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EFFECTS OF CONFINEMENT ON ARCTIC CHAR IN THE WOOD RIVER LAKE SYSTEM, ALASKA

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ABSTRACT

Arctic char, Salvelinus alpinus (Linnaeus), feed on sockeye salmon, Oncorhynchus nerka (Walbaum), smolt during the summer migration of the smolt from the Wood River lake system to Nushagak Bay. In an attempt to increase sockeye salmon production in the Wood River lakes, and yet maintain the Arctic char population, the Alaska Department of Fish and Game implemented an Arctic char confinement project. The project was initiated in 1975 with the experimental confinement of 200 Arctic char at Little Togiak River mouth. Results of this research experiment indicated that confined fish lost both weight and girth during confinement, but a decrease in survival was not detected. The initial research project was made operational with the confinement of several thousand Arctic char at the Agulukpak River mouth in 1976, 1977, and 1978, and at the Agulowak River mouth in 1977 and 1978.

Two types of pens were used to confine the fish. The pen at the Agulukpak River mouth in 1976 and 1977 was a shore based enclosure net set in calm, shallow water, while the pens at the Little Togiak River mouth in 1975, the Agulowak River mouth in 1977 and 1978, and at the Agulukpak River mouth in 1978, were floating enclosures anchored in deep, open water.

Recapture rates of Arctic char released from floating pens indicated that confinement had little to no affect on post release survival. However, recapture rates of Arctic char released from the shore based pen showed a significant effect of confinement in reducing long term survival.

Both condition factor and fat reserves of Arctic char confined at Little Togiak, Agulukpak, and Agulowak River mouths were found to decline during confinement. However, Arctic char were able to regain normal condition factor and fat reserves two months after release from the pens. Repeated confinement may reduce the ability of Arctic char to recover. Annual growth rate (in fork length) was significantly reduced due to confinement. Greatest growth reduction occurred for fish confined two consecutive years. Neither ovary development nor spawning frequency was affected by confinement.

INTRODUCTION

Arctic char, Salvelinus alpinus (Linnaeus), feed on sockeye salmon, Oncorhynchus nerka (Walbaum), smolt during the summer migration of the smolt from the Wood River lake system (Figure 1) to Nushagak Bay. The narrow rivers of the system concentrate the migrating smolt and make them easy prey to Arctic char. Arctic char predation on smolt is limited almost exclusively to these concentration sites (Nelson 1966).

Between 1920 and 1925, an Arctic char eradication program was conducted by the federal government in an attempt to increase sockeye salmon production in the Wood River lakes. Three thousand to twelve thousand Arctic char were removed annually from the mouth of the Agulowak River (Rogers, Gilbertson, and Eggers 1972). This program was replaced by a bounty system in 1928, under which fishermen were paid five cents per Arctic char tail. Detailed records of Arctic char catches during the bounty period are not available, but based on the amount spent on bounties and the price per fish, thousands of fish were removed (Rogers et al. 1972). The bounty system was terminated in 1940. There was a sharp decline in the commercial harvest of sockeye salmon in the Nushagak District by the late 1940's which has continued through the 1970's.

The Alaska Department of Fish and Game has attempted to revive the declining Nushagak fishery. Control of Arctic char predation upon sockeye salmon smolt was one promising method of increasing sockeye salmon production (Foerster and Ricker 1941). However, a non-lethal control method was sought because Arctic char is a valuable sport fish and an important component in the tropho-dynamics of the Wood River lake system. The Department's answer to the dual problem of increasing sockeye salmon production while maintaining the Arctic char population has been to remove Arctic char from the system's narrow river mouths and to hold them in pens until the smolt migration is completed. Two aspects of Arctic char predation on smolt in the Wood River lake system made this approach feasible: the discrete feeding concentrations of Arctic char that form at the river mouths and the short duration of this predation.

The confinement project was initiated in 1975, with the experimental confinement of 200 Arctic char at Little Togiak River mouth. The project was made operational with the confinement of several thousand Arctic char at the Agulukpak River mouth in 1976, 1977, and 1978, and at the Agulowak River mouth in 1977 and 1978.

The short term objective of the confinement project was to reduce Arctic char predation on sockeye salmon smolt, while the long term objective

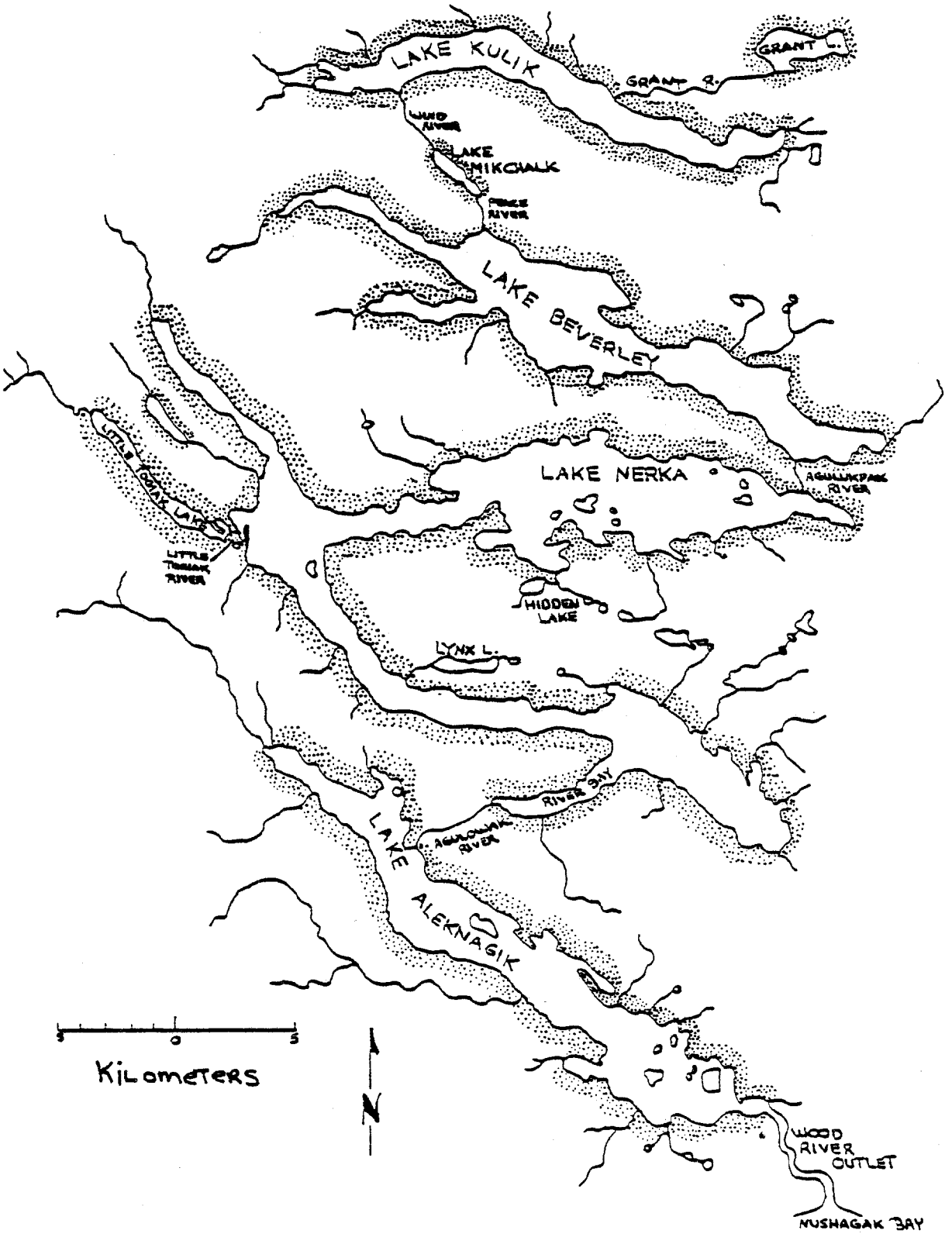

Figure 1. The Wood River lake system, Bristol Bay, Alaska.

and benefit was to increase adult sockeye salmon returns. By statistically combining number of Arctic char removed from the feeding concentrations with smolt consumption levels and digestion rate of smolt within Arctic char stomachs (Meacham 1977), a preliminary estimate of the number of smolt "saved" from Arctic char predation follows:

Location	Estimated number of smolt "saved"	Estimated value 1/
Agulukpak, 1976	341,573	$ 68,827
Agulukpak, 1977	225,833	$ 51,377
Agulukpak, 1978	56,809	$ 15,657
Agulowak, 1977	906,933	$206,327
Agulowak, 1978	1,111,715	$306,389
Total	2,642,863	$648,577

1/ Smolt value is based on a smolt to adult survival of 6.5 percent and a commercial fishery value per adult of $3.10 in 1976, $3.50 in 1977 and $4.24 in 1978.

The objective of this report is to assess some effects of confinement on the Arctic char. The presentation is divided into two parts. The first examines the experimental confinement study at the Little Togiak River in 1975, and the second examines the confinement projects conducted at the Agulukpak and Agulowak River mouths between 1976 and 1978.

PART I. LITTLE TOGIAK RIVER MOUTH CONFINEMENT STUDY, 1975

METHODS

Arctic char were captured with hook and line, gillnet, and trapnet gear at and in the vicinity of the Little Togiak River mouth in June and July, 1975. Captured fish were anesthetized with MS-222 (tricane methane sulfonate), measured for fork length (mm), weight (gr), and girth (mm),

tagged with an individually numbered Floy internal anchor tag, and placed in the confinement pen. As a control, other captured Arctic char were anesthetized, measured (fork length), tagged, and released.

Three individual floating pens, each measuring 3 meters on a side and 3 meters deep were used to confine Arctic char. All pens were anchored in deep water with the bottom of the pens above the substrate. Pelletized fish food was introduced into each pen at the rate of 1% of total fish body weight per day. Weight and girth of confined fish were measured periodically throughout the study. In order to determine effects of different durations of confinement upon Arctic char, fish were released from pens in groups. The tag number of each released fish was recorded so that duration of confinement could be determined when individual fish were recaptured.

Arctic char tagged during this study were recaptured between 1976 and 1978. The effect of confinement on the survival of Arctic char after release from the pens was determined by fitting the model:

$$P(t) = P(0)e^{-\beta t^2} + \epsilon_t$$

to the observed recapture rate, $P(t)$, of char confined for t days, where $P(0)$ and β are positive constants, ϵ_t is the error, and e is the base of natural logarithms, approximately 2.7182. This model is derived in Appendix 1. It results from the reasonable assumption that a small increase in confinement time should result in an observed decrease in the recapture rate which is jointly proportional to the recapture rate, the confinement time, and the increase in confinement time.

RESULTS AND DISCUSSION

Of 228 Arctic char captured and confined, 29 (13%) died in the pens, 6 (2%) were sacrificed for sampling purposes, 29 (13%) escaped, and the remaining 164 (72%) were released at the completion of the study. A total of 108 Arctic char were tagged and immediately released as a control group.

Both confined and unconfined Arctic char released at Little Togiak River mouth in 1975 were recaptured between 1976 and 1978. Of the 164 confined fish released, 38 (23%) were recaptured, while 22 (20%) of the 108 unconfined fish were recaptured (Appendix 2). There was no statistically significant relationship ($p = 0.15$; $t_m = 63$ days) between duration of confinement in 1975 and subsequent recapture rate of these fish, although it appears that recapture rate of fish confined in excess of 42 days may have been decreased (Figure 2).

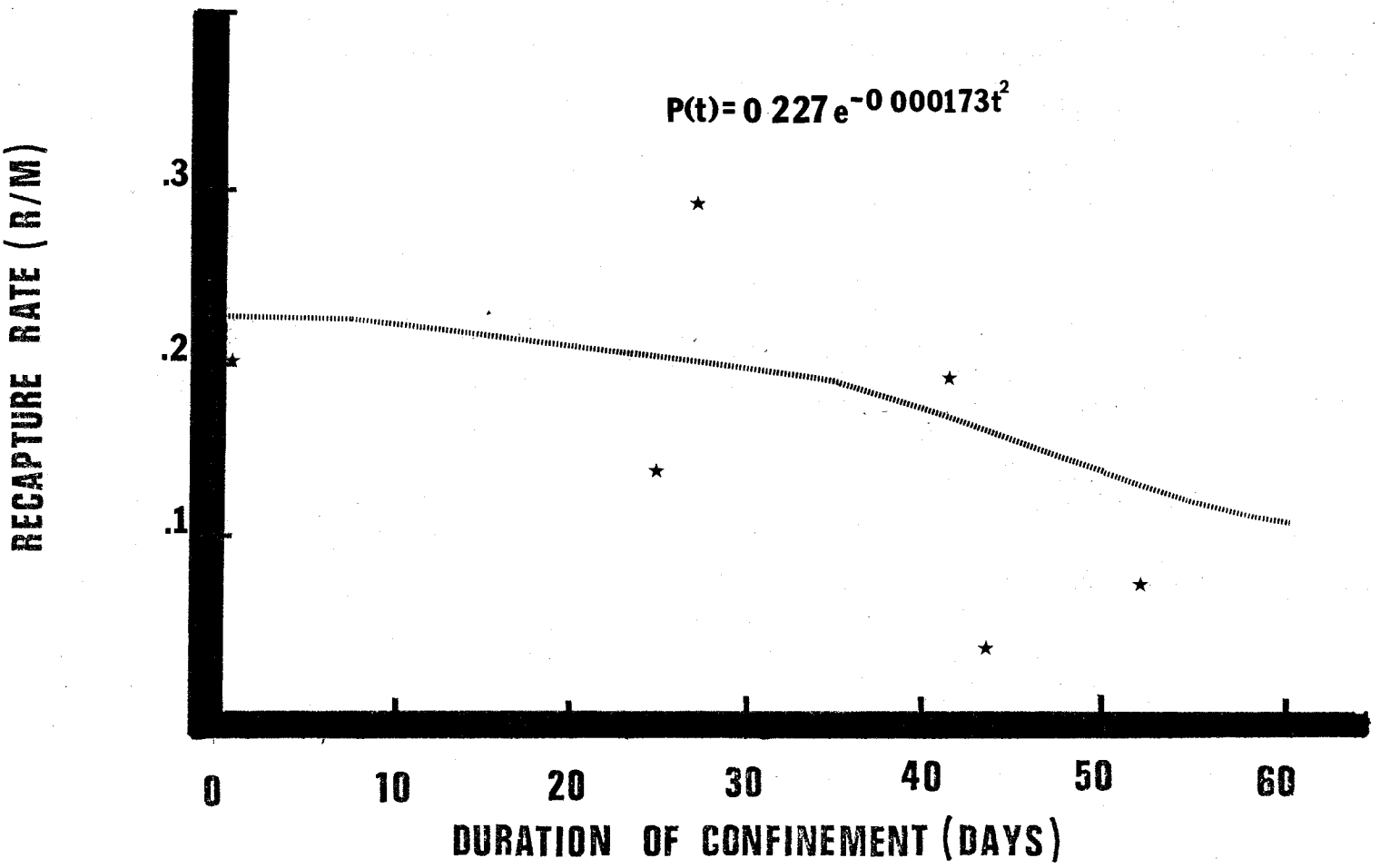

Figure 2. Recapture rate of Arctic char confined at Little Togiak River mouth during 1975 and recaptured during 1976 through 1978.

