FISHERIES SCIENCE 2001; **67**: 134–137

Original Article

# Effect of smolt size on postrelease survival of hatchery-reared masu salmon *Oncorhynchus masou*

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***SUMMARY:*** The relationship between mean weights of hatchery-reared masu salmon *Oncorhynchus masou* smolts at release and the subsequent recovery rates by coastal commercial fisheries in Hokkaido, northern Japan, was investigated using the maximum likelihood method. A strongly positive correlation was observed, showing smolts with a mean of 32.6 g obtained an approximately 20-fold recovery rate of those with a mean of 14.8 g. The model with log-transformed independent variable ($Y_i = -11.237 + 4.239 \ln X_i$) was selected as the most parsimonious model to represent the release size ($X_i$) and recovery rate ($Y_i$) relationship.

***KEY WORDS:*** **Akaike information criterion, masu salmon, maximum likelihood method, *Oncorhynchus masou*, smolt size.**

## INTRODUCTION

Many studies have documented that smolt-to-adult survival of wild anadromous salmonids is positively correlated with smolt size.[1–6] This correlation is also supported by work on hatchery-reared fish (e.g. for coho salmon *Oncorhynchus kisutch*,[7,8] for chinook salmon *O. tshawytscha*,[9,10] and for cutthroat trout *O. clarki*).[11,12] However, little is known of the influence of smolt size on postrelease survival for hatchery-reared masu salmon *O. masou*, presumably due to a lack of evaluation programs for success of hatchery releases of this species. Masu salmon stocks have been enhanced by hatchery programs in Japan,[13] and information on the optimal smolt size is needed to improve stocking technologies.

Miyakoshi *et al.*[14] conducted a two-stage random sampling survey of commercial landings at fish markets in Hokkaido, northern Japan, and estimated the recovery rate of hatchery-reared masu salmon by coastal commercial fisheries. Although the absolute smolt-to-adult survivals could not be determined in their study because the escapements were not surveyed and a portion of the marked fish might be landed outside the survey area,[15] the estimated recovery rate by fisheries can be regarded as an index of marine survival.

The aim of the present paper is to examine the relationship between smolt size at release and estimated recovery rate by fisheries. In analyzing the size–survival relationship, estimated variances for each estimate[14] were taken into account and the most parsimonious model was selected using a maximum likelihood method and Akaike information criterion (AIC).[16]

## MATERIALS AND METHODS

In late May 1993–1995, two private hatcheries, Otobe and Shosanbetsu Hatcheries, stocked masu salmon smolts in Hokkaido, northern Japan. Miyakoshi *et al.*[14] estimated the recovery rates of hatchery-reared masu salmon smolts by coastal commercial fisheries in Hokkaido through a two-stage sampling survey of landings. Briefly, 33–36 fish markets were sampled from the markets located in the western part of Hokkaido, and survey days were sampled at 7–10 days intervals from January to June 1994–1996. On the survey days, all masu salmon landings were examined for marks indicated by fin clips, and numbers of total and marked masu salmon were recorded. The total

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Received 17 May 2000. Accepted 2 August 2000.

numbers of marked masu salmon landed were estimated with respective variances using the formulae described by Kitada *et al.*[17]

The data of smolt size and the subsequent recovery rate were fitted to eight models (Table 1). We assumed that the mean smolt sizes had been measured accurately (i.e. the measurement error of the independent variable is negligible), and the estimated variances for the recovery rates were taken into account when the size–survival relationship was examined.

Assuming a normal error distribution, the likelihood function is given as follows:

$$L = \prod_{i=1}^{n} \frac{1}{\sqrt{2\pi\hat{\sigma}_i^2}} \exp\left\{-\frac{\{Y_i - E(Y_i)\}^2}{2\hat{\sigma}_i^2}\right\},$$

where $n$ is the number of data, $Y_i$ is the estimated recovery rate of the smolt group $i$, and $\hat{\sigma}_i^2$ is the estimated variance of the recovery rate of the smolt group $i$. The functional form of $E(Y_i)$ is given in Table 1. Maximizing log $L$ numerically by using a simplex minimization, maximum likelihood estimates of $\alpha$, $\beta$, and/or $\gamma$ were obtained. Standard errors of these parameters were estimated numerically from the Hessian matrix. The optimal model illustrating the relationship between smolt size and recovery rate was determined on the basis of AIC:

$$\text{AIC} = -2(\text{maximum log likelihood value}) + 2p,$$

where $p$ is the number of free parameters. The model that gives the minimum AIC was selected as the most parsimonious model.

## RESULTS

A strongly positive relationship was observed between smolt size and the subsequent recovery rate by commercial fisheries. There was an approximately 20-fold difference in recovery rates between the smallest and largest smolts (Fig. 1). The estimates of the parameters and AIC values respective to each model are shown in Table 1. Model 3 (i.e. the model with log-transformed independent variable) showed the smallest AIC value and was thought to be the most parsimonious model to illustrate the size–survival relationship (Table 1).

## DISCUSSION

A positive relationship between smolt size of hatchery-reared masu salmon and their contribution to the commercial fisheries was clearly observed, indicating it is effective to raise larger smolts to increase the commercial masu salmon stock. The relationship between mean smolt size at release ($X_i$) and recovery rate by commercial fisheries ($Y_i$) was explained most appropriately by Model 3 with log-transformed independent variable ($Y_i = -11.237 + 4.239 \ln X_i$). The relationship between smolt size and survival was often analyzed by a simple linear regression. In the present study, recovery rates for hatchery-reared masu salmon smolts were estimated with measurement errors and the relative errors were not the same. Intrinsically, these estimated values should not be used as a variable in standard regression analyses.[18] The maximum likelihood estimation method is appropriate to analyze such data sets.

