The effect of size, fin erosion, body silvering and precocious maturation on recaptures in Carlin-tagged Baltic salmon (*Salmo salar* L.)

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The effects of fin damage, size at release, coloration and precocious maturation on the survival of hatchery reared salmon (*Salmo salar* L.) smolt were evaluated on the basis of recaptures of Carlin-tagged stockings. Colouring of skin and moderate fin erosion was of little or no consequence for determining the value of the fish for stocking. Precocious males have a lower survival rate than immature fish. Larger fish give more returns compared to smaller ones, but this may also be due to selective fishing or size selective tagging mortality rather than better survival among larger fish.

1. Introduction

Hatchery reared salmon (*Salmo salar* L.) smolt are used in Finland to stock rivers as a means of replacing losses in wild smolt production due to the use of the rivers for generation of hydroelectric power. The quality and condition of the reared salmon is important for their survival in nature, and the recognition of any characters that might be of predictive value with respect to the survival of the fish would be important to the success of the stocking operation.

Several external factors have been used to assess the quality of reared salmon. In most cases survival increases with increasing smolt size at release (Carlin 1969, Lundqvist et al. 1988, Eriksson 1989). However, this is not always evident (Soivio et al. 1988).

A number of colour changes take place during the smolting process: darkening of the fins, disappearance of the side spots and a change of colour in the skin and scales to a silvery shade (Gorbman et al. 1982). The rate of silvering may be correlated with fish size (Kazakov & Kozlov 1985), but the timetable for these changes under hatchery conditions is not always the same as under natural conditions (Soivio et al. 1988). Such changes can nevertheless reflect the

smolting state and thus be predictive of the survival of the fish after release.

Precocious maturation in male Atlantic salmon is widely known both in nature and in hatcheries (Leytzerovich & Melnikova 1979, Saunders et al. 1982). Herbinger & Newkirk (1990) have found large differences between families of cultivated Atlantic salmon, indicating the inheritance of precocious maturation, although environmental conditions can also affect their development (Adams & Thorpe 1989). Early maturation partly prevents the future seaward migration (Hansen et al. 1989) and they may have a lower survival rate than immature smolts (Lundqvist et al. 1988).

Fish often sustain fin damage under hatchery conditions, and this can reduce the survival of stocked fish (O'Grady 1984), although fin erosion has not been observed to have an effect on the catch of tagged salmon in all investigations (Eskelinen et al. 1988).

The aim of this work was to assess the predictive value of size at release, coloration of skin, fin erosion and precocious maturity with respect to the survival of stocked salmon smolt on the basis of recaptures of Carlin-tagged stockings.

2. Material and methods

The salmon studied here originated from the River Iijoki stock and consisted of three different parental stocks (ML 5/1983, ML 6/83, and ML 15/1983). They were reared in separate groups at the Taivalkoski State Aquaculture (65°42′N, 28°03′E) in Northern Finland. The eggs were fertilized at the end of September in 1984 and hatched in spring 1985. The fry and parr were reared in 7 m² circular plastic indoor ponds during the first year, at a density of 2100 fish/m² during the first summer and 1300 fish/m² during the first winter. In the second summer the parr were moved to outdoor ponds, where they were reared at a density of 500–800 fish/m². This was reduced to 250–300 fish/m² during the second winter and 70–110 fish/m² from that time onwards. The fish were fed on commercial pelleted salmon food (EWOS). Water from the River Ohtaoja was used for hatching, but because of

the low water temperatures in that river development to smolting state took three years.

Altogether 3997 salmon were marked with Carlin tags, about half of them (2000) in autumn on September 4th 1986 and the remainder on April 13–15th 1987. The group tagged in the autumn consisted of salmon from two parental stocks (ML 5/1983 and ML 6/1983) and those tagged in the spring were all from one parental stock (ML 15/1983). The fish were anaesthetised with MS 222 before tagging.

External factors of individual fish were examined during the tagging process. The fork lengths of all the tagged fish were measured to an accuracy of 1 mm during tagging. The colouring of the skin and scales was classified into categories 0 to 4, where 0 indicated fully silvered fish with parr marks totally absent and 4 brownish fish with parr marks clearly visible. Erosions on the caudal or dorsal fins were recorded, and any cases of maturity of male fish were judged on the basis of ripening of testes.

Both groups were released at the Praava fishing harbour (65°17′N, 25°17′E) in the Bothnian Bay on June 3 in 1987. Two smolts in the spring group, and also twenty fish in the autumn-tagged group died during the winter mostly by jumping out of the pond. The recapture data includes all recaptures reported and processed before the end of December 1992.