Attempts to feed confined fish (pelletized food) were unsuccessful. Confined fish would not feed and lost both weight and girth during confinement. Percent weight and girth depletion was significantly correlated with duration of confinement (Figure 3). Confined Arctic char drew upon stored energy reserves to maintain their basic metabolic functions.

PART II. AGULUKPAK AND AGULOWAK RIVER MOUTH CONFINEMENT PROJECTS, 1976-1978

METHODS

Capture and Confinement

Agulukpak River, 1976: Arctic char were caught with a hand operated purse seine as well as with gillnets and hook and line gear at the Agulukpak River mouth in June and July, 1976. Captured fish were anesthetized with MS-222, measured for fork length (mm), tagged with a Floy internal anchor tag, and placed in the confinement pen. A different tag color was used each week of the project. The pen, located in a calm bay approximately 500 m from the river mouth, was a shore based, natural bottomed enclosure (30 m on a side, 60 m across, and ranging in depth between 0 and 3.6 m).

On July 9, 1976, about 2,000 confined fish were released, and approximately 1,000 fish were held 11 days longer to study further effects of confinement. The color-coded tags were replaced with individually numbered tags before the last 1,000 fish were released on July 20, 1976.

Agulukpak River, 1977: Methods were the same used in 1976, except that only purse seine and hook and line gear were fished, and all captured Arctic char were immediately tagged with individually numbered tags. All fish were released from the pen on July 22, 1977. A total of 129 additional Arctic char were tagged, measured, and released immediately following capture as a control group.

Agulukpak River, 1978: The pen used to confine Arctic char at the Agulukpak River mouth was changed in 1978 from a shore based type to a large, floating enclosure (15 m on a side and 4.6 m deep) anchored over deep water. Captured Arctic char were tagged and measured as in 1977, and were released on July 12, 1978.

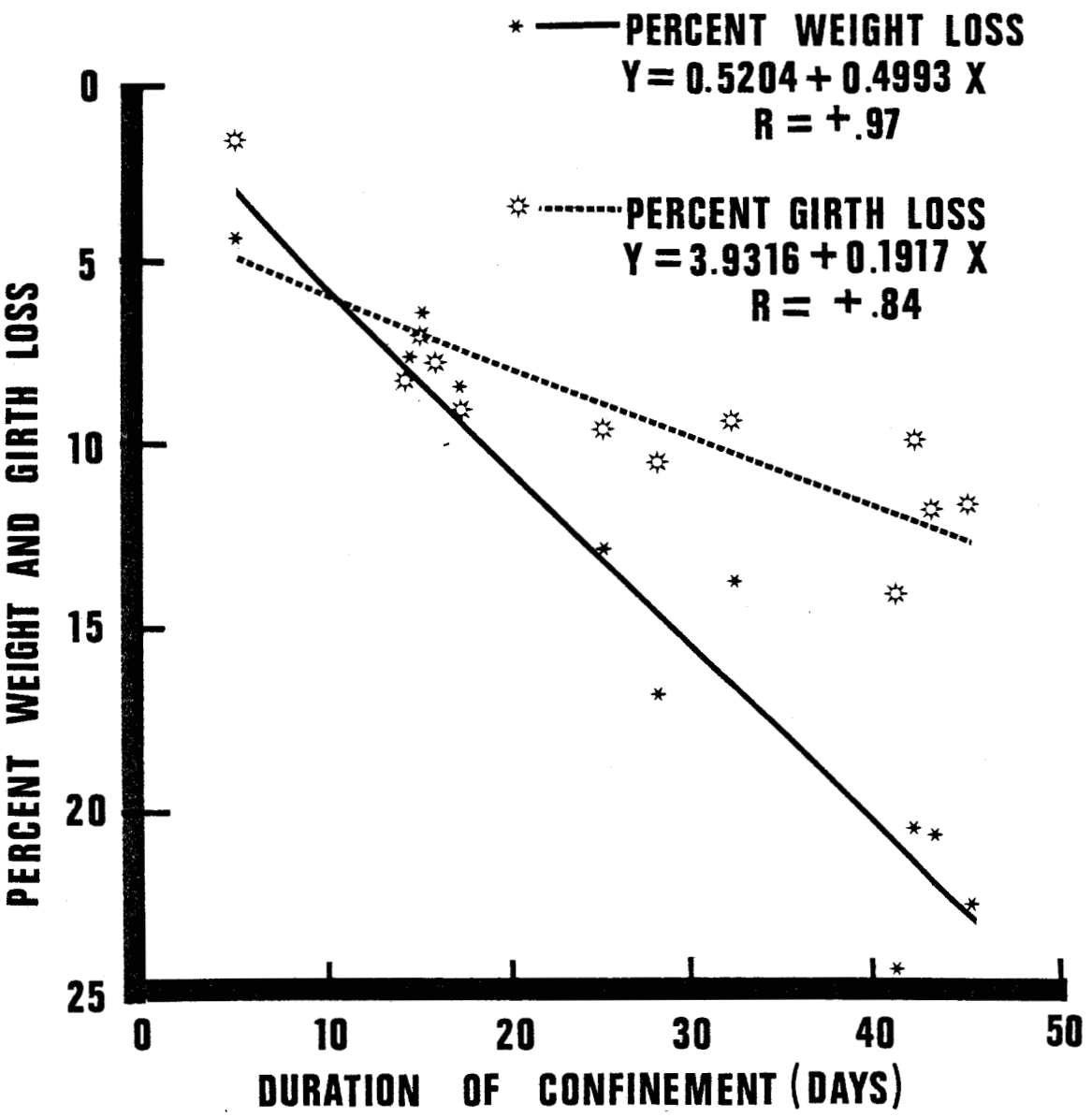

Figure 3. Percent weight and girth loss for Arctic char confined at Little Togiak River mouth in 1975. Points represent mean values for samples of ten or more fish.

Agulowak River, 1977 and 1978: Arctic char were captured with hand operated purse seines and hook and line gear at Agulowak River mouth during both 1977 and 1978. Fish were tagged and measured as described above. A floating enclosure as used at Agulukpak River mouth in 1978 was used to confine fish. Two pens were used in 1977, while in 1978, all fish were confined in a single pen. Fish were released on August 6 in 1977 and on August 10 in 1978. Three hundred sixty-two Arctic char were captured throughout the summer and tagged, measured, and released as a control group in 1977, while 273 fish were handled similarly and were tagged and released in 1978.

Survival

Arctic char mortality during capture and confinement was directly enumerated by recording actual number of fish that died during all five confinement projects. Subsequent survival of fish confined and released was estimated by regression analysis (Appendix 1) of recapture rates (dependent variable) and duration of confinement (independent variable).

Growth

Tagged Arctic char released at Agulukpak and Agulowak River mouths in 1977 were recaptured in June and July, 1978. Annual growth increment was calculated by subtracting the fork length at time of tagging from fork length at time of recapture. Effect of confinement on growth was estimated by regression analysis (weighted) of annual growth increment (dependent variable) and duration of confinement (independent variable).

Feeding Habits

Stomach content samples of confined Arctic char were taken from the Agulukpak River mouth pen on July 10 and 17, 1977, and at Agulowak River mouth pen on July 25, 1977. Sampled fish were anesthetized with MS-222, and their stomachs were evacuated using a stomach pump (Meacham 1977). Visual classification of stomach contents was recorded and fish were returned to the pen.

Condition Factor

Condition factor is traditionally used by fishery biologists as a measure of a particular fishes health or "plumpness". A low condition

factor implies a less robust fish than one with a higher condition factor. Arctic char in the present study were sampled periodically from both confinement pens and river mouths. Fork length (L) was measured in millimeters, weight (W) was measured in grams, and condition factor (K) was calculated according to the isometric formula:

$$K = (W/L^3)\ (10^5)$$

Fat Reserves

Arctic char sampled for condition factor were also examined for body fat content. Primitive field conditions and large sample sizes prohibited use of quantitative fat extraction techniques. Therefore, percent body fat was estimated based on a specific gravity technique developed by Tester (1940), and refined by Horak (1966). The approach was based on the hypothesis that a fatty fish would be more buoyant in water (i.e., have lower specific gravity) than a less fatty fish. Sampled fish were sacrificed and body cavity opened. Contents of the digestive tract and the gonads were removed, the air bladder deflated, and the body wiped clean. Each fish was weighed to the nearest 0.1 g, suspended in a tank of water from a balance and weighed again to the nearest 0.1 g. Water temperature was recorded, and care was taken to expel all air from submerged samples. Specific gravity of each fish was calculated according to the formula:

$$\text{Sp. Gr.} = \frac{Wa\ (D)}{Wa\ Ww}$$

where Wa was the weight of the fish in air, Ww was the weight of the fish in water, and D was the density of water. To determine percent body fat, the calculated specific gravity was used in the formula:

$$\text{Percent Body Fat} = 100 \left[\frac{Df}{Dff-Df}\right]\left[\frac{Df}{\text{Sp. Gr.}} - 1\right]$$

$$= 100 \left[\frac{0.9348}{1.100 - 0.9348}\right]\left[\frac{1.1000}{\text{Sp. Gr.}} - 1\right]$$

$$= 100 \left[\frac{6.2245}{\text{Sp. Gr.}} - 5.6586\right]$$

where Df was the density of body fat and Dff was density of the fat-free body. The value for density of body fat (0.9348) was taken from results of laboratory fat extraction (Horak 1966) from 20 rainbow trout, Salmo gairdneri (Richardson).

The value for density of the fat-free body (1.1000) has been considered a "biological constant" which varies only within narrow limits from one animal species to another (Behnke 1961; Mendez and Kallias 1977).

Although the specific gravity approach to measuring fat reserves was outdated by more modern physiological methods, it was well suited to the present investigation. Horak (1966) justified application of his unmodified formula to fish species other than rainbow trout, stating that differences in percent body fat between individuals of the population would be apparent, even though they might not represent an absolute measure of fat content.

Fecundity

Female Arctic char sampled for condition factor and percent body fat measurements were examined to determine effect of confinement on number and size of their eggs. Some additional samples were obtained solely for fecundity measurements. Ovaries were removed from each female, weighed to the nearest 0.01 g and preserved in 10% formalin.

Preserved ovary samples were examined in the laboratory after the field season. Each preserved sample was weighed, number of eggs in a weighed subsample was counted, and fecundity was estimated by the formula:

$$\text{eggs/}\varphi = \frac{\text{weight of ovary}}{\text{weight of subsample}} \times \text{number of eggs in subsample}$$

Number of eggs in five ovary samples was estimated by this method, and then total number of eggs in each of these ovaries was totally counted. The subsample method consistently overestimated fecundity. Actual egg counts averaged 0.76 of the estimated fecundity (S.D. = 0.09, n=5). All subsequent subsample estimates were multiplied by a correction factor of 0.76.

Mean egg diameter was estimated by lining up, end to end, a subsample of eggs from each ovary sample, and counting the number of eggs that occupied 100 mm. Egg diameter was then estimated by the formula:

$$\text{Mean egg diameter} = \frac{100 \text{ mm}}{\text{number of eggs}}$$

RESULTS AND DISCUSSION

Survival During Confinement

Arctic char confinement mortality at the Agulukpak River mouth was 4.3% in 1976, 17.9% in 1977, and 0.7% in 1978 (Table 1). Confinement mortality at Agulowak River mouth was 2.1% in 1977 and 3.2% in 1978. High mortality occurred only at the Agulukpak River mouth in 1977 and appeared to be related to high water temperatures during handling.

The majority of Arctic char that died during confinement at the Agulukpak River in 1977 had been handled (i.e., captured, anesthetized, measured, tagged, and placed in the pen) during the first two weeks of July (Figure 4). If starvation due to low energy reserves was the cause of confinement mortality, one would expect an opposite pattern; high mortality of fish confined in early June, declining to low mortality for those fish confined in July. Apparently, some factor other than starvation was the cause of confinement mortality. To avoid any effects on mortality due to different capture gears, only fish caught by purse seine were included in the analysis.

