Fishery Data Series No. 92-27

Effects of Age-at-Release on the Relative Contribution, Survival, and Run-Timing of Coho Salmon Adults to the Marine Sport Fishery of Resurrection Bay, Alaska, during 1990 and 1991

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ABSTRACT

A portion of the age-1 and age-0 smolt released during 1989 and 1990 into Seward Lagoon, a tributary to Resurrection Bay, Alaska, was marked with coded wire tags and had adipose fins removed. A portion of the coho salmon harvested during the 1990 and 1991 marine sport fisheries of Resurrection Bay was examined for missing adipose fins and snouts were collected from all coho salmon having a missing adipose fin for later removal and decoding of coded wire tags. Almost identical numbers of tags from smolt stocked as age 0 and age 1 were recovered during 1990 while during 1991 nearly four times as many tags from smolt stocked as age 1 were recovered than from smolt stocked at age 0. There was no significant difference in the contribution of smolt stocked as age 0 and age 1 during 1990, but during 1991, smolt stocked as age 1 contributed significantly more to the fishery than did smolt stocked at age 0. However, these results are confounded by effects of blood sodium levels at the time of smolt release. Adults stocked as age-1 smolt returned earlier during both years. No inferences could be made regarding differences in relative survival of smolt stocked as age 1 and age 0.

KEY WORDS: Age-at-release, age-0 smolt, age-1 smolt, coded wire tags, hatchery production, relative survival, contribution to fisheries, run timing, Resurrection Bay, Seward, coho salmon, blood sodium levels.

INTRODUCTION

The marine and fresh waters of Resurrection Bay and adjacent coastal areas (Figure 1) support diverse and abundant resources of several important sport fish species including the five species of Pacific salmon *Oncorhynchus*, halibut *Hippoglossus stenolepis*, lingcod *Ophiodon elongatus*, and several species of rockfish *Sebastes*. A major sport fishery has developed for these resources with the principal target being coho salmon *O. kisutch*. Currently, Resurrection Bay supports one of the largest marine sport fisheries (in both effort and harvest) for coho salmon in Alaska (Mills 1991). Since 1977, an average of over 7,000 boat-trips of effort have been expended to harvest over 15,000 coho salmon annually (Figure 2).

To satisfy increasing recreational angler demands, the Alaska Department of Fish and Game (ADF&G) began a stocking program in the early 1960s with the goal of stabilizing and expanding the coho salmon stocks of Resurrection Bay. The program began in 1963 with an experimental rehabilitation and stocking of coho salmon fingerlings into Bear Lake. A second facet of the stocking program began in 1968 with the annual stocking of hatchery-reared coho salmon smolt at various locations. Though there has been considerable variation from one site and one year to another, smolt-to-adult survivals have approached 15% with contributions to the sport harvest as high as 35%.

Until 1983, smolt released into Resurrection Bay were produced at the Fire Lake and Fort Richardson hatcheries. Beginning in 1983, however, smolt released into Resurrection Bay were produced at the Elmendorf hatchery due primarily to a shift in operations at the three hatcheries. The 1983 to 1985 coho salmon smolt stocked from Elmendorf hatchery contributed poorly to the fishery (average contribution equaled 2.1% at Seward Lagoon) in comparison to past stockings (Vincent-Lang 1987). The cause of the poor survival was attributed to disease problems at the Elmendorf hatchery. High summer creek temperatures and seasonal turbidity caused disease outbreaks that led to fewer fish released, poorer adult returns, and risks to other hatchery stocks. To avoid these problems, coho salmon were reared for their first year at the Trail Lake hatchery beginning in 1986. After a year at this hatchery, fingerlings were transferred to the Elmendorf hatchery in the fall after high creek temperatures declined. This strategy reduced the disease problems and increased abundance and quality of stocked fish.

In 1987, the Trail Lake hatchery was turned over to Cook Inlet Aquaculture Association and the ability to raise fingerlings for transfer to Elmendorf hatchery for smolt production is projected to end beginning with the 1992 release year. Therefore, the state is again faced with producing smolt for their entire life at Elmendorf hatchery. To avoid the past problems, the Elmendorf hatchery began an experimental accelerated-growth rearing program aimed at producing age-0 coho salmon smolt for stocking. Using heated water, the hatchery produced an 18 gram age-0 smolt in 8 months. It was hoped that this strategy could be used to avoid past disease problems. If the strategy of producing age-0 smolt contributes adults to the marine sport fishery, the hatchery will begin all age-0 coho salmon smolt production in fall of 1992 (FY93). If it is not a viable alternative, the hatchery will continue to raise age-1 coho using the available well water to maximum advantage and continue efforts to develop more well water.