Several selection coefficients were estimated for the external factors to describe the differences between the total population released and fish recaptured. Selective values for the different categories of polymorphic traits were determined on the basis of their relative frequencies among the recaptured and among non-recaptured fish according to Manly (1985). The selective value for a given morph i relative to best morph is the relative fitness

$$w_i = \left(n_i'/n_i \right)/\left(n_A'/n_A \right) \qquad (1)$$

where n_i is the frequency of a known morph before selection and n_i' after selection, and n_A' and n_A respective frequencies for the best morph. Selection differentials (s) with respect to fork length were calculated in terms of the difference between the mean length of the fish released and that recorded for the recaptured fish at the time

of tagging. To allow comparison of autumn and spring tag-groups these selection differentials were standardized by dividing them by the standard deviation upon release

$$i = (\bar{x}_a - \bar{x}_b)/\sqrt{v_b} \qquad (2)$$

where i is standardized selection differential, $\bar{x}_a$ and $\bar{x}_b$ are the means of the groups, and v_b the variance upon release (see Falconer 1981, Endler 1986). To control the possible non-linearity in survival across the range of fork lenghts, relative survival probabilities were also estimated across the entire range of this character using non-parametric cubic-spline technique (Schluter 1988).

Since the variables are not necessary independent, the significant differences at release and recapture could only be attributed to the effect of the associated character. Green & Macdonald (1987) have justified the use of log-linear models as an appropriate statistical technique for analysing the effects of several non-independent variables on the survival of stocked fish.

We used the computer package GLIM (e.g. Aitkin et al. 1990) to fit the log-linear models. Because it was not possible to detect stage of maturity among the male fish in the spring group, and smolt coloration among individuals of the autumn group was not yet developed, the different groups were analysed separately. The factors modelled in spring group were fork length, colouration and fin erosions; in autumn group the maturation stage was also considered but colouration excluded. For the analysis the fork lengths were ranked to the nearest 2 cm in both groups, and colour into two classes (<2, ≥2). Natural logarithm of number of fish relesed in each class were included to the model as an explanatory variable with a coefficient of 1 (by specifying it as an "offset" in GLIM terminology) (Green & McDonald 1987, Aitkin et al. 1990).

As pointed out by Green & McDonald (1987) fish release-recapture data like used in the present study is "messy" in statistical sense i.e. it do not come from a designed experiment. Accordingly we used also Akaike's information criterion i.e. advocated models that maximizes the information contained in the model when selecting an appropriate model (e.g. Chistensen 1990). For log linear models maximizing information amounts to choosing the model X that minimizes:

$$A_x = G^2(X) - 2(df) \qquad (3)$$

where $G^2(X)$ is the the likelihood ratio test statistics for testing the X model against saturated model, and df is test degrees of freedom (Christensen 1990).

3. Results

3.1. Recaptures

The recapture rate among the autumn-tagged fish was relatively low, 97 of the 1980 smolt released (4.9%) being recaptured later. The recapture rate was significantly higher in the spring-tagged group, 161 out of the 1995 fish released being recaptured (8.1%, $G_{(1)} = 16.6$; $P < 0.001$). Most fish were obtained during their second (69.0%) or third year (24.4%) in the sea. Only a minor proportion were caught in their first (3.5%) or fourth and fifth year in the sea (3.1%). There were no differences in yearly recaptures between the tagging groups ($G_{(1)} = 4.09$; $P > 0.10$).

Most of the recaptures were obtained from the main basin of the Baltic Sea (69.1%). About 27% of the recaptured fish were catched from the Gulf of Bothnia (3.2% from the Bothnian Sea and 23.7% from the Bothnian Bay). Only one fish was catched from the inland waters, Kiiminkijoki River, which is about 20 kilometers south from the stocking site.

3.2. Size

The average fork length was significantly larger in the recaptured salmon than in the whole initial population at the time of tagging (Table 1).

Table 1. Fork lengths (mean ± SD) at the time of tagging for released and recaptured salmon, selection differentials (s) and standardized selection differentials (i) for the spring-tagged and autumn-tagged groups. Selection coefficients were calculated from logarithms of actual values. P based on t-tests between recaptured and non-recaptured salmon.