Water temperatures were higher at the Agulukpak River confinement site in 1977 than they were in 1976, or in 1978 (Figure 4). The difference in temperatures was especially apparent in July, when water surface temperature at Agulukpak River mouth reached a maximum of 16.5°C in 1977. The pattern of confinement mortality coincided with the increase in water temperature from early June to late July. The handling period is a time of stress for fish, and it appeared that warm water temperatures at the time of handling resulted in increased confinement mortality.

Survival After Confinement

Of 3,313 confined Arctic char released from the shore based pen at the Agulukpak River in 1976, 868 (27%) were recaptured in the summer of 1977, and 201 (6%) additional char were recaptured in the summer of 1978 which had not been confined in 1977 (actual data is listed in appendices). Regression of the 1977 and 1978 recapture rate of these fish against the duration of 1976 confinement (Figure 5) resulted in statistically significant results (1977: $p < 10^{-33}$, $t_m = 26$ days; 1978: $p < 10^{-13}$, $t_m = 21$ days); as the duration of confinement increased, the number of fish recaptured in succeeding years decreased. The model predicts that confinement of Arctic char for 26 days would result in a 50 percent reduction in survival to 1977, and confinement for 21 days would result in a 50 percent reduction in survival to 1978.

Table 1. Total catch, catch mortality, and confinement mortality of Arctic char during the five confinement periods.

	Agulukpak River Mouth:						Agulowak River Mouth:			
	1976		1977		1978		1977		1978	
	No.	%	No.	%	No.	%	No.	%	No.	%
Total Catch 1/	3,543	100.0	2,337	100.0	1,808	100.0	5,504	100.0	6,186	100.0
Catch Mortality	77	2.2	83	3.6	11	0.6	66	1.2	45	0.6
Confinement Mortality	153	4.3	418	17.9	13	0.7	113	2.1	226	3.2
Total Released	3,313	93.5	1,836	78.5	1,784	98.7	5,325	96.7	5,915	96.2

1/ Does not include fish sacrificed for biological sampling purposes nor those fish released immediately for population estimation purposes.

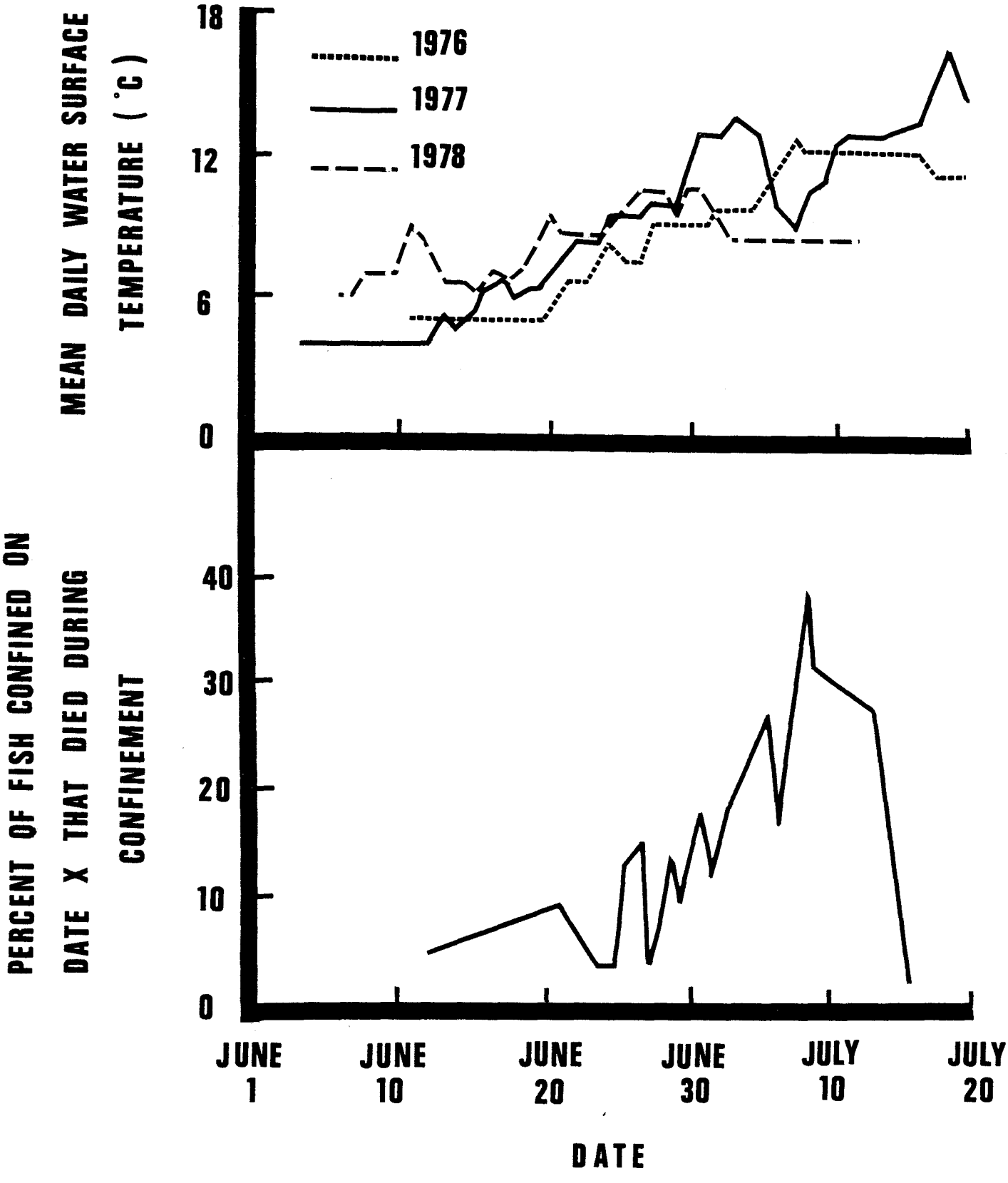

Figure 4. Mean daily water surface temperatures at the Agulukpak River mouth confinement pen in 1976, 1977, and 1978 (above), and the pattern of confinement mortality at the Agulukpak River in 1977 (below).

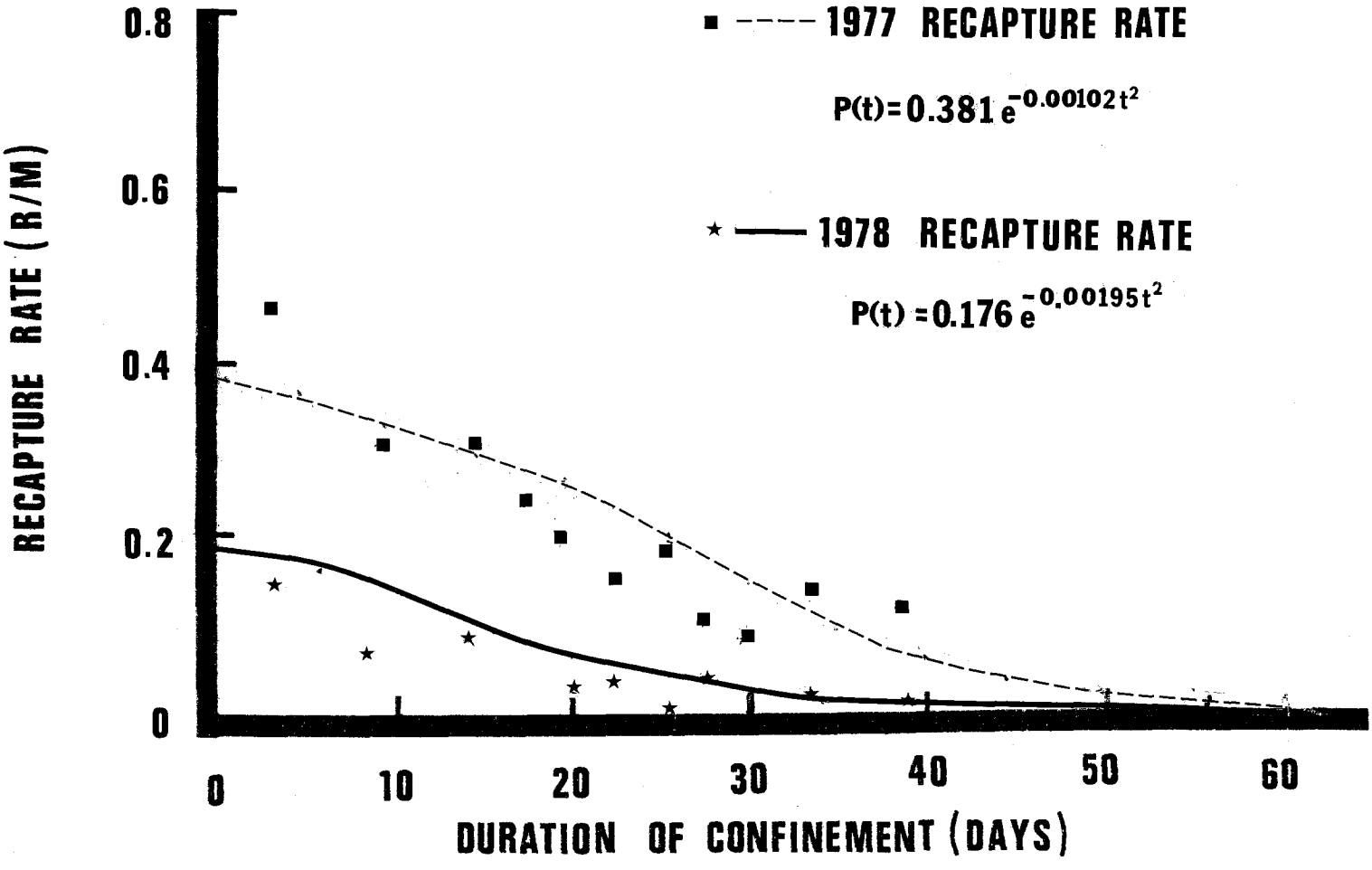

Figure 5. Recapture rate of Arctic char confined at the Agulukpak River in 1976 and recaptured during 1977 and 1978.

Of 1,180 Arctic char confined for their first time at the Agulukpak River in 1977, 271 (23%) were recaptured in the summer and fall of 1978. There was a significant statistical relationship ($p = 0.00025$, $t_m = 47$ days) between the duration of confinement in 1977 and the recapture rate of these fish in 1978 (Figure 6). However, two points should be considered:

(1) An estimated 300 to 400 Arctic char escaped from the pen in late June. Timing and magnitude of the escape was estimated based on the recapture of the escaped fish later in the summer. Since tag numbers of confined fish were not checked at the completion of the project, it is not known exactly which individuals remained in the pen and which individuals escaped. Actual duration of confinement for these 300 to 400 fish was not from the date that they were put in the pen until the date that the pen was dismantled, but only until the date they escaped. This introduces an unmeasured source of variability into the regression analysis of 1978 recapture rates.

(2) Over 17% of the Arctic char confined at the Agulukpak River in 1977 died during confinement. If confinement mortality had been low, as in the other years of the project, perhaps a more significant post-release effect on mortality would have been observed. Only the hardier individuals were released to be recaptured in 1978.

The low post-release survival of Arctic char confined at the Agulukpak River in 1976, and the high mortality during confinement in 1977, indicate that a shore based pen is not a desirable method of confining Arctic char if high survival of those confined char is an objective. A floating pen was used at the Agulukpak River in 1978. However, only 37 (3.5%) of the 1,051 fish confined for their first time at the Agulukpak River mouth in summer, 1978, were recaptured during the fall, 1978. Lack of sufficient recapture data inhibits a statistical comparison of effects of shore based and floating pens on post-release survival. Confinement mortality in 1978 (0.7% of all fish caught) was substantially lower than it had been in 1976 (4.3%) or in 1977 (17.9%), but this is probably related to different water temperature regimes during the three years of the project as well as the difference in pen designs and length of time that fish were held.