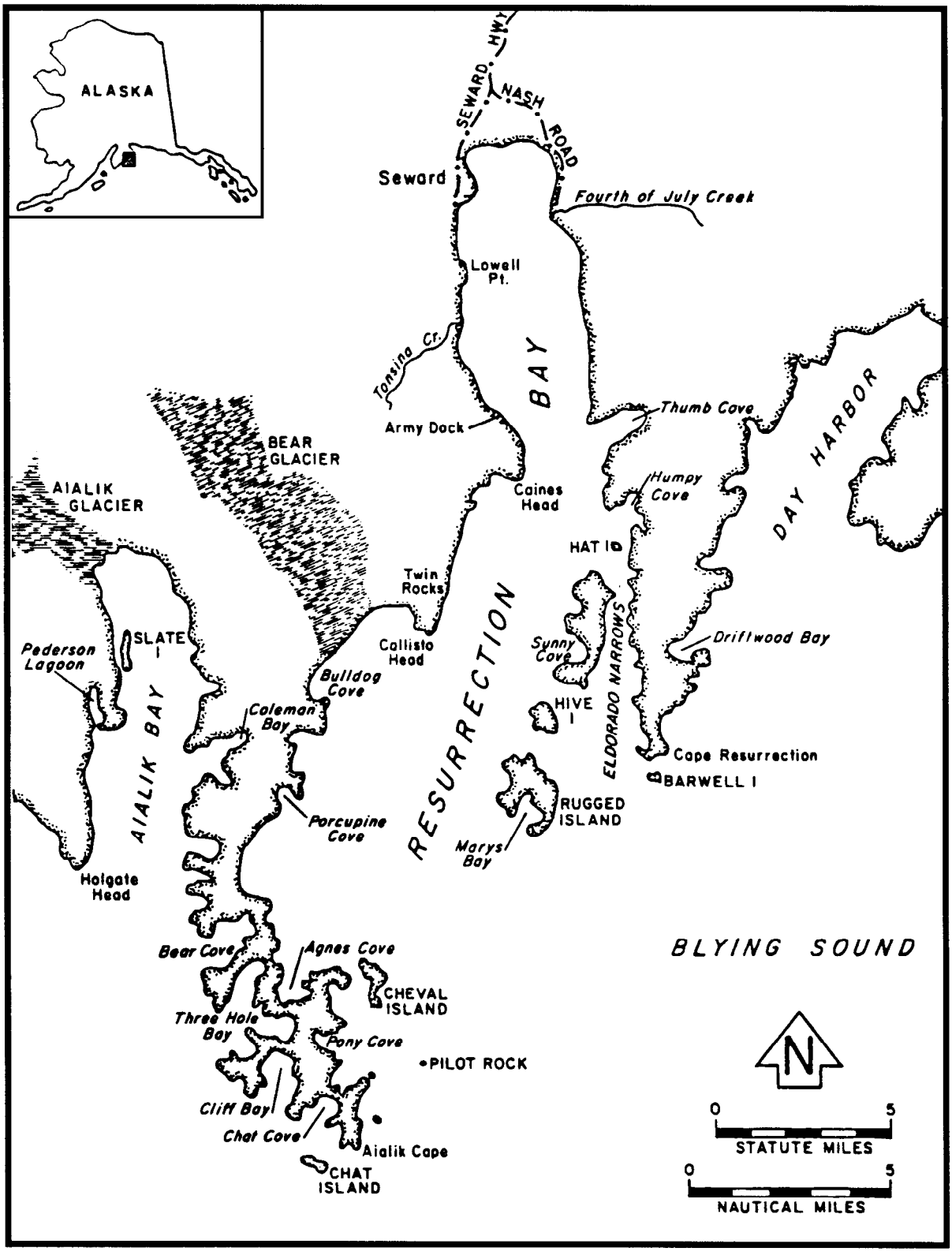

Figure 1. Resurrection Bay, Alaska.