Group	Released	Recaptured	s	i	t	P
Spring	22.0 ± 2.7	22.9 ± 2.1	0.04	0.06	5.5	<0.001
Autumn	18.0 ± 1.5	18.9 ± 1.3	0.05	0.05	6.5	<0.001

Standardized selection differentials for the log-transformed data were similar in both tagging groups. The variance in fork lengths was significantly smaller among the recaptured fish than those of non-recaptured ones both in spring-tagged (F'=1.4; P<0.05) and in autumn-tagged groups (F'=1.84; P<0.001). The non-parametric relative survival probabilities increased monoto-

nously in the autumn-tagged group (Fig. 1), suggesting that the decrease in variance could be due only to observed directional selection (Falconer 1981, Lande & Arnold 1983). Among the fish tagged in spring the relationship between fork length and survival was, however, slightly convex (Fig. 2), indicating possible stabilizing selection.

The differences in fork length upon release seem to persist to some degree at recapture. The time spent in the sea was shown to be the main factor affecting size at recapture in multiple regression analysis, but the length on release also had significant effect to it in both tag groups when the time was controlled (Table 2), although the partial correlation coefficients were fairly low: 0.08 in spring group and 0.11 in autumn group.
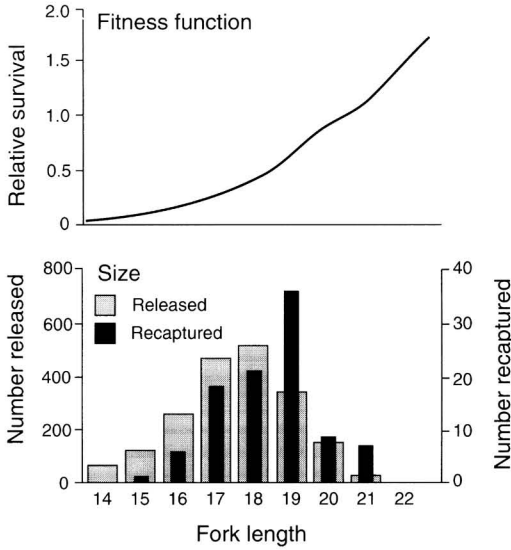

Fig. 1. Size distribution of the autumn-tagged salmon group on release and recapture, together with non-parametric fitness function based on these values.

Table 2. Multiple regression analysis of the fork length at recapture in the spring-tagged group and the autumn-tagged group. The independent variables are fork length at the time of tagging and months spent at sea before recapture.

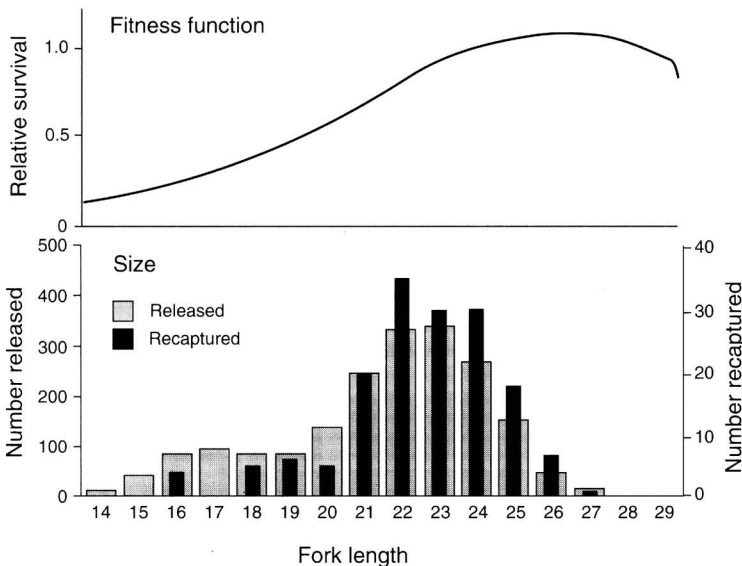| Variable	B	SE	t	P
Spring-group				
Fork length	10.8	3.8	2.8	<0.01
Months in sea	17.7	2.0	9.0	<0.001
Autumn-group				
Fork length	33.7	14.8	2.3	<0.05
Months in sea	13.6	2.6	5.2	<0.001

