The 1989 Northern Squawfish Population at Bonneville Dam First Powerhouse, Columbia River

by

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ABSTRACT

Northern squawfish, Ptychocheilus oregonensis, are well-known predators of juvenile salmonids in Pacific Northwest rivers and may substantially deplete the number of subyearling chinook salmon passing Bonneville Dam. To assess predation impacts and evaluate management decisions, population estimates of northern squawfish are needed. Angling was used to derive a population estimate of northern squawfish at Bonneville Dam First Powerhouse during summer 1989. A crew of three to six fished from the forebay deck of the powerhouse with light sport-tackle and artificial lures. Between 5 and 19 July, a total of 2,464 adult northern squawfish were captured and 2,399 tagged. Tagged fish were recovered as early as the day after tagging; a total of 35 were recovered. The catch per unit of effort (CPUE) for the marking period averaged approximately 19 northern squawfish per hour. Nine additional tagged fish were recovered from 226 squawfish captured on 4 August. Three different statistical methods were applied to the catch data to provide population estimates of northern squawfish ranging from 54,480 to 61,828.

INTRODUCTION

Northern squawfish, Ptychocheilus oregonensis, are well-known predators of juvenile salmonids, Oncorhynchus spp., in Pacific Northwest rivers (Ricker, 1941; Thompson, 1959; Wydoski and Whitney, 1979), and concentrations of these fish near hydroelectric projects on the Columbia and Snake Rivers (Figure 1) are documented (Raymond et al., 1975; Beamesderfer and Rieman, 1991). Large concentrations of squawfish near hydroelectric projects prey on salmonids (Rieman et al., 1991) and may reduce fish guidance efficiency of submersible traveling screens (Gessel et al., 1991). Predation can be substantial: Uremovich et al. (1981) estimated 3.8 million juvenile salmonids were consumed in Bonneville Dam forebay during the 1980 outmigration by an estimated peak squawfish population of >18,000. Observations at Bonneville Dam First Powerhouse (Figure 1) indicate that there are large concentrations of squawfish immediately upstream from the dam (forebay area) from June to August each year.

Purse seines, trap nets, gill nets, electrofishing, and angling have been used to sample northern squawfish populations in Columbia River reservoirs. With the exception of angling, these methods must be modified when used near hydroelectric dams. Trap nets and purse seines cannot be used in strong currents, but they have been used successfully in tailrace and forebay areas with reduced currents. Gill nets may injure or kill adult salmonids entering or exiting fishways. Electrofishing is usually more effective in shallow, slow current areas. Angling, although not generally a sampling method of choice, is an effective method for fish capture when target species are concentrated, as is the case with northern squawfish at hydroelectric dams. Thus, for this study, we used angling to derive a 1989 population estimate of northern squawfish at Bonneville Dam First Powerhouse. This estimate was compared to the 1980 estimate of 18,000 northern squawfish made at the same location by Uremovich et al. (1981).

METHODS

Angling was conducted from the forebay deck at Bonneville Dam First Powerhouse during summer 1989, from 5 to 19 July, and again on 4 August. A crew of three to six fished light sport-tackle with artificial lures (rubber worm lures of various types and colors). Captured northern squawfish were placed in 500-L holding tanks supplied with river water and then moved to a tagging station, generally in less than 1 hour. Fish were measured to fork length (cm), tagged with a numbered Floy[1] anchor tag, and marked with a hole punch on the left opercle. They were then released into a recovery net-pen in the forebay to exit volitionally. The catch and length of fishing time were

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service.

recorded for each angler to derive catch per unit of effort (CPUE). Tag number, date, and location of recaptures were also recorded.

Three different methods were used for estimates of population (N) using the following notations:

m	=	number of periods
M_i	=	total marked fish in forebay at the start of the ith sampling period ($i = 1, \ldots, m$).
C_i	=	total sample taken in period i.
R_i	=	number of recaptures in the sample C_i.
R	$= \sum R_i$	total recaptures during the experiment.

Method 1: Schnabel (adjusted)

Schnabel's (1938) approximation to the maximum likelihood estimator of population, N, from multiple censuses (Ricker, 1975), as adjusted by Chapman (1952, 1954) was

$$N = \sum_{i=1}^{m} \frac{C_i M_i}{R + 1} \qquad \textbf{(1)}$$

Approximate 95% confidence limits for this estimator were obtained by treating R as a Poisson variable and substituting limits found in Ricker (1975) for R in (1) above.