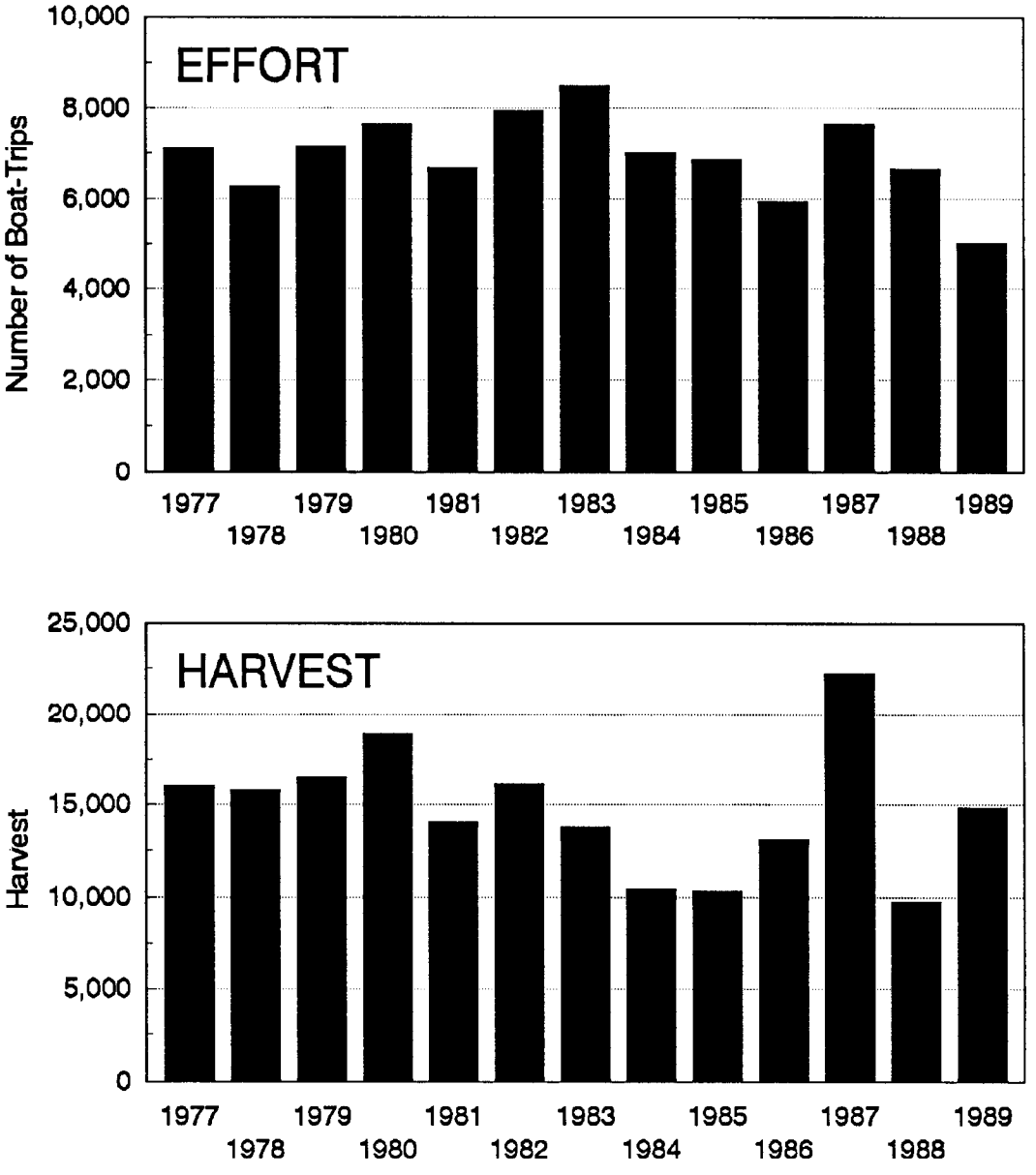

Figure 2. Effort and harvest of coho salmon during the recreational marine boat fishery in Resurrection Bay, Alaska.

This study was conducted to assess whether smolt-to-adult survival and adult run timing from age-1 and age-0 smolt is comparable. Differences in the timing of the return between the two release lots are very important since production from age-1 smolt stockings has contributed significantly to the harvests during the annual Silver Salmon Derby[1]. Up to 40% of the annual Derby harvests in recent years has resulted from age-1 smolt stockings. If fish from age-0 stocking return later than those from age-1 stocking, such differences could result in fewer fish being available for harvest during the Derby, a period when about 50% of the annual fishing effort is expended. The resulting economic[2] and social impacts could be enormous. However, a potential benefit of an age-0 program is increased smolt production at the Elmendorf hatchery. Given present capacities, the hatchery can produce 510,000 age-0 coho salmon smolt as opposed to only 360,000 age-1 coho salmon smolt.

The 25-year history of the Resurrection Bay project has been summarized by Vincent-Lang (1987). For more detailed descriptions and background information on each year's efforts, refer to Logan (1962-1969), McHenry (1970-1986), Conrad et al. (1987), Sonnichsen et al. (1987), Vincent-Lang and McHenry (1988a, 1988b), and Carlon and Vincent-Lang (1989a, 1989b, 1990a, 1990b).

STUDY OBJECTIVE

The objective of this study is to examine differences in contribution to the sport fishery, relative survival, and run timing of coho salmon released as age-0 and age-1 smolt.

PROCEDURES

Nearly identical portions of the age-1 and age-0 smolt released during 1989 and 1990 into Seward Lagoon were marked with a coded wire tag (CWT) and had their adipose fin removed (Table 1). Smolt were marked using the procedures described in Moberly et al. (1977). A portion of the coho salmon harvested during the 1990 and 1991 marine sport fisheries of Resurrection Bay were examined for missing adipose fins[3]. Snouts were collected from all coho salmon having a missing adipose fin and were sent to the department's CWT laboratory for removal and decoding. Data were collected during three time periods: (1) Pre-Derby, the period extending from mid-July (when hatchery-reared coho salmon begin to return to Resurrection Bay) through the last day

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[1] A Silver Salmon Derby (henceforward referred to as the Derby) is conducted annually in Resurrection Bay starting on the second Saturday in August and extending 9 days through the following Sunday.

[2] During 1986, recreational anglers fishing coho salmon in Resurrection Bay expended just under $2 million (Jones and Stokes 1987). It is generally recognized that much of this expenditure occurs during the annual Silver Salmon Derby.