Fig. 2. Size distribution of the spring-tagged salmon at the time of tagging and at recapture, together with non-parametric fitness function based on these values.
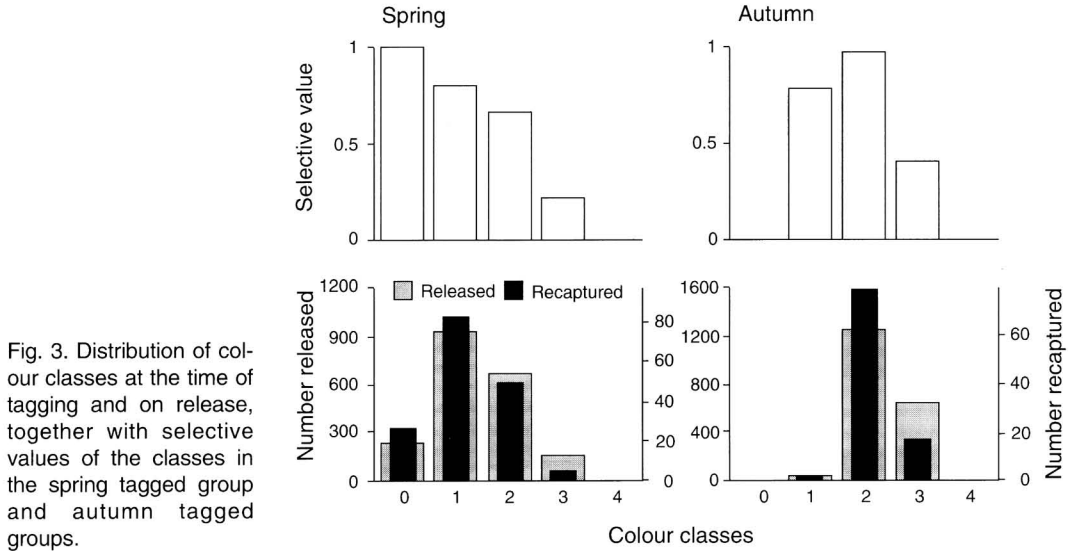
Fig. 3. Distribution of colour classes at the time of tagging and on release, together with selective values of the classes in the spring tagged group and autumn tagged groups.

3.3. Coloration

About one tenth of the spring-tagged group of stocked salmon were ranked in class 0, with parr marks totally absent (Fig. 3), most of them being placed in group 1. Only two fish were brownish in colour with parr marks clearly distinguishable. Silvery smolt had the largest selective values. Difference between the colour distributions among released and recaptured fish was significant ($X^2_{(3)} = 9.6$; $P < 0.05$).

The typical silvery smolting coloration was not developed in the autumn-tagged group in the same manner as it was in the spring group, and there was only one entirely silvery fish (Fig. 3). Most of the fish were ranked in groups 2 and 3, and three fish were dark-coloured brownish parr. The selective values of different colour groups in autumn-tagged group were rather similar than in spring-tagged group, and the difference between the distributions was significant ($X^2_{(2)} = 11.69$; $P < 0.01$).

3.4. Fin erosions

There were significantly ($X^2_{(1)} = 246.2$; $P < 0.001$) more erosions either the caudal or dorsal fins among the spring-tagged group, than among the autumn-tagged group (Fig. 4), indicating that the erosions arise during the winter. The erosions
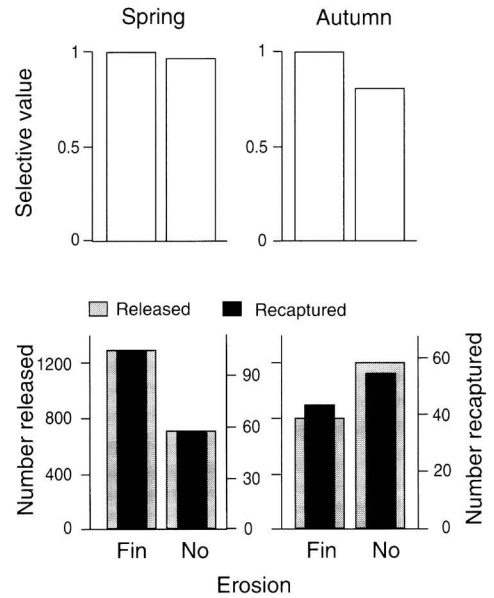

Fig. 4. Frequencies of erosions of fins among salmon at the time of tagging and at recapture, together with selective values for the spring-tagged group and the autumn-tagged group.

were generally minor and there were no totally worn-out fins. There were no differences in survival probabilities between the fish bearing or not bearing erosions in either the spring group ($X^2_{(1)} = 0.03$; $P > 0.01$) or the autumn group ($X^2_{(1)} = 0.8$; $P > 0.01$).

3.5. Precocious maturity

315 out of the 2000 salmon tagged in the autumn were functionally mature, i.e. running ripe. These precocious males gave significantly less returns from stocking than the immature fish (Fig 5; Fishers exact-test, $P < 0.007$). The average weight of the precocious males recovered was 1.6 kg ($SD = 0.6$, $n = 4$), which was was lower than the average weight of all the salmon caught (3.4 kg, $SD = 1.7$, $n = 46$).