Of 5,277 confined Arctic char released from the floating pen at the Agulowak River during the summer of 1977, 249 (5%) were recaptured in the fall of 1977 and 2,417 (46%) were recaptured in the summer of 1978. The recapture rate of those fish was not significantly related (fall 1977: $p = 0.33$, $t_m = 149$ days; summer 1978: $p = 0.13$, $t_m = 189$ days) to the duration of 1977

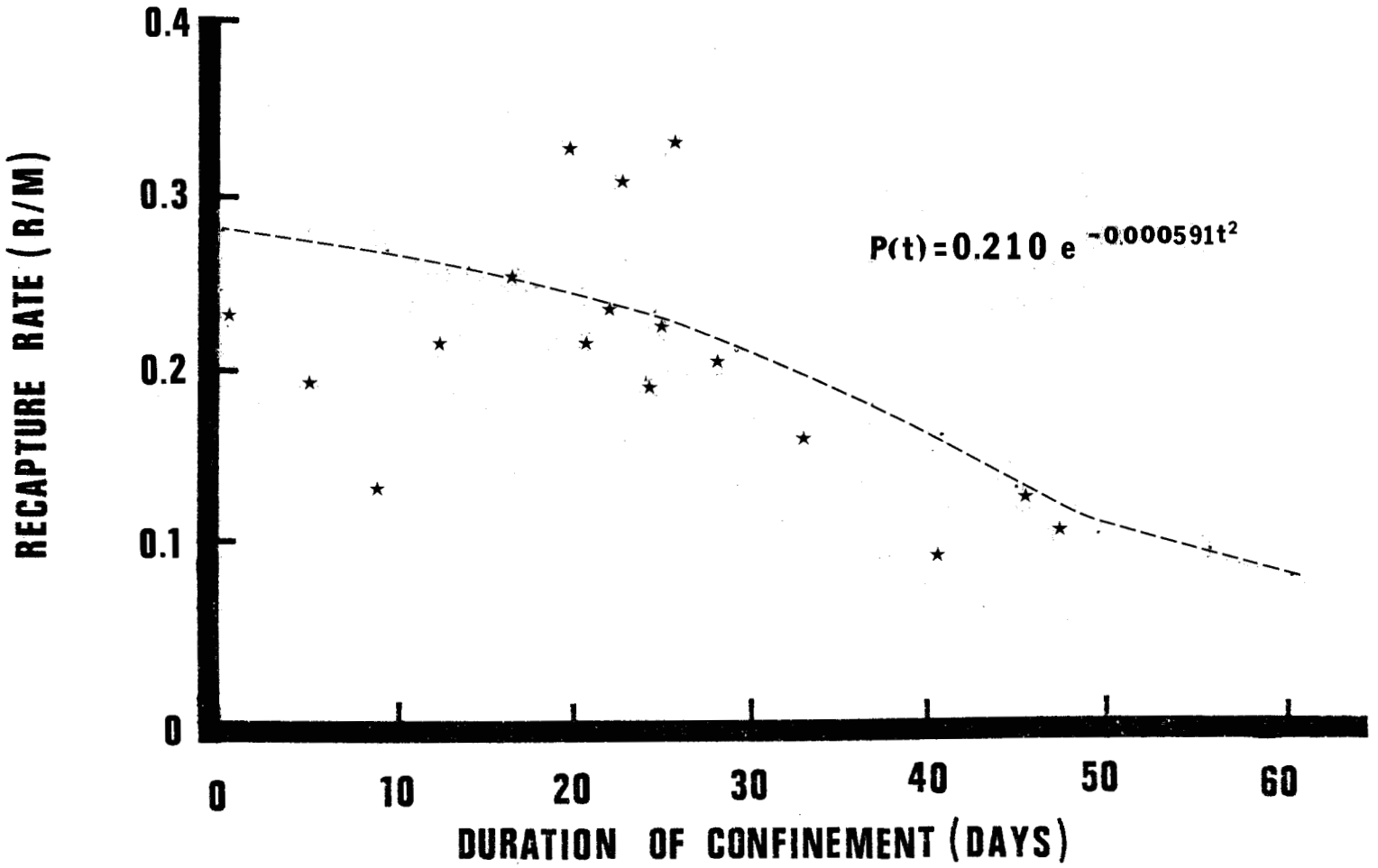

Figure 6. Recapture rate of Arctic char confined at the Agulukpak River in 1977 (for their first time) and recaptured during 1978.

confinement (Figures 7 and 8). Since fish were tagged and released at the Agulowak River mouth in 1977 as a control, direct comparison of the recapture rate of confined and unconfined Arctic char was possible. During fall, 1977, 5% of the unconfined fish and likewise 5% of the confined fish were recaptured. In summer, 1978, 32% of the unconfined fish were recaptured, and 46% of the confined fish were recaptured. Apparently, confinement in the floating pen at the Agulowak River in 1977 had no effect on post-release survival. Additionally, since there was no major escape of char from the pens and confinement mortality was quite low at this location during 1977, we conclude that confinement did not significantly affect sur-

Survival of Arctic char confined for their first time during the summer of 1978 and recaptured during fall, 1978, at the Agulowak River mouth was not significantly ($p = 0.77$, t_m is undefined because $\hat{b}$ is positive) affected by duration of confinement (Figure 9). This analysis supports the conclusion that confinement of char in the Agulowak River mouth floating pens did not affect survival.

Growth

Annual growth rates for Arctic char confined in 1977 which were recaptured in the summer of 1978 proved highly variable. Errors in measuring the fish and/or recording the data were causes for extreme values and differential growth was likely responsible for the rest of the variability. To obtain the most reliable growth data possible, three "exclusion rules" were established:

(1) Only fish measured between June 10 and July 20, 1977, and recaptured between June 10 and July 20, 1978, were used in analyses to insure that each fish considered had a reasonably similar growth period.

(2) Only Agulowak River Arctic char whose initial fork length was between 420 and 480 mm, and only Agulukpak River Arctic char whose initial fork lengths were between 400 and 499 mm, were included. These interval ranges were made as small as possible to limit the variability due to size dependent growth, but were kept broad enough to obtain substantial sample sizes at both sites.

(3) Only growth in the range of -25 mm/year to +73 mm/year was included. These boundaries were established to

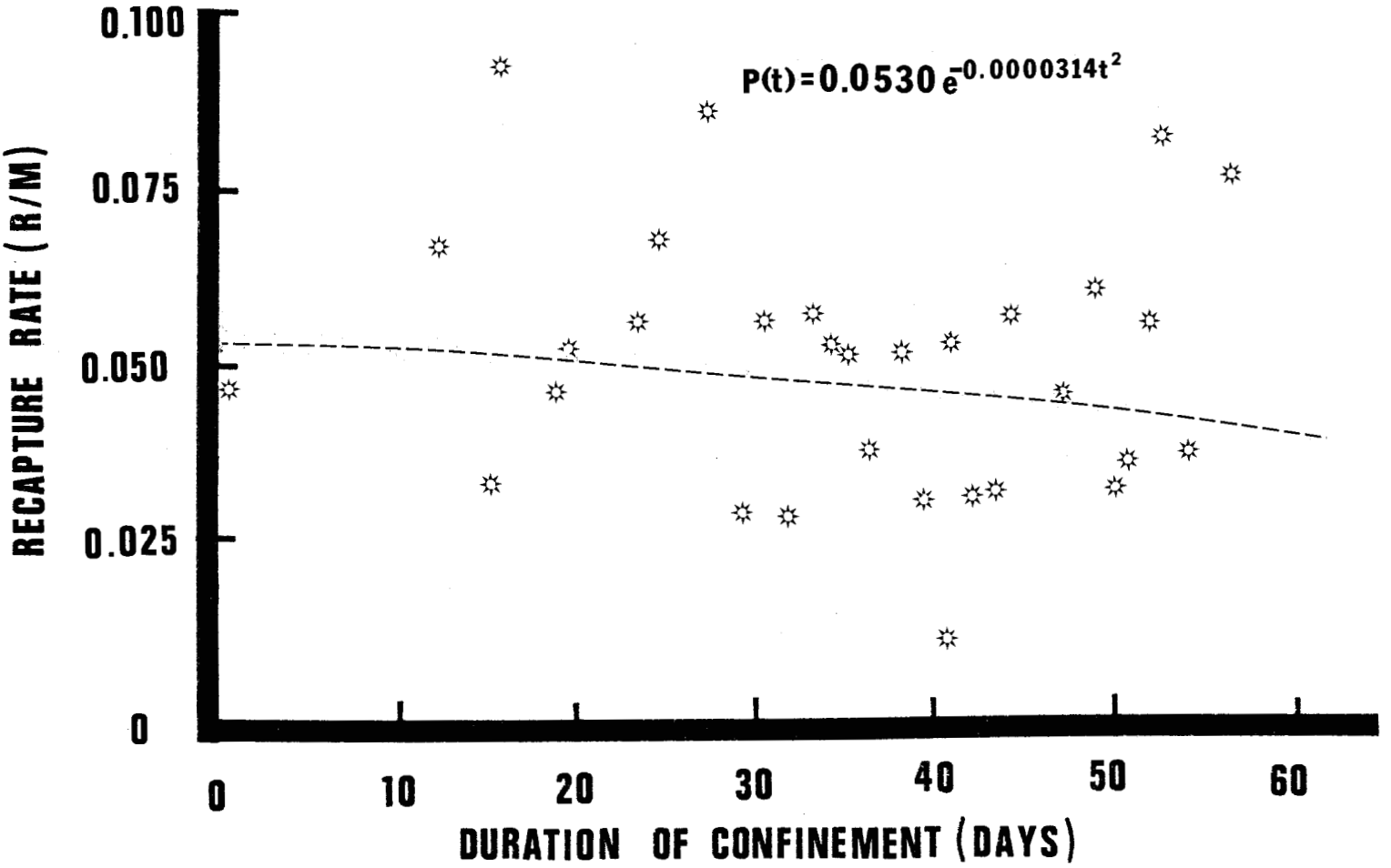

Figure 7. Recapture rate of Arctic char confined at the Agulowak River mouth in summer, 1977 and recaptured during fall, 1977.

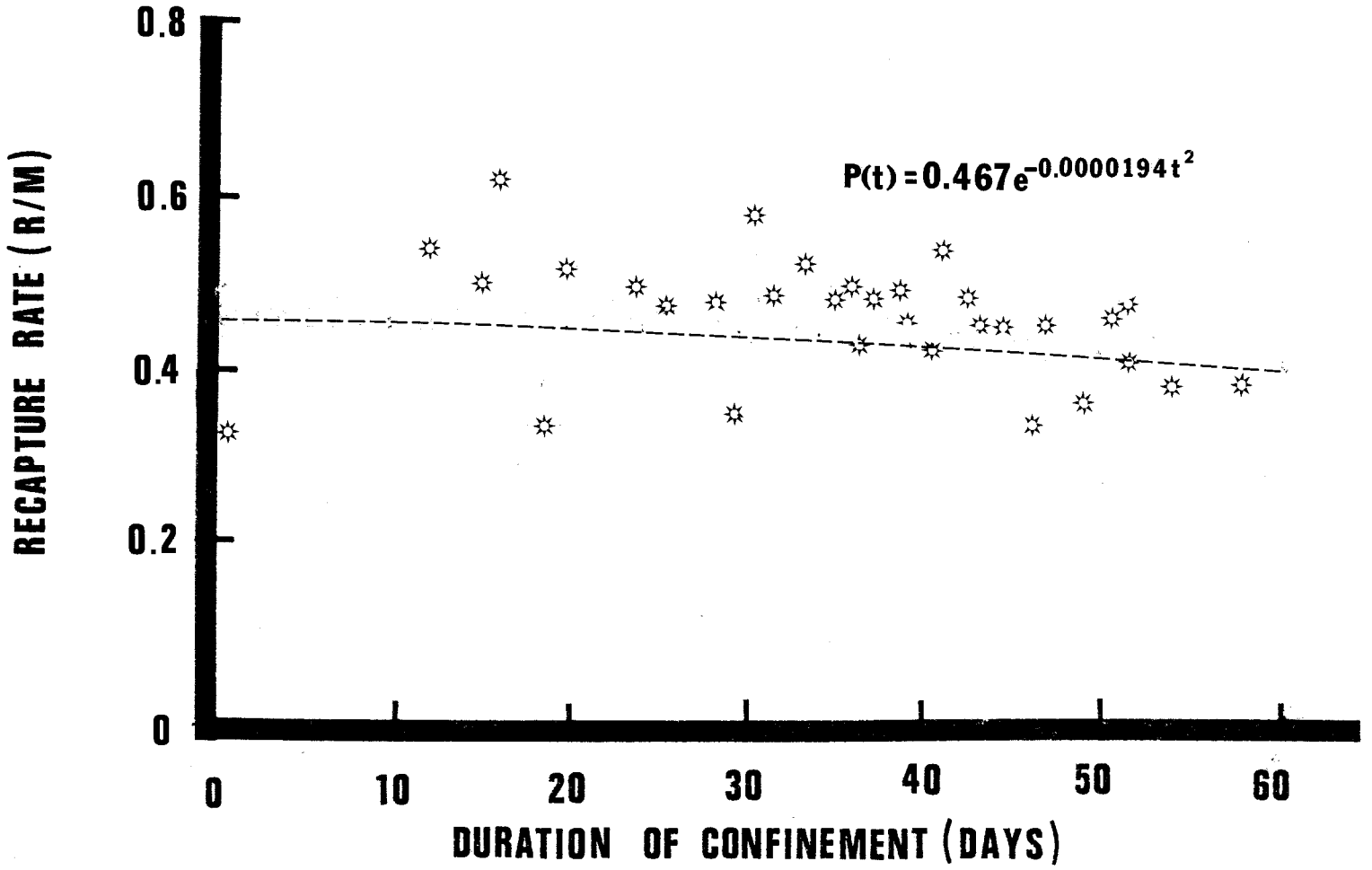

Figure 8. Recapture rate of Arctic char confined at the Agulowak River mouth in 1977 and recaptured during 1978.

