UNIVERSITY OF CALIFORNIA, DAVIS

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO   SANTA BARBARA • SANTA CRUZ

COLLEGE OF AGRICULTURAL AND
ENVIRONMENTAL SCIENCES
AGRICULTURAL EXPERIMENT STATION

AQUACULTURE PROGRAM
ANIMAL SCIENCE DEPARTMENT
UNIVERSITY OF CALIFORNIA
DAVIS, CALIFORNIA 95616
(916) 752-7600

9-1-83

Dear Bob,

Enclosed is a manuscript that Fred Utter and I are submitting to the Can. J. Fish. Aquat. Sci. It is the first of two manuscripts from my master's thesis. I would very much appreciate your comments and critical evaluation. I have cited you quite often in the manuscript and want to make sure my statements are all acurate. I am particularly concerned about the last sentence in the Discussion.

I am currently working on my Ph.D. in genetics here at Davis. While working as a fishery biologist for the Wash. Dept. of Game, I came to the conclusion that I had better learn something about quantitative genetics and animal breeding theory if I wanted to work professionally as a "fisheries geneticist. So I chose Davis and Graham Gall for my doctorate program. I am investigating the genetic relationship between growth rate and age of sexual maturity in fish using the mosquitofish as an experimental model. Consequently, I am not involved in the electrophoretic or "systematic" work that goes on here although I stay aware of what is going on. Some of your statements in recent reviews and correspondences that have come to my attention have hit the nail right on the head and I sympathize with your viewpoint. I have tried to maintain myself as an impartial observer though. Maybe we can discuss it someday. My wife is begging me for a vacation to Colorado.

I hope the enclosed manuscript adequately cites your work. I feel guilty having had to rely to a large extent on state fishery research reports but, as far as I know, alot of the field data appears nowhere ~~els~~ else. Looking forward to your critique.

Sincerely,

Don Campton

Packwood L
— LD"—
MS ?

import hatch
non-native
— salmon - Cloometer
— S. trutta Dexter — S. marmoratus
Vancouver I. —
— mussel R.
— Falls - 0.91.0 — stock smolts

NATURAL HYBRIDIZATION BETWEEN STEELHEAD TROUT (*Salmo gairdneri*) AND COASTAL CUTTHROAT TROUT (*Salmo clarki clarki*) IN TWO PUGET SOUND STREAMS

Donald E. Campton[1]

Washington Cooperative Fishery Research Unit[2],
College of Fisheries, University of Washington,
Seattle, WA 98195, USA

and

Fred M. Utter

Coastal Zone and Estuarine Studies Division,
Northwest and Alaska Fisheries Center,
National Marine Fisheries Service,
National Oceanic and Atmospheric Administration,
2725 Montlake Blvd., East
Seattle, WA 98112, USA

---

[1]Present address: Aquaculture Program, Department of Animal Science, University of California, Davis, CA 95616, USA.

[2]Cooperators are: U.S. Fish and Wildlife Service, Washington State Department of Fisheries, Washington State Department of Game and the University of Washington.

D 748

Campton, D. E. and F. M. Utter. 1983. Natural hybridization between steelhead trout (Salmo gairdneri) and coastal cutthroat trout (Salmo clarki clarki) in two Puget Sound streams. Can. J. Fish. Aquat. Sci. 40:____.

ABSTRACT

A genetic investigation of sea-run cutthroat trout populations in the Puget Sound area revealed numerous juvenile individuals in two streams with electrophoretic phenotypes intermediate to those expected for steelhead trout (Salmo gairdneri) and coastal cutthroat trout (Salmo clarki clarki). These electrophoretically-intermediate fish were concluded to be natural steelhead-cutthroat hybrids based on their restricted occurrence in only two of 23 streams surveyed, the known distributions of spawning adults of the two parental species in these streams and multivariate analyses of the electrophoretic data. The existence of these natural hybrids raises many questions concerning the biological bases for maintaining species integrities in regions of sympatry and further suggests the possibility that hatchery and management practices could be reducing natural barriers to hybridization.

Key Words: hybridization, Salmo gairdneri, Salmo clarki clarki, steelhead trout, cutthroat trout, electrophoresis.

Running Head: Campton and Utter: Steelhead-Cutthroat Hybridization

INTRODUCTION

Closely-related fish species hybridize in nature much more frequently than do species of most other vertebrates (Hubbs 1955; Mayr 1963). Within the trout genus *Salmo*, natural hybridization has been reported between Atlantic salmon (*S. salar*) and brown trout (*S. trutta*) in both Europe and North America (Payne et al. 1972; Solomon and Child 1978; Beland et al. 1981) and between introduced rainbow trout (*S. gairdneri*) and many indigenous trout species, including several inland subspecies of cutthroat trout (*S. clarki subsp.*), in the western United States (Schreck and Behnke 1971; Behnke 1979; references in Dangel et al. 1973). Along the west coast of North America, anadromous forms of coastal cutthroat trout (*S. clarki clarki*) and rainbow trout (i.e., steelhead trout) naturally coexist in sympatry thereby providing biological justification for the existence of two distinct *Salmo* species in western North America.

Natural hybridization between coastal cutthroat trout and coastal rainbow trout has never been formally described. Several investigators have noted juvenile trout specimens appearing morphologically intermediate between the two *Salmo* species (DeWitt 1954; Needham and Gard 1959; Hartman and Gill 1968) but no definitive statements could be made regarding the nature of the putative hybrids because *S. gairdneri* juveniles and *S. clarki clarki* juveniles cannot be distinguished unambiguously based on morphological criteria. These two species have traditionally been distinguished by the presence of basibranchial teeth in *clarki* and their absence in *gairdneri*. However, basibranchial teeth are very difficult to detect under field conditions and are often not present in young-of-the-year cutthroat trout (Dymond 1928; Miller 1950; Behnke 1979). Physical characteristics such as spotting pattern, length of the maxillary bone and shape of the parr marks can help identify these two species under field conditions

basibr.
> 40 mm
pelvic
scales

(Crawford 1927; Miller 1950; Hartman and Gill 1968; McConnell and Snyder 1972) but these criteria are usually quite subjective and by no means definitive. Consequently, if natural hybridization has occurred, it would have probably gone undetected unless systematic efforts had been made to specifically search for natural hybrids (see Behnke 1979).

In recent years, protein electrophoresis has been shown to be a powerful tool for distinguishing hybrid individuals from each of the parental species (e.g., Nyman 1970; Menzel 1977; McCleod et al. 1980; Danzman and Down 1982). In particular, Busack and Gall (1981) detected extensive introgressive hybridization between Paiute cutthroat trout (_S. clarki seleniris_) and rainbow trout where morphological data suggested only pure cutthroat trout were present. ?

Reinitz (1977a) described electrophoretic criteria for distinguishing west-slope cutthroat trout (_S. clarki lewisi_), rainbow trout and their F_1 hybrids but, as pointed out by Allendorf (1978), these criteria are not applicable to the coastal subspecies of cutthroat trout.

In this paper, we report the unexpected discovery of numerous steelhead-cutthroat hybrids in two Puget Sound streams based on electrophoretic criteria. The biological and management implications of these hybrid findings are discussed.

MATERIALS AND METHODS

SAMPLED POPULATIONS

Electrophoretic differences between _S. gairdneri_ and _S. clarki clarki_ were first established by examining several hatchery populations of coastal cutthroat trout, steelhead trout and domesticated rainbow trout (Table 1). Extensive geographical examinations of both _Salmo_ species provided supplemental background information on intraspecific genetic variation (Allendorf 1975; Campton 1981).

Juvenile trout samples were collected with the aid of a backpack electroshocker from 23 streams in the Puget Sound area during September and October, 1977 (Campton 1981). Of these 23 streams, wild trout sampled from the following two streams are described in this report: (1) Harvey Creek (also known as Armstrong Creek), a tributary to the Stillaguamish River near Arlington, WA and (2) Big Mission Creek, a tributary to the southern arm of Hood Canal near Belfair, WA (see Williams et al. 1975). Separate samples totaling 450 fish were collected from four sites within Harvey Creek (1.9, 2.4, 2.9 and 3.2 km upstream from its confluence with the Stillaguamish River) and a total of 262 fish were collected from three sites within Big Mission Creek (0.8, 5.4 and 8.8 km upstream from its mouth on southern Hood Canal). Individuals were not identified according to species prior to being electrophoretically examined although both gairdneri and clarki were thought to be present based on external morphological characteristics (McConnell and Snyder 1972). All fish were less than 150 mm in length (FL) and were believed to be pre-smolt juveniles representing anadromous populations. Scales were taken from sub-samples of fish to determine age-length relationships at each sample site. Samples were sealed inside plastic ziploc bags, frozen in the field, transported on dry ice and subsequently stored at -25°C for up to six months prior to electrophoretic analysis.

ELECTROPHORESIS

Horizontal starch-gel electrophoresis followed the procedures described by Utter et al. (1974) and May et al. (1979). Starch gels were prepared with a 13% mixture of Electrostarch (Electrostarch Company; Madison, Wisconsin) and the appropriate gel buffer solution. The following four buffer systems were used:

1. Gel (pH 8.5): 0.05 M tris, 0.05 M citric acid, 0.006 M lithium hydroxide, 0.03 M boric acid; Electrode (pH 8.1): 0.06 M lithium hydroxide, 0.30 M boric acid (Ridgway et al. 1970);
2. Gel (pH 8.5): 0.045 M tris, 0.025 M boric acid, 0.001 M EDTA; Electrode (pH 8.6): 0.180 M tris, 0.100 M boric acid, 0.004 M EDTA (Markert and Faulhaber 1965);
3. Gel (pH 6.5): 0.002 M citric acid, pH adjusted to 6.5 with N-(3-aminopropyl) morpholine; Electrode (pH 6.5): 0.04 M citric acid, pH adjusted to 6.5 with N-(3-aminopropyl) morpholine (Clayton and Tretiak 1972);
4. Gel (pH 6.5): same as gel buffer 3; Electrode (pH 7.8): 0.155 M tris, 0.043 M citric acid (electrode buffer from Shaw and Prasad 1970).

Enzyme systems examined and loci detected are listed in Table 2. Staining methods followed standard procedures and have been extensively described elsewhere (e.g., Shaw and Prasad 1970; Harris and Hopkinson 1976; Allendorf et al. 1977). Loci and alleles were designated according to the nomenclature system proposed by Allendorf and Utter (1979). The common *Salmo gairdneri* allele was assigned a standard mobility of 100 and coastal cutthroat trout alleles as well as variant *gairdneri* alleles were measured anodally relative to this standard.

Several isozyme systems in salmonid fishes are represented by duplicated loci with common allelic forms of identical electrophoretic mobilities (Allendorf et al. 1975; May et al. 1979). Allele frequencies at these duplicated loci were calculated for both loci combined because allelic variation could not be attributed to a specific locus.

Based on electrophoretic phenotypes, wild trout sampled from each stream were individually classified as steelhead trout (SH), cutthroat trout (CT) or as putative steelhead-cutthroat hybrids (HB). Each subsample was assigned a four-letter abbreviation where the first two letters designate the species (SH, CT or HB) and the last two letters designate the stream (HA for Harvey Creek, BM for Big Mission Creek). Allele frequencies were calculated separately for each subsample.

HYBRID CROSSES

The electrophoretic phenotypes of known steelhead x coastal cutthroat hybrids were examined by crossing hatchery adults of the two parental species. Two mature adults of each sex and species were obtained from the Washington State Department of Game in February, 1981; steelhead trout were from the Cowlitz River hatchery and coastal cutthroat trout were from the Tokul Creek hatchery. These fish were placed on ice and brought to the Northwest and Alaska Fisheries Center (N.M.F.S.), Seattle, where the gametes were collected and eggs fertilized on the day of collection. Eight progeny lots were produced including two of each parent species and two of each reciprocal hybrid combination. Fish were reared for approximately six months post-fertilization or until sufficient size had been achieved to obtain adequate tissue volumes for electrophoresis.

STATISTICS

Nei's (1972) index of genetic similarity was calculated between all hatchery populations and wild trout subsamples described above. Duplicated loci were treated as two loci with identical allele frequencies in the index calculations. These estimated genetic relationships were graphically displayed in two dimensions by performing a principle coordinates analysis (Gower 1966; Everitt 1978) on the genetic similarity matrix.

The aberrant and somewhat unique genotypic combinations expressed by individuals classified as hybrids were graphically displayed by performing a principle components analysis on the allelic scores of individual wild fish collected from the two streams described above. Allelic scores for each fish were coded as either 0, 1 or 2 for single locus systems or as 0, 1, 2, 3 or 4 for duplicated locus systems. Eigenvalues and eigenvectors for both the principle components and principle coordinates analyses were calculated with the EIGRS subroutine from the I.M.S.L. (International Mathematics and Statistical Library) package of FORTRAN subroutines.

RESULTS

Rainbow (steelhead) trout and coastal cutthroat trout expressed different common alleles at the following loci: CPK-2, GLP-1, IDH-3,4, ME-4 and SDH-1 (Figs. 1 through 5; allele frequencies are given in the Appendix). All other loci listed in Table 1 were characterized by common alleles of identical electrophoretic mobility in the two *Salmo* species. AAT-3, AGP-2, CPK-1, LDH-1, LDH-2 and SDH-2 were each fixed for a single allele in all samples. All offspring from the hybrid crosses codominantly expressed both parental alleles at all loci and were easily distinguishable from offspring of the pure parental crosses (Figs. 1-5).

Wild trout individuals from the 23 sampled streams (Campton 1981) were each identified according to species based on their composite genotypes at GLP-1, IDH-3,4, ME-4 and SDH-1. Although *S. gairdneri* and *S. clarki clarki* have previously been identified by the presence of either two- or three-banded phenotypes for muscle CPK (Utter et al. 1973, 1979), CPK phenotypes could not always be clearly distinguished (see Fig. 1). Species identifications based on the four isozyme system listed above were, however, obvious and straightforward; we encountered few dificulties in distinguishing *S. gairdneri* from *S. clarki clarki* in 21 of the 23 sampled streams.

Substantial numbers of fish from the remaining two streams, Harvey Creek and Big Mission Creek, could not be assigned to either of the two trout species; these fish expressed electrophoretic phenotypes suggestive of a mixed steelhead-cutthroat ancestry. Many of these fish were heterozygous at all four of the distinguishing isozyme systems. Other fish were homozygous at two or more of the four systems but for the *clarki* and *gairdneri* alleles at different loci. Fish expressing these intermediate genotypic combinations were rarely observed in samples from the other streams and were therefore hypothesized to be steelhead-cutthroat hybrids. The number and distributions of fish electrophoretically identified as steelhead trout, cutthroat trout and hybrids are summarized in Table 3.

Based on their estimated genetic similarities (Table 4), the hatchery populations and wild trout subsamples were projected as three distinct groups of populations in the principle coordinates analysis (Fig. 6). Fish classified as cutthroat trout from Big Mission Creek (CTBM) and Harvey Creek (CTHA) grouped very closely to the cutthroat trout hatchery populations from Hood Canal (CTHC) and the Stillaguamish River (CTSR). Likewise, fish classified electrophoretically as steelhead trout from the same two streams (SHBM and SHHA) grouped very closely with the *Salmo gairdneri* samples of hatchery origin. On the other hand, the two subsamples from Big Mission Creek and Harvey Creek electrophoretically classified as steelhead-cutthroat hybrids (HBBM and HBHA) grouped together approximately midway between the gairdneri and clarki clusters. In addition, the Beaver Creek hatchery population of coastal cutthroat trout was projected as being more closely related to the two hybrid subsamples than to the other hatchery clarki populations. This result was not unexpected and is discussed below.

The principle coordinates projection illustrates the intermediate genetic nature of fish classified as hybrids when those fish are collectively treated as single samples. However, a 50:50 mixture of "pure" steelhead trout and "pure" cutthroat trout would produce results very similar to those depicted in Figure 6 for the putative hybrids. This confounding problem is circumvented in Figure 7 where individual fish from Big Mission Creek and Harvey Creek are projected onto the first two principle component axes based on their individual genotypic scores. In this figure, the gairdneri and clarki individuals formed two distinct and well-separated groups. Individuals classified electrophoretically as hybrids were projected onto the first two principle axes as a broad cloud of points in the space between the clarki and gairdneri clusters. These putative hybrids did not overlap with the gairdneri cluster but did overlap somewhat with the clarki cluster.

The two multivariate projections in Figures 6 and 7 provide relatively accurate visual representations of the electrophoretic data. The first two principle axes accounted for over 90% of the total variability among both the inter-population similarity indices in the principle coordinates analysis (Fig. 6) and the individual genotypic scores in the principle components analysis (Fig. 7). Very little information was therefore lost by projecting these multi-dimensional relationships onto the first two principle axes in both analyses.

The anomolous position of the Beaver Creek hatchery population of coastal cutthroat trout in Figure 6 warrants special comment. This hatchery stock was developed during the 1960's as an anadromous population but adult returns to the Beaver Creek hatchery from juvenile smolt releases were consistently insufficient to sustain the hatchery population and a captive broodstock was eventually developed (Johnston and Mercer 1976). There are undocumented Crawford reports, however, of hatchery personnel crossing steelhead trout with Beaver Creek cutthroat trout in order to meet the production requirements of this stock (James M. Johnston, Washington State Department of Game, personal communication). In addition, marked steelhead-cutthroat hybrids were deliberately released from the Beaver Creek hatchery during 1967 and 1968 (Crawford 1979) but these fish were supposedly not used in future spawnings. Crawford (1979) notes, however, that Beaver Creek cutthroat trout express a wide range of coloration and speckling patterns varying from truly "cutthroat-types" to others closely resembling steelhead trout. Thus, electrophoretic profiles for these fish support earlier suspicions that the Beaver Creek stock of coastal cutthroat trout is not a sea-run cutthroat stock at all but rather a domesticated population of introgressed steelhead-cutthroat hybrids.

DISCUSSION

The electrophoretic criteria we used to distinguish *S. gairdneri*, *S. clarki clarki* and their putative hybrids are admittedly qualitative in nature. Ideally, one would want at least one locus fixed for alternate alleles in the two species being identified. This was not true for *S. gairdneri* and *S. clarki clarki* except at CPK-2 but phenotypes for this locus could not always be clearly distinguished. Nevertheless, multivariate analyses of the electrophoretic data clearly demonstrated quantitatively the genetic distinctness of the two Salmo species, the intermediate genetic composition of fish classified electrophoretically as hybrids and the accuracy of distinguishing among the two parental species and their putative hybrids in mixed species samples based on electrophoretic phenotypes. The multivariate analyses also demonstrated the effectiveness of these techniques in identifying suspected hybridization in a hatchery population. We therefore believe that the genotypically-intermediate fish found at specific sites in Harvey Creek and Big Mission Creek were in fact the descendents of at least two natural hybrid matings between steelhead trout and coastal cutthroat trout.

The extent of backcrossing and introgression resulting from natural hybridization between S. gairdneri and S. clarki clarki cannot be determined with the results presented in this report. Because one or both of the parental species are naturally polymorphic at the four distinguishing isozyme systems, backcross or F_2 progeny cannot be distinguished unambiguously from F_1 hybrids. The preferential expression of maternal or paternal genomes in hybrid offspring (e.g., Hitzeroth et al. 1968; Ohno 1969; Engel et al. 1977) could also produce F_1 hybrid phenotypes suggestive of a backcross or F_1 mating, although all offspring from our hybrid matings codominantly expressed both parental alleles (Figs. 1-5). Nevertheless, we believe the electrophoretically-intermediate fish described in this paper are most likely first generation hybrids based on the high proportion of heterozygotes observed at GLP-1, ME-4 and SDH-1. Low frequency polymorphisms in coastal cutthroat trout for variant gairdneri alleles at AGP-1, LDH-4 and ME-4 do suggest, however, that backcrossing and introgression of alleles from S. gairdneri to S. clarki clarki may occasionally be successful, and possibly, a natural phenomenon.

We have assumed that the hybrids we detected resulted from the interbreeding of cutthroat trout with steelhead trout and not from the interbreeding of cutthroat trout with resident rainbow trout. There are several reasons for this assumption. Within the Puget Sound area, anadromous forms of both species are relatively abundant and clarki and gairdneri juveniles can be found in most accessible streams that have not suffered from environmental degradation. In particular, Big Mission Creek and Harvey Creek are known to support adult runs of both species. Furthermore, native populations of resident rainbow trout are quite rare in western Washington and are found primarily in a few isolated lakes (e.g., Crescent, Packwood). It is possible, nonetheless, that hatchery-produced rainbow trout are responsible for the interspecies hybridization we detected between S. gairdneri and S. clarki clarki because large numbers of domesticated rainbows are planted each year into a multitude of lakes and streams in the Puget Sound area. However, adult size rainbow trout were not observed in any of the 23 streams from which steelhead trout and coastal cutthroat trout juveniles were collected. The highly localized stocking of hatchery rainbows, their quick and almost immediate removal by sport anglers and the low over-wintering survival of fish that do escape the intensive sport fishery would further argue against the rainbow trout hypothesis (James M. Johnston, personal communication). This hypothesis nevertheless remains uninvestigated.

The mechanisms preventing complete hybridization between S. gairdneri and S. clarki clarki are not well understood. The ability of these two closely-related species to coexist sympatrically and yet maintain their species integrities has generally been attributed to co-evolved differences in spawning time and habitat preference and not to any genetic incompatibilities or other post-zygotic isolating mechanisms (Needham and Gard 1959; Behnke 1972, 1979). In the Pacific

Northwest, coastal cutthroat trout spawn between January and March whereas peak spawning for steelhead trout typically occurs between March and May (Johnston and Mercer 1976; Phillips et al. 1980). These two species also tend to segregate according to stream size and profile; cutthroat trout usually spawn in small, low gradient creeks or in the upper low-flow reaches of large creeks whereas steelhead trout prefer to spawn in larger, swifter-flowing streams (Hartman and Gill 1968). Despite these spatial and temporal differences, the time and place of spawning for the two species do overlap considerably. In the Puget Sound area, steelhead trout actually begin spawning in January before reaching a peak in activity sometime between March and May (Phillips et al. 1980). In Petersburg Creek in southeast Alaska, steelhead trout and cutthroat trout spawn during the same time period (April-May) but spawners of the two species are spatially segregated (Jones 1977). In the Puget Sound area, however, the within-stream distributions of steelhead trout redds and cutthroat trout redds overlap considerably in a large number of spawning tributaries (Washington State Department of Game, unpublished data). Thus, the within-stream segregation and temporal separation of spawning adults may not be the only factors helping to maintain the genetic integrities of these two species.

The numerous young-of-the-year hybrids we detected electrophoretically coupled with the absence of a complete prezygotic isolating mechanism raises many questions as to why adult steelhead-cutthroat hybrids have not been previously reported. As sea-run adults, these two species are easily distinguished by obvious differences in size, shape, coloration, and overall outward appearance. One would superficially expect F_1 hybrid adults to be readily identifiable by some combination of unique intermediate characteristics.

We offer two possible explanations for this apparent anomaly. It is possible that hybrid adults appear morphologically very similar to one of the two parental species. Although steelhead-cutthroat hybrids are easy to produce artificially, formal physical descriptions of juvenile and adult hybrids are lacking. Alternatively, a high incidence of mortality and/or migratory disorientation may occur among the hybrids following their first year of life. This second hypothesis immediately suggests an obvious post-zygotic isolating mechanism by which species integrities are maintained. Because S. gairdneri and S. clarki clarki are generally represented by anadromous populations where both species naturally coexist sympatrically, a fair degree of homing and freshwater migration are required by maturing adults of both species for individual populations to be maintained. In the case of steelhead trout, this migratory behavior also includes an extensive saltwater migration as well. We therefore suggest that the species-specific migration patterns of steelhead trout and sea-run cutthroat trout (see discussions by Scott and Crossman (1973) and Wydoski and Whitney (1979) for life history differences) may both be disrupted in hybrids such that hybrid adults fail to relocate their home stream or other suitable spawning streams following outmigration to saltwater. The fact that the Beaver Creek hatchery population has yielded very few adult returns from juvenile smolt releases supports this speculation.

Current hatchery and fishery management practices in the Pacific Northwest may be contributing to an increased incidence of natural hybridization between S. gairdneri and S. clarki clarki where historically it was rare. A major portion of all artificially-propagated winter-run steelhead trout in western Washington state are derived from a single hatchery source. This stock (the Chambers Creek stock) has been artificially selected for over 30 years for early k2/2ma K selection against non-native

run-time and early sexual maturation as a means of obtaining one year old smolts (Crawford 1979). As a result, the run and spawning times for these fish now coincide very well with the natural run and spawning times for sea-run cutthroat trout. These coincident spawning times would therefore be expected to lead to an increased encounter rate between adults of the two species on the spawning grounds. In addition, if domesticated rainbow trout of hatchery origin are in fact responsible for all or part of the interspecies hybridization we detected between *S. gairdneri* and *S. clarki clarki*, then the release of these fish into open waters where cutthroat trout populations are present or accessible must be seriously questioned. The introduction of hatchery-reared rainbow trout into areas of the Salmon and Clearwater Rivers in Idaho where steelhead trout and west-slope cutthroat trout (*S. clarki lewisi*) were both native inhabitants usually resulted in mass interspecies hybridization between the native cutthroat trout and the introduced rainbow trout (Behnke 1972).

CONCLUDING REMARKS

The prudent and far-sighted management of steelhead trout and coastal cutthroat trout along the west coast of North America requires that the mechanisms preventing mass hybridization between these two species be thoroughly understood. Natural hybridization between steelhead (or rainbow) trout and coastal cutthroat trout has generally been assumed to be a rare and isolated event (Miller 1950; Needham and Gard 1959; Behnke 1972). Our findings suggest that the production of hybrid offspring may not be uncommon in streams where both species spawn. The apparent infrequency of adult hybrids further suggests a post-zygotic isolating mechanism (e.g., migratory disorientation) may be contributing to the preservation of species integrities. On the other hand, the

Gordon Hartman

assumption of complete interfertility of S. gairdneri and S. clarki clarki (Needham and Gard 1959; Behnke 1979) has never been documented in the literature nor adequately determined experimentally by testing the fertility of F_1 hybrids or backcross progeny relative to the pure parental species. Such information is needed because the widespread planting of steelhead trout, rainbow trout and sea-run cutthroat trout could potentially be promoting mass interspecies hybridization where naturally it was rare. The ability of hatchery-produced rainbow trout to naturally spawn with coastal cutthroat trout also needs immediate investigation. We believe management agencies in the Pacific Northwest and Canada should begin seriously addressing these questions regarding interspecific hybridization between S. gairdneri and S. clarki clarki clarki.

ACKNOWLEDGMENTS

We thank James M. Johnston and Stewart P. Mercer of the Washington State Department of Game for their assistance in procuring samples and for their continual administrative support. The senior author (DEC) also extends his special thanks to the Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle for providing laboratory facilities and desk space. Dr. Graham A. E. Gall critically reviewed this manuscript and provided many helpful suggestions for its improvement.

This work was supported by the Washington State Department of Game. Research funds were granted to and administered by the Washington Cooperative Fishery Research Unit, University of Washington. The assistance of Drs. Richard R. Whitney (unit leader), Gilbert B. Pauley, and James L. Congleton (assistant unit leader) is acknowledged and appreciated.

LITERATURE CITED

Allendorf, F.W. 1975. Genetic variability in a species possessing extensive gene duplication: genetic interpretation of duplicate loci and examination of genetic variation in populations of rainbow trout. Ph.D. thesis, University of Washington, Seattle, WA.

Allendorf, F.W. 1978. Electrophoretic distinction in rainbow (*Salmo gairdneri*) and cutthroat (*S. clarki*) trout, (Letter to the Editor). J. Fish. Res. Board Can. 35: 483.

Allendorf, F.W. and F.M. Utter. 1973. Gene duplication within the family Salmonidae: disomic inheritance of two loci reported to be tetrasomic in rainbow trout. Genetics 74: 647-654.

Allendorf, F.W. and F.M. Utter. 1979. Population genetics, p. 407-454. *In* W. S. Hoar, D.S. Randal and J.R. Brett (eds.) Fish Physiology, Vol. 8. Academic Press, New York, N.Y.

Allendorf, F.W., N. Mitchell, N. Ryman and G. Stahl. 1977. Isozyme loci in brown trout (*Salmo trutta* L.): detection and interpretation from population data. Hereditas 86: 179-190.

Allendorf, F.W., F.M. Utter and B. May. 1975. Gene duplication within the family Salmonidae. II. Detection and determination of the genetic control of duplicate loci through inheritance studies and the examination of populations, p. 415-432. *In* C.L. Markert (ed.) Isozymes IV: Genetics and Evolution. Academic Press, New York, N.Y.

Behnke, R.J. 1972. The systematics of salmonid fishes of recently glaciated lakes. J. Fish. Res. Board Can. 29: 639-671.

Behnke, R.J. 1979. Monograph of the native trouts of the genus *Salmo* of western North America. Published jointly by U.S. Forest Service, U.S. Fish and Wildlife Service, and U.S. Bureau of Land Management.

Beland, K.F., F.L. Roberts and R.L. Saunders. 1981. Evidence of Salmo salar x Salmo trutta hybridization in a North American river. Can. J. Fish. Aquat. Sci. 38: 552-554.

Busack, C.A. and G.A.E. Gall. 1981. Introgressive hybridization in populations of Paiute cutthroat trout (Salmo clarki seleniris). Can. J. Fish. Aquat. Sci. 38: 939-951.

Campton, D.E. 1981. Genetic structure of sea-run cutthroat trout (Salmo clarki clarki) populations in the Puget Sound area. M. S. thesis, University of Washington, Seattle, WA.

Clayton, J.W. asnd D.N. Tretiak. 1972. Amine-citrate buffers for pH control in starch gel electrophoresis. J. Fish. Res. Board Can. 29: 1169-1172.

Crawford, B.A. 1979. The origin and history of the trout brood stocks of the Washington Department of Game. Fishery Research Report, Washington State Game Dept., Olympia, WA.

Crawford, D.R. 1927. Field characters identifying young salmonid fishes in fresh waters of Washington. Univ. Wash. Publ. Fish. 1: 64-76.

Cross, T.F. and R.D. Ward. 1980. Protein variation and duplicate loci in the Atlantic salmon, Salmo salar L. Genet. Res., Camb. 36: 147-165.

Cross, T.F., R.D. Ward and A. Abreu-Grobois. 1979. Duplicate loci and allelic variation for mitochondrial malic enzyme in the Atlantic salmon, Salmo salar L. Comp. Biochem. Physiol. 62B: 403-406.

Dangel, J.R., P.T. Macy and F.C. Withler. 1973. Annotated bibliography of interspecific hybridization of fishes of the subfamily Salmoninae. NOAA Technical Memorandum NMFS NWFC-1, U.S. Department of Commerce, Washington, D.C.

Danzmann, R.G. and N.E. Down. 1982. Isozyme expression in F1 hybrids between carp and goldfish. Biochem. Genet. 20: 1-15.

DeWitt, J.W., Jr. 1954. A survey of the coastal cutthroat trout, Salmo clarki clarki Richardson, in California. Calif. Fish Game 40: 329-335.

Dymond, J.R. 1928. The trout of British Columbia. Trans. Am. Fish. Soc. 58: 71-77.

Engel, W., J. Op't Hof and U. Wolf. 1970. Genduplikation durch polyploide evolution: die isozyme der sorbitdehydrogenase bei herings- und lachsartigen Fischen (Isospondyli). Humangenetik 9: 157-163.

Engel, W., P. Kuhl and J. Schmidtke. 1977. Expression of the paternally derived phosphoglucose isomerase genes during hybrid trout development. Comp. Biochem. Physiol. 56B: 103-108.

Everitt, B.S. 1978. Graphical techniques for multivariate data. North-Holland, New York, N.Y.

Gower, J.C. 1966. Some distance properties of latent root and vector methods used in multivariate analysis. Biometrika 53: 325-338.

Harris, H. and D.A. Hopkinson. 1976. Handbook of enzyme electrophoresis in human genetics. American Elsevier Publishing Co., New York, N.Y.

Hartman, G.F. and C.A. Gill. 1968. Distributions of juvenile steelhead and cutthroat trout (Salmo gairdneri and S. clarki clarki) within streams in southwestern British Columbia. J. Fish. Res. Board Can. 25: 33-48.

Hitzeroth, H., J. Klose, S. Ohno and U. Wolf. 1968. Asynchronous activation of parental alleles at the tissue-specific gene loci observed on hybrid trout during early development. Biochem. Genet. 1: 287-300.

Hubbs, C.L. 1955. Hybridization between fish species in nature. Syst. Zool. 4:1-20.

Johnston, J.M. and S.P. Mercer. 1976. Sea-run cutthroat in saltwater pens: broodstock development and extended juvenile rearing (with a life history compendium). Fishery Research Report, Project AFS-57-1, Washington State Game Dept., Olympia, WA.

Jones, D.E. 1977. A study of steelhead-cutthroat in Alaska. Annual performance report and completion report, Vol. 18, Project No. AFS 42-5. Alaska Dept. of Fish and Game, Juneau, Alaska.

Markert, C.L. and I. Faulhaber. 1965. Lactate dehydrogenase isozyme patterns of fish. J. Exp. Zool. 159: 319-332.

May, B., J.E. Wright and M. Stoneking. 1979. Joint segregation of biochemical loci in Salmonidae: results from experiments with *Salvelinus* and review of the literature on other species. J. Fish. Res. Board Can. 36: 1114-1128.

Mayr, E. 1963. Animal species and evolution. Harvard University Press, Cambridge, Massachusetts.

McCleod, M.J., D.L. Wynes and S.I. Guttman. 1980. Lack of biochemical evidence for hybridization between two species of darters. Comp. Biochem. Physiol. 67B: 323-325.

McConnell, R.J. and G.R. Snyder. 1972. Key to field identification of anadromous juvenile salmonids in the Pacific Northwest. NOAA Tech. Rep., NMFS Circ. No. 366, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle, WA.

Menzel, B.W. 1977. Morphological and eletrophoretic identification of a hybrid cyprinid fish, *Notropis cerasinus* x *Notropis c. cornutus*, with implications on the evolution of *Notropis albeolus*. Comp. Biochem. Physiol. 57B: 215-218.

Miller, R.R. 1950. Notes on the cutthroat and rainbow trouts with the description of a new species from the Gila River, New Mexico. Occas. Papers Mus. Zool., No. 529. University of Michigan Press, Ann Arbor, MI.

Needham, P.R. and R. Gard. 1959. Rainbow trout in Mexico and California with notes on the cutthroat series. Univ. Calif. Publ. Zool. 67: 1-124.

Nei, M. 1972. Genetic distance between populations. Am. Nat. 106: 283-292.

Nyman, L. 1970. Electrophoretic analysis of hybrids between salmon (*Salmo salar*) and trout (*Salmo trutta*). Trans. Am. Fish. Soc. 99: 229-236.

Ohno, S. 1969. The preferential activation of maternally derived alleles in development of interspecific hybrids. Wistar Symp. Monogr. 9: 137-150.

Payne, R.H., A.R. Child and A. Forrest. 1972. The existence of natural hybrids between the European trout and the Atlantic salmon. J. Fish Biol. 4: 233-236.

Phillips, C., W. Freymond, D. Campton and R. Cooper. 1980. Skagit River salmonid studies, 1977-1979. Fishery Research Report 80-24, Washington State Department of Game, Olympia, WA.

Reinitz, G.L. 1977a. Electrophoretic distinction of rainbow trout (*Salmo gairdneri*), west-slope cutthroat trout (*S. clarki*), and their hybrids. J. Fish. Res. Board Can. 34: 1236-1239.

Reinitz, G.L. 1977b. Inheritance of muscle and liver types of supernatant NADP-dependent isocitrate dehydrogenase in rainbow trout (*Salmo gairdneri*). Biochem. Genet. 15: 445-454.

Ridgway, G.J., S.W. Sherburne and R.D. Lewis. 1970. Polymorphism in the esterases of Atlantic herring. Trans. Am. Fish. Soc. 99: 147-151.

Ropers, H.-H., W. Engel and U. Wolf. 1973. Inheritance of the S-form of NADP-dependent isocitrate dehydrogenase polymorphism in rainbow trout, p. 319-327. *In* J.H. Schroder (ed.) Genetics and mutagenesis of fish.

Springer-Verlag, New York, N.Y.

Schreck, C.B. and R.J. Behnke. 1971. Trouts of the upper Kern River Basin, California, with reference to systematics and evolution of western North American Salmo. J. Fish. Res. Board Can. 28: 987-998.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184, Fisheries Research Board of Canada, Ottawa. 966p.

Shaw, C.R. and R. Prasad. 1970. Starch gel electrophoresis of enzymes - a compilation of recipes. Biochem. Genet. 4: 297-320.

Sneath, P.H.A. and R.R. Sokal. 1973. Numerical Taxonomy. W.H. Freeman and Co., San Francisco, CA.

Solomon, D.J. and A.R. Child. 1978. Identification of juvenile natural hybrids between Atlantic salmon (Salmo salar L.) and trout (Salmo trutta L.). J. Fish Biol. 12: 499-501.

Stoneking, M., B. May and J.E. Wright, Jr. 1979. Genetic variation, inheritance and quaternary structure of malic enzyme in brook trout (Salvelinus fontinalis). Biochem. Genet. 17: 599-619.

Utter, F.M., F.W. Allendorf and H.O. Hodgins. 1973. Genetic variability and relationships in Pacific salmon and related trout based on protein variations. Syst. Zool. 22: 257-270.

Utter, F.M., F.W. Allendorf and B. May. 1979. Genetic basis of creatine kinase isozymes in skeletal muscle of salmonid fishes. Biochem. Genet. 17: 1079-1091.

Utter, F.M., H.O. Hodgins and F.W. Allendorf. 1974. Biochemical genetic studies of fishes: potentialities and limitations, p. 213-238. In D.C. Malins and J.R. Sargent (eds.) Biochemical and biophysical perspectives in marine biology, Vol. 1. Academic Press, New York, N.Y.

Williams, R.W., R.M. Laramie and J.J. Ames. 1975. A catalog of Washington streams and salmon utilization; Volume 1, Puget Sound region. Washington State Dept. of Fisheries, Olympia, WA.

Wydoski, R.S. and R.R. Whitney. 1979. Inland fishes of Washington. University of Washington Press, Seattle and London.

Appendix. Allele frequencies at polymorphic loci for the sampled populations. "ND" implies no data were collected for these samples at the specified loci.

		Hatchery *Salmo gairdneri*				Hatchery *Salmo clarki clarki*					Harvey Creek			Big Mission Creek		
Loci	Alleles	RBGD	RBST	SHWR	SHCC	CTBC[a]	CTCR	CTHC	CTSR	CTTC	SHHA	HBHA	CTHA	SHBM	HBBM	CTBM
AAT-1,2	110	-	-	0.008	-	-	-	-	-	-	-	-	-	-	-	-
	100	1.000	1.000	0.992	0.997	0.925	0.764	0.753	0.901	1.000	1.000	0.920	0.850	0.997	0.966	0.842
	85	-	-	-	0.003	0.075	0.233	0.236	0.099	-	-	0.080	0.150	0.003	0.034	0.158
	70	-	-	-	-	-	0.003	0.011	-	-	-	-	-	-	-	-
ADH	-100	1.000	1.000	1.000	1.000	0.990	0.978	0.940	1.000	1.000	1.000	0.986	0.965	1.000	1.000	1.000
	-200	-	-	-	-	0.010	0.022	0.060	-	-	-	0.014	0.035	-	-	-
AGP-1	-100	1.000	1.000	0.766	1.000	1.000	1.000	1.000	1.000	1.000	0.950	0.943	0.994	1.000	1.000	1.000
	100	-	-	0.234	-	-	-	-	-	-	0.050	0.057	0.006	-	-	-
CPK-2	114	1.000	1.000	1.000	1.000	ND	-	-	-	-	1.000	0.514	-	1.000	0.488	-
	100	-	-	-	-		1.000	1.000	1.000	1.000	-	0.486	1.000	-	0.512	1.000
GLP-1	120	-	-	-	-	-	-	0.068	-	-	-	0.043	0.041	-	0.049	0.023
	110	-	0.050	0.031	-	0.550	0.968	0.777	0.964	0.865	0.100	0.443	0.913	-	0.445	0.820
	100	1.000	0.950	0.844	1.000	0.450	0.032	0.155	0.036	0.135	0.900	0.514	0.046	1.000	0.506	0.157
	90	-	-	0.125	-	-	-	-	-	-	-	-	-	-	-	-

Appendix. Continued.

		Hatchery *Salmo gairdneri*				Hatchery *Salmo clarki clarki*					Harvey Creek			Big Mission Creek		
Loci	Alleles	RBGD	RBST	SHWR	SHCC	CTBC[a]	CTCR	CTHC	CTSR	CTTC	SHHA	HBHA	CTHA	SHBM	HBBM	CTBM
IDH-2	120	0.365	0.250	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	100	0.635	0.750													
IDH-3,4	124	-	0.042	0.016	0.043	-	0.037	0.007	-	-	-	-	-	0.009	-	-
	100	0.897	0.641	0.637	0.750	0.425	0.198	0.106	0.131	0.024	0.775	0.723	0.106	0.833	0.535	0.045
	72[b]	0.026	0.033	0.171	0.105	0.386	0.754	0.639	0.815	0.976	0.075	0.152	0.788	0.125	0.465	0.949
	44	0.077	0.267	0.168	0.102	0.189	0.011	0.248	0.054	-	0.150	0.125	0.106	0.033	-	0.006
	38	-	0.017	0.008	-	-	-	-	-	-	-	-	-	-	-	-
LDH-3	141	-	-	-	-	ND	ND	-	-	-	-	-	0.020	-	-	0.005
	100	1.000	1.000	1.000	1.000			1.000	1.000	1.000	1.000	1.000	0.956	1.000	1.000	0.995
	52	-	-	-	-			-	-	-	-	-	0.024	-	-	-
LDH-4	100	1.000	1.000	0.854	0.813	0.995	0.988	1.000	1.000	1.000	0.950	0.943	1.000	0.956	1.000	1.000
	74	-	-	0.146	0.187	0.005	0.012	-	-	-	0.050	0.057	-	0.044	-	-
LDH-5	100	1.000	1.000	1.000	1.000	0.990	0.992	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	95	-	-	-	-	0.010	0.008	-	-	-	-	-	-	-	-	-

Appendix. Continued.

		Hatchery *Salmo gairdneri*				Hatchery *Salmo clarki clarki*					Harvey Creek			Big Mission Creek		
Loci	Alleles	RBGD	RBST	SHWR	SHCC	CTBC[a]	CTCR	CTHC	CTSR	CTTC	SHHA	HBHA	CTHA	SHBM	HBBM	CTBM
MDH-1,2	100	1.000	1.000	1.000	0.997	0.992	0.998	1.000	0.974	1.000	1.000	0.979	0.932	1.000	1.000	1.000
	73	-	-	-	0.003	-	-	-	-	-	-	0.014	-	-	-	-
	48	-	-	-	-	0.008	0.002	-	0.026	-	-	0.007	0.068	-	-	-
MDH-3,4	110	-	-	0.005	-	0.008	0.020	-	-	0.049	-	-	-	-	-	0.014
	100	0.811	0.958	0.821	0.903	0.920	0.968	0.736	0.923	0.851	0.850	0.879	0.924	0.864	0.780	0.867
	85	0.189	0.042	0.005	0.008	0.035	0.002	-	-	0.018	-	-	-	-	0.101	-
	78	-	-	0.169	0.089	0.037	0.010	0.264	0.077	0.082	0.150	0.121	0.076	0.136	0.119	0.119
ME-3	100	ND	ND	0.875	0.859	ND	ND	ND	ND	ND	ND	ND	1.000	ND	0.732	1.000
	92			0.125	0.141								-		0.268	-
ME-4	110	-	0.067	-	-	0.550	ND	1.000	1.000	0.916	-	0.424	0.993	-	0.325	0.977
	100	1.000	0.933	1.000	1.000	0.450		-	-	0.084	1.000	0.576	0.007	1.000	0.675	0.023
PGD	105	-	-	-	-	-	0.007	-	0.041	-	-	-	0.021	-	-	-
	100	1.000	1.000	1.000	1.000	0.980	0.963	0.967	0.821	1.000	0.950	1.000	0.963	1.000	0.915	0.967
	90	-	-	-	-	0.020	0.030	0.033	0.138	-	0.050	-	0.016	-	0.085	0.033

Appendix. Continued.

		Hatchery *Salmo gairdneri*				Hatchery *Salmo clarki clarki*					Harvey Creek			Big Mission Creek		
Loci	Alleles	RBGD	RBST	SHWR	SHCC	CTBC[a]	CTCR	CTHC	CTSR	CTTC	SHHA	HBHA	CTHA	SHBM	HBBM	CTBM
PGI-1	154	-	-	-	-	0.040	0.238	0.180	0.500	-	-	0.029	0.402	-	0.018	0.306
	100	1.000	1.000	1.000	1.000	0.960	0.762	0.748	0.500	1.000	1.000	0.971	0.592	1.000	0.982	0.594
	15	-	-	-	-	-	-	0.072	-	-	-	-	0.006	-	-	0.100
PGI-2	190	-	-	-	-	-	-	-	-	-	-	-	0.001	-	-	-
	154	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000	0.978
	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.016
	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.006
PGI-3	110	-	-	-	-	-	0.013	-	-	-	-	-	-	-	-	-
	100	1.000	1.000	0.917	1.000	1.000	0.960	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	90	-	-	0.083	-	-	0.027	-	-	-	-	-	-	-	-	-
PGM	100	0.990	0.733	1.000	1.000	0.995	0.987	0.981	0.985	1.000	1.000	1.000	0.983	1.000	0.866	0.956
	85	0.010	0.267	-	-	0.005	0.013	0.019	0.015	-	-	-	0.017	-	0.134	0.044
PMI	100	1.000	1.000	1.000	1.000	0.995	0.807	1.000	0.959	0.454	1.000	0.986	0.972	1.000	1.000	0.989
	95	-	-	-	-	0.005	0.193	-	0.041	0.546	-	0.014	0.028	-	-	0.011

Appendix. Continued.