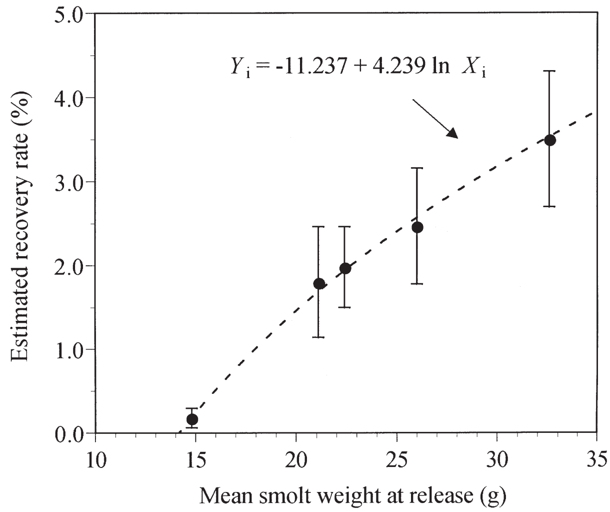


**Fig. 1** Relationship between recovery rate by commercial fisheries and mean weight of masu salmon smolts at release from Otobe and Shosanbetsu Hatcheries in 1993–1995. $X_i$ is the mean weight of smolt group $i$ and $Y_i$ is the estimated recovery rate of the smolt group $i$. Vertical bars show the 95% confidence interval for each estimate.

Other than sizes at release, however, river strains and releasing sites were different between hatcheries or among years.[14] These factors may affect the survival of hatchery-reared fish.[19,20] We speculate the effect of smolt size on postrelease survival is greater, and the large variation in mean smolt sizes made it possible to detect the relationship clearly (i.e. the range of mean weight of smolts was 14.8–32.6 g).

For coho, chinook salmon, and steelhead trout *O. mykiss*, smolt sizes affect the age structure of returning fish.[5,7,9] However, there are no reports of large anadromous masu salmon smolts returning as precocious jacks in Japan, although Tsiger *et al.*[21] described the existence of jacks of masu salmon in Russia. While smolt size does not affect age structure of anadromous masu salmon, Utoh[22] found

**Table 1** Detailed results from investigating parameters of each model to illustrate the relationship between smolt size of hatchery-reared masu salmon at release and subsequent recovery rate by commercial fisheries

| Model | Formula[1] | Estimated value and SE of parameters | | | | | | AIC |
|---|---|---|---|---|---|---|---|---|
| | | α | SE(α) | β | SE(β) | γ | SE(γ) | |
| 1 | $E(Y_i) = \alpha + \beta X_i$ | –2.865 | 0.266 | 0.207 | 0.016 | | | 1.135 |
| 2 | $E(Y_i) = \alpha + \beta X_i^{1/2}$ | –7.071 | 0.592 | 1.888 | 0.148 | | | –0.408 |
| 3 | $E(Y_i) = \alpha + \beta \ln(X_i)$ | –11.237 | 0.916 | 4.239 | 0.332 | | | –1.089 |
| 4 | $E(\ln(Y_i)) = \alpha + \beta \ln(X_i)$ | –14.506 | 0.916 | 4.763 | 0.332 | | | 8.295 |
| 5 | $E(Y_i) = \alpha\{1 - \exp(\beta + \gamma X_i)\}$ | 5.369 | 2.850 | 0.790 | 0.617 | 0.0558 | 0.0429 | 0.876 |
| 6 | $E(Y_i) = \alpha + \beta X_i + \gamma X_i^2$ | –4.938 | 1.424 | 0.420 | 0.145 | –0.0050 | 0.0034 | 0.939 |
| 7 | $E(Y_i) = \alpha + \beta X_i^{\gamma}$ | –6.986 | 4.490 | 1.886 | 2.536 | 0.4963 | 0.2683 | 1.645 |
| 8 | $E(Y_i) = \dfrac{\alpha}{1 + \exp(\beta + \gamma X_i)}$ | 3.213 | 0.401 | 8.987 | 1.211 | 0.4230 | 0.0071 | 2.895 |

[1] $X_i$ is mean weight of the smolt group $i$ at release, and $Y_i$ is estimated recovery rate of smolt group $i$ by commercial fisheries.

in juvenile masu salmon that larger males are more likely to mature early as non-anadromous residual males. Also, it has been reported in some salmonids that smolts larger than a critical threshold size show a lower survival than the maximum.[4,6,11] In a review paper, Ewing and Ewing[23] found an inverse relation between rearing density and the subsequent survival of smolts; the higher density the lower survival. Increasing the size of smolts reared in hatcheries either results in a decrease in the number of fish reared or an increase in the rearing densities. Future research is needed therefore in raising anadromous masu salmon smolts for increasing commercial fish harvest, to investigate the optimal size and/or density of smolts to be reared from an economical view point of hatchery operation.

## ACKNOWLEDGMENTS

The surveys at fish markets were undertaken by the staff of Hokkaido Fish Hatchery, the Fisheries Expansion Offices, and fishermen's cooperative associations. The fish were reared by the staff of the Otobe town and the Shosanbetsu village offices. We would like to thank the many people who participated in the mark-recovery program. We acknowledge W. R. Heard for reviewing the early draft of this paper. The paper was also improved by the valuable comments of two anonymous reviewers.

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