Twenty one males in the spring group still had ripening testes, but the maturity stage of the rest could not be determined unambiguously because the breeding season was already over.

3.6. Target of selection

Not all the variables considered were independent ones. The degrees of association (Goodman & Kruskall's gamma) between the polymorphic characters and fork length, classified to the nearest cm, are presented in Table 3. The larger salmon were more silvery than the smaller ones, while the smaller salmon had lower prevalence of fin erosion in both tagging groups. The precocious males were significantly smaller than the immature fish, and were also more brownish in colour.

Log-linear analyses to explain the recapture probabilities suggested that only the main effects without any interractions are needed explain the proportions of recaptures in both data sets. Among the autumn-tagged group the model which included the main effects of fork length and maturation gave a good fit with the data ($G^2_{(21)} = 12.42$; $P > 0.10$). Removal of the latter variable did not significantly reduce the fit ($G^2_{(1)} = 2.58$; $P > 0.10$),
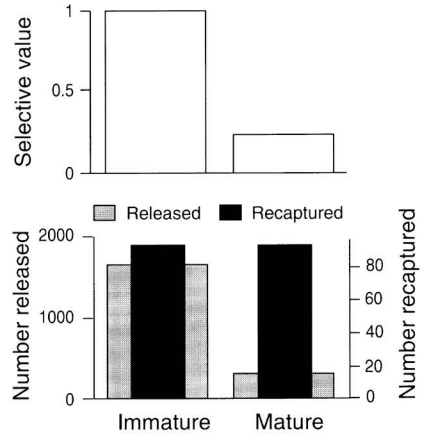

Fig. 5. Frequencies of matured males and immature males and females at the time of tagging and at recapture, together with selective values for the autumn-tagged group.

so that the simplified model was still an adequate representation of the data ($G^2_{(22)} = 15.00$; $P > 0.10$). However, the A_x value (–29.58) for model including the both factors was slightly smaller than the value (–29.00) of the simlified model, suggesting that the information contained by the more complicated model was larger. Thus we cannot outrule the effect of precocious maturation on recaptures.

Graphical representation of the more complex model (Fig. 6) nevertheless suggests that the survival difference between the matured and immature fish was more distinct among the larger size classes, in which there where only a few observations.

In the spring tagged group the model including only the fork length as an explanatory factor was an adequate representtaion of the data ($G^2_{(44)} = 37.23$; $P > 0.10$), and this model was also the most informative one.

Table 3. Degree of association (Goodman & Kruskall's gamma) between the characters examined in stocked salmon. The associations in the autumn-tagged group are given on the right side (n = 1980) and the associations in the spring-tagged group on the left side ($n = 1995$).

	Fork length	Colour class	Presence of erosions	Maturation stage
Fork length	–	–0.692***	0.104***	–0.680***
Colour class	–0.679***	–	–0.010	0.872***
Presence of erosions	0.455***	–0.553***	–	–0.079

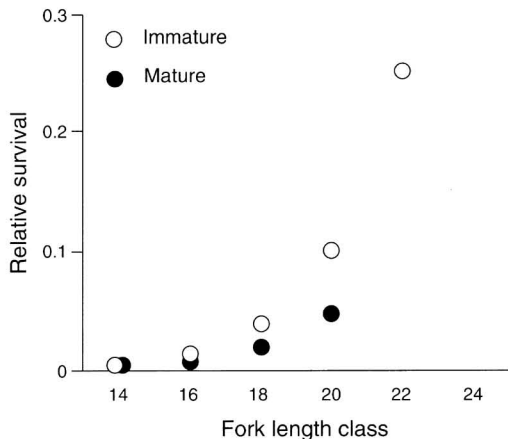***Significant at $P < 0.001$ in log-likelihood test.

Fig. 6. Fitted survival probabilities for mature males and immature males and females in relation to fork length class in a model including the main effects of both variables.

Adding erosion or colour as a explanatory factor to the best log-linear models in either data sets did not increase statistical signifigance of the models suggesting that the observed significant differences in coloration between recaptured and non-recaptured fish were only passive side-effects of size-depended survival.

