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Population Estimates of Northern Squawfish, *Ptychocheilus oregonensis*, at Bonneville Dam First Powerhouse, Columbia River

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Population Estimates of Northern Squawfish, *Ptychocheilus oregonensis*, at Bonneville Dam First Powerhouse, Columbia River

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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 in the Bonneville Dam First Powerhouse forebay pool 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.

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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 (Fig. 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 more than 18,000. Recent observations at Bonneville Dam First Powerhouse (Fig. 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,

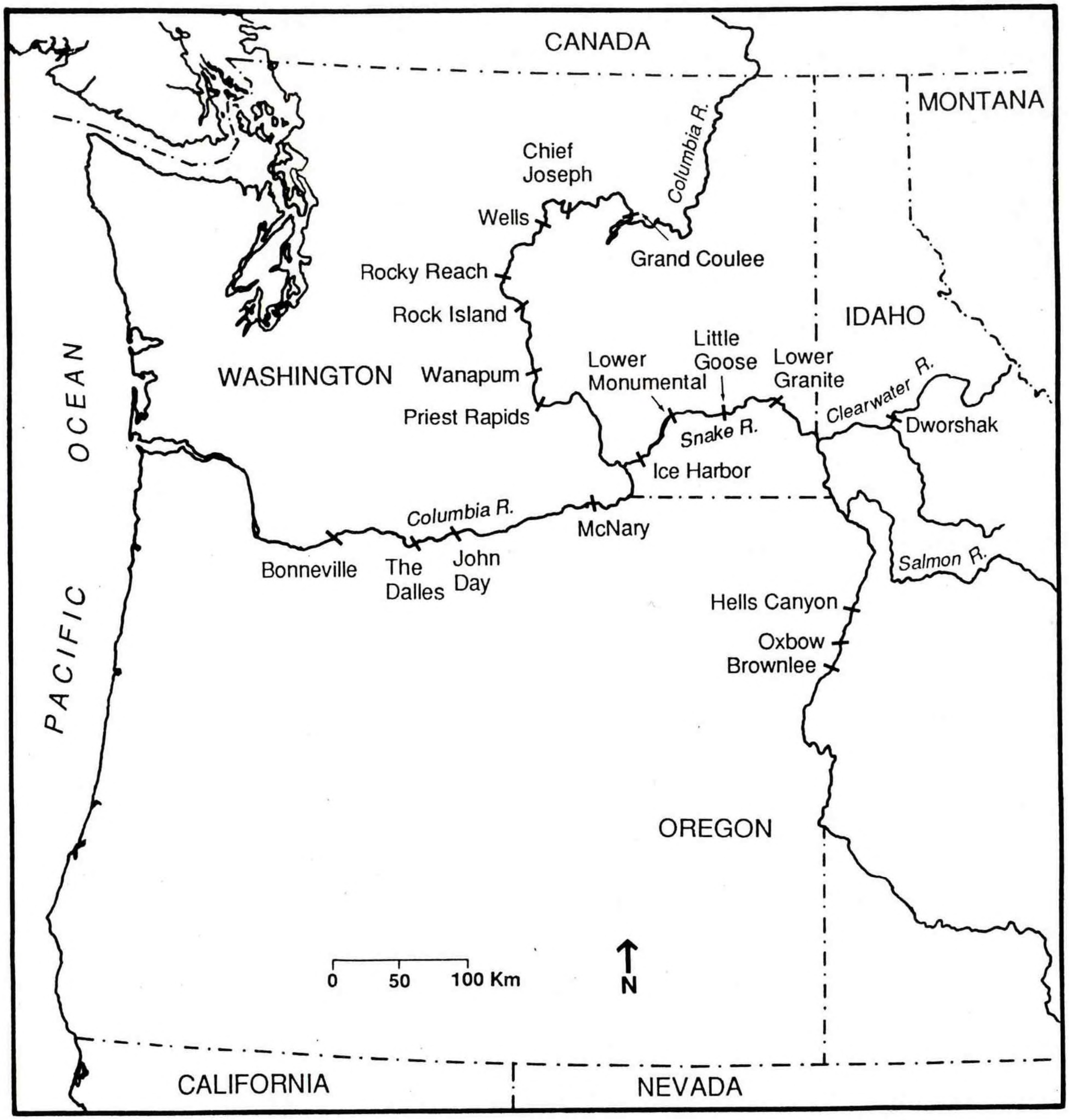

Figure 1. Hydroelectric dams in the Columbia River Basin.

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 in the Bonneville Dam First Powerhouse forebay pool.

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

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

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	$= \Sigma R_i$	total recaptures during the experiment.

Method 1: Schnabel (adjusted)

Schnabel's (1938) approximation to the maximum likelihood estimator of population abundance, 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].