		Hatchery *Salmo gairdneri*				Hatchery *Salmo clarki clarki*					Harvey Creek			Big Mission Creek		
Loci	Alleles	RBGD	RBST	SHWR	SHCC	CTBC[a]	CTCR	CTHC	CTSR	CTTC	SHHA	HBHA	CTHA	SHBM	HBBM	CTBM
SDH-1	230	-	-	-	-	-	0.002	-	-	-	-	-	0.001	-	-	-
	190	-	-	-	-	0.294	0.828	0.889	0.916	0.964	0.050	0.571	0.966	-	0.646	0.814
	100	1.000	1.000	1.000	1.000	0.706	0.170	0.111	0.084	0.036	0.950	0.429	0.033	1.000	0.354	0.186
SOD	142	0.286	0.350	0.245	0.469	0.170	0.050	0.091	0.260	-	0.350	0.371	0.191	0.427	0.463	0.156
	100	0.714	0.650	0.755	0.531	0.830	0.925	0.909	0.740	1.000	0.650	0.629	0.809	0.573	0.537	0.844
	43	-	-	-	-	-	0.025	-	-	-	-	-	-	-	-	-

[a] The Beaver Creek Hatchery stock is believed to be an introgressed population of steelhead-cutthroat hybrids (see text).

[b] The 72 allele frequency at IDH-3,4 for *S. clarki clarki* represents the sum of the frequencies of the 65, 72 and 80 electromorphs (Figure 3).

Table 1. Hatchery populations of coastal cutthroat trout, steelhead trout and domesticated rainbow trout sampled for electrophoretic analysis. All populations are maintained by the Washington State Department of Game and are thoroughly described by Crawford (1979).

Population name	Abbreviation	Number of fish
Salmo clarki clarki		
Beaver Creek cutthroat trout	CTBC	100
Cowlitz River cutthroat trout	CTCR	200
Hood Canal cutthroat trout	CTHC	286
Stillaguamish River cutthroat trout	CTSR	98
Tokul Creek cutthroat trout	CTTC	97
Salmo gairdneri		
Chambers Creek steelhead trout	SHCC	96
Washougal River steelhead trout	SHWR	95
Goldendale rainbow trout	RBGD	49
South Tacoma rainbow trout	RBST	30

Table 2. Enzymes examined and loci detected in rainbow trout and coastal cutthroat trout.

Enzyme	Loci	Tissue[a]	Buffer
Aspartate aminotransferase	AAT-1,2	M	1
	AAT-3	E\	2
Alcohol dehydrogenase	ADH	L	1
Alpha-glycerophosphate dehydrogenase	AGP-1	M	4
	AGP-2	M	4
Creatine phosphokinase	CPK-1,2	M	1
Glycyl-leucine peptidase	GLP-1	M,E	2
	GLP-2	E	2
Isocitrate dehydrogenase	IDH-1[b]	M	3
	IDH-2[b]	M	3
	IDH-3,4	L	3
Lactate dehydrogenase	LDH-1	M	1
	LDH-2	M	1
	LDH-3	M,E	1,2
	LDH-4	L	1
	LDH-5	E	2
Malate dehydrogenase	MDH-1,2	L	3
	MDH-3,4	M	4
Malic enzyme	ME-1,2[b]	M	3
	ME-3[b]	M	3
	ME-4	L	4

Table 2. Continued.

Enzyme	Loci	Tissue[a]	Buffer
Phosphoglucoisomerase	PGI-1	M	1
	PGI-2	M	1
	PGI-3	M,L	1
Phosphoglucomutase	PGM	M	1
Phosphogluconate dehydrogenase	PGD	M,L	4
Phosphomannoisomerase	PMI	M,E	2
Sorbitol dehydrogenase	SDH-1	L	1
	SDH-2	L	1
Superoxide dismutase	SOD	L	1

[a] M = skeletal muscle, L = liver, E = eye.

[b] These loci were not examined in all samples.

Table 3. Numbers and distributions of fish electrophoretically identified as steelhead trout, cutthroat trout and putative steelhead-cutthroat hybrids at each sample site in Harvey Creek and Big Mission Creek. Electrophoretic identifications were based on composite genotypes at <u>GLP-1</u>, <u>IDH-3,4</u>, <u>ME-4</u> and <u>SDH-1</u>. Stream km refers to the number of kilometers upstream from the creek's terminus.

			Number of fish	
Location	Stream km	Species	Age 0+	Age 1+
<u>Harvey Creek</u>				
Site 1	1.9	Steelhead	4	-
		Cutthroat	34	48
		Hybrids	20	-
Site 2	2.4	Steelhead	6	-
		Cutthroat	47	38
		Hybrids	15	-
Site 3	2.9	Cutthroat	51	42
Site 4	3.2	Cutthroat	85	60
<u>Big Mission Creek</u>				
Site 1	0.8	Steelhead	36	-
Site 2	5.4	Steelhead	54	-
		Cutthroat	16	29
Site 3	8.8	Cutthroat	17	28
		Hybrids	82	-

Table 4. Genetic similarity values (Nei 1972) among sampled populations. Index values are based on all loci in Table 1 excluding IDH-1, IDH-2, ME-1,2 and ME-3 which were examined in only a few samples.

	RBGD	RBST	SHWR	SHCC	CTBC	CTCR	CTHC	CTSR	CTTC	SHHA	HBHA	CTHA	SHBM	HBBM	CTBM
RBGD	1.000														
RBST	0.992	1.000													
SHWR	0.991	0.991	1.000												
SHCC	0.995	0.994	0.994	1.000											
CTBC	0.959	0.967	0.968	0.961	1.000										
CTCR	0.852	0.861	0.870	0.858	0.967	1.000									
CTHC	0.831	0.846	0.850	0.837	0.961	0.989	1.000								
CTSR	0.815	0.830	0.832	0.824	0.950	0.992	0.988	1.000							
CTTC	0.810	0.822	0.830	0.816	0.941	0.984	0.975	0.976	1.000						
SHHA	0.996	0.994	0.996	0.998	0.967	0.867	0.848	0.832	0.825	1.000					
HBHA	0.963	0.964	0.964	0.965	0.988	0.942	0.938	0.926	0.914	0.970	1.000				
CTHA	0.816	0.831	0.834	0.824	0.952	0.994	0.992	0.998	0.979	0.833	0.928	1.000			
SHBM	0.997	0.993	0.994	0.999	0.962	0.859	0.838	0.825	0.818	0.999	0.965	0.825	1.000		
HBBM	0.951	0.954	0.955	0.955	0.985	0.956	0.945	0.940	0.932	0.959	0.991	0.941	0.957	1.000	
CTBM	0.822	0.836	0.842	0.830	0.955	0.993	0.991	0.995	0.982	0.837	0.925	0.996	0.832	0.943	1.000

FIGURE LEGENDS

Fig. 1. CPK-1,2 phenotypes in muscle. Phenotypes 1 and 3 are the common CPK patterns for *S. gairdneri* and *S. clarki clarki* respectively. Two loci code for CPK in salmonid fishes and allelic forms at each locus are represented by two bands due to a hypothesized post-translational modification of the polypeptide products (Utter et al. 1979). The two loci appear fixed for the same allele in *clarki* but different alleles in *gairdneri*. Offspring from the hybrid matings all expressed phenotype 2. (1) CPK-1(100/100), CPK-2(114/114); (2) CPK-1(100/100), CPK-2(100/114); (3) CPK-1(100/100), CPK-2(100/100).

Fig. 2. GLP-1 phenotypes in muscle. Phenotypes 1 and 3 are the common GLP patterns for *S. gairdneri* and *S. clarki clarki* respectively although both species are polymorphic for the two alleles illustrated. Individuals identified as heterozygotes as well as offspring from the hybrid matings expressed phenotype 2. Two additional alleles (not illustrated) were also observed (see Appendix). (1) GLP-1(100/100); (2) GLP-1(100/110); (3) GLP-1(110-110).

Fig. 3. IDH-3,4 phenotypes in liver. Phenotypes 1 through 5 are *S. clarki clarki* and phenotypes 6 through 10 are *S. gairdneri* (see Allendorf and Utter 1973, Ropers et al. 1973 and Reinitz 1977b for details of this isozyme ssytem). Five electrophoretic alleles were initially observed (Appendix) and most individuals were characterized by multiple-banded phenotypes. In general, *S. clarki clarki* individuals expressed two or more copies of the 72 allele while *S. gairdneri* individuals almost always two copies of the 100 allele. However, after the data for this paper were collected, refined resolution of the IDH-3,4 isozyme system

using gels prepared with a 1:1 mixture of Electrostarch and Sigma starch (Sigma Chemical Company, St. Louis, MO) revealed the "72 allele" in clarki to actually be comprised of three distingishable electromorphs which were designated the 65, 72 and 80 alleles. The 65 and 80 alleles were not observed in *S. gairdneri*.

(1) IDH-3,4(100/80/80/65); (2) IDH-3,4(100/72/65/65);
(3) IDH-3,4(100/72/72/44); (4) IDH-3,4(80/72/72/44);
(5) IDH-3,4(100/80/72/44); (6) IDH-3,4(124/100/100/44);
(7) IDH-3,4(124/100/100/72); (8) IDH-3,4(100/100/100/72);
(9) IDH-3,4(100/100/100/44); (10) same as (7).

Fig. 4. ME-4 pheontypes in liver. Phenotypes 1 and 3 are the common gairdneri and clarki phenotypes respectively. The ME-3 locus in muscle is also expressed in liver but at a reduced intensity. Interactions between the two loci can be seen above where the cutthroat trout bands are blurred relative to the rainbow trout bands. In gairdneri, the common alleles at ME-3 and ME-4 have the same mobility but in clarki, the common alleles at the two loci have different mobilities. Offspring from the hybrid matings expressed a broad electrophoretic band intermediate in mobility between those for the two parental species (phenotype 2). This hybrid phenotype (photograph not shown) was identical to the polymorphism observed in cutthroat trout (see Appendix) and was interpreted as the ME-4(100/110) heterozygote. Note: ME-3 and ME-4 constitute the fast ME fraction. The slow ME fraction (ME-1,2) was observed as a single invariant band of identical mobility in both species (see Cross et al. 1979 and Stoneking et al. 1979 for

further details on the ME isozyme systems in salmonid fishes). (1) ME-4(100/100); (2) ME-4(100/110); (3) ME-4(110/110).

Fig. 5. SDH-1,2 phenotypes in liver. Pheotypes 1 and 3 are the common *gairdneri* and *clarki* phenotypes respectively. All *S. gairdneri* individuals of hatchery origin expressed phenotype 1. Cutthroat trout, on the other hand, appeared to be segregating for the above three phenotypes as if a single diallelic locus conforming to Hardy-Weinberg expectations were responsible for this variation where phenotype 2 was assumed to be the heterozygote. In particular, the Beaver Creek population was highly polymorphic for this variation where 46, 35 and 9 individuals respectively expressed phenotypes 1, 2 and 3 above. Offspring from the hybrid matings all expressed phenotype 2 where the *gairdneri* and *clarki* parents were characterized by phenotypes 1 and 3 respectively. These patterns were therefore interpreted as reflecting variation at a single locus (SDH-1) with a second locus (SDH-2) fixed for the same allele in both species. These interpretations follow the two-locus model previously described for this tetrameric enzyme (Engel et al. 1970; Allendorf et al. 1975; May et al. 1979; Cross and Ward 1980). (1) SDH-1(100/100); (2) SDH-1(100/190); (3) SDH-1(190/190).

Fig. 6. Principle coordinates projections of the sampled populations onto the first two principle axes. Elements of each eigenvector for the transformed genetic similarity matrix (Table 4) were scaled such that their sum of squares was equal to the corresponding eigenvalue. A minimum spanning tree (Sneath and Sokal 1973) has been superimposed upon the projected population points in order to assess nearest neighbor relationships.

Fig. 7. Principle components projections of individual fish collected from Harvey Creek and Big Mission Creek. Line segments respectively enclose all individuals identified electrophoretically as steelhead trout (closed circles), cutthroat trout (open squares) and steelhead-cutthroat hybrids (open circles). These projections are based on the number of GLP-1(100), GLP-1(110), IDH-3,4(100), IDH-3,4(72), ME-4(100) and SDH-1(100) alleles expressed by each fish. Principle components were derived from the variance-covariance matrix of these allelic scores. As in Fig. 6, elements of each eigenvector in the transformation matrix were scaled such that their sum of squares was equal to the corresponding eigenvalue, thereby reflecting the variance associated with each principle component.

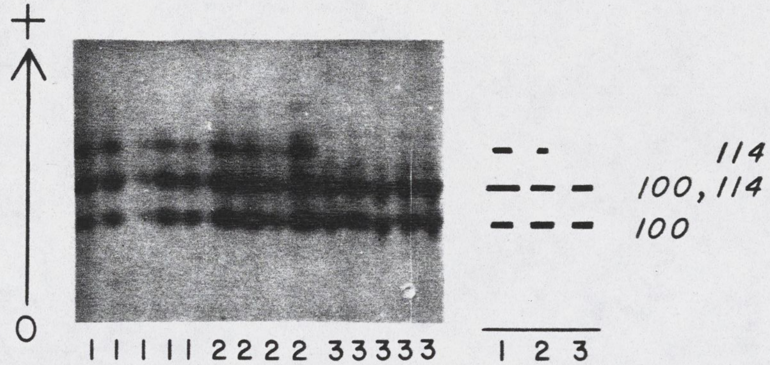


Fig. 1

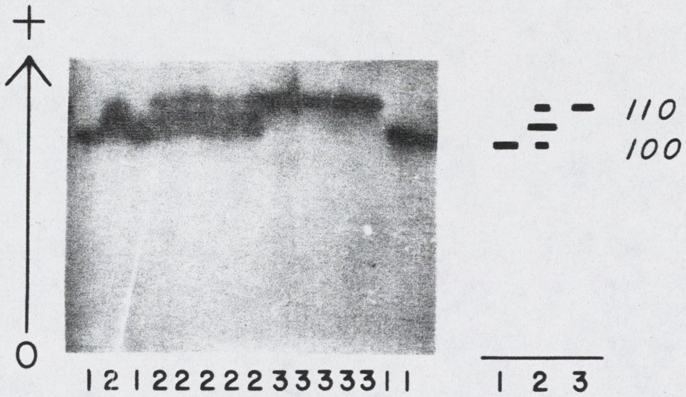


Fig. 2

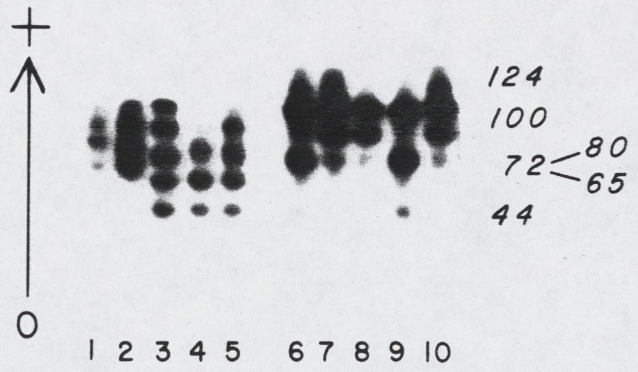


Fig. 3

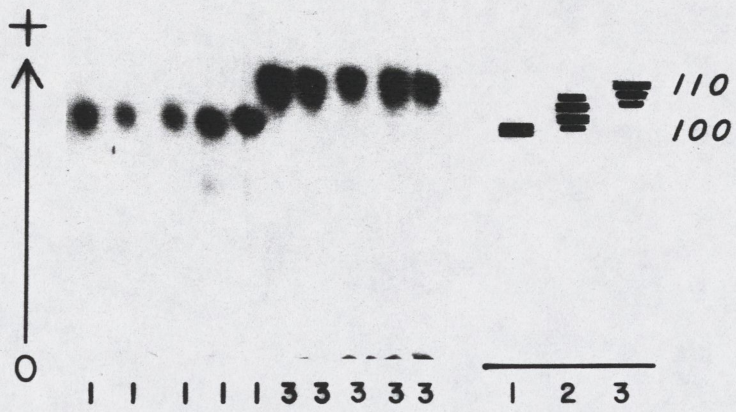


Fig. 4

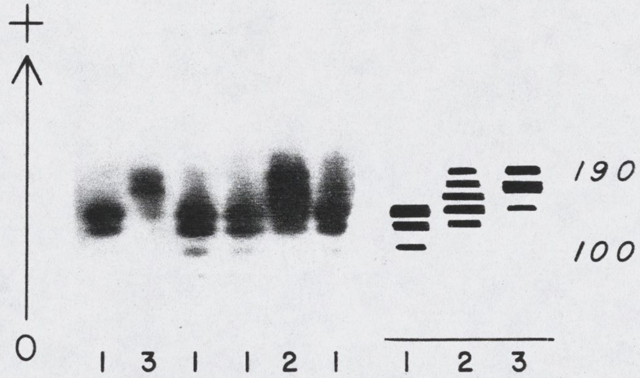


Fig. 5

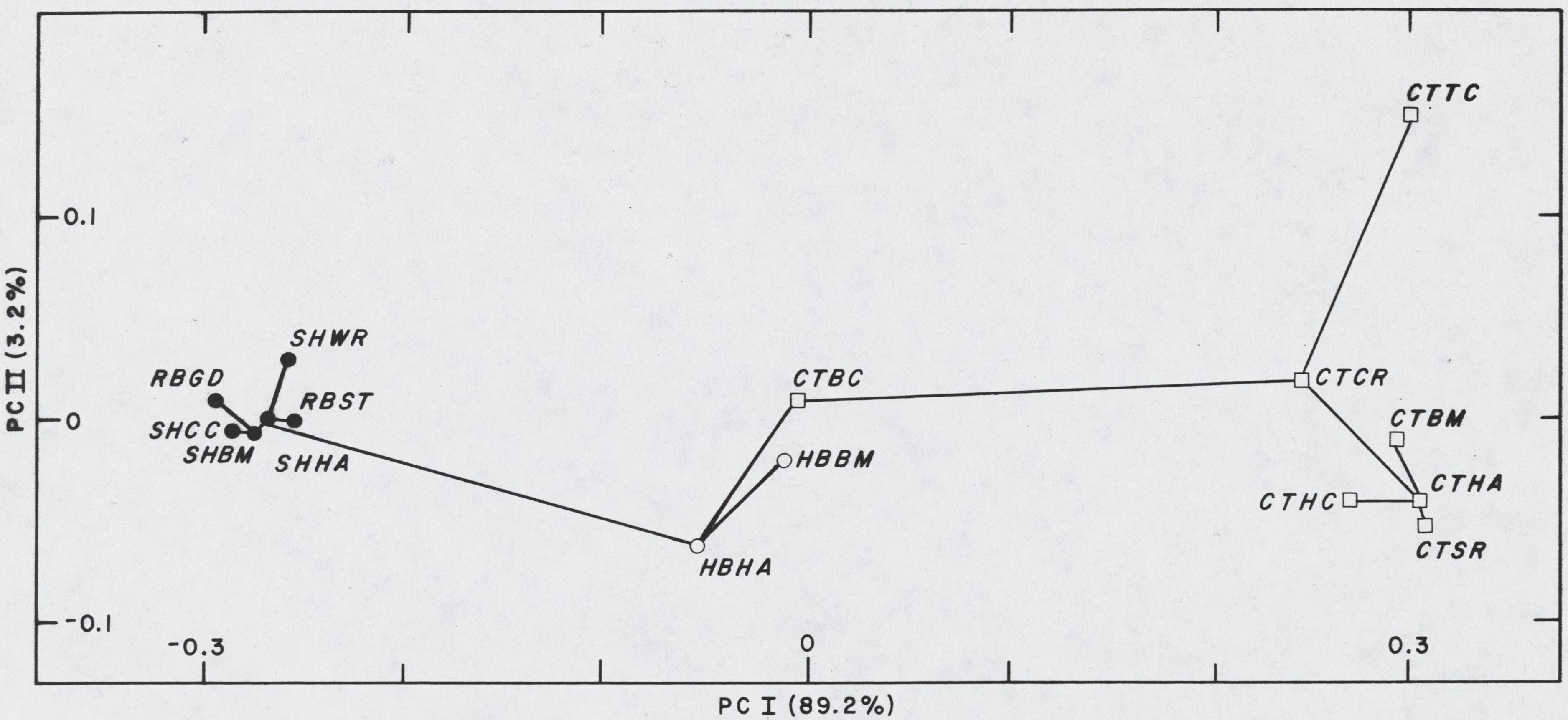

CTTC
0.1
PC II (3.2%)
SHWR
RBGD
RBST
CTBC
CTCR
0
SHCC
SHBM
SHHA
HBBM
CTBM
CTHA
CTHC
CTSR
HBHA
-0.1
-0.3
0
0.3
PC I (89.2%)

Fig. 6

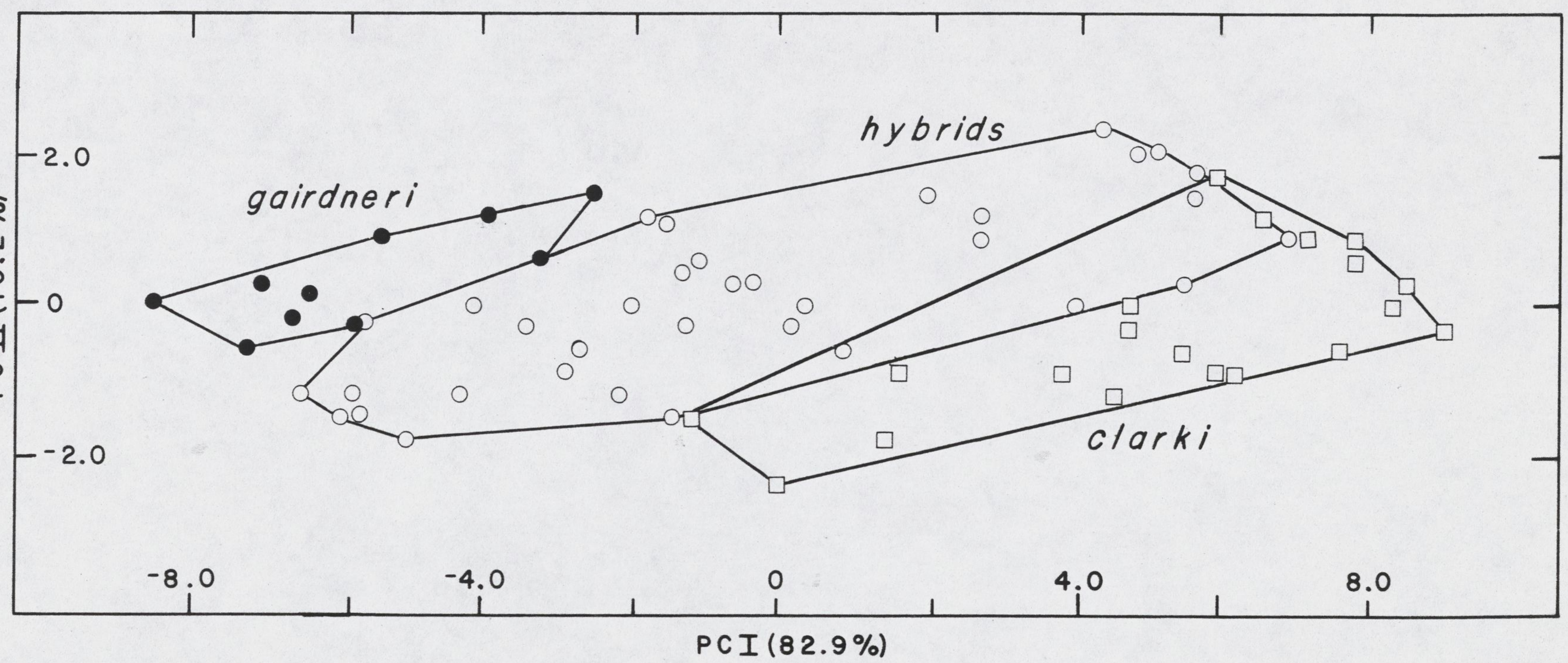


Fig. 7

R.13

AN EXAMINATION OF THE
ANADROMOUS TROUT PROGRAM OF
THE WASHINGTON STATE GAME DEPARTMENT

by

LOYD A. ROYAL

October 30, 1972

Mr. Carl N. Crouse
Director, Department of Game
600 North Capitol Way
Olympia, Washington 98504

Dear Sir:

In accordance with your directive of March 1, 1971, the writer has reviewed all aspects of the anadromous trout program of this department. During the examination of the program, the interrelation of all stream rearing salmonids became obvious, hence, it was necessary to include an analysis of fish cultural activity related to all stream rearing salmonids, including coho and chinook salmon.

The attached report emphasizes the need for coordination and consultation with other fishery agencies, both state and federal, and justifies the need for changes in management techniques, practices, and concepts by all concerned.

Detailed recommendations, based on findings in the attached report and relating to management, will be forwarded under separate cover.

Yours truly,

Loyd A. Royal
Fisheries Research Coordinator

LAR:fmm

TABLE OF CONTENTS

Page

An Examination of the Anadromous Trout Program of The Washington State Game Department

INTRODUCTION

All cold-blooded animals have inherited quite rigid tolerance limits to changes in their living environment during the various stages of their life history. In the case of the anadromous salmonids, not all of these tolerance limits have been isolated by definition but a great amount of information is available illustrating a high degree of variability between species and between races or stocks of the same species. While no one has presented for technical examination or discussed all the existing knowledge on the subject of environmental tolerance limits of anadromous fish, this knowledge is quite extensive and is available mainly as unpublished data. These data indicate that the environment preceding, during, and immediately after seaward emigration has a great impact on ultimate survival and is probably the most important and most sensitive phase in the life cycle of the species. A knowledgeable person on the subject recognizes the importance of this information and the vital need for acquiring additional data in order to design the best possible management program relating to a particular species.

It is apparent from the results obtained in the procedures being carried out by the Washington and Oregon Game Commissions that anadromous trout could have relatively wide tolerance limits to certain variations in their freshwater environment, more so, perhaps, than do the other species of anadromous salmonids, including coho salmon. Steelhead populations have been crossbred and transferred as "forced smolts" randomly throughout the streams of both Oregon and Washington. In a preliminary examination of adult returns resulting from the above practice, it is quite apparent that the returns have been sufficient to justify a continuation of the program and to satisfy fishermen that the current operation is productive.

Modern methods of artificially propagating and rearing anadromous trout involve the principle of stimulating development of the embryo and the resulting fry so that an emigrating smolt can be produced in the spring of its first year, rather than in the second or third years, which is the normal situation. The natural environmental cycles relating to the normal reproduction of each steelhead population are generally ignored, primarily because the process of artificially stimulating development of foreign stocks has produced returning steelhead populations of significant economic importance. However, in spite of the satisfying results of the current program, both in Washington and Oregon, there is some indication that inherited environmental tolerance limits are still operative. Such limits may be obstructive to the obtaining of increased survival rates from the present program and might prevent the accrual of additional benefits from an expanded program involving the same river systems. The possibility that these limitations exist in the survival of hatchery smolts and in the production of returning adults appears to be important in planning for procedural improvements in the present steelhead program.

While anadromous salmonids are essentially slaves to their freshwater environment, with their ultimate survival dependent to a large extent on the fluctuations of that environment, they also have a complex relationship with each other. Statistics establishing the numerical relationship of each species to another are difficult to obtain because of man's harvesting of some populations while mixed in areas remote from the river of origin and his deleterious effect on their freshwater environment. Logging, pollution, irrigation, and hydro-electric projects, as well as other developments, have disturbed the environment in a manner which has resulted in upsetting the natural relationship of one salmonid to another and also their total productivity.

A general assessment of the commercial catch on the Columbia River in pounds by species during the late 1800's indicates that in the area above Bonneville, steelhead comprised about 10 percent of the anadromous salmonid complex, chinook salmon approximately 75 percent, with coho and sockeye salmon filling the balance. Elsewhere in the state, the steelhead apparently formed a much smaller part of the naturally controlled complex, with the percentage dropping to below 5 percent and often as low as 2 or 3 percent. Presumably, the minor role played by the steelhead, even in the Columbia River, is related to its freshwater life history, which normally requires two years minimum stream residence before emigration to the sea. Its degree of minority appears to be correlated positively with the natural productivity of the river systems of concern. Little is known about how the structure of the total complex is actually established, although predator-prey relationships, available food, and the hydraulic characteristics of the stream are known to be major controlling influences.

Defining the ecological controls and how they function to downgrade the part played by the steelhead in the normal salmonid complex is important. More important, however, is the need for recognizing that the complex exists and harmonizing management programs for individual species involving fish culture practices so that this complex is not upset in such a manner as to nullify the benefits from natural propagation or to favor the development of one species at the expense of one or all of the others. Artificial propagation should be directed toward supplementing natural production without interfering with it or unilaterally destroying or injuring the potential of one species to obtain possible benefits for another.

The anadromous trout program of the Washington State Game Department will be examined in the light of the above discussion and changes will be recommended which would appear to have a potential for increasing survival rates of the anadromous trout. Current methods and practices involved in the management of all anadromous populations, salmon as well as trout, must be considered to determine if they are consistent with the need for protecting and increasing the production of all species.

STATISTICS

Total Catch Statistics

An adequate and practical system of collecting catch statistics is fundamental to the development and improvement of a fisheries management program. The more sophisticated the system the greater its value, but cost must, of practical necessity, be an important limiting factor in its design. Conceivably, a major part of the funds used in managing the steelhead fishery could be expended in the collection of data on fish catches. Hence, the establishing of an adequate statistical system operating within practical cost limitations has been a major problem facing all fish and game organizations who are concerned with harvests by up to hundreds of thousands of people. All such organizations have had to limit their collection of data to a sampling system from which the total harvest and the harvest in the desired geographical subdivisions could be computed.

The Washington State Game Department was one of the first organizations to develop the punch card system for measuring the pheasant harvest and was the first to adopt this method (1947) as a means of measuring the catch of steelhead. Two modifications have been made in the latter method. Initially, the card covered the winter season only and represented the catch of steelhead taken in the months of December through April. This catch consisted primarily of winter steelhead but a minor catch of summer-run steelhead (5 to 7 percent) was included which originated mainly in the Columbia River and its tributaries.

The first modification of the original system occurred in 1962 when the punch card was placed on an annual basis and the summer-run catch was separated statistically from the winter-run catch on the basis of local information.

The second modification, initiated January 1, 1970, involved an annual card, the same as previously, except that a $2.00 fee was charged. People over 70 and under 16 years of age were exempt from payment of the fee, although they were required to have a card in possession and return same with their catches noted. The impact of these two modifications on the accuracy of the estimated catches will be discussed later.

The total season's catch of both winter- and summer-run steelhead is calculated from the data in Table I as follows: The number of punch cards returned is divided into the number issued to determine a "projection factor". The number of steelhead reported on the punch cards returned is then multiplied by the projection factor to provide an estimate of the total catch of each run. The number of punch card holders not fishing steelhead, fishing steelhead, and those actually catching steelhead as recorded on the cards returned are multiplied by the same projection factor to obtain the season's total of each.

The failure of all punch card holders to return their cards and the necessity of computing a projection factor for determining total statistics has been the subject of considerable discussion and investigation. The Oregon State Game Commission authorized an extensive investigation into the report

TABLE I

Winter Steelhead Punch Card Data

Winter-Run	Punch Cards Issued	Punch Cards Returned	Projection Factor	Total Catch	Actual Steelhead Fishermen	Number Catching Steelhead	Percent Successful
1969-70	142,610	48,774	2.93	116,000	113,855	53,916	47.5
1968-69	200,050	56,025	3.57	207,250	138,800	57,100	41.1
1967-68	202,750	56,000	3.62	226,100	140,975	52,150	37.0
1966-67	202,675	58,125	3.48	225,850	137,650	63,150	45.9
1965-66	187,525	58,775	3.19	249,000	140,375	74,250	52.9
1964-65	171,400	54,500	3.16	174,175	121,000	57,600	47.6
1963-64	160,375	51,967	3.08	237,750	114,350	57,025	49.9
1962-63	151,700	44,575	3.40	198,300	112,500	59,050	52.5
1961-62	144,975	39,225	3.69	193,300	110,400	59,300	53.7
1960-61	93,350	24,925	3.75	117,450	82,325	29,225	35.5
1959-60	87,875	21,800	4.02	148,275	77,700	31,200	40.5
1958-59	84,450	19,750	4.45	126,500	Data missing		
1957-58	85,425	18,800	4.54	140,750	73,925	28,800	38.9
1956-57	85,350	18,950	4.51	120,550	75,050	27,475	36.6
1955-56	88,500	22,125	4.00	161,325	78,200	31,700	40.5
1954-55	90,400	25,400	3.55	130,775	79,350	29,500	37.1
1953-54	89,300	26,800	3.33	168,800	78,775	31,525	40.0

card system in use since 1953 in the State of Oregon for the collection of statistics on sportcaught steelhead and salmon. The method and results of the study are fully reported in "An Evaluation of the Punch Card Method of Estimating Salmon-Steelhead Sports Catch", by Hicks and Calvin (1964). The authors reached several conclusions relating to a bias to nonresponse, namely, that nonreporting anglers catch less fish than those who return their cards. A formula was devised which is now used in an attempt to correct for this bias. The degree of bias has proven quite consistent over a ten-year period as is evident from Table 2, which lists the deviations in percentage from the uncorrected estimate of the Oregon Steelhead Catch.

TABLE 2

Steelhead

	Revised Catch	Percent Deviation
1960	80,175	15.7
1961	69,613	16.3
1962	106,067	16.0
1963	97,468	15.6
1964	85,954	17.9
1965	111,439	16.7
1966	168,083	17.3
1967	143,040	18.1
1968	153,909	17.7
1969	130,432	17.2
Average..	113,718	16.9

In 1966, the Washington Department of Game resampled 5 percent of the fishing license holders through a specially designed questionnaire. Among others, the following questions were asked:

Did you obtain a steelhead punch card for 1966?

Did you fish for steelhead?

How many steelhead did you catch?

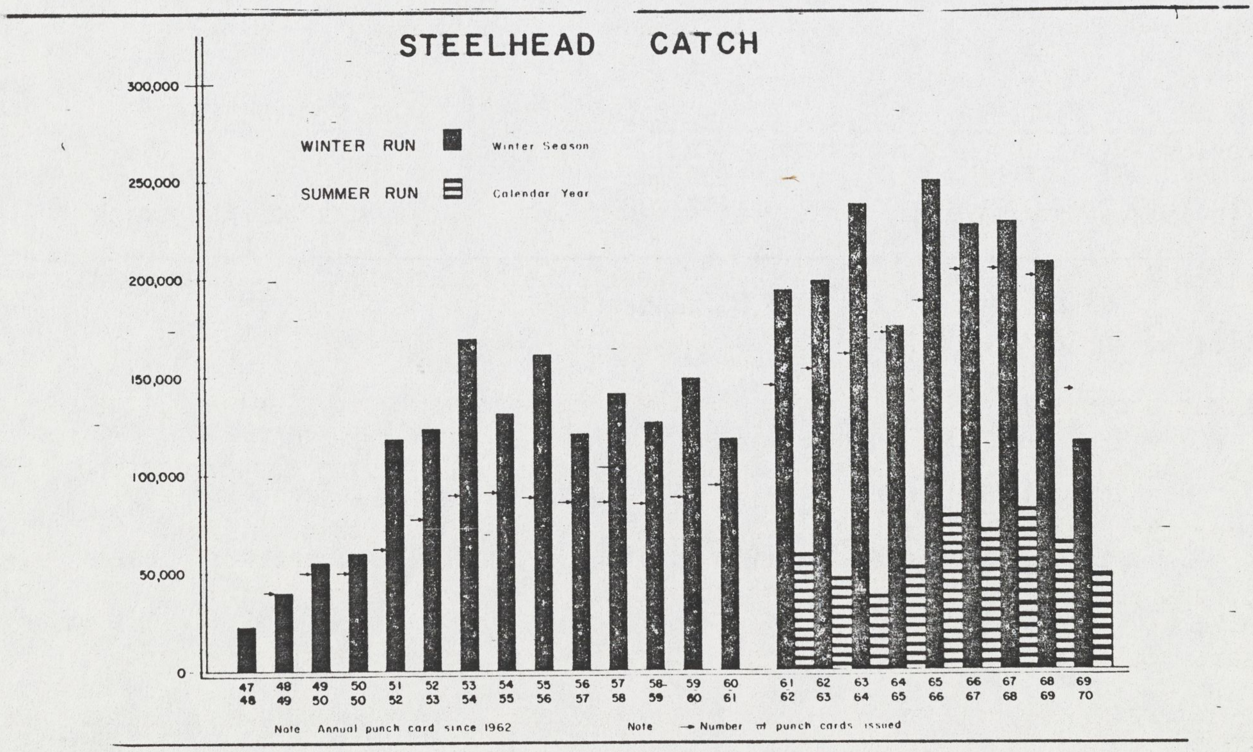
The results showed that 134,700 anglers actually fished for steelhead, compared with 140,375 calculated from the punch cards returned; or, a minus bias of only 4.2 percent chargeable to nonresponse. The total catch of steelhead, as calculated from the questionnaire, was estimated at 352,400 fish, compared with 347,100 calculated from the return of punch cards -- a difference of only plus-1.5 percent.

It is obvious from the foregoing that any sampling system, involving small individual catches and large numbers of people, has consistent errors characteristic of the system which are difficult to define in arithmetic terms and, therefore, it may not be necessary to remove them because of this established consistency. The consistency of the degree of error which is evident in the negative bias of nonresponse calculated by Hicks and Calvin and in any other analysis of total catch statistics for steelhead suggests that the system is workable in the more simple form designed by the State of Washington. Even though an error exists in computed statistics, as long as that error is consistent with time, the variations in the total catches will be real and representative of such natural variables as may be operative. It is a logical conclusion that the reactions of a large group of people will be consistent from year to year.

While the punch card system for calculating total catch appears to be the most practical and economical method for estimating the total catch, the consistency of any inherent error depends upon the maintenance of the same system of operation. A modification of the system can upset the relationship of the resulting statistics with those of previous years. It is possible that a new reaction on the part of the public could result in a major error in calculation.

Previously, it was stated that two modifications had been made since 1947 -- one in 1962 and another in 1970. The modification in 1962 changed the punch card system from being applicable to the winter steelhead season only (December to April), to the calendar year which includes part of two winter steelhead seasons and a complete summer season. In the case of the winter steelhead, the catch for the months of November and December is calculated using the projection factor for that year. This data is then added to the January through April catch of the year following, which is estimated by the projection factor of that year. Coincident with this change, the number of punch cards issued and the number returned (Table I) increased substantially, while the average projection factor declined. Along with the decline in the projection factor, the total catch, number of steelhead fishermen, and percentage of successful fishermen went up. A conclusion can be drawn from these data that the number of steelhead available increased suddenly with a resulting increase in fishing interest, catch, and the percentage of successful fishermen. Observation of the characteristics of the steelhead fishery supports the contention that as numbers of available fish increase public interest reflected by intensity increases. On this basis the sudden rise in the catch of winter steelhead for the 1962 winter season (Figure 1) in conjunction with the modification of the punch card system described earlier would be due to increase in the number of available steelhead rather than an error in the estimate related to the modification of the basic system.

Figure 1



A second consideration in analyzing the cause for the increased catch must be the rise in fishing intensity and its relation to the catch-escapement ratio. If the catch increased at the expense of escapement, the numerical size of which is not known, then the catch increase due to this factor does not represent an increase in population size. However, as intensity increases and having in mind the psychological environment and character of the fishery which will be discussed later, the catch per unit should decline due to competition, even though a population increase may provide the same number of available steelhead per fisherman. The data in Table 3 show that for the period 1962-1969 the average number of fishemen actually fishing for steelhead increased 63 percent over that for the period 1954-1961, with the catch increasing 53.1 percent. The catch per unit dropped from 1.79 to 1.68, a decline of only 6.1 percent. If the winter steelhead population had not tended to increase with the increase in fishermen and the catch remained the same as shown in Table 4, the C.P.U. would, theoretically, drop 38.5 percent, or from 1.70 to 1.10 fish per fisherman.

TABLE 3

Number of Fishermen		Actual Catch	Catch Per Unit
1954-1961	77,904	139,306	1.79
1962-1969	127,006	213,238	1.68
	+ 63 percent	+ 53.1 percent	- 6.1 percent

If the population had theoretically remained the same as represented by the catch, the following would have been the case. Actually of course, the population declined since with equal populations and increased intensity the catch should have increased.

TABLE 4

Number of Fishermen		Catch	Catch Per Unit
1954-1961	77,904	139,306	1.79
1962-1969	127,006	139,306	1.10
+ 63 percent		0.0 percent	- 38.5 percent

An example of the effect of a reduction in population size was evident in the year 1970, when the winter steelhead catch declined significantly (Table 5).

TABLE 5

Number of Fishermen		Actual Catch	Catch Per Unit
1954-1961	77,904	139,306	1.79
1970	113,855	116,006	1.02
+ 46.1 percent		- 16.7 percent	- 43.0 percent

It is difficult to assess the several variables involved in estimating total population size. Competition, as stated previously, would tend to reduce the catch per unit but improved fishing gear, by increasing the efficiency of the fishery, would tend to increase the catch per unit at the expense of the escapement. General opinion of experienced fishermen favors the influence of competition as being the most important of the two factors, leaving the 6.1 percent actual decline in the Catch Per Unit for the period of 1962-1969 due to the failure of the total population to increase at least proportionately with the increase in fishing intensity. If this were so, the average annual winter steelhead catch for the period of 213,238 fish is 13,871 fish short of the theoretical average catch of 227,109 which would have been recorded if the population size had increased sufficiently to maintain the C.P.U. in spite of the increase in fishing intensity. The theoretical population figure for 1970 is calculated by multiplying the number of fishermen (intensity) for 1970 by the average Catch Per Unit for the period 1954-1961 and subtracting the actual catch for 1970; 113,855 x 1.79 = 203,593 steelhead, less 116,006 = 88,000 decline from the theoretical catch if the population had not declined.

The economic impracticability of accurately measuring catch-escapement ratios necessitates a final judgment as to variation in this ratio due to variation in intensity, the effect of competition, improved fishing gear and population size. General field observations indicate that the total escapement does not vary in size to a large extent from year to year, regardless of population size, once the producing stream is subject to a high fishing intensity which is now the case with important winter steelhead streams in the State of Washington. This was particularly true in 1970 when the number of winter steelhead was considerably below that of previous years, yet the usual number of steelhead was observed in several major spawning areas. Again, in 1971, when the population increased substantially over the one recorded in 1970, the total escapement apparently did not increase significantly on the basis of comparable aerial counts of spawning redds.

There are individual exceptions to this general situation which can be caused by weather. Heavy and fairly continuous rains may render a particular river unfishable for a sufficient period of time to make it impossible to harvest a normal percentage of the fish. However, there is considerable evidence that if fish available in December are not caught in that month, they can be taken in January, and vice versa. In the last fifteen years examined, opposite trends in the catch occurred for each of the two months in ten of the fifteen cases. In the five cases (1960, 1962, 1964, 1965, and

1966) where the catch trend for the two months is the same (either up or down over the previous year), substantial increases or decreases occurred in the total catch over that of the previous year, which changed the predominate reverse relationship of the catch trend between the two months. Again, in dealing with total catch for the season, the adverse effect of weather on the ability to take a maximum harvest in a specific stream tends to be masked in the total catch, but not entirely so.

In examining all the factors affecting the current catch of winter steelhead, one is impressed by the similarity of the situation with that known to prevail in the harvest of pheasants. In the latter case, there is a substantial decline in hunter interest as the percentage of the total population harvested increases and the effort required to harvest the remaining population increases substantially. It has been established that the carry-over of pheasants (escapement) actually varies a relatively small amount, regardless of variation in the original population size and the hunting intensity. A decline in fishermen interest certainly exists in the harvest of winter steelhead in individual streams so that it is reasonable to assume that a certain minimum level of abundance is the final control of the escapement and the escapement is of fixed size within relatively minor limits of variation, regardless of population size. In a publication by the Michigan Department of Conservation (R. A. MacMullan, 1954) the following statement is made: "On the Rose Lake Wildlife Experimental Station near Lansing for several years hunting pressure averaged around 200 hunters per 100 acres. On the surrounding farm land (which had around the same number of pheasants) pressure was only about 50 hunters per 100 acres -- one quarter as much. Yet hunters shot only a few more cocks on Rose Lake. Here, too, the law of diminishing returns operates. At the beginning of the season, it takes hunters only a few hours to bag a pheasant. But after cocks are scarce, it may take several days hunting by a dozen hunters to bag one bird. Hunters become discouraged and quit hunting."