4. Discussion

Increasing survival with increasing smolt size has been documented on a number of occasions (Carlin 1969, Lundqvist et al. 1988, Eriksson 1989b). According to Lundqvist et al. (1988) the relationship between survival and size is a linear one, the survival of immature smolt increasing by 2.5% per cm of length and that of the precocious males 1.4% per cm. Our results indicate also a relationship between size and survival, but among the largest fish in spring tagged group the recapture rates decclined. There could be a stabilizing selection component present, but it also possible that the decline in relative survival probabilities is not real, and due only to the scarity of data in the largest size classes.

The influences of size may be associated with predation, in that larger fish naturally have less predators than smaller ones. Salmon introduced into a river area have been reported being inten-

sively eaten by piscivorous fish (Larsson 1985, Hvidsten & Mokkelgjerd 1987). The Bothnian Bay is a shallow sea area where predation can also be intensive. Larger fish may have more potential food items available than smaller ones. The main food items for post-smolt in the Gulf of Bothnian are insects of terrestrial origin (Jutila & Toivonen 1985), but they can also start feeding on fish soon after reaching the sea area (Mitans 1970), where upon the larger post-smolt can consume more fish in their diet compared to the smaller ones (Jutila & Toivonen 1985). A more diverse diet may increase the survival probability of the larger fishes.

Size selective tagging mortality due to the tagging procedure can also have some effect; Carlin-tags can stress smaller fish more than larger ones (Isaksson & Bergman 1978, Kennedy et al. 1982). However, in microtagged brown trout larger smolts gave significantly more returns compared to smaller ones despite the neglible effect of the tag (Niva & Juntunen 1993).

Precocious males are common in nature, as they are in hatcheries (Leyzervich & Melnikova 1979, Saunders et al. 1982, Soivio et al. 1985). The results of Soivio et al. (1988) show that approximately 10% of salmon from the Neva stock reared under hatchery conditions were precocious males, while 15% of salmon from Swedish hatcheries used in sea-water challenge tests were precocious males (Lundqvist et al. 1986), which is close to the frequency found here.

Smolting and early maturation are conflicting physiological processes. Smolting prepares the fish for abandoning its freshwater adaptations while maturation leads to the retention of such adaptations (Thorpe 1986). Basis of sexual maturation has a genetic component (Thorpe et al. 1983, Herbinger & Newkirk 1990), but it can also be affected by environmental factors (Thorpe 1986, 1990, Adams & Thorpe 1989). Return rates among stocked precocious males are reported lower than those of immature males and females (Leyzerovich & Melnikova 1979, Lundqvist et al. 1988, Eriksson 1989a, Berglund et al. 1992). We also found that maturation state may have some effect to recapture rates, but since the sex of the immature fish could not be detected in our study (or in any study), it is not, however, clear whether the difference in survival is due only to

differences between the sexes or to differences between immature and mature fish as well.

The silvering of the skin during smolting is due to guanine deposition (Gorbman et al. 1982). This develops in spring in the wild, but under hatchery conditions it can take place at the previous autumn (Soivio et al. 1988). We found an association between between the rate of silvering and fork lenght of the fish. Similar results have been obtained by Kazakov & Kozlov (1985). We found no evidence of any effect of colouring on the survival of released salmon, even though it was associated with the selectively important feature of fork length.

The development of fin erosion is common in hatcheries. Nearly all the juvenile groups examined among the Neva salmon stock had fin erosion (Soivio et al. 1988). Erosions can impair swimming ability and manoeuvrability of fish (Maheskhumar 1985, ref. Soderberg & Meade 1987). O'Grady found that fin-damaged brown trout (*S. trutta* L.) had lower survival rate than a less damaged group, whereas Eskelinen et al. (1988) showed that the grade of fin erosion had no effect on the catches from different salmon groups. Our results are in accordance with those of Eskelinen et al. (1988) in that the number of salmon recaptured did not differ between the fin erosion and non-erosion groups. Even though the larger fish had more erosion than the smaller ones, they still survived better. The discrepancies between the published results may be due to the level and origin of the erosion. The present material did not contain any cases of totally worn-out fins or badly eroded fins and the regeneration of damaged fins can be fairly good (Johnsen & Ugedal 1988).

The explicit assumption is made in our analysis (as seems to be common to all mark-recapture experiments) that the recovery rates do not vary between size or other phenotypic classes. Our data indicate that the differences in length at the time of release may also be maintained in the lengths of catched salmon recovered, at least to some extent. Fishing with drift nets can be selective for the fastest growing (i.e. largest) salmon in the population first. Thus, it is possible that our recaptures are biased towards larger size. But in any case, from the viewpoint of the success of fish stocking larger smolt give more recaptures than with smaller ones.

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