

FRI-UW-8109
August 1981

FISHERIES RESEARCH INSTITUTE
College of Fisheries
University of Washington
Seattle, Washington 98195

EARLY MARINE SURVIVAL AND MIGRATORY BEHAVIOR OF
JUVENILE CHUM SALMON RELEASED FROM THE
ENETAI HATCHERY, WASHINGTON IN 1980.

by

Nicholas J. Bax and Clifford J. Whitmus

This work was supported by the Washington Sea Grant Program
and the National Marine Fisheries Service, under the National
Oceanic and Atmospheric Administration, U.S. Department of
Commerce, and by the Washington State Department of Fisheries.

Approved:

Submitted: August 19, 1981

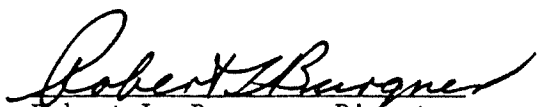

Robert L. Burgner, Director



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ABSTRACT

Three hundred and eighty thousand juvenile chum salmon were spray-marked with fluorescent pigment and released from the west shore of southern Hood Canal on May 19, 1980. At the same time two groups of 60,000 juvenile chum, distinguishable from the first group and each other by differing colors of fluorescent pigment, were transported to saltwater holding pens to acclimate. The migration routes, survival and growth of the released fish were examined for five days using surface townetting and beach seining. One seventh of the juveniles recaptured in the nearshore zone and two-thirds of those recovered in the pelagic zone had crossed at least two miles of open water before being recaptured along the east shore of Hood Canal. The juveniles crossing the canal were neither longer nor heavier than those remaining on the west shore. The fish remaining in nearshore areas on the west shore were found concentrated on the Skokomish River flats throughout the duration of the study. After two days one of the smaller groups was released on the Skokomish flats. It was assumed that this group and the first group experienced the same survival over the ensuing days. Under this assumption the relative numbers of subsequent recaptures of both groups could be used to estimate the numbers of the first group present when the second group was released. Thus the survival of the first group over two days could be estimated once migration from the area was accounted for. The third group of juvenile chum was released onto the Skokomish flats four days after the initial release. Using the above procedure and under the same assumptions the survival of the initial group over four days was estimated. Additionally the survival of the first of the two groups which had been acclimated in a saltwater pen was estimated for the first two days following its release. The survival of those juveniles remaining on the flats from the initial hatchery release was estimated to be $51 \pm 11\%$ (S.E.) and $55 \pm 11\%$ (S.E.) two days after their release, under the assumptions of zero and maximum recorded emigration, respectively. Estimates for the survival of the first group which had been acclimated in a salt water pen were $42 \pm 9\%$ (S.E.) and $52 \pm 12\%$ (S.E.) under the above assumptions. The survival rate appeared constant over the four-day period studied with survival of the initial group recaptured on the flats being between $20 \pm 4\%$ (S.E.) and $26 \pm 5\%$ (S.E.) after four days. The growth rate of the recaptured fish was estimated to be 8.6% body weight/day, but the data were variable. The possibility of size selective mortality was investigated but no definite conclusion was drawn.

ACKNOWLEDGMENTS

Many individuals have contributed to the success of this project. The manuscript was reviewed and many helpful suggestions made by Douglas Chapman, Ernest Salo, Robert Burgner, Donald Gunderson, Charles Simenstad, and Kurt Fresh. The authors remain solely responsible for any errors in the paper.

Our special thanks go to Larry Rutter, Nic Wilbur, Rick Miller, and Heidi Rooks of the Point No Point Treaty Council's Enetai Hatchery, without whose cooperation this study would not have been possible.

Bruce Snyder helped coordinate the project and along with the field crew of Ken Bruya, Gary Duker, Gary Maxwell, Gloria McDowell, and Steve Schroder gave many helpful suggestions and excellent company.

Carol Sisley and Lila Stacey typed the original manuscript which was finalized by Dorothy Beall and her staff. The figures were prepared by JLM Design.

This project was supported by the Washington Sea Grant Program and the National Marine Fisheries Service under the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and by the Washington State Department of Fisheries.

INTRODUCTION

The Washington State Department of Fisheries (WDF) has selected chum salmon (Oncorhynchus keta) as the primary species for artificial enhancement and Hood Canal, a fjord-like extension of Puget Sound, as the principal area for chum salmon enhancement. The WDF has two hatcheries on the Skokomish River (George Adams and Hunter Springs) and one at Hoodsport (Hood Canal) (Fig. 1). The Department of the Interior, Fish and Wildlife Service (USFWS) operates a hatchery on the Quilcene River, and the University of Washington has a spawning channel and small hatchery on Big Beef Creek. The Point No Point Treaty Council has a small hatchery at Enetai, and the Port Gamble Tribe has a hatchery at Port Gamble. In addition, WDF has installed streamside egg boxes on many streams in Hood Canal. Hood Canal also has naturally-produced chum salmon stocks. With continued enhancement of wild and hatchery stocks of chum salmon, a total of more than 60 million juvenile chum salmon may emigrate annually (personal communication with WDF and USFWS, October 1980).

Early marine residence is regarded by many as being a, if not the, critical phase in the life history of chum salmon, determining the numerical strength of the adult return (Bakkala 1970; Peterman 1978). Gilhousen (1962) stated that "conditions in the marine environment have been so variable that variation in fry abundance has had a secondary effect on total survival." With the exception of Parker's estimates of 55-77% average mortality for pink salmon (O. gorbuscha) during the first 40 days of marine life (Parker 1968), there are few estimates available for salmonid mortality during their initial period in the marine environment. Parker may have underestimated mortality as his mortality rate for the early period of marine life was based on the final 25 days in enclosed waters and then extrapolated to include the earlier period when the salmon fry first entered the estuary. Burrows (1969) found evidence of a high estuarine mortality and large changes in physiological characteristics in the 7 days between the release and recapture of chinook salmon smolts (O. tshawytscha). Preliminary estimates based on recaptures in February 1978 and February 1979, suggested that the mortality of juvenile chum salmon from Big Beef Creek hatchery over the first two days was 29% and 44% for the two years, respectively (Salo et al. 1980).

Hatchery-reared chum salmon fry enter the marine environment immediately, or almost immediately, upon release from the hatchery and thus hatchery release strategies determine the size of the fry and the time at which they enter this critical point in their life. Martin (1976) found that adult returns of pink salmon that had been reared 120 days as juveniles and released at 132 mm (F.L.) in September were 1.2%, compared with returns of 2.7% for those reared 90 days and released in July at 59 mm (F.L.). Studies by Blackbourn (1976) on Fraser River pink salmon have suggested that environmental variables including river discharge, solar radiation, as well as the migration timing and the initial size of

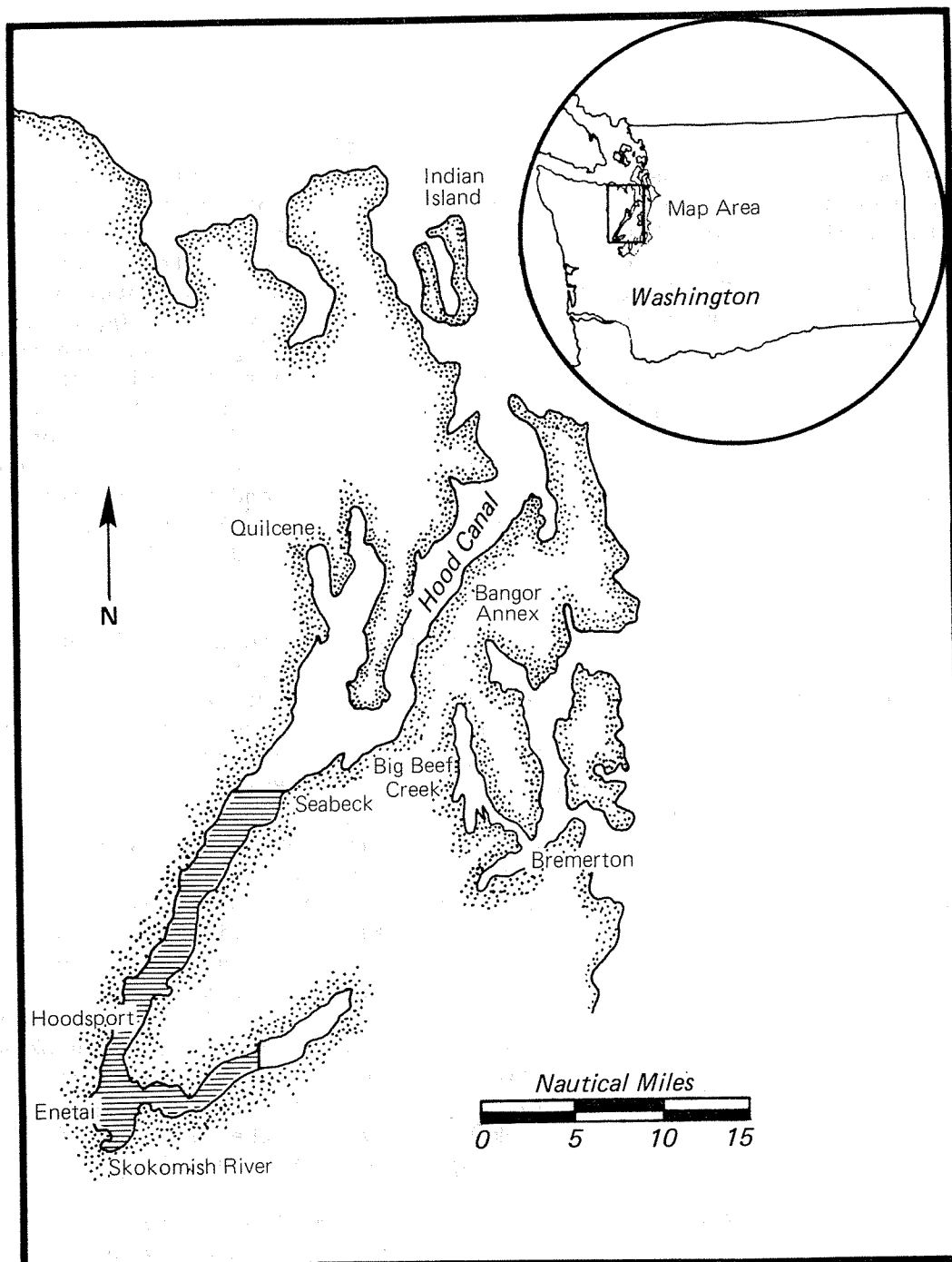


Fig. 1. Location of sampling area (horizontally shaded) and the major areas of hatchery enhancement in Hood Canal, Washington, 1980.

the juveniles affected the survival of the pink salmon. Previous studies in Hood Canal have determined that the rate of migration for hatchery-reared juvenile chum salmon decreased by an average of 0.7 km/day per month from March through June in 1977 (Bax, unpublished data) and by 2.0 km/day per month from March through June in 1979 (Salo et al. 1980). Walters et al. (1978) concluded that the slower the migration speed the higher the mortality. If this is the case, then the later hatchery releases into Hood Canal in May and June may be suffering high immediate mortality due to the slow rate of migration at this time. Indeed Japanese hatchery operators consider that although delaying the release of juvenile chum salmon until ice-out in the rivers and the spring plankton bloom enhances survival, further delaying the release is detrimental if ocean temperatures exceed 15°C (Mathews and Senn 1975).

This project continues studies by the Fisheries Research Institute of the University of Washington on the salmon outmigrations in Hood Canal started in 1975. These studies funded by the Washington Sea Grant Program and the United States Department of the Navy have detailed the migration routes and temporal distribution of juvenile salmon in Hood Canal (Salo et al. 1980). Studies by Simenstad et al. (1980) have investigated the food of juvenile salmon and its availability in Hood Canal. Although the early marine residence is considered to be a critical period in the life of chum salmon few quantitative data exist. It is the purpose of this project to evaluate a short term mark-recapture program in the estimation of the survival of juvenile chum salmon over two and four days after their release from a hatchery. The method does not require interpretation of their rate of return as adults and thus provides not only a rapid result but one free of biases from variable ocean and harvesting mortalities.

We possess the technology for producing millions of additional chum salmon but know little about either their survival subsequent to release or the absolute numbers of fish Hood Canal can support. Thus, knowledge of the survival of juvenile chum salmon and factors affecting it, as well as knowledge of their spatial and temporal distribution and their food requirements would assist hatchery managers in determining the optimum size, time, and number of fish to be released. This, in turn, may further the goal of enhancement, that being to produce significant increases in the numbers of returning adults.

METHODS AND MATERIALS

Study Area

The study area is located in Hood Canal, Washington. Hood Canal a positive fjord-type estuary (Winter, Banse and Anderson 1975), approximately 60 miles long and 2-3 miles wide, is located in the northwest

corner of Washington State (Fig. 1). The area of Hood Canal sampled was bounded by Hood Point on the north and Twanoh State Park on the southeast.

Sampling was designed to assess the daily distribution of marked juvenile chum salmon released from Enetai Hatchery (Fig. 1). Previous studies in southern Hood Canal (Whitmus and Olsen 1979) had indicated where sampling sites should be established. Sites were chosen every 1-3 miles within the sampling area at sheltered, moderately sloping beaches where the beach seine could be retrieved with little chance of snagging on rocks or debris (Fig. 2). Townet transect locations were chosen to correspond to the beach seine sites (Fig. 3). There was insufficient time to sample all sites daily. The most information could be obtained by defining the peak of the distribution of the released groups and sampling their distribution as time permitted.

Fluorescent Pigment Marking Techniques

The marking of juvenile fish with fluorescent pigment, as described by Jackson (1959) has been shown to be an efficient and economical technique for marking large numbers of juvenile chum salmon (Whitmus and Olsen 1979). The pigment is a fluorescent, biologically inert polystyrene pigment which is not readily excited by daylight but will fluoresce under ultraviolet illumination. Fluorescent pigment particles (70% between 30 and 350 μ) were forced through the epidermis and into the dermis of the juveniles using a small sandblasting gun and compressed air at ~ 8.6 kg/cm². The sandblasting gun was modified to use 1 liter polyethylene bottles instead of the standard metal canister. The gun was fitted with a 5.3 mm siphon orifice and a 5.2 mm discharge orifice. Air was supplied by 6.9 m³ air cylinders fitted with a 2-stage oxygen regulator. The gun was connected to the regulator by a flexible air hose.

A marking trough, designed to maximize the numbers of juvenile fish that could be marked with minimum stress, originally developed by the WDF, was modified for our use (Fig. 4).