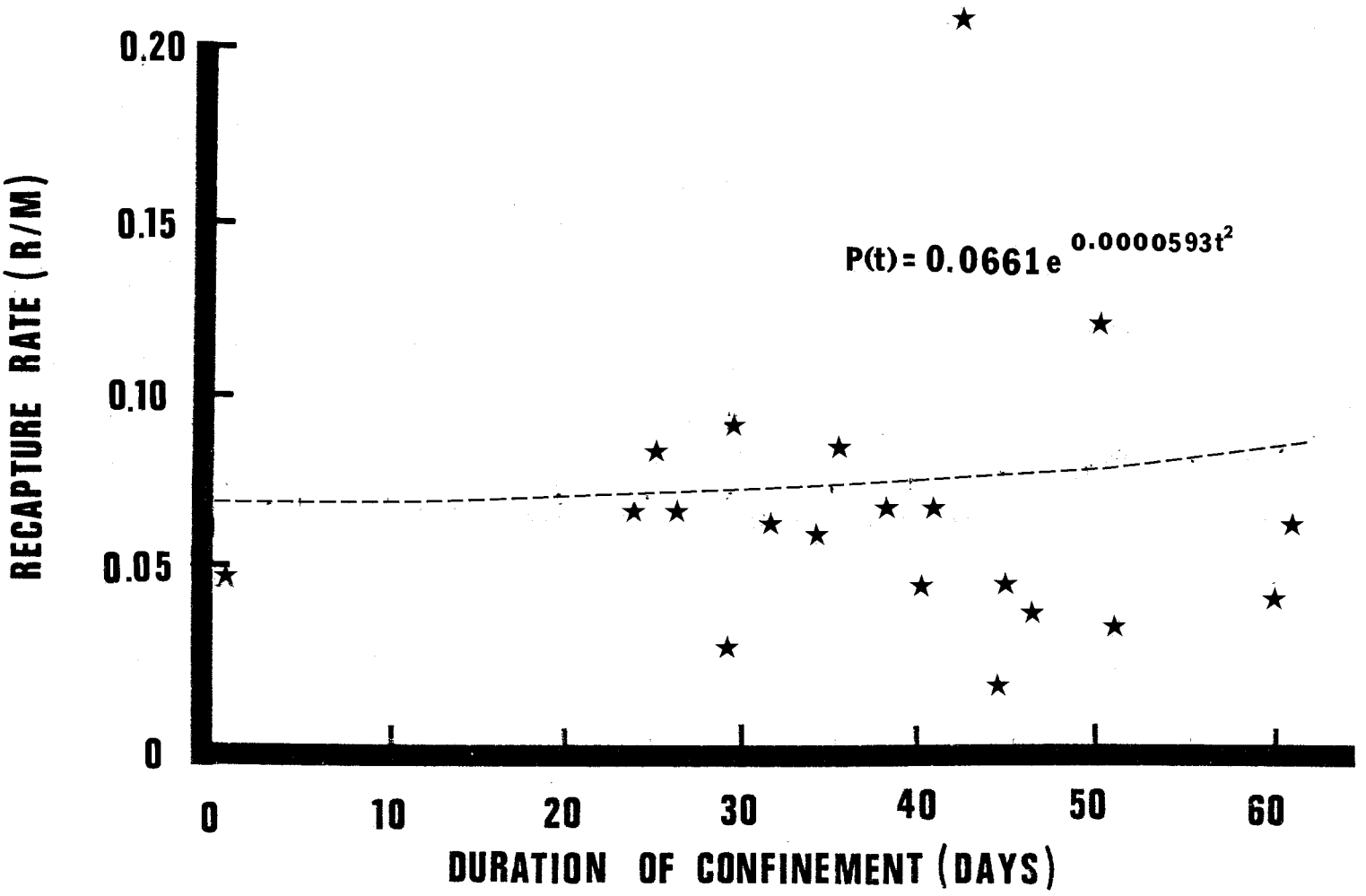

Figure 9. Recapture rate of Arctic char confined at the Agulowak River mouth in summer, 1978 (for their first time) and recaptured during fall, 1978.

eliminate "growth" that was likely due to data recording errors. Upper and lower limits were established by obtaining the mean growth $\pm$ 1.64 standard deviation calculated for all unconfined Arctic char tagged during the fall, 1977, and recaptured during the fall, 1978, in Lakes Nerka and Aleknagik. Fall tag and recapture data were used so that all of the summer growth could be included.

Growth rate of Arctic char confined at the Agulowak River regressed against the duration of confinement (Figure 10) yielded a statistically significant negative slope ($p < 10^{-15}$). Actual data is included in appendices. The statistical model predicted that unconfined Arctic char would grow 29 mm/per year, while Arctic char confined for 51 days would grow only 14 mm/per year. The data base for the Agulukpak River was not as rigorous as that for the Agulowak River. Six point estimates were included in the regression of growth rate against duration of 1977 confinement (Figure 11), but some of the point estimates were based on the recapture of only 10 fish. The resulting regression however, was statistically significant ($p = 0.043$).

Fifty-three Arctic char that had been confined at the Agulukpak River mouth during both 1976 and 1977 were recaptured during 1978. The sample was too small for regression analysis, however the comparison of the mean growth of these fish with the 151 Arctic char confined in 1977 only indicated that double confinement reduced the annual growth rate by about 30 percent (Table 2). Note that duration of confinement and mean length at time of tagging was similar for both groups of fish being compared in Table 2.

Confinement had a significant effect on reducing growth rate of Arctic char the year following release, and repeated confinement further reduced growth rate (based on the Agulukpak River data). Buklis (1978) stated that confinement did not affect the annual growth rate of Arctic char. However, his conclusion was based on comparing the growth pattern of Arctic char confined at Agulukpak River in 1976 with that of Arctic char tagged and released at the Agulowak and Peace Rivers in 1976 (comparing fish from different areas). Area-specific growth patterns probably masked differences due to confinement.

Feeding Habits

The objective of the Department of Fish and Game's confinement program was to prevent Arctic char from feeding on sockeye salmon smolt by removing them from areas of smolt concentration. Presumably, confined fish would still be able to feed on whatever food items passed into the pens. To test this hypothesis, stomach contents were examined from Arctic char

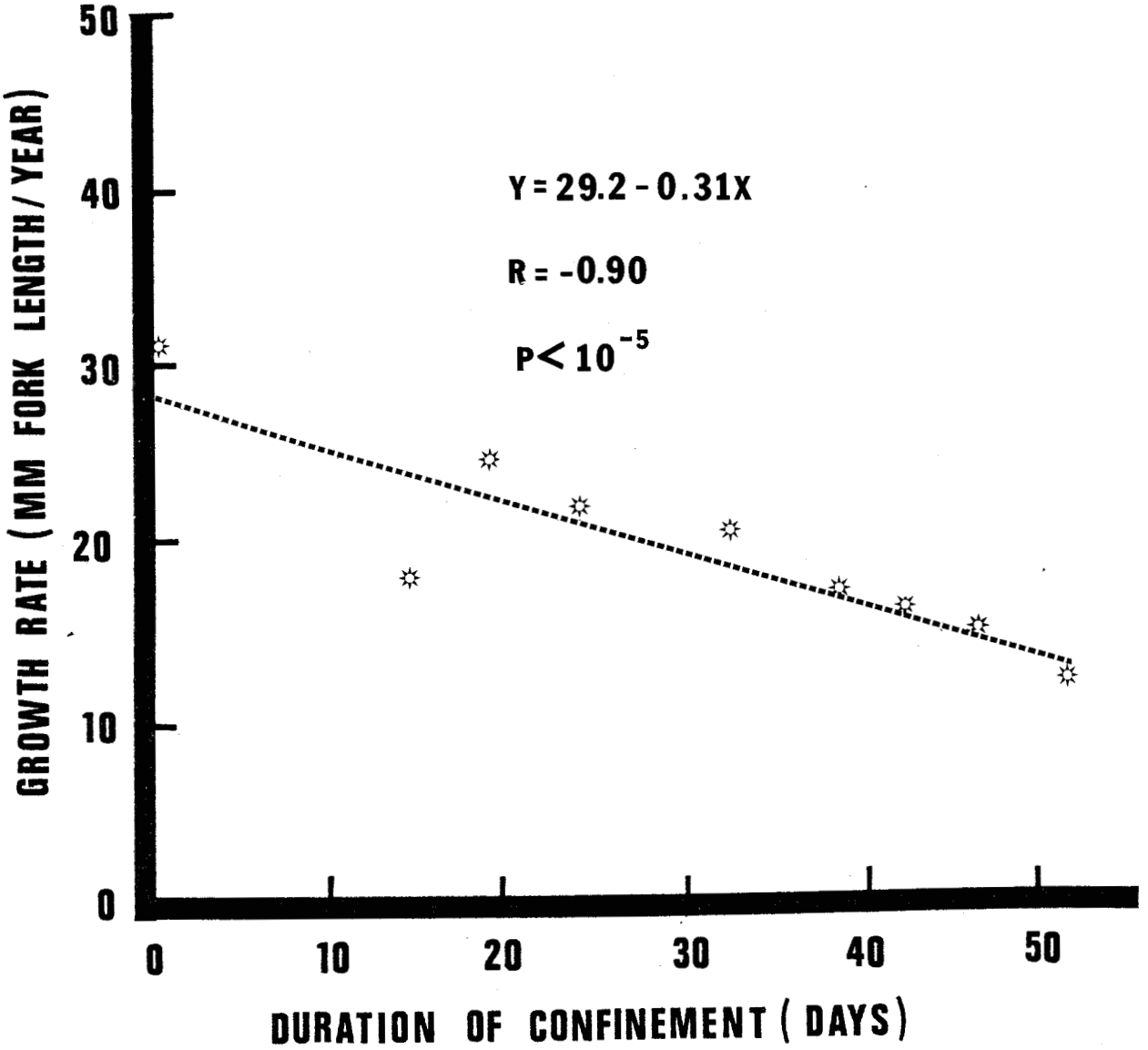

Figure 10. Mean growth rate of Arctic char released in 1977 and recaptured during 1978 at the Agulowak River mouth.

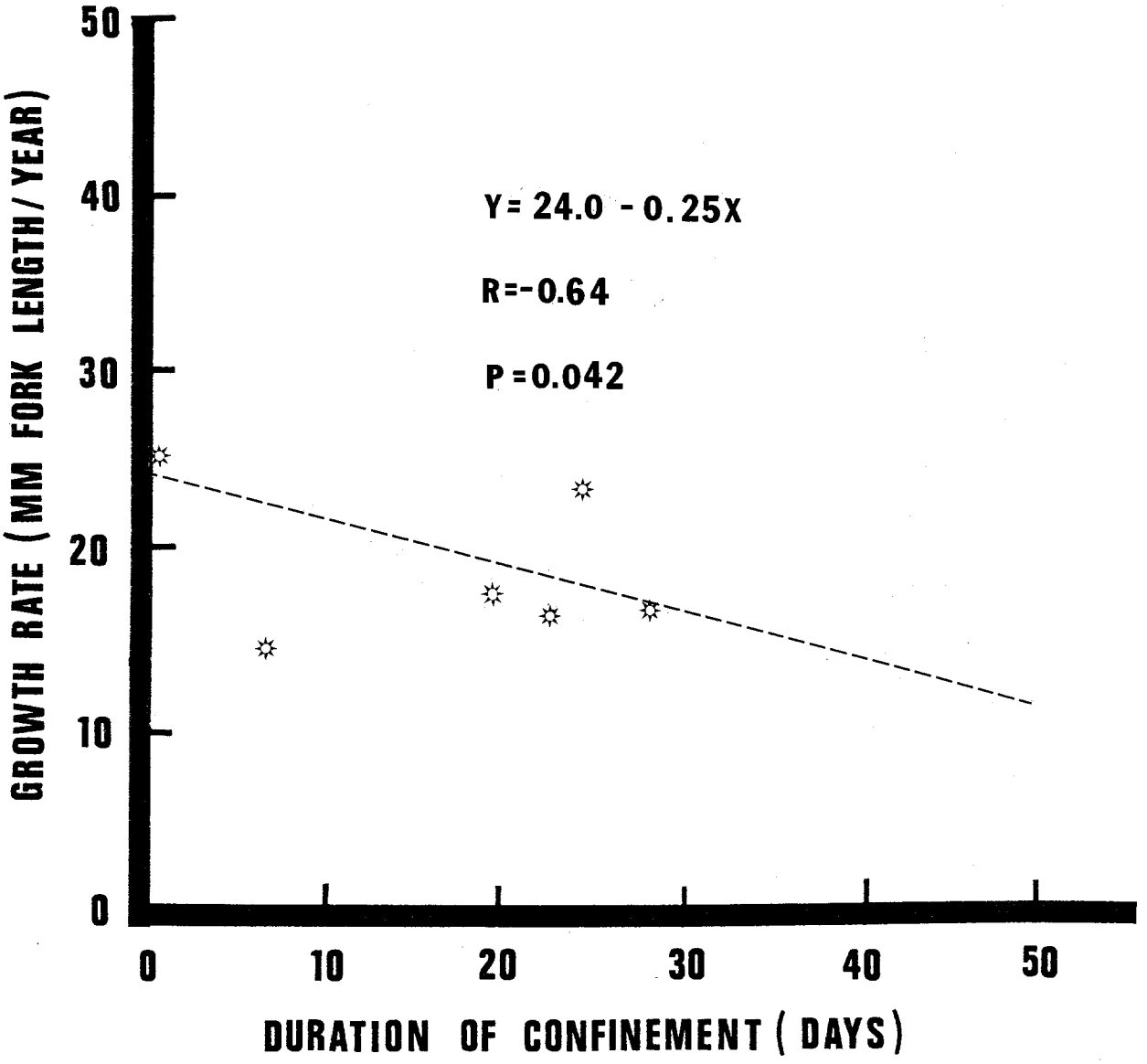

Figure 11. Mean growth rate of Arctic char released in 1977 and recaptured during 1978 at the Agulukpak River mouth.

Table 2. Comparison of the growth rate of Arctic char confined during 1977 with the growth rate of Arctic char confined during both 1976 and 1977 at the Agulukpak River mouth.

Group	Sample size	Duration of 1977 confinement (days)		1977 fork length 1/		Growth in fork length/year (mm)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Confined in 1976 & 1977	53	23	10	467	21	12	14
Confined in 1977 only	151	22	8	462	26	17	16
Probability 2/		0.284		0.190		0.063	

1/ Includes only those fish whose fork length in 1977 was between 400 and 499 mm.