[3] Coho salmon returning to Resurrection Bay waters return after spending only 1 year in salt water (Vincent-Lang 1987).

Table 1. Number of age-0 and age-1 smolt released into Seward Lagoon (Resurrection Bay), Alaska, during 1989, 1990, and 1991.

	Age-0 Smolt		Age-1 Smolt	
Year	# Released	# Tagged	# Released	# Tagged
1989	93,353	15,911	58,808	16,063
1990	88,777	15,393	56,842	15,679
1991	84,057	15,212	35,000	15,151

prior to the opening of the Derby, (2) Derby, the period during the annual 9-day Silver Salmon Derby, and (3) Post-Derby, the period from the first day after the Derby extending through mid-September.

Chi-square tests were conducted to test the hypothesis that adults tagged as age-0 and age-1 smolt contributed equally to the Resurrection Bay sport fishery during the Derby strata and during the entire season. These chi-square tests were performed using the chi-square module of the software package MINITAB (MINITAB 1988).

Run timing and survival can influence the contribution of stocked smolt to the fishery. To examine the effects these two variables had on the contribution from age-0 and age-1 smolt, we considered tags recovered during two time periods in a matrix:

$$\begin{bmatrix} \pi_{01} & \pi_{02} \\ \pi_{11} & \pi_{12} \end{bmatrix} \tag{1}$$

where π_{ij} equals the number of tagged coho salmon released as age-i smolt that returned during recovery time period j. Each π_{ij} is a function of the number ($N_{i.}$) and marine survival rate ($S_{i.}$) of coho salmon tagged as age-i smolt, the proportion (p_{ij}) of adult coho salmon released as age-i smolt that returned to the Resurrection Bay fishery during time period j, and the proportion ($\alpha_{.j}$) of the harvest sampled during time period j.

Because nearly equal numbers of smolt were tagged in each age group during both years, $N_{0.} = N_{1.} = N$; therefore, the above matrix becomes:

$$\begin{bmatrix} NS_0.p_{01}\alpha_{.1} & NS_0.(1-p_{01})\alpha_{.2} \\ NS_1.p_{11}\alpha_{.1} & NS_1.(1-p_{11})\alpha_{.2} \end{bmatrix}. \tag{2}$$

The hypothesis of equal run timing between the two release groups was tested using an odds ratio (Agresti 1990) calculated as:

$$\theta = \frac{\pi_{01}\ \pi_{12}}{\pi_{02}\ \pi_{11}} = \frac{p_{01}\ (1-p_{11})}{(1-p_{01})\ p_{11}}. \tag{3}$$

The parameter estimate θ was modified to give an estimator with less bias and a smaller mean squared error (Agresti 1984) as follows:

$$\theta = \frac{(n_{01} + 0.5)\ (n_{12} + 0.5)}{(n_{02} + 0.5)\ (n_{11} + 0.5)} \tag{4}$$

where n_{ij} equals the number of tags from adult coho salmon released as age-i smolt that were recovered during time period j. The natural logarithm of θ, denoted as log θ, converges more rapidly to its asymptotic normal distribution than does θ; therefore, we calculated log θ and estimated the standard deviation of log θ as:

$$SE(\log\ \theta) = (1/n_{01} + 1/n_{02} + 1/n_{11} + 1/n_{12})^{0.5} \tag{5}$$

and calculated $100(1-\alpha)\%$ confidence intervals of log θ. Confidence intervals for θ were calculated by exponentiating the upper and lower confidence values of log θ.

Based on this approach, if the odds ratio:

1. $\theta = 1$, then adults of age-0 and age-1 smolt have equal run timing;
2. $\theta < 1$, then adults of age-1 smolt are more likely to return earlier than those of age-0 smolt; and
3. $\theta > 1$, then adults of age-1 smolt are more likely to return later than those of age-0 smolt.

Additionally, if the confidence interval of θ does not contain 1, then the run timing between the two age groups is significantly different.

To examine effects that age-at-release has on relative survival, we estimated the statistic ϕ as:

$$\phi = \frac{n_{0j}}{\sum_{i=0}^{r-1} n_{ij}} = \frac{S_0 \cdot p_{0j}}{\sum_{i=0}^{r-1} S_i \cdot p_{ij}} \qquad (6)$$

where r equals the number of rows in the matrix.

With only two groups, this equation reduces to:

$$\phi = \frac{n_{oj}}{n_{0j} + n_{1j}} = \frac{S_{0j}\ p_{0j}}{S_{0j}\ p_{0j} + S_{1j}\ p_{1j}} \cdot \qquad (7)$$

This estimate is a function of both marine survival and run timing and allows for inferences on survival only in the following circumstances:

When $\theta = 1$ (equal run timing) and

$\phi = 0.5$, then equal survival
$\phi > 0.5$, then age-0 smolt had better survival
$\phi < 0.5$, then age-1 smolt had better survival.

