at night and 10% fewer squawfish are caught when a trap is fished exclusively at night.

Fishing season (days)	Number of traps	Squawfish catch (33 f/n**)	Squawfish catch (54 f/n**)	Salmonid catch (1.49 f/n**)	Salmonid catch (7.72 f/n**)	Salmonid mortality of 9,800 fish	Salmonid mortality of 32,200 fish
100	61	201,300	329,400	9,089	47,092	25	127

**f/n = fish per night

Note: Theoretical mortality based upon 1991-92 data, which indicate a .0027 mortality rate of salmonid captures.

Table 9. Length-frequency distribution for squawfish captured in Merwin traps.

Length (mm)	Hamilton et al. 1970	Lemier and Mathews	UW, 1991-1992	Total	Overall percent	UW percent
≤200	214	5	373	592	0.07	0.07
200-249	934	74	699	1,707	0.21	0.13
250-299	1,061	86	1,514	2,661	0.32	0.28
300-349	88	97	1,350	1,535	0.19	0.25
350-399	51	49	881	981	0.12	0.16
400-449	48	43	408	499	0.06	0.08
450-499	13	14	168	195	0.02	0.03
≥500	4	7	19	30	0.004	0.004
Total	2,413	375	5,412	8,200		

Overall Percent > 250 mm = 71
UW Percent > 250 mm = 80

Source: Hamilton et al. (1970); Lemier and Mathews (1962); Mathews et al. (1991, 1993)

Table 10. Summary of incidental catch from Merwin traps fished in the Columbia River

Species	Scientific name	Lemier and Mathews 1961-1962		Bentley et al. 1975		University of Washington 1991-1992	
		Total	% of catch	Total	% of catch	Total	% of catch
Common Carp	*Cyprinus carpio*	6,609	10.25	47	0.37	41	0.09
Chiselmouth	*Acrocheilus alutaceus*	10,385	16.11	5,703	44.43	2,979	6.32
Squawfish	*Ptychocheilus oregonensis*	17,347	26.90	1,017	7.92	9,753	20.69
Peamouth	*Mylocheilus caurinus*	272	0.42	144	1.12	19,263	40.86
Redside Shiner	*Richardsonius balteatus*	397	0.62	146	1.14	0	0
Suckers	*Catostomus spp.*	21,244	32.95	5,474	42.64	2,767	5.87
Bass (Lg, Sm)	*Micropterus spp.*	4	0.01	0	0	190	0.4
Crappie	*Pomoxis spp.*	1,577	2.45	81	0.63	25	0.05
Bluegill Sunfish	*Lepomis macrochirus*	5	0.01	0	0	20	0.04
Walleye	*Stizostedion vitreum*	0	0.00	9	0.07	105	0.22
Whitefish	*Coregonus williamsoni*	84	0.13	59	0.46	5	0.01
Chinook	*Oncorhynchus tshawytscha*	313	0.49	49	0.38	405	0.86
Steelhead	*Oncorhynchus mykiss*	1,047	1.62	59	0.46	2,013	4.27
Sockeye	*Oncorhynchus nerka*	88	0.14	6	0.05	3,068	6.51
American Shad	*Alosa sapidissima*	87	0.13	0	0	4,502	9.55
White Sturgeon	*Acipenser transmontanus*	124	0.19	14	0.11	428	0.91
Pacific Lamprey	*Entosphenus tridentus*	4,839	7.50	2	0.02	1,528	3.24
Catfish, Bullhead	*Ictaluras spp.*	58	0.09	27	0.21	53	0.11
	Total	64,480		12,837		47,145	

Source: Bentley et al. (1975); Lemier and Mathews (1962); Mathews et al. (1991, 1993)

Table 11. Comparison of electrofishing catch by ODFW predator indexing crews in the John Day Reservoir inside and outside of the McNary Dam boat-restricted zone, 1984-1986.

	1984	1985	1986	1984-86
John Day Reservoir				
Squawfish catch	874	799	511	2184
Effort (hours of on time)	293	452	384	1129
CPUE	2.98	1.77	1.33	1.93
McNary BRZ				
Squawfish catch	440	822	1367	2629
Effort (hours of on time)	13	23	57	93
CPUE	33.85	35.74	23.98	28.27

Source: Beamsderfer et al. (1987); Nigro et al. (1984, 1985)

Table 12. Historical CPUE of northern squawfish by electrofishing on the Columbia and Snake rivers (effort in on-time hours).

Year	Source	Squawfish	On-time hours	CPUE
1990	ODFW Predator Indexing (Dave Ward, ODFW, Clackamas, OR pers. comm.	2,143	101.75	21.06
1990	USFW Consumption studies (Dave Ward, ODFW, Clackamas, OR pers. comm.	1,182	83.25	14.20
1991	ODFW Predator Indexing (Dave Ward, ODFW, Clackamas, OR pers. comm.	1,401	132.00	10.61
1991	USFW Consumption studies (Dave Ward, ODFW, Clackamas, OR pers. comm.)	1,263	89.50	14.11
1991	USFW/NMFS hatchery release studies (Tom Poe, USFW, Cook, WA, pers. comm.)	2,012	19.68	102.24
1992	ODFW Predator Indexing (1992 Field activity reports, Dave Ward, ODFW, Clackamas, pers. comm.)	4,754	125.25	37.96
1992	USFW hatchery release studies (1992 Field activity reports, Tom Poe, USFW, Cook, WA, pers. comm.)	3,584	92.25	38.85
1992	NMFS Creek studies (1992 Field activity reports, Paul Bentley, NMFS, Hammond, WA, pers. comm.)	2,565	135.20	18.97
1992	SOF Removal efforts (1992 Field activity reports, Brian Mahoney, SOF, Seattle, WA, pers. comm.)	4,076	43.16	94.44
	1990-1992 Totals	22,980	822.04	*27.95

*Average CPUE all studies

Table 13. UW experimental electrofishing catch and effort, 1992.

Date	Area	Duration (on time hours)	Squawfish	Salmonids Smolts	Salmonids Adults	Total fish	Sqf/Hr
4-May	Lyons Ferry	3.31	62	78	6	816	18.75
11-May	Lyons Ferry	5.61	111	59	0	1,925	19.77
18-May	Boyer Marina	4.09	164	91	2	2,172	40.13
25-May	Boyer Marina	2.15	111	21	1	1,329	51.75
Total Snake River		15.16	448	249	9	6,242	29.57
1-Jun	Maryhill	4.24	188	38	1	2,920	44.38
8-Jun	Maryhill	5.38	287	6	2	1,169	53.34
15-Jun	Umatilla	2.78	357	10	11	4,300	128.55
22-Jun	The Dalles	1.63	629	3	9	1,369	386.55
29-Jun	The Dalles	3.69	557	4	12	1,638	150.79
6-Jul	Cascade Locks	2.68	611	0	2	1,711	227.99
13-Jul	Hood River	3.63	162	2	2	5,749	44.59
27-Jul	The Dalles	3.98	837	4	6	4,621	210.27
Total Columbia River		28.01	3,628	67	45	23,477	129.53
Total All Areas		43.17	4,076	316	54	29,719	94.44

Source: 1992 SOF weekly field activity reports, Brian Mahoney, SOF, Seattle, WA, pers. comm.