2/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.

Table 3. Stomach contents of Arctic char sampled from the confinement pens at the Agulukpak and Agulowak River mouths.

Agulukpak Confinement				Agulowak Confinement	
July 10, 1977		July 17, 1977		July 25, 1977	
Duration of Confinement (Days)	Stomach Contents	Duration of Confinement (Days)	Stomach Contents	Duration of Confinement (Days)	Stomach Contents
1	16 smolt	3	empty	19	empty
1	6 smolt, 2 leeches	7	detritus	20	empty
1	4 smolt	9	detritus	22	detritus
1	4 smolt	14	detritus	22	detritus
1	empty	15	detritus	22	empty
7	empty	15	detritus	24	detritus
8	empty	16	detritus	25	empty
8	empty	16	detritus	25	empty
8	empty	17	detritus	28	empty
10	empty	18	2 mosquitoes	29	1 stonefly
10	empty	18	empty	30	detritus
10	empty	19	detritus	32	detritus
11	empty	19	empty	32	detritus
11	empty	20	detritus	33	empty
13	empty	23	detritus	33	empty
13	empty	26	detritus	36	detritus
14	empty	34	empty	36	empty
16	empty	35	detritus	36	empty
28	empty	41	2 adult dipterans	39	empty
		43	empty	41	empty

confined in: (1) the shore based pen at the Agulukpak River; and (2) the floating pens at the Agulowak River. Results indicated that confined fish did not feed (Table 3). During the first day of confinement, Arctic char stomachs contained smolt eaten before capture. However, stomachs from fish confined longer were generally empty, contained only small pieces of detritus or occasional insects.

Condition Factor and Fat Reserves

Since confined Arctic char did not feed, one would expect these fish to utilize their energy reserves in order to maintain basic metabolic functions. To test this hypothesis, confined and unconfined Arctic char were sampled on several occasions between June and September, 1977, and condition factor and percent body fat were measured.

Arctic char measured in 1977, one year after confinement at Agulukpak River mouth did not significantly differ in condition factor or percent body fat from those Arctic char that had never been confined (Table 4). Arctic char confined at the Agulukpak River mouth in 1977 included fish previously confined in 1976, and fish never previously confined. Arctic char from both groups sampled from the pen on July 22, 1977, had similar condition factor and percent body fat values (Table 5). The conclusion drawn was that char confined during two consecutive summers did not draw more heavily upon energy reserves thus reducing percent body fat and condition factor than those char confined the first time.

To determine more directly the effect of confinement on Arctic char fat content and condition factor values, those confined fish in Agulowak River mouth pens and those unconfined fish at the Agulowak River mouth were sampled. Both condition factor and percent body fat of confined fish was significantly lower than that measured for unconfined fish (Table 6). The conclusion reached was that confined Arctic char had drawn upon fat reserves during confinement.

To assess the abilility of Arctic char to regain depleted fat reserves utilized during confinement, confined fish were sampled and measured for condition factor and percent body fat two months after release from confinement pens. Arctic char confined at the Agulukpak River and at the Agulowak River during summer, 1977, regained normal condition factor and fat reserves by September, 1977 (Table 7). However, fish confined at Agulukpak River mouth during two consecutive summers (1976 and 1977) did not regain normal condition factor and fat reserves by September, 1977.

Table 4. Fork length, condition factor, and percent body fat of Arctic char sampled between June 14 and 23, 1977, at the Agulukpak River mouth.

	Sample size	Fork length (mm)		Condition factor		Percent body fat	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Previously confined 1/	31	521	45	0.92	0.14	21.35	2.24
Unconfined	33	513	49	0.87	0.13	20.33	2.90
Probability 2/		0.46		0.52		0.12	

1/ Confined fish had been held at the Agulukpak River mouth during 1976.

2/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.

Table 5. Fork length, condition factor, and percent body fat of Arctic char sampled on July 22, 1977, from the pen at the Agulukpak River mouth.

	Sample size	Fork length (mm) Mean	Fork length (mm) Standard deviation	Condition factor Mean	Condition factor Standard deviation	Percent body fat Mean	Percent body fat Standard deviation
Confined 1977	22	507	51	0.99	0.09	23.72	2.03
Confined 1976 & 1977	16	502	47	0.92	0.19	23.60	3.10
Probability 1/		0.74		0.13		0.86	

1/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.

Table 6. Fork length, condition factor, and percent body fat of Arctic char sampled between July 23 and 25, 1977, from the Agulowak River mouth and pens.

	Sample size	Fork length (mm)		Condition factor		Percent body fat	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Confined	19	473	56	0.87	0.17	22.02	1.92
Unconfined	20	459	49	1.13	0.16	24.66	2.40
Probability 1/		0.40		0.000		0.001	

1/ Probabilities listed are the analysis of variance F-ratio probabilities for the appropriate comparison.

Table 7. Fork length, condition factor, and percent body fat of Arctic char sampled between September 18 and 29, 1977, from Lakes Nerka and Aleknagik.

	Sample size	Fork length (mm)		Condition factor		Percent body fat	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Unconfined	21	490	55	1.09	0.15	22.81	2.51
Confined 1976 (Agulukpak)	24	495	51	1.02	0.15	21.98	2.33
Confined 1977 (Agulukpak)	21	517	39	1.07	0.15	23.64	3.78
Confined 1976 & 1977 (Agulukpak)	12	496	45	0.95	0.12	20.76	1.90
Confined 1977 (Agulowak)	24	495	45	1.01	0.15	23.69	2.94
Probability 1/		0.37		0.04		0.02	

1/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.

Fecundity

In some areas of their range, Arctic char spawn annually, while in other areas they spawn in alternate years (Grainger 1953). Thompson (1959) studied fecundity of Arctic char in the Wood River lake system, but did not address the question of spawning frequency.

In the present investigation, ovary samples collected during September, 1977, were of two distinct groups: ovaries weighing less than 40 g and containing eggs averaging less than 2 mm in diameter, and ovaries weighing more than 80 g and containing eggs averaging more than 3.5 mm in diameter. Ovary samples collected during June and July, 1977, did not show a bimodal distribution (Figure 12). Apparently Arctic char living in the Wood River lake system are alternate year spawners. Those char with ovaries weighing less than 40 g were considered even-year spawners, while char with ovaries weighing more than 80 g were considered odd-year spawners. Fish destined to spawn in the fall underwent rapid ovary development between July and September. Therefore, confined and unconfined Arctic char sampled in June and July, 1977, were treated as homogeneous groups for comparison, whereas Arctic char sampled during September, 1977, were separated into even- and odd-year spawners before being compared.

Arctic char which had been confined in 1976 at Agulukpak River mouth and recaptured in June, 1977 were compared to fish that had never been confined. Fecundity was significantly lower for previously confined fish (2,004 eggs) than for unconfined fish (2,655 eggs), although egg size was similar for the two groups (Table 8). However, Arctic char sampled from the confinement pen at Agulukpak River mouth in July, 1977, showed no significant difference in fecundity or egg diameter between those fish confined during two consecutive summers and those fish confined for their first time (Table 9). Arctic char sampled from Agulowak River mouth and confinement pens in July, 1977, also showed no significant differences in fecundity or egg diameter between the confined and unconfined fish (Table 10).

Arctic char sampled at creek mouths in Lakes Nerka and Aleknagik in September, 1977, were separated into even- and odd-year spawners before testing for differences between the confined and unconfined fish. There were no significant differences in fecundity or egg diameter between confined and unconfined Arctic char in either spawning group (Tables 11 and 12). Also, confinement apparently did not affect natural spawning frequency of Arctic char. Ninety-four Arctic char were sampled for fecundity measurements during September, 1977, and the percentages (based on ovary weight) of even- and odd-year spawners were:

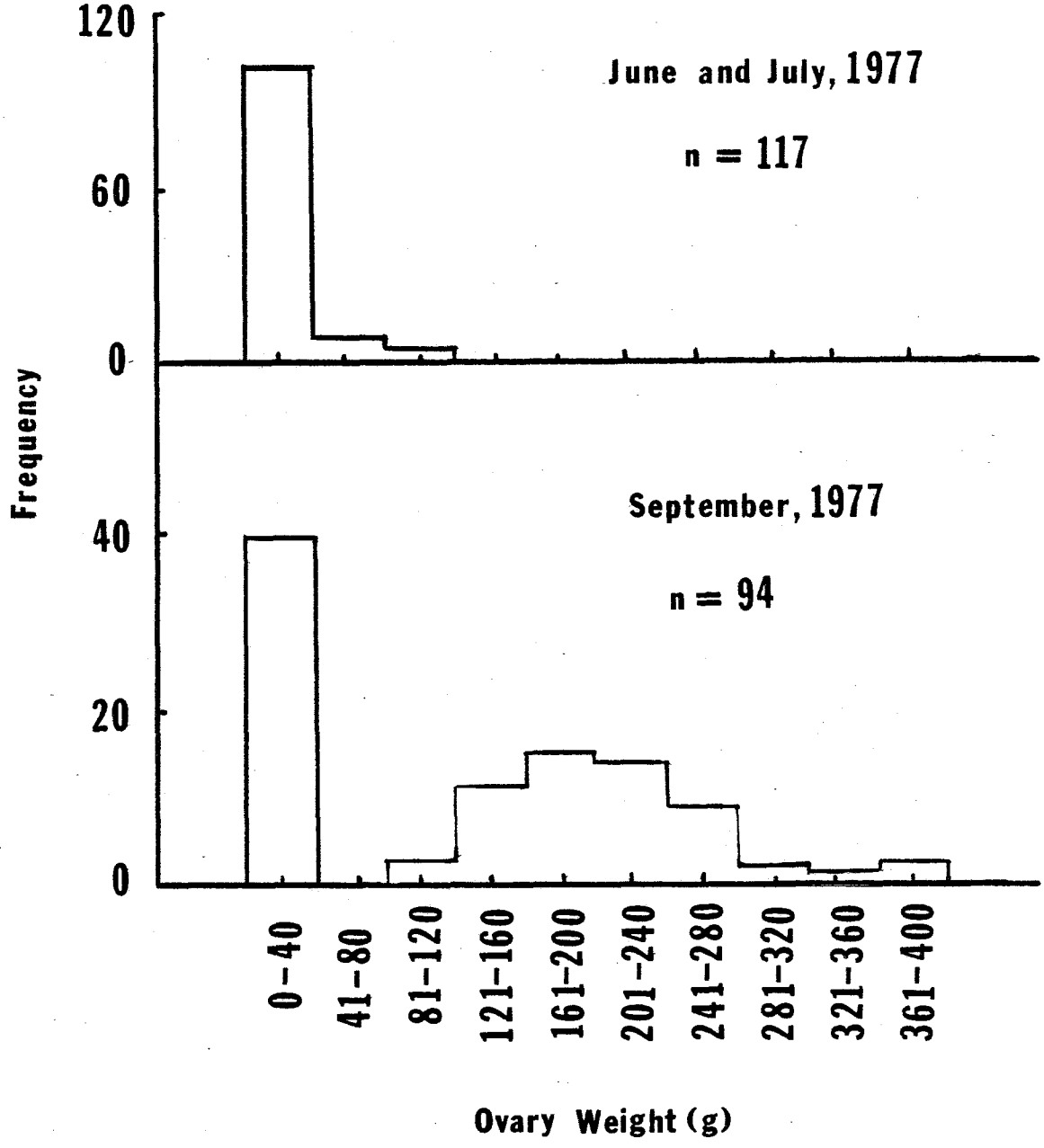

Figure 12. Frequency distribution of ovary weights of both confined and unconfined Arctic char sampled from Lakes Nerka and Aleknagik in June and July, 1977 (above), and in September, 1977 (below). All fish were greater than 375 mm in fork length.

Table 8. Fork length, fecundity, and egg diameter of Arctic char sampled between June 14 and 23, 1977, at the Agulukpak River mouth.

	Sample size	Fork length (mm)		Fecundity		Egg diameter (mm)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Previously confined[1]	19	483	33	2,004	630	1.70	0.18
Unconfined	17	484	36	2,655	988	1.71	0.37
Probability[2]		0.90		0.02		0.91	

1/ Confined fish had been held at the Agulukpak River mouth in 1976.

2/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.

Table 9. Fork length, fecundity, and egg diameter of Arctic char sampled on July 22, 1977, from the pen at the Agulukpak River mouth.

	Sample size	Fork length (mm)		Fecundity		Egg diameter (mm)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Confined 1977	12	472	25	2,172	809	1.91	0.43
Confined 1976 & 1977	7	485	33	2,605	1,053	1.92	0.42
Probability 1/		0.35		0.33		0.92	

1/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.

Table 10. Fork length, fecundity, and egg diameter of Arctic char sampled between July 23 and 25, 1977, at the Agulowak River mouth and pens.

	Sample size	Fork length (mm)		Fecundity		Egg diameter (mm)	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Confined	12	503	35	2,270	990	1.76	0.43
Unconfined	12	442	43	1,746	872	1.81	0.74
Probability 1/		0.001		0.18		0.83	

1/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.

Table 11. Fork length, fecundity, and egg diameter of Arctic char sampled between September 18 and 29, 1977, from Lakes Nerka and Aleknagik, and later determined to be even-year spawners based on ovary weight[1].