When $\theta < 1$ (age-1 smolt returned earlier than age-0 smolt) and

$\phi > 0.5$, then age-0 smolt had better survival
$\phi \leq 0.5$, then no inference regarding survival is possible.

When $\theta > 1$ (age-1 smolt returned later than age-0 smolt)

$\phi \geq 0.5$, then no inference regarding survival is possible
$\phi < 0.5$, then age-1 smolt had better survival.

Because few tags were recovered before the Derby during both years, we combined recoveries during the Pre-Derby and Derby strata. In 1991, 90% of

the tag recoveries occurred during the Post-Derby strata. We therefore divided the Post-Derby strata during 1991 into two periods of equal length: ≤ 2 weeks and 2-4 weeks after the Derby.

RESULTS

Contribution to the Fishery

Almost identical numbers of tags originating from smolt stocked as age 0 and age 1 were recovered from the Resurrection Bay marine sport fishery during 1990, while during 1991 nearly four times as many tags originating from smolt stocked as age 1 were recovered than from smolt stocked at age 0 (Table 2). Based on these recoveries, we detected no significant difference ($\chi^2 = 0.01$, 1 d.f., $P > 0.10$) in the contribution of smolt stocked as age 0 and as age 1 during 1990, but that smolt stocked as age 1 contributed significantly ($\chi^2 = 111.8$, 1 d.f., $P < 0.001$) more to the fishery during 1991 than did smolt stocked at age 0.

Run Timing

Adults stocked as age-1 smolt returned earlier during both 1990 ($P < 0.10$) and 1991 ($P < 0.05$) than did adults stocked as age-0 smolt (Table 3 and Figure 3). During 1990, nearly 75% of the tags from age-1 smolt were recovered by the end of the Derby whereas over 50% of the tags from age-0 smolt were recovered during the Post-Derby. During 1991, returns of both age-0 and age-1 smolt were later than during 1990 and a small number of both returned during the Pre-Derby and Derby strata. As a result, there was no significant ($P > 0.10$) difference in the run timing during these strata during 1991. However, within the Post-Derby strata in 1991 when most tags were recovered, adults stocked as age-1 smolt returned earlier ($P < 0.05$) than adults stocked as age-0 smolt (Table 3).

Survival

Because estimates of phi were generally <0.5 and adults released as age-1 smolt returned earlier than those released as age-0 smolt, no inferences could be made regarding differences in relative survival between the two age groups (Table 4).

DISCUSSION AND RECOMMENDATIONS

Adults stocked as age-1 smolt returned earlier than those stocked as age-0 smolt to Resurrection Bay waters. In many situations, the later run timing of adults stocked as age-0 smolt would not present a problem, as anglers can shift their effort to a later time. In the case of Resurrection Bay, however, the later run timing of the adults stocked as age-0 smolt reduces the contribution that age-0 smolt have to the Silver Salmon Derby. Since production from age-1 smolt stockings have contributed up to 40% of the annual Derby harvests in recent years, replacing age-1 smolt production with age-0 smolt production will result in fewer fish being available for harvest during the Derby. Considering the potential economic and social impacts, we

Table 2. Number of coded wire tags recovered during the 1990 and 1991 Resurrection Bay, Alaska, sport fisheries from adult coho salmon released as age-0 and age-1 smolt.

Year	Strata	Dates		Recoveries	
		Begin	End	Age 0	Age 1
1990	Pre-Derby	07/01	08/10	6	3
	Derby	08/11	08/19	5	15
	Post-Derby	08/20	09/20	13	7
	Total	07/01	09/20	24	25
1991	Pre-Derby	07/19	08/09	2	6
	Derby	08/10	08/18	4	25
	Post-Derby	08/19	09/02	32	153
		09/03	09/17	37	94
	Total	07/19	09/17	75	278

Table 3. Odds ratios and confidence intervals comparing run timing of adult coho salmon during the 1990 and 1991 Resurrection Bay, Alaska, sport fisheries released as age-0 and age-1 smolt.

	1990 Recoveries			1991 Recoveries		
Strata Compared	Odds Ratio	90% CI	95% CI	Odds Ratio	90% CI	95% CI
Pre-Derby/Derby *vs* Post Derby	0.35	0.13-0.91	0.11-1.10	0.73	0.35-1.54	0.30-1.78
≤2 weeks Post-Derby *vs* 2-4 weeks Post-Derby				0.53	0.34-0.84	0.31-0.91
Pre-Derby/Derby/ ≤2 weeks Post-Derby *vs* 2-4 weeks Post-Derby				0.53	0.34-0.81	0.31-0.88