Method 2: Schumacher-Eschmeyer

Schumacher and Eschmeyer (1943) used the regression slope estimator in the plot of recovery rate versus the number of marked fish to obtain the following estimator:

$$N = \frac{\sum_{i=1}^{m} C_i \, M_i^2}{\sum_{i=1}^{m} M_i \, R_i} \qquad \textbf{(2)}$$

Approximate 95% confidence limits for N were obtained by first calculating limits for $1/N$ and then inverting those limits. The confidence limits for $1/N$ were based on a t-value with m-1 degrees of freedom and the standard error (S.E.) of $1/N$ [see (3) below].

$$\text{S.E.}(1/N) = \sqrt{\frac{\sum_{i=1}^{m} \frac{R_i^2}{C_i} - \frac{\left(\sum_{i=1}^{m} R_i \, M_i\right)^2}{\sum_{i=1}^{m} C_i \, M_i^2}}{(m-1) \sum_{i=1}^{m} C_i \, M_i^2}} \qquad \textbf{(3)}$$

Method 3: Peterson (adjusted)

The 5-19 July marking periods were considered one marking period and 4 August as a single sampling period. A straightforward Peterson estimator was used for N (adjusted for bias) (Ricker, 1975; Seber, 1982) as follows:

$$N = \frac{(C_i + 1)\,(M_i + 1)}{R_i + 1} \qquad \textbf{(4)}$$

where i = 4 August.

Approximate 95% confidence limits for this estimator were again obtained by treating R_i as a Poisson variable and substituting limits found in Ricker (1975) for R_i in (4) above.

The choice of sampling period length for population estimates in Methods 1 and 2 was subjective, so data were grouped into different-sized sampling periods to determine an "optimum" grouping (John Skalski, Quantitative Science Department, University of Washington, Seattle, personal communication). Four groupings were considered (4 August was excluded since it was separate from the other days): 1) individual days, 2) days grouped in twos (first three together), 3) days grouped in threes, and 4) days grouped in fours (first three together).

Grouping days reduced the inherent sampling variation (binomial or Poisson) and increased the number of recaptures per sampling period which reduced bias in the estimators (Ricker, 1975). However, information was lost each time data were pooled. The optimum grouping was determined by comparing plots for observed recovery rate of tagged fish versus number of tagged fish in the population at the time of sampling. The smallest grouping which provided a good linear fit for this plot was selected (a good fit corresponded to a small sampling variation). Further grouping improved the fit but not enough to outweigh the loss of information.

RESULTS

Between 5 and 19 July a total of 2,464 adult squawfish were captured and 2,399 were tagged (Table I). Tagged fish were recovered as early as the day after tagging. Average CPUE for the tagging period was approximately 19 squawfish per hour (range 0-40). The majority of fish were caught during early morning and evening hours. We recaptured a total of 35 tagged fish during the 5-19 July tagging period (Table II). Two additional tagged fish were recaptured outside the forebay area; one by dip net near Cascade Locks, Oregon, approximately 5 miles upstream, and the other by Oregon Department of Fish and Wildlife personnel electrofishing in the tailrace at Bonneville Dam Second Powerhouse (on 1 August). These two fish were not used in any statistical analysis. Nine additional tags were recovered from 226 squawfish captured on 4 August.

Grouping recoveries into 3-day blocks to define sampling periods appeared optimum. Population estimates derived from the three methods were fairly close in agreement, ranging from 54,480 to 63,017 northern squawfish (Table III). Wide confidence intervals made the differences between the three estimates insignificant. However, we consider the derived values only as estimates of the general order of magnitude of the northern squawfish population.

DISCUSSION

There were two possible sources of error in these methods: 1) bias of the estimators due to sample size, and 2) bias and lack of validity of the estimators due to failure of assumptions.

The Schnabel and Peterson estimators were both adjusted to be relatively unbiased. The Schnabel and Schumacher-Eschmeyer estimators were reasonably unbiased for sample size since all $R_i \geq 3$ (Ricker, 1975). Also, since $R > 7$ on 4 August, sample bias was negligible for the Peterson estimate (Seber, 1982).