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

Method 3: Peterson (adjusted)

The 5-19 July marking periods were considered one marking period and 4 August as a single sampling period. The Schnabel estimator used in Method 1 was therefore reduced to a Peterson estimator and 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, Pers. commun., September 1989). 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 1). 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 2). Two additional tagged

Table 1. Mark/recapture summary from northern squawfish research at Bonneville Dam First Powerhouse, 1989.

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

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

Table 2. Continued.

Tag number	Date tagged	Location[1]	Date recaptured	Location[1]	Days after tagging
01658[4]	July 12	S	August 1		
02393	July 19	N	August 4	N	16
01707	July 13	S	August 4	N	22
00134	July 6	N	August 4	N	29
00721	July 9	S	August 4	N	26
01009	July 9	N	August 4		26
00094	July 6	N	August 4	S	29
00725	July 9	S	August 4	N	26
02416	July 19	N	August 4	N	16
01523	July 11	N	August 4	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 Dam Second Powerhouse.

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 3). Wide confidence intervals made the differences between the three estimates insignificant. 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).

Table 3. 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)

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. Outmigration of fish would have produced a positive bias in the Peterson 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 2). 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).

Decreases in salmon populations in the Columbia River system may be partially related to the apparent increased northern squawfish population at Bonneville Dam between 1980 (Uremovich et al. 1981) and 1989 (from 18,000 to > 50,000). Although these population estimates are only for the forebay area at Bonneville Dam First Powerhouse, it is possible that similar increases have occurred at other sites.

There is evidence that hydroelectric dams delay juvenile salmonid migrations (Raymond 1988), and concurrent with dam construction, average river temperatures have increased markedly at Bonneville Dam between the 1950s and 1980s (Fig. 2). Northern squawfish concentrations at hydroelectric projects on the Columbia River are a product of these artificial conditions.

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.

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

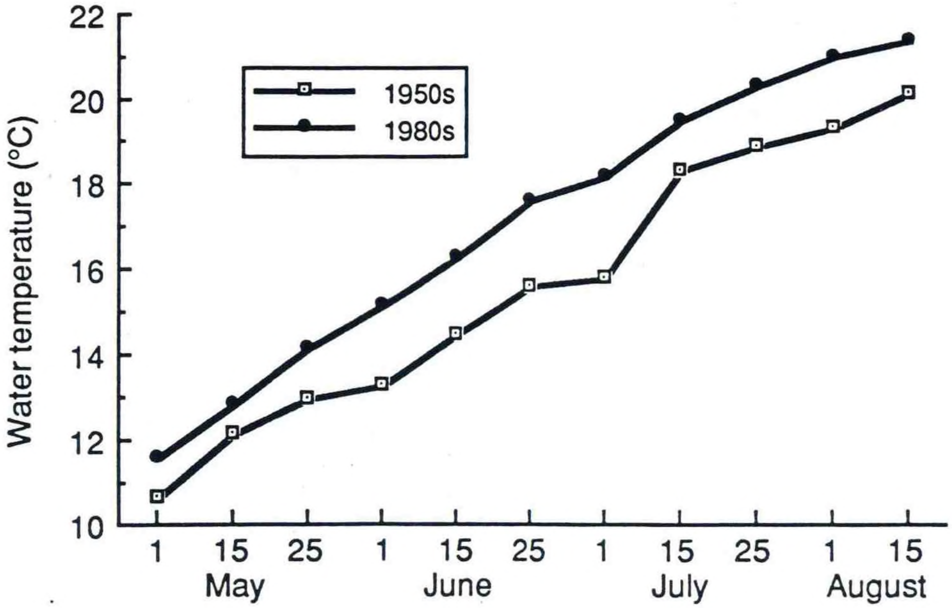

Figure 2. Average Columbia River water temperature at Bonneville Dam during the 1950s and 1980s. Data compiled from U.S. Army Corps of Engineers Annual Fish Passage Reports, Columbia and Snake River Projects.

25 June and 5 July (based on average water temperatures). Thus, most of the subyearling chinook salmon migration was completed during the northern squawfish spawning period and predation was limited.

Both the delayed salmonid migrations and the increased water temperatures have altered this relationship. With the increase in average water temperatures in the 1980s, most northern squawfish spawning probably has occurred between 5 and 25 June, while the subyearling chinook salmon migration has occurred from 1 June through 15 August. Therefore, northern squawfish spawning has been completed well in advance of the completion of the salmonid migration, possibly subjecting the salmon to increased predation.

Predator/prey relationships are of necessity delicately balanced. Any situation that substantially favors the predator must be short-lived or eventually both species may suffer. It appears that the construction of some hydroelectric dams has provided a setting that affects this balance. In selected areas (forebays and tailraces of the dams) northern squawfish may now concentrate predation during the protracted 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).

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