Since the residual or hunting season carry-over population remained approximately the same for the two plots, regardless of a great difference in intensity which resulted in a 1.0 to .25 C.P.U. ratio, this would further justify a conclusion that the total steelhead escapement will tend to be the same each year. It is recognized that some variation will exist, particularly in individual streams where the escapement may increase due to weather conditions but limits of variation in the minimum escapement of individual streams and in the total escapement will be sufficiently narrow that they can be largely ignored in the practical management of the fishery which currently operates under a preserve system for headwater spawning. Therefore, increases and decreases in the annual catch are closely related to a similar change in the population of winter steelhead modified to some extent in years of high winter runoff.

The validity of the above conclusion relates to the harvest of winter steelhead by hook and line. It is well established that commercial gear, including gill nets and set nets, can take up to 100 percent of a salmonid population under certain conditions and that, in such a case, severe and variable restrictions are necessary to provide the desired escapement. Since there is no commercial season for steelhead in marine areas, the Indian reservation fishery will usually harvest fish that are wholly deductible from the potential hook-and-line catch, rather than from the escapement. This statement applies until the Indian harvest, which is taken by modern commercial gear, is sufficiently large to reduce the number normally reaching the spawning ground. Such a circumstance would not only eliminate any public interest in taking steelhead by hook and line but would reduce the rather consistent number of fish which would otherwise reach the spawning grounds. Whenever the harvest is taken solely by hook and line, the law of diminishing returns apparently provides a built-in protection for the number of brood stock available, regardless of the original size of the population.

The initiation of the $2.00 fee for the annual punch card in 1970 should not have had any significant impact on the accuracy of the computation of the annual catch. The foregoing discussion presents data and information which indicate that the drop of 88,000 fish in the total winter steelhead catch for 1970 represents a drop of an equal amount in the total population and is not related to the initiation of the above fee.

The question arises as to why there should have been a sudden and substantial increase in the number of winter steelhead available to the fishermen in 1962 which was maintained, with one exception (1965), for the eight-year period from 1962 to 1969 (Figure 1). Examination of the smolt planting records shows little change in the number planted annually during the period from 1958 to 1961, which includes the plantings in 1960 that produced the predominate share of the 1962 adult run. While environmental conditions favorable to survival apparently controlled the 1962 production to some extent, these same conditions did not necessarily prevail in all of the years of high catches following the 1962 run. It is interesting to note that a complete changeover from a wet to pellet diet occurred in 1959, representing the rearing period for the 1960 smolts that produced the 1962 steelhead run. The pelleted diet has been used continuously since 1959. It is a logical conclusion that the change in diet was responsible primarily for increased steelhead production beginning in 1962 and this conclusion gains support from the observed increase in the survival rate of coho when reared on the pelleted diet.

In summary, it may be stated that the total seasonal catch statistics obtained from punch cards, within some possible limit of consistent error due to bias of non-reporting, are usable as representing not only the actual catch but the total population, even though the escapement is not known. Evidence of a consistency in the numerical size of the total annual escapements, regardless of run size, results in any variation in total catch being directly related to a variation in the size of the total population, except when caused by adverse weather conditions which are measurable. This relationship exists only when intensity is great enough to activate the law of diminishing returns as reflected in the declining interest of the fishermen, which now appears to be the case in all the important winter steelhead producing streams of the state. It is the consistency in sizes of the total escapements unrelated to run size which prevents the use of standard formulas in establishing population size on the basis of effort and catch.

Catch Statistics by Month

The previous discussion has resulted in a favorable conclusion on the usability of the Washington punch card system for computing the total catch of winter steelhead and its application to the management of the fishery. The total catch statistics are also subdivided into catch by months and both seasonal and monthly statistics are assigned to individual streams. It is most important that the validity of each of these statistical subdivisions of the total catch be examined for, if valid within usable limits, they can supply an essential tool in the management of the winter steelhead resource.

The total monthly catch could indicate a change in the population return structure brought about by the introduction of a stock of steelhead genetically different from the original native population. Such a change might be caused by extensive transfers of Chambers Creek brood stock offspring. A change in run timing might result from the consistent spawning of early run fish, artificial stimulation of development rates during incubation, and the production of smolts in one year instead of the two or three years required in the stream.

It has been established that the foregoing tends to produce steelhead which are available in the sports fishery earlier than the wild or native population, with a substantial percentage of the adult hatchery fish returning to the rivers in December. Table 6 lists the data from several marking experiments that illustrate the differential time of return of Chambers Creek stock of hatchery origin from that of the naturally produced fish.

TABLE 6

Return of Hatchery Steelhead and Wild Steelhead
Based on Field Checks of Marked and Unmarked Fish

Elochoman River - 1962-1963

Month	Number of Hatchery Fish	Number of Wild Fish	Percent Hatchery Fish
December	204	214	48.8
January	171	156	52.3
February	253	235	51.8
March	94	359	20.8

Elochoman River - 1963-1964

Month	Number of Hatchery Fish	Number of Wild Fish	Percent Hatchery Fish
December	232	236	49.6
January	121	121	50.0
February	19	50	28.0
March	71	267	21.0

Humptulips River - 1962-1963

Month	Number of Hatchery Fish	Number of Wild Fish	Percent Hatchery Fish
December	86	23	79.0
January	40	16	71.0
February	14	13	52.0
March	6	8	43.0

TABLE 6 (Continued)

Bogachiel River - 1970-1971

Month	Number of Hatchery Fish	Number of Wild Fish	Percent Hatchery Fish
December	72	29	71.3
January	38	11	77.6
February	10	11	47.6
March	0	12	0.0

Sol Duc River - 1954-1955

Month	Number of Hatchery Fish	Number of Wild Fish	Percent Hatchery Fish
December	53	88	37.6
January	29	98	22.8
February	27	88	23.5
March	2	77	2.5
April	1	46	2.1

Satsop River - 1953-1954

Month	Number of Hatchery Fish	Number of Wild Fish	Percent Hatchery Fish
December	25	105	19.2
January	16	220	6.8
February	15	183	7.6
March	5	185	2.6
April	0	72	0.0

Similar findings are reported by the Oregon State Game Commission Research Division (1963). Their data on the contribution of adult hatchery reared winter steelhead to the sport fishery on Wilson River from 1960 to 1962 are presented below.

		Total Catch	Catch Hatchery Fish	Hatchery Fish
1960	December	1,273	911	72%
	January	847	379	45%
	February	529	322	61%
	March	827	380	46%
1961	December	1,204	727	60%
	January	449	178	40%
	February	87	19	22%
	March	266	79	30%

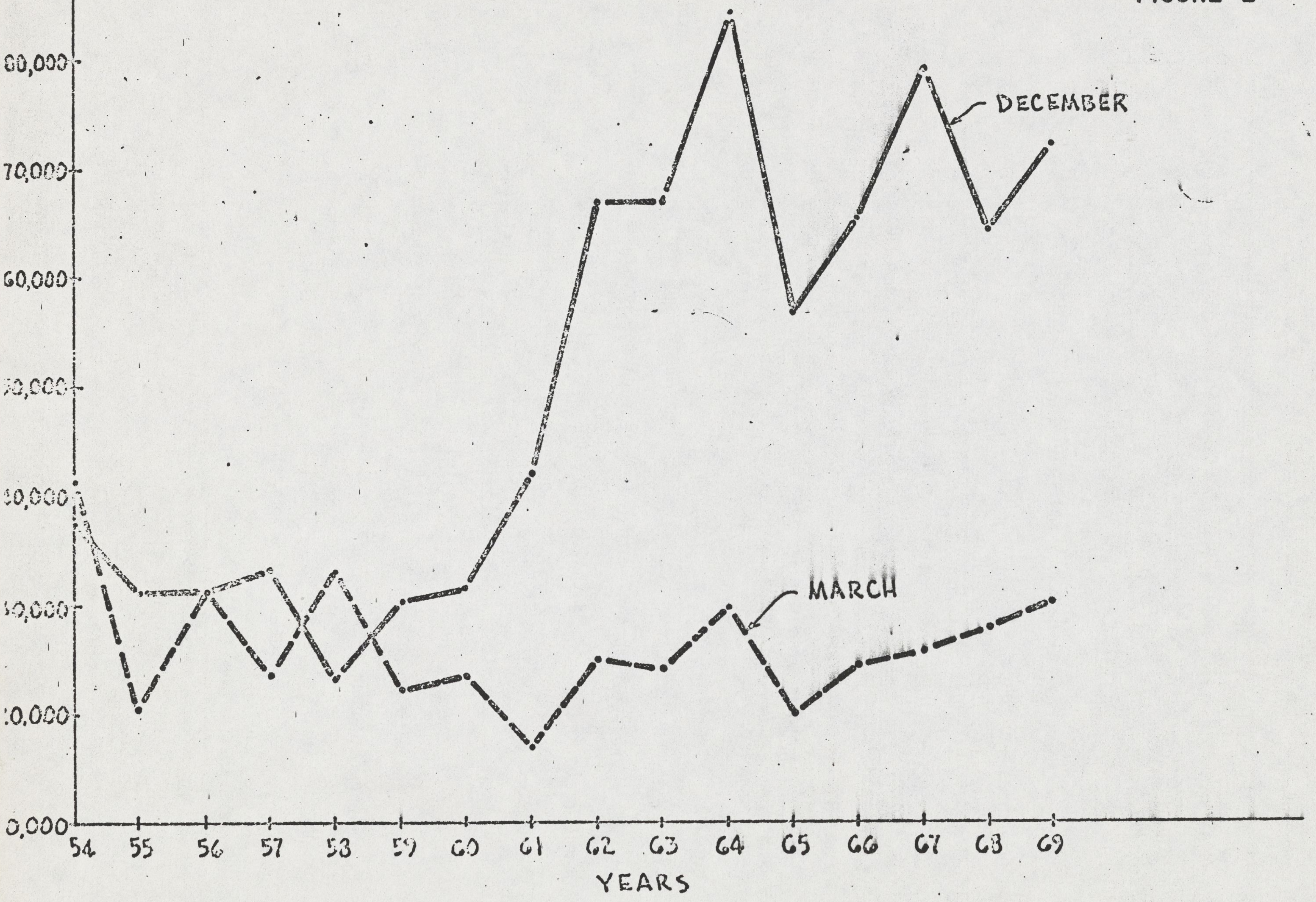
		Total Catch	Catch Hatchery Fish	Hatchery Fish
1962	December	798	317	40%
	January	663	265	40%
	February	375	85	23%
	March	313	73	23%

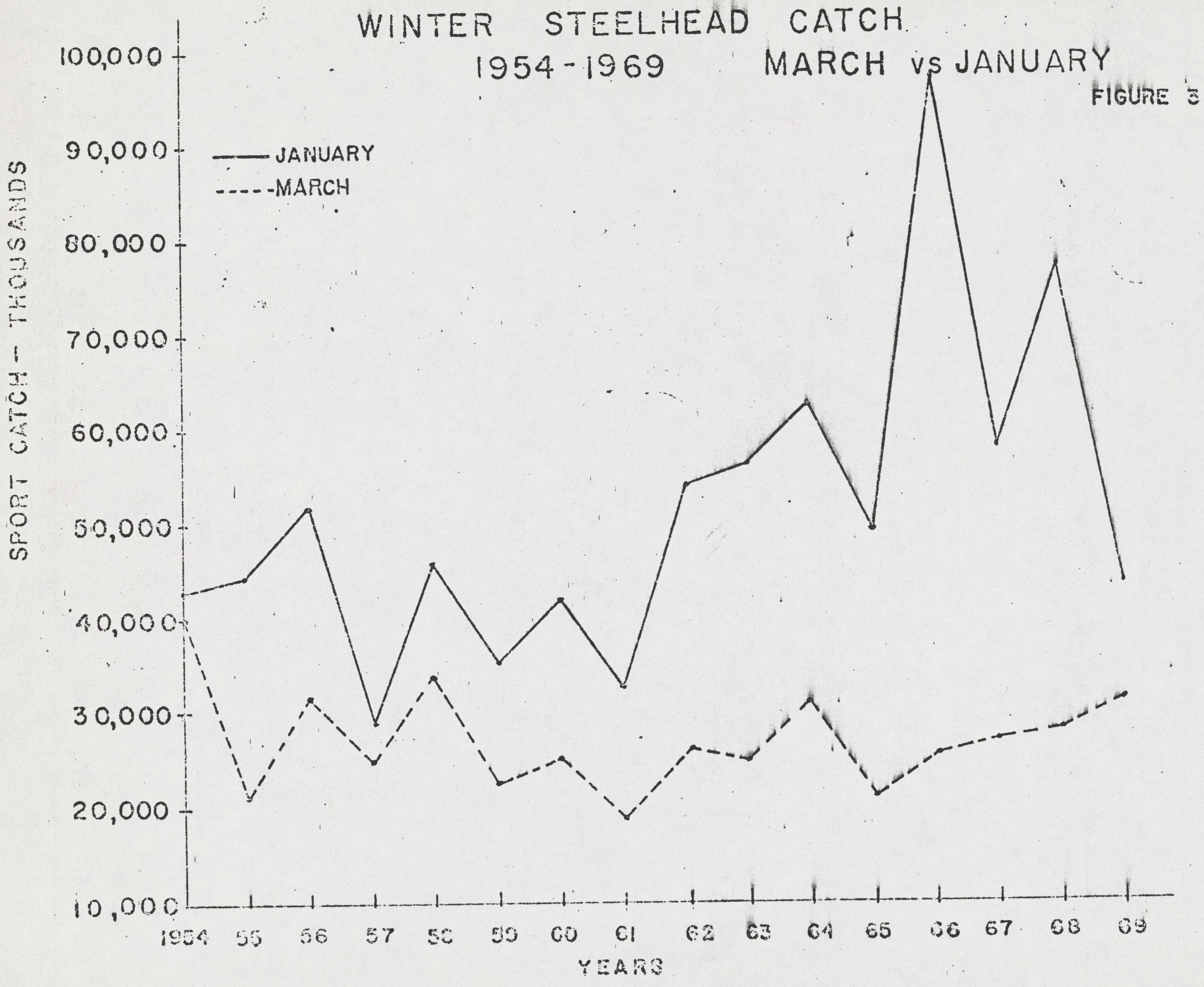
Since the number of hatchery smolts planted increased substantially in both numbers and range of distribution from 1950 to date, it follows that the total number of adults caught in December should have increased over the number caught in March. Figure 2, based on monthly total catch statistics, shows that the distribution of the catch between these two months has changed rather drastically in recent years. Figure 3 reveals a similar change for January compared with March but the difference is not as great as illustrated in Figure 2 for December-March. This change in timing shown by the marked fish data, supported by a similar change using total monthly catch statistics, proves the validity of the latter for use in the management of the winter steelhead resource.

There are other factors which may influence the projected catch of winter steelhead by individual months that are not masked, as they tend to be in total catch figures. It was stated earlier that weather conditions can affect the monthly catch to quite a degree, although evidence existed that fish not caught in December were still available, at least in part, to the January fishery and vice versa. Table 7 illustrates the dominant reverse trend in the December and January catches when the catches of each of these months are compared with those of the preceding year. In February and March, when the weather and related runoff is more stable, this reverse trend does not occur. The fact that the December and January monthly trends exist and can be related to monthly runoff data demonstrates further that the monthly figures are sufficiently accurate to be used in the formulation of management policies.

WINTER STEELHEAD CATCH MARCH vs. DECEMBER
1954 - 1969

FIGURE 2





WINTER STEELHEAD CATCH
1954-1969 MARCH vs JANUARY
FIGURE 3
JANUARY
MARCH
SPORT CATCH - THOUSANDS
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
1954
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
YEARS

TABLE 7

WINTER-RUN STEELHEAD CATCH
PERCENTAGE DISTRIBUTION BY MONTH

	Nov.	Dec.	Jan.	Feb.	March	April	Total Catch
1954		38,431	42,404	34,275	42,077	11,628	162,500
		22.8	25.1	20.3	24.9	6.9	
1955		31,822	44,194	27,575	21,534	5,676	130,773
		24.3	33.7	21.2	16.4	4.3	
1956		31,016	51,856	36,588	32,180	11,064	161,624
		19.2	32.1	22.6	19.9	6.8	
1957		34,249	28,225	23,823	24,823	8,271	120,602
		28.4	23.4	19.8	20.6	6.9	
1958		23,281	46,685	29,492	33,719	6,156	139,323
		16.7	33.5	21.2	24.2	4.4	
1959		31,184	35,484	29,298	22,795	7,769	126,507
		24.6	28.0	23.2	18.0	6.1	
1960		32,309	41,923	40,216	24,920	9,511	148,279
		21.8	27.8	27.1	16.8	6.4	
1961		43,371	32,981	15,709	18,304	8,385	117,449
		36.9	28.1	13.4	15.6	7.1	
1962	1,246	67,831	54,037	37,284	26,074	6,284	193,533
	0.6	35.1	27.9	19.3	13.5	3.2	
1963	1,246	67,831	56,510	39,003	25,229	7,329	196,821
	0.6	34.3	28.6	19.7	12.8	3.7	
1964	1,952	84,559	61,576	47,358	31,005	9,735	235,260
	0.8	35.7	26.0	20.0	13.1	4.1	
1965	3,038	57,499	48,868	35,970	20,680	7,098	173,732
	1.7	33.0	28.0	20.6	11.9	4.1	
1966	1,906	67,056	96,818	48,267	25,623	7,683	249,077
	0.8	27.0	38.9	19.4	10.3	3.1	
1967	8,457	79,781	58,308	41,756	26,140	10,575	224,401
	3.7	35.4	25.8	18.5	11.6	4.6	
1968	6,799	64,939	73,491	40,043	28,249	11,074	225,830
	3.0	28.7	32.5	17.7	12.5	4.9	
1969	8,879	72,417	42,715	37,567	31,245	9,739	207,254
	4.3	34.9	20.6	18.1	15.1	4.7	
1970	3,648	37,338	28,011	22,434	15,933	5,875	116,226
	3.1	32.1	24.1	19.3	13.7	5.0	

Note is made that while the December catch of steelhead has increased substantially since 1959 (Figure 2), the March catch, consisting primarily of naturally produced fish, shows a slight decline. When the estimated adult catch of steelhead originating from hatchery produced smolts is subtracted from the total March catch, the catch of wild steelhead shows a significant decline. This point will be discussed later in detail but is referenced here to present additional evidence that total monthly catch statistics have a usable value, regardless of a possible but consistent positive error affecting the accuracy of the figures.

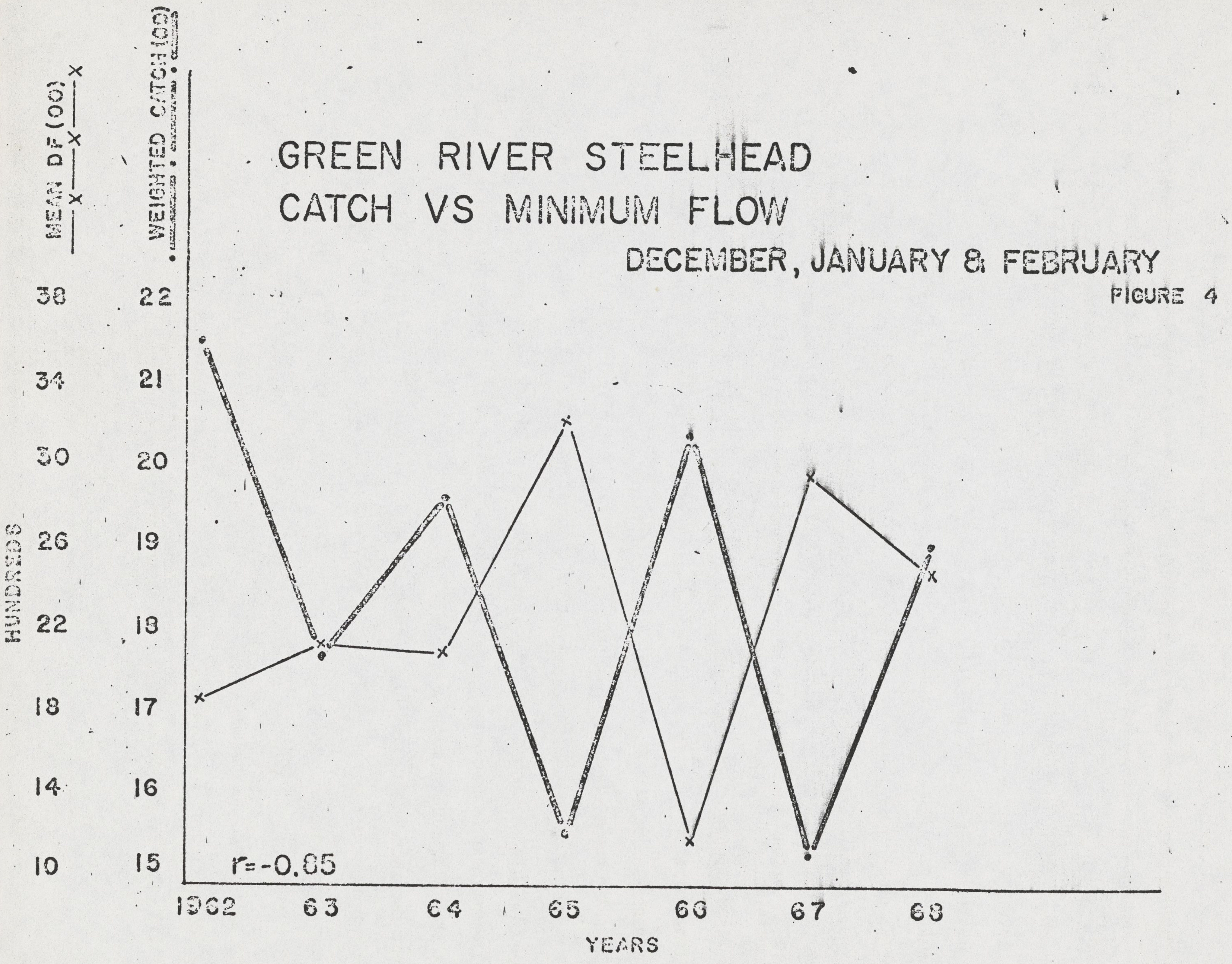
Catch Statistics by Rivers

The statistic of considerable value to management is the catch by individual streams. This subdivision of the total season's catch of winter steelhead is obtained by recording the number of punch cards reporting catches for a specific river, totaling the catch reported for that river, and then applying the statewide projection factor for cards not returned to obtain the estimated season's catch for the individual river. This statistic is probably more vulnerable to variable error than the season's catch, or the total catch by months, since it involves segments of the total number of steelhead fishermen, rather than the whole. Individual groups of fishermen may react differently from each other in their bias of nonresponse, which can only result in varying degrees of bias in the calculated catch for individual rivers. However, there is reason to believe that the bias of nonresponse, while probably variable between rivers, is consistent from year to year for the same river. An examination of the yearly catches for each stream estimated by the method described above indicates such a consistency in the annual level of production that the error of bias must be reasonably consistent as well. As long as the error in calculation is consistent, the variation in the annual catches would be related to factors of concern to the management of the resource.

In an unpublished manuscript entitled, "Some Factors Affecting Steelhead Harvest Rates in the State of Washington" (1970) the author, D.O. Braaten, states that "water conditions during prime fishing months (December through February) are an important feature in respect to the number caught. It is remarkable that in nine of the eleven streams studied, some function of water flow during upstream migration was the most influential factor (controlling catch)." If the amount of bias error were not consistent (from year to year) for each river, such a relationship between flow and catch could hardly be established. Figure 4, taken from the above report, depicts the negative correlation between flow and the winter steelhead catch for Green River. These data indicate that the catch of steelhead from this stream can vary up to 25 percent due to flow conditions, regardless of run size.

Three major attempts have been made to measure the bias error in the catch statistics of individual rivers as computed from the punch cards. In 1962, 1963, and 1964, a rack was placed across the mouth of the Elochoman River and a tagging program instituted which, in 1963 and 1964, more than fulfilled all the statistical requirements of a successful enumeration program. The program was not successful in 1962, since neither tagging nor recovery was consistent throughout the run. In addition, insufficient tags were recovered to be of any statistical value.

A calculated total of 2,947 steelhead entered the river in 1963 and 2,539 in 1964. The catch for the two years, as estimated from the punch cards, was 2,931 and 2,446, respectively, which was approximately the same as the calculated total run. It should be noted that number of fish difference in the two sets


GREEN RIVER STEELHEAD
CATCH VS MINIMUM FLOW
DECEMBER, JANUARY & FEBRUARY
FIGURE 4
MEAN DF (00) —x—x—x
WEIGHTED CATCH (00)
HUNDREDS
38
34
30
26
22
18
14
10
22
21
20
19
18
17
16
15
r=-0.85
1962
63
64
65
66
67
68
YEARS

of data for the two years was approximately the same, indicating that the punch card data showed a similar decline in numbers to that revealed by the tagging data. In view of a substantial escapement in both years, the amount of escapement measured the bias error in the punch card system for the two years as applied to the Elochoman River. However, the bias error was created artificially, at least to a major extent, by the effect of the experimental operation. Constant creel checks -- a total of 695 in 1963 and 828 in 1964 -- accompanied by personal explanations of the project and the marking of all punches checked, would result in an artificial increase in the number of punch cards returned and a related increase in the calculated catch because an average projection factor is used in making that calculation. The accuracy of the catch calculation depends on maintaining a consistent reaction of the fishermen to the punch card system. Any influence other than normal exerted on the fishermen fishing a particular stream can cause a bias error, either positive or negative, depending on the nature of that influence. Since a catch of only 1,080 was recorded for the year preceding the three-year experiment and 1,660 for the year following, the normal bias error inherent in the punch card system for the Elochoman River appears to be quite low. Even when the bias error was increased artificially by the experiment, the exaggerated error remained relatively consistent for 1963 and 1964 and probably for 1962 as well, although accurate data on run size for that year was not available. The catch of 1958 fish calculated from the punch cards for 1962 appears too high and, no doubt, was artificially increased because of numerous field checks related to the limited experiment of that year.

A second experiment to evaluate the punch card system as applied to the catch of winter steelhead by river systems was conducted on the Washougal River in January, February, and March, 1959. Car counts, number of fishermen, and fishing success, separated by weekdays and weekends, including holidays were combined to arrive at an estimated catch of 850 steelhead for the period, compared with 878 calculated a year later from the punch cards. A comparison of the two sets of data shows very little bias error inherent in the punch card system as applied to the Washougal River for the study period involved. In this instance, no punch cards were marked in the field and the fisherman, when checked, had no reason to believe that he was contributing data for an experimental program. This operation was in direct contrast to the one described above for the Elochoman River, where the fisherman was stimulated to turn in his punch card specially marked in the field by a wildlife agent.

In 1963 and 1964, an extensive sampling system involving road and creel checks was placed in operation on the North Fork of the Stillaguamish River to measure the catch of steelhead by this method compared with the catch as calculated from the punch cards. Creel checks included the marking of the punch cards, which should have increased the percentage return of the punch cards, thus artificially increasing the calculated punch card catch. The calculated catch from the sampling method was 4,994 steelhead for the 1962-1963 winter steelhead season and 4,233 for 1963-1964. The punch card catch was 4,815 in 1963 and 6,786 in 1964. The latter figure appears to be the most reasonable one, since the punch card catch should be artificially high due to the marking of the punch cards during the field checks. Careful questioning of people actually involved in the execution of the experiment and the preparation of an unpublished report (Southward and Douglas, Washington Department of Game, 1965) fails to provide a logical answer for the low figure in 1963. One can only conclude that either the calculations made from the field sampling for 1963 were in error or some unknown factor was operative temporarily to create an error in the punch card results.

The sensitivity to error of catch statistics computed by individual rivers can hardly be overemphasized. Since the above study involved one tributary of several of the Stillaguamish River, it is interesting to note that 14 percent of the steelhead taken in the North Fork of the Stillaguamish were reported by the fishermen as being taken in the main Stillaguamish River. This error is considered to be a minimum because of the frequent field checks involved. If a normal situation had prevailed, the identification error might have been 20 or even 25 percent. Therefore, the punch card catch for the main Stillaguamish River would be high by that amount and the catch for the North Fork reduced by a similar amount. This recorded error, caused by false identification of the origin of catch, when added to a possible positive error due to bias of nonresponse, would create a substantial positive error in the catch for the main river but a compensating one for tributaries. Obviously, there is a problem created by breaking down the catch of a specific watershed into subsections or tributaries. However, even though the error may be large, if it is reasonably consistent, the variations in the catch calculated from the punch cards would be real and representative of factors important to management. Since there is no guarantee that other sampling methods which involve only a portion of the population and require weighting to obtain total figures do not have errors also, one must conclude that no practical substitute for the punch card system has been designed as yet for general application. The validity of the total catch figures by season and by month appears to be established. Provided the use of calculated catches for individual river systems is restricted to trends or averages and accent is not placed on the catch for single years, these catches appear to have considerable value to management. However, knowledge and experience are necessary prerequisites for application to management of catch statistics computed for individual rivers.

Catch Statistics of Wild and Hatchery Stocks

The only data relating to the sports catch of anadromous trout originating from hatchery smolts and from natural reproduction have been collected during random surveys, mainly of the steelhead catch, to determine the survival rate of hatchery smolts. Usually the hatchery fish are identified from deformed dorsal fins caused by crowding during initial rearing, or from clipped fins or, more often, from both. Part, but not all, of the hatchery fish have deformed dorsal fins, which result in a possible negative error in computing the total number of returning hatchery adults. The percentage of adult fish of hatchery origin, while probably low due to the number having normal dorsal fins, is restricted by the number of hatchery smolts planted in any single year. However, in spite of the limitations of the program, hatchery steelhead, based on sampling of marked to unmarked fish in selected river systems frequently approaches 70 to 75 percent of the total catch.

An adequate method for measuring wild and hatchery production of adult steelhead in key river systems must be inaugurated on a continuous basis if future management of the total resource is to be maintained on a sound biological basis.

Scale sampling of the catch apparently provides the most practical tool for identifying the origin of the monthly catch in major river systems. The percentage distribution and characteristics of wild and hatchery fish taken in the sports catch will provide basic information on possible changes in the ecology of the anadromous trout population which may result from hatchery operation. Such changes may include differences in age, weight, percentage of repeat spawners, migration timing, etc. The collection of the above data will provide a better means of measuring the effects of planting policies and survival rates involved in a fish quality study which is now carried out in a somewhat haphazard manner.

Since the sampling data will determine the relative percentages of wild and hatchery fish, any error in total numbers of each classification that may result from positive errors in the annual punch card data is of little consequence. It is the change, if any, in the proportion of each from year to year that is of biological importance.

The writer has written a separate recommendation in respect to scale sampling and recording of related data to initiate this important program, beginning with the 1971-1972 winter steelhead season (Appendix A).

Hatchery Production and Planting Statistics

Accurate and detailed hatchery records provide a basis for measuring the economic and biological success of the rapidly expanding anadromous trout rearing program. Returning runs of hatchery fish to major river systems, which will be measured by the previously recommended scale sampling program as weighted by the punch card data, can then be related to hatchery methods, including size and time of planting, pathological history, diet records, the environment prevailing during transportation to and at the planting site, and the ability of the smolts to make a successful transition to salt water.

Record keeping in the central office for earlier years has been far from satisfactory. Existing planting records have been filed by counties, which are difficult to use since the records may be separated for a single river system flowing through two or more counties. The subdivision of the planting records for a single river contributes also to mistakes in recording.

One of the first tasks involved in this study, which required several weeks of effort, consisted of compiling an annual record of plantings and related adult catches for winter- and summer-run steelhead and a planting record for sea-run cutthroat. Through the cooperation of the Fishery Management Division, a new method of recording hatchery data has been designed which will provide past, present and future data, as outlined on a file card duplicated below.

WINTER STEELHEAD PLANTING AND RETURN RECORD

RIVER -

PLANTS					RETURNS				
Year	Number	Size Range	Stock	Rearing Hatchery	Punch Card	Field Check Hatch	Field Check Wild	Scale Reading Hatch	Scale Reading Wild

The ability of anadromous smolts to survive as adults depends on several factors, one of the most important being fish quality. Fish quality in this case relates to diet, pathological history, growth, size and ability to undergo the fresh-to-salt-water interchange with a minimum of stress. Past hatchery records do not provide an adequate measure of fish quality for relating to the adult survival rate. The survival rates existing within the framework of current and future operations must be measured both experimentally and in a gross manner based on scale samplings and punch card data. Such fundamental information provides a necessary basis for improving fish cultural methods with accompanying increases in adult production.

Appendix B discusses the need for adequate quality records and makes certain recommendations in connection therewith.

NATURAL ECOLOGY OF SALMONIDS

Research associated with the development of a fish cultural program to increase the supply of various species of salmonids has shown that certain characteristics of the natural life history of the species involved must be duplicated if the program is to be reasonably successful. Research has indicated also that certain characteristics can be modified, if desirable, to achieve a higher benefit-cost ratio in terms of returning adult fish. All of the programs involving individual species have been largely unrelated to date, yet a natural relationship obviously exists between species which controls maximum production of each within the whole salmonid complex. This relationship between species has been largely ignored and insufficient information is available to fully define it. It is essential that the known life history of each species be summarized for later examination to determine if fish cultural practices are in obvious conflict in any way with these life histories. Such a conflict could prevent maximum benefits from accruing, not only from the natural reproduction of individual species but from all species. For practical reasons, this discussion will be limited to those species which can be classified primarily as the stream-rearing type.

Steelhead

The steelhead population of the State is divided into two major groups, namely, those referred to as winter-runs and the other as summer-runs. There are modifications to these two strains which return to the rivers in the fall or the year around. The Wynoochee River has a fall run along with a winter run and steelhead enter the Columbia River every month of the year. The fresh-water life history of all types is essentially the same except for variation in time of entry into the rivers. Spawning occurs from January through May, with the spawning of naturally produced summer-runs tending to overlap the spawning period of the winter-runs when both species exist in the same watershed.

All runs of steelhead spawning above Bonneville Dam are summer-runs which logically is the result of rigorous winter climate in the spawning tributaries. In the more moderate coastal climate, the winter-run is the dominate population but often coexists with a smaller population of summer-run fish in a number of major river systems. Historically, the summer-runs in the coastal rivers appear to have represented a larger segment of the total steelhead population than is the case now. Coincident with logging, which caused a reduction in summer flows and an increase in the summer water temperatures, the percentage of the total population represented by the summer-run fish has declined.

Most coastal rivers having their headwaters in the coastal hills apart from the higher mountain areas of the state have no historic record of summer-run populations, which presents possible evidence that the summer thermal environment may be critical to the existence of this type of steelhead. The observed tendency of the summer-run fish to seek the colder headwater areas or colder tributaries having deep holding pools during the summer period of maturation adds support to the possibility that flow as well as water temperature may be a critical factor in the maintenance of summer-run populations in coastal streams. However, the factor or factors controlling survival and their differential effect on separate stocks of the same species and on different species inhabiting the same stream have not been fully delineated nor have these factors been defined as an operational function. Such a study involves so many variables that well-founded conclusions are most difficult to obtain, hence, it is suffice to state that the development of the coastal watersheds has apparently caused a greater decline in the native summer runs of steelhead than has been the case with the native winter steelhead populations.

While summer-run steelhead may or may not spawn at a different time than those of the winter-run type, compensation probably occurs in the rate of development from the egg to fry emergence stage. Data obtained by the International Pacific Salmon Fisheries Commission[1] on the rate of development of Fraser River sockeye eggs show considerable compensation in the rate of development of early and late spawned eggs, which results in a shorter period of time between the peak of fry emergence for the two groups than existed between peak times of spawning. Fry from the two separate stocks of steelhead should tend to emerge at close to the same time, hence, they must be competitive for

1/ Unpublished Data - International Pacific Salmon Fisheries Commission habitat and food wherever both stocks exist in the same area.

It is logical to assume that the tendency of the summer-run fish to mature and spawn in the colder areas of the coastal watersheds could result in a larger percentage of the smolts having three years of stream residence than is the case with winter steelhead. The rate of growth and period of annual growth theoretically would be less than that which would prevail for winter steelhead. Such a situation might not prevail in the upper tributaries of the Columbia, where the water is more alkaline and, therefore, more productive of food. However, winter steelhead are not found in these streams.

It is suggested that the age classification of both coastal summer-run and winter-run steelhead smolts be compared, if possible, to aid in a better understanding of the fresh-water life history of the two different runs. It is probable that the coastal summer-run type is merely a genetic adjustment to fill a niche available in certain streams which cannot be used by steelhead having the fresh-water life history characteristic of the winter steelhead. This niche could conceivably be more sensitive to watershed changes than that utilized by winter steelhead. Genetic adaptation to west coast streams apart from that for the runs inhabiting the Columbia River might be sufficiently different to inhibit successful transplants. Such is the case with Columbia River chinook salmon which to date have not been <u>successfully</u> transplanted to Puget Sound streams and vice versa. The use of native summer-run brood stock may be essential to achieving satisfactory fish cultural benefits in Puget Sound rivers and, perhaps, the west coast streams as well (Appendix C).

Limited data is available on actual emergence time of steelhead fry, which will vary somewhat in relation to spawning time and the thermal environment. Larson and Ward (1955) in recording a downstream movement or redistribution of steelhead fry in the Wynoochee River state as follows: "The first fry appear in the trap sometime during the latter part of May and reach a peak from the latter part of June to the middle of July." Larson reported to the writer that the fry at emergence were 33 mm. in total length, at which time scales were being formed.

Meigs and Pautzke (1941) reported catching winter steelhead fry in Newaukum Creek, a tributary of Green River, on June 12, 1941. They state as follows: "The net results of one hours's continuous seining yielded six small steelhead trout approximately one and three-eighths inches in length (36 mm.)." Meigs and Pautzke corroborate Larson's observation that winter-run steelhead scales are laid down at about 33 mm. in length, so in the case of the Newaukum Creek sample, fry emergence had occurred possibly two weeks prior to June 12, probably in late May. Unpublished data available in the files of the Washington Department of Game reveal that the peak of spawning of winter steelhead usually occurs in the Skookumchuck River between May 15 and May 20 and that steelhead fry are relatively abundant by the middle of July, averaging 32 to 33 mm. in total length for buttoned-up fry.

In 1955, Larson installed a fyke net in Bingham Creek, tributary of the east fork of the Satsop River. He noted (Unpublished data) that nearly all of the winter steelhead fry trapped had evidently just absorbed their yolk sacks and the consistency in the length of the fish caught, regardless of time, indicated that only the young fry were moving downstream. Table 8 lists the sizes in mm. of steelhead caught in fyke nets in Bingham Creek.

Since the great majority of steelhead in Bingham Creek spawn in March, April and May and the water temperature in this stream is relatively stable, it is not surprising that the compensation in the rate of development during

TABLE 8

Size in mm.	Numbers by Months May	June	July	August
28	0	1	1	0
29	0	3	0	1
30	0	13	3	4
31	1	25	36	54
32	11	107	83	111
33	16	135	138	69
34	2	147	72	18
35	1	57	31	13
36	1	24	9	2
37	0	4	0	3
Average Length	32.8	33.3	33.0	32.4

incubation is reduced to a minimum, resulting in fry emergence extending into August. Fry emergence declines rapidly in the Wynoochee River after July 15.

Upon emergence, the fry seek shallow, protected areas of the stream, where the majority seem to remain during the summer months of their first year. Throughout the summer of 1971, the writer observed winter-run fry in several large river systems, including the lower portion of each, where they reach a size estimated at 5 to 8 cm. in total length by September, depending on existing conditions for growth.

The growth rate of winter steelhead fry during their first summer of stream residence was established for the Grays Harbor area by Larson in 1954 (unpublished data). He conducted seining operations on the Wynoochee, Humptulips, Satsop, and Wishkah rivers, and Table 9 lists the average, or mean lengths of the fish taken during July, August, and September. A rather wide variation in growth between rivers is indicated which relates to time of emergence and the rearing environment.

TABLE 9

River	Total Lengths July	August	Sept.
Wynoochee	32.2 mm.	43.9 mm.	69.4 mm.
Humptulips	34.8 mm.	38.0 mm.	61.9 mm.
Satsop	37.4 mm.	42.6 mm.	57.6 mm.
Wishkah	35.0 mm.	37.1 mm.	48.0 mm.

The staff of the Washington Department of Game has obtained considerable data in recent years on the size and movement of young salmonids within a river system. Monthly electro-shocking on Twelve Creek, tributary to the Skookumchuck River, showed that the young winter steelhead fry emerging in late June or early July reached a size of 5 to 6 cm. in September, 5 to 9 cm. in October, with some leaving the stream in November, presumably to inhabit the lower main river during the winter months. In July of the following year, these fish being 8 to 15 cm. in total length apparently return to Twelve Creek, and/or other cold tributaries, where they spend the summer months with the young fry of the year, presumably to escape the higher water temperature of the lower main river system, again leaving in the fall to take up downstream residence until the following spring, when they become emigrating smolts. Data from electro-shocking experiments on several cold water tributaries of other river systems confirm the Twelve Creek data, although the occurrence and timing of the movements varies somewhat, depending apparently on variation in the thermal cycle. The within-system movement of steelhead fingerling obviously does not occur in those streams where thermal barriers are not created.

Bjornn (1971) in studying trout movements in two Idaho streams confirmed the Washington State data to some extent. He found that a downstream movement of steelhead yearling commenced in November but continued throughout the winter which apparently is not the case in coastal streams. He also noted that some fish migrated upstream during the summer months but the facility was inadequate to measure upstream migration.

Further confirmation of the above is available in the observations of R. E. Andrews (1958) who stated, "A recheck of the main river (Alsea River, Oregon) to the lower river trap with Scuba skin-diving equipment, on August 17, corroborated the results of the July electro-fishing. Juvenile steelhead were not present as far as the observers could determine. Present indications are that juvenile steelhead, wild and of hatchery origin, utilize the main portions of the river during the summer months very little or not at all."

The apparent movement of juvenile steelhead to and from the lower rivers is of particular importance and must be considered in assessing the effect of proposed artificial barriers. This point will be discussed later in more detail.

A conclusion can be reached from these data that the young winter steelhead fry spend their first summer throughout the river system -- probably to a major extent in the area adjacent to or below their birthplace. In the late fall, large numbers but not all, of the subyearlings leave the colder tributary streams for the lower river system only to return to the colder streams in the early summer months of the following year when, presumably, water temperatures become oppressive. The yearling fish leave the cold water areas again in the fall but smolt and emigrate to sea the following spring. Therefore, cold water areas would be practically barren of young steelhead except for subyearlings during the winter months and practically no fish except subyearlings would exist in the lower part of the main rivers when high water temperatures prevail in the latter areas. Observations by the writer during the past summer on several large river systems tend to confirm the summer presence or absence of fish, by size, as indicated by electro-shocking experiments and other observations reported above.

Meigs and Pautzke (1941) report that 78 percent of 50 young steelhead taken in Newaukum Creek on April 15, 1941 were three and one-half to five inches in length (9 to 12 cm.), indicating that these fish were approaching one year of age. The remainder of the sample, being fish up to seven and one-half inches in length, were considered to be either smolts of the year or fish that would remain in Newaukum Creek for their third year of stream residence. On June 12, 1941, the authors report taking five young steelhead "averaging five and one-half inches" in length, which they classified as yearling steelhead.

Larson, in his annual report for 1952 (Washington Department of Game), states that young winter steelhead (Grays Harbor streams) reach a maximum length of about six and one-half inches by the end of their second summer and an average length of about six inches sometime in September. The writer sampled several steelhead streams with hook and line in September 1971. While this method of sampling probably results in taking the larger fish, it is apparent that a number of fish over six inches in total length are available in all streams by September, which confirms Larson's findings above. It should be noted that the fish taken by the writer were not aged and may include some 2-plus aged fish. His data is listed in Table 10 following.

The parr-smolt transformation in naturally produced winter steelhead appears to be size dependent and seasonal in occurrence. Wagner (1970) reports "Young steelhead which have reached a size of about 16 cm. (fork length) will smolt in the spring. A fish might be one, two, or three years of age at the time of smolting, depending upon its rate of growth. The process is characterized by a

TABLE 10

Date	River	Sample Size	Range Total Length (Inches)	Av. Length (Inches)
9/11/71	Dungeness	10	4-3/4 to 7-1/4	6.26
9/13/71	North Fork Nooksack	6	5-1/8 to 7-1/8	5.69
9/17/71	North Fork Calawah	2	6-1/2 to 6-5/8	6.56
9/20/71	Bogachiel	7	6-0 to 6-3/4	6.44
9/20/71	East Fork Satsop	7	5-5/8 to 7-3/8	6.61
9/27/71	North Fork Toutle	12	5-1/4 to 7-1/8	6.37

marked decrease in body depth, coefficient of condition, and by changes in chemical composition. The coefficient of condition for fish of migrant size (16 cm. or greater in fork length) declines continually from February through May. A marked increase in condition occurs during the post-smolt period, June-July. In comparison, the mean coefficient of condition for smaller fish (15.9 cm. or less in fork length) declines from December to February but remains relatively stable from March through June, with an upward trend in July."

Wagner's data explains, by inference, the reason why steelhead fry which might be displaced downstream upon emergence and disseminated to the sea do not survive; also why undersized steelhead residualize for an additional year of stream life preceding their seaward emigration. It is obvious also from an examination of available data that seaward emigration is restricted to the spring months if young fish are to survive to the adult stage. There appears to be some doubt, however, that smolting in relation to length is as precise as presented by Wagner.