There are three key assumptions on which these estimators depend:

1) random interspersion of marked fish into the general population.
2) equal catchability of all fish within each sampling period, including both marked and unmarked fish (not necessarily among sampling periods).
3) closure of the population (i.e., no inmigration or outmigration during the experiment).

Assumptions 1 and 2 were very difficult to examine with these data. Sustained mark-recapture sampling (individual tags) may have provided data to test these assumptions (Otis et al., 1978; John Skalski, personal communication); however, statistical methods have been developed to compensate for assumed bias (Pollock et al., 1984). Failure of Assumptions 1 and 2 would have led to serious bias in the Schnabel and Peterson estimates

(Otis et al., 1978), and somewhat less serious bias in the Schumacher-Eschmeyer estimate. If fish did not intersperse well, the bias would probably have been negative, leading to an underestimate of the true population. If short-term interspersion did not occur (within the 2-week tagging period), the 4 August Peterson estimate would have been larger than the other two estimates. Since it was not, short-term interspersion did not appear to be a serious problem. If tagged fish had become "hook-shy" the bias would have been positive, leading to an overestimate of the population. We are uncertain whether this occurred. However, since we recaptured some fish the day after tagging, it is reasonable to assume that the bias was minimal.

Assumption 3 must only be approximately met for the usefulness of these methods (Ricker, 1975). The Peterson estimate calculated N at the time of the second sample (4 August) and so required closure of the population (for inmigration) only during the sampling period; in this case, 1 day. Outmigrating fish would have produced a positive bias in the Peterson estimate. Overton (1965) described a method to account for known removals from the population estimate.

A sampling period of only 1 month was sufficient to ensure that Assumption 3 was reasonable for the Schnabel estimate (Ricker, 1975). A good linear fit for the plot of recovery rate versus number of tagged fish indicated that it was reasonable to assume population closure (Seber, 1982). Inmigration would have made the Schnabel and Schumacher-Eschmeyer estimates larger than

N on 5 July, and smaller than N on 4 August (Table II). Outmigration would have had the opposite effect. The effect of both would have created negative or positive bias depending on the magnitude of each. The relative agreement of the Peterson estimate with the other two population estimates provided evidence that large-scale inmigration or outmigration was not occurring.

The Schumacher-Eschmeyer estimate was utilized to provide a robust population estimate under the three key assumptions. The estimate of standard error for $1/N$ is quite robust (Seber, 1982) and the estimate of N is somewhat robust. The Schumacher-Eschmeyer estimate should be used along with other estimates (Seber, 1982).

Northern squawfish concentrations at hydroelectric projects on the Columbia River are a product of an artificial condition. Decreases in salmon populations may be partially related to the apparent increased northern squawfish population between 1980 (Uremovich et al., 1981) and 1989 (18,000 to > 50,000) at Bonneville Dam. The timing of northern squawfish spawning and changes in juvenile salmonid migration periods in the vicinity of Bonneville Dam may exacerbate predation problems. Northern squawfish in the Columbia River Basin spawn when water temperature is about 16°C (Jepsen and Platts, 1959; Patten and Rodman, 1969). Patten and Rodman (1969) described northern squawfish spawning behavior in Merwin Reservoir on the East Fork of the Lewis River in Clark County, Washington (approximately

70 km downstream from Bonneville Dam). They indicated that spawning probably occurs throughout June and July and that large concentrations of northern squawfish are in the spawning area for only a few days.

Hydroelectric dams delay juvenile salmonid migrations (Raymond, 1988). Concurrent with dam construction, average river temperatures increased markedly at Bonneville Dam between the 1950s and 1980s (Figure 2).

Prior to completion of the hydroelectric dams on the lower Columbia River, the major portion of the summer subyearling chinook salmon migration at Bonneville Dam probably occurred between 1 June and 1 July. In the 1950s and earlier, the majority of northern squawfish spawning probably occurred between 25 June and 5 July (based on average water temperatures). Thus, most subyearling migration was completed prior to the end of northern squawfish spawning.

Both the delayed summer juvenile salmonid migrations and the increased water temperatures have altered this relationship. In the 1980s, most northern squawfish spawning probably occurred between 5 and 25 June (based on average water temperatures), while the subyearling chinook salmon migration occurred from 1 June through 15 August. As a consequence, northern squawfish may now concentrate predation at the peak of the juvenile subyearling chinook salmon outmigration. This situation may substantially impact the Snake River fall chinook salmon, recently listed by the National Marine Fisheries Service (NMFS) as a threatened species under the Endangered Species Act (NMFS 1992).