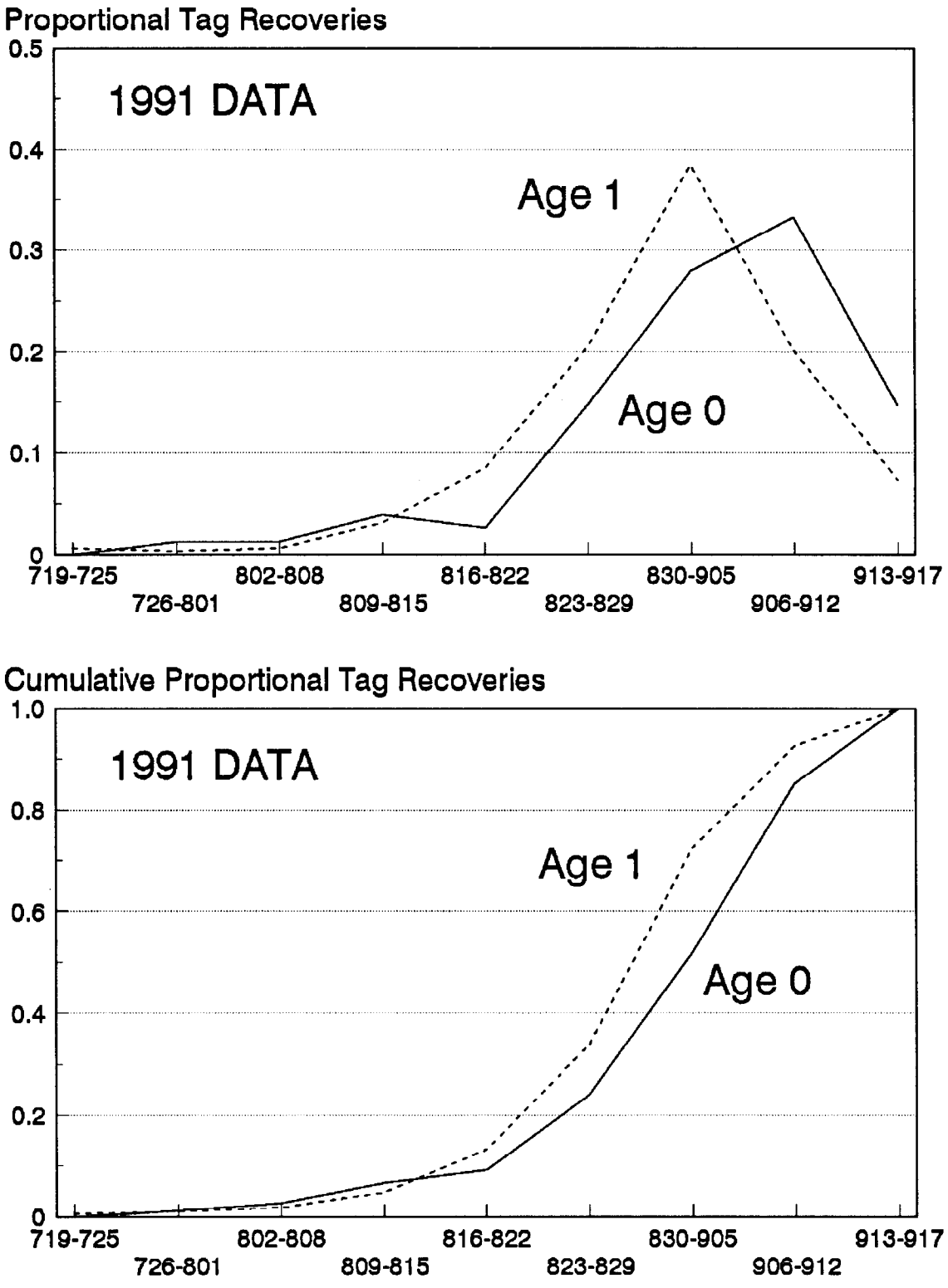

Figure 3. Distribution of age-0 and age-1 tag returns by week, Resurrection Bay boat sport fishery, 1991.

Table 4. Estimates of phi[a] used to examine differences in relative survival of adult coho salmon released as age-0 and age-1 smolt in Resurrection Bay, Alaska.

Recovery Year	Pre-Derby/ Derby	Post-Derby	≤2 Weeks Post-Derby	2-4 Weeks Post-Derby	Entire Season
1990	0.38	0.65			0.49
1991	0.16	0.22	0.17	0.28	0.21

[a] In all cases, odds ratio was <1.

recommend that the Elmendorf hatchery not convert to an age-0 coho salmon smolt stocking program for Resurrection Bay.

The reasons for the observed differences in run timing are currently unknown. One possible reason could be the reduced size-at-age of the age-0 smolt compared to the age-1 smolt. In this study, smolt stocked as age 0 were released at a maximum of 18.5 g whereas smolt released at age 1 were released at a weight over 21.0 g. Other hatchery staff experimenting with age-0 coho salmon smolt production have found that adults stocked as smaller age-0 smolt also return later than adults stocked as larger age-1 smolt. In combination, these data correlate with the adults from the larger age-1 smolt coming back earlier. The hypotheses that size-at-release affects adult run timing may be worth further investigation.