A. E. Andrews (1958) presents data on the fork length and weights of 555 wild smolts taken from the Alsea River in 1959. Andrews' data is detailed in Table 11 following.

TABLE 11

Age Class	Sample Size	Weight Range (Grams)	Length Range (Centimeters)
I	41	17.9 to 46.8	11.7 to 16.5
II	393	33.9 to 59.5	14.5 to 18.2
III	120	46.6 to 76.9	16.5 to 20.5

Andrews states, "Extensive overlapping between the three groups in weight and length is indicative that some age I fish exhibit rapid growth and age III fish develop more slowly, while age II fish may be considered normal in respect to growth." He also reports that "Wild smolts were observed to move downstream during the day and night, with the most rapid movement occurring just after sunset and just before sunrise."

Similar findings are reported verbally by R. E. Noble of the Washington State Fisheries Department at Minter Creek, although Noble believes that more daylight movement occurs in turbid water.

Pautzke and Meigs (1940) report that the mean length of 80 smolts of all ages taken by sportsmen in Green River as 6.63 inches s.l. or 16.6 cm. This figure is probably low due to the possibility that some resident fish or pre-smolts may have been included. T. V. Gudjonsson (1946) reports that 91 percent of 285 seaward migrant steelhead from Minter Creek were of a length between 13.0 cm. and 18.5 cm. s.l., with the mode at 15.0 cm. s.l.

Larson, in his Annual Report for 1953, reported catching 11 wild winter steelhead migrants from the Satsop River during May which averaged 6.94 inches in total length.

Maher and Larkin (1954) analyzed scale samples from several hundred wild steelhead caught in the Chilliwack River, British Columbia, over a five-year period from 1949 to 1953. Table 12 lists their data on the calculated annual average fork length and total length of both smolts and adults, separated as to age classes.

TABLE 12

SEASON OF CAPTURE	Age Group 2/2				2/3				3/2				3/3			
	Smolt		Adult		Smolt		Adult		Smolt		Adult		Smolt		Adult	
	Fork Lgth cm.	Total Lgth Ins.	Fork Lgth cm.	Total Lgth Ins.	Fork Lgth cm.	Total Lgth Ins.	Fork Lgth cm.	Total Lgth Ins.	Fork Lgth cm.	Total Lgth Ins.	Fork Lgth cm.	Total Lgth Ins.	Fork Lgth cm.	Total Lgth Ins.	Fork Lgth cm.	Total Lgth Ins.
1948-49	16.5	6.84	70.9	28.8	15.3	6.36	78.7	31.9	19.0	7.84	71.6	29.0	19.5	8.04	80.5	32.6
1949-50	16.2	6.72	67.3	27.3	15.2	6.32	81.0	32.8	21.5	8.84	70.6	28.6	19.6	8.08	82.0	33.2
1950-51	17.6	7.28	70.6	28.6	15.3	6.36	82.0	33.2	18.9	7.80	69.6	28.2	19.8	8.16	82.8	33.5
1951-52	17.9	7.40	68.6	27.8	16.1	6.68	80.5	32.6	20.2	8.32	69.1	28.0	18.9	7.80	80.0	32.4
1952-53	16.9	7.00	70.6	28.6	16.4	6.80	82.0	33.2	20.1	8.28	71.1	28.8	20.6	8.48	82.8	33.5
Average	17.0	7.05	69.6	28.2	15.7	6.50	80.8	32.7	19.9	8.22	70.4	28.6	19.7	8.12	81.6	33.0

The data in Table 12 show that the smaller smolts tend to remain an extra year in salt water, hence, they produce a greater percentage of large adults than do the more normal-sized smolts. Other investigators confirm these findings by Maher and Larkin, which are of significance to sportsmen who prize larger fish. These data will be discussed later when they are applied to the fish cultural program.

Since the length of smolts reported above includes fish below the critical length for smolting, as reported by Wagner, the latter cannot be as precise as stated. However, the smolt-to-adult survival rate of the smaller fish is obviously lower than that of the larger fish and this might be due, at least in part, to the failure of all of the smaller fish to undergo the changes required for successful transition to the sea.

The length of wild smolts is most important to the fish culturist, since smolts produced in approximately one year of hatchery rearing must be as large as, and preferably larger than the wild smolts, most of which have been subjected to at least two years of stream rearing.

Wagner's data indicate that unless suitable growth is obtained in the rearing pond, the fish will not smolt and tend to residualize for an additional year, with an accompanying very poor adult survival rate. It is a general rule that salmonid smolts reared in a hatchery must be larger than their wild counterparts if a favorable survival rate is to be obtained.

Since the length of wild steelhead smolts is of special significance and the referenced investigators have used various criteria for establishing length, Table 13 lists the data as recorded by the individual investigators and the related calculated total length, using conversion data furnished by Dr. H. H. Wagner.

The total length of smolts tends to vary somewhat from stream to stream, depending on the growth environment, but the critical minimum size appears to be 6 inches in total length compared with the 6.64 inch critical size reported by Wagner. The mean total length of individual samples of the more normal two-year smolts apparently varies from 6.5 to 7.5 inches, with the mean approaching 7 inches, or approximately 8.5 fish to the pound. It is obvious that the one-year smolts represent the faster growing fish, with the three-year smolts having a slower rate, although the mean size of the smolts increases with age. There is always a question as to the adequacy of the methods used in

TABLE 13

River	Investigator	Length	Total Length inches
Alsea River	A. E. Andrews	14.5 cm. to 18.2 cm. f.l (2 years of age)	6.0 to 7.52 (all ages)
Minter Creek	T. V. Gudjonsson	13.0 cm. to 18.5 cm. s.l. (all ages)	6.0 to 8.36 mode 7.0 (total sample)
Green River	C. Pautzke R. Meigs	16.6 cm. s. l. (all ages)	7.52 (mean total sample)
Satsop River	R. Larson	6.94 inches t.l. (all ages)	6.94 (mean total sample)
Chilliwack River	F. P. Maher	16.4 cm. f. l. (average age 2 years)	6.78
	P. H. Larkin	19.8 cm. f.l. (average age 3 years)	8.17

sampling wild fish, since the larger fish usually have a greater capacity for avoiding the sampling gear. It must be assumed that the lengths of the above samples represent minimum figures. More data on the total length of wild smolts would be desirable in order to provide a sound base for designing a satisfactory hatchery rearing and planting policy (Appendix D).

Gudjonsson reports that an examination of adult scales indicated that 3 percent of the fish migrated as smolts at one year of age, 85 percent at two years of age, and 12 percent at three years old. Meigs and Pautzke state that 16 percent of their sample was one year of age, 73 percent two years and 11 percent three years old. Andrews stated that "Analysis of scales from 555 wild smolts revealed the following percentages in four freshwater age classes: 7.3 percent were age I, 70.8 percent were age II, 21.6 percent were age III, and 0.002 percent (1 fish) was age IV." Chapman (1957) reports 1.5 percent of his adult sample migrated at one year of age, 80 percent two years, and 18 per cent three years of age. Larson and Ward report that the freshwater age of adult steelhead caught in the Hoh River for 1949 and 1950 was 3.5 and 2.7 percent one year of age; 89.9 and 85.0 percent two years of age; and 7.4 and 2.0 percent three year olds. Scales from adult fish taken in the Cowlitz River in 1947 and 1948 revealed that 13 percent of the fish had smolted in their first year, while 85.0 and 80.0 percent were two years old and 2.0 and 7.0 percent smolted in their third year.

There appears to be a definite relationship between environment and rate of growth, which results in a variation in the percentage age distribution for smolts in different rivers and probably in the same river from year to year.

Gudjonsson reports that the seaward migration of winter steelhead smolts in Minter Creek takes place from about the middle of April to about the middle of June, with the major share of the total migration occurring between April 29 and May 20. Downstream trapping facilities on the Alsea watershed (Wagner et al 1963) indicate that the bulk of the smolt movement was during the month of May, with the peak movement usually occurring during the first two weeks in May. Pautzke and Meigs reported that the peak of smolt migration in Green River was probably during the first two weeks of May. Larson and Ward reported "that the peak of migration of young steelhead normally is during the first two weeks in May in the Grays Harbor area." However, they also reported that "Sampling in the lower areas of certain streams of the Olympic Peninsula has shown large numbers of migrant steelhead trout moving out of the streams during the month of June." Ward reports verbally that a similar late migration occurs in the Nisqually River. The indicated pattern of late or delayed migration of winter steelhead appears to be associated with streams having a cold thermal environment and a headwater area consisting of some glacial action. Additional data is required to confirm the above observations by Larson and Ward on late migration of steelhead smolts (Appendix D). Data collected by the U. S. National Marine Fisheries Service on the downstream migration of summer steelhead smolts in the Columbia River show that the bulk of the fish appear in the lower Snake River during May, with some fish appearing in April and June. Apparently the time of smolt migration is approximately the same for all streams with the majority of the fish emigrating between April 25 and May 20 except in such cases reported by Larson and Ward.

The data on food consumed by stream-type salmonids are not extensive, yet the total "yield capacity" of any stream must be related more to available food than any other factor. The degree of dominance exercised by individual species under a naturally controlled salmonid complex probably relates to other factors but food must control the total natural production of all species in a collective sense. Therefore, the feeding habits of the individual species by size, time, and place becomes of paramount importance in assessing the effect of fish cultural operations on the natural reproductive capacity of the stream.

Needham (1934a) and Shepherd (1928) present data on the food of steelhead juveniles in Waddell Creek, California. These data are detailed in Table 14. Needham's data were obtained from 22 fish taken from Waddell Creek on August 9 and 19, 1933. The fish varied from 2.6 inches to 6.9 inches and averaged 4 inches in length. Shepherd's data came from 55 fish taken from the same stream on October 16, 1926 (2), July 2, 1927 (12), July 4, 1927 (12), December 27, 1927 (5), January 7, 1928 (10), January 8, 1928 (13), and January 9, 1928 (1). The average length of the samples was 16.9 cm.

TABLE 14

Class of Food	Needham Total Number Present	Needham Percent of Total	Shepherd Total Number Present	Shepherd Percent of Total
Trichoptera (Caddis flies)	557	50.5	1,615	43.5
Diptera (true flies)	400	36.3	393	10.6
Hemiptera (true bugs)	56	5.1	22	0.6
Coleoptera (beetles)	53	4.8	24	0.6
Hymenoptera (ants, bees, wasps)	13	1.2	6	0.2
Homoptera (leaf hoppers)			10	0.3
Plecoptera (stone flies)			39	1.1
Ephemeroptera (mayflies)			24	0.6
Odonata (dragon flies)			1	+
Arachonida (water mites)			7	0.2
Isopoda (isopods)			1,046	28.0
Amphipoda (amphipods)			424	11.4
Salmon eggs			35	+
Miscellaneous	23	2.1		

Messersmith (1958) studied the food habits of smolt steelhead trout in the Alsea River, Oregon. He concluded as follows: "Stomach content analysis showed that 12 percent of the wild smolts and 3 percent of the hatchery-reared smolts had empty stomachs. This examination also revealed that hatchery-reared smolts were eating approximately 55 percent as much food, by weight, as were wild smolts. To eat the same weight of food, they would have to eat 6.69 times as many organisms as the wild smolts. Terrestrial organisms were of minor importance to the wild fish but made up 12.5 percent by weight and 3.9 percent by number of the hatchery-reared smolt diet. On the average, by weight, number, and by percent occurrence, Ephemeroptera were the most important organisms utilized by the wild and hatchery-reared smolts. Other organisms which ranked high were Coleoptera by weight, Trichoptera by weight and number, and Diptera by number."

Messersmith found that the feeding habits of steelhead smolts not only varied between hatchery fish and wild fish in the same stream but between wild fish in different streams. Note is made that steelhead smolts do feed extensively prior to their entrance into salt water.

Johnston (1967) studied the food and feeding habits of juvenile coho salmon and steelhead trout in Worthy Creek, Washington and determined that the diet of steelhead juveniles varied little between types of habitat. Figure 5 illustrates the food items eaten by coho and steelhead juveniles for one of the areas under observation.

Moore, et al (1934) in studying the feeding habits of brook trout, two species of dace and the common bullhead in a New York trout stream found that all species ate much the same diet consisting of all available aquatic food and that supplied by surface drift. The use of a common food source by all species making up the fish biomass in a stream indicates that all species are competitive for food not just those making up the salmonid complex.

The relationship of food supply to the abundance of any one of several species of fish inhabiting the same stream is complicated by several factors including the physical habitat of each species. Nevertheless it appears that the total food supply will be fully utilized by the naturally reproducing populations and all species will be competitive for the same food supply.

An important facet of the life history of naturally produced or wild steelhead is age at maturity. The species has a rather complex life, which involves possibly twenty or more combinations of age in freshwater and the total age of the mature adults. These combinations, while important in the management of the fisheries resources, are of little direct concern to the harvester. He is concerned primarily with weight, and the larger the fish,

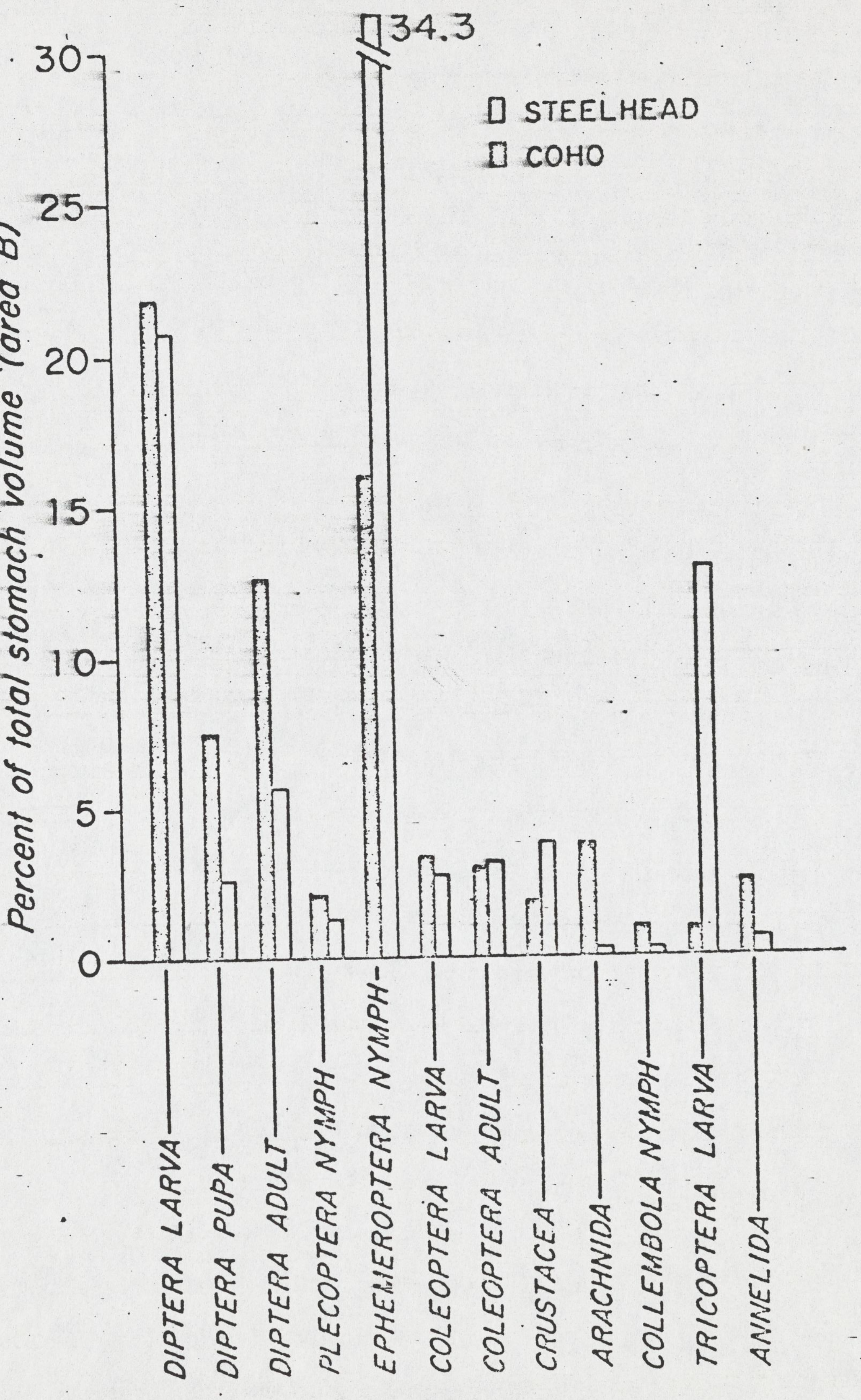


Figure 5 The percentage volumes of food organisms which constituted more than one per cent of the total stomach volume of either coho or steelhead

TABLE 15

Age Classification of Wild Winter Steelhead

Freshwater and Saltwater Checks	Larson and Ward River and Year - Percentage of Catch Green 1940	Green 1941	Chehalis 1948	Hoh 1949	Hoh 1950	Cowlitz 1947	Cowlitz 1948	Average	Chapman Alsea 1951-55	Maher & Larkin Chilliwack 1949-53
1-1	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1
1-2	10.0	12.8	4.0	0.0	2.0	2.0	4.0	5.0	0.2	1.0
1-3	6.0	5.9	5.0	3.5	0.7	10.0	8.0	5.6	0.9	0.8
1-4	0.0	0.0	0.5	0.0	0.0	1.0	1.0	0.4	0.3	0.0
2-1	4.0	9.4	7.0	3.5	1.3	3.0	2.0	4.3	4.0	0.3
2-2	52.0	51.2	66.0	77.9	71.1	63.0	52.0	61.9	52.5	31.1
2-3	17.0	8.4	15.0	10.5	17.5	19.0	26.0	16.2	21.8	30.7
2-4	0.0	1.5	0.5	0.0	0.0	0.0	0.0	0.3	2.0	0.1
3-1	3.0	4.4	0.0	0.0	0.0	0.0	1.0	1.2	1.3	0.1
3-2	4.0	3.4	2.0	4.6	6.7	1.0	5.5	3.9	13.6	17.7
3-3	2.0	0.5	0.0	0.0	0.7	1.0	0.5	0.6	2.9	17.3
3-4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4
4-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
4-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
4-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4

the more that fish is prized.

Any fish cultural program designed to increase the supply of adult fish may arouse suspicion that such a program is having a negative effect on the average weight of adults produced. In view of extensive fish cultural programs now operative in the Northwest region, it becomes of particular importance that the age and weight of wild fish be recorded for later comparison with similar data for adult steelhead originating from fish cultural operations. Unfortunately, little, if any applicable data are available on native summer-run steelhead, but Table 15 lists the freshwater and saltwater age composition of winter-run fish taken in several major river systems. The predominant age groups include 2/2 and 2/3, with a fair number of the 1/2 and 1/3 represented in streams providing favorable conditions for freshwater growth and a significant number of 3/2 and 3/3 fish returning to the colder or less productive streams. It has been noted previously that age in freshwater is inversely related to growth and several investigators have observed that the slower the growth in fresh water, the greater the percentage of fish returning after spending three years in the ocean. Little published data is available on the length and weight of wild adult steelhead but it has been firmly established that age or size of emigrating smolts has little influence on the average size of the returning adult; rather, it is the number of years spent in the ocean that has the direct major influence. This conclusion is illustrated by Maher and Larkin (1954) for wild winter steelhead in Table 16.

One year in the ocean type usually consist entirely of precocious males and the mean length does not vary significantly between adults migrating as one, two, or three year old smolts. The same smolt age-adult size relationship applies to the other maturing age groups. Thus, each extra year in the ocean before maturity contributes substantially to the length and weight of the returning adult, with three-year-old or smaller smolts tending to positively influence the period spent in the ocean prior to maturity. It has been observed that re-spawners do not gain substantially in weight because of the long period of fasting in fresh water and the physical shock resulting from the spawning act.

TABLE 16

Mean Length of Steelhead Trout of Various Ages
From the Chilliwack River - 1949 to 1953

Age Group	Number of Fish	Mean Total Length Inches		Age Group	Number of Fish	Mean Total Length Inches	
1/1	1	19.7		1/3	6	32.8	
2/1	2	19.4	19.3	2/3	235	32.8	33.1
3/1	1	18.7		3/3	126	33.1	
				4/3	3	33.6	
1/2	8	28.8					
2/2	234	28.3	28.5	2/4	1	39.0	36.7
3/2	134	28.4		3/4	3	34.4	

Maher and Larkin list the four fish classified as /4, as repeat spawners. While the sample is too small for accurate statistical comparison, it should be noted that three of the four individuals averaged 34.4 inches, compared with 33.1 inches for initial spawners spending three years in the ocean.

Chapman (1957) reported that of the repeat spawners (17% of population) in the Alsea River in 1953, 81% were returning for a second spawning and 19% for the third, with a sex ratio of 1.0 male to 2.5 females. Few males survive the spawning migration and repeat spawners are primarily females. However, the percentage of the total population surviving to repeat the spawning act is relatively small.

Bali (1958) noted that the percentage of the steelhead catch represented by repeat spawners declined rapidly by geographical areas from south to north,

TABLE 17

Percentage of Repeat Spawners of Steelhead Trout
Recorded for Individual River Systems

River	Year	Percent Respawners	Investigator
Green	1940	5.0	Pautzke and Meigs
Green	1941	6.9	Pautzke and Meigs
Chehalis	1948	9.0	Larson and Ward
Hoh	1949	14.0	Larson and Ward
Hoh	1950	6.7	Larson and Ward
Cowlitz	1947	4.4	Larson and Ward
Cowlitz	1948	7.8	Larson and Ward
Alsea	1953	17.1	Chapman
Alsea	1954	12.4	Chapman
Alsea	1955	3.2	Chapman
Oregon North Coast Streams	1955	27.9	Bali
Oregon South Coast Streams	1955	53.3	Bali

a trend easily identified in Table 17.

The natural steelhead population of the State of Washington is almost wholly anadromous in its life history. Few winter steelhead residualize in the streams and the few that do appear to be precocious males. Wild summer-run steelhead appear to residualize with greater frequency than the winter-run fish, particularly in the upper Columbia River watershed but only observational data are available to confirm this. In any event, under natural conditions for reproduction, the summer-run steelhead can be considered a truly anadromous stock as far as management is concerned.

Cutthroat

While the coastal cutthroat are anadromous and their life history is grossly similar to that of steelhead, significant differences exist between the two species which are of importance to management. Each coastal river in Washington appears to have a resident cutthroat population in at least some of the headwater streams and at the same time contains an anadromous strain which apparently is very sensitive to residualism. It may be possible that the resident population maintains the sea-run population through the development of anadromous tendencies in specific individuals based, possibly, on either size or age or a combination of both. However, this statement has a philosophical background, since data are not available to establish all of the life history characteristics of the species while in fresh water.

Unpublished data collected by the Washington Department of Fisheries at Minter Creek reveal that 100 to 400 adult cutthroat spawners produce 1,000 to 5,000 smolts annually; also that the upstream migration of maturing adults "commences in December and ends in early April" (peaks vary from January to March). The migration is timed very closely with that of the native winter steelhead run and spawning takes place from January to April with the peak somewhat in advance of that for steelhead.

In the Elochoman River, adults may move into the lower river as early as August, and the peak in the upstream spawning migration is in November, or about two months in advance of the steelhead. Actual spawning of wild sea-run cutthroat extends from the latter part of December to April according to data obtained from Jack Hattrick, Superintendent of the Beaver Creek Trout Hatchery.

At Minter Creek, substantial numbers of adult sea-run cutthroat reportedly move in and out of the narrow estuarine area with the tide, commencing in the month of August. The fish do not move up the creek and enter the adult fish collection facility, located a few hundred feet above the high-tide line, until positive upstream migration starts in December.

Sumner (1962) reports a somewhat similar situation in the Nestucca River, Oregon. In this stream, "some sea-run trout run upstream several miles in July and stay in deep holes until the coming of fall and winter rains." The actual upstream migration of adult cutthroat, as reported by Sumner, in Sand Creek, Oregon, started in late October and peaked in November. Spawning of the adults appeared to be earlier than for steelhead, although actual dates are not specified.

The presence of maturing sea-run cutthroat in the estuarine and lower river areas during the late summer, often as early as July, has been observed in most, if not all, coastal streams draining this region and is a distinct departure from the migration characteristics of adult steelhead. The movement of steelhead from salt to freshwater is a more positive action unaccompanied by any extended delay in the estuary.

The kelts of both sea-run cutthroat and steelhead move out of the streams with the smolts of both species although the first appearance of emigrating kelts basically occurs in advance of the smolt migration. Sumner (1962) reported that in Sand Creek, Oregon, "Spent adults of both trout species returned downstream mainly during the fingerling migration period". Noble reports a similar migration of kelt steelhead and cutthroat in Minter Creek (Washington State Department of Fisheries, unpublished data).

Cramer (1940) reports a weight loss for cutthroat of 36% immediately after spawning and Sumner records a weight loss of 29% when taken in a downstream trap after spawning was completed. Obviously the failure of both steelhead and cutthroat adults to feed in freshwater prior to spawning, combined with expenditure of stored protein and fat required during their freshwater sojourn, limits growth and an increase in weight between repeat spawnings. Giger (1972) reports that the feeding of kelts evidently begins immediately after spawning hence the regaining of weight lost prior to spawning is quite rapid.

The downstream migration of cutthroat smolts in Minter Creek peaks from the latter part of April to May 20, during the same period reported for coho and steelhead smolts. However, there is a tendency for some cutthroat, usually the smaller sized fish, to migrate well into June, which is not the case with steelhead. Other investigators, including Sumner, note that the cutthroat smolt migration, while peaking at the same time as steelhead, extends beyond that of the latter species. Sumner reports that 33.6% of the Sand Creek cutthroat smolts migrated in April, 42.7% in May, and 12.6% in June. Skeesick (1965) reports that the downstream migration of cutthroats in Munsel Creek, Oregon, begins in March, peaks in April and May, and ended in June.

The intra-stream life of the sea-run cutthroat is not clear. Sumner reports, "The downstream movement of initial migrants was by stages. Fingerlings marked in a small tributary of Sand Creek above the traps apparently left their natal stream at the age of one year in the usual downstream spring migration period and spent a year in the main stream above the rack, some of them passing down through the trap the following spring." The unpublished data at Minter Creek does not substantiate Sumner's data except to a small extent. Most of the fish trapped in the spring appeared to be true smolts, with a few yearling fish about 3-1/2 inches in length which had not smolted.

The electro-shocking experiments carried out by the Washington Game

Department, referenced previously, do not indicate a complete downstream movement from the cooler tributaries in the fall or an upstream movement in early summer, as was the case with young winter steelhead. Furthermore, there was no evidence of a pre-smolt migration at one year of age as was indicated by Sumner. If a pre-smolt migration occurred in the larger Washington streams, there would be a significant buildup of cutthroat yearlings in the main part of each river system during the summer months and such a buildup has not been observed. In fact, as noted previously, most lower main river areas are virtually barren of naturally produced salmonids during the summer months except for young steelhead, coho and chinook of the year. It should be noted that juvenile cutthroat and steelhead, especially fish under 6 inches in length, are very difficult to identify except by a complete taxonomic examination.

The cutthroat smolts at Minter Creek are reported to be close to but not quite as large as the steelhead smolts and the informed opinion prevails that the majority of the fish are two years of age with some three years and, perhaps, a few four year olds. Lowery (1966), in studying the growth of coastal cutthroat in a tributary of Deer Creek, Oregon, showed that the length of the incoming year class approximated 5.5 cm. in September, which represents nearly the same growth as indicated for steelhead fry. Electro-shocking experiments in Washington streams reveal that yearling cutthroat averaged about one centimeter less than steelhead of the same age. Cutthroat eggs are smaller than those of steelhead and the emerging fry are reported by Sumner to be 25 mm. in length compared with 33 mm. for emerging steelhead. The difference in size of initial fry would account for some of the difference in reported size of smolts of the two species.

The basic growth rate of sea-run cutthroat (current broodstock offspring) in the hatchery appears to approach that for steelhead but may not be comparable since the growth rate of sea-run cutthroat in the hatchery has probably been enhanced more than that of steelhead by several generations of selective breeding.

The freshwater age of cutthroat varies substantially from area to area depending on environmental conditions. Sumner reports that of fish caught in the downstream trap on Sand Creek, 13% were 1/; 28% were 2/; 42.3% were 3/; 20.6% were 4/; and 4% were 5/. Giger (1972 - unpublished manuscript) has summarized all of the findings on sea-run cutthroat in Oregon and it is unfortunate that his data are not yet available in writing. His aging of downstream migrants agrees generally with that of Sumner but the life history of the cutthroat appears to have significant variations over a wide geographical area.

Assuming that the age analysis by Sumner is correct, this provides some circumstantial evidence that the "resident population" found in most headwater streams is actually the source of all sea-run cutthroat populations. However, until scales from sufficient fish of known age are used to establish a scale reading reference of proven value, the aging of cutthroat in freshwater from scales appears fraught with difficulty.

The smoltification of cutthroat and downstream migration at Minter Creek appears to be a positive action, except for the smaller fish. Some downstream movement of the latter occurs but these fish do not have the silvery appearance of the true smolt. Local investigators did not consider them to be smolts but representatives of a within-stream movement. Up and downstream movement within the watershed was noted by Lowry, who concurred with Sumner that some fish left the smaller tributaries during the usual downstream migration period and then spent a variable length of time in the main stream. However, Lowry reports a downstream movement from the natal tributaries through most of the year.

Lowry also noted that residualism existed in Deer Creek. He reports that

"Movement of older trout (only fish over 125mm. were tagged) above the fish trap in Deer Creek varied little during the summer to much in the winter and spring . . . By November a general upstream movement was evidenced and continued through mid-February. By then many of the larger trout (180 to 275mm.) were in the small tributaries or further up the main stream. Gravid female trout as small as 150 mm. were observed on redd sites and apparently paired with ripe males." The above observations add evidence that a single coastal cutthroat population may include individuals having anadromous and others having residualizing characteristics. Skeesick reported that stream growth averaged 4 mm. and marine growth at 21 mm. per month.

Giger's data (1972), forwarded as a courtesy to the writer, provides interesting facts. In the Alsea Estuary, kelts and smolts soon disappear but pre-smolts up to 170 mm. in length move downstream into the estuary and take up what appears to be a non-migratory residence (Figure 6). These fish probably do not mature the following fall as is the case reported for sea-run smolts. Thus, it is established at Alsea that there is a definite downstream movement of smaller fish that do not leave the estuary and remain in the pre-smolt stage. The data indicate also that the estuary parr consist to a large extent of the latter part of the spring emigration which does not include the larger fish evident earlier in the season (Figure 7). Not only are the parr smaller than the smolts but according to Giger's data they average one year younger in age. This fact is illustrated in Figure 8. The length frequency of the anglers catch of cutthroat in the Alsea Estuary is illustrated from Giger's data in Figure 9, in which resident juveniles are classified as parr, initial migrants as first maturing adults and ingeminators as repeat spawners.

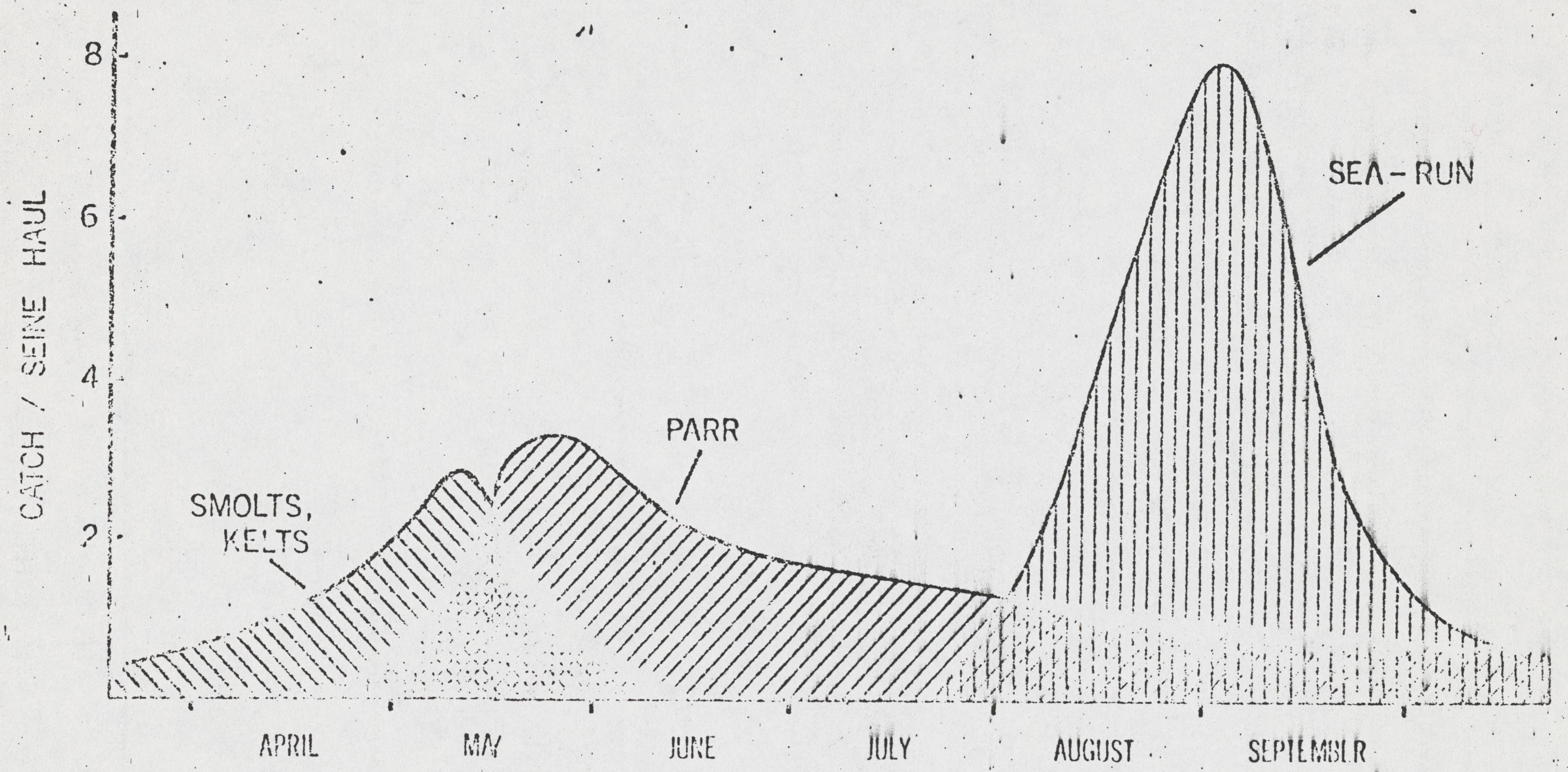


Figure 6. Giger's data on the classification of cutthroat trout taken in the Alsea estuary. (Parr are resident pre-smolts)

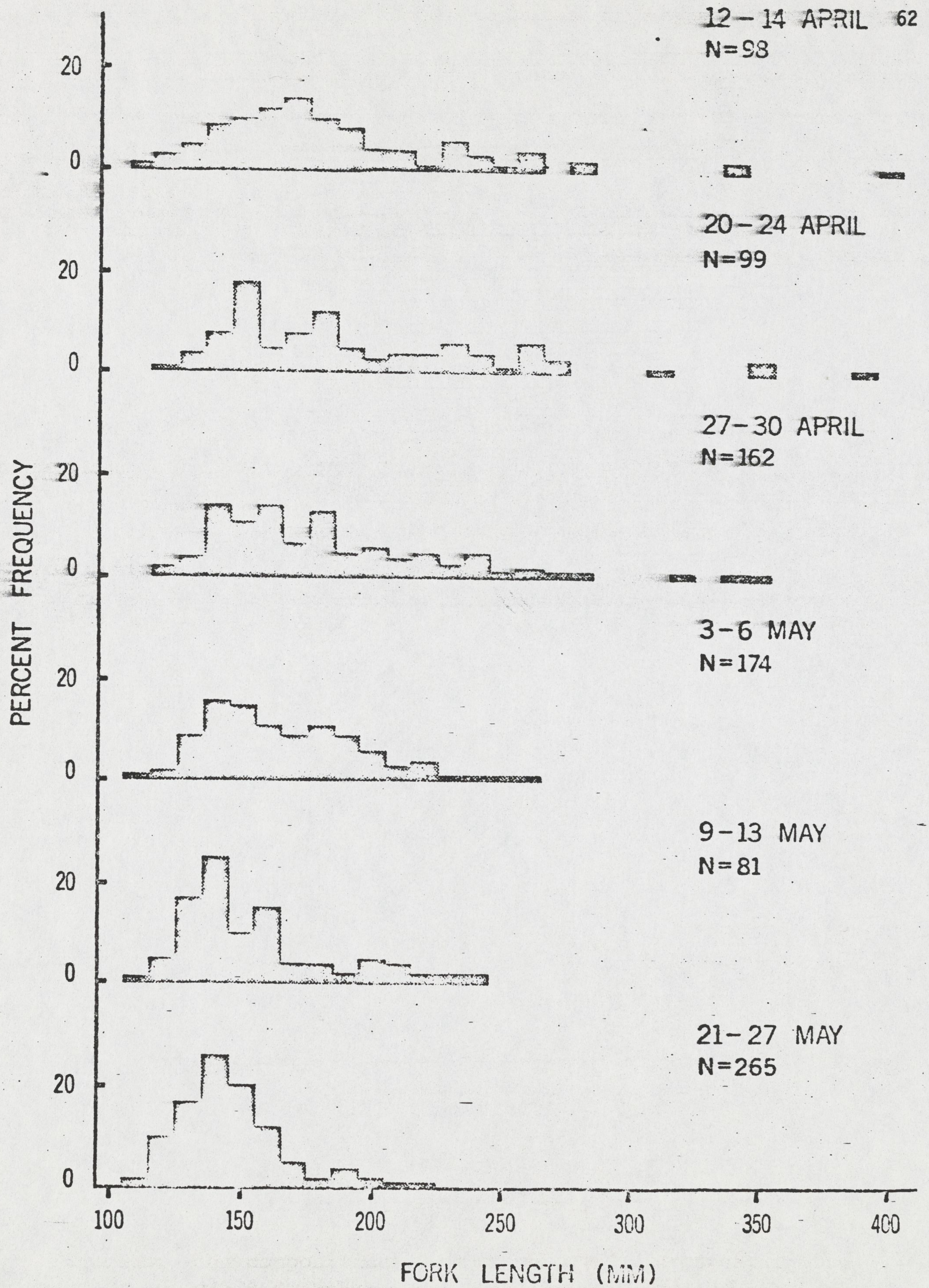


Figure 7. Seasonal change in size composition of wild downstream migrant cutthroat trout, Crooked Creek Weir, Alsea River, 1970. (47 miles above estuary)

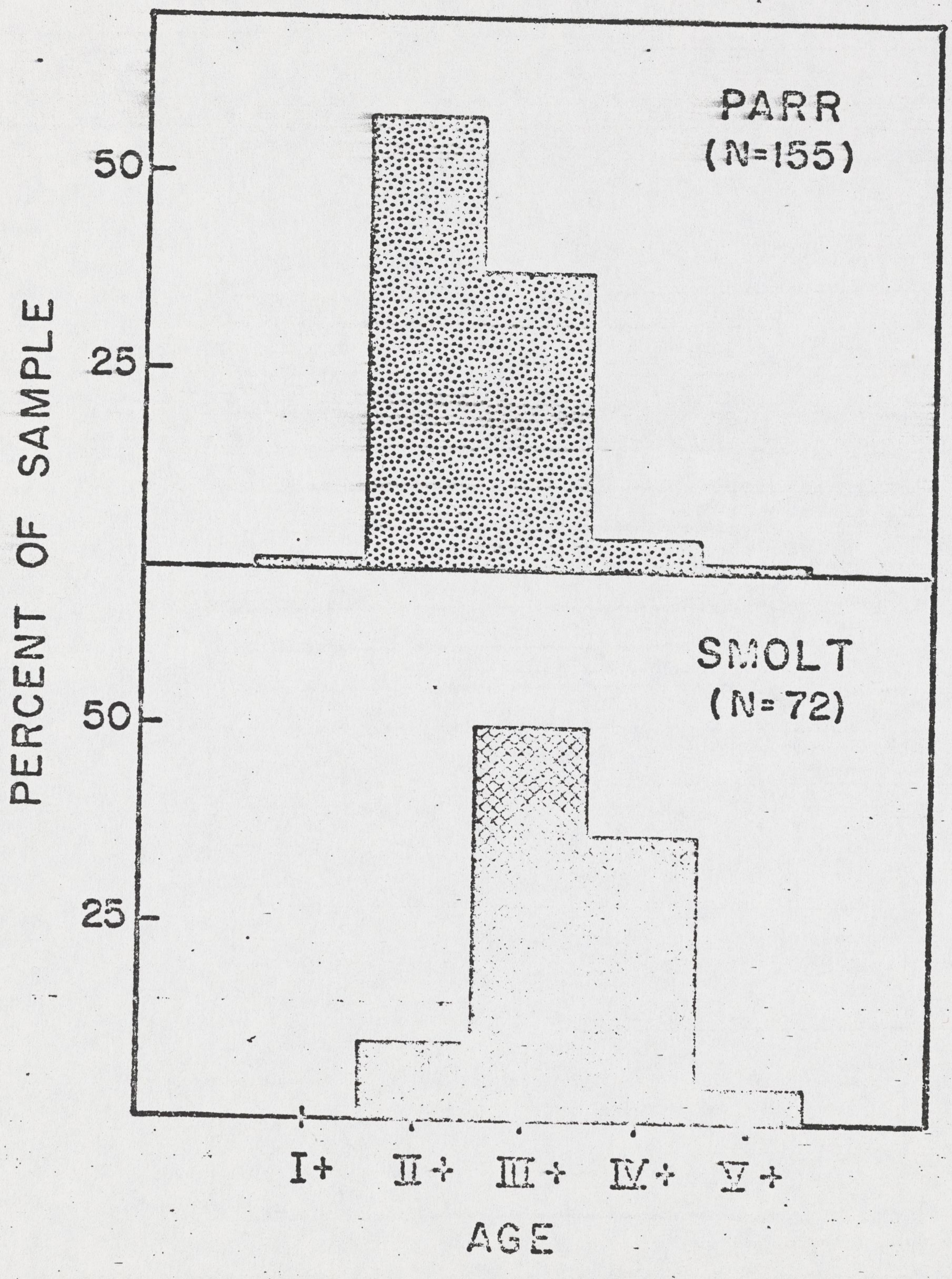


Figure 8. Age composition of parr and smolt cutthroat in the Alsea estuary.

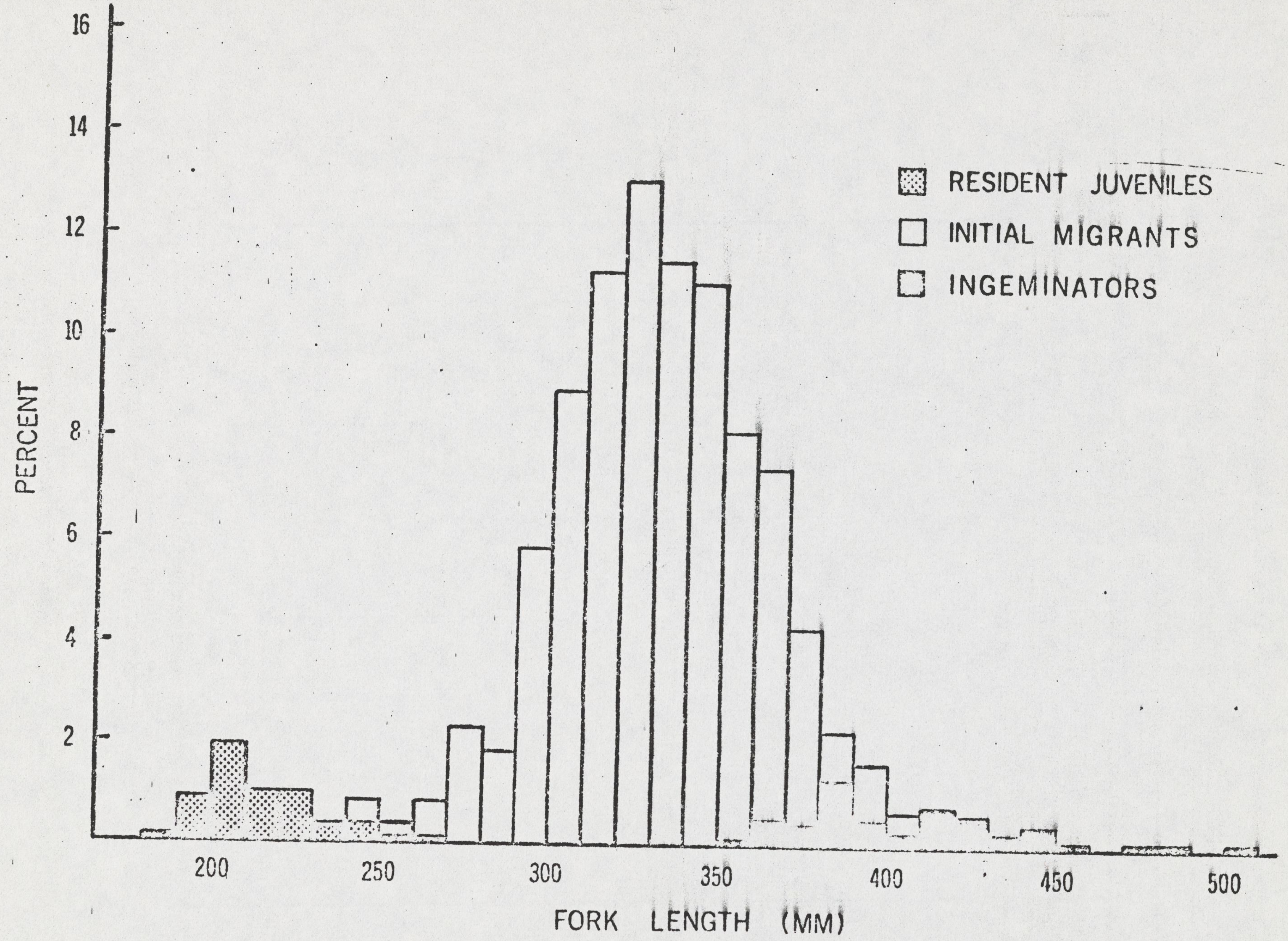


Figure 9. Length frequency of a random sample of 805 wild cutthroat trout from the angler catch, Alsea estuary fishery, combined data for 1965-1970.