REFERENCES

Beamsderfer, R. C. and Rieman, B. E. 1991. 'Abundance and distribution of northern squawfish, walleye, and smallmouth bass in John Day Reservoir, Columbia River', *Trans. Am. Fish. Soc.*, **120**, 439-447.

Chapman, D. G. 1952. 'Inverse multiple and sequential sample censuses', *Biometrics* **8**, 286-306.

Chapman, D. G. 1954. 'The estimation of biological populations', *Ann. Mathemat. Stat.*, **25**, 1-15.

Gessel, M. H., Williams, J. G., Brege, D. A., Krcma, R. F., and Chambers, D. R. 1991. 'Juvenile salmonid guidance at the Bonneville Dam Second Powerhouse, Columbia River, 1983-1989', *N. Am. J. Fish. Manage.*, **11**, 400-412.

Jepsen, P. W. and Platts, W. S. 1959. 'Ecology and control of the Columbia River squawfish in northern Idaho lakes', *Trans. Am. Fish. Soc.*, **88**, 197-202.

National Marine Fisheries Service (NMFS). 1992. 'Final rule: Threatened status for Snake River spring/summer chinook salmon, threatened status for Snake River fall chinook salmon', Federal Register [50 CFR Part 227; Docket No. 910847-2043, 22 April 1992], **57**(78):14653-14663.

Otis, D. L., Burnham, K. P., White, G. C., and Anderson, D. R. 1978. 'Statistical inference from capture data on closed animal populations', *Wildl. Monogr., Number 62.* 135 pp.

Overton, W. S. 1965. 'A modification of the Schnabel estimator to account for removal of animals from the population', *J. Wildl. Manage.*, **29**, 392-395.

Patten, B. G. and Rodman, D. T. 1969. 'Reproductive behavior of northern squawfish, *Ptychocheilus oregonensis*', *Trans. Am. Fish. Soc.*, **98**, 108-111.

Pollock, K. H, Heinz, J. E., and Nichol, J. D. 1984. 'The use of auxillary variables in capture-recapture and removal experiments', *Biometrics*, **40**, 329-340.

Raymond, H. L. 1988. 'Effects of hydroelectric development on spring and summer chinook salmon and steelhead in the Columbia River Basin and the fish's response to enhancement programs', *N. Am. J. Fish. Manage.*, **8**, 1-24.

Raymond, H. L., Sims, C. W., Johnsen, R. C., and Bentley, W. W. 1975. 'Effects of power peaking operations on juvenile salmon and steelhead trout', U.S. National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Seattle. 46 pp.

Rieman, B. E., Beamesderfer, R. C., Vigg, S., and Poe, T. P. 1991. 'Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River', *Trans. Am. Fish. Soc.*, **120**, 448-458.

Ricker. W. E. 1941. 'The consumption of young sockeye salmon by predaceous fish', *J. Fish. Res. Board Can.*, **5**, 293-313.

Ricker, W. E. 1975. 'Computation and interpretation of biological statistics of fish populations', *Bull. Fish. Res. Board Can., Number 191.* 382 pp.

Schnabel, Z. E. 1938. 'The estimation of the total fish population of a lake', *Am. Mathemat. Mon.*, **45**, 348-352.

Schumacher, F. X. and Eschmeyer, R. W. 1943. 'The estimate of fish population in lakes or ponds', *J. Tenn. Acad. Sci.*, **18**, 228-249.

Seber, G. A. F. 1982. *Estimation of Animal Abundance and Related Parameters*, Oxford Univ. Press, New York. 654 pp.

Thompson, R. B. 1959. 'Food of the squawfish (*Ptychocheilus oregonensis*) (Richardson) of the lower Columbia River', *U.S. Fish Wildl. Serv., Fish. Bull.*, **60**(158), 43-58.

Uremovich, B. L., Cramer, S. P., Willis, C. F., and Junge, C. O. 1981. 'Passage of juvenile salmonids through the ice and trash sluiceway and squawfish predation at Bonneville Dam, 1980', Oregon Department of Fish and Wildlife, Portland, Oregon, Report to U.S. Army Corps of Engineers, Contract DACW57-78-C-0058. 46 pp.