Prior to marking, the fish were removed from the hatchery pond, weighed and transferred to a holding trough. Approximately 500-750 fish were transferred by dip net from the holding trough and evenly distributed in the plexiglass marking trough. The fish were immediately sprayed with one 8 second pass of the spray gun at 47.5 cm, the trough inverted and the fish washed into a recovery trough leading to a hatchery pond (Plate 1). Using this method we were able to mark 40,000 fish (mean fork length 50 mm) per hour. One pound of pigment was used to mark 5,000 fish.

Mortalities were enumerated prior to release (a minimum of 3 days after marking). A subsample of each marked group was retained for evaluation of mark retention. The first group to be released was released by removing the central standpipe in the rearing ponds, thus flushing the juvenile chum into a small creek leading to Hood Canal. At the same time the second and third groups were transferred to saltwater pens in

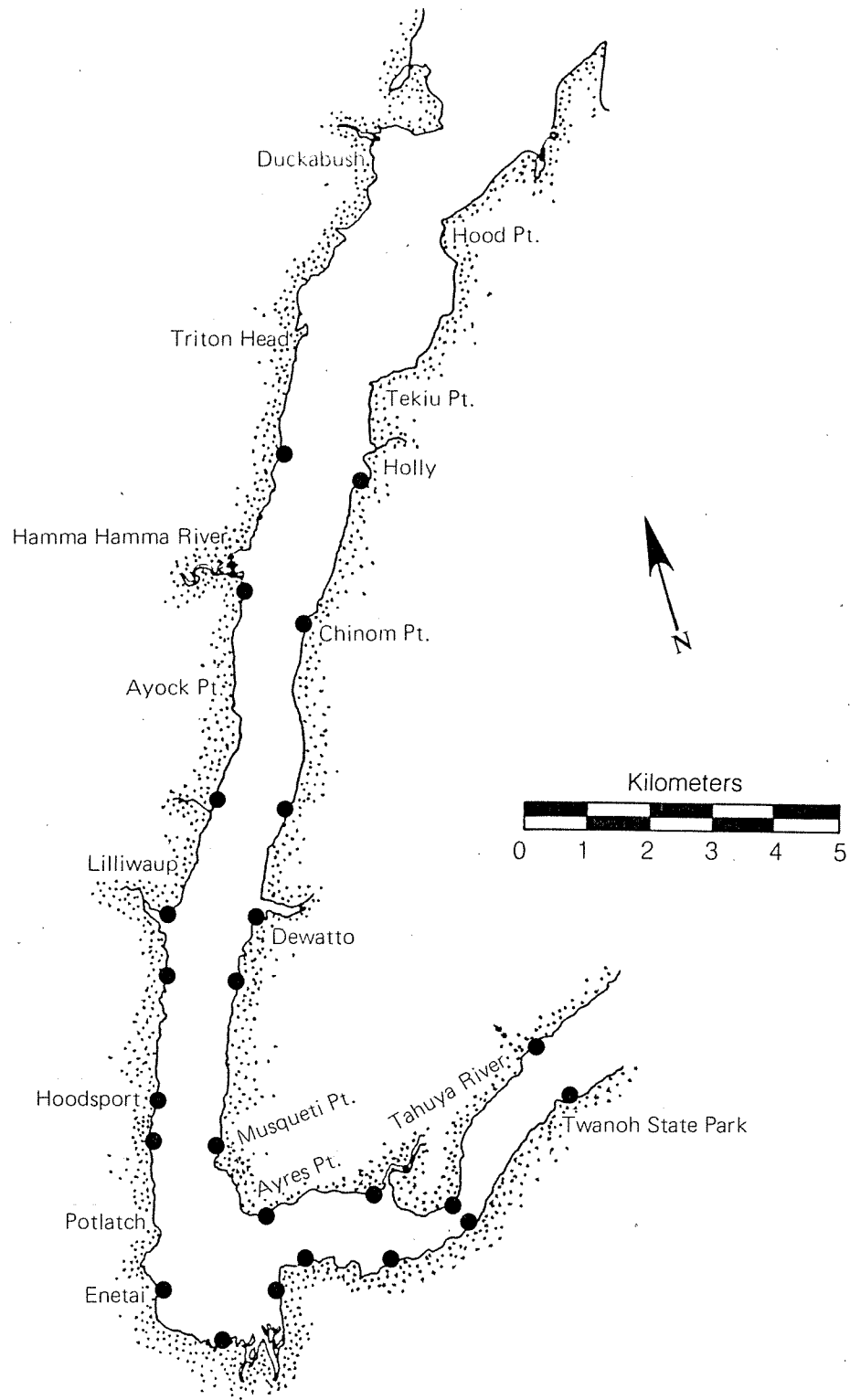


Fig. 2. Location of beach seine sampling sites in Hood Canal, Washington, 1980.

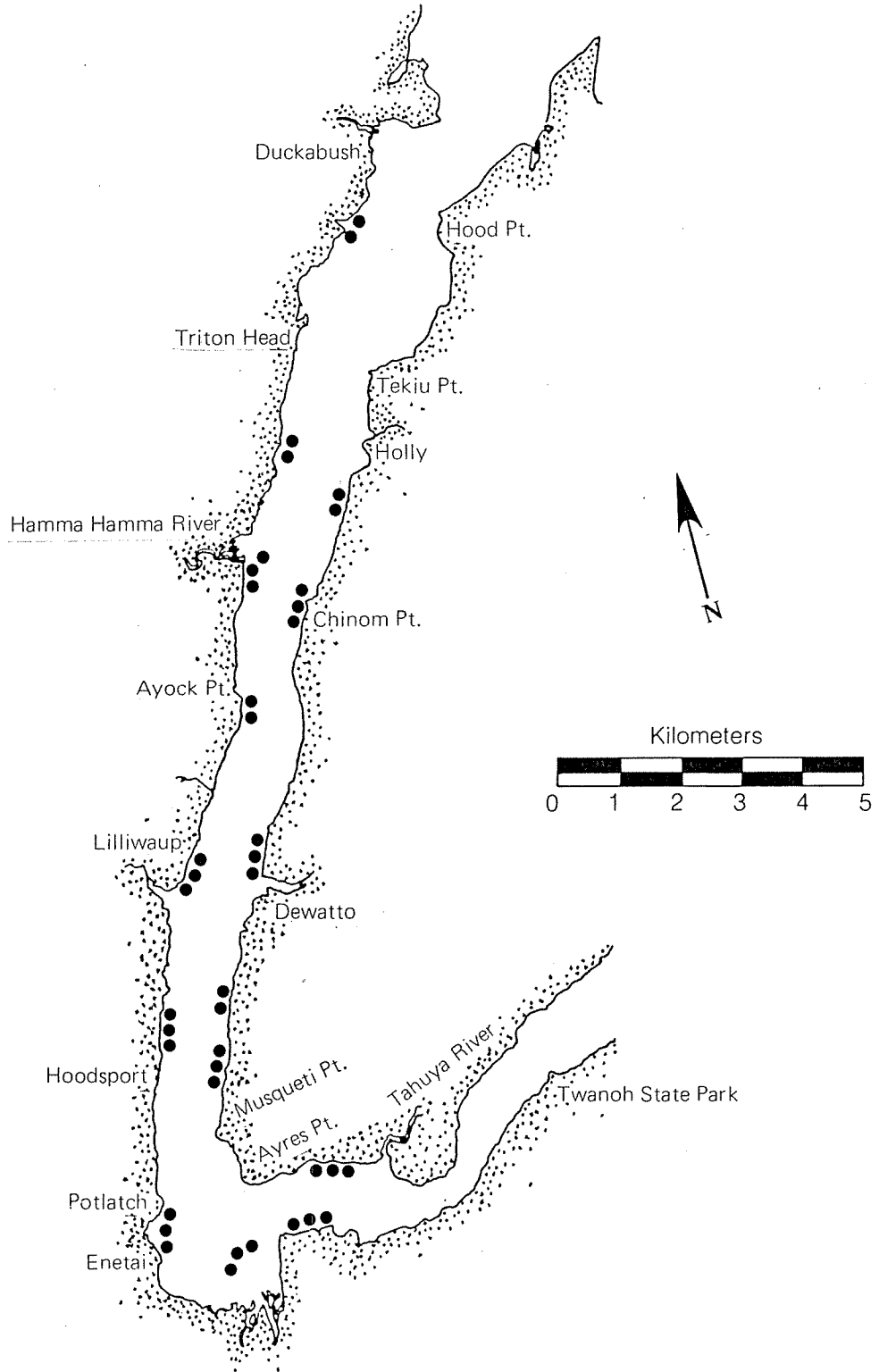


Fig. 3. Location of townet transects in Hood Canal, Washington, 1980.

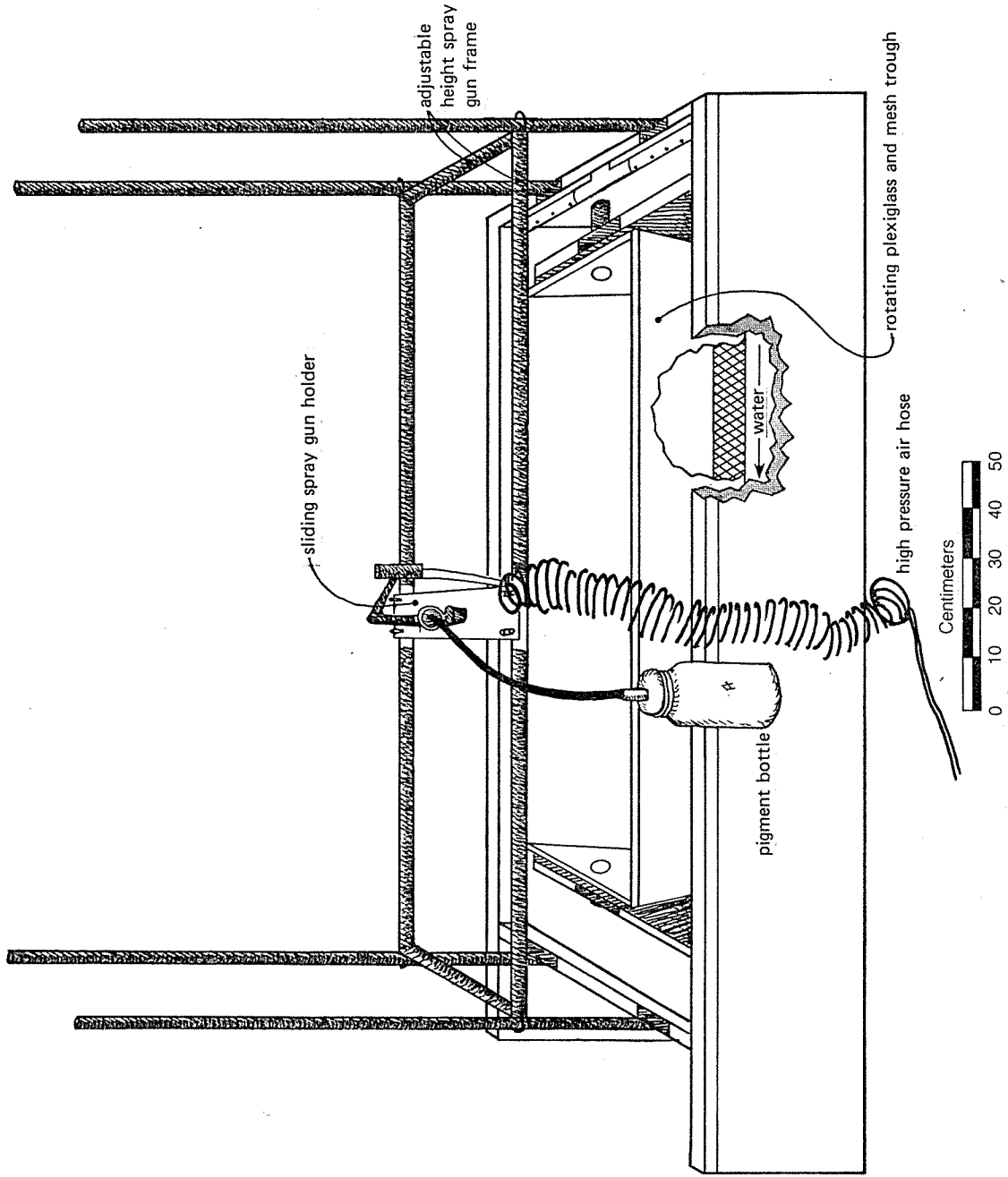


Fig. 4. Marking apparatus used to spray mark juvenile chum salmon with fluorescent pigment.

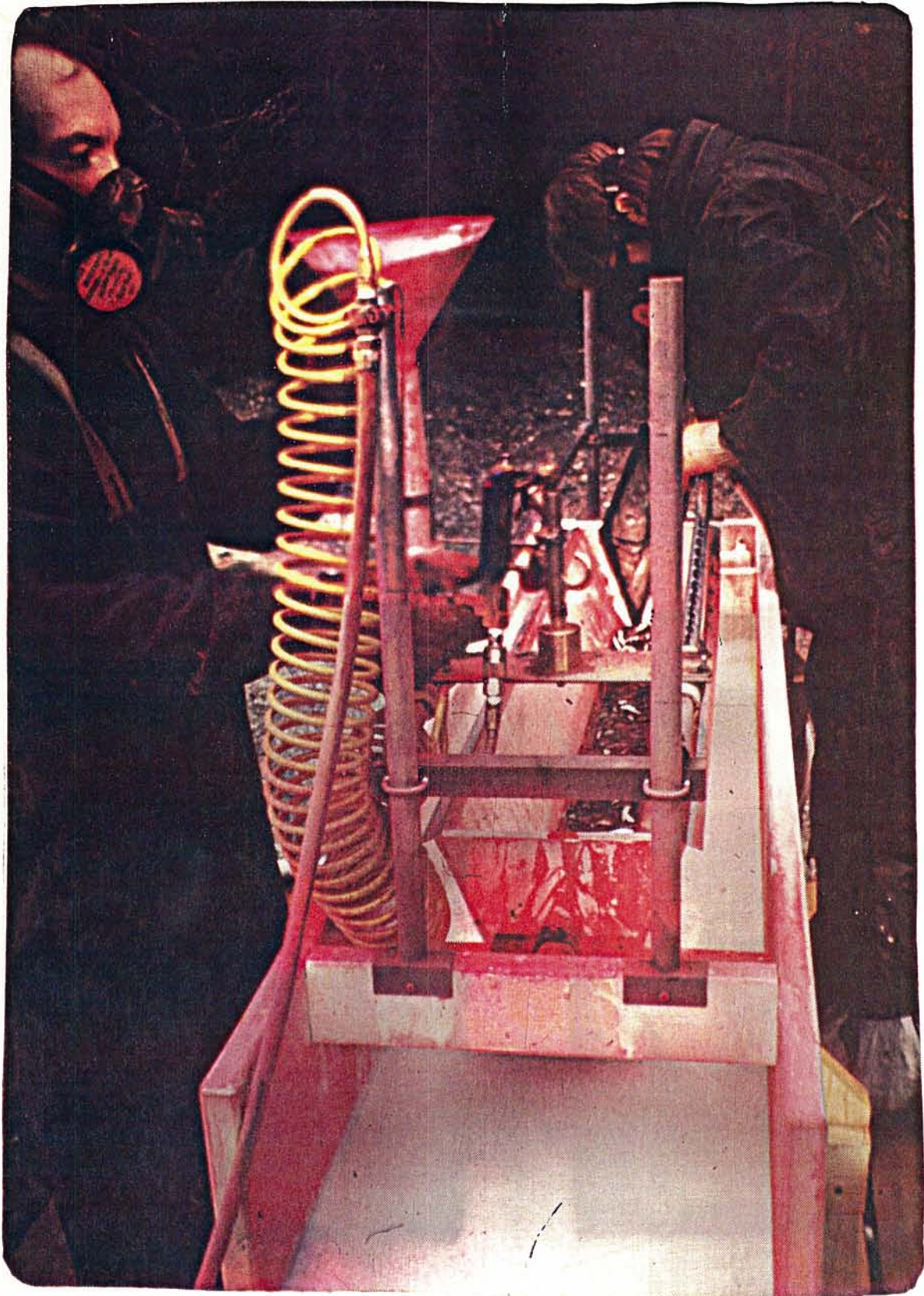


Plate 1. Spray marking of juvenile chum salmon with fluorescent pigment.