Observations in the State of Washington do not disprove Giger's data under similar geographical circumstances but where estuaries are not available it is obvious that the parr either do not survive or must mature in more saline waters, returning to spawn in this case possibly one year later which is probably the situation in the Alsea Estuary.

The feeding habits of cutthroat are somewhat similar to that of coho according to Lowry. He reports that "Diptera was the most important order of insects and both Coleoptera and Ephemeroplera were prominent in the trout diet. Since trout and coho fed on the same order of insects, some competition for food may have existed." The importance of food competition between salmonid species in controlling individual population size has not been defined, but it appears that the similarity in food utilized by the various species, including non-salmonids (cottids, whitefish, squawfish, etc.) must be the major factor in determining the total fish biomass. Predation appears to be a lesser influence since it is in evidence mainly under artificial conditions. Lowry reports that "During the time coho fry were emerging, as well as later, we captured (150-250 mm.) cutthroat trout near and even right among these fry. Even when the belly of a trout was distended with food, we rarely found juvenile salmonids in the stomach. However, in the unnatural situation in the downstream trap, 92 percent by weight of the stomach contents of 12 cutthroat trout consisted of coho fry."

The food utilized by cutthroat trout in Deer Creek, Oregon, as determined by Lowry, is presented in Table 18.

The size and age classification of returning cutthroat spawners, as reported by different workers, is somewhat confused. This confusion may be the result of incomplete data in part. Different growth rates, different geographical environment and inadequate samples apparently contribute to the lack of clear

TABLE 18

Percentage Occurrence by Dry Weight of Food Items
Removed from the Stomachs of
Trout from Deer Creek in 1963

Food Material	Sampling Dates 9 Feb	23 Feb	9 Mar	23 Mar	6 Apr	20 Apr	4 May	18 May	1 June	12 June	All Samples Combined
Aquatic Arthropods (except crayfish)	11.4	44.0	34.8	4.4	31.1	69.9	19.0	24.4	17.3	14.1	19.6
Frogs	--	--	--	58.8	--	--	--	--	--	--	16.6
Earthworms	20.4	42.5	37.6	--	28.9	0.3	40.2	--	--	--	15.6
Juvenile salmonids	--	--	--	33.1	--	--	2.8	--	0.1	--	9.7
Fish remains	--	0.9	--	--	25.1	9.0	--	17.3	--	58.3	7.6
Sculpins	--	--	--	--	--	--	27.1	--	28.7	--	7.5
Unidentifiable material	11.8	10.3	6.4	2.5	10.7	16.5	8.8	6.4	5.3	7.8	6.8
Crayfish	--	--	--	--	--	--	--	19.6	46.2	--	6.6
Terrestrial arthropods	0.2	trace	1.0	0.3	4.3	4.4	1.6	32.2	2.1	19.9	3.7
Salmonid eggs	56.2	2.3	--	--	--	--	--	--	--	--	3.7
Salamanders	--	--	20.3	--	--	--	--	--	--	--	2.3
Sculpin eggs	--	--	--	1.0	--	--	--	--	0.4	--	0.3
Total sample weight (mg)	601	429	1,093	2,673	793	303	1,321	281	1,226	759	9,477
Number of fish in the sample	7	20	20	21	19	19	20	6	19	20	171
Mean size of fish in the sample (mm)	147	148	157	152	129	146	146	136	164	156	149

definition of this phase of the life history.

Sumner reports that the cutthroat returning to Sand Creek, Oregon, in their first year of sea life averaged 13.1 inches fork length, with the fish having spent an estimated four years or more in fresh water being only slightly larger than the fish spending less than that time before smolting. Sumner also reports that "Only three of 122 specimens appeared to show no spawning at the first of two or more sea annuli." It is interesting to note that on the basis of Sumner's data almost all fish return to spawn each year until the rigors of spawning, natural mortality, fishing mortality, and predators gradually eliminate each year class.

Sumner's data on the age and spawning history of upstream migrating cutthroat at the Sand Creek trap for 1946 to 1949 have been reassembled in Table 19. It is assumed that Sumner considered the outer edge of the scale as an annulus for establishing salt water age although the final annulus would be associated later with a spawning check.

TABLE 19

Data Reassembled from Table 6 - Sumner (1962)

First Spawning			Second Spawning			Third Spawning			Fourth Spawning		
Age	Number	Fork Length	Age	Number	Fork Length	Age	Number	Fork Length	Age	Number	Fork Length
2/1	11	12.7 in.	2/2	12	15.2 in.	2/3	1	16.4 in.	5/4	1	16.6 in.
3/1	111	12.9 in.	3/2	52*	14.7 in.	3/3	11	16.2 in.	6/4	1	16.9 in.
4/1	106	13.1 in.	4/2	36	14.5 in.	4/3	4	16.6 in.			
5/1	24	13.2 in.	5/2	3	14.7 in.	5/3	1	16.1 in.			
6/1	1	13.5 in.									
	253	13.1 in.		103	14.8 in.		17	16.3 in.		2	16.75 in.

* 50 fish repeat spawners; 2 first spawners

Sumner's data does not indicate the eventual maturity of what Giger refers to as parr since Giger's parr classification could hardly mature the fall following entrance into the estuary. Sumner's data (Table 19) shows 100% of the fish maturing the fall after entrance into salt water with almost 100% repeat spawning each year with very little growth between year classes. Lacking Giger's age classification supporting the length frequencies (Figure 9), one can assume the length frequencies for initial spawners represent fish having spent one season at sea. Some parr probably returning after one season in the estuary and one year at sea may be included. The fork length of initial spawners, as recorded by Giger, varies between 10.8 inches to 16.0 inches for an average of about 13.+ or similar to Sumner's size for initial spawners (Table 19). However, Giger's length frequencies for ingeminators or repeat spawners does not allow for a second group of spawners at a mean length of 14.8 inches as shown by Sumner. Giger's second-year adults, or second repeat spawners, appear to average about 15.5 inches fork length.

No data are available in Washington on the age at maturity and the occurrence of repeat spawners of wild anadromous cutthroat. However, in spite of stimulated growth rate resulting from selective breeding, only 30% of the cutthroat brood stock at the Elochoman Hatchery mature the first year after smolting. Several marking experiments involving substantial numbers of yearling cutthroat reared and released in the Elochoman Hatchery (Table 20) show that more fish return the second year after release than return in the first year. A number of the yearlings may have remained in the lower Columbia River during their first summer which would classify them as parr rather than as true smolts. Such a circumstance would probably result in a delay in maturation of one year. Thus, it cannot be concluded that all of the true smolts going to sea do not return as maturing fish the August following the release date.

The returns (Table 20) are not complete since they represent only those fish trapped on Beaver Creek, a tributary of the Elochoman River but they should be representative of the whole. It is interesting to note that the first plant in 1964 were the largest fish of the several experiments referenced and that the greater percentage of returnees occurred the same season. This evidence favors the planting of large smolts if residualizing of a large part of the release and the possible delay of one year in maturation is to be avoided.

TABLE 20

Marked Cutthroat Experiment at the Elochoman Hatchery

BROOD YEAR	RELEASE YEAR	NUMBER RELEASED	AVERAGE WEIGHT	NUMBER RETURNED		
				SAME YEAR	1 YEAR	2 YEARS
1962/63	1964	17,205	3/#	118	19	?
1965/66	1967	42,312	5 to 7/#	25+	240	54
1966/67	1968	41,305	6/#	80	130	?
1968/69	1970	42,758	4 to 6/#	86	141	?

Coho Salmon

The coho salmon is by far the most dominant species of the stream-rearing salmonid complex. Most, if not all streams in the State of Washington, regardless of their physical environment, have a reproducing population which usually is numerically superior to all other salmonids of the stream-rearing type.

The adult populations normally enter their spawning stream in November and December but specific races, usually small in number, may appear as early as

July and as late as March. Spawning precedes that of the steelhead and cutthroat by as much as two months, hence, fry emergence tends to be considerably in advance of that for the latter two species. Exact data on fry size is not available, although emerging fry usually average about 1,200 fish per pound compared with 2,000 per pound for steelhead. Much of this weight difference lies in the shape of the fish, rather than in length. Thus, coho fry have a distinct initial advantage over steelhead and cutthroat fry in competition for food. Since coho emerge earlier and weigh more initially, there is a considerable difference in size by the time the steelhead and cutthroat fry emerge from the gravel.

Practically all coho spend one year in the stream prior to smolting. A few spend two years in the stream exhibiting little increase in total size over that of the one-year smolts. According to Noble, it is impossible to age 2-year-old smolts from their scales and the existence of same has been determined from the planting of marked fingerlings. Noble noted also that some 2-year smolts spend an extra year in the ocean returning as five-year-old fish instead of the usual three years.

Salo and Bayliff (1958) have presented the most complete data on the life history of the coho. These investigators report that fry emergence is mostly in March and April in advance of the downstream migration of yearling smolts, which peaks in late April and early May. When fry emergence occurs, a number of fry reportedly move downstream, as is the case with steelhead and cutthroat. Coho fry have been observed entering salt water but no one has observed an adult scale showing evidence that the fish migrated to sea as a fry. It is probable that any cutthroat and steelhead entering salt water as fry eventually perish, as do the coho fry.

Electro-shocking experiments by the staff of the Washington Department of Game and observations of staff members of the Washington Department of Fisheries indicate that coho of the year, like steelhead, leave the cooler streams for the lower watershed areas in the late fall. Unlike steelhead, the coho smolt the following spring and do not return as juveniles to their stream of origin.

Figure 5, presented previously from Johnston's data, shows that coho and steelhead fingerlings are competitive in their feeding habits, although the diets of coho show more seasonal variations than steelhead diets. Johnston concluded also that coho fed more on surface foods and steelhead fed more on foods associated with substrate.

Rees (1959) studied the feeding habits of the coho in Little Bear Creek tributary to the Sammamish River, Washington. He states, "The food preference of the silver salmon in Little Bear Creek seem to be fairly typical for this species. Stomach samples from other parts of the Puget Sound drainage, from the lower Columbia River system, and from Grays Harbor streams showed a close correspondence in the choice of organisms eaten. The few trout taken incidentally with silver salmon catches were insufficient for a good comparison as to type and size of food eaten but the stomach contents did indicate feeding habits similar to silver salmon of comparable size." Data by Rees on the food eaten by coho fingerlings is presented in Table 21.

Salo, Noble and Gudjonsson collectively present data which show that coho, steelhead, and sea-run cutthroat all peak their smolt emigration in Minter Creek the latter part of April and the first three weeks of May. This synchronizing of the emigration of the three species indicates that the same factors affect the smolting of all three species. Salo and Bayliff report that the first 25 percent of the smolt emigration had a mean length of 103.0 mm., the next 25 percent 100.2, while the last of the migrants had a mean length of 94.8. The migration of the largest smolts first, and the smallest last, is characteristic of cutthroat and steelhead.

TABLE 21

Analysis of the stomachs of 207 silver salmon fingerlings, 33 to 77 mm. in length, collected between July 1952 and August 1953 from Little Bear Creek.

Test Area	Percentage of the total organisms found in stomachs	Percentage frequency of occurrence	Mean number per stomach		
Diptera	63.5	87.9	13.1		
Ephemeroptera	9.2	51.6	1.9		
Coleoptera	0.9	17.6	0.2		
Plecoptera	0.4	7.7	0.1	Total fish	113
Trichoptera	0.5	6.6	0.1		
Collembola	11.1	33.0	2.3	Containing food	91
Terrestrial insects	14.4	41.8	3.0	Empty	22
Control Area					
Diptera	63.9	90.6	11.8		
Ephemeroptera	11.1	56.5	2.0		
Coleoptera	3.0	28.2	0.6		
Plecoptera	1.2	15.3	0.2	Total fish	94
Trichoptera	0.4	5.9	0.1		
Collembola	5.6	24.7	1.0	Containing food	85
Terrestrial insects	15.2	54.1	2.8	Empty	9

The most important conclusion reached by Salo and Bayliff relates to the stream rearing capacity of Minter Creek. They conclude from their studies that "The stream has been demonstrated to have a capacity of about 25,000 to 35,000 yearlings". . . and that "The maximum natural production from Minter Creek can be realized with about 300 female spawners and an equivalent number of males."

The recommended escapement to absorb the rearing capacity of Minter Creek is far below the usual escapement in spite of a major commercial and sport fishery during the salt-water life history of the species. Other investigators tend to confirm the fact that only minimum escapements of stream rearing salmonids, including anadromous trout, are necessary to maintain maximum natural reproduction.

Salo and Bayliff noted that with increased fresh-water survival there was a corresponding decrease in marine survival and vice versa; also, that overloading the stream rearing capacity with hatchery fish tended to reduce the condition factor and ultimate survival rate of both wild and hatchery fish. The fundamental data presented by these authors and R. Noble, while not providing all the answers to the population controls functioning during the fresh-water life history of the coho, does establish that if natural reproduction is to be fully maintained that hatchery operations should be supplemental to and not in competition with wild fish. On the basis of the Minter Creek data, Noble states that "the planting of advanced hatchery fingerlings prior to smolting, which creates a surplus to the rearing capacity of the stream, merely results in the survival of the strongest hatchery and wild fish to maturity with no increase in the size of the adult population."

There is no evidence that coho smolts delay in the estuary as do sea-run cutthroat parr. However, large numbers of wild coho smolts remain over summer in the inland sea represented by Puget Sound and migrate to the high seas in the fall. Others may remain in Puget Sound over winter and mature without having had a high seas existence. Apparently a much larger percentage of hatchery smolts emigrate to the high seas than is the case with wild coho smolts.[1]

1/ Wright S.F. 1972. Personal Communication, Wash. Dept. of Fish.

Chinook Salmon

The chinook salmon population like the steelhead is divided into different types, including the "spring-run", "summer-run" and "fall-run". Since native summer-runs reproduce mainly in the upper Columbia River watershed this discussion will be limited to the known facts relating to the fresh-water life history of the spring and fall fish. These fish were quite numerous in earlier years in the principal lower Columbia tributaries and most of the larger streams elsewhere in western Washinton.

The spring-runs are found particularly in large river systems in western Washington, with a glacial source. These fish enter the lower Columbia River as early as February but elsewhere it is usually in April, May and June. Generally, spawning takes place during late August and September in the colder headwater areas, with the fish spending several weeks maturing in deep resting pools which is a characteristic similar to that of the summer steelhead. Spring-run stocks have declined in abundance in recent years in a manner similar to that of summer-runs of steelhead.

Fry emergence is relatively late in spite of the early spawning period, because of cold temperatures prevailing during the winter months in headwater spawning areas. Mattson (1962) reports that the exact time of fry emergence has not been established in the Willamette watershed because of varying thermal environment between streams. He reports the first emergence of fry in the upper Molalla River in mid-March and as late as early June in other tributaries.

Seining operations at various stations on the Willamette system indicate that the length of residence of juveniles in a spawning tributary may range from near zero to about one year after fry emergence. Three distinct periods of downstream migrations were observed by Mattson: (1) a late winter-spring movement of fry; (2) a fall movement of advanced fingerlings; and, (3) a spring movement of yearlings. Mattson did not determine whether the fish in the first two cases actually proceeded to sea immediately or remained for indefinite periods in the estuarine area of the Columbia River which extends into the mouth of the Willamette River. Mattson, in studying the scales of returning adults decided that 92% of the 5-year-old adults, the predominant maturing age group, was composed of yearling migrants but a small percentage were of the advanced fry type indicating that some of the latter must have entered the sea in their first year. Unfortunately, Mattson combined both fall and the next spring migrants in the yearling migrant category and presents no actual evidence of when any of the migrants entered the sea.

Observations by several investigators of the Oregon Fish Commission substantiate that Mattson's reported movements of juvenile spring chinook apply generally but the opinion prevails that few advanced fry leaving the parent stream actually enter the sea and survive as adults; also that the fall emigration is to escape adverse winter thermal conditions in the colder upstream areas. Apparently the juveniles of both categories either remain in fresh-water at some point enroute or most of them perish as they leave the estuary which is the case with coho. There is a need for establishing the complete time, size, and place life history of the spring chinook juveniles prior to actual entrance into their marine existence. Lack of this knowledge prevents the development of sophisticated fish cultural management programs which would not conflict with the natural reproduction of this species and other stream rearing salmonids which inhabit the fresh-water and estuarial areas.

One must conclude that most, but not all, adult spring chinook spend one year in fresh-water although emigration from the parent tributary may have occurred as an advanced fry in the spring following emergence or as a fingerling in the fall. Some evidence indicates that a few advanced spring chinook fry may have migrated to the sea but the percentage of the returning adult run produced by these juveniles is evidently small. The general emigration of spring chinook fingerlings from the parent tributaries in the fall may have successfully survived an entrance into salt-water at that time but other evidence is available which raises the possibility that the fall migrants do not actually enter salt-water until the following spring. The food requirements of fingerling spring chinook during the late fall and winter months must be at a minimum since Mattson's data shows little growth occurs from October to April. Hence lower river or estuary habitation over-winter would present little demand on the available food supply.

The fall-run chinook start entering most rivers in September and the peak in spawning activity is almost always during the first two weeks in October. Unlike spring chinook, the fall chinook enter most streams of moderate to large size regardless of the nature of the headwaters and usually spawn in the lower reaches of the main stream where water temperatures are more moderate during the period of incubation.

Little is known about the freshwater life history of naturally produced fall chinook since large hatchery plants of this strain have been made for several decades in most of the principal producing streams. Rich and Holmes (1929) conducted several marking experiments with hatchery-reared spring and fall chinook in the Columbia River. Experiments with spring chinook were found most successful when the young were released in fresh-water as yearlings. Best success with fall chinook was obtained when juveniles were reared only a short period. They conclude: "As fingerlings of the spring chinook run normally spend the entire first year in fresh-water, best return would be expected from the longer period of rearing . . . In the case of fall chinook, which normally leave the stream soon after the yolk sac is absorbed, the shorter period of rearing might be expected to be most successful." Rich (1925) documents a change in scale pattern of adult chinook in the Columbia River from predominately stream type scales in the spring (spring chinook) to predominately ocean type scales in the fall (fall chinook).

It appears on the basis of limited information that wild fall chinook juveniles leave the parent stream and enter the estuary as advanced fry, up to three months after emergence. Some of the smaller juveniles may remain in fresh-water for a full year before emigrating to the sea as a yearling smolt. Stein (1971) observed that most fall chinook juveniles in the Sixes River, Oregon remain in fresh-water until early summer and then enter the estuary for a period of improved growth before actually taking up a marine habitat.

P. E. Reimers (unpublished data, 1964-67) believes that when the fall freshets begin, movement of hatchery-reared fall chinook juveniles begins and the fish leave the river and the estuary for the ocean, although some small fish remain and migrate as yearlings the following spring. Published data substantiating this important observation is not yet available except in part for Sixes River, Oregon, which may or may not be representative of the more northern area including the State of Washington. If Reimer's observations can be substantiated as representative generally, the fall chinook juvenile has a far greater tolerance in its time relationship to salt water than any of the other anadromous salmonids. Based on hatchery release data, which will be discussed in detail later, it appears that the immediate transition from the river to the estuary is possible up to the end of June, which is not the case with steelhead and coho.

Salo (1969) in his studies of the ecology of the Duwamish Estuary, Washington indicates that hatchery-reared fall chinook fingerlings spend at least two months in the estuary but after the downstream migration was completed (in the Duwamish River) the numbers decreased steadily. Salo depicts area-time abundance in his figure 6 which is reproduced as figure 10.

Deschamps et al (1971) report that "fall chinook salmon migrants that are captured in upper Grays Harbor (Chehalis River Estuary) fall into three major categories. Fish taken during January, February and March which range from 35 to 50 mm. fork length are below normal migratory size and are classed as fry or "premature migrants". Their group is probably carried into the area involuntarily during heavy winter freshets. . . . The second and most common category is the fingerling or "normal migrant" which exhibits well-defined parr marks and commonly enters the seine catches from April to mid-September. Fingerlings range from 50 to 100 mm. fork length and demonstrate gradual increases in average size from 60 to about 85 mm. as the run progresses. Seine catches during August and September were a mixture of fingerlings or normal migrants and a third category termed "bay feeders". Bay feeders included fish over 100 mm. fork length which are characterized by deeper bodies, loose scales, more pronounced spotting on the back and near or complete absence of distinguishable parr marks."

Neither Stein, Salo, or Deschamps et al confirm Reimers belief that there is a substantial fall migration of fall chinook to the estuary. In fact Salo and Deschamps et al confirm Stein's conclusion that fall chinook migrate to the estuary in late spring and early summer where they delay at least in part until a later date possibly in the fall when entrance into a fully marine environment probably occurs. On the other hand entrance into fully saline water may involve

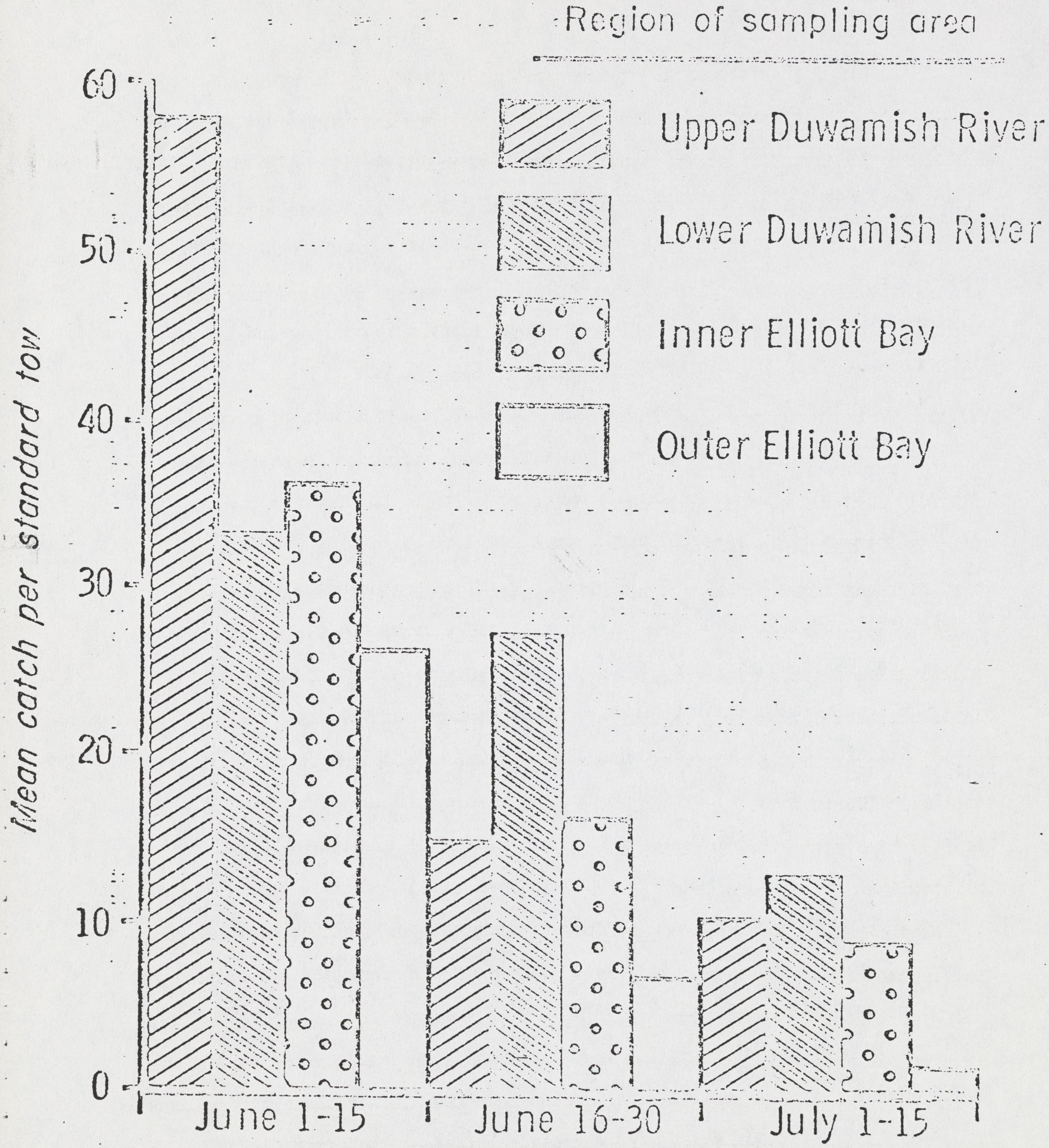


Figure 10

Changes in distribution and average abundance of juvenile Chinook salmon in the Duwamish Estuary during the 1968 sampling season.

a time-related size selective factor.

It has been observed by the writer and others that both juvenile and adult chinook appear to tolerate warmer water than the other salmonid species. Stein, in studying the social interaction between juvenile coho and fall chinook on Sixes River, Oregon, states that "due to various physiological, behavioral, and morphological features, coho appear to be adapted to conditions in cool, small streams, while chinook (fall-run) appear to be adapted to rearing conditions in the warm main river and estuary."

Little information has been published on the feeding habits of juvenile chinook of either of the two types. Reimers (1968) reports, "Throughout the natural stream areas (Sixes River, Oregon) the distribution of fall chinook juveniles was patchy. However, groupings of fish in particular areas rarely represented aggregations or schools. Close examination suggested that these groups were in locations where maintenance of position was possible and presumably food was abundant, such as eddy areas where fast riffles enter pools. These groups displayed agonistic behavior, which apparently led to the formation of size hierarchies." The writer has observed the same action on the part of juvenile hatchery released fall chinook juveniles within the river habitat, principally in the lower part of several tributaries of the lower Columbia River. Since no data has been published on food consumption, it can only be assumed from field observations that the juvenile chinook feed on diptera, diptera larvae and other organisms eaten by other salmonids, hence are competitive for the total food supply available in the stream.

Hermann (1970) in studying the food habits of juvenile fall chinook in the lower Chehalis River (intertidal zone) noted that the stomach contents included mostly marine crustaceans and immature insects. It appears from the diet that either the crustaceans were moving in with the tide or the fish were moving back and forth with the tide. In any event this diet is not considered representative of that which would have been consumed if the young fish were inhabiting the stream area above the intertidal influence.

Species Relationships

Studies by Salo and Bayliff of coho survival rates in Minter Creek (1958) show that in spite of an intense sport and commercial fishery during the marine life of this racial population, the escapement usually is in excess of that required for a maximum rate of reproduction within the limits of stream rearing capacity. Smoker's correlation (1955, 1956) between stream run-off and survival rate of both western Washington coho and Minter Creek steelhead, without regard to the escapement, further substantiates the work by Salo and Bayliff. An assumption can be made from this, that the number of adult stream rearing salmonids available for reproduction is usually in excess of that required for producing juveniles to utilize the stream rearing capacity. While this assumption may not be valid in every case, it is consistent with other studies of relatively dominant animal populations which show that harvest rates usually have little influence on the success or failure of the incoming year classes. Since the above assumption is based on sound evidence, it follows that fish culture practices which involve the planting of juvenile salmonids which remain in the stream either as pre-smolts or as residualized inhabitants create adverse competition with wild fish of the same species.

Noble (1972) summarized the situation in part when he stated that the planting of advanced coho hatchery fingerlings as surplus to the rearing capacity of a stream merely results in the survival of the strongest hatchery and the strongest wild fish to maturity with no actual increase in the size of the total adult population. It should be noted under Noble's "law" that the stronger hatchery fish do substitute in part for the weaker of the wild fish so that the original native population should gradually decline with a continuance of such a practice over a period of years. This will happen apart from the possible adverse effect of gene disturbance in the wild stock created by the introduction of any foreign stocks. Since the native stock is the result of natural selection over centuries of time, the introduction of foreign or hatchery stocks changed through the process of selective breeding, can hardly be expected to improve the strength of the native stock in its competition for existence.

Numerous studies have been made of the natural control of species abundance within the total fish population. Each species has established niches or territories at various stages of its fresh water life history and it is generally accepted that the physical features of each stream exert a major control on the percentage abundance of each species without regard to the abundance of food supply. However, there is an obvious relationship between the total food supply and the total fish biomass so it is reasonable to assume that surplus stocking of any one species of pre-smolts will not only fail to benefit the single species, as reported by Noble, but will probably reduce the survival rate of the other species involved. However, as stated previously, there is no way at present to accurately assess this probability so pending further difficult research it is logical to assume that this danger is real.

Fraser (1969) presents the results of an excellent experiment on a varying density relationship between steelhead and coho fry over a period of 163 days. While eventual adult survival may be affected by the condition of the fish at the end of the experiment, the data do reflect the results of the varying degree of competition between steelhead and coho during the period measured. Fraser's data (His Table VII) is presented in Table 22. In each case LC and LS means "low density" involving 50 fish and HC and HS means "high density" involving 1,500 fish.

TABLE 22

The Terminal Net Standing Crop of All Groups of Fry at the End of the Experiment (163 days). The Figures are Grams of Fish (Biomass) Per Stream Channel.

	Group				
Species	LC LS	LC HS	HC LS	HC HS	Total
Coho	179.98	153.62	945.63	59.14	1338.37
Steelhead	483.78	872.58	77.58	231.04	1667.98
Total	663.76	1029.20	1023.21	290.18	

For some unexplained reason the steelhead in the experiment represented a dominant role in the biomass produced which is not the normal case in the stream. Fraser shows convincing evidence, within the limits of the experiment that "all low-density fry populations had high survival regardless of the companion species density." He concludes under the conditions of the experiment that, "Survival of both species of fry (163 days) appeared to be largely species specific."

However, the effect of interspecific competition is readily observable in the data presented. The biomass of steelhead is severely affected by the relationship of a high density coho population to a low density steelhead population even though the survival rate of the steelhead was not affected during the experiment. The biomass of both species, living under a condition of high density, declined drastically, being less than half that recorded when both populations were reduced from 1,500 to 50 fish.

Thus, the potential effect of superimposing large numbers of artificially cultured fingerlings of one or more species on each other in terms of biomass production is readily observable. Furthermore, while the survival rate during the experiment was largely species specific and the survival rate of the low density group was unaffected by a high density - low density relationship, the later effect on the adult survival rate may be decidedly adverse.

On the basis of the foregoing, supplementing of stream rearing salmonids populations with pre-smolt fingerlings from the hatchery rearing pond should not be considered as a practical method for increasing adult populations. However, the stream environment of most of our streams has deteriorated as a result of logging, dams and related reservoirs, water diversions and pollution. The degrading of the stream environment has not only diminished the food supply but has reduced the number of niches or territories available to the fish biomass through reduced stream flow; both reductions occurring mainly during the critical late spring and summer-rearing period. Another adverse factor, which has received little attention to date, is the unmeasured effect of artificial obstructions on the within stream movement of the juvenile salmonids discussed earlier.

Every effort is being made to preserve the natural environment of our streams but the natural production of stream-rearing salmonids will continue to decline since each water development has some adverse effect on natural reproduction. However, coincidental with this decline, there has been a major increase in harvest interest. Obviously, there is a continuing need for artificially stimulating the production of these fish. Equally obvious is the need for carrying out such operations as a supplement to and not in competition with natural reproduction.

While the limitation of stream rearing capacity is becoming increasingly apparent, the relationship of the estuary environment to survival has hardly been considered, let alone defined. Several studies have indicated that runoff at the time juvenile salmonids are emigrating to the sea may be of importance to ultimate survival. Whether runoff involves the sensitive interchange between fresh-water and salt-water in terms of emigrating salmonids is not known but it is logical to consider that such a possibility exists.

On the basis of existing data, coho and steelhead do not have a habitat relationship to the estuary, apparently migrating directly either to the inland sea or to a strictly marine existence. Chinook and sea-run cutthroat utilize the estuary for habitat at least in part, prior to their actual entrance into the sea. Salo and Stein present evidence that chinook juveniles, particularly the fall spawning type, spend several months in the estuary. Giger submits evidence that sea-run cutthroat, under 170 mm. in length, spend the entire summer and part of the fall months in the Alsea River estuary. Thus it seems important that the relationship of the estuary to survival be better understood. The increased number of salmonids being planted from the hatcheries requires that these operations be planned in terms of maximum survival in both fresh-water and in the estuary. Only a knowledge of how the estuary controls survival, if it is does, can permit possible improvement in a fish management program as related to the estuary and ultimate accuracy in predicting adult survival. This requirement appears particularly applicable to fall chinook and sea-run cutthroat.

Ultimately a knowledge of environmental limitation, if any, on survival of the salmonids in the inland sea and the possible interrelationship of the species may be of importance in determining limits of survival. Of the anadromous species of salmonids, only the juvenile steelhead and sockeye salmon usually proceed through the inland seas to the high seas with dispatch. Will the waters of Puget Sound support unlimited numbers of salmonid juveniles, or will they provide an effective and possibly varying control on the abundance of the several species involved? Interspecific competition and food supply may be involved which could limit the size of specific populations regardless of increased effort in supplying the area with cultured salmonids.

CURRENT FISH CULTURAL PROGRAMS

The maintenance of the native stocks of stream rearing salmonids within the limits of stream capacity is fundamental to obtaining maximum benefits from fish cultural operations for the least expenditure of money. Noble's observations indicate that surplus stocking of pre-migrants may destroy the wild population in time. Hatchery operations must be based on the principle that they are supplemental to and not in obvious conflict with natural reproduction.

Steelhead

Release Size

Pautzke and Meigs became concerned in 1940 with developing a hatchery program in the Washington Game Department to increase the supply of winter steelhead. These men laid a solid foundation for the program by studying the natural life history of the species. Early in their work they established that the planting of pre-smolts produced few adult steelhead and was not an economic operation. Their early experiments pre-dated the Minter Creek data on coho but their results fully confirm Salo and Bayliff on the limits of stream rearing capacity.

It did not appear practical to substitute for stream life of the winter steelhead by holding fish in rearing ponds for two years so an effort was made to find a warm water supply capable of producing a smolt in one year. The South Tacoma Hatchery was selected as an experimental base since it had one of the warmest water supplies in western Washinton, and Chambers Creek adjacent to the hatchery, had a native run of steelhead.

Larson and Ward (Supra) reported on a number of marking experiments with Chambers Creek stock carried out in the late 1940's and early 1950's to determine the size and time that juvenile steelhead should be planted. Yearling steelhead at 9 and 12 fish per pound planted in May in the Samish River apparently smolted in part and emigrated ito salt water. The adult survival rate was 6.4 and 4.8 per cent respectively. Six additional plants, involving yearling fish ranging in size from 14 to 35 fish per pound, had a survival rate ranging from only 0.2 to 0.8 percent. Obviously a major share of the latter residualized and became competitive with wild fish.

Later experiments on Chambers Creek shows a progressive increase in adult survival rate of 6.7 percent for 7.5 fish per pound to 12.7 percent for 4.4 fish per pound. It can be concluded from this early work initiated by Pautzke and Meigs that juvenile steelhead when planted should be of a size at least as large and preferably larger than the two and three year old wild smolts which average seven inches in length or 8.5 fish per pound. Smaller fish tend to residualize and the survival rate is too low to justify the operation. Residualized fish become competitive with the wild fish hence any survival is probably deductible from that of the wild population. In later years it has been generally accepted that hatchery fish of any species should be larger than their wild counterparts and an average size of 8 inches in total length or 6 fish per pound for winter-run steelhead is indicated for all hatchery plants if rapid emigration to salt water and a maximum adult survival rate is to be obtained. Unfortunately much of the data supporting the above conclusions has not been published.

In the winter of 1959-60 the Research Division of the Oregon State Game Commission initiated a study similar to that carried out by Pautzke and Meigs to assess the role of artificial propagation of winter steelhead as a means of supplementing natural reproduction. This excellent investigation as reported on by Wagner (1967) substantiates the findings of Pautzke and Meigs.

Wagner concluded that "Survival of hatchery reared steelhead in relation to size has been variable as a result of the existence of a number of uncontrolled factors. Nevertheless the trend towards increased survival when fish are released at a larger size is apparent." He presents a summation graph of the survival rates of several experimental groups. This graph is reproduced here as Figure 11. The common mean for high survival is six fish per pound. A somewhat arbitrary decision of an eight inch average for hatchery fish to meet the requirement of having these fish larger than wild fish results in approximately the same conclusion. It is interesting to note, also, that the mean survival rate of fish at 11 to the pound is only 2 percent while the mean survival rate is 7 percent for fish at six fish per pound, an increase of 250 percent.

Wagner, in discussing the required time and size of planted hatchery steelhead smolts, states the following as a policy consistent with stream ecology, "Ideally, the stream is to serve only as a highway to the sea and not as a post-liberation rearing area for the hatchery product. In keeping with this end, it is essential that the hatchery fish migrate seaward shortly after release and not remain in the stream . . . ."

Small fish tend to residualize and stay in the stream where they are competitive at least for a time with the wild fish. During the summer following the spring release these fish lose condition and gradually starve to death or perish later prior to reaching maturity. In the summer of 1971, the writer observed the residualizing of thousands of hatchery steelhead yearlings up to 7-1/2 inches in length in the Cowlitz River. Samples were taken from late July to October and little growth was noted during this important growing period. At times the fish seemed incapable of changing color to match the environment

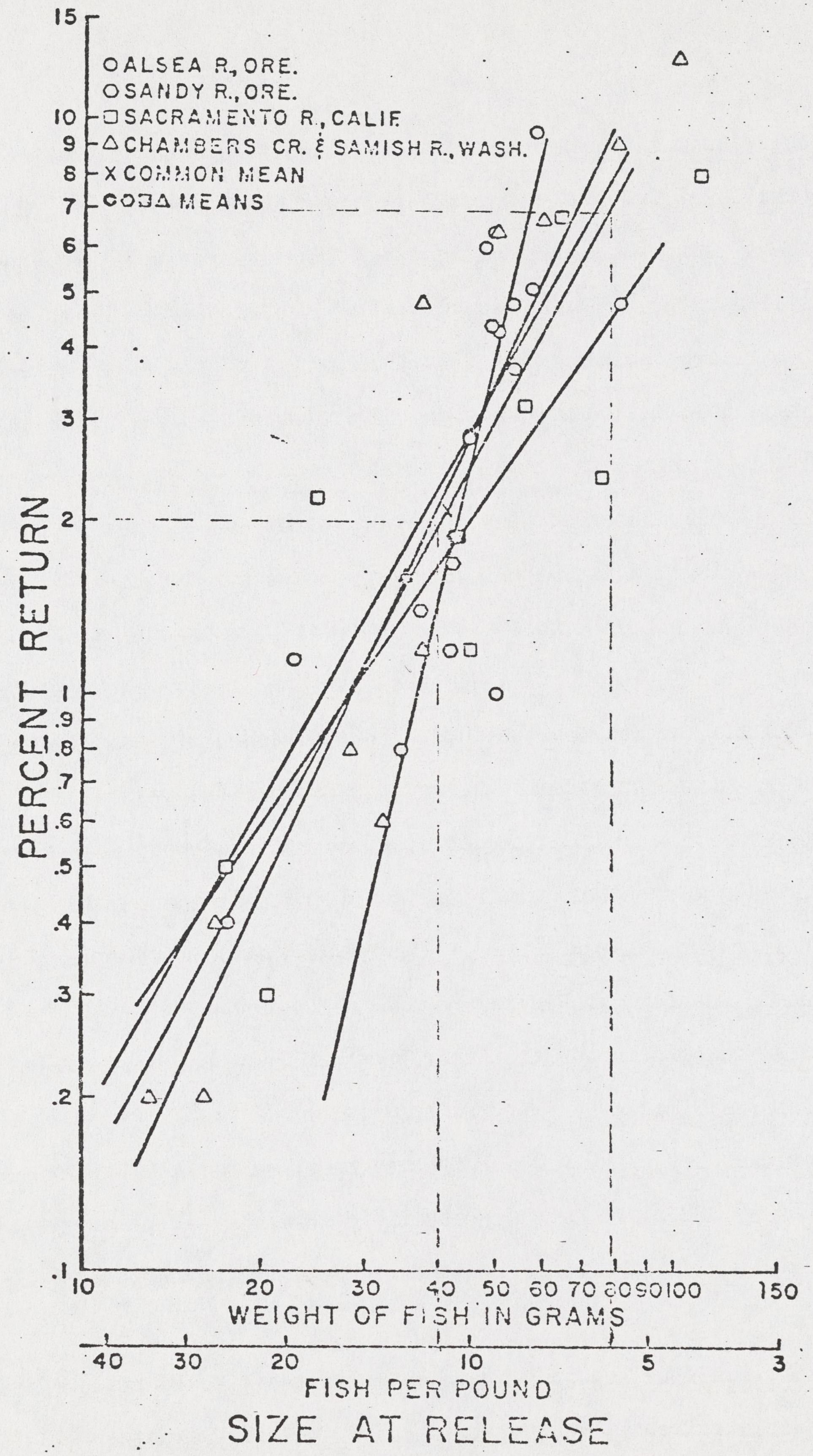


Figure 11: Relationship between size at release and adult return for hatchery-reared steelhead in California, Oregon and Washington.

which is a characteristic symptom of fish in poor condition. Chapman noted in the Alsea River that of 7,900 fish planted at 10 per pound, a total of 2,300 failed to move downstream. He caught marked fish from the release throughout the summer and stated that, "These residual fish did not appear to be in good condition." "Some resorption was evident at the margins of scales from residual fish." The same observation was made on the scales of residual fish taken in the Cowlitz River by the writer.

Wagner, et al (1963), observed that, "95 percent of the 5.5 per pound group captured were trapped in 10 days whereas 18 days were required to trap 95 percent of the 9.0 per pound group. Only scattered recoveries were made of fish from the 24.9 per pound group." This data indicates that the smaller the fish the greater residualism and the greater the inter- and intraspecific competition. Wagner, et al state, "On eight out of nine release groups, the mean size of the fish captured while moving downstream from any given release group was larger than the mean size of the steelhead stocked, indicating that the smaller individuals -- were not moving seaward . . . ." The writer noted that none of the residual steelhead in the Cowlitz River were over 7-1/2 inches in total length although substantial numbers larger than that had been released from the hatchery.

While numerous small hatchery fish residualize and become competitive within the stream rearing capacity, very few survive to the adult state. Wagner reports that only 50 out of 16,808 adult hatchery steelhead showed a second fresh-water annulus on the scales, although frequent residualism was noted during the course of the experiments.

Juvenile summer-run steelhead appear to be more sensitive to residualism than those of winter steelhead. Whether this is an inherited trait or is the natural result of differences in life history is not known. The summer-run fish do not grow quite as fast as the winter-run hence it is more difficult to bring the fish up to size in one year. The Washington Game Department frequently holds summer-run juveniles for two years in order to obtain a maximum return of adults.

Data for determining the required release size of hatchery reared summer-run steelhead is not as extensive as for the winter run but size requirements appear to be the same as for winter steelhead in respect to adult survival. Everest (1971), in reporting on the summer-run steelhead in the Rogue River stated, "The number and size of returning hatchery fish is directly related to size at release. On the first upstream migration, the return of adults released as smolts at 4.7 and 6.0 per pound was approximately double that of fish released at seven and eight per pound and 10 to 70 times greater than fish released at 11 to 13 per pound."

The importance of size in the planting of potential steelhead smolts to obtain maximum survival has been recognized by the Washington Game Department for a number of years. The size of fish planted usually ranges from 6.5 to 8.5 fish per pound depending on the growth conditions of the year and the thermal cycle in specific hatcheries. Modern diet mixtures involving a high protein base make it possible to further increase the size of the fish planted by approaching the six fish per pound average. The benefits of achieving this goal in terms of increased adult survival rates are well worth the effort in terms of an improved cost-benefit ratio. The planting of pre-smolts or advanced fingerlings has been largely eliminated but occasional plants of undersized yearlings (culls) are still made since the cost of retaining the fish for an extra year is rather high. However, undersized fish produce few if any adults and should never be released in an area where they can cause both inter- and intraspecific competition. If it is not practical to retain these fish as "rainbow trout" for release in reservoirs or lakes, they should be destroyed.

The full effect of planting undersized steelhead on the wild population of steelhead or other salmonids is becoming increasingly evident. Considerable information shows that large numbers of advanced fingerlings would be damaging not only to the wild steelhead population, but to the whole salmonid complex as well because sufficient escapement of each species usually is present to absorb the stream rearing capacity. Consideration should be given to the harvesting of any residual fish after the need for protecting the emigrating smolts, is over. This question will be discussed later under regulations. It is suffice to conclude at this point that size is very important to the ultimate survival rate and without it the fish represent an economic loss and waste of the license holder's money as well as a danger to the maintenance of natural reproduction.