Wydoski, R. S. and Whitney, R. R. 1979. *Inland fishes of Washington*, Univ. Washington Press, Seattle. 220 pp.

Table I. Mark/recapture summary from northern squawfish research at Bonneville Dam First Powerhouse, 1989.

Date	Number caught	Number tagged	Cumulative tagged	Number recaptured	Cumulative recaptured
5 July	58	58	58	0	0
6 July	112	112	170	0	0
7 July	81	81	251	0	0
8 July	424	423	674	1	1
9 July	622	616	1,290	6	7
10 July	106	106	1,396	0	7
11 July	149	147	1,543	2	9
12 July	125	121	1,664	3	12
13 July	67	66	1,730	1	13
14 July	68	66	1,796	2	15
15 July	265	228	2,024	8	23
16 July	179	173	2,197	6	29
17 July	53	52	2,249	1	30
18 July	115	112	2,361	3	33
19 July	40	38	2,399	2	35
4 Aug	226	0	2,399	9	44

Table II. Recapture summary of individually tagged northern squawfish at Bonneville Dam First Powerhouse, 1989.

Tag number	Date tagged	Location[1]	Date recaptured	Location[1]	Days after tagging
00150	6 July	N	8 July	N	2
00066	6 July	N	9 July	N	3
00122	6 July	N	9 July		3
00143	6 July	N	9 July	N	3
[2]			9 July	N	
00475	8 July	N	9 July	S	1
00239	7 July	N	9 July	S	2
00032	5 July	N	11 July	N	6
00348	8 July	N	11 July	N	3
00391	8 July	N	12 July	N	4
01103	9 July	N	12 July	N	3
00531	8 July	S	12 July	N	4
00636[3]	8 July	S	10 July		2
01645	12 July	N	13 July	N	1
00865	9 July	N	14 July	S	5
01153	9 July	N	14 July	N	5
01252	9 July		15 July	N	6
01454	11 July		15 July	S	4
01810	14 July		15 July	N	1
01262	9 July		15 July	S	6
01548	11 July		15 July	S	4
01135	9 July		15 July	S	6
00087	6 July	N	15 July	N	9
00803	9 July		15 July	S	6
00115	6 July	N	16 July	S	10
00736	9 July	S	16 July	S	7
01435	11 July	N	16 July	N	5
00564	8 July	N	16 July	S	8
00186	7 July	N	16 July	S	9
00263	8 July	N	16 July	S	8
01288	9 July	N	17 July	N	8
00180	7 July		18 July	N	11
00608	8 July		18 July	N	10
01590	12 July	N	18 July		6
01269	9 July	N	19 July	N	10
01680	12 July	N	19 July	N	7

Table II. Continued.

01658[4]	12 July	S	1 August		
02393	19 July	N	4 August	N	16
01707	13 July	S	4 August	N	22
00134	6 July	N	4 August	N	29
00721	9 July	S	4 August	N	26
01009	9 July	N	4 August		26
00094	6 July	N	4 August	S	29
00725	9 July	S	4 August	N	26
02416	19 July	N	4 August	N	16
01523	11 July	N	4 August	N	24

[1]Indicates area where originally caught or area of recapture. N(orth) and S(outh) indicate end of powerhouse. Blank space indicates unknown.

[2]Fish was hooked, but lost into the ice and trash sluiceway which empties downstream from the dam.

[3]Fish was captured by dip net at Cascade Locks, Oregon.

[4]Fish was double tagged; recaptured by electrofishing gear in tailrace area below Bonneville Second Powerhouse.

Table III. Three estimators of northern squawfish population (*N*) with associated 95% confidence limits.

Estimator	*N*	Confidence limits
Schnabel (adjusted)	58,891	(44,022, 80,599)
Schumacher-Eschmeyer	63,017	(53,475, 76,703)
Peterson (adjusted)	54,480	(30,099, 108,960)

Figure Captions

Figure 1.--Hydroelectric dams in the Columbia River Basin.

Figure 2.--Average Columbia River water temperature at Bonneville Dam during the 1950s and 1980s. Data compiled from U.S. Army Corps of Engineers Annual Fish Passage Reports, Columbia and Snake River Projects.