The poor contribution of adults stocked as age-0 smolt during 1990 may not only be the result of their late run timing but also to poor blood sodium levels at the time of their release (Table 5). Poor blood sodium levels at time of release have been shown to increase mortality of salmon in salt water (Clarke 1982). In this study, the age-1 smolt released during 1990 had the lowest blood sodium levels and demonstrated the highest number of tag recoveries (Figure 4). In comparison, all other smolt releases had higher blood sodium levels at the time of their release. These findings agree with previously unpublished data relating blood sodium levels to subsequent return rates (Figure 5) and suggest that smolt released with low blood sodium levels may produce better returns.

Given that it appears that age-0 smolt production is technically feasible in terms of producing adults, we do not recommend stopping age-0 smolt production and research completely at this time. In other situations, the late run timing of adults stocked as age-0 smolt may be inconsequential or even desirable. An excellent example is the proposed stocking program for Northern Cook Inlet (NCI) (Delaney and Vincent-Lang 1991). Beginning in 1992, over 800,000 age-1 coho salmon smolt will be stocked into NCI waters to provide increased fishing opportunities for recreational anglers (Meyer et al. 1991). A major concern at this time is the interception of these fish in commercial fisheries primarily targeted towards sockeye salmon. Stocking of a later-run fish has been proposed to reduce interception during these fisheries; however, brood source has been a concern. Given the late run timing of adults stocked as age-0 smolt, age-0 smolt production may be a viable alternative, especially if production problems associated with blood sodium levels can be solved. Age-0 and age-1 smolt were tagged and stocked into Resurrection Bay during 1991. Both smolt releases had favorable and comparable blood sodium levels. Evaluation of the returns of these marked fish to Resurrection Bay during 1992 will provide valuable data towards answering these questions.

ACKNOWLEDGEMENTS

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Table 5. Levels of blood sodium for age-0 and age-1 smolt released into Seward Lagoon (Resurrection Bay), Alaska, during 1989, 1990, and 1991.

Release Year	Blood Sodium Level		Number Tagged		Number Recovered	
	Age 0	Age 1	Age 0	Age 1	Age 0	Age 1
1989	175	173	15,911	16,063	24	25
1990	175	166	15,393	15,679	75	278
1991	166	166	15,212	15,151		