The above data illustrate the importance of rearing fish to larger size, particularly since the number of fish per pound represents an average rather than a representative weight for the individual fish. Conceivably, no matter how large the average size, some fish might be below the required size for smolting. The larger the average size, the smaller the number of fish that would residualize. Figure 12 includes length frequency curves for 110 yearling steelhead averaging 5.5 fish per pound and 142 fish averaging 8 fish per pound. Wagner's data on smolting indicates that approximately 8% of the 8 per pound sample would residualize since this number would be less than 6.64 inches in length. None of the 5.5 per pound sample would be below the critical smolting length and remain in the stream. However, the writer observed a number of residualized fish in the Cowlitz River up to 7.5 inches in length. Perhaps all of the hatchery fish between 6.64 (Wagner's data) and 7.5 inches do not residualize but an unknown percentage do. In any event, previous investigators

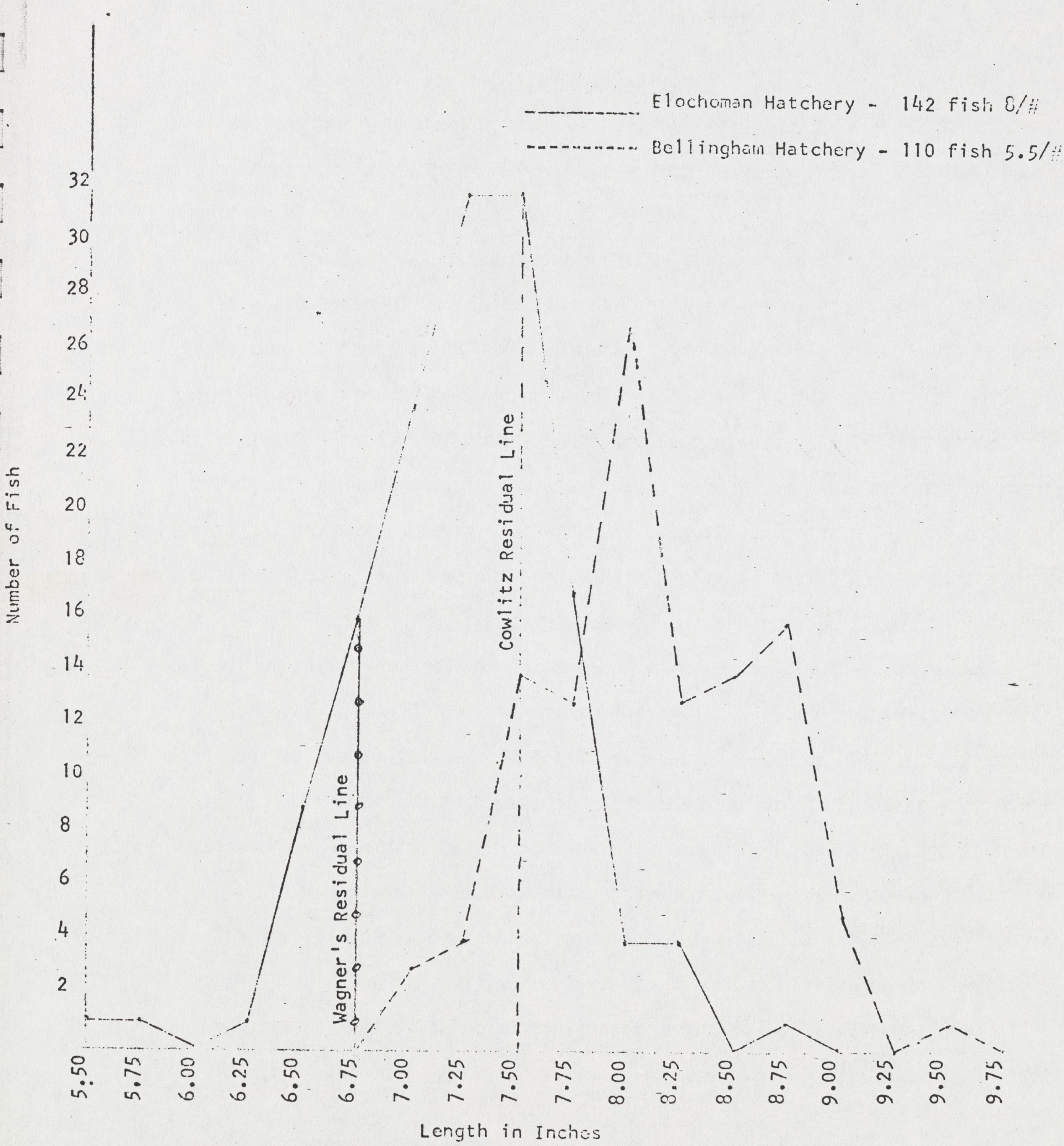


Figure 12 Length Frequency Polygon - Yearling Steelhead

agree that fish weighing 6 per pound or less produce a far greater rate of return than do 8 fish per pound.

Time of Smolt Release

It has been mentioned previously that timing of hatchery smolt migration should coincide with the normal peak of downstream wild smolt migration. Either summer or winter-run smolts planted earlier than April delay their migration and suffer a reduced rate of survival. Fish planted after May, except possibly in estuarial areas, tend to residualize and survival is low. On the basis of marking experiments carried out by the department, the ideal time for planting in terms of maximum survival appears to be from April 20 to May 15.

Wagner (1967) stated, "In general, the movement pattern of hatchery fish from the raceway appeared similar to the movement of wild fish in the stream." He added the following conclusion: "The data from marking experiments indicate a necessity for release of hatchery fish during the period of wild migratory activity for maximum survival."

The survival of hatchery smolts in relation to time of release may be variable as a result of uncontrolled factors which have not been fully measured. Wagner (1971) noted that artificial variations in temperature cycles influenced the magnitude and duration of downstream migration response but did not affect the onset of smolting. He also determined that migration times were advanced or delayed by phase and frequency adjustments in the photoperiod cycle. There is evidence that the natural variation in these factors may be related either positively or negatively to the adult survival rate.

Unpublished data on the timing of migration of Chilko Lake sockeye smolts (Int. Pac. Salmon Fish. Commission.) show that early warm spring weather results in an early emigration of smolts which, in turn, appears to result in a poor adult survival rate. Late migration associated with cold weather appears to favor a relatively high adult survival rate. Whether the indicated survival relationship is direct or associated with flow and therefore is actually an artifact is not known. Smoker noted a direct correlation between total runoff during stream residence of the juvenile and adult survival of steelhead in Minter Creek. However, Smoker's runoff data actually may be related more to fry-to-smolt survival than to the smolt-to-adult survival, but he provides no information to determine this. Braaten (1970) recorded a favorable relationship between flow at the time of smolt release in certain streams and the adult survival rate. Thus, it is difficult to assess the effect of variables such as temperature and flow on the proper time of release. Lacking confirmation on the effect of these factors, it appears desirable in a year having a cold spring to release a week or more later than the average time for the peak of wild smolt emigration and, if possible, at a time of relatively high flow.

Since the life of the anadromous salmonid involves sequential habitat, each of which appears to be environmentally oriented, the possibility of controlling smolting by artificial means to obtain beneficial results does not appear to the writer as holding much promise as a general practice. Wagner (1971) recommended applying artificial controls to a production hatchery based on his experimental findings. Therefore, if benefits are to be forthcoming, carrying out of his recommendation will provide an assessment of the value of such controls. Wagner states, "An essential part of future programs should be to determine what the effect of early migration of steelhead smolts has on marine survival, life history, and growth of this species (steelhead) and its ecological relationships with other species."

While the writer is not optimistic about the practical success of Wagner's work in regard to developing an earlier smolting date, the operation may lead to a better understanding of the smolting process and its relation to survival. The danger lies in the adverse effect of the program on any hatcheryman prone to release his fish in advance of the proper time (peak emigration of wild fish) and demonstrates little concern for variations in natural water temperature cycles. The writer in several instances has observed the practice of starving fish to artificially create the characteristic movement of smolting steelhead in order to justify an early release. Both starvation and early releases are not consistent with the available data relating to high survival rates.

It appears to the writer that a well organized but limited research program directed toward measuring the effect of flow and temperature on the otherwise optimum time of planting should be undertaken. If the possible negative influences of these factors were eliminated, the benefits could be substantial. Up to 100% or more variation in smolt-to-adult survival rates certainly exists. The question is, what factors are most responsible for these variations? The isolation and assessment of each is a difficult task but, fortunately, any research unit established by the Washington State Game Department would be aided and supplemented by the excellent work being undertaken by the neighboring State of Oregon. Pending accumulation of additional information, the existing information should be applied through an improved and more intimate relationship than now exists between the main office and the individual hatcheryman. Early season planting and any planting of undersized fish should be eliminated and the hatchery system reorganized and redesigned to that end wherever required.

Either of the two practices cannot be taken in a nonchalant manner, for substantial sums of money have been invested in the product.

Smolt Quality

While proper time and size of release are necessary for obtaining a favorable smolt to adult survival rate, the quality of the fish released is the final determinate. Quality involves pathological history, diet, rearing environment, periodic grading, planting environment, and the transfer of fish. Experienced fish pathologists accept as fact that virulent outbreaks of disease usually are the result of stress created by adverse rearing environment, feeding procedures or inadequate diets rather than the mere presence of a pathogen. The ability of a salmonid to survive may be permanently impaired at the very outset of a rearing program. Pinheading and irregular growth rates can start with carelessness in the initial feeding of fry and this is often followed by permanent deterioration of the gill structure from bacterial infection. However, the writer does not propose to present an operation manual on hatchery procedures. It is suffice to state that much of the success of a hatchery program lies in the experience and judgment of the hatchery superindendent. That is why a superintendent is frequently referred to as a "good" or "poor" fish culturist. However, the activities of the superintendent should be under continuing observation with experienced advice and information given promptly whenever required to aid in his improving the quality of his product.

The Washington Game Department has had a progressive attitude in the design and operation of its salmonid program. The new rearing facilities provided and the diets used have incorporated the most advanced information available. However, as the program has been enlarged in recent years there appears to be some tendency toward "gross production", rather than a production of quality fish capable of a maximum survival rate. Some tardiness is evident in the improvement of older hatcheries where physical barriers prevent the achievement of maximum quality as well as size of product. There is a need for a more dominant administrative attitude towards correcting instances of operating weaknesses in the growing hatchery system. Capital cost is not a factor if rearing environment is below optimum, thus limiting the quality of the final product and the adult survival rate. If a hatchery is not achieving economic stability because of physical limitations, either the facility should be redesigned or abandoned in favor of a better location.

The maintenance of technical liaison between the administrative office and the operating facilities has not kept pace with the growth in the department's fish cultural program. The administrative service should be enlarged sufficiently to guarantee that adequate rearing facilities are provided with the feeding and rearing programs, and disease control satisfactory for each station. Such a service can be supplied only from the main office with the regional biologist acting as a local observer of day to day operation.

Experimental control of operating procedures including diet should be carried out by each superintendent on a continuing basis to provide a foundation for improved operations applicable to his particular station. Each station may differ from another in water chemistry and the thermal cycle. Such differences may require special diets, different from those accepted generally, if stress and related disease is to be avoided and maximum growth associated with good health is to be obtained.

The differences in the most favorable diet and growth rate between hatcheries raises the question to be considered later; viz, why do some streams react favorably to hatchery plants of yearling steelhead while others do not.

The susceptibility of some hatchery stocks to shock during transportation or to almost immediate outbreaks of the deadly vibrio disease upon introduction into salt water raises the question of the true state of health of the yearling smolt which is not always evident in a casual assessment of appearance. As suggested earlier, there is a serious need for a small compact administrative research unit to obtain and collate information required for improving operating policies resulting in a higher and more uniform smolt to adult survival rate. Doubling the survival rate which is reasonably possible within the actual current variation in survival rates means a 100% increase in dollar return with very little increase in cost. Rigid adherence to controlling those factors known to adversely affect survival is primarily a matter of responsibility, not money.

Another administrative responsibility involves the continuing education of the hatchery superintendent. This should eliminate the practice of starving yearling steelhead to create early smolts, premature planting, and aid in increasing the size of the product thus reducing the number of undersized fish which have no value, except as catchable trout in landlocked areas. The cost of failing to live up to these responsibilities would then be better understood by those in direct charge of the rearing units. Similarly, the deadly buildup in amonia in overloaded planting trucks and the planting from a warm water environment in the hatchery or planting truck into a cold stream and its adverse affect on survival of the fish involved would be more realistically appreciated by the operator. The number of fish planted has no value except as represented by returning adults. A better dissemination of available knowledge pertinent to the no - no's of hatchery procedure and an active program for obtaining new information through research would be of considerable help to those directly involved in fish culture, creating a better team spirit.

The definition of fish quality is a viable one, subject to constant improvement as is the case in the culture of other plants and animals. Competition to meet the rising harvest interest requires that "status quo" be on constantly changing basis. More fish planted does not necessarily increase the supply even though costs increase proportionate to the number of fish planted.

Satisfactory records for measuring the quality of the fish planted have not been kept in past years. This subject was discussed on page 32 and in appendix B.

It has been mentioned earlier that size, time of release and quality of the product are all associated with the smolt to adult survival rate. The functioning of these three factors cannot be measured as individual influences in every case but the importance of attempting to do so cannot be overemphasized.

In addition to residualism due to planting of undersized fish, large numbers of fish apparently disappear after planting. A downstream trap was installed on Beaver Creek, tributary to the Elochoman River, to collect all downstream migrants. On April 15, 1966, two lots of 1,000 marked winter steelhead, averaging seven fish per pound, were planted one mile above the trapping facility. The downstream migration was essentially over on May 6, yet only 56 percent of one lot and 65 percent of the other were recorded in the trap. Of those fish trapped, 54 percent appeared within six days. Observation the following summer failed to reveal the presence of the unaccounted for fish.

Wagner (personal communication) reports similar findings in Oregon. Electrofishing carried out later in the season failed to account for fish that remained above the trapping facility. It is most important to management that the extent of residualism be measured and the fish harvested as soon as practical. In addition, the frequency and extent of unknown mortality and its cause should be investigated.

If residualism and unknown mortality account for up to 50 percent loss in all streams, as was the case in smaller experimental streams, the survival rate of the balance is far higher than any figures recorded to date. To place this information in its proper perspective it is conceivable that up to 500,000 out of every 1,000,000 fish planted are lost as a potential for returning adult winter steelhead.

Fish of top quality, total smolting, and rapid emigration of all planted fish to the ocean should be a major goal for further increasing the adult steelhead populations and thus improving the economics of the operation.

Age and Size of Hatchery Adults

The sportsman is concerned with how hatchery-reared smolts affect the characteristics of returning adults. These characteristics involve age, size, migration timing, homing, fighting qualities of adults, and the possible effect of hatchery fish on maintenance of the wild populations.

The best example of the effect of a hatchery smolt program on the maturing age of winter steelheads is presented by Wagner for hatchery fish and Chapman for wild fish (Table 15). Chapman (1957) summarized ages of wild steelhead on the Alsea River from 1951 to 1955 and Wagner (1967) presents ages of 17,780 hatchery adults for the same river during the period 1958 to 1962. Since age is only important to the sportsmen as it relates to the size of the fish caught, the following comparison will be restricted to saltwater age at maturity.

Size and age of the smolts have little direct relationship to the size of the adult. Age /1, /2, /3, /4 refer to years spent in the sea prior to maturity, not to total age, which includes the period spent in freshwater.

Wild fish produced 5.4% jacks or age /1 compared with 4.6% hatchery fish

Wild fish produced 66.4% age /2 compared with 89.9% hatchery fish

Wild fish produced 25.6% age /3 compared with 5.5% hatchery fish

Wild fish produced 2.4% age /4 compared with 0.0% hatchery fish

A variation will occur in saltwater age classification of hatchery adult steelhead between rivers and years but the percentage of age /3 in most cases may be expected to favor wild fish. On the Wilson river, Wagner reports the age classification of 8,712 hatchery fish as 2.9% of age /1, 87.7% of age /2 and 9.4% of age /3. No hatchery fish of age /4 were reported in either the Alsea or Wilson rivers. It is these fish which reach a size exceeding 20 pounds.

Rearing hatchery smolts to a large size in one year tends to reduce the percentage of age /3 and eliminate age /4, yet this practice is essential to placing the hatchery operation on a sound economic basis. It is the slower growing juveniles that tend to remain in the ocean an extra year or longer before maturation. By doing so, more of them return at age /3 weighing 9 to 15 pounds and even larger for age /4, instead of 4 to 9 pounds, which is the usual weight of age /2 fish. To slow down growth in the rearing pond contributes to undesirable residualism and poor adult survival. The only possibility of increasing the hatchery production of /3 or /4 aged fish is to experiment with selective breeding of older fish in the hope that some genetic influence may exist. Experiments involving the use of selection for large fish have been conducted by the Washington Game Department for several years, with some apparent success. However, the experiments have not been under sufficient control to determine whether the apparent success is due to stimulated growth rate or increased age of return from saltwater.

Available data are inadequate to assess whether hatchery and wild fish of the same age differ in size. Chapman (supra) gives no data for examination but concludes that hatchery adults are slightly smaller and have a slightly poorer condition factor. Adequate data for accurately measuring the weight of the two groups requires that samples be of similar age and approximately the same time of migration. The program outlined under Appendix A should provide information for deciding this question.

While some annual growth increment occurs in repeat spawners, it is considerably less than that of fish which spend an extra year feeding in the ocean prior to maturity. Data on this question will also become available from the scale collection program outlined in Appendix A, which is now operative.

Wagner noted that 5.4% of the 17,780 hatchery steelhead on the Alsea and 4.8% on the Wilson rivers were repeat spawners, whereas Chapman recorded 133 repeat spawners out of 1,195 wild fish observed over a period of three years. The annual percentage reported by Chapman varied from 3.15% for 1955 to 17.09% for 1953, for a three-year average of 11.1%. There is an indication from the above data that the percentage of repeat spawners is less for hatchery fish than it is for the wild fish. This would further reduce the percentage of somewhat larger fish in hatchery returns compared with that for wild fish. Further, the lesser percentage of repeat spawners apparently supports Chapman's conclusion that adult returns from hatchery fish do not have a condition factor equal to that of wild fish. However, the earlier spawning hatchery fish may find it more difficult to regenerate their energies during the seasonal conditions prevailing at the time.

It must be concluded at present that in order to maintain the steelhead runs at a high level of abundance, we may have to sacrifice a percentage of larger fish, although the total number of such fish harvested may be equal to or exceed that produced by the smaller number of naturally propagated fish. Further carefully controlled experimantation with selective breeding may nullify the current situation.

Return Timing of Hatchery Adults

In order to provide for a maximum rearing period and approach the size requirements for producing hatchery smolts in one year, the Chambers Creek winter steelhead stock has been utilized almost exclusively for planting in the streams of western Washington. This winter-run has evolved to early returning fish in association with two standard hatchery practices. The first consists of placing the adults in holding ponds with a water supply several degrees warmer than that of the creek, thus stimulating the time of maturation. The second practice and probably the most important involves taking the eggs from the earliest maturing fish each year, incubating them in the warm water of the hatchery water supply, and thus increasing the rearing time available to produce a smolt for release the following spring. These fish, when planted in other streams as well as Chambers Creek, result in an adult run returning 30 days or more earlier than their wild counterparts. To aid the rearing stations having a cooler water supply, the fry hatched at South Tacoma hatchery are frequently reared for a period before transfer to these facilities.

Although Chambers Creek stock has been successfully transplanted to many streams, adults from the Samish and Green Rivers have been transferred back on occasion to the South Tacoma hatchery for ripening and a source of eggs to augment those taken from Chambers Creek. Nemah River and other stocks have also been released into Chambers Creek, so presumably the present Chambers Creek run has a rather complicated gene background.

The summer-run hatchery stock of steelhead has originated from the native run in the Washougal River. Selective egg taking from the early maturing fish unaccompanied by stimulated maturation has resulted in an earlier maturation of this stock similar to that occurring with the Chambers Creek stock. The lack of stimulated maturation at the Skamania Hatchery on the Washougal River summer-run steelhead raises a question as to the significance of this factor in causing earlier timing.

Most of the hatchery adults now return 30 days or more earlier than the wild fish, the winter-runs starting in November and peaking in December and January, although some fish contribute to the February and March sport catch. The rather spectacular effect of introducing Chambers Creek stock into the streams of western Washington on the changed timing of the adult runs was illustrated earlier in Figures 2 and 3 as a part of the analysis of the catch statistics. On page 23 the following statement was made: "Note is made that while the December catch of winter steelhead has increased substantially since 1959, the March catch, consisting primarily of wild fish, shows a slight decline. When the estimated adult catch of steelhead originating from hatchery-produced smolts is subtracted from the total March catch, the catch of wild steelhead shows a significant decline."

The tendency of a major share of hatchery steelhead (both summer and winter-runs) to return and spawn several weeks earlier than their wild counterparts raises a serious question as to their capability to reproduce themselves naturally. They are mistimed with the natural thermal cycle which the native fish must have adjusted to in order to achieve a maximum survival rate. In the case of Fraser river sockeye (unpublished data I.P.S.F.C.) such mistiming can result in a failure to reproduce themselves although the critical upset created in their life history that causes total mortality is not well defined. Perhaps steelhead are sufficiently tolerant of changes in thermal environment during their fresh-water life history that early return and associated early spawning will not endanger their survival rate. The important point to be made is that there is no information available as yet on the ability of a hatchery steelhead to reproduce itself naturally. If they do reproduce successfully they might conceivably revert to type in regard to timing of adult return. Perhaps the adjustment, if it occurs, is immediate or the re-adjustment to normal timing may take several generations.

The number of generations required for a major change in return timing due to hatchery operations has not been accurately recorded but the change has been quite rapid since apparently a major change in timing was observed at Chambers Creek in a few generations. If earlier timing of the adult run can be achieved by continued selection of early maturing fish for an egg supply it logically follows that the process can be reversed and a dramatic rise obtained in the number of adults returning in March and April similar to that already recorded for November, December, and January. Fishing conditions are far more pleasant in November, December, March and April than they are in January and February. The only apparent obstacle to producing late run fish from late spawning parents of either winter or summer steelhead lies in the reduced rearing season and the related difficulty in producing yearling smolts in the shorter period available. Improved diets producing more rapid growth and careful attention to the thermal regime provided during maturation and rearing indicates the possibility of producing a run of late fish. Experimentation is already underway to achieve this end but difficulty exists in meeting thermal requirements in most of the hatcheries. There is a need for reorganizing the thermal regime of sufficient percentage of the hatcheries not only to meet the requirements of producing late fish but to increase the dependability of the whole hatchery system for achieving smolt size requirements in the cooler years.

It is unfortunate that the harvesting of late run fish will always be associated with catching early run fish which are either fully matured, spawning, or spawned out. However, if there is a major demand for late season fishing, this harvest interest should be met, if practical.

Homing of Adult Hatchery Steelhead

The sensitivity of the homing instinct in wild steelhead has never been delineated. Information available for other salmonids indicate that a significant amount of straying occurs between neighboring streams, particularly when the thermal cycle and the chemistry of the water appear to be similar. On the other hand, there is a tendency for most salmonids to return to the origin of the embryo. It is obvious from a survey of the literature that there is some variation between species in the sensitivity of the homing instinct. The functioning of this instinct is particularly important in case of steelhead since the fishery is limited entirely to the watersheds where they reproduce. The success of a steelhead rearing program is more easily quantified if homing is precise in relation to the receiver stream. Furthermore, if fish tend to return to the exact point of release whether it be in the donor or recipient stream the interest of the sportsmen can be fulfilled by providing fish at the most desirable harvest location.

Pautzke and Meigs (1940) tagged 5,000 immature hatchery steelhead which were planted in upper and middle Green River in 1937. They report that "29 adult recoveries were checked in the main river, six were recovered in Soos Creek, a tributary of the same river, although the creek had not been planted. One fish was captured in the North Fork of the Klatskanine River in Oregon . . .

Another fish was taken in the Skagit River . . . A third fish was reported taken in the Snoqualmie River . . ."

Larson (1955) released a group of marked winter steelhead yearlings into the Satsop River watershed in 1953. In 1955 a total of 46 marked adult steelhead were returned by sportsmen. Of this number 25 were caught in the Satsop River, 12 in the Wynoochee River, also a tributary of the Chehalis River having its confluence about six miles downstream from the Satsop. One was returned from the Humptulips River which enters Grays Harbor also, some 15 miles distant from the mouth of the Chehalis River. It should be noted that fish released in this experiment were reared in water from the Wynoochee River which may have influenced some fish to return to this stream.

Wagner (1967) reports that "Creel checks on the Trask River indicated a high incidence of straying of adult steelhead from the 1964 release of steelhead in Wilson River. Of the 136 fish observed, 15 fish or 11% originated from the Wilson River." Trask River has a separate confluence in Tillamook Bay located about two miles from the mouth of Wilson River.

Ayerst (1964) released 16,000 marked winter steelhead smolts in the Dosewallips River in April, 1961. Of the returning adult run, 19 were observed in the sports catch on the Dosewallips River and nine on the Duckabush River having its confluence with Hood Canal some four miles south of that of the Dosewallips.

Fish raised and marked at Barnaby Slough and released in Skagit River are observed rather frequently in the sports catch from the Stillaguamish watershed.

A complete recored of straying is almost impossible to obtain although tagging by Pautzke and Meigs probably is more representative than those experiments involving marked fish. The latter system does not provide fish easily recognized by sportsmen and marks are often duplicated for the same brood year in fish destined to different river systems. In addition, recovery of a marked fish in a separate river system is not a guarantee that the fish in question will not eventually return to the stream of planting origin. Unpublished data collected by the International Pacific Salmon Fisheries Commission show that sockeye tagged in neighboring tributaries of the same river system frequently are observed in a tributary other than the stream in which they were tagged. In this case the thermal cycle and water chemistry are similar. Fessler (1971) reports that "In September, 1969, 147 hauls were made with a 300-foot beach seine to capture and tag 73 adult summer steelhead at the mouth of the Deschutes River. Twenty-six have been returned by anglers. Of them, seven were from the lower one miles of the Deschutes, two were from approximately 12 miles above the mouth, and 17 were returned by anglers fishing the Snake River and its tributaries. Tag returns from the Snake River system indicate that there is considerable amount of straying of upper Columbia River steelhead into the mouth of the Deschutes River."

It can be concluded from the above that a significant percentage of surviving adult steelhead planted as smolts in a particular river may be harvested in tributaries of the same river system and neighboring river systems as well, with at least some fish returning to rivers some distance from the river of planting origin.

The homing instinct of transplanted steelhead smolts is obviously confused to some degree by sharp differences in the environmental characteristics of the receiving stream from those of the doner rearing location. Likewise, a similarity in environmental characteristics of several neighboring streams to that of the recipient stream appears to result in a weakening of the homing instinct causing some diversity in adult distribution. Nevertheless the degree of homing to the recipient stream appears adequate in most cases to warrant planting of smolts since a substantial increase in catch usually results from such plants. However, the possibility exists that the Chambers Creek stock may find environmental barriers in some streams which prevent obtaining of maximum benefits from planting these fish in such areas. Where adult returns are disappointingly low, consideration should be given to use of brood stock more adapted by evolution to such a different environment (See Appendix C).

The inaccessibility of portions of streams and limitations in suitable fishing waters have led to experimentation in planting location, relying on the homing instinct, in an attempt to obtain a more favorable availability of the returning adults to the sportsmen.

The Washington Game Department has conducted numerous marked fish experiments relating adult return to the release point. Unfortunately, none of the observations have been published or recorded in a usable manner. It can be concluded from a discussion of this work that there is a tendency for a majority of the returning adults to concentrate in the planting location but upon the approach of maturation many will distribute themselves to nearby suitable spawning areas. The adults from smolts planted near the mouth of the stream tend to stray extensively to other streams.

Wagner (1967) reports in detail on several experiments carried out in the State of Oregon. Pertinent data are illustrated in Tables 23 and 24.

Wagner concluded, "In general, manipulation of the release location appears to be an effective means of increasing the contribution of hatchery-reared steelhead to the sport fishery on certain streams. It should be correlated with the known distribution of fishing effort." Wagner did not comment on what appears to be an interesting part of his data. When the planted

TABLE 23

The Observed and Estimated Catch of Adult Fish Returning from the 1964 Release Groups by Geographic Location on the Alsea River in 1965-66

	Location of Recovery		
Release Group	Upper River	Middle River	Lower River
Upper River	91[1/] (1,747)[2/]	47 (280)	60 (501)
Lower River	31 (595)	33 (197)	72 (603)
Angler-Days of Use	9,849	5,534	11,333

1/ Observed
2/ Estimated

TABLE 24

The Observed and Estimated Catch of Adult Fish Returning from the 1964 Release Groups by Geographic Location on the Wilson River in 1965-66

	Location of Recovery		
Release Group	Upper River	Middle River	Lower River
Upper River	25[1/] (330)[2/]	33 (316)	50 (601)
Middle River	10 (132)	78 (747)	96 (1,153)
Lower River	4 (52)	17 (163)	150 (1,810)
Angler-Days of Use	7,095	11,577	11,612

1/ Observed
2/ Estimated

fish originated from a station on the upstream portion of the planted stream there is a tendency for a significant number of fish to proceed back towards the station of origin and past the planting location. When fish are transferred from another watershed they appear to concentrate at the planting location with very few moving upstream.

The writer concludes from his examination of data related to the homing of hatchery steelhead, (1) that the planting of hatchery smolts may be expected, in most cases, to return sufficient adult steelhead to the stream of planting origin to warrant continuation of transplantion as a satisfactory method for increasing the harvest of steelhead, (2) that homing to the exact release location is usually sufficiently high to warrant use of such a practice in meeting the interests of the sportsmen except when the fish originate from a rearing system located above the planting site, (3) that exact distribution of returning adults be more carefully measured as it relates to diverse fresh-water environment, (4) that whenever the adult return fails consistently to react favorably to transplants, use of a different broodstock should be considered, and (5) that controlled observations on homing, as they related to improved management practices, be continued and recorded in a manner suitable for adding to the basic knowledge on this subject.

Relationship of Hatchery Steelhead to Wild Steelhead

This subject is extremely complicated for many reasons involving principally whether or not hatchery steelhead are capable of reproducing themselves, whether or not planting policies tending to separate hatchery and wild adults on the spawning grounds have any real value; whether a residual population of young hatchery fish exists because of small fish releases; and planting practices relating to other species of salmonids.

In 1971, the reports on a winter steelhead check of the sport catch by wildlife agents were compiled to determine the percentage of total catch contributed by hatchery plants in specific rivers. Table 25 lists the results of this survey.

TABLE 25

River	Year	Percent of Hatchery Fish	Smolt Plants 2 Years Earlier
Humptulips	1971	75.0%	70,000
Bogachiel	"	71.0%	46,500
Hoh	"	34.0%	50,000
Sol Duc	"	19.0%	37,500
Johns	"	73.0%	10,000
Naselle	"	57.0%	30,000
Lyre	"	73.0%	21,000
Elwah	"	79.0%	20,500
Dosewallips	"	84.0%	20,000
Duckabush	"	63.0%	20,000
Satsop*	"	2.2%	14,500

* Failure of the Satsop River to respond to a plant of 14,500 smolts in 1969 is consistent with previous findings by Department personnel who released marked steelhead smolts in the Satsop and Humptulips Rivers in 1960. The adult return to the Humptulips River was six times greater than that to the Satsop River. Similar plants in 1964 in the Satsop and Wishkah Rivers returned practically no fish. There appears to be little doubt that industrial pollution of upper Grays Harbor was responsible for the poor return. Peculiarly, wild steelhead smolts appear to withstand the pollution stress when hatchery fish cannot. (A memorandum in respect to needed correction of this problem was provided the Director on April 13, 1971.)

The aforementioned estimates may not be based on sufficient samples to meet statistical requirements in every case but they are minimum estimates. Marked fish, mutilated dorsal fins, or both were used as a means of identifying hatchery fish. In some instances fish were planted which later could not be identified. Assessment of the catch of winter steelhead in major streams such as the Green, Snohomish, Stillaguamish, Skagit and Samish Rivers in other years indicates that the contribution of hatchery fish is similar to that recorded in Table 25, namely, between 70 and 80 percent. Since all figures are minimal, it appears that a conservative estimate of the total annual catch contributed by hatchery plants is between 75 and 80 percent. Since 14% of a marked fish group returning to Chambers Creek during the 1971-72 winter steelhead run did not have a mutilated dorsal fin, the percentage of winter hatchery steelhead in heavily planted streams could conceivably approach 90 percent. It is probable that the percentage of hatchery fish in the summer runs of steelhead, at least to the tributaries of the lower Columbia, approach that given above for winter steelhead. The run of this population in the North Fork Washougal River was estimated at less than 100 fish when the Skamania hatchery commenced operations in 1956. Currently, the annual escapement to the hatchery varies between four and six thousand fish.

Figure 2 illustrates a slight decline in the March catch of winter steelhead over the past 15 years. Marked fish surveys show that some of the March catch consists of hatchery fish, although it is difficult to arrive at a reasonable estimate of the average percentage composition. However, it is obvious that any deduction for hatchery fish would decrease the March catch and increase the decline of wild fish.

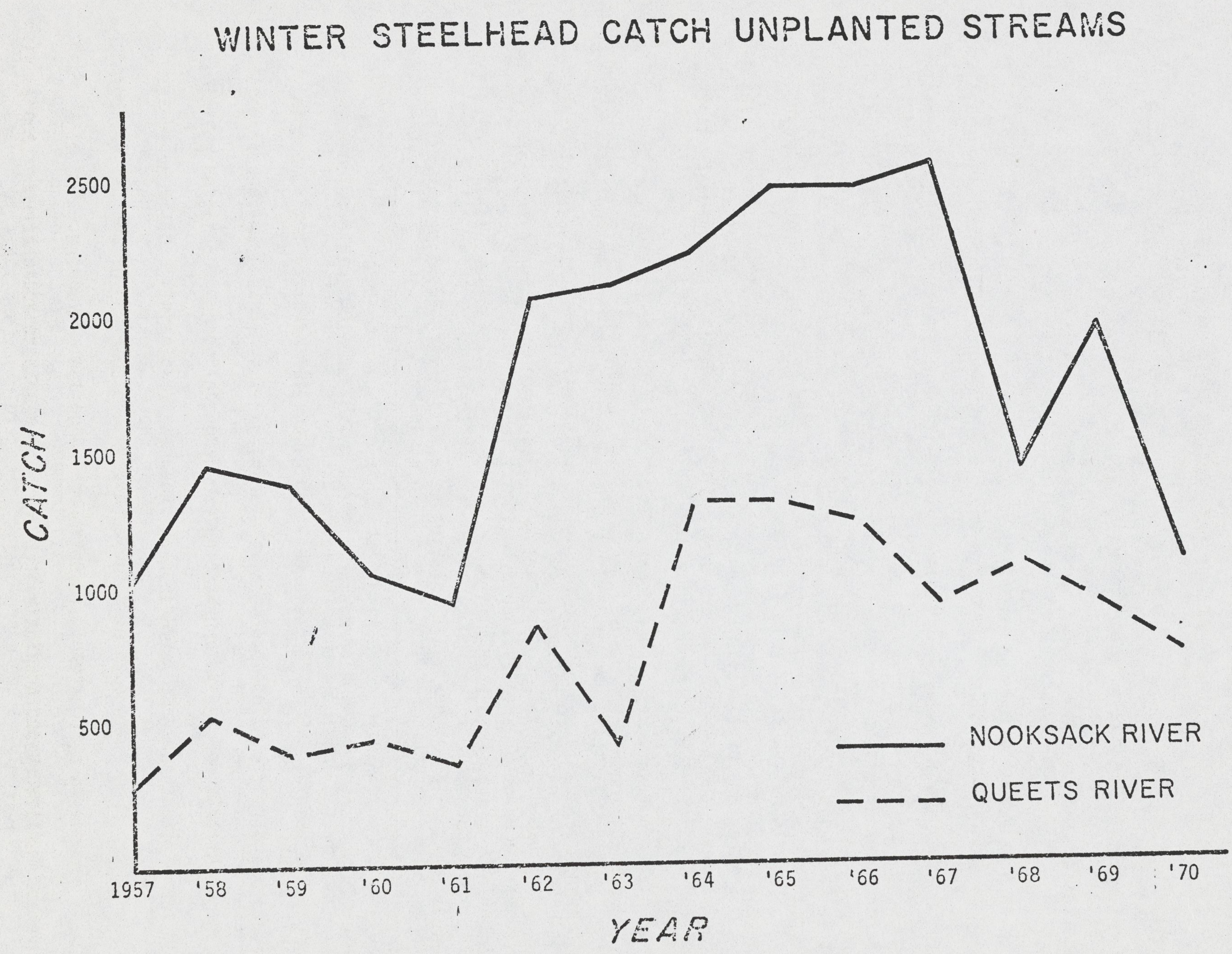
One can assume with some justification that the decline in the wild fish population is greater than can be charged to environmental deterioration. Evidence supporting the latter may be found in examining the catches in those streams which have not been planted such as the Queets and Nooksack Rivers (Figure 13) as well as the Chehalis and Quinault Rivers. Neither the March catch nor total catch in these rivers shows a decline. In fact the catches show a significant increase for the past ten years. Apparently the increased catch was due to increased fishing intensity which caused a maturity of the fisheries to a point where the catch approached stability and therefore represented the approximate size of the annual runs.

One can only conclude from the foregoing that the wild winter and probably the summer steelhead populations have declined with the development of the hatchery program involving all stream rearing salmonids including steelhead. In this case wild steelhead include both naturally produced hatchery fish, if any, and the original stock of wild fish.

In the face of a declining, naturally produced population of steelhead and an increased escapement of hatchery fish spawning naturally, the question of whether or not hatchery fish are capable of reproducing themselves becomes important. Logically, one must assume that the productivity of the latter is either low or non-existent and that of any wild fish very poor. Either of the two stocks of spawners normally should be in sufficient numbers for their offspring to absorb the natural rearing capacity of the stream if it were unaffected by fish cultural practices. Even if the main escapement of hatchery fish spawned 30 days or more earlier than wild fish it is difficult to conceive on the basis of some limited knowledge that the later hatchery escapement would not be sufficiently timed with the thermal cycle to produce smolts and return adults even if the earlier fish could not. It appears pertinent to proceed further into an analysis of why wild stocks, including naturally reproduced hatchery fish, apparently are not maintaining themselves in those streams being subjected to plants of hatchery fish.

Wild steelhead are known to spawn throughout the watershed of any specific river, particularly in the upper half of the main river and its tributaries.

FIGURE 13



WINTER STEELHEAD CATCH UNPLANTED STREAMS
2500
2000
1500
1000
500
CATCH
1957
'58
'59
'60
'61
'62
'63
'64
'65
'66
'67
'68
'69
'70
YEAR
NOOKSACK RIVER
QUEETS RIVER

Planting of hatchery smolts has been restricted mainly to the lower part of the main river and avoided in tributaries. One could surmise that a combination of the homing instinct and present planting policy would tend to separate wild stocks from hatchery stocks during their freshwater existence. However, on pages 38, 39 and 71 the writer noted that steelhead and coho juveniles emigrate each fall from the colder tributaries and the upper part of the main river system to the lower river, presumably to escape undesirable winter water temperatures. In moving to the lower river system, emigrating juveniles of both species become a homogenous population over winter where any effects of inter and intraspecific competition would be in full force. Since the fall and winter season appears to be a major adjustment period for stream resident salmonids in western Washington, any expected benefits due to any isolation of spawning and initial rearing of wild stocks is lost.

Frequent reports are received from wildlife agents to the effect that there has been a gradual disappearance of steelhead in tributary streams, presumably consisting primarily of naturally reproduced fish. The adverse effect of creating inter and intraspecific competition by over stocking of any and all streams with resident salmonids was presented earlier in some detail. The apparent failure of residualized hatchery juveniles to produce significant numbers of adults and intermixing during the winter months of wild juveniles with hatchery juveniles of any stream rearing salmonids indicates that a negative adjustment in the total population of all species would occur. Therefore it is impossible to segregate one species from another in considering the effect of hatchery planting policies and the maintenance of the wild stocks. As Wagner said (1967) "The success of the hatchery program in supplementing the natural production of winter steelhead smolts depends in part on the elimination or reduction of factors which might adversely affect the wild stock or reduce the number of viable hatchery smolts reaching the sea. Ideally, the stream is to serve only as a highway to the sea and not as a post-liberation rearing area for the hatchery product. In keeping with this end, it is essential that the hatchery fish migrate seaward shortly after release and not remain in the stream where competition and predation might result in reduced survival of native and introduced populations."

There is no evidence of overspawning due to return of substantial numbers of hatchery adults in competition with wild fish although escapement is apparently adequate in most cases to more than absorb the stream rearing capacity for the offspring. The writer discussed this subject on pages 12 to 15 and Salo and Bayliff (1958) showed that the coho salmon escapement almost always exceeded that required to absorb the stream rearing capacity for this species, in spite of an intense commercial fishery. Smoker (1955, 1956) demonstrated a relationship between stream flow and the adult return of both steelhead and coho without regard to escapement. If surplus fry are produced, natural forces, especially downstream drift, appear to control the size of the resident fry population early in life to limits of the stream rearing capacity. This is a natural adjustment in numbers and there is no evidence that the total fish biomass is endangered in any way by natural production of surplus young of any species. It should be noted, however, that planting of advanced fry of any stream-rearing salmonid bypasses this relatively harmless early adjustment period, which is mainly intraspecific in character, and could create a dangerous degree of interspecific competition.

To measure the relationship of hatchery to wild steelhead, either winter or summer run, and the effect of several situations detailed above requires, among other things, a continuing census of at least the proportional numbers of the two populations on an annual basis. Such information is not available, and will not be until the program recommended in Appendix A is in full effective operation.

Any conclusion from these data is handicapped to some degree as Wagner (1967) said "by the lack of historical records concerning the abundance of the wild population prior to and after the introduction of hatchery fish. In addition, an assumption would have to be made of the negative changes in the wild population which would result from a deteriorating natural environment." Current runs of wild fish are known to be quite small, but whether they are smaller than normal, in relation to existing stream rearing capacity due to fish cultural practices involving the several species of salmonids, is not known with certainty.

Limited information on population dynamics of stream rearing salmonids combines with a considerable amount of logic indicates that existence of naturally produced steelhead and perhaps of any stream rearing salmonid is in a precarious state. However, the future existence of wild steelhead may not be hopeless under improved management practices involving all species of stream rearing salmonids. Only localized experimentation can provide a reasonable and usable estimate of production of wild steelhead in competition with other naturally produced salmonids. Later the influence of current fish cultural operations could be determined in conjunction with a program of planting directed toward supplementing wild fish production with true smolts of the species involved instead of using pre-smolts in a futile effort to produce more fish. Vincent (1972) in a study of the Madison River in Montana concluded, (1) that after the planting of catchable trout ceased in 1969, the wild population increased 180% by the fall of 1971, (2) that the populations remained stable until catchables were stocked in 1970-71. After the plant, trout numbers decreased 49%. Vincent also concluded that in 3 months 95% of the planted catchables were gone, due mainly to natural mortality.

Vincent's findings do not conflict with planting of migratory salmonid smolts, but does explain why residualized hatchery juveniles fail to produce adults and the negative effect of such residualism on maintenance of wild fish stocks. His work indicates also that elimination of residualism due to hatchery plants should permit the restoration of wild stocks.

To clarify the indicated conclusions from the foregoing discussion it seems important to summarize principal points shown to have some basis in fact.

1. The wild steelhead population has declined in recent years due in part to intraspecific competition brought about by planting of limited numbers of small sized juveniles which residualized and became competitive. Interspecific competition created by hatchery programs operating on sea-run cutthroat trout, coho and chinook salmon collectively may have been a major influence contributing to the decline.
2. There is no evidence to date that steelhead of hatchery origin are not capable of reproducing themselves, although only the latter part of the run may be timed sufficiently with the thermal cycle to reproduce successfully.
3. Any attempt to maintain the wild stock of steelhead by restricting smolt planting areas apparently is doomed to failure, because of the major degree of mixing of offspring in the lower river systems with all other stream rearing populations during the late fall and winter months.
4. Elimination of all hatchery produced salmonids not classed as true smolts should permit wild stocks to compete for existence in a normal manner resulting in a rapid increase in these stocks to the limits set by stream rearing capacity. Not only should wild stocks increase under such circumstances but the adult survival rate of the hatchery plants should increase as well.
5. No long term benefits should accrue in the total production of stream-rearing salmonids from the practice of planting most "barren" portions of the upper watersheds in western Washington because of late fall

and winter emigration of juveniles to the lower river where they become subject to both intra and interspecific competition during a major adjustment period in the population.

Sea-Run Cutthroat

Only limited data on hatchery production of this species are available in the State of Washington, since full-scale observations were not made until 1968. Information compiled from unpublished observations tends to substantiate that collected by the Oregon Game Commission, thereby providing a sound basis for future hatchery operations.