	Fork length (mm)			Fecundity			Egg diameter (mm)		
	Mean	Standard deviation	Sample size	Mean	Standard deviation	Sample size	Mean	Standard deviation	Sample size
Unconfined	410	42	(21)	2,422	971	(21)	1.44	0.12	(21)
Confined 1976 (Agulukpak)	472	36	(4)	2,414	589	(3)	1.61	0.13	(3)
Confined 1977 (Agulukpak)	471	35	(3)	2,989	473	(3)	1.54	0.12	(3)
Confined 1977 (Agulowak)	492	51	(7)	2,155	728	(7)	1.52	0.11	(7)
Confined 1976 & 1977 (Agulukpak)	473	27	(5)	2,039	749	(4)	1.54	0.17	(4)
Probability[2]	0.000			0.63			0.14		

1/ Fecundity and egg diameter data is missing for two ovary samples that were lost in transit from the field camp to the laboratory.

2/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.

Table 12. Fork length, fecundity, and egg diameter of Arctic char sampled between September 18 and 29, 1977, from Lakes Nerka and Aleknagik, and later determined to be odd-year spawners based on ovary weight 1/.

	Fork length (mm)			Fecundity			Egg diameter (mm)		
	Mean	Standard deviation	Sample size	Mean	Standard deviation	Sample size	Mean	Standard deviation	Sample size
Unconfined	477	31	(25)	1,973	534	(25)	4.67	0.34	(25)
Confined 1976 (Agulukpak)	473	17	(8)	1,760	340	(6)	4.49	0.20	(6)
Confined 1977 (Agulukpak)	497	24	(6)	1,890	386	(6)	4.78	0.43	(6)
Confined 1977 (Agulowak)	485	26	(14)	1,760	331	(13)	4.72	0.25	(13)
Confined 1976 & 1977 (Agulukpak)	470	--	(1)	1,243	---	(1)	4.45	----	(1)
Probability 2/	0.32			0.51			0.42		

1/ Fecundity and egg diameter data is missing for three ovary samples that were lost in transit from the field camp to the laboratory.

2/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.

Group	1977 Spawner No.	%	1978 Spawner No.	%
Confined in 1977	21	58	15	42
Unconfined in 1977	33	57	25	43

The above results show that confinement did not affect fecundity, egg size, or spawning frequency of Arctic char. Although a significant decrease in fecundity was noted in fish confined at Agulukpak River mouth in June, 1977, (Table 8), no significant difference in fecundity was noted between previously confined and unconfined fish sampled in September, 1977 (Tables 11 and 12).

SUMMARY

To reduce Arctic char predation on sockeye salmon smolt in the Wood River lake system, the Alaska Department of Fish and Game implemented an Arctic char confinement program in the summer of 1975. Over 200 Arctic char were confined at the Little Togiak River mouth as an experimental study. Attempts to feed pelletized fish food as a supplementary diet to the confined Arctic char were unsuccessful. The experiment indicated that confined Arctic char lost both weight and girth during confinement, although survival after release from the pens was not significantly affected.

A full scale program was initiated within the Wood River Lake system with confinement of several thousand Arctic char at the Agulukpak River mouth in 1976, 1977, and 1978, and at the Agulowak River mouth in 1977 and 1978. An estimated 2,642,863 smolt worth an estimated $648,577 in adult salmon returns to the fishery were "saved" from Arctic char predation.

Results again indicated that confined Arctic char did not feed. In response to eventual starvation, confined Arctic char drew upon fat reserves. They were able to regain lost fat reserves after release from the pens, although the ability to recover was reduced by repeated confinement. Annual growth (in length) was reduced by confinement, and apparently, repeated confinement further reduced annual growth rate. Neither ovary development nor spawning frequency was affected by confinement.

Warm water temperatures at the Agulukpak River confinement site in 1977 corresponded with high mortality of confined Arctic char (17.9% of all fish caught). Arctic char mortality during confinement at Agulukpak River mouth in 1976 and 1978, and at the Agulowak River in 1977 and 1978, was relatively low (less than 5% of all fish caught).

Confinement of Arctic char in the shore based pen at Agulukpak River mouth in 1976 and 1977 resulted in reduced survival to succeeding years. Confinement of Arctic char in the floating pen at the Agulowak River in 1977 and again in 1978 did not have a significant affect on survival of Arctic char. The floating pen appears to be the more viable method of confining Arctic char when the objective is to hold them away from migrating sockeye salmon smolt without causing significant mortality.

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APPENDIX

Appendix 1. A model relating recapture rate to confinement time.

Derivation of the Model: Letting $P(t)$ be the recapture rate for a group of char released after t days of confinement, a reasonable difference equation model for a small increase in confinement time Δt is

$$P(t+\Delta t) = P(t) - c\,P(t)\,t\,\Delta t \qquad (1)$$

In words, this relationship specifies that a small increase in confinement time results in a decrease in the observed recapture rate which is proportional to the recapture rate $P(t)$, the confinement time t, and the increase in confinement time Δt. c is an arbitrary positive constant. Of the three variable factors, the easiest to justify is Δt. It seems clear that larger Δt should result in larger decreases in the recovery rate. $P(t)$ is included because, for example, a 1-day increase in confinement would be expected to cause a larger decrease in a current recapture rate of 0.5 than in one of, say, 0.05. Finally, the effect of a small increase in confinement time should be more pronounced with confinement times which are already large, when the fish are in poorer condition.

Subtracting $P(t)$ from both sides of equation 1 and dividing by Δt gives

$$\frac{P(t+\Delta t) - P(t)}{\Delta t} = -c\,P(t)\,t \quad . \qquad (2)$$

The limit, as Δt becomes very small, is the differential equation

$$\frac{dP(t)}{dt} = -c\,P(t)\,t \quad . \qquad (3)$$

Integrating,

$$\int \frac{dP(t)}{P(t)} = -c \int t\,dt \quad ,$$

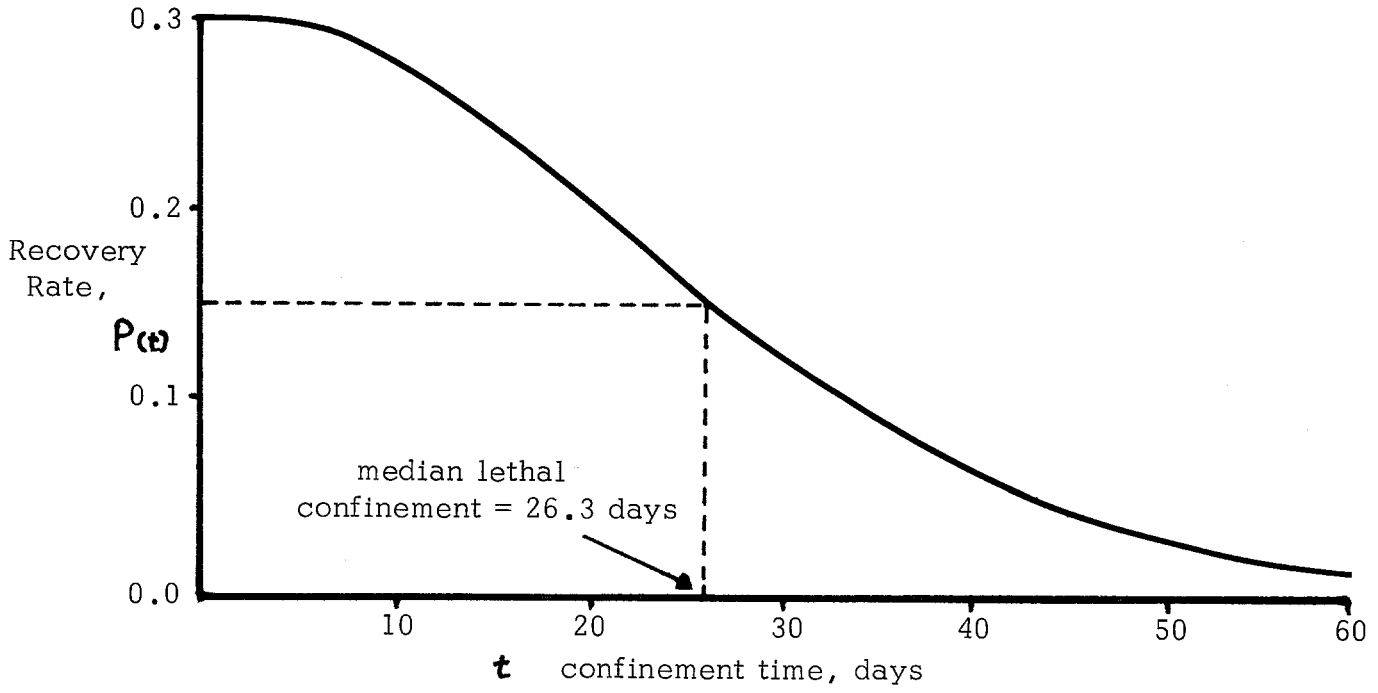
or

$$\ln[P(t)] = -ct^2/2 + Q \quad . \qquad (4)$$

Q is a constant of integration. Exponentiating both sides of (4) and simplifying gives $P(t) = Ke^{-\beta t^2}$, where $\beta = c/2$ and $K = e^Q$. When there is no confinement, $t = 0$ and $e^{-\beta t^2} = 1$, which shows that $K = P(0)$, and the solution to (3) is

$$P(t) = P(0)e^{-\beta t^2} \quad . \tag{5}$$

The figure below shows the behavior of the model for $P(0) = 0.3$ and $\beta = 0.001$ (i.e. $P(t) = 0.3e^{-0.001t^2}$).



The dotted lines illustrate the graphical determination of the median lethal confinement time, t_m , which is an estimate of the confinement time required to reduce the recapture rate to one half its value without confinement. By definition,

$$0.5\,P(0) = P(0)e^{-\beta t_m^2} ,$$

or, after simplifying,

$$t_m = \sqrt{\frac{\ln(0.5)}{-\beta}} \quad \text{for} \quad \beta > 0 \ . \tag{6}$$

This measure is analogous to the half life of radioactive elements and the median lethal dose used in bioassay.

Fitting the model to observed recapture data: If the observed recapture rate is not zero,

$$\ln[P(t)] = \ln[P(0)] - \beta t^2 , \tag{7}$$

which is just

$$y_i = a + bx_i \quad \text{with } y_i = \ln[P(t)],\ a = \ln[P(0)],\ x_i = t^2 \text{, and } i = 1, 2, \ldots, k \text{, where there are } k \text{ release times, with } t \text{ the } i \text{ th release time.}$$

Noting that $P(t)$ is the parameter of a binomial distribution with sample size $M(t)$,

$$\mathrm{Var}\{P(t)\} = \frac{P(t)[1 - P(t)]}{M(t)} , \tag{8}$$

where $M(t)$ is the number of char released after t days of confinement.

What is needed, however, is the variance of $ln[P(t)]$. Kendall and Stuart (1963, p. 232) show that, approximately,

$$Var\{ln[P(t)]\} = \left[\frac{\partial ln[P(t)]}{\partial P(t)}\right]^2 Var\{P(t)\} = \frac{Var\{P(t)\}}{P^2(t)} ,$$

which reduces to

$$Var\{ln[P(t)]\} \cong \frac{[1 - P(t)]}{M(t)P(t)} . \qquad (9)$$

Because the variances of the y_i depend on the number of char released and the recapture rate, a weighted least squares regression is appropriate. Following the methods outlined in Draper and Smith (1966, pp. 77-80) the following estimates for a $(\equiv ln[P(0)])$ and b $(\equiv -\beta)$ are obtained:

Let $$\Delta = \left(\sum_{i=1}^{k} \frac{M_i P_i}{1 - P_i}\right)\left(\sum_{i=1}^{k} \frac{x_i^2 M_i P_i}{1 - P_i}\right) - \left(\sum_{i=1}^{k} \frac{x_i M_i P_i}{1 - P_i}\right)^2 . \qquad (10)$$

Then

$$\hat{a} = \frac{1}{\Delta}\left\{\left(\sum_{i=1}^{k} \frac{x_i^2 M_i P_i}{1 - P_i}\right)\left(\sum_{i=1}^{k} \frac{y_i M_i P_i}{1 - P_i}\right) - \left(\sum_{i=1}^{k} \frac{x_i M_i P_i}{1 - P_i}\right)\left(\sum_{i=1}^{k} \frac{x_i y_i M_i P_i}{1 - P_i}\right)\right\}$$

(11)

and

$$\hat{b} = \frac{1}{\Delta}\left\{\left(\sum_{i=1}^{k}\frac{M_i P_i}{1-P_i}\right)\left(\sum_{i=1}^{k}\frac{x_i y_i M_i P_i}{1-P_i}\right) - \left(\sum_{i=1}^{k}\frac{x_i M_i P_i}{1-P_i}\right)\left(\sum_{i=1}^{k}\frac{y_i M_i P_i}{1-P_i}\right)\right\}. \quad (12)$$

Variances of these estimates are

$$Var\{\hat{a}\} = \frac{1}{\Delta}\sum_{i=1}^{k}\frac{M_i P_i}{1-P_i} \quad \text{and} \quad (13)$$

$$Var\{\hat{b}\} = \frac{1}{\Delta}\sum_{i=1}^{k}\frac{x_i^2 M_i P_i}{1-P_i} \quad . \quad (14)$$

The covariance is

$$Cov\{\hat{a},\hat{b}\} = -\frac{1}{\Delta}\sum_{i=1}^{k}\frac{x_i M_i P_i}{1-P_i} \quad . \quad (15)$$

If the numbers of char released are at least moderate, and the recapture rates not too small, then the distribution of $\hat{b}$ will be close to normal, and the simple null hypothesis

$$H_0 : \beta = 0$$

can be tested against the one-tailed alternative

$$H_A: \beta > 0$$

using the statistic

$$\hat{Z} = \frac{\hat{b}}{\sqrt{Var\{\hat{b} \mid H_0\}}} , \tag{16}$$

rejecting H_0 when $\hat{Z} \leq Z_\alpha$, where Z_α is the standard normal variable defined by

$$Prob\{Z \leq Z_\alpha\} = \alpha .$$

$Var\{\hat{b} \mid H_0\}$ is just equation 13, with all occurrences of P_i in (10) and (13) replaced by

$$P^* = \frac{\sum_{i=1}^{k} M_i P_i}{\sum_{i=1}^{k} M_i} . \tag{17}$$

Here P^* is an obvious estimate of the common value for all P_i when H_0 is true, $\beta = 0$, and P_i does not depend on confinement time t . In the text the significance probability

$$p = Prob\left\{Z \leq \frac{\hat{b}}{\sqrt{Var\{\hat{b} \mid H_0\}}}\right\} \tag{18}$$

is given.