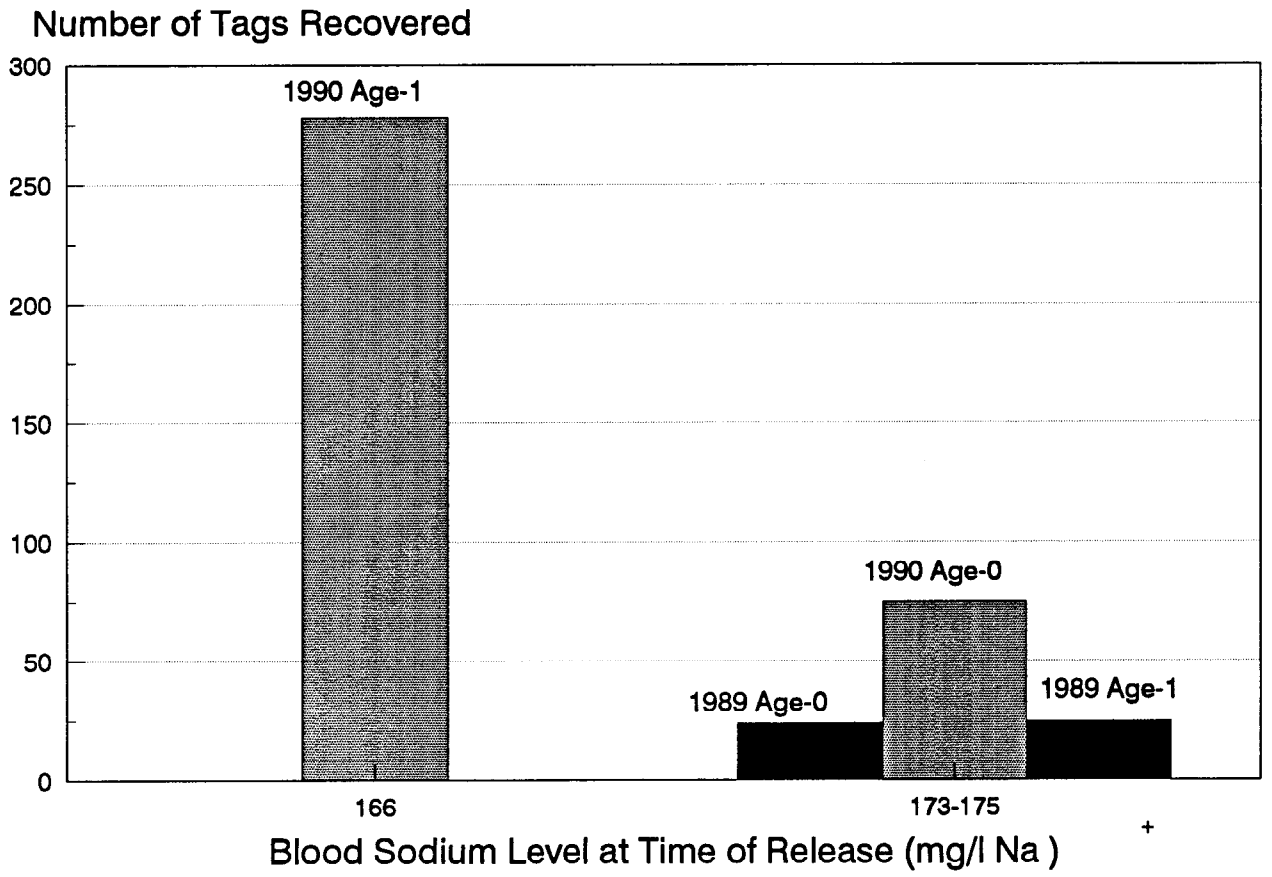

Figure 4. Relationship between blood sodium levels at time of release on the return rate of age-0 and age-1 smolt released into Seward Lagoon (Resurrection Bay), Alaska, during 1989 and 1990.

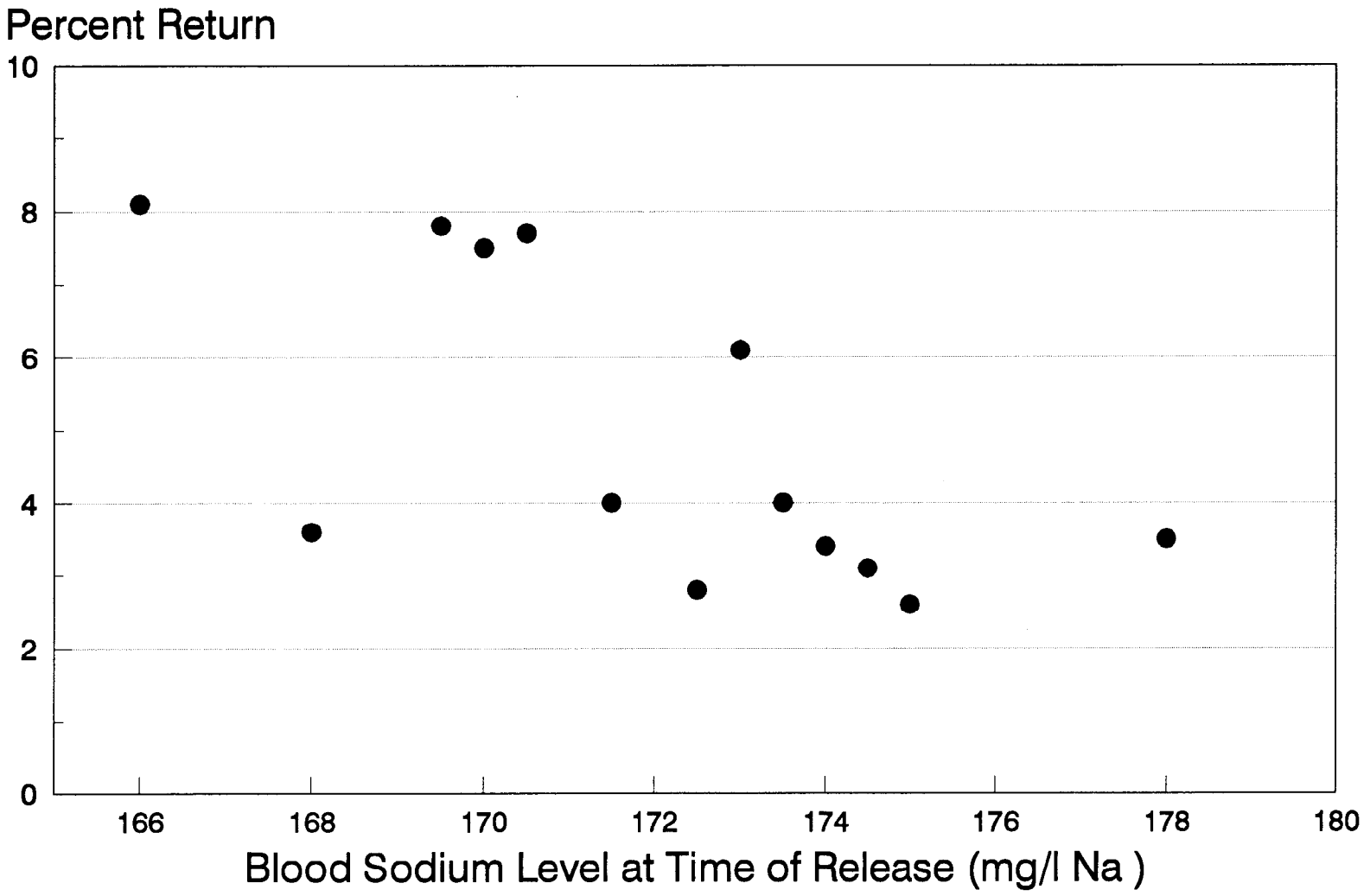

Figure 5. Relationship between blood sodium levels for smolt at time of release and subsequent adult return reared at the Elmendorf hatchery, 1983-1991 (unpublished data).

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