Release Size

While the natural growth rate of this species appears somewhat lower during its stream existence than that of either the summer- or winter-run steelhead, the size of hatchery smolts must be larger if good survival is to be obtained and extensive residualism avoided. Giger (1972) reports that sea-run cutthroat smolts should average 3 to 4 fish per pound, with few fish under 8 inches in length when released. Hatchery releases of this size fish result in greatly reduced residualism and a rapid emigration to the sea. On page 60, it was noted that cutthroat less than 170 mm. fork length, or approximately 7.5 inches total length, residualized in the Alsea estuary in Oregon and did not mature the following fall as did those over 7.5 inches, which migrated directly to the sea. Skeesick (1965) in a study of coastal cutthroat released into Munsel Lake, Oregon, reports that "Fish planted at a larger size contributed most heavily to the migration" and that "The large fish migrated earlier".

Oregon has established a policy which specifies that hatchery smolts averaging 3 to 4 fish per pound should be planted between May 20 and 25 and 1 to 3 days prior to the opening of the stream trout season. While emigration of these large-sized smolts is rapid, substantial catches are made the first two days of the fishing season, with 80 to 90% of the total spring season's catch being made at this time. Potential residuals are mainly eliminated soon after the plant and excellent survival rates are obtained in the return of maturing adults the following summer and early fall. This program has considerable merit in that some stream fishing is provided after most of the salmonid smolts have emigrated and the fishery serves as a stream cleanup of any residual anadromous salmonids which would otherwise remain as competitors to naturally produced fish, whatever the species.

A major rearing and planting program was inaugurated at the Shelton trout hatchery in 1970. The critical need for obtaining large-sized smolts was not defined at the time and in 1970 the mean size of the smolts produced was 7.2 inches, fork length or, by lot between 6.2 and 10 fish per pound. In 1971, the average size of the fish planted increased to 8.4 inches and in 1972 to 8.6 inches. Using the Oregon data of 8 inches for the minimum length of smolts released (Figure 14), the residualism from the Shelton hatchery plants would be expected to approach 69.7% in 1970, plus up to 10% additional and 24.8% and 23.8% in 1971 and 1972, respectively. Evidence that these figures are realistic was collected by Hisata (1972). On the basis of a creel census conducted on the Skokomish River in 1971, Hisata estimates a catch of 12,351 marked cutthroat during the latter part of May, June, and July from an initial plant in early May of 58,000 cutthroat smolts. Since almost half of the catch was recorded in July, long after the normal emigration period, the assumption that the total catch represented residual fish as a logical one. Fish were observed in the stream well into September, although estimated catch figures were not compiled after the end of July. The figure of 21.2% representing residualism, therefore, is significantly

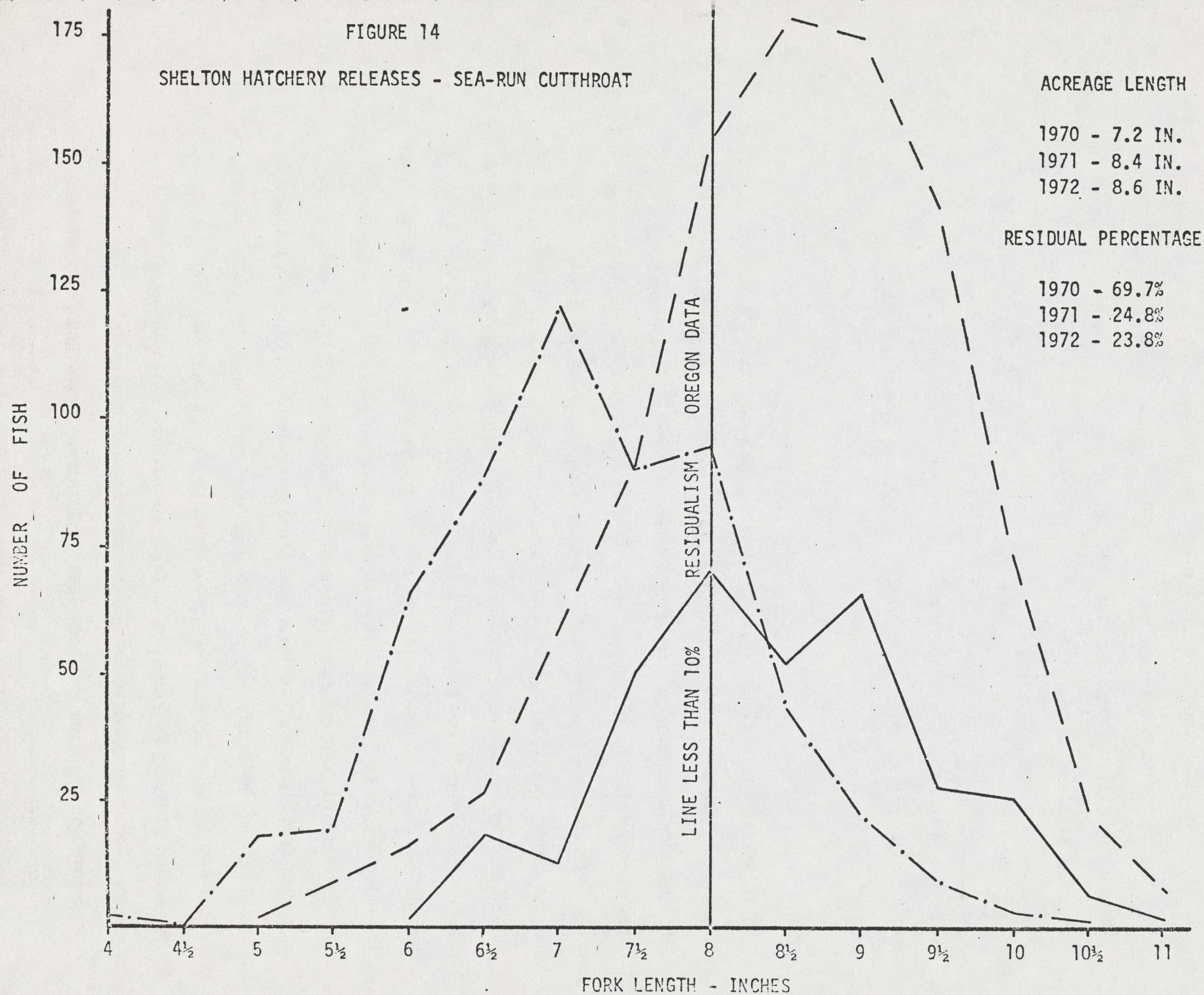


FIGURE 14
SHELTON HATCHERY RELEASES - SEA-RUN CUTTHROAT
ACREAGE LENGTH
1970 - 7.2 IN.
1971 - 8.4 IN.
1972 - 8.6 IN.
RESIDUAL PERCENTAGE
1970 - 69.7%
1971 - 24.8%
1972 - 23.8%
OREGON DATA
RESIDUALISM
LINE LESS THAN 10%
NUMBER OF FISH
175
150
125
100
75
50
25
4
4½
5
5½
6
6½
7
7½
8
8½
9
9½
10
10½
11
FORK LENGTH - INCHES

below the actual figure. A conclusion can be reached from these data which support Oregon's findings that smolts should be of a size approaching 3 to 4 fish per pound if residualism is to be kept to a minimum, even though it apparently cannot be eliminated entirely. Meeting this size specification is difficult, since the need for raising steelhead smolts to 6 fish per pound before release as yearlings cannot always be met by many of the existing hatchery rearing systems. Nevertheless, the program, to be successful in reducing extensive residualism and for producing maximum numbers of mature sea-runs, requires that the smolts released be of the size indicated.

Time of Smolt Release

It has already been established that the wild cutthroat migration from the stream coincides with that of the steelhead and coho except for an extention into June which is not the case with the latter two species as a normal case. However, the June migrations of cutthroat consist of the smaller fish which are mostly below 170 mm. in fork length hence presumably they do not leave the estuarial area of the stream during the following summer (Giger 1972).

Since the highest survival rates have been obtained from hatchery smolts of steelhead and coho released in late April and early May it would be assumed that similar timing in releasing sea-run cutthroat smolts would be most effective. Unfortunately, there are no good data available on April releases but May releases not only allow additional time for obtaining the required smolt size but emigration appears to be more rapid and adult survival rate is relatively high. Gufler (1967) released several lots of marked sea-run smolts above the downstream trap in Beaver Creek. No weights are given for the releases but those released in May migrated almost immediately while many of those released in March did not emigrate until May. Gufler commented that the "fish released in February and March and remaining in the creek until May were in very poor condition." Gufler's data is detailed in Table 26.

Giger (1970) commented as follows: "Data accumulated since 1966 show that maximal returns to river and estuary fisheries are obtained when fish are stocked in May several days prior to the angling season. Releases before or after this time (April data not available) result in drastically reduced spring harvests as well as slightly inferior tidewater returns. Average annual returns from May releases were more than twice those from March releases." In either case the returns appeared high. The mean March return was about 22% and for May it was approximately 46%. Survival of those fish entering the ocean was estimated to be 20 to 40 percent at times.

TABLE 26

Migrant Cutthroat Plants and Returns to the Downstream Trap During the Spring of 1967

Releases			Trap Returns			
Date	Number	Mark	Month	Ad LV	Ad LV UC	Ad LV LC
Feb. 28	1,000	Ad LV	Feb.	0	0	0
March 29	1,000	Ad LV UC	March	145	172	0
April	0		April	69	149	0
May 18	300	Ad LV LC	May	239	189	175
June	0		June	32	22	57
Totals	2,300			485	532	232
Percent Migration				48.5%	53.2%	77.3%

In conclusion, many of the March fish will remain in the stream until May, regardless of size, suffering at least in some cases, from insufficient food supply which can only result in a lowered survival rate. Releases should be in May to obtain maximum size before planting and the highest rate of survival.

Smolt Quality

Little can be added to the discussion of smolt quality of steelhead detailed on pages 97 to 101, all of which is applicable similarly to cutthroat. Residualism is far more prevalent in cutthroat than either winter or summer run steelhead and as stated earlier, size is a most critical factor in obtaining high survival.

In addition to steelhead smolts planted above the downstream trap at Beaver Creek, (See page 100) similar lots of cutthroat smolts were planted. In 1965, a total of 2,500 marked fish averaging six fish per pound were released above the trap on April 15. Only 50% or 1,254 fish were recovered and the emigration extended up to May 26 whereas the migration of winter steelhead smolts was over by May 8.

The disappearance of substantial numbers of both planted cutthroat and steelhead raises a serious procedural question and a specific research program should be directed towards understanding the underlying causes and eliminating them if possible. As stated earlier, if a 50% loss in fresh-water of all planted hatchery fish is the normal case, considerable effort is justified in an attempt to reduce this major obstacle to improving the benefits from hatchery operations.

Age and Size of Hatchery Adults

One of the major effects of a successful hatchery program on cutthroat is a reduction in the freshwater age from up to five years (Sumner 1962) to one year, provided the fish are large enough to eliminate major residualism either in the stream or in the estuary. Saltwater maturity under these circumstances occurs the year of migration, as is the case with wild fish, and repeat spawning each year thereafter appears to be the normal situation. No comparative data are available on the survival of hatchery and wild kelts. Gufler (1967) reported that "A total of 756 spawned out sea-run cutthroat (hatchery origin) were released approximately one mile above the downstream trap in late December and

January. They were recorded through the trap from eight hours to two months after release. The majority, however, migrated within a few days after release. A total of 443, or 58.6%, of the adult cutthroat were recorded through the trap from December 22, 1966 through May 7, 1967." In a similar experiment with unspawned steelhead, a total of 54% were recorded in the downstream trap from February to April, with most fish being trapped in March. Giger (1970) indicates that cutthroat probably have a higher post-spawning survival rate than do steelhead. Giger also states that "Angler tag returns revealed that hatchery stocks were two-and-one-half times more easily caught that wild fish, probably because of differences in feeding characteristics." Giger reports (verbal conservation) that "March releases tend to mature one week earlier than fish released in May."

Selection at the Beaver Creek hatchery of the early maturing adults for egg taking has resulted in maturation of the returning hatchery adult at least three weeks earlier than is the case with wild fish, and straying from home stream is so prevalent that true survival rates are most difficult to obtain. Giger (1967) reports that "Over 38% of the Alsea catch of 1966 releases were fish released in the Siuslaw system, 35 miles to the south. Conversely, Alsea releases taken in the Siuslaw totaled only six percent of the catch of 1966 releases. This greater northward movement of released fish bears further observation."

Watson and Hoffman(1968) released 10,000 tagged cutthroat eight to nine inches in length in North River on May 8, 1968. Tagged fish were recovered in the same year from three streams tributary to Grays Harbor; from North River and three other tributaries of Willapa Harbor; from the Columbia River and Cowlitz River and also from Necanicum River on the Oregon coast. Hattrick, superintendent of the Beaver Creek hatchery on the Elochoman River, reports verbally that he estimates from marking experiments that straying of cutthroat planted in the

Elochoman System amounts to at least 30% being mainly to the tributaries of the Columbia River below Bonneville Dam.

As stated earlier, accurate survival statistics on adult hatchery cutthroat are difficult to obtain. Estimated catches, based on a detailed survey of the sport fishery in Hood Canal, are disappointingly small considering the size of the planting program: 146,000 in 1970 and 174,000 in 1971. Only 645 fish, or less than half of one percent, were estimated as being caught between August 1 and October 31, 1970. Few adults were observed returning to the planted streams in the fall. In contrast, Oregon's data discussed earlier show very satisfactory survival rates, indicating that many of the cutthroat planted in Hood Canal streams are either not migrating, straying from the area, or conditions are not satisfactory for marine survival of hatchery fish. Although the average size of the smolts planted was below the specification for avoiding excessive residualism, the quality of the fish appeared to be excellent. It is interesting to note that more than twice as many fish were recovered in saltwater from a release of 15,000 marked fish in the Potlatch tailrace of the Skokomish River power plant, which discharges directly into Hood Canal, than were recovered in saltwater from 58,000 fish planted in the Skokomish River. Cutthroat smolts have been planted also in the Deschutes, Samish, and Stillaguamish Rivers, with similar poor survival of sea-run adults. While survival observations leave much to be desired, these observations indicate such a poor return of adults that the program can be considered a failure, other than possibly at the Beaver Creek hatchery, located on the Elochoman River system.

Hisata (1972), in reporting a catch of 12,351 residuals in the Skokomish River from May 23 through July of 1971 from a plant of 58,000 smolts averaging 8.2 inches in fork length, has demonstrated that this program provides an excellent basis for a stream-catchable program superior to rainbow trout, which soon disappear from the stream. Hisata observed the presence of residual cutthroat throughout the summer and into the fall months, although no catch records were collected after July 31, when 21.2% of the total plant had been caught.

In view of the great sport fishing value of an adult sea-run population, whether in salt water or in streams, and the epicurean quality of the maturing fish, a duplication of Oregon's success on their coastal rivers is highly desirable. Unfortunately, this is not the case in Puget Sound to date and present operations in Washington need careful reassessment.

Several observations are made in connection with a needed reassessment of the department's sea-run cutthroat program. Adequate survival data have not been collected for the Beaver Creek hatchery program, and these data are essential to the proper evaluation of the operation. An extensive fishery exists throughout the lower Columbia River and its tributaries and to a lesser extent in the ocean off the mouth of the Columbia River. In view of the widespread straying of Beaver Creek cutthroat after planting and return as adults and as high was 4.2% adult return to the Beaver Creek trap, it is suggested that a survival estimate be made using a combination of tagged releases selected for size, and creel sampling over the expected distribution of maturing fish. Release of tagged groups should be in May and preferably just before the stream fishing season opens, since these criteria appear to relate to a high survival rate both in Oregon and at the Beaver Creek hatchery. The size selected should represent average release size in past years and also a group averaging three to four fish per pound, having a nine inch average fork length, with fish less than eight inches eliminated. This would provide data for the first time in Washington similar to that obtained for Oregon waters. It appears probable that attention to size of release at Beaver Creek will justify the operation, provided an adequate sampling of the potential area of recovery is made.

While the size of fish released under the Hood Canal program is not up to specifications needed to reduce residualism to a minimum, it was sufficiently close in 1971 and 1972 to warrant a much higher catch in saltwater during the summer months, when wild maturing sea-runs are available along the beaches throughout Puget Sound.

It would appear with the increased fish size (8.6") of the 1972 release of cutthroat into Hood Canal, that a final assessment can be made of the practicality of the operation. Since 10,000 of 92,000 smolts released were tagged, instead of marked, improved recoveries representing any straying should be available. Unfortunately, the tagged fish were not selected for size and represent the size range of the total group rather than fish over 8 inches and averaging 9 inches fork length. If the recovery of tagged fish in Hood Canal and possibly elsewhere during the summer of 1972 does not indicate a substantial increase in availability to the sportsmen, the present program should be redesigned or abandoned.

One possible alternative to the present program might be to develop a brood stock from fish of Puget Sound origin. The present hatchery stock originated primarily from wild Alsea sea-run cutthroat which are now held as brood stock throughout their life, with some wild fish being added periodically. Fish used in the Hood Canal program originated from Oregon brood stock now developed into a local brood stock held at the Elochoman hatchery. Returning adults to the Beaver Creek hatchery are mixed with the captive stock but are in the minority. In the past, wild adults from the Toutle and Nemah rivers have been added but essentially all adults have originated from coastal areas having relatively large estuarial areas which are not duplicated in Puget Sound.

It would seem logical that a brood stock be developed using wild adults returning to Puget Sound streams which have a different environmental relationship between fresh and saltwater. With Beaver Creek eggs taken from brood stock originating from the Alsea river in Oregon, hatched at the Aberdeen hatchery on Grays Harbor and reared at the Shelton hatchery on Hood Canal conceivably a tendency towards increased residualism could exist. The latter has merit as a source of non-migrating stock for stream fishermen but to date has not provided sufficient numbers of fish available in saltwater to justify that part of the operation. It is interesting to note that while few maturing adults appear to be available in Hood Canal, the Beaver Creek program located on a coastal stream may be an economic success once straying is measured and the size of fish released is increased to an acceptable level.

The extensive residualism resulting in the hatchery program for sea-run cutthroat means that this operation can contribute heavily to inter- and intra-specific competition in fresh-water unless particular emphasis is laid on a harvest program. The advantage of the Oregon program of planting large-size fish two or three days before the trout season opens permits a substantial protected emigration to the estuary and the high seas. The opening of the trout season shortly after planting time allows the needed elimination of both residual cutthroat and steelhead thus providing short-term recreation and more favorable conditions for the survival of the incoming year class of naturally produced fish of both species.

Relationship of Hatchery Cutthroat to Wild Cutthroat

The tendency of hatchery-reared cutthroat to residualize after planting is usually much greater than that of steelhead. The pressure of hatchery fish remaining in the stream could create serious intra-specific competition on the wild cutthroat stocks if the two stocks are in residence in the same area. However, as noted on page 58, a major downstream migration of cutthroat from headwater areas in the fall months and an upstream migration in the early summer apparently does not occur, hence wild cutthroat maintaining their stream residence in the upper watershed on a year around basis would not undergo a population adjustment based on the carrying capacity of the lower river during the winter months. Therefore it would appear that hatchery-reared cutthroat residualizing in the lower river would not be competitive with a major portion of the wild cutthroat population.

The development of a stream catchable program using cutthroat during the summer months would probably create some interspecific competition with naturally producing salmonids, particularly juveniles of the incoming year classes of steelhead, coho, and chinook. This question should be resolved by detailed observation before embarking on an extensive planting program of residualizing cutthroat in streams containing a wild population of anadromous salmonids other than cutthroat. In this regard, the Oregon coastal program of planting large-size sea-run smolts just before the opening of the trout season in late May appears to have considerable merit. As mentioned previously, good fishing is provided by the program for a week or two, while at the same time potential competitors are eliminated and the stream left in a favorable rearing condition for other salmonids. Summer and early fall fishing for maturing adults is provided in the estuary and in the lower stream, leaving the bulk of the watershed available for the natural reporduction of salmonids. However, before the Oregon coastal program can be accepted for Washington streams, the problems of eliminating major residualism and obtaining improved marine survival must be solved.

Coho Salmon

The hatchery program involving this species is probably the most extensive of its kind in the world and has been eminently successful in returning adult fish. Much of this success relates to the life history of the coho. The wild juveniles emigrate as smolts at the end of one year, hence, the rearing system is not taxed to produce larger smolts than those produced naturally. The need for producing steelhead or cutthroat smolts in the hatchery in one year which are larger than wild smolts two or more years of age, creates a most difficult problem involving the adult survival rate of the latter two species.

Ample evidence is available to indicate substantial increases in the recent annual runs of coho resulting from the State's smolt rearing program. Senn and Satterthwaite (1971), reporting on the results of marking 1,455,000 smolts at 13 stations, state that "The total survival to adults ranged from 0.7% to 8.2% between stations" and that "the average benefit cost ratio approximated 2.5:1."

The stream rearing habits of the coho are quite similar to those of anadromous trout, hence, current stocking policies, which include advanced fry and fingerlings can easily create dangerous inter- and intraspecific competition. In view of the facts detailed earlier (Noble, 1972, Fraser, 1969, Vincent, 1972, Salo and Bayliff, 1958, Smoker, 1955 and 1956), any planting of pre-smolt coho in most streams can be expected to have a negative influence on the natural production of all stream rearing salmonids. Planting of pre-smolt coho imposes a surplus demand on the available food supply of the waters immediately affected. Furthermore, the fall emigration of juveniles from the headwater areas including those surviving from plants in "barren" areas located in the colder areas, adds an additional load on streams during the winter months when a major adjustment in population size apparently takes place.

The need for grading out culls, taking surplus eggs as insurance against unexpected disasters in the over-all hatchery program, and the false impression that "barren waters" created by obstructions to the upstream migration of adults represent potential productive rearing areas all lead to the planting of pre-smolt coho. The evidence is clear that such a practice can be extremely detrimental to the maintenance of the wild population of all species involved. The importance of eliminating this practice is emphasized by the record of plantings from State salmon hatcheries in western Washington over the past six years as detailed in Table 27. (Annual Reports, State Fisheries Department).

TABLE 27

Plantings of Hatchery Produced Coho in Western Washington

YEAR	1966	1967	1968	1969	1970	1971
Fry (Reared up to 15 Days)	4,234,000	4,724,000	3,790,000	9,805,000	8,444,000	20,245,000
Fingerlings (Pre-smolts)	2,578,000	3,835,000	2,142,000	1,430,000	3,236,000	15,949,000
Yearlings (Smolts)	20,855,000	20,793,000	19,744,000	29,664,000	31,185,000	33,844,000
TOTAL	27,667,000	29,352,000	25,856,000	40,899,000	42,865,000	69,583,000

Apparently no evidence is available to justify the "barren area" program involving a great increase in fry and fingerling plants of hatchery coho in 1971. On the basis of the available information, this program is illogical and would tend to destroy the natural reproduction of all stream rearing salmonids. It is most important that an agreement be reached among all agencies concerned that the principle of hatchery operation as evolved by Wagner (1967) be accepted and carefully adhered to (see page 88). The populations of all wild salmonids in specific streams should be enumerated before and after the inauguration of Wagner's operational principle to ascertain if any increase occurs as indicated by Vincent (1972).

Evidence that homing of hatchery coho to the planting area is most precise has been presented by many investigators and is generally accepted fact. The homing of adults from hatchery smolt coho plantings, like steelhead, has a value to management in that surplus hatchery smolts can be planted in streams having the greatest public interest.

While the planting of pre-smolt coho has the same deleterious effect as undersized or residualized steelhead and cutthroat on the stream ecology, few hatchery coho smolts ever residualize, as is the case with the two species of trout. An interesting side effect of the successful coho hatchery program lies in the gradual disappearance of the maturing population remaining in Puget Sound. These "homesteading" fish provided a major sport fishery during the winter, spring, and summer of their maturing year. The factors contributing to the disappearance of these fish is not clear. It appears that the hatchery smolts, being larger than wild ones, proceed to the open ocean and do not homestead. There are informed theories that the homesteaders originated either from the smaller wild fish emigrating at the end of the season in late May of from particular streams which have declining populations of coho because of deteriorating environment. In either case, it is probable that wild fish production has suffered from fry or pre-smolt plants of hatchery fish. In fact, very little is known about the status of wild coho stocks in western Washington, it being probable that they have declined substantially in numbers due to the planting program involving pre-smolts of coho and chinook and, to some extent, of undersized anadromous trout. The development of new policies governing the planting of hatchery salmonids might aid in the restoration of the homesteading population as well as providing an increase in the number of adult coho returning each year from natural reproduction.

Chinook

Lack of knowledge on the fresh water life history of spring chinook makes it difficult to assess the effect of fish cultural operations on the life history of naturally reproducing fish.

Circumstantial evidence indicates that release size of hatchery fish should be ten fish per pound and preferrably much larger to obtain maximum survival, although survival of hatchery spring chinook juveniles has not been particularly promising in past years. In fact, most operations have been an economic failure and have failed to substantially increase the runs. However, an estimated adult survival of 5 to 11 percent of individual plants in southern Oregon streams indicates the possibility of designing an equally successful hatchery program with this stock as has been obtained with steelhead and coho. Data supporting this conclusion are available from the Wind River Hatchery operated by the U.S. Bureau of Sports Fish and Wildlife on upper Wind River where a native spring chinook run did not exist. In 1962, 610 adults returned to the river from an initial plant of 1,250,000 juveniles weighing 32 fish per pound. In 1971, the return escapement totaled 9,348 adults from a plant in late April of 1,600,000 yearlings averaging 21 fish per pound. Preliminary estimates of adult escapement in 1972 total over 10,000 fish from a late April plant of 757,000 yearling juveniles weighing 16 fish per pound.

It is imperative that the required operational procedures consistent with the natural life history be defined. As with all species considered to date, it is obvious that hatchery fish must be larger than the wild equivalent. In fact, the positive difference in size required for good survival of spring chinook juveniles may be greater than for steelhead and coho. The reason for this is not clear but pending an understanding of the size need of spring chinook juveniles, the return figures speak for themselves.

Figure 15, from data furnished by the Oregon Fish Commission indicates a positive correlation between size and adult survival, although most of the fish released do not approach the size of ten fish per pound or larger, now considered to be optimum. Figure 16, also from Oregon Fish Commission data, shows a positive relationship between growth of juveniles and adult survival rate.

With controlled temperature regimes and high protein diets, fish larger than ten fish per pound can be produced by the fall of the first rearing year. This has led in recent years to fall releases on the Willamette, and other Columbia River tributaries and a relatively high survival rate has been obtained, although no published information is available to indicate when the fall released fish actually enter the sea. Conceivably, these fish merely go downstream into the lower Columbia River, where low water temperatures and a minimum food demand during the winter months permits a high survival rate of a limited number of fish until the following spring, when the fish may enter their marine existence. The observed migration of wild spring chinook as yearlings in the spring of the year after a previous fall emigration from the colder spawining tributaries would indicate that a possible layover in the lower Columbia River would occur in the case of fall plants. If the winter delay in emigration from fresh water actually happens in the case of fall releases regardless of fish size, the planting of increased numbers of hatchery fish could eventually tax the food supply in the estuary, with a negative effect on survival. McConnell and Snyder (1970) in an unpublished manuscript tend to confirm the above discussion. These authors state "In September, 1969, marked fall and spring chinook were

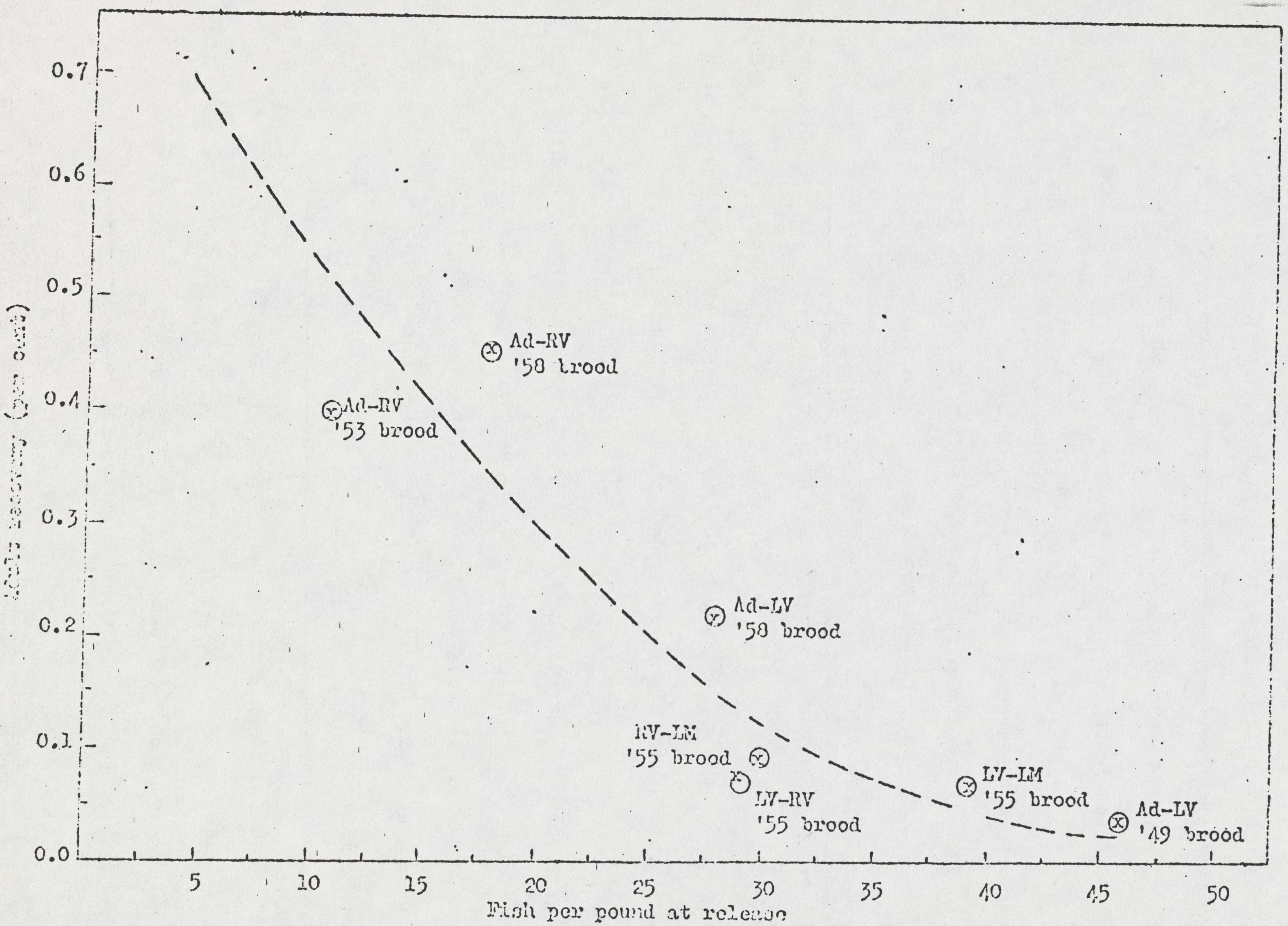


Figure 15 Per cent recovery of adult spring chinook at Willamette Hatchery, relative to their size at release

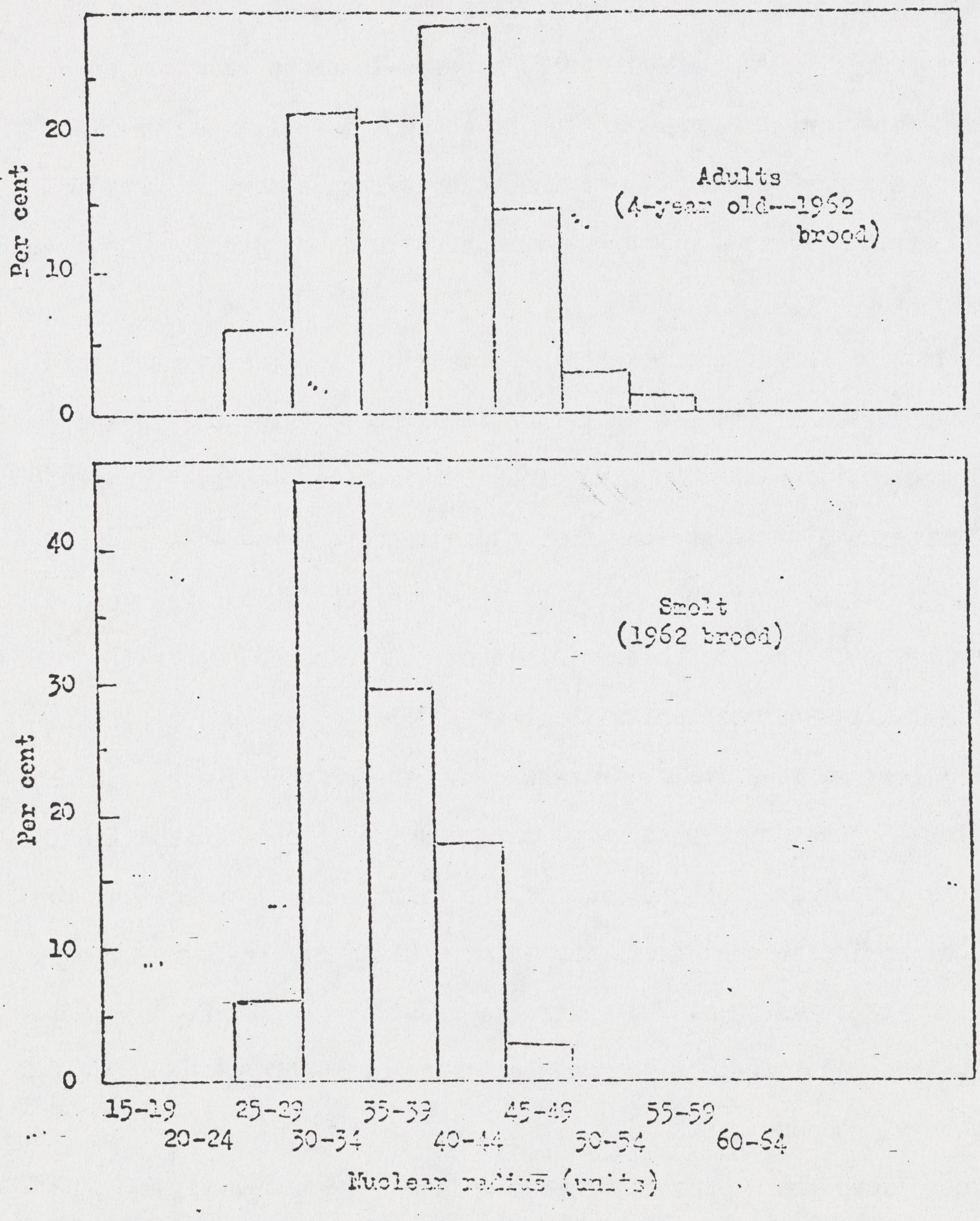


Figure 16 Comparison of the nuclear radius of juvenile and adult scales, Willamette Hatchery

released into the Cowlitz River and entered the Columbia River (at RM 68) during conditions of low flow. Marked fish from both groups moved upstream and were captured in the Columbia River at the four beach seine sampling stations between river-mile 70 and river-mile 78. They were taken throughout the winter from October 1969 to May 1970." At present, there appears to be no research program directed toward defining what happens to spring chinook juveniles emigrating from the tributary streams in the fall of the year, although survival studies between fall and spring releases of large-size juveniles are currently underway in both Washington and Oregon.

Oregon research on spring chinook has resulted in a conclusion that the influence of size at time of release on the ratio of age classes or average weight of returning adults cannot be predicted at this time. However, there is an indication that smaller fish tend to produce more five-year-olds adults than large fish, the latter returning a substantial number of four-year-old adults. Further research should substantiate the latter, since such a finding would be consistent with what happens with other species of salmonids. If small fish have a poor survival rate, increased numbers of four-year-old adults may be an inevitable result of a successful hatchery operation. In addition, field observations reveal that as the size of the fish released increases, the number of residual spring chinook jacks increases. These fish mature in fresh water at one year of age and should be caught as trout since they are of no value otherwise, and tend to reduce the rearing capacity for the incoming year classes of naturally produced salmonids.

It can be concluded that current information on hatchery operations involving spring chinook leaves much to be desired if a successful hatchery program is to be evolved. Additional information is needed also to guarantee that inter- and intra-specific competition resulting from hatchery operations is eliminated, or at least minimized both in fresh water and the estuary.

The natural life history of the fall chinook has been confused by aberrant reactions of young fish to devious hatchery practices. It appears probable that young of the year of this species in the State of Washington migrate to the estuary mostly before the end of May where they delay varying periods of time before entering their truly marine existence (Salo, 1969). However, current sampling operations by the Washington Department of Fisheries reportedly indicate that naturally produced fall chinook are present in substantial numbers in the stream until July. Thus, true emigration time is rather confused. Sims (unpublished data) reports that 75 mm. fork length apparently is a size selective factor for appearance of fall chinook juveniles in the Columbia River estuary. Fish under that size apparently remain upstream regardless of time until that average size is attained. Swartz (1971) concluded from rather voluminous data collected from fall chinook releases in Oregon that "Analysis of release and recovery data indicates that prolonged rearing to achieve a larger smolt size has failed to increase survival. In fact, the data suggest a definite decrease in survival for fish released after mid-May (20 weeks rearing period) regardless of smolt size." Over a period of several decades numerous marking experiments have been carried out by Northwest fish cultural agencies to determine optimum survival in relation to time of release but the results have been largely ignored. The same experiments are still being continued in search of some Utopian operation whereby maximum survival can be otained without regard to the inherited reactions of the stock. Oregon's data not only is quite conclusive but shows that if fall chinook releases are to depart from fresh water immediately and thus eliminate stream competition, they should be 100 fish per pound or larger and released not later than late May. Perhaps, this is not entirely consistent with the natural life history of the fish, but it appears synonomous with a sound hatchery practice.

The best returns from Green River fall chinook planted in many streams flowing into Puget Sound are obtained from planting juveniles of the year before the latter part of May of a size not smaller than 100 fish per pound. Later plants tend to stay in fresh water until the following spring when they migrate as yearlings in greatly reduced numbers often lower than 5% of the original number planted. During the interim the food supply of the stream is overtaxed with a probable negative effect on the overall natural production of salmonids.

The residualizing of fall chinook caused by aberrant reactions to illogical planting policies was observed by the writer in the Toutle River in 1971. Similar observations were made by Reimers and Loeffel (1967) who noted that hatchery fish weighing 217 to 366 fish per pound had been planted in the Toutle, Kalama, Washougal and Lewis Rivers which was associated with the presence of residuals throughout the following summer. These authors concluded that "Should natural production of salmonids in the Toutle River be sufficient to utilize the stream's productive ability then hatchery releases in June may not be adding to this system's net salmon production (or anadromous trout production - Ed.). The Washougal, Kalama and Lewis Rivers could have similar situations."

Current data are quite conclusive on how hatchery practices should coincide with the natural life history of fall chinook. The one experiment, holding some promise, is the rearing of juveniles for one full year and releasing the fish in late April or early May which is the natural time for the fish to emigrate. Such an experiment could result in good survival but the economics of the operation may be in doubt except in special cases because of the high growth rate and related food demand of the fish being held for a full year beyond the normal time of downstream migration. The apparent natural delay of fall chinook juveniles in the estuary raises a serious question as to the ability of that area to serve as a feeding reservoir for large releases of hatchery juveniles augmented by releases of other salmonids such as sea run cutthroat. Perhaps the rearing of juveniles for one full year might eliminate the delay but no evidence is available as yet to support such a theory. Ellis and Royal (unpublished data) reared fall chinook in the late 1930's at several Puget Sound hatcheries for release in the fall and later as yearlings the following spring. Diets were unsatisfactory at that time for such an operation, but of those fish released in the fall few fish returned. Spring yearling releases survived much better but significant numbers of precocious males returned the following fall and some individuals had never left fresh water.

There are no published data available which clearly illustrate the effect of fish cultural operations on the age of maturity of returning fall chinook adults. It is believed generally that larger numbers of males mature as two and three-year-olds than is the case with naturally produced fish and more three-year-old females as well even though the juveniles are released after a relatively short rearing period of a few months. No comparative data is available for reference to clearly identify a difference although evidence on other species would support such a conclusion. Cleaver (1969) discussed Rich's data (1925, Table 9) which indicated that adult Columbia River fall chinook in 1919-20 were mainly in their fourth and fifth year. Current data show these fish to be mostly two, three and four years of age. Cleaver suggested several possibilities for the change in age distribution, one of which was a greatly increased ocean fishery on immature fish; he also mentioned that "it is reasonable to believe that conditions for reproduction (hatcheries) may have been selective for a genetic shift towards earlier maturity."

Rose and Arp (1970) analyzed the contribution of twelve Columbia River hatcheries to the harvest of 1962 brood fall chinook. They concluded that the benefit-to-cost ratio was 1.3:1. Arp, Rose and Olhausen (1970, 1972) made a similar study of the 1963 and 1964 brood years and calculated benefit-to-cost ratios of 4.1:1 and 2.2:1 respectively. It appears obvious, regardless of variable procedures between individual hatcheries, that the total operation is an economic success. With gradual elimination of reduced survival rates due to hatchery design limitations, the economic stature of fish cultural operations on fall chinook can be increased and intra- and interspecific competition phased out accordingly. Probably, the most important facet in the relationship of current fish cultural operations on fall chinook to the problems of serious inter-specific competition is the fact that 84,000,000 fingerlings and 11,000,000 advanced fry were planted by the State in 1971. Table 28 illustrates the increasing number of fall chinook planted in Washington streams between 1966 and 1971. A substantial share of these fish were either fry, below size requirements, or were planted late in the season thus becoming involved in the freshwater food chain which would be fully taxed by naturally reproducing salmonids. Only negative effects on salmonid production can result from such a situation which conflicts with Wagner's philosophy of using the stream solely as a highway to the sea for all hatchery releases.

TABLE 28

Plantings of Hatchery Produced Fall Chinook

Year	1966	1967	1968	1969	1970	1971
Fry (Reared up to 15 days	2,561,000	8,594,000	3,600,000	6,588,000	2,082,000	11,000,000
Fingerlings: Pre smolts & smolts	52,227,000	46,590,000	59,114,000	64,355,000	71,576,000	84,000,000
Total	54,788,000	55,184,000	62,714,000	70,943,000	73,658,000	95,000,000

SUMMARY DISCUSSION

The foregoing has detailed available facts related to the ecology of the salmonid complex, examined the functioning of fish cultural operations on each of the stream rearing salmonids and outlined obvious conflicts which could restrict the benefits both total and specific. The important question, yet unanswered, is whether or not limits are appearing in the benefits being derived from expanding fish cultural operations which in turn may be related to either the ecology of the stream, the estuary, or the marine habitat consisting principally of the inland sea, or all of these areas combined. This question will be examined as it may affect the individual species of anadromous trout. However, as stated on page 4 "current methods and practices involved in the management of all anadromous populations, salmon as well as trout, must be considered to determine if they are consistent with the need for protecting and increasing the production of all species".

Winter Steelhead

The numerous variables known to be involved in year to year fluctuations of winter steelhead catch by rivers and also the total catch makes it necessary to select those statistics which appear to show time trends in productivity. The many individual examples of initial success in increasing the winter steelhead runs in the major river systems of Western Washington, which have been duplicated in Western Oregon, are a matter of record and need no further clarification or detailed presentation here. However, with the existence of a fully developed fishery for the past ten years and the catch representing the approximate run size we can now examine the apparent effect on total catch of a rapidly increasing fish cultural operation. Table 29 shows the annual plantings of winter steelhead smolts averaging 10 fish per pound and larger compared with the annual catch two years later when the dominant aged adult population returns.

The data in Table 29 present striking evidence that planting increased numbers of winter steelhead smolts in recent years has not increased the number of returning adults. In view of earlier success in obtaining recorded individual smolt to adult survival rates up to 12.7%, the negligible increase in the number of adults returning from an increase of 43% in the annual number of smolts planted over the past five years required careful examination. Obviously, something has happened which has nullified the effect of the expanded program. In fact, an unbiased examination of the data in depth indicates the possibility of a modest decline in total annual production even though the exaggerated negative survival rate in the 1970 return is eliminated from consideration.

It can be observed from a study of the catch from individual rivers that year to year fluctuations in catch are not always consistent with those of the

TABLE 29

Year	*No. of Smolts Planted	Year	No. of Adults Caught	Smolt to Adult Ratio
1960	1,288,000	1962	193,300	6.66
1961	1,370,000	1963	198,300	6.90
1962	1,529,000	1964	237,750	6.43
1963	1,464,000	1965	174,175	8.40
1964	1,776,000	1966	249,077	7.13
Annual Average	1,485,000		210,520	7.05
1965	1,717,000	1967	225,850	7.60
1966	1,993,000	1968	226,100	8.81
1967	1,767,000	1969	207,250	8.52
1969**	2,866,000	1971	215,040	13.42
1970	2,906,000	1972	(200,000)***	14.53
Annual Average	2,250,000 - 43% increase		216,850 - 3.00% increase	10.37

* Only fish 10 per pound or larger listed

** 1968 planting and 1970 adult return eliminated since it was an aberrant survival year for both hatchery and wild fish

*** Estimated catch

total catch, yet it is the overall results of the program that must be examined primarily to determine the benefits or lack of benefits derived. If factors are to be isolated which may be responsible for variable rates of told survival it becomes important to separate a single stream, if possible, which reflects the variation in the total catch. Using the local environmental data available for such a stream, natural influences and their effect can be isolated to determine if negative environmental trends are currently operative rather than survival limits related to expanded fish cultural operations. Green River, usually the second largest winter steelhead producer in the state provides such a study area. Figure 17 illustrates the close relationship of the annual catch of steelhead in this stream with that of the total catch.