Hood Canal. On the evenings designated for their release the second and third groups were transported in saltwater tanks on the R/V TENAS to their release sites and released.

To estimate the effective release number (i.e., the number of fish with detectable marks), the percentage of the poorly marked fish which could not be detected during field mark evaluation was determined. All samples collected on the third day after release and separated into "marked" and "unmarked" categories in the field were retained. It was assumed that because of unlimited time and better conditions, analysis in the laboratory would yield 100% of the marked fish in the retained samples, including both well-marked and poorly marked. The numbers of marked fish not detected during field analysis (determined by laboratory re-analysis) were compared with the numbers designated poorly marked prior to release using the chi-square goodness of fit test. The numbers of fish not detected during the field mark examination did not differ significantly ($.50 < p < .75$) from the laboratory-determined poorly marked percentages, suggesting that these poorly marked fish were not detected in the field mark analysis. The experimental design does not require estimation of the marked to unmarked ratio and thus the estimated number of poorly marked and unmarked juveniles was simply subtracted from the release number.

Recapture of Juvenile Chum

A floating beach seine and a surface townet were used to assess the abundance of marked chum salmon. These standardized beach seining and townetting techniques have been used in a wide range of juvenile salmonid studies in which the principal objectives were to determine migration routes and timing (e.g., Whitmus and Olsen 1979; Fresh et al. 1979; Salo et al. 1980). No attempt was made to estimate the midwater distribution of the juveniles since previous studies by Stober and Salo (1973), Barraclough and Phillips (1978) and Tyler (1972) have shown that the majority of juvenile chum salmon are located in the top 3 m of the water column. Townetting was confined to the 10-m depth contour because catches decline rapidly with increasing distance from shore (Salo et al. 1980) but sampling any closer to shore would risk damaging the net. The catches on the 10-m depth contour have been found representative of the offshore distribution sampled by the townet.

Nearshore sampling was conducted with a floating 37-m beach seine with 18-m, 3-cm stretch mesh wings and a 0.6-m x 2.4-m x 2.3-m bag of 6-mm stretch mesh (Fig. 5). The net was set by an outboard-powered skiff 30 m from and parallel to the shore. The net was then drawn symmetrically to the shore by two persons on each bridle line of the seine. At 10 m from shore the net was closed, funneling the fish into the bag (Plate 2). Each set took from 3- to 3-1/2 min from the start of laying out the net to the time the bag was brought to the beach. Generally only one set was made at each site, but replicate sets were made at sites where large catches of marked fish were taken.

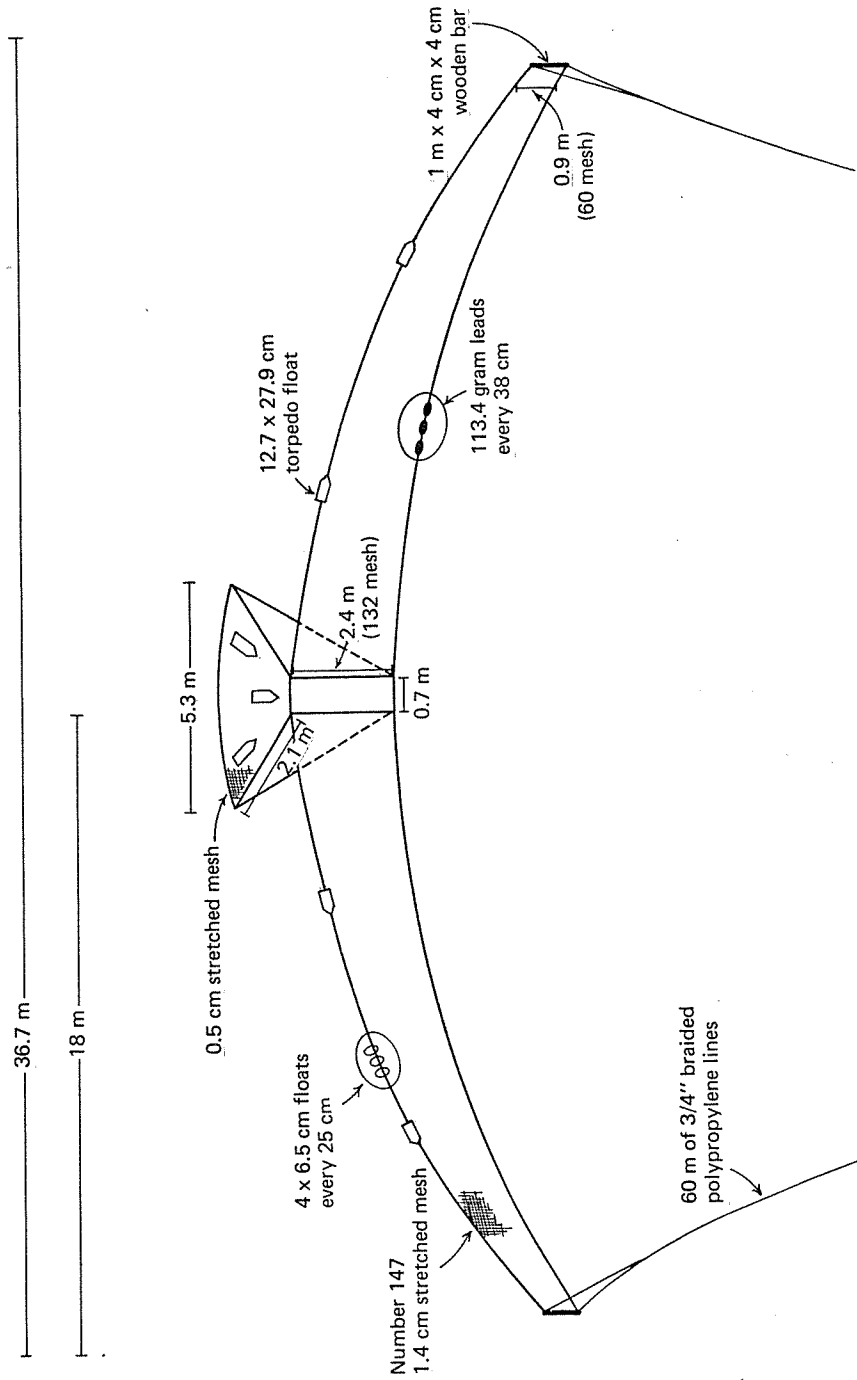


Fig. 5. Floating beach seine used in the collection of juvenile salmonids in Hood Canal, Washington, in 1980.

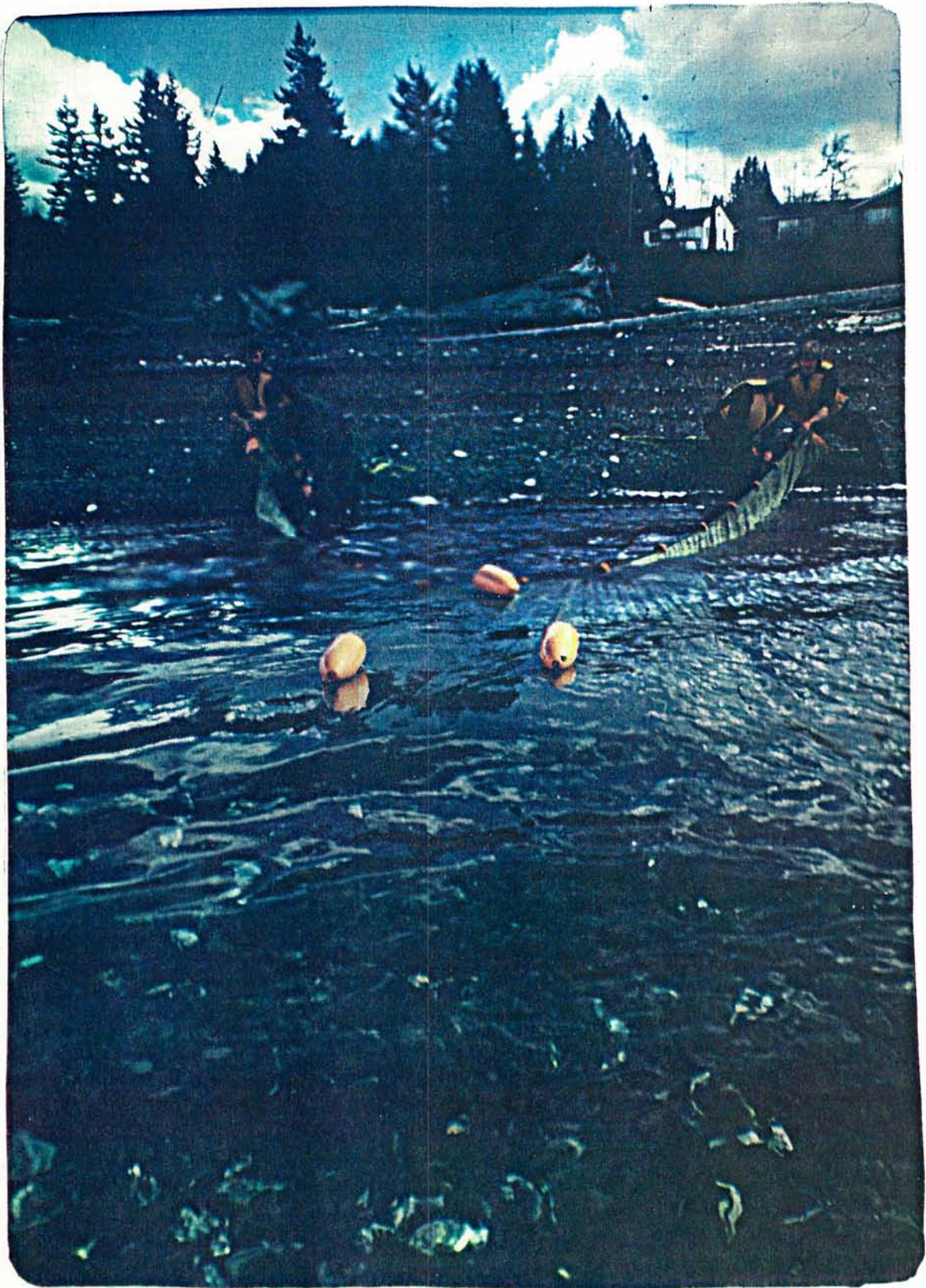


Plate 2. Beach seining in Hood Canal, Washington.

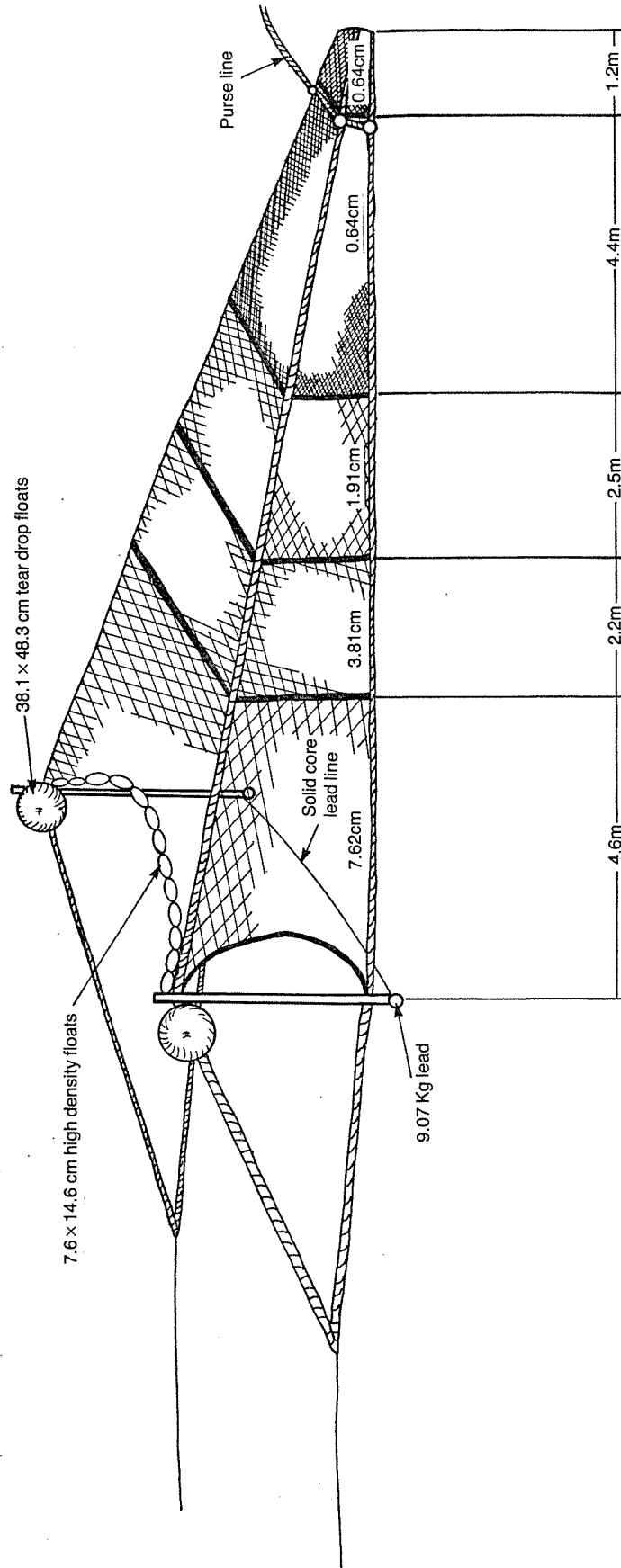


Fig. 6. Townet used in the collection of juvenile salmonids in Hood Canal, Washington, in 1980.

Offshore sampling was conducted using a surface townet towed between two boats, the 11.4-m R/V TENAS and the 7.8-m motor whaleboat NARWHAL. The mouth opening of the net measured 6.1-m wide by 3.1-m deep (of which about .5 m was above the water) with mesh sizes grading from 76 mm at the mouth to 5 mm at the bag (Fig. 6). The wings of the net were spread vertically by 3.75-cm diameter galvanized pipes which were connected with a short nylon bridle to single warps leading to each vessel (Plate 3). The net was towed with the tide at between 0.9-1.1 m/sec i.e., fast enough to keep the headrope at the wings just breaking the surface) depending on weather, tide, and the amount of drag caused by debris in the net. The cod end of the net was pursed every 10 min by a crew in an outboard skiff, and all fish removed for processing. This procedure obliterated the need to haul the townet after each 10-min tow.

To standardize catch data accounting for instances when more than one beach seine set or townet transect was made at one site in the course of a day a catch-per-unit-effort (CPUE) is defined here as the catch in one beach seine set or one ten minute townet transect. Since measurements of the efficiency of the two gear types are not available the two CPUEs cannot be quantitatively compared.

Sampling of Fish

Salmonids caught were sorted, enumerated and subsamples of no greater than 150 juvenile chum salmon taken from each beach seine and townet haul. The juvenile chum salmon were killed with tricaine methanesulfonate (TMS) and placed under ultraviolet illumination (black light) to determine the number marked. The marked juveniles were then preserved in 10% buffered seawater formalin. Our own (Salo et al. 1980) and Parker's (1963) experiments have shown substantial changes in the length and weight of salmon fry after death. To increase the precision of our length-weight analyses the subsamples were kept for eight days before measuring, by which time variations in these length and weight changes due to preservation had been reduced. Large hauls were weighed in the field using a spring scale, and a numerical estimation of the total haul made from the average weight of the chum salmon in the subsample. There may have been a slight overestimate of numbers because the average weight of the fish was reduced after shrinkage in formalin; it is not thought that the error was greater than 5% (Salo et al. 1980). Preserved fish were individually weighed (to the nearest 0.01 g) and measured (to the nearest 1 mm). Data on unmarked outmigrants were also recorded but are not analyzed in this report.

Size-Selectivity of Gear

The size-selectivity of the sampling gear was examined in order to accurately quantify growth and size-selective mortality. Groups of measured fish were released in front of the beach seine and townet and the length frequency distributions before release and after recapture compared.

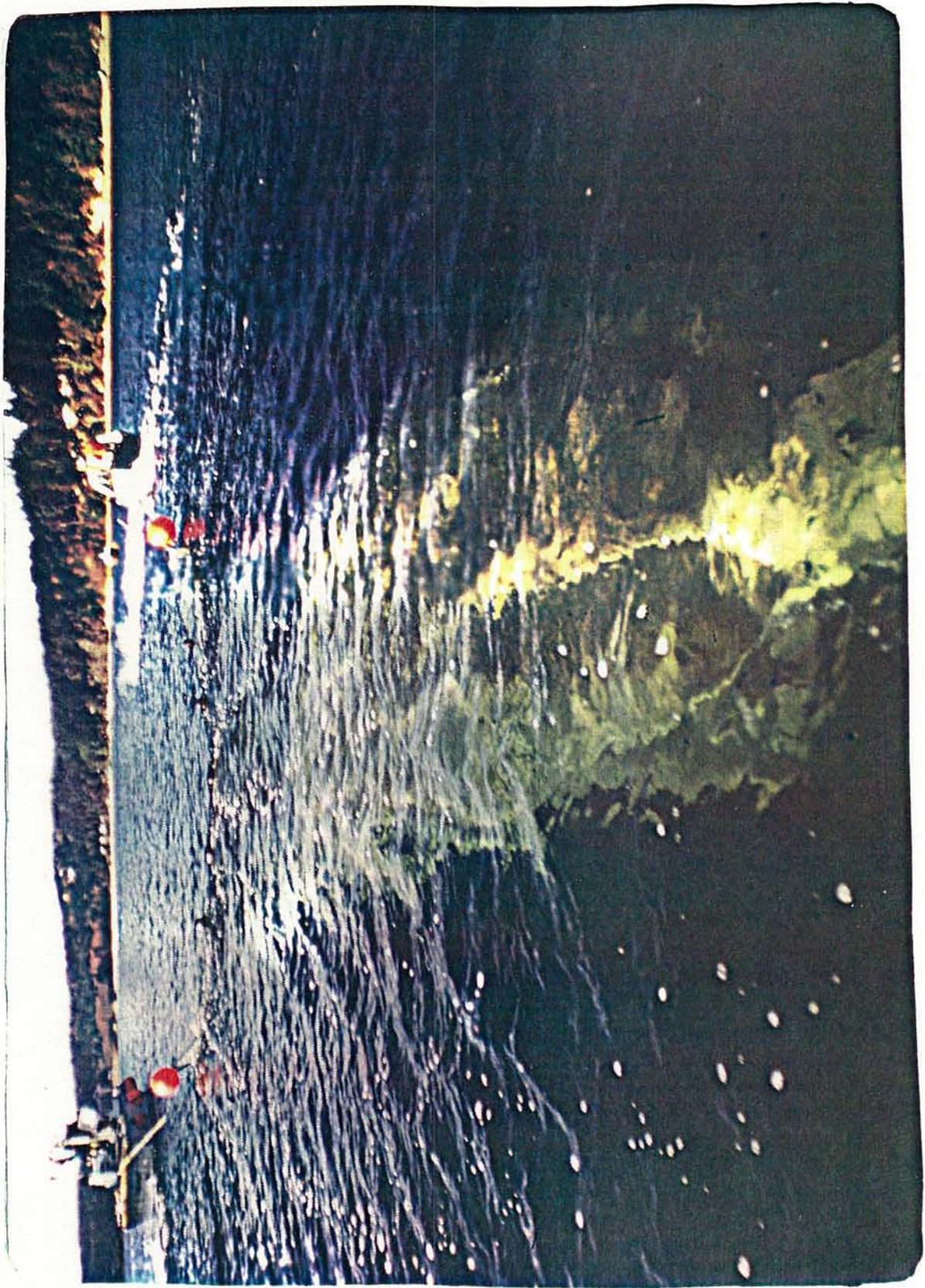


Plate 3. Townetting in Hood Canal, Washington.

Five hundred fish were selected from an original group of 9,400 juvenile chum salmon (size and origin of fish were the same as used in the mark-recapture experiment) for each gear size-selectivity trial. At alternate selectivity trials a control subsample of 100 fish was withdrawn from the original group to obtain the length frequency distribution and detect any change in the distribution of the original group due to possible selective withdrawals. The five hundred fish were placed in a floating net holding pen (wood frame 1 m x 0.7 m x 0.3 m covered with 3 mm stretched mesh netting; top open) attached to a skiff near the trial site and allowed to acclimate for 5 min before release. After 5 min the fish resumed a more "normal" behavior pattern in that they began to spread out and feed.

We performed 5 townet trials. These trials were conducted in the middle of Hood Canal where prior sampling determined that no other fish were present. The acclimation pen was positioned such that the two towing vessels would pass on both sides of the pen. The fish were released when the pen was 16 m from the mouth of the net and between the two boats. It appeared that the fish did not react to the towing vessels until the pen was 20 m from the net. After releasing the fish the skiff and holding pen floated over the top of the approaching net. The net was initially towed for 5 min before the bag was pursed and all fish removed. Five min was chosen for the initial tow because that is the average time that fish are in the net during the standard 10-min tows. After we checked the bag the net was towed an additional 10 min to capture any fish in the net which had not fallen back to the bag after the first 5 min and the bag again checked. This was repeated until the released fry were no longer being caught; normally this was after the second tow. All fish were retained and preserved, as described under fish sampling.

Four beach seine size-selectivity trials were run. An area of gravel beaches in Hood Canal with inclines typical of our sampling sites was chosen because the slope of the beach would affect the distance from shore at which the leadline of the net reached the bottom and could thus affect its selectivity. A beach seine set was made before the selectivity trials in order to confirm the absence of wild juvenile chum salmon. After approximately 5 min of acclimation in the pen the fish were released ~3 m from shore, as the beach seine was being set. The net was hauled as described above and a subsample of ~100 juvenile chum salmon retained from the catch for later length and weight analysis. The remaining juvenile chum salmon were enumerated and released.

Estimation of Marine Survival

Estimates of the early marine survival of the fluorescently marked juvenile chum salmon released from the Enetai hatchery into Hood Canal were based on subsequent releases of new marks after two and four days at the center of the first group's distribution. It was then possible to estimate the survival over the time between the original release and

the introduction of the new marks by the change in ratio between the size of the groups when released and when recaptured on subsequent days (Chapman and Murphy 1965; Seber 1973). Thus any mortality operating on the initial release group (M_1) before the introduction of the second group (M_2) would be detected as a decrease in the recaptures of the initial group (m_1) in relation to recaptures from the second group (m_2). Thus the survival (S_1) of M_1 between its time of release and the time of release of M_2 can be estimated by:

$$S_1 = \frac{M_2}{M_1} \cdot \frac{m_1}{m_2}$$

The variance of this estimate is dependent upon the possible errors involved in the estimate, and its estimation is described fully in Appendix I.

The assumptions that have to be satisfied for the successful use of this method are:

- 1) The distribution of M_1 must be known so that M_2 can be released at its peak.
- 2) Upon release M_2 will show similar behavior to M_1 , including migratory patterns, catchability and mortality rates.
- 3) The marking procedure must not influence the mortality of the juveniles once released if the estimate is to be representative of unmarked hatchery releases.

Growth Estimation

Ricker (1968) states that "growth during the first year of a fish's life, or at least the earlier part of it, tends to be exponential." To express growth, an exponential curve was fitted by regressing log weight on days since release. Growth, expressed as percent body weight gain per day (percent body wt/day), was determined by calculating (using the regression formula) weights on any 2 consecutive days and then calculating the percent change.

RESULTS

Fluorescent Pigment Marking

From May 12 through May 15 we marked 3 groups of juvenile chum salmon (mean fork length 50.2 mm, mean weight 0.97 g); 381,800 yellow or blue, 63,300 orange and 63,300 red. The marking mortality and retention data are summarized in Table 1. The mortality in the orange and red

Table 1. Marking mortality and mark retention from fluorescent pigment spray marking of juvenile chum salmon.

Group	Percentage			
	Mortality	Well marked	Poorly marked	Unmarked
Yellow-Blue	2.6	72.2	17.8	10.0
Orange (Orange)	6.3	87.1	10.9	2.0
Red	10.0	87.3	8.5	4.2

groups was much higher than in the yellow-blue, because these two groups were held in net pens in the hatchery pond which inhibited the water flow, while the yellow-blue group was unrestrained in the hatchery pond. The mortality directly attributable to marking for all groups combined was 3.8%.

On May 18 the two-day and four-day survival groups (orange and red) were transferred to salt water holding pens at Hoodspout where they remained until release. During the time the fish were held in the pens, a storm caused severe mortalities (1,000 orange and 39,000 red). The effective release sizes are given in Table 2. The releases of these groups on May 22 and 24, respectively, were made in the evening after completion of the day's ternet and beach seine sampling.

Size-Selectivity of Gear

Statistical tests indicated significant differences in length frequency distributions among control subsamples, and among ternet and beach seine catches (Table 3). However, as the differences among catches paralleled the differences among the control subsamples, we felt justified in pooling control subsamples and pooling all catches for each gear type.

In three of the five ternet trials over 99% of the recaptures were in the first 5 min tow. On the two occasions when larger numbers of juvenile chum were recaptured in the second tow, the mean size of fish in the second tow was larger than in the first ($p < .001$) (Table 4a). As our survey sampling design allowed at least two tows at each site, it was decided to combine the 5 min and 10 min tows for this analysis, and obtain an overall measure of size-selectivity.

The beach seine pooled recapture data did not differ ($p = 0.99$) from the pooled control subsample but the ternet data did ($p = 0.0031$, Table 4b). To illustrate which sizes were being selected against by the ternet a linear regression of the size distribution of the expected and observed recaptures per 500 fish released was performed for each gear (Fig. 7). The expected length frequency of the recaptures was simply the length frequency of the pooled control subsample adjusted by the mean recapture rate per 500 fish released for each gear. It can be seen that the observed and expected regression lines for fish caught by beach seine were very similar, indicating no size-selectivity, whereas the ternet regression lines were dissimilar, indicating fewer fish being caught than expected after approximately 50 mm (point at which the two regression lines intersect).

Migratory Behavior

On May 19, the day after release of the yellow-blue group of marked juvenile chum salmon, the fish had spread out both north and south of the release point and approximately one-seventh of the nearshore population (beach seine, Figs. 8 and 9) and two-thirds of the offshore fish

Table 2. Original and effective release sizes of marked juvenile chum salmon released from May 18 to 22, 1980 at Enetai, Hood Canal, Washington.

Group	Number marked	Unmarked and poorly marked fish	Mortalities	Effective Release
Yellow-Blue	381,819	140,712	9,227	263,545
Orange	63,252	7,520	4,957	50,775
Red	63,281	2,273	45,378	15,629

Table 3. Tests of significance on differences in length frequency distributions of replicate sub-samples, townet and beach seine catches of juvenile chum salmon.

Test	Cases	Haul					x ²	Signif.
		1	2	3	4	5		
Between control subsamples	404	Number	100	100	100	102	14.2770	0.0026
		& rank	171.8	208.9	232.6	197.5		
Between first townet samples	488	Number	99	99	102	88	31.7096	0.0000
		& rank	189.3	219.0	256.2	282.0		
Between second townet samples	96	Number	78	0	0	0	3.0182	0.0823
		& rank	46.1	---	---	---		
Between beach seine samples	411	Number	104	102	103	102	8.4407	0.0377
		& rank	212.0	196.0	185.6	230.5		

Table 4. Tests of differences in length frequency distributions between a) the first and second tow following a release and b) original release and subsequent recaptures of juvenile chum salmon.

Test	Cases		Kolmogorov-Smirnov 2-sample test				K-s	2-tailed P
	Sub-sample	Gear	Total	Abs	Max diff			
a) First townet sample	2nd	1st	584	.2816	.2816	-0	2.5221	0.0000
vs second townet sample	96	488						
b) Pooled samples vs pooled control subsamples	bs ¹	411	815	-.0239	.0170	-.0239	0.3405	0.9998
Pooled samples vs pooled control subsamples	tn ²	584	988	-.1164	-0	-.1164	1.7986	0.0031

¹bs = beach seine
²tn = townet

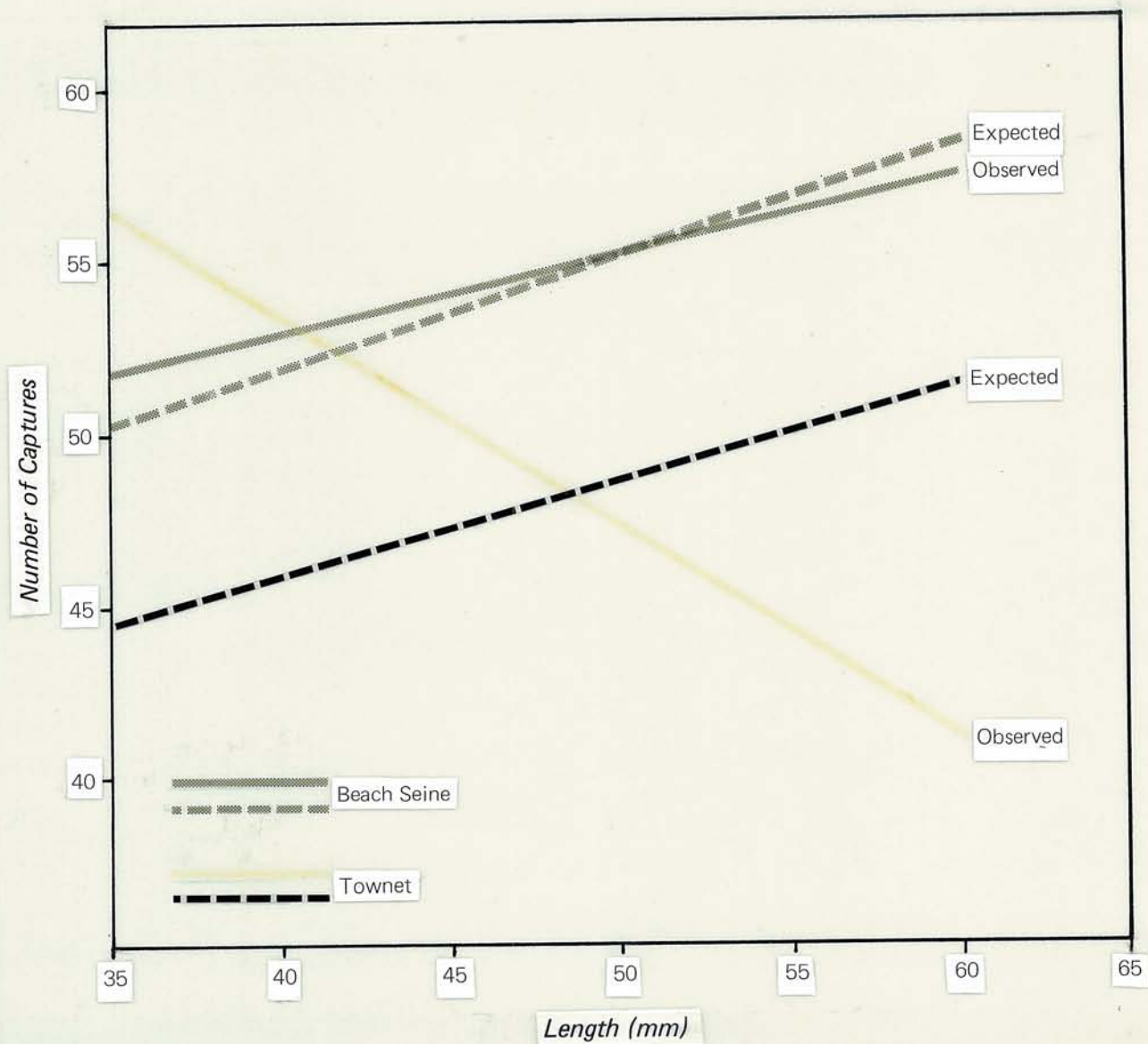


Fig. 7. Observed and expected regression lines of the length of juvenile chum salmon recaptured with the beach seine and townet from a release of 500 fish during gear efficiency trials in 1980. (The expected regression line is the number of fish caught per unit length if the fish were recaptured with the same length frequency as when they were released.)

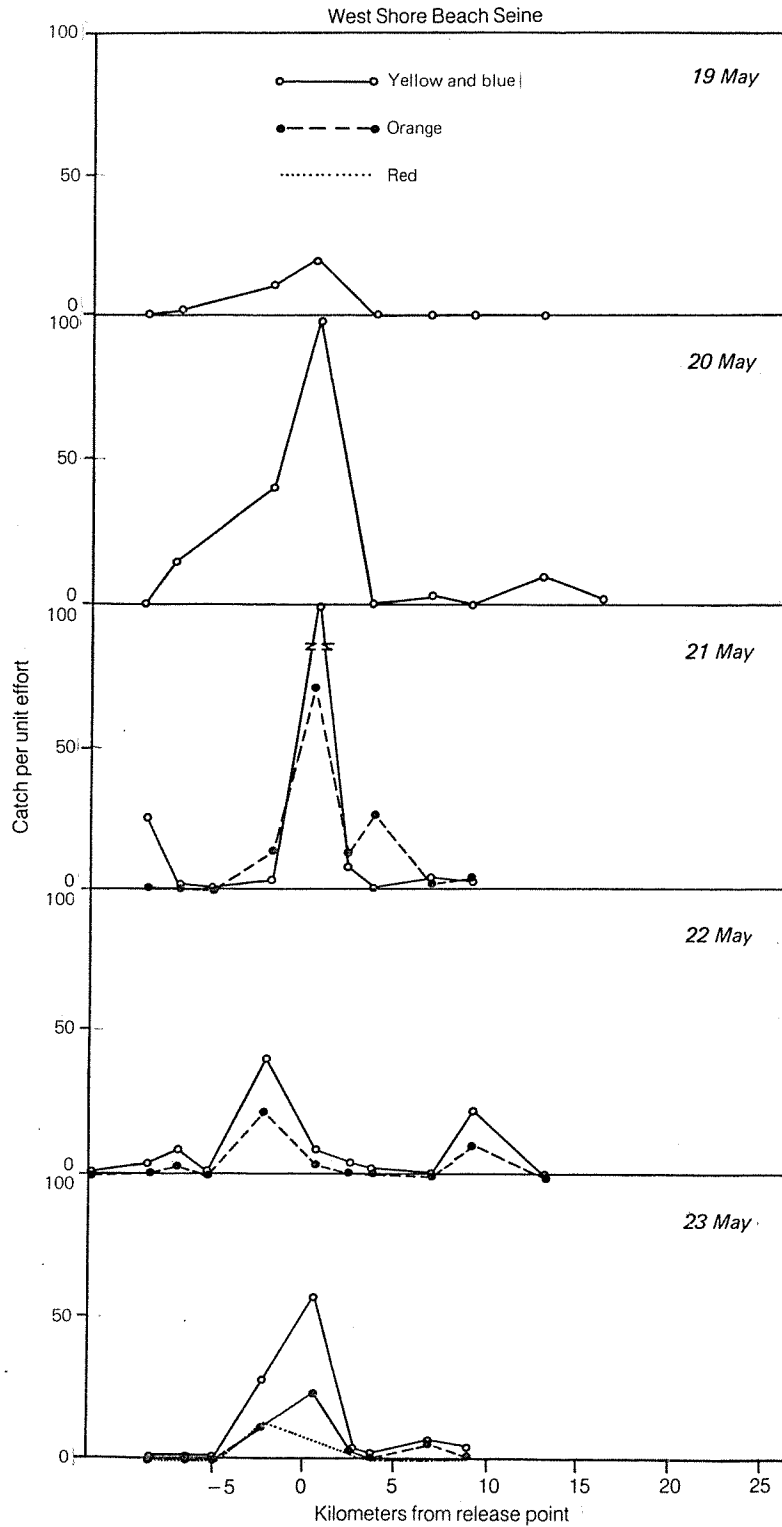


Fig. 8. Distribution of west shore beach seine CPUE of marked juvenile chum salmon released from Enetai, Hood Canal on May 18 (yellow and blue), 20 (orange), and 22 (red), 1980.

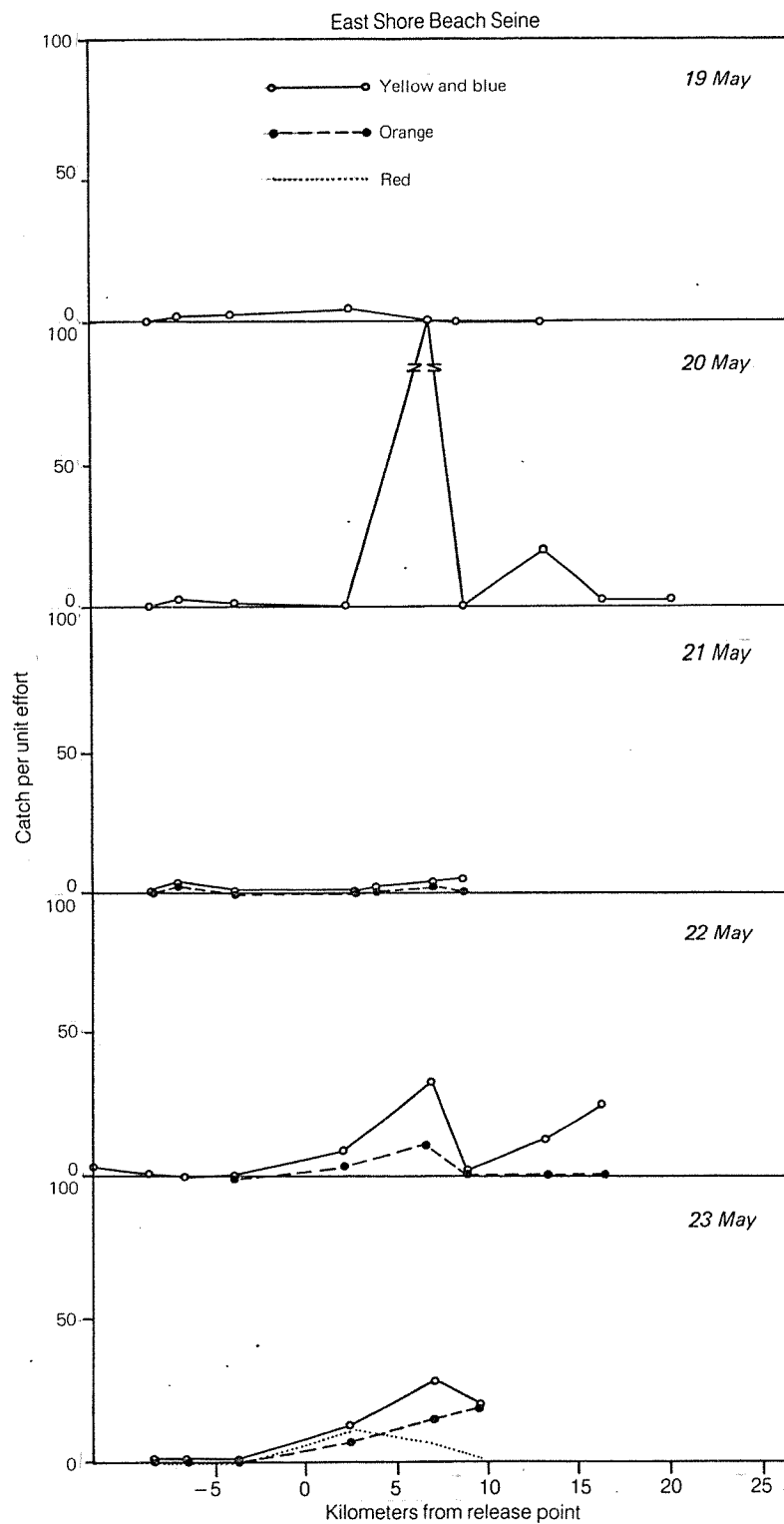


Fig. 9. Distribution of east shore beach seine CPUE of marked juvenile chum salmon released from Enetai, Hood Canal on May 18 (yellow and blue), 20 (orange), and 22 (red), 1980.

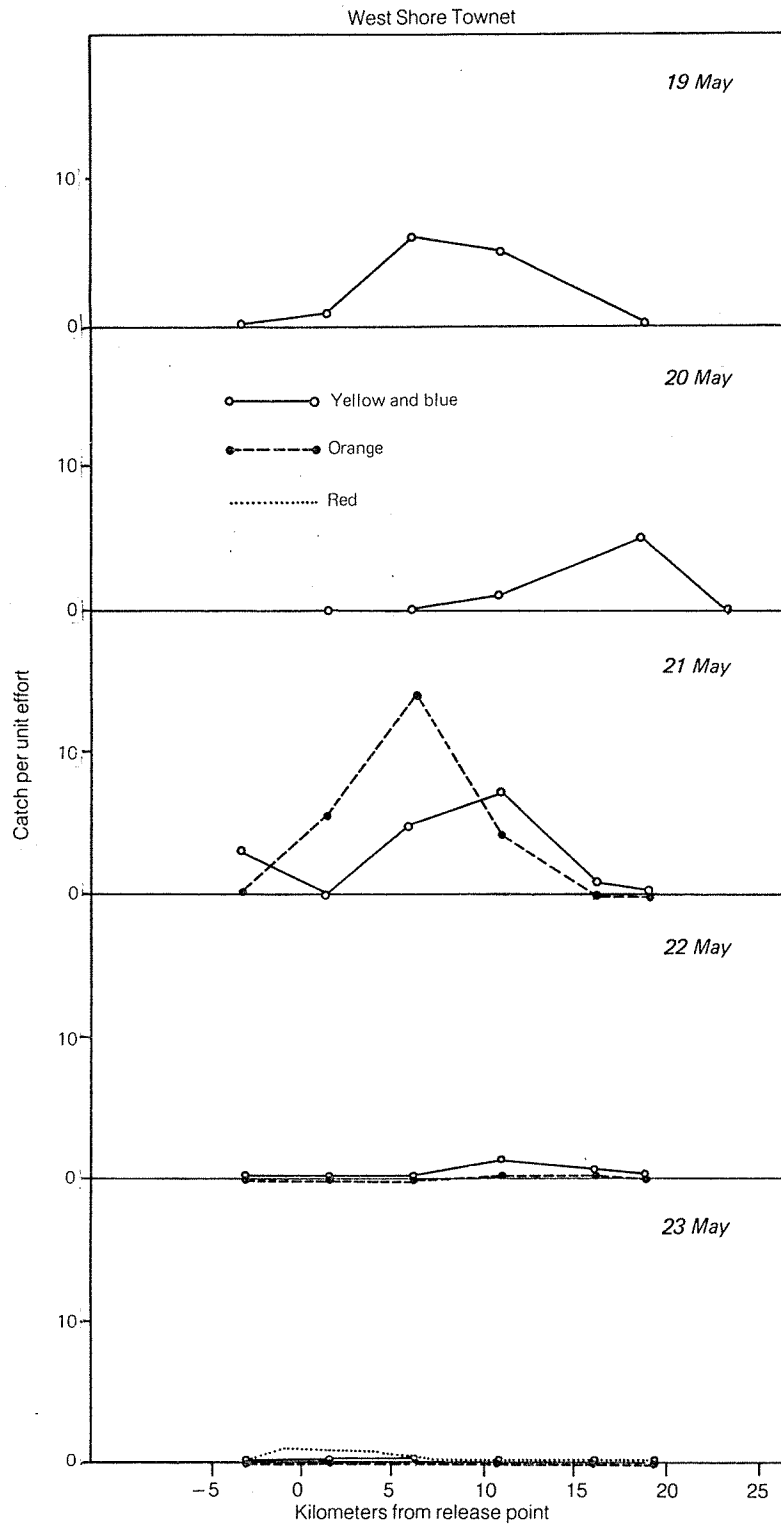


Fig. 10. Distribution of west shore tow net CPUE of marked juvenile chum salmon released from Enetai, Hood Canal on May 18 (yellow and blue), 20 (orange), and 22 (red), 1980.

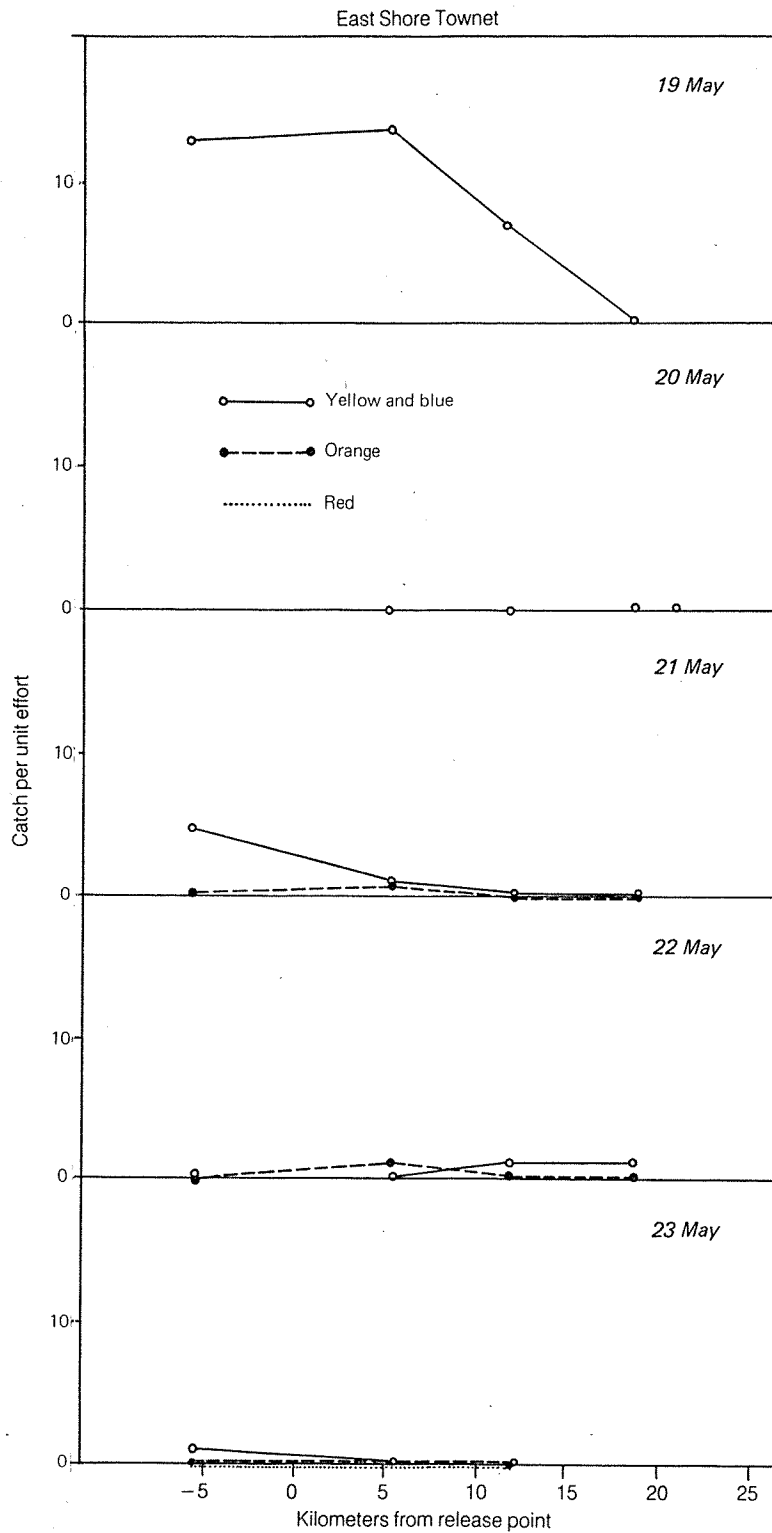


Fig. 11. Distribution of east shore townet CPUE of marked juvenile chum salmon released from Enetai, Hood Canal on May 18 (yellow and blue), 20 (orange), and 22 (red), 1980.

(towntnet, Figs. 10 and 11) had crossed the canal to the east shore. A Model I, two-way analysis of variance showed no significant differences in the lengths or weights between juvenile chum salmon caught on the two shores with either gear ($p > .2$ in all cases, Table 5a). Larger juvenile chum salmon were caught with the tow net than with the beach seine ($p < .001$; Table 5b). The large proportion of juvenile chum salmon that was caught on the east shore showed that a considerable cross-canal migration had occurred on the night of the release, however as catches with the tow net (in the offshore zone) were lower than those with the beach seine (in the nearshore zone) during the sampling period, there was little further migration through offshore waters. This large difference in number of recaptures between beach seine and tow net is not considered to be solely an effect of different gear efficiencies as gear selectivity trials and previous Hood Canal studies (Salo et al. 1980) have shown high catches of juvenile chum salmon of similar and larger sizes with this tow net. The marked decrease in recaptures with the tow net after the first day on the east shore (Fig. 11) and after the third day on the west shore (Fig. 10) shows migration out of the sampling area by those juvenile chum salmon found in the offshore zone sampled by the tow net.

We appeared to have sampled the entire distribution of marked fish that were available to the beach seine on the west shore on all 5 sampling days; however, the east shore distribution may not have been defined daily. The locus of the west shore beach seine population was found on the Skokomish flats during the study (Fig. 8). It is not known whether the marked fish caught away from the Skokomish flats, but still on the west shore, were actively migrating or were part of a more diffuse, but still stationary, distribution. The recaptures of marked fish caught with the beach seine on the east shore changed daily (Fig. 9) and we cannot with confidence describe the distribution of the east shore population.

The beach seine sites at Enetai, the release point, and at the Skokomish flats, ~2 km from the release point, had a consistently higher catch-per-unit-effort (CPUE) than other sites (Fig. 8). Since this area appeared to be the peak of the distribution at two and four days after release, the two survival estimate groups were released at Enetai.

On May 20 the orange group (50,775) was released at 2230 hr near Enetai. By the next day, the distribution of orange fish was similar to that of the yellow-blue group after one day. On subsequent days of sampling, the west shore distribution of orange fish continued to be similar to that of the yellow-blue group (Fig. 8); sampling on the east shore did not consistently cover the entire range of both groups and there may have been some differences in their distributions (Fig. 9).

The four-day survival group (15,629 marked red) was released at 2230 hr on May 22. The distribution of the red group on the first, and only, day studied was not noticeably different from the orange group on the west shore (Fig. 8). The center of the distribution of the red

Table 5. Model I two-way ANOVAs to compare lengths and weights of juvenile chum salmon caught with the beach seine and townet on the east and west shores of Hood Canal, May 1980.

a) Comparison between shores.						
Beach seine (n = 394)				Townet (n = 192)		
	Source	F	Sig.		F	Sig.
Length	day	7.820	.001	Length	day	1.762 .138
	shore	1.434	.232	shore	.090	.765
	inter-action	3.012	.018	inter-action	2.312	.102
Weight	day	17.926	.001	Weight	day	4.071 .003
	shore	1.345	.232	shore	.081	.777
	inter-action	2.036	.089	inter-action	2.010	.137

b) Comparison between gears.

Townet $\bar{x} = 49.6$ mm			n = 585
Beach seine $\bar{x} = 47.6$ mm			
Source	F	Sig.	
Day	10.452	.001	
Gear	10.463	.001	
Inter-action	.643	.632	

group was not as far from the release point as the other two groups on the east shore (Fig. 9).

Estimation of Marine Survival

The chosen sampling design involved following juvenile chum salmon by sampling at predetermined locations with a beach seine and townet. One of the main assumptions of this method of estimating survival is that the abundance distributions of the different marked groups are similar at the time of sampling. However, it has already been shown in the previous section on migratory behavior that this assumption was not met in every case. There were few recaptures of marked fish with the townet, and the changing distribution of those few recaptures indicated that emigration from the survey areas was occurring (Figs. 10 and 11). East shore beach seine data did not cover the northern end of the distribution (Fig. 9). The west shore beach seine recaptures (Fig. 8), showed a stable and sympatric distribution of the first two marked groups centered about Enetai. A chi-square test showed that the ratio of recaptures of the first two groups did not change over time ($\chi^2 = 4.185; 25 > p > .10$), indicating that neither group was emigrating at a faster rate than the other. Accordingly, the latter data set was used to estimate survival, the west shore area sampled by the beach seine is referred to as the "sampling area" subsequently in this section.

The manner in which the survival is estimated does not distinguish between mortality and emigration from the sampling area. Two approaches were taken to estimate this emigration. Firstly, as the distribution of marked juveniles in the sampling area from the first group was centered on the release point or the adjacent Skokomish River flats during the course of the study (Fig. 8), it was assumed that, after a large initial emigration to the east shore and to offshore areas immediately upon release, there was no subsequent emigration from the sampling area. The second approach assumed that all marked juvenile chum salmon caught north or east of the Skokomish flats on the west shore would have emigrated out of the sampling area by the next day. The proportion of the population formed by these "emigrants" was estimated as the proportion of the total area under the CPUE graph (Fig. 8) found east or north of the Skokomish flats (i.e., further than ± 3.2 km from the release point, Enetai) on a daily basis. The daily proportions remaining on the flats were graphed and Model I linear regressions run (Fig. 12). An estimate of emigration and its variance was calculated for each group to cover the period until its comparison group was released. To account for the simultaneous operation of mortality and emigration an iterative procedure was used to compute emigration as a proportion of the original population. This technique assumes that observed emigration was operating on a population midway in size between the original population and the population remaining at the time of introduction of the comparison group. Once emigration was estimated in this manner, survival was recomputed

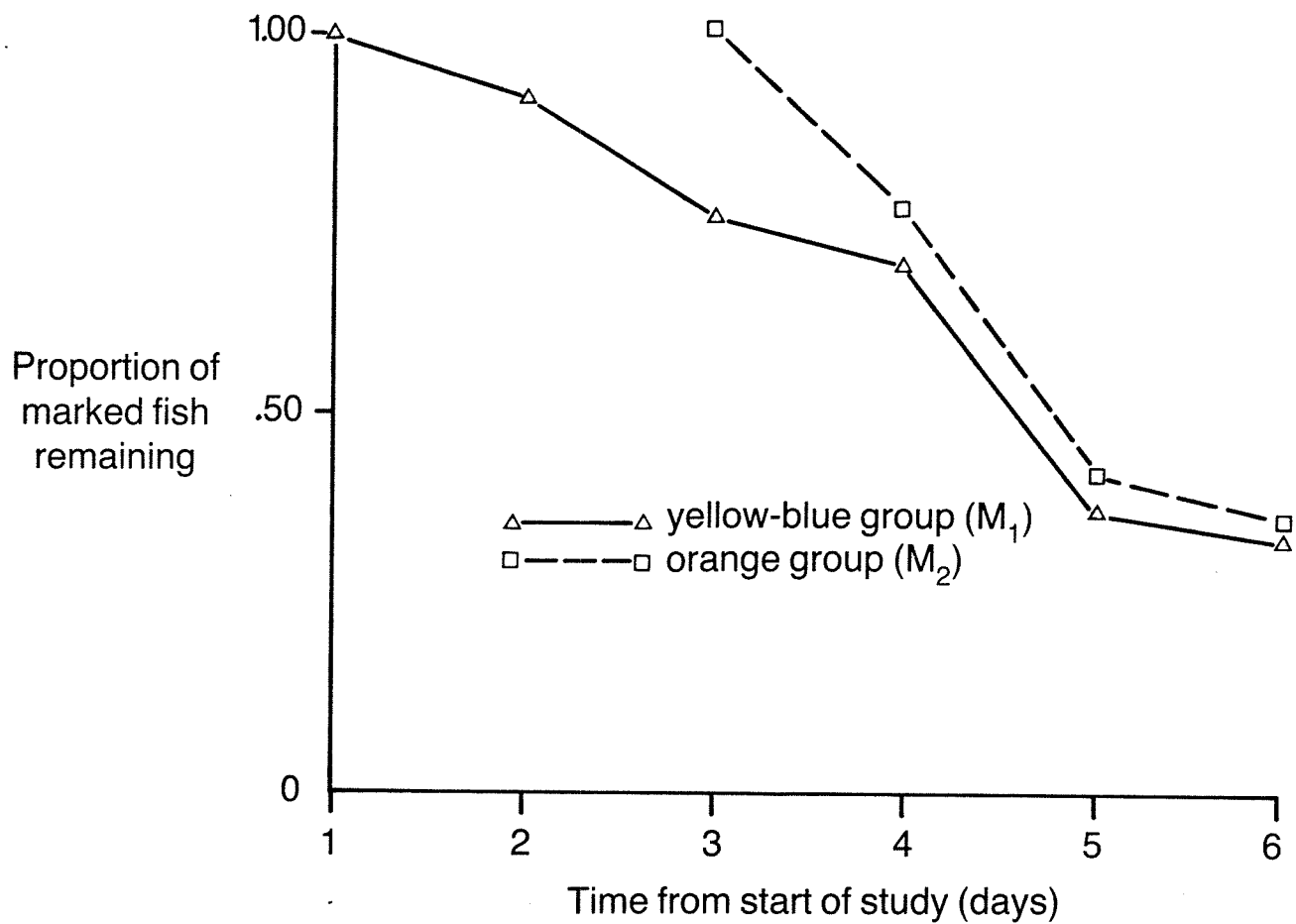


Fig. 12. Proportion of populations of marked juvenile chum salmon (minus) initial dispersal) remaining on the Skokomish flats in Hood Canal, after their release on May 18 and 20, 1980.

accounting for the effective decrease in size of the original population. This procedure was repeated until the values stabilized to the third significant digit. It is considered that this method may overestimate emigration, leading to a conservative mortality estimate. Firstly, it is unlikely that all marked fish caught away from the Skokomish flats would have migrated out of the sampling area by the following day--previous estimates of the migration speed of juvenile chum salmon of a similar size range released from the Hood Canal hatchery (WDF) in April and June 1977 are 9 and 4 km/day, respectively (Whitmus and Olsen 1979). Secondly, basing the proportion of marked fish on and off the Skokomish flats on only length of shoreline and CPUE does not take into account the extensive sublittoral habitat available to salmonids on the Skokomish flats.

Factors needed to be taken into account in calculating the variance are 1) the variance associated with estimating mark retention, which is simply the variance of a poisson variable, 2) the variance associated with emigration described above, and 3) the variance associated with the heterogeneity of the samples. The heterogeneity is seen as a difference in the ratio of one marked group to the other from sample to sample (Table 6b). The calculation of these variances, and hence, the variance associated with the survival estimate, is described fully in Appendix I. It is shown that the assumptions of equal emigration of the marked groups from the sampling area does not add to the variance estimate to the first order approximation (Appendix I).

With three marked releases we were able, using the above method, to obtain three estimates of survival. These were the survival of group M_1 over the first 2 and 4 days of their marine residence (i.e., until the introduction of M_2 and M_3), and the survival of group M_2 over their first 2 days of marine residence (i.e., until the introduction of M_3).

The survival estimates and their confidence limits were computed under the assumptions of zero and of maximum emigration (Table 6c, Fig. 13). The mean estimates of survival over two days were .51 and .42 for M_1 and M_2 , respectively assuming zero emigration. These estimates increased slightly to .55 and .52 when calculated correcting for any emigration. The similarity of the estimates under either assumption suggests that the survival estimates are not strongly influenced by recorded emigration over the short time period involved. However, when the emigration rate is higher as it is for M_2 in comparison to M_1 (Fig. 12) -- or when a longer time interval is considered--mean survival estimate of M_1 over 4 days was .20 and .26 for zero and maximum emigration, respectively--then the influence of emigration on the survival estimates increases.

The assumption of an equal mortality rate of M_1 (released from the hatchery) and M_2 and M_3 , (held in salt water pens and then transported

Table 6. Summary of mark-recapture data and survival estimates for juvenile chum salmon released from May 18 to 22, 1980 at Enetai, Hood Canal, Washington.

		Initial release	Sampling day (i)				
			1	2	3	4	5
Effective release:	M_1	263,545					
	M_2			50,775			
	M_3					15,629	
Recaptures:	m_{1i}		53.1	111.0	380.0	71.2	213.0
	m_{2i}				127.4	36.5	91.0
	m_{3i}						61.0

b) Chi-square analyses to test for equivalence in ratio of group A to group B between samples.

Group A	/	Group B	n	x^2	Significance
M_1	/	M_2	17	54.83	$p \ll .001$
M_1	/	M_3	5	42.95	$p \ll .001$
M_2	/	M_3	6	30.13	$p \ll .001$

c) Survival estimates.

Group	Time period (days)	Estimated survival		95% confidence bounds	
		Zero ¹	Maximum ¹	Zero ¹	Maximum ¹
		emigration	emigration	emigration	emigration
M_1	2	.51	.55	.29, .72	.34, .76
M_1	4	.20	.26	.12, .28	.15, .36
M_2	2	.42	.52	.24, .61	.29, .76

¹See text for definition of these conditions.

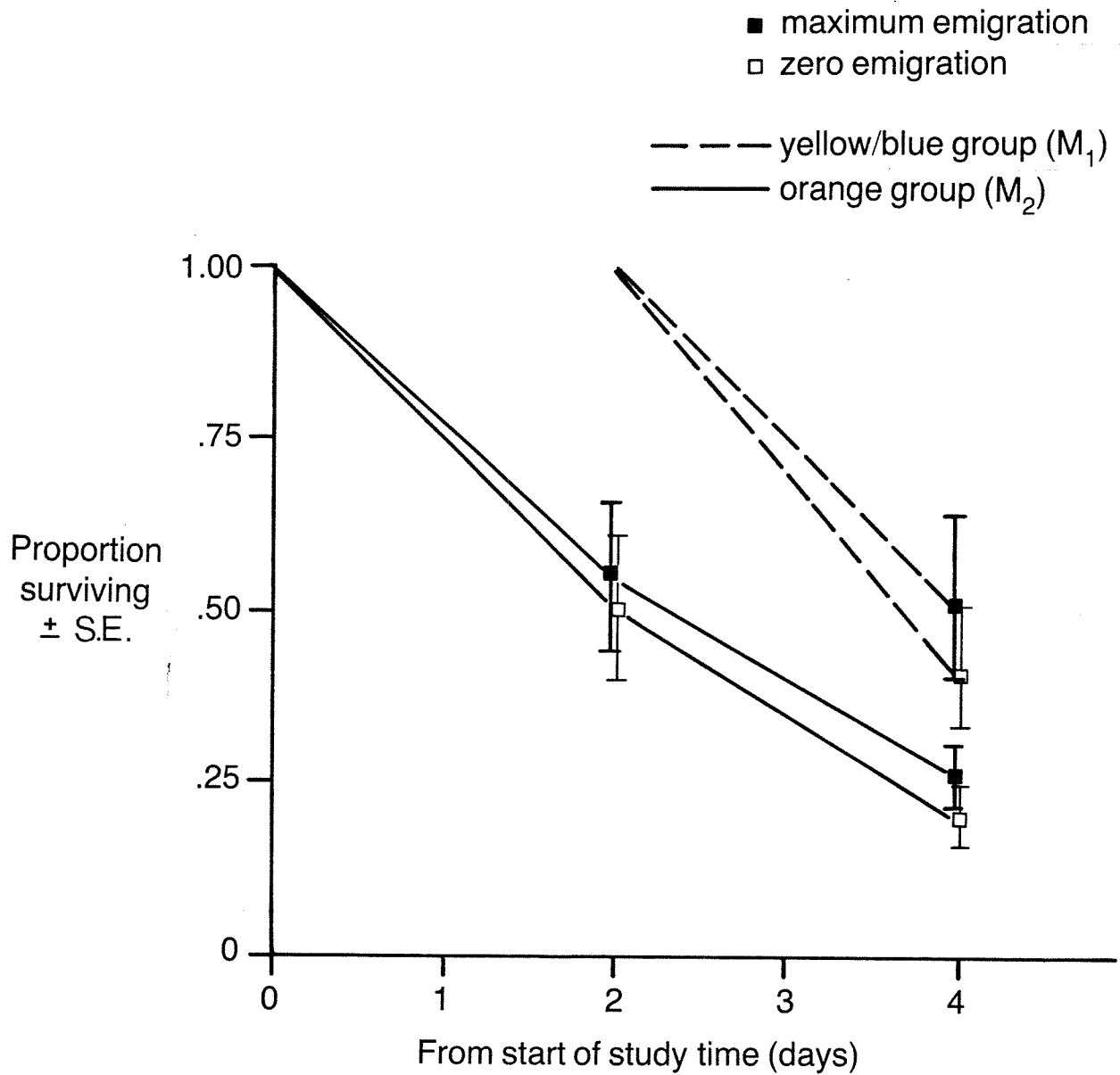


Fig. 13. Rate of survival of marked juvenile chum salmon remaining on the Skokomish flats, Hood Canal, after their release in May 1980.

to the release point) is upheld by the similarity in mean survival estimates between M_1 and M_2 over the two days subsequent to release (Table 6c and Fig. 13).

The survival of M_1 is estimated over two time periods--two and four days. These estimates do not indicate any change in the rate of survival over this time period. If any undetected emigration was occurring its effect would be cumulative over the study possibly masking any increase in survival rate with time.

Growth Estimate and Size-Selective Mortality

Marked recaptures from the May 18, 1980, release (yellow or blue) were the only fish used in the growth estimate. The other groups (red and orange) were not sampled over a long enough period to estimate growth. We used only beach seine recaptures, since the townet had been found to be size-selective. A Model I, two-way analysis of variance with gear and day as independent variables showed a significant difference in the dependent variable, length, between gears (townet larger, $p < .001$, Table 5b). Thus, our growth estimate may be biased toward lower than actual growth if the larger juveniles available to the beach seine at the start of the experiment moved offshore during the study. Additionally, we could not use data collected at the time of release because some of the larger juveniles moved into the offshore area immediately upon release.

The regression of log weight on day of recaptures from day 1 to day 5 yielded the following regression formula:

$$\log_{10}w = 0.036 t - 0.147$$

where w = weight in grams and t = days after release. From this regression formula we calculated the growth rate to be 8.6% body wt/day. The coefficient of determination (r^2) for this regression was 0.16. Considering the low r^2 , this growth rate must be regarded with a great deal of caution. Past estimates of the growth of juvenile chum salmon in Hood Canal which were based on ~ 25 days (Whitmus and Olsen 1979, Prinslow et al. 1980) have shown a lower growth rate and higher r^2 values, although total recaptures were approximately the same. In order to determine if the high growth rate and low r^2 could be explained by the short period of time over which recaptures were made, we compared this data to 25 days in 1979 (Prinslow et al. 1980). Growth rate was 6.9% body wt/day and the r^2 from this regression was 0.60. Using only the first 4 days of data, the regression indicated the growth rate was 10.5% body wt/day and the r^2 value 0.12.

The growth rate calculated for only the first four days is significantly higher than that calculated for the whole 25 day period as shown

by analysis of covariance ($.05 > p > .025$). It is unlikely that this initially higher growth rate is due to an artifact of our sampling procedures as our only identified bias (offshore migration of larger juvenile chums salmon) would cause an apparently lower initial growth rate. Parker (1971) suggested that size-selective predation may cause an apparently high growth rate.

In order to determine if there was any size-selective mortality (relative decrease in numbers of smaller fish) or emigration, (relative decrease in the numbers of larger fish) the length frequency of marked fish captured in the beach seine on day 1 was used to predict the length frequency of fish captured in the beach seine on day 5, compensating for growth as estimated above. If no size-selectivity mortality or emigration took place, the predicted length frequency for day 5 would be expected to be the same as that observed. Day 5 expected length frequency was compared with the observed frequency using the Kolmogorov-Smirnov goodness of fit test. Sampling sites where significantly different size distributions from the average were caught were not used in these analyses. There was no detectable size-selective mortality ($p = .57$), however this analysis was not very sensitive due to the small sample size ($n = 88$).

The results indicate that growth upon entry into the marine environment does not follow a simple exponential model, at least for the hatchery fish captured in this study.

DISCUSSION

In any experiment involving the marking of animals the question of the effect of the marking process upon the ensuing behavior of the animal must be addressed. The fluorescent spray marking technique used here was selected because it requires a minimal amount of fish handling. There was a small immediate mortality associated with the marking (3.8%) but no further substantial mortality in the 3 days (minimum) that they were held prior to release. Previous experimenters using this technique have reported no difference in mortalities between marked and control juvenile chum salmon held in salt water pens for 30 days after marking (Olsen, personal communication).¹ Healey et al. (1976) formed the tentative conclusion that there was no inhibition of growth among spray-marked rainbow trout fry when compared with an unmarked group. Parker et al. (1962), however, drew attention to the increase in susceptibility to predation of marked fish. This increase was due not only to the physical appearance of the mark (no significant in our technique) but also to the behavioral changes brought about by the stress of marking: decrease in swimming rate, breakdown of normal schooling behavior, and a change from active to passive avoidance of predators.

In this experiment the stresses on the juveniles due to the release procedure probably superceded those remaining from the marking process.

¹Scharleen Olsen, Washington State Department of Fisheries.

The first group, from which we derived our growth estimate and the majority of our behavioral observations, was released by the customary method at the Enetai hatchery--removal of the central standpipe in the rearing ponds so that juveniles would be washed down a 20-cm diameter pipe to the 1/4 km creek leading into Hood Canal. The second and third groups suffered stress during their confinement in salt water pens inadequately protected from the inclement weather conditions. They were further stressed on being transferred from the pens to circulating salt water tanks on the R/V TENAS for transport and release. Studying the stress responses of coho salmon smolts to transportation, Specker and Schreck (1980) found that "the number of fish migrating on the first day (after release) appeared to be inversely related to the degree of stress en route, but the movements of all groups were similar thereafter." Additionally, they found that "transportation reduced the ability of coho salmon smolts to tolerate a second stressing agent." Thus, it is to be expected that the migratory behavior of the juvenile chum salmon may have been affected by their transport to the release site. Furthermore, if a second stressing agent was present in the marine environment their survival chances may have been further diminished. Although there is some indication of a lower survival of M_2 compared to M_1 when emigration is assumed negligible, this difference diminishes if emigration out of the sampling area is considered. The cause of this change can be explained by the higher emigration rate of M_2 when compared to that of M_1 on the day after release (Fig. 12). We can conclude that M_2 was not stressed to a greater degree than M_1 as evinced by the similar survivals and the higher rate of emigration of M_2 on the first day.

The essentially stationary distribution of the juvenile chum salmon on the west shore was contrary to the results of previous Hood Canal studies where the migration rate was found to be between 3 and 14 km/day (Whitmus and Olsen 1979; Salo et al. 1980). Although there were seasonal and annual variations in the migration rate of juvenile chum salmon measured previously in Hood Canal (Bax et al. 1980), extended residence in one area was never encountered. This residence on the west shore may have been due to the proximity of the release area to the Skokomish River tide flats, an area which concurs with other researchers' definitions of juvenile chum salmon nursery areas (Allen 1974; Mason 1974; Cooney et al. 1978; Healey 1979). Previous releases of chum salmon from hatcheries on the Skokomish River (George Adams fish hatchery in 1977; Hunter Springs fish hatchery in 1979) have been suspected of showing a delayed migration (Bax et al. 1978, 1980). It does not seem likely that the lack of rapid migration in this study resulted from stress, as reported by Specker and Schreck (1980) for juvenile coho salmon, because other aspects of the migratory behavior of the juvenile chum salmon followed the behavior observed in previous Hood Canal studies (Whitmus and Olsen 1979; Whitmus, unpublished data). These were the initial crossing of Hood Canal by one seventh to two thirds of the release and the subsequent fan-like dispersal on both shores.

A principal assumption involved in our estimation of survival is that emigration from the sampling area was equal for all groups. Emigration could take two forms: 1) emigration from the sampling area by M_1 , after the initial dispersal, but before M_2 was released on day 3, or 2) emigration once both groups were released. In the first case, emigration would be indistinguishable from mortality and would be included in our estimate. By estimating survival first under the assumption of zero emigration after the initial dispersal and obtaining a second estimate incorporating what we consider to be an overestimate of emigration we expect to have bracketed the true survival rate. Emigration of the first form was found to have only a small effect on the survival estimates over the period studied. No attempt was made to correct for any differences in emigration between the two groups once both had been released. The data indicated that M_2 may have emigrated at a higher rate than M_1 (Fig. 12), however at no time did total percentage emigration from M_2 surpass that from M_1 , and thus true survival would not be below that estimated from assuming zero emigration.

There are few prior studies with which to compare our estimates of early marine survival. Parker (1962) assuming "ecological similarity" between pink and chum salmon estimated that the survival of juvenile chum salmon during the 5-month coastal period was 5.45%. In a later study, Parker (1968) estimated that from 2-4% average daily loss occurred to a pink salmon population during the initial 40-day period of sea life. It is important to note that observations were not taken on the initial 10-day period which "may have seriously underestimated the initial mortality rate," and that the assumptions involved precluded placing any great emphasis on these "most probable values." Results from other research suggesting the importance of environmental and other variables during the early marine phase on the return of adult chum salmon in Hood Canal (Gallagher 1979) and adult pink salmon in other areas (Vernon 1958; Gilhousen 1962; Blackbourn 1976; Kron 1976; Taylor 1976; Jones 1980) support the concept of the early marine environment being a critical period in the life history of chum salmon. If we assume in this study that the survival rate remains constant over the four day period, as is suggested by the estimates for M_1 (Fig. 13), then average daily loss was 29%. This is an order of magnitude greater than Parker's (1968) estimate which covered a period two weeks later in the marine migration of Bella Coola pink salmon.

It has been suggested that, as in freshwater, predation by coho salmon smolts could play an important part in the early marine mortality of juvenile chum salmon (Parker 1971) and there have been several suggestions of high coho salmon smolt predation on juvenile chum salmon in Hood Canal, although no samples were taken to confirm this (Heiser and Finn 1970; Kaczynski et al. 1973). More recent studies (Bax et al. 1978; Fresh et al. 1979) suggest that predation by coho salmon smolts occurs only at a low rate, if at all, in Puget Sound (0 and 0.08% of the diet, respectively) and in this study 48 coho salmon smolts ($\bar{x} = 116 \pm 6$ mm [S.E.], F.L.) caught in the beach seine with several hundred juvenile

chum salmon at 9:10 a.m. on the Skokomish River flats had practically empty stomachs and no identifiable fish remains. Fish other than coho salmon smolts may be important predators of juvenile chum salmon. In a previous study in Hood Canal (Simenstad and Kinney 1978) it was found that 19% of the sea-run cutthroat trout, 17% of the staghorn sculpin, 8% of the chinook salmon smolts, and one out of the two Pacific cod sampled had chum salmon remains in their stomachs, although they did not form a large percentage of the diet spectrum of the predator species (3%, 3%, and 2%, respectively). Dunford (1975, cited by Cardwell and Fresh 1979) found that chum salmon juveniles comprised some 25-65% of the April prey biomass of chinook salmon smolts and 30.5% of the prey biomass of staghorn sculpin in the Fraser River estuary. Other predator species reported to prey heavily on juvenile chum salmon include herons and common mergansers at Big Qualicum (Allen 1974). On Protection Island, Washington, Manuwal (1977, cited by Cardwell and Fresh 1979) estimated that juvenile salmon made up 5% of the prey biomass for a breeding population of 34,000 auklets. Further, as Cardwell and Fresh (1979) caution, if the standing stocks of predators are large, as they may be in Puget Sound, then even a small percentage of their total prey biomass would be a substantial proportion of a juvenile chum salmon population.

Potential predators, with the exception of the 48 coho salmon smolts, were not examined in this study and so we cannot, except by inference, implicate predation as a cause of the substantial mortalities observed. Data supporting the concept of a high rate of predation occurring on the juvenile chum salmon population under study is the apparently high growth rate (9%) in this study and during the initial period of a similar study in Hood Canal (10%) (Whitmus, unpublished data) compared with growth rates over a longer period in the latter study (7%) and with other studies (Phillips and Barraclough 1978; Healey 1979). Parker (1971) suggested that size-selective predation on juvenile salmon would lead to an apparently high growth rate, however size-selective mortality was not demonstrated in this study.

The juvenile salmon used in this study may be especially susceptible to predation. Hatchery-reared Atlantic salmon smolts (Salmo salar) were found different from wild smolts by Bakstansky et al. (1979) in their migration behavior and distribution, and inferior in their ability to remain stable in the water column, in their state of musculature and in their osmoregulatory ability. Popov (1953 cited by Kanayama 1968) pointed out, that hatchery-reared chum salmon fry lack the adaptability to changing natural conditions in comparison with wild fry of the same size. Kanayama (1968) found that wild chum salmon fry were already conditioned to respond to potential predators during downstream migration, unlike hatchery fry and that the freshwater survival of hatchery fry was increased after their conditioning to an electroshocking "predator." A similar study by Thompson (1966) found increases in survival in freshwater of up to 27% for conditioned coho and chinook salmon smolts over their unconditioned siblings. Bams (1979) found the fry-to-adult survival of pink salmon to be suppressed by 6-8% in the case of hatchery fish

when compared with naturally-produced fish. Bams went on to say that this difference in ocean survival may be associated with a delayed mortality of inferior stock, "artificially kept alive in the hatchery." In a similar study at Auke Bay, Taylor (1976) found that the ocean survival of hatchery-produced pink salmon fry was only 59% of those produced in the creek, although this difference may be explained at least partly by temporal factors. Thus there are some indications that the high mortality we found, whether or not caused by predation, might be partly accounted for by the loss of fry "artificially" kept alive by modern hatchery techniques.

A different effect of hatchery releases on the predation of juvenile salmon is the response of predators to the releases. Larsson (1977) found that the abundance of burbot (Lota lota) increased within 50 m of the release point of juvenile Atlantic salmon as releases began. Similar increases in the abundance of predators were observed at the release point of hatchery-reared juvenile chum salmon in Big Beef Creek (Whitmus, unpublished observation) and in Prince William Sound (Cooney, personal communication).² In this study an estimated 5,000 coho salmon smolts were caught in a single beach seine haul at the point where 372,000 juvenile chum had entered Hood Canal from the Enetai hatchery the previous evening. Catches of coho salmon smolts decreased precipitously over the next four days at this site. Unfortunately, no samples were taken prior to the hatchery release to determine if indeed the higher abundance of coho salmon smolts could have been in response to the hatchery release. Coho salmon smolts have not been found to predate upon juvenile chum salmon in previous Hood Canal studies (Simenstad and Kinney 1978), however it is possible that coho salmon smolts, which can be voracious consumers of juvenile chum salmon in freshwater (e.g., Hunter 1959, Beall 1972) and in salt water aquaria (Parker 1971), responded to the hatchery release with a changed feeding strategy. Our only stomach samples of coho salmon smolts were taken when both prey and predator numbers had decreased considerably. Such a switch in the diets and feeding behavior of predators has been noticed following hatchery releases of juvenile sockeye salmon (Oncorhynchus nerka) by Thompson and Tufts (1967) and of Atlantic salmon by Larsson (1977).

If the mechanism of predation in the estuarine environment changes in the above manner in response to releases of hatchery-reared salmon then it would imply that hatchery managers need consider both immediate and longer term predation pressures in evaluating rearing and release criteria. It is not sufficient to produce juvenile salmonids in good shape when they leave the hatchery as good survival in the marine environment might be based on quite different characteristics (Carlin 1969). While it is possible through the rearing of juvenile chum salmon before

²R. Ted Cooney, Institute of Marine Science, University of Alaska, Fairbanks, Alaska, 99701.

release to obtain fourfold increases in adult returns (Sakuramoto and Yamada 1980) it is not known whether this is due to the larger size at release or the later release timing (Abe 1976 and Machidori 1978; cited by Sakuramoto and Yamado 1980). Furthermore, it is not known whether this effect of rearing was produced by a change in mortality over the short or over the long term. While it may be possible to manipulate release timings and rearing strategies to impact the short term predation pressures, longer term predation pressures, either as the primary or secondary cause of mortality, may not be so easily influenced. It is important in this context to understand the part played by food availability and distribution (Walters et al. 1978, Simenstad et al. 1980), disease such as viral erythrocytic necrosis (MacMillan 1980) and other, including abiotic, factors in determining the level of predation pressures. There is a danger that through the influence of artificial spawning and rearing strategies the adaptability of the chum salmon stocks concerned to their natural environment may be reduced as the cost of increasing their short term survival.

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APPENDIX

MARINE SURVIVAL ESTIMATION

The estimated survival of M_1 fish from the time of their release until the time of release of M_2 was computed as:

$$S_1 = \frac{M_2}{M_1} \cdot \frac{m_1}{m_2}$$

where: M_1 = first group released
 M_2 = second group released
 m_1 = recaptures from first group once both groups are released
 m_2 = recaptures from second group.

The estimation of the variance of the survival estimate depends on the assumptions made in the experiment. In the simplest case M_1 and M_2 are known, and m_1 and m_2 are considered to be random poisson variables and thus:

$$EV(m_1) = E(m_1) = m_1$$

$$EV(m_2) = E(m_2) = m_2$$

No finite population correction is necessary as the proportion sampled is so small.

Using the delta method to estimate the variance of S_1 (Seber 1973, p. 7)

$$EV(\hat{S}_1) = (\hat{S}_1)^2 \left[\frac{1}{m_1} + \frac{1}{m_2} \right]$$

In the more complicated case more variances have to be taken into account:

- a) variance due to estimation of M_1 and M_2 accounting for incomplete mark retention;

\hat{M}_1 and \hat{M}_2 can be treated as binomial variables

$$\text{then } EV(\hat{M}_1) = (M_1^*)^2 \frac{\hat{p}(1-\hat{p})}{n} \left(\frac{1-n}{M_1^*} \right)$$

where M_1^* = total number in marking group

\hat{p} = proportion of M_1^* marked

n = subsample tested for mark retention

b) variance due to emigration from sampling area;

Let \hat{M}_j be the number remaining in the sampling area from group M_j and r be the proportion of each group remaining

then $\hat{M}_j' = \hat{M}_j r$

and

Assuming that m_1 and m_2 are poisson variables

$$EV(m_1) = E(m_1) = S_1 \cdot m_2 \cdot \frac{\hat{M}_1 r}{\hat{M}_2 r}$$

which can be shown to equal m_1 , as before.

Thus, the equal emigration of both groups will not bias the estimate, and further will not affect the variance of the estimate, to the first order approximation

c) variance due to heterogeneity of samples

If the ratio of m_1 to m_2 is found to vary among samples (χ^2 test of homogeneity) the overall variance can be found as the sum of the individual variances (assuming that replicate samples were taken to obtain the sample variance). As replicate samples were not available at all sites, the available variances were assumed representative.

i.e., as $\sum \sum m_{1ij} = m_1$

then $\sum \sum \text{var}(m_{1ij}) = \text{var } m_1$

or in the case of unequal replications

k. $EV(m_{1ij}) = EV(m_1)$, where $k = i.j$ and $EV(m_{1ij})$ is the assumed representative variance.

Incorporating these variance components (a to c) in our survival estimate, using the delta process again

$$\begin{aligned}
EV(\hat{S}_1) &= \left[\frac{\hat{M}_2}{\hat{M}_1} \cdot \frac{1}{\hat{m}_2} \right]^2 EV(\hat{m}_1) + \left[\frac{\hat{M}_2}{\hat{M}_1} \cdot \frac{\hat{m}_1}{\hat{m}_2^2} \right]^2 EV(\hat{m}_2) \\
&+ \left[\frac{\hat{M}_2}{\hat{M}_1^2} \cdot \frac{\hat{m}_1}{\hat{m}_2} \right] EV(\hat{M}_1) + \left[\frac{1}{\hat{M}_1} \cdot \frac{\hat{m}_1}{\hat{m}_2} \right] EV(\hat{M}_2)
\end{aligned}$$

where covariance terms are omitted as although m_1 and m_2 are dependent upon M_1 and M_2 , they are not dependent upon their estimators \hat{M}_1 and \hat{M}_2 . simplifying:

$$EV(\hat{S}_1) = \hat{S}_1^2 \left[\frac{EV(\hat{m}_1)}{\hat{m}_1^2} + \frac{EV(\hat{m}_2)}{\hat{m}_2^2} + \frac{EV(\hat{M}_1)}{\hat{M}_1^2} + \frac{EV(\hat{M}_2)}{\hat{M}_2^2} \right]$$

where $EV(m_1)$, $EV(m_2)$, $EV(M_1)$ and $EV(M_2)$ are defined above.

Using the same procedures and incorporating variance due to emigration of the first group (M_1) before the addition of M_2 , it can be shown:

$$EV(\hat{S}'_1) = (\hat{S}'_1)^2 \left[\frac{EV(\hat{m}_1)}{\hat{m}_1^2} + \frac{EV(\hat{m}_2)}{\hat{m}_2^2} + \frac{EV(\hat{M}_1)}{\hat{M}_1^2} + \frac{EV(\hat{M}_2)}{\hat{M}_2^2} + \frac{EV(\hat{R})}{\hat{R}^2} \right]$$

where $EV(R)$ is derived from the linear regression of proportions remaining on the Skokomish flats (R_i) on days since release.