In a number of cases, only a few char were released. In order to obtain reasonably precise estimates of P_i , the releases for several confinement times were combined. In this event, the appropriate common confinement time was estimated by a weighted average:

$$\bar{t} = \frac{\sum_{j=1}^{n} t_j R_j}{\sum_{j=1}^{n} R_j} \quad , \tag{19}$$

where the releases for n days have been combined.

Appendix 2. Recapture rate of Arctic char confined at Little Togiak River mouth during 1975, and recaptured between 1976 and 1978.

Duration of 1975 Confinement (Days)	Number Released in 1975 (M)	Number Recaptured in 1976-78 (R)	Recapture Rate (R/M)	Group Recapture Rate[1/] (ΣR/ΣM)
0	108	22	0.2037	0.2037
10	4	0	0.0	
12	5	0	0.0	
16	2	0	0.0	
20	1	0	0.0	
22	6	1	0.1667	
23	1	0	0.0	
24	4	1	0.2500	
25	1	0	0.0	
26	9	3	0.3333	0.1515
28	34	10	0.2941	0.2941
30	3	0	0.0	
32	17	2	0.1176	
33	6	2	0.3333	
41	12	4	0.3333	0.2105
42	21	2	0.0952	
43	11	0	0.0	0.0625
44	9	1	0.1111	
45	4	0	0.0	
46	6	0	0.0	
48	4	0	0.0	
49	2	0	0.0	
50	1	0	0.0	
51	1	1	1.0	0.0741
0	108	22	0.2037	
10-51	164	38	0.2317	

1/ Data are combined into release groups of 30 or more fish.

Appendix 3. Recapture rate of Arctic char confined at the Agulukpak River mouth during 1976 and recaptured during 1977 and 1978.

Duration of 1976 Confinement (Days)	Number Released in 1976 (M)	1977		1978	
		Number Recaptured (R)	Recapture Rate (R/M)	Number Recaptured (R)	Recapture Rate (R/M)
3	79	38	0.4810	13	0.1646
9	876	293	0.3345	77	0.0879
15	758	252	0.3325	68	0.0897
19	157	42	0.2675	3	0.0191
20	335	77	0.2299	6	0.0179
23	253	46	0.1818	13	0.0514
26	302	59	0.1954	5	0.0166
28	259	34	0.1313	12	0.0463
30	47	5	0.1064	1	0.0213
34	57	10	0.1754	2	0.0351
39	99	12	0.1212	1	0.0101
3-39	3222	868	0.2694	201	0.0624

Appendix 4. Recapture rate of Arctic char confined at the Agulukpak River mouth during 1977 (for their first time) and recaptured during 1978.

Duration of 1977 Confinement (Days)	Number Released (M)	Number Recaptured (R)	Recapture Rate (R/M)	Group Recapture Rate (ΣR /ΣM) 1/
0	129	30	0.2326	0.2326
2	8	2	0.2500	
3	5	0	0.0	
4	6	1	0.1667	
6	29	7	0.2414	
7	4	0	0.0	0.1923
8	8	1	0.1250	
9	33	4	0.1212	
10	4	0	0.0	
11	10	2	0.2000	0.1273
12	37	8	0.2162	
13	27	6	0.2222	0.2188
14	6	1	0.1667	
15	17	6	0.3529	
16	19	5	0.2632	
17	9	1	0.1111	0.2549
18	5	0	0.0	
19	30	5	0.1667	
20	105	40	0.3810	0.3214
21	65	14	0.2154	0.2154
22	63	15	0.2381	0.2381
23	175	54	0.3086	0.3086
24	67	13	0.1940	0.1940
25	118	26	0.2203	0.2203
26	47	17	0.3617	
27	18	5	0.2778	0.3385
28	41	12	0.2927	
29	29	2	0.0690	0.2000

continued

Appendix 4. (continued)

Duration of 1977 Confinement (Days)	Number Released (M)	Number Recaptured (R)	Recapture Rate (R/M)	Group Recapture Rate 1/ (ΣR /ΣM)
30	9	2	0.2222	
31	16	4	0.2500	
32	6	1	0.1667	
33	4	0	0.0	
34	3	0	0.0	
35	5	1	0.2000	
38	4	0	0.0	
39	3	0	0.0	0.1600
40	19	2	0.1053	
41	10	1	0.1000	
42	8	0	0.0	
43	14	2	0.1429	0.0980
44	20	3	0.1500	
46	28	3	0.1071	0.1250
47	8	0	0.0	
48	15	3	0.2000	
49	23	2	0.0870	0.1087
0	129	30	0.2326	
2-49	1180	271	0.2297	

1/ The data are grouped into 50 or more fish.

Appendix 5. Recapture rate of Arctic char confined at the Agulowak River mouth during summer, 1977, and recaptured during fall, 1977.

Duration of 1977 Confinement (Days)	Number Released (M)	Number Recaptured (R)	Recapture Rate (R/M)	Group Recapture Rate ($\Sigma R / \Sigma M$) 1/
0	362	17	0.0470	0.0470
10	25	2	0.0800	
14	35	2	0.0571	0.0667
15	145	5	0.0345	0.0345
16	74	7	0.0946	0.0946
19	192	9	0.0469	0.0469
20	131	7	0.0534	0.0534
22	4	1	0.2500	
24	175	9	0.0514	0.0559
25	246	17	0.0691	0.0691
27	26	4	0.1538	
29	43	2	0.0465	0.0870
30	101	3	0.0297	0.0297
31	105	6	0.0571	0.0571
32	134	4	0.0299	0.0299
34	304	18	0.0592	0.0592
35	149	8	0.0537	0.0537
36	135	7	0.0519	0.0519
37	107	4	0.0374	0.0374
39	208	11	0.0529	0.0529
40	308	10	0.0325	0.0325
41	278	3	0.0108	0.0108
42	151	8	0.0530	0.0530
43	130	4	0.0308	0.0308

continued

Appendix 5. (continued)

Duration of 1977 Confinement (Days)	Number Released	Number Recaptured (R)	Recapture Rate (R/M)	Group Recapture Rate ($\Sigma R / \Sigma M$) 1/
44	387	12	0.0310	0.0310
45	345	20	0.0580	0.0580
47	48	3	0.0625	
48	385	18	0.0468	0.0485
49	23	2	0.0870	
50	174	10	0.0575	0.0609
51	158	5	0.0316	0.0316
52	139	5	0.0360	0.0360
53	191	11	0.0576	0.0576
54	59	5	0.0847	0.0847
55	46	1	0.0217	
57	5	1	0.2000	0.0392
58	44	4	0.0909	
59	20	1	0.0500	0.0781
0	362	17	0.0470	
10-59	5230	249	0.0476	

1/ The data are grouped into 50 or more fish.

Appendix 6. Recapture rate of Arctic char confined at the Agulowak River mouth during 1977, and recaptured during 1978.

Duration of 1977 Confinement (Days)	Number Released (M)	Number Recaptured (R)	Recapture Rate (R/M)	Group Recapture Rate ($\Sigma R / \Sigma M$) 1/
0	362	117	0.3232	0.3232
7	1	1	1.0000	
9	1	0	0.0	
10	25	15	0.6000	
12	5	2	0.4000	
13	5	1	0.2000	
14	35	20	0.5714	0.5417
15	145	73	0.5034	0.5034
16	74	46	0.6216	0.6216
17	5	1	0.2000	
18	4	1	0.2500	
19	192	65	0.3385	0.3333
20	131	67	0.5115	0.5115
22	4	2	0.5000	
24	175	86	0.4914	0.4916
25	246	115	0.4675	0.4675
26	8	5	0.6250	
27	26	11	0.4231	
28	43	21	0.4884	0.4805
30	101	36	0.3564	0.3564
31	105	62	0.5905	0.5905
32	134	66	0.4925	0.4925
34	304	158	0.5197	0.5197
35	149	72	0.4832	0.4832
36	135	65	0.4815	0.4815
37	107	47	0.4393	0.4393
38	141	68	0.4823	0.4823

continued

Appendix 6. (continued)

Duration of 1977 Confinement (Days)	Number Released (M)	Number Recaptured (R)	Recapture Rate (R/M)	Group Recapture Rate 1/ ($\Sigma R / \Sigma M$)
39	59	29	0.4915	0.4915
40	308	138	0.4481	0.4481
41	278	118	0.4245	0.4245
42	151	81	0.5364	0.5364
43	130	64	0.4923	0.4923
44	387	175	0.4522	0.4522
45	345	150	0.4348	0.4348
46	6	2	0.3333	
47	48	16	0.3333	0.3333
48	385	171	0.4442	0.4442
49	23	16	0.6957	
50	174	58	0.3333	0.3756
51	158	71	0.4494	0.4494
52	139	64	0.4604	0.4604
53	191	80	0.4188	0.4188
54	59	25	0.4237	0.4237
55	46	18	0.3913	
56	8	3	0.3750	0.3889
57	5	2	0.4000	
58	44	21	0.4773	
59	20	8	0.4000	
60	5	0	0.0	
61	1	0	0.0	
62	4	1	0.2500	
63	2	0	0.0	0.3951
0	362	117	0.3232	
7-63	5277	2417	0.4580	

1/ The data are grouped into 50 or more fish.

Appendix 7. Recapture rate of Arctic char confined at the Agulowak River mouth during summer, 1978 (for their first time) and recaptured during fall, 1978.

Duration of 1978 Confinement (Days)	Number Released (M)	Number Recaptured (R)	Recapture Rate (R/M)	Group Recapture Rate ($\Sigma R / \Sigma M$) 1/
0	273	13	0.0476	0.0476
17	4	1	0.2500	
22	6	1	0.1667	
23	7	1	0.1429	
24	80	3	0.0375	0.0619
25	112	9	0.0804	0.0804
26	44	3	0.0682	
27	55	3	0.0545	0.0606
28	33	1	0.0303	
29	68	2	0.0294	0.0297
30	86	8	0.0930	0.0930
31	99	6	0.0606	0.0606
32	36	2	0.0556	
33	9	1	0.1111	
35	103	6	0.0583	0.0608
36	232	20	0.0862	0.0862
38	33	1	0.0303	
39	99	8	0.0808	0.0682
40	40	1	0.0250	
41	163	8	0.0491	0.0443
42	61	4	0.0656	0.0656
43	123	26	0.2114	0.2114
45	226	4	0.0177	0.0177
46	131	6	0.0458	0.0458
47	183	7	0.0383	0.0383
50	31	3	0.0968	
51	50	7	0.1400	0.1235

continued

Appendix 7. (continued)

Duration of 1978 Confinement (Days)	Number Released (M)	Number Recaptured (R)	Recapture Rate (R/M)	Group Recapture Rate ($\Sigma R / \Sigma M$) 1/
52	60	2	0.0333	0.0333
54	3	1	0.3333	
59	24	3	0.1250	
61	102	2	0.0196	0.0465
62	31	1	0.0323	
63	11	1	0.0909	
64	30	2	0.0667	
67	8	1	0.1250	0.0625
0	273	13	0.0476	
17-67	2383	155	0.0650	

1/ The data are grouped into 50 or more fish.

Appendix 8. Mean growth rate of Arctic char released during 1977 and recaptured during 1978 at the Agulowak River mouth.

Duration of 1977 confinement (days)	Sample size (n)	1977 1/ Fork length (mm) Mean	Fork length (mm) Standard deviation	Growth in fork length per year (mm) Mean	Growth in fork length per year (mm) Standard deviation
0	42	446	17	31	20
15	27	450	19	18	20
20	19	444	20	25	20
25	29	452	20	22	18
34	30	457	17	21	22
40	27	459	17	17	16
44	38	452	17	16	19
48	29	453	18	15	17
53	20	452	16	12	16
0	42	446	17	31	20
15-53	219	453	18	18	19
Probability 2/		0.018		0.000	

1/ Includes only those fish whose fork length in 1977 was between 420 and 480 mm.

2/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.

Appendix 9. Mean growth rate of Arctic char released during 1977 and recaptured during 1978 at the Agulukpak River mouth.

Duration of 1977 confinement (days)	Sample size (n)	1977 1/ Fork length (mm)		Growth in fork length per year (mm)	
		Mean	Standard deviation	Mean	Standard deviation
0	34	454	28	26	19
6-9	10	464	33	15	18
20	32	463	28	18	18
23	25	465	26	17	15
25	14	461	26	24	18
28-30	10	467	20	17	11
0	34	454	28	26	19
6-30	91	464	26	18	17
Probability 2/		0.073		0.021	

1/ Includes only fish confined for their first time in 1977, and whose fork length was between 400 and 499 mm.

2/ Probabilities listed are analysis of variance F-ratio probabilities for appropriate comparisons.