Considering the inherent weakness of the punch card system as applied to individual rivers, which was discussed earlier (page 23), the indicated consistent relationship of the catch of winter steelhead in Green River to that of the State total is most fortunate.

Table 30 lists the annual smolt plants in Green River, the annual catch two years later and the gross relationship of the two in terms of the number of smolts planted for each steelhead caught (1968 plant and 1970 catch eliminated). While an unknown number of wild smolts exist each year and the surviving adults are included in the catch, it does not appear that exclusion of this unknown factor will affect the conclusions drawn from the known data.

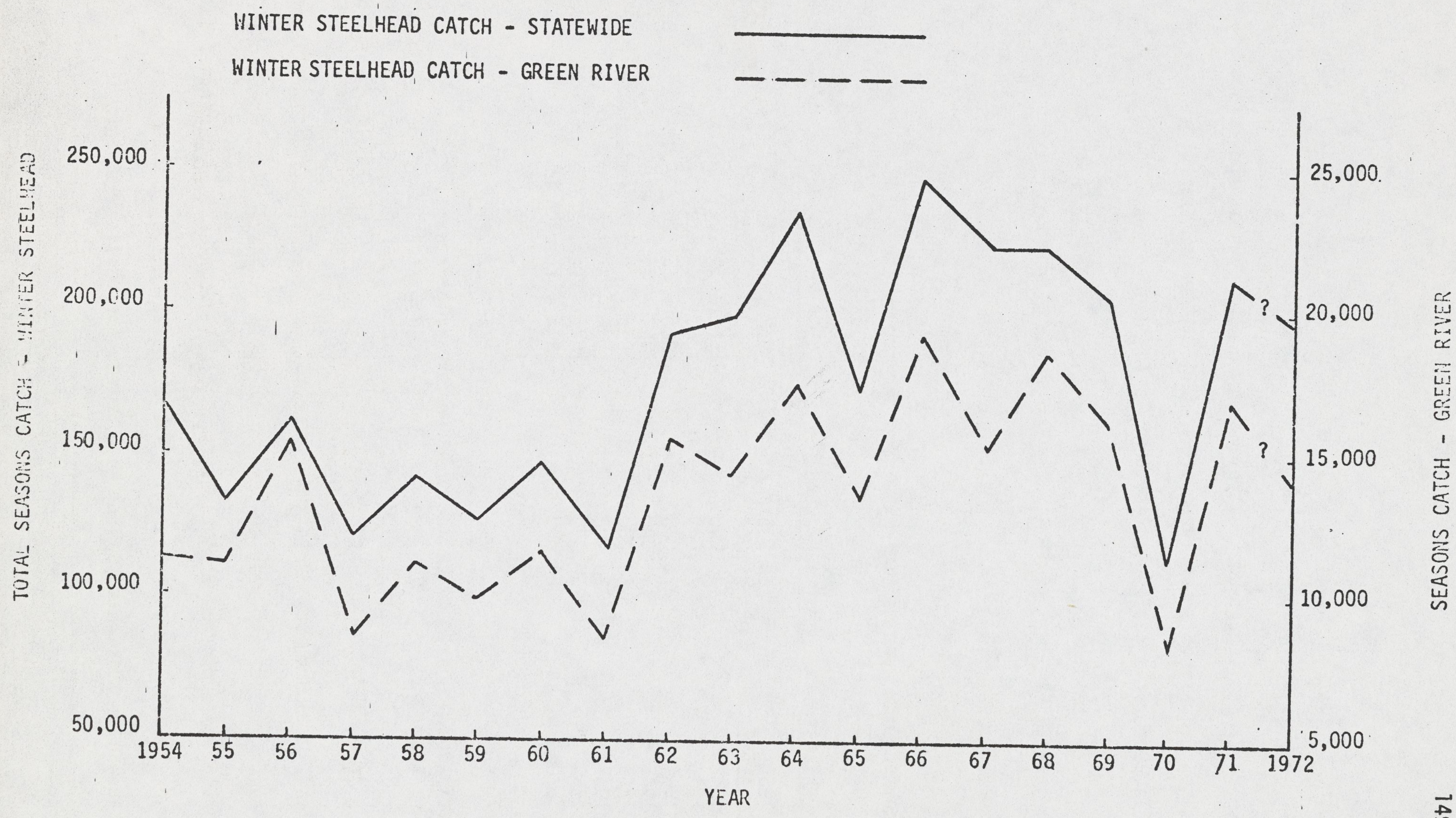
TABLE 30

Year Planted	Smolts Planted	Catch 2 years later	Smolts to Adult Ratio
1960	70,000	1962 - 15,700	4.45
1961	70,000	1963 - 14,664	4.77
1962	54,000	1964 - 17,484	3.08
1963	90,000	1965 - 13,613	6.61
1964	95,000	1966 - 19,468	4.88
1965	67,000	1967 - 15,271	4.39
1966	79,000	1968 - 18,906	4.18
1967	86,000	1969 - 15,998	5.38
1969	155,000	1971 - 17,303	8.96
1970	112,000	1972 - 14,000*	8.00

* Estimated on basis of catch for November and December, 1971

A study of the data in Tables 29 and 30 leads to two specific points of interest. One observation is that the total Green River catch does not vary to a major extent from year to year which could indicate a density barrier to population expansion that tends to mask all other variables related to survival. If true, this is a most frustrating influence in meeting the demands for increasing the winter steelhead population. Unless the density barrier, if it exists

FIGURE 17



WINTER STEELHEAD CATCH - STATEWIDE
WINTER STEELHEAD CATCH - GREEN RIVER
TOTAL SEASONS CATCH - WINTER STEELHEAD
250,000
200,000
150,000
100,000
50,000
SEASONS CATCH - GREEN RIVER
25,000
20,000
15,000
10,000
5,000
1954
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
1972
YEAR
?
?

as indicated, can be eliminated all benefits from further expansion and improvement of fish cultural operations will be nullified. It is interesting to note also that with increased smolt plants in Green River as shown in Table 30, adult production has not increased -- a situation similar to that shown in Table 29 for the total plant-catch relationship.

Major examples of a declining survival rate, apparently related to increased plants, are shown in Table 31.

TABLE 31

Skagit River

Year Planted	Smolts Planted	Catch 2 Years Later	Smolt-to-Adult Ratio
1960	80,000	1962 - 18,541	4.31
1961	83,000	1963 - 21,420	3.87
1962	133,000	1964 - 34,900	3.81
1963	74,000	1965 - 20,829	3.55
1964	224,000	1966 - 26,683	8.39
1965	144,000	1967 - 24,833	5.79
1966	175,000	1968 - 31,524	5.55
1967	128,000	1969 - 21,958	5.82
1969	269,000	1971 - 17,303	15.54
1970	224,000	1972 - 17,000*	13.17

North Fork Stillaguamish River

Year Planted	Smolts Planted	Catch 2 Years Later	Smolt-to-Adult Ratio
1960	34,000	1962 - 4,974	6.83
1961	39,000	1963 - 4,815	8.09
1962	41,000	1964 - 6,786	6.04
1963	40,000	1965 - 6,098	6.55
1964	55,000	1966 - 7,844	7.01
1965	70,000	1967 - 7,814	8.95
1966	68,000	1968 - 7,631	8.91
1967	61,000	1969 - 4,011	15.20
1969	67,000	1971 - 4,745	14.12
1970	71,000	1972 - 3,458*	20.53

Skykomish River

Year Planted	Smolts Planted	Catch 2 Years Later	Smolt-to-Adult Ratio
1960	29,000	1962 - 8,754	3.31
1961	33,000	1963 - 8,450	3.90
1962	41,000	1964 - 10,131	4.04
1963	37,000	1965 - 8,031	4.60
1964	49,000	1966 - 10,834	4.52
1965	65,000	1967 - 12,155	5.34
1966	58,000	1968 - 9,531	6.08
1967	55,000	1969 - 7,586	7.25
1969	100,000	1971 - 6,849	14.60
1970	60,000	1972 - 11,746*	5.10

* Estimated on basis of catch for November and December 1971

There are certain river systems where the annual catch is apparently correlated with the number of fish planted. Each of these examples appears representative of short-run streams of moderate-to-small size. The Lyre and Samish Rivers are characteristic and the data are listed in Table 32. The value of the planting program in the Lyre River is emphasized by the fact that the average annual catch was 265 winter steelhead for four years prior to planting and an average of 1,622 for four years after about 10,000 smolts were planted each year, a five-fold increase.

TABLE 32

Lyre River

Year Planted	Smolts Planted	Catch 2 Years Later	Smolt-to-Adult Ratio
1960	10,000	1962 - 1,615	6.19
1961	10,000	1963 - 1,667	5.99
1962	10,000	1964 - 1,577	6.34
1963	13,000	1965 - 1,629	7.98
1964	20,000	1966 - 2,543	7.86
1965	15,000	1967 - 1,435	10.45
1966	25,000	1968 - 2,521	9.91
1967	14,000	1969 - 1,960	7.14
1969	21,000	1971 - 2,336	8.98
1970	15,000	1972 - 1,800*	8.30

Samish River

Year Planted	Smolts Planted	Catch 2 Years Later	Smolt-to-Adult Ratio
1960	43,000	1962 - 3,493	12.31
1961	49,000	1963 - 3,723	13.16
1962	42,000	1964 - 3,538	11.87
1963	53,000	1965 - 2,630	20.15
1964	56,000	1966 - 4,121	13.58
1965	57,000	1967 - 5,684	10.02
1966	53,000	1968 - 4,492	11.80
1967	39,000	1969 - 4,358	8.94
1969	55,000	1971 - 4,735	11.61
1970	63,000	1972 - 4,350*	14.50

* Estimated on basis of catch for November and December 1971

In spite of a general decline in survival rate from increased plantings in certain major rivers the past few years, initial plantings of relatively small size in the Elwha River have shown substantial adult returns in recent years. This is consistant with the results from initial plants of winter steelhead smolts in earlier years in most of the major rivers of the state. Table 33 details the operations in this watershed. Like the Lyre and Samish Rivers, all plantings, of necessity, must be made near the mouth of the river because of a high hydro-electric facility located about five miles upstream.

TABLE 33

Elwha River Plants vs. Adult Returns

Year Planted	Smolts Planted	Catch 2 Years Later	Smolt-to-Adult Ratio
1963	0	1965 - 1,298	0
1964	0	1966 - 1,652	0
1965	24,000	1967 - 1,405	17.10
1966	15,000	1968 - 1,551	9.67
1967	15,000	1969 - 2,590	5.80
1969	20,000	1971 - 3,269	6.10
1970	15,000	1972 - 3,400	4.41

There is no question that quality, size, and time of fish releases are important factors in laying the foundation for maximum survival of hatchery salmonids. The importance of these factors has been discussed previously and demonstrated many times in the past in the struggle to increase the benefits from hatchery operations to meet the public demand. All of the problems raised by aberrant hatchery practices and their negative effect on both natural reproduction and the survival ratio of hatchery releases are not in dispute. The serious question remaining is the possibility of a density barrier, as indicated in Tables 29 and 30, which is difficult to comprehend in a logical sequence. If it exists with steelhead, it should eventually be created and affect each of the other stream rearing salmonids as a particular adult population increases. Will such a barrier be related to the natural productivity of the individual species for each stream, or could it be directly related to the ability to survive interspecific competition for food and a possible density factor during seaward migration, even though the time factor might be of short duration before the fish enter their marine existence?

Lacking suitable data, any discussion of the possible cause or causes for the indicated limit on steelhead production must be philosophical, based on available information and logic. First, however, it is essential that environmental trends affecting survival be examined to determine if negative environment may have been operative over the past five years.

Braaten (1970), Shepard (1972), Wendler and Rothfus (1955) found a negative correlation between flow and catch in several major steelhead producing streams in Western Washington. Smoker (1956) illustrated a positive relationship between stream flow during the residence period of wild steelhead and adult return to Minter Creek. Unpublished data of the International Pacific Salmon Fisheries Commission show a high and positive correlation between flow at the time of emigration of sockeye smolts and a somewhat similar correlation in the case of pink salmon fry and eventual adult survival. Smoker (1955) established a usable positive relationship between annual runoff in Western Washington and the total coho salmon production two years later.

An examination of Figure 18 reveals that fishing conditions in Green River during December through February have been generally more favorable over the past five years than for the previous five-year period which would have a positive effect on the catch in relation to run size. Figure 18 indicates also that the size of the run and the related catch appears to be influenced more by runoff during smolt migration than the catch is by low runoff during the fishing season. The average annual flow during April and May is much the same for the two five-year periods being compared. The average annual runoff in April and May was 234,000 acre feet from 1960 to 1964 (1962 to 1966 catch) and 224,000 acre feet from 1965 to 1970 (1968 not included). However, the runoff was more variable during the latter five-year period (1970 return year not considered) which might have some negative effect on survival of smolts, although it is difficult to conceive that this variation might explain the failure of the catches to increase.

All available information indicates that any salmonid population on the high seas tends to be racially homogenous in structure, hence, adult survival rates for all streams should fluctuate uniformly under the influence of ocean environment. As long as major exceptions in survival rates occur in specific years or over a period of years for specific streams, the existence of any change in planting-survival relationship cannot be attributed to the ocean but to variable conditions elsewhere -- in this case, in freshwater and/or the related estuary. Only in

1970 did the run decline generally in all streams, raising the legitimate point that negative survival occurred as a result of adverse ocean environment.

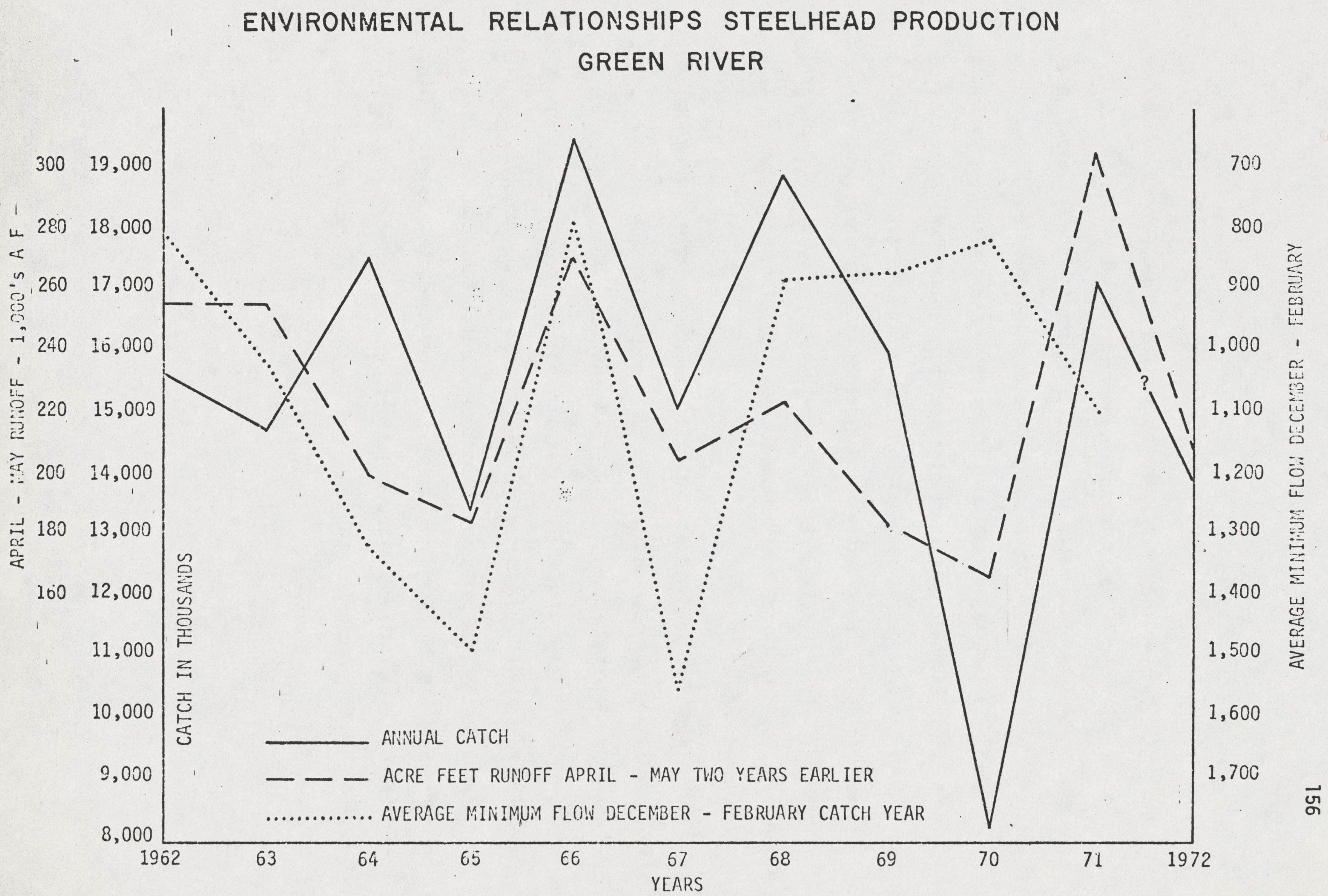
Since a barrier to obtaining increased runs of winter steelhead from increased smolt plants apparently exists after a certain level of planting is reached, defining the factor or factors creating this barrier becomes of paramount importance. Lacking any data other than hatchery smolt plants and the catch of unknown origin and age, one cannot approach the problem without the careful elimination of those hatchery practices which appear to be inconsistent with good survival because of their possible interference with the ecological balance in the stream and in the estuary. All of the possible interference has been detailed in the foregoing discussion and even the obvious possibilities may not be the entire answer.

The sensitivity of anadromous fish to changes in the ecological balance, while known to be extremely delicate, has not been properly measured. Perhaps the relating of natural population balance of each species to available food in the stream in combination with the physical characteristics of that stream may be somewhat superficial and requires further interpretation. However, with so many known variables already functioning, it is important that the effects of those variables be carefully weighed to better understand any remaining limitations to expanding hatchery operations.

Known Factors Related to Survival

Although the effect of known factors related to survival may be individually masked by a "density barrier", a discussion of each one may prepare a foundation for further understanding of the total survival problem.

FIGURE 18



ENVIRONMENTAL RELATIONSHIPS STEELHEAD PRODUCTION
GREEN RIVER
APRIL - MAY RUNOFF - 1,000's A F
CATCH IN THOUSANDS
AVERAGE MINIMUM FLOW DECEMBER - FEBRUARY
300 280 260 240 220 200 180 160
19,000 18,000 17,000 16,000 15,000 14,000 13,000 12,000 11,000 10,000 9,000 8,000
700 800 900 1,000 1,100 1,200 1,300 1,400 1,500 1,600 1,700
1962 63 64 65 66 67 68 69 70 71 1972
YEARS
?
ANNUAL CATCH
ACRE FEET RUNOFF APRIL - MAY TWO YEARS EARLIER
AVERAGE MINIMUM FLOW DECEMBER - FEBRUARY CATCH YEAR

Diet

It is important to point out that hatchery fish are still inferior to wild fish, justifying continuing research on diet improvement directed towards increasing adult survival rates. Messersmith (1958) observed that the feeding habits of emigrating hatchery steelhead smolts were significantly different from those of wild smolts. Residualizing hatchery steelhead show an adverse condition factor, with some reabsorption of the scales in the months following release, according to Chapman (1957). In 1972, the writer confirmed Chapman's findings in respect to steelhead and searun cutthroat in the Cowlitz River (unpublished data). Wagner (1967) found that very few hatchery steelhead parr remaining in freshwater for an additional time after release ever survived to return as an adult.

The inability of hatchery smolts to withstand stresses comparable to wild smolts is evidenced by the existence of substantial wild runs of steelhead in the Chehalis River watershed. The wild offspring must pass through a heavily polluted area in the Chehalis River estuary, which apparently cannot be tolerated by hatchery salmonids. Deschamps and Senn (1969) released marked coho smolts of the 1964 brood into the Humptulips River, which flows into Grays Harbor below the polluted estuary of the Chehalis River. A similar plant was made in the Satsop River, tributary of the lower Chehalis. Returns in 1967 showed that the Humptulips plant contributed 65% more fish to the sport and commercial fishermen than did the Satsop River plant. Similar experiments with the 1965 brood of coho favored the Humptulips plant by 250% over that in the Satsop River. Marked steelhead smolts released by the Washington Game Department (unpublished data) in the Humptulips and Chehalis River systems in 1960 returned 600% more adult steelhead to the Humptulips fishery than to that of the Chehalis system. Similar plants in 1964 in the Satsop and Wishkah Rivers, tributaries to the lower Chehalis River, returned practically no fish.

Enormous strides have been made in diet improvement since the late 1950's. This has improved the rate of growth, food conversion, reduced the prevalence of disease caused primarily by diet deficiency, and improved the apparent quality of the smolts produced. However, little effort has been expended in measuring the "real quality" of the fish which is defined as the ability of the fish to survive to maturity. Wagner (personal communication) raises the interesting point that diet coincident with the normal decline in condition factor preceding smolting could be important to the survival quality of the hatchery product.

Limited research by Washington and Oregon Fisheries Departments has indicated that the Oregon moist pellet is superior to the dry diet in terms of adult survival rate. The number of summer-run adult steelhead returning to the Skamania hatchery, where the moist diet is used exclusively, generally supports the research on this subject to date. In spite of this, the dry diet is used predominately in Washington's steelhead rearing operations and no practical attempt has been made to specifically relate adult survival to diet.

It is logical to conclude that the physiological inferiority of the hatchery steelhead smolt reduces his ability to withstand the shock of transplantation, the delicate interchange to salt water in the estuary and to develop a normal feeding regime, either in the stream, estuary, or adjacent environs. Perhaps his ability to compete with increasing numbers of his own identity and other salmonids species as well is sufficiently impaired that a "density barrier" is created by this inferior physiological condition under the stress of increased numerical densities of all salmonids emigrants.

Whatever the actual cause of mortality of hatchery steelhead smolts after release, physiological weakness due to diet, should be reduced insofar as possible as a contribution to improved quality. Rate of growth, food conversion rate, minimum prevalence of disease, and unit cost are very important to a practical rearing program. Extensive research is being carried out by several agencies to provide better diets in terms of "apparent" fish quality. Only minimal effort is being directed toward measuring quality in terms of maximum adult survival rate.

It is suggested, with the many agencies already organized to conduct this research, that the Department of Game stimulate these agencies to solve the whole problem presented by hatchery diet, rather than concentrating on sectionalized portions of it. Under this suggested program, the remaining responsibility of the department would involve limited adaptation experiments executed at the individual hatcheries under specific guidelines. While an environment suitable for producing hatchery fish physiologically equal to wild fish may never be achieved due to natural selection, the ability of the hatchery smolt to survive can be improved by diet research. Even if a "density barrier" is created by a lowered ability to survive, a stronger and more adaptable hatchery smolt could conceivably raise the barrier to permit a greater numerical limit in the returning adult population than now exists.

Rearing Environment

The importance of size in obtaining maximum adult survival has been discussed earlier. A high protein diet is essential for adequate growth but the thermal structure of the rearing environment can be critical also. Only a few of the department's hatcheries have an assured supply of thermal units in their water systems to provide for adequate growth each year. Transfers are made from station to station to compensate for lack of available thermal units and the size requirement of six fish per pound is not always met. When the spring warm-up is delayed, a number of rearing stations are unable to meet even a seven-fish-per-pound average. All available information should be utilized and action taken to insure that size requirements are met, regardless of adverse weather conditions. This is particularly necessary at the Cowlitz hatchery to eliminate the extensive residualism of released steelhead observed below this station every year. Currently, plans are underway to install water recirculation and temperature control systems at two of the Department's hatcheries in the Columbia River area. These installations will be financed by the Federal Government and should be a major step in the right direction.

The occurrence of disease resulting from environmental stress including pond design has been greatly reduced but there is a need for further action when such action is obviously justified. The effect of disease and the treatment itself can be permanently debilitating. There is a tendency to consider the reduction of mortality from disease as a primary concern, rather than effect of the treatment in causing possible permanent side effects which can only reduce the ability of fish to survive to maturity.

Since most disease outbreaks are now recognized to be the result of adverse environmental stress, disease prevention through improved rearing environment must go hand in hand with disease treatment. During the past year a full time fish pathologist has been assigned to the fisheries management program (see Appendix B). Plans are being made to relate water temperatures at each rearing station to the annual occurrence of virulent pathogens so that each hatchery superintendent will be alerted in advance to the inevitable relationship of temperature to the outbreak of specific diseases and be prepared to administer a preventative or curative treatment. The next step requires that more active consideration be given to possible and practical methods for permanent elimination of stress factors leading to disease outbreak. In the development of new methods for controlling environmental stress the Department through proper liaison could rely primarily on other agencies already organized to conduct such research.

A major share of the winter steelhead planted in Washington streams is subject to transportation from the rearing to planting site. Transportation environment can become a major factor in the fish's ability to survive and superficial observation has been found to be insufficient for determining the effect of transportation. In fact, the requirements for creating a favorable transportation environment have not as yet been fully defined. The writer has not been impressed by the recognition of even the known requirements for transportation by a few of those involved in this operation. There is a tendency of some to worry more about the work involved than in trying to guarantee that the fish are planted under the most favorable environmental conditions for their eventual survival to maturity. A better and more complete definition of the required transportation environment appears to be needed but such a definition can best be supplied by agencies other that the Department. However, improved supervision of the operation and education of those involved can only be provided within the Department.

Planting Location

Extensive marking of steelhead smolts in the state over a period of two or more decades has failed to provide usable data for formulating a desirable location release program. The Oregon Game Commission has conducted some work which is not clearly definitive. The hauling of salmon smolts by the Washington Department of Fisheries to downstream sites located a considerable distance below the hatchery apparently increases the survival rate of the hauled fish over that for similar fish released at the hatchery. The tendency of steelhead smolts to have a higher survival rate when released close to the estuary in such streams as the Lyre, Elwah, and Samish Rivers would indicate that a reduction in the time factor involved in reaching the estuary reduces the mortality related to inter and intra-specific competition. Predation and adverse effects of environmental stress could be somewhat proportional to the time factor in reaching the sea. However, due to the homing of adult steelhead to the planting location, selection of the latter may require a compromise between the desirable sportsmen harvest and a maximum smolt survival rate.

Potential Intra- and Inter-specific Competition between Hatchery Salmonid Smolts After Release

Adverse competition caused by the planting of pre-smolts or fish that residualize has been discussed extensively earlier in the manuscript. Detailed reference has been made to possible intra- and interspecific competition of hatchery smolts of several species of stream rearing salmonids within the total ecology of the stream and estuary. Johnson (1972) determined that "Success of chum salmon returns to hatchery racks was inversely related to hatchery coho production". He states further that "coho and chum, and/or pink salmon are produced simultaneously in nearly all streams, presumably at a rate that is ecologically balanced." "When hatchery coho are introduced, their biomass becomes greater than normal and undoubtedly more than the stream can support. Under these conditions, predation upon smaller fry would be expected to increase sharply." The data presented by Johnson showing the decline in chum and pink stocks, particularly the chum stocks in apparent relation to hatchery plant of coho are rather startling. Johnson recommends that coho smolt plants be delayed until after May 1 to eliminate excessive predation by coho smolts and "place coho into the natural environment at the proper timing for this species". Johnson also recommends that large scale outplanting (coho) into streams be eliminated.

All of the foregoing illustrates that winter steelhead smolts are under relatively severe stress when released from the hatchery and mortality factors become operative immediately upon release. The disappearance of up to 50% of a plant when released only a mile above a collection weir, as referenced earlier, substantiates this conclusion. Difference in feeding habits of wild fish, re-absorption of scales when remaining in fresh water, the failure of hatchery fish remaining in fresh water for a year after release to survive to maturity, increased survival rate related to release nearer the estuary, the proven superior ability of wild fish over hatchery fish to withstand the toxic effect of pollution further substantiate the existence of a stimulated mortality factor operative on hatchery fish. It is quite clear the predation is not the sole causative agent of death. Rather, it appears more likely that physiological weakness or reduced ability to adapt, resulting in fatal disease, is the principal causative agent.

Superimposed on the stresses initiated by weaknesses of hatchery fish is a density stress, which results from increased plants of steelhead and rapidly increasing numbers of other species of salmonids. On the basis of existing knowledge on population stress, it is logical to assume that numbers alone can result in competitive stresses that will act as a density barrier to survival. Stresses (and the resulting mortality) can be cumulative.

Experiments in measuring ability of smolts to survive direct introduction into salt water reveals that 100% mortality can result from Vibrio diseases within 96 hours. The Oregon Game Commission (1971) reports that "experimental rearing of juvenile chinook and coho salmon in a saltwater impoundment at Lint Slough near Waldport, Oregon has demonstrated the catastrophic influence that Vibrio anguillarium can have on a population of salmonids in brackish water."

Currently, the Department introduces and retains sample lots of steelhead smolts from several rearing stations for a period of several days in salt water as a measure of "quality". On several occasions, up to 100% mortality has resulted from an outbreak of Vibrio disease within three or four days. Wood (1968) states that "stress is an important factor in precipitating or increasing the severity of a Vibrio disease outbreak".

It seems logical that any improvement in the ability of a steelhead smolt to withstand stress should improve his ability to survive, thus raising the minimum limits of a "density barrier". Those planting practices, involving all stream rearing salmonids, which tend to reduce natural reproduction are very costly and should be eliminated. Naturally produced smolts will always survive at a higher rate than those produced in the hatchery. However, it appears that density barriers would be created eventually by density alone and this should affect all species. Whether or not competition and dominance will maintain the minority position of the steelhead after the smolt stage, remains a potentiality.

Irrespective of the end point reached in any particular location, results can be expected to vary between areas. Survival rates may remain higher in one watershed and related estuary than another, based solely on the historically established capacity of each area to produce a particular species.

If one accepts the foregoing philosophy, the design and construction of super hatcheries having great capacity for specific species may be a serious biological error. On the basis of present indications, to proceed with such a development, except in stages, could end in economic disaster.

Summer Steelhead

Experimental plants of summer run smolts were made in the tributaries of the lower Columbia River starting early in the 1950's. However, it was not until 1960 that regular plants were scheduled for the Kalama, Klickitat and Washougal Rivers. The program using Washougal River stock expanded rapidly, and regularly scheduled plants in the North Fork of the Skykomish and the North Fork of the Stillaguamish Rivers commenced in 1961. By 1963 the program was extended further to include the East Fork of the Lewis, Wind, Toutle, Told, and Dosewallips Rivers. Native runs, mostly of small size, existed in all streams planted with the exception of the Toutle Rivers.

An annual average of 201,000 smolts were planted between 1960 and 1965 in the Kalama, Toutle, Washougal, and East Fork Lewis Rivers with an annual average catch of 4,733 adults in the returning years. During the period from 1965 to 1969 the annual average group plant was increased to 396,000 or 195,000 greater than was planted during the previous five year period. The resulting annual catch increased 8,054 fish for a calculated survival rate based on catch alone of 4.13%. With a 40-60 catch-escapement ratio which is a conservative estimate, the survival rate for the increased plants in the above four rivers is over 10%. The high survival rate for the increased plants shows that the streams involved were receptive to the increased number of smolts. This is in contradiction to the adverse reaction shown by a number of other streams to increased plants of winter run smolts.

Unfortunately, the survival rate of smolts of Washougal stock planted in such representative streams in Puget Sound as the North Fork of the Skykomish and Stillaguamish Rivers has averaged about 0.7% on the basis of the catch or 1.75% using a 40-60 catch escapement ratio for the period from 1965-1969. While the planting of the tributaries of the lower Columbia River has been an eminently successful operation, the planting of tributaries of the Puget Sound area has been a disappointment. This problem was discussed in Appendix C where it was recommended that a local brood stock be developed. If developing a local brood stock of summer run steelhead is not practical due to small number of wild fish currently available, it was suggested that the source of eggs be confined to Washougal brood stock actually returning to the recipient stream.

In view of the earlier discussion of a possible density limitation on the planting of winter steelhead it is necessary to consider why a large summer run population can be superimposed on a relatively large existing winter steelhead population in the Lower Columbia River tributaries without an apparent adverse influence on the survival rate of either population. As mentioned above, the scheduled planting of summer runs did not commence until 1960. The Toutle River had no native run and the native population in the North Fork of the Washougal River was estimated at less than 100 fish and 300 or 400 for the whole river in 1956. The planting of winter steelhead in these streams commenced in the early 1950's, hence the planting of summer run smolts represented a superimposing of one population on another established population of substantial size.

Table 34 indicates the positive effect of the smolt planting schedule (10 fish per pound or larger) on both populations with no real evidence of a "density barrier" which could be appearing in other regions such as Puget Sound.

TABLE 34

Planting and Catch Relationship in 3 Lower Columbia Streams

Year Planted	Smolts Planted	Catch 2 Years Later	Smolt to Adult Ratio
Toutle River - Summer Runs			
1963	41,000	1965 - 385	106.0
1964	97,000	1966 - 2,392	40.7
1965	97,000	1967 - 2,724	35.6
1966	67,000	1968 - 3,021	22.2
1967	98,000	1969 - 3,602	27.2
1969	84,000	1971 - 4,539	18.5
Toutle River - Winter Runs			
1963	62,000	1965 - 5,696	10.9
1964	100,000	1966 - 6,542	15.3
1965	90,000	1967 - 6,929	13.0
1966	106,000	1968 - 6,976	15.2
1967	113,000	1969 - 6,517	17.33
1969	160,000	1971 - 7,315	21.87
Kalama River - Summer Runs			
1963	104,000	1967 - 3,777	27.53
1964	102,000	1966 - 5,365	19.0
1965	97,000	1967 - 6,117	15.85
1966	82,000	1968 - 6,135	13.36
1967	99,000	1969 - 4,104	24.12
1969	86,000	1971 - 4,491	19.14
Kalama River - Winter Runs			
1963	76,000	1965 - 3,761	20.2
1964	64,000	1966 - 3,981	10.7
1965	70,000	1967 - 6,652	10.52
1966	77,000	1968 - 3,730	20.64
1967	80,000	1969 - 4,488	17.82
1968	86,000	1971 - 4,864	17.68

Washougal River - Summer Runs

Year Planted	Smolts Planted	Catch 2 Years Later	Smolt to Adult Ratio
1963	105,000	1965 - 1,120	93.75
1964	111,000	1966 - 1,798	61.73
1965	99,000	1967 - 1,713	57.8
1966	132,000	1968 - 2,150	61.4
1967	106,000	1969 - 2,056	52.06
1969	98,000	1971 - 1,748	56.06

Washougal River - Winter Runs

Year Planted	Smolts Planted	Catch 2 Years Later	Smolt to Adult Ratio
1963	84,000	1965 - 4,008	20.95
1964	101,000	1966 - 4,461	22.64
1965	75,000	1967 - 3,356	22.34
1966	97,000	1968 - 3,390	28.61
1967	76,000	1969 - 3,608	21.06
1969	95,000	1971 - 4,683	20.28

One could hypothesize that the decimation of the steelhead population in much of the watershed of the Upper Columbia and Snake Rivers, due to irrigation and power development in the early part of the century, would leave a vacant niche in the lower Columbia River during the smolt migration. Thus, any population control which might exist in the latter would permit a large expansion of the steelhead smolt population in the lower tributaries without stimulating a survival limitation in the estuarial area. However, a major criticism of this hypothesis can be found in the winter run smolt-adult relationship for Grays River detailed in Table 35.

In view of the data in Tables 34 and 35, a logical deduction can be made that the Columbia River estuary is not controlling the benefits from smolt planting; rather, the control must be in the individual stream. If the foregoing deduction represents the situation, increased plants of winter run smolts in the Toutle, Kalama, and Washougal Rivers would have provided proportionate increases in the returning adult winter run provided summer run smolts had not been planted.

TABLE 35

Planting and Catch Relationship in Grays River

Winter Steelhead

Year Planted	Smolts Planted	Catch 2 Years Later	Smolt to Adult Ratio
1960	40,000	1962 - 1,875	21.33
1961	25,000	1963 - 1,582	15.80
1962	34,000	1964 - 2,504	13.57
1963	34,000	1965 - 2,422	14.03
1964	41,000	1966 - 2,000	20.50
1965	40,000	1967 - 1,654	24.18
1966	62,000	1968 - 1,835	33.78
1967	42,000	1969 - 2,291	18.33
1969	95,000	1971 - 2,418	39.28
1970	132,000	1972 - 2,500*	52.80

* Estimated on basis of catch for November and December, 1971.

It has been suggested that the relative failure of the summer run rearing program in the Puget Sound area may be due to the source of brood stock (Washougal River). This remains a distinct possibility, but perhaps the winter run program which shows signs of approaching a density barrier in the streams of concern may forestall the development of a successful summer run program, irrespective of the source of brood stock. Only controlled experimentation can lead to an accurate definition of proper management procedures in the latter area.

Sea Run Cutthroat

The strong tendency of hatchery reared cutthroat to residualize combined with a 10-inch minimum size limit and a delayed opening of the trout season until July 1 in a number of major river systems creates a major problem in inter-specific competition. Cutthroat appear to be more predaceous than steelhead and lack of available food supply creates an unfavorable situation for the incoming year class of naturally produced salmonids. It has been stated earlier that the release of cutthroat at a size of 3 to 3.5 fish per pound a few days prior to a late May opening of the trout season tends to provide a successful program in the coastal area of Oregon. However, the Columbia River program involving the Elochoman River is showing signs of decreasing adult returns to the hatchery which means that increasing reliance must be placed on resident broodstock for an egg source. The Elochoman eggs have not proven successful as a source of fish for planting in the Puget Sound area, particularly in the Stillaguamish River where the program has been abandoned and in Hood Canal Streams. Large numbers of fish residualize and marine survival is too low to warrant a continuation of these operations.

It is suggested that the Elochoman stock be upgraded by the addition of coastal type wild fish, that greater effort be expended towards increasing the size of migratnts and adequate research be conducted to determine the habits of the fish after release mainly through tagging and recovery experiments. Before the Puget Sound program is abandoned, a local source of wild broodstock should be developed (possibly from Minter Creek stock where collection facilities are already available). Size of fish planted is most important and a follow-up life history study should be made of the releases similar to that recommended above.

Plants of sea-run cutthroat should be made a few days before the trout season opens and the minimum size limit reduced to 6 inches that those fish remaining in the stream be eliminated by the trout fishery as soon as possible.

Consideration should be given to using pre-smolt sea-run fish as a source of resident stream fish in preference to rainbow trout which disappear soon after release in most West Coast streams. However, careful observation should be made to determine if such plants are detrimental to the natural production of salmonids before establishing such a planting program as an official policy.

The contribution of the cutthroat toward creating a "density barrier" or the effect of such a barrier which appears to exist with steelhead on the ultimate survival of cutthroat is not known. This point should be considered in all operations involving this species. The latter should be considered entirely e xperimental until research clarifies the position of this species within the salmonid complex.

Prediction of Run Size

Available information shows that the survival rate of stream-rearing salmonids is influenced positively with runoff during stream residence, during the normal low-water period, and at the time of migration. While this relationship is strongly indicated, the cause is far from being understood, except for flows during the low-flow period. Nevertheless, the relationship exists and appears to be a major control of population size (see pages 153 - 156). The year 1970 is the only one on record where the failure of the steelhead run might be attributed justifiably to adverse marine existence and 1960 is the only year, between 1935 to date, when ocean environment is suspect as the case for the failure of the coho run.

The catch of steelhead can be negatively modified somewhat by a closely spaced series of floods, but the run size has already been predetermined. Artificial rearing of salmonids has created population controls which are sometimes superimposed on the natural ones. However, until a "density barrier" is created, these controls appear mostly submerged by the natural ones. Even though steelhead hatchery smolts spend relatively little time in the stream after planting, the flow at the time appears to have a major impact on their ability to survive.

Once the "density barrier" is created, any prediction of expected run size based on natural environment and number of smolts planted becomes meaningless.

When the "density barrier" is removed by eliminating the cause, whatever it is, or the plants reduced below those related to reduced survival, the prediction of both the wild and hatchery run appears possible on a statewide basis. Such a prediction defines only whether the total run should be poor, average, or good. The rare instance of a poor run due to adverse ocean environment cannot be predicted on the basis of existing information, nor has a potentially fruitful approach to the problem been developed.

On the basis of the above information, it appears that the 1973 and 1974 steelhead runs would be expected to be above average in numbers. However, it is probable that the run size for these years will be below expectations because of a possible density barrier created by the increased number of smolts planted and by the possible adverse effect of a large increase in the number of pre-smolts and smolts of other salmonids planted in recent years.

CONCLUDING STATEMENT

The Washington Game Department sucessfully pioneered the steelhead rearing program using basic life history information as a guide in designing its experimental effort. The benefits to the sportsmen have been outstanding and these benefits have provided stimulus to other agencies involved also with the propagation of anadromous trout. The culturing of all stream rearing salmonids has expanded at an accelerated pace during the past decade to the point where new and serious limitations to adult survival are being created. Any possibility of defining and removing these limitations requires close liaison between those concerned with salmon and those responsible for increasing the anadromous trout populations. The foregoing discussion has been presented in an attempt to create a new concept in the management of all stream rearing salmonids consistent with the demand for an ever increasing harvest.

LITERATURE CITED

ANDREWS, R. E. 1958. Factors influencing the seaward migration of smolt steelhead trout in the Alsea River, Oregon. Masters Thesis, Ore. State College.

ARP, H. A., J. H. ROSE AND S. K. OLHAUSEN. 1970, 1972. Contribution of the Columbia River hatcheries to harvest of 1963 and 1964 brood fall chinook salmon. Econ. Reasibility Rpt. Nos. 1 and 2, Econ. Feas. Sect. Natl. Marine Fish Service.

AYERST, J. D. 1964. Special Report, Washington State Game Department. Unpublished.

BALI, M. B. 1958. Scale analysis of steelhead trout from various coastal watersheds of Oregon. Masters Thesis, Ore. State College.

BJORNN, T. C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. Trans. Am. Fish. Soc., Vol. 100, No. 3.

BRAATON, D. O. 1970. Some factors affecting steelhead harvest rates in the State of Washington. Wash. Coop. Fish. Unit, Univ. of Wash. (Unpublished Manuscript)

CHAPMAN, D. W. 1957. Studies on age, growth and migration of steelhead trout in the Alsea River, Oregon. Masters Thesis, Oregon State College.

CLEAVER, F. C. 1969. Effects of ocean fishing on 1961 brood fall chinook salmon from Columbia River hatcheries. Research Rpts. Fish. Comm. of Ore., Vol. 1, No. 1.

CRAMER, F. K. 1940. Notes on the natural spawning of cutthroat trout in Oregon. Proc. 6th Pac. Sci. Congress, 3.

DESCHAMPS, G., AND H. SENN. 1969. Investigation of effects of Grays Harbor waters on coho emigration. Wash. Dept. of Fish.

DESCHAMPS, G., S. F. WRIGHT AND R. E. WATSON. 1971. Fish migration and distribution in lower Chehalis River and upper Grays Harbor, Wash. Dept. of Fish., Tech. Rpt. No. 7.

ELLIS, C. H., AND L. A. ROYAL. 1941. Unpublished data. Marked juvenile releases of Green River chinook reared at several Puget Sound hatcheries. Wash. Dept. of Fish.

EVEREST, F. H. JR. 1971. An ecological and fish cultural study of summer steelhead in the Rogue River, Oregon. Ann. Prog. Rpt., Oregon State Game Comm.

FESSLER, J. L. 1971. Deschutes River summer steelhead ecology. Prog. Memo., Fisheries No. 4, Oregon State Game Comm.

FRASER, F. J. 1969. Population density effects on survival and growth of juvenile coho salmon and steelhead trout in experimental stream channels. Sym. on salmon and trout streams. Univ. of Brit. Col.

GIGER, R. D. 1970. Ecology of coastal cutthroat trout progress in game and sport fishery research 1963-1970. Ore. State Game Comm.

----------. 1972. Personal Communication. See Amer. Fish. Soc. Lit. cited.

----------. 1972. Unpublished manuscript, "Ecology and management of coastal cutthroat trout in Oregon". Fish. Res. Rpt. No. 6. Res. Div., Ore. State Game Comm.

GUDJONSSON, T. V. 1946. Age and body length at the time of seaward migration of immature steelhead trout in minter Creek. Master Thesis. Univ. of Wash.

GUFLER, D. 1967. A summary of downstream trap studies at Beaver Creek hatchery. Unpublished manuscript, Wash. Dept. of Game.

HERMANN, R. B. 1970. Food of juvenile chinook and chum salmon in the lower Chehalis River and upper Grays Harbor. State Dept. of Fish., Tech. Rpt. No. 7.
HICKS, R. H., AND L. D. CALVIN. 1964. An evaluation of the punch card method of estimating salmon - steelhead sport catch. Tec Bull. 81, Oregon State Univ.
HISATA, J. S. 1972. The sea-run cutthroat program for Hood Canal. Unpublished manuscript, Wash. Dept. of Game.
JOHNSON, R. C. 1972. Potential interspecific problems between hatchery coho smolts and juvenile pink and chum salmon. Unpublished manuscript. Wash. Dept. of Fish.
JOHNSTON, J. M. 1967. Food and feeding habits of juvenile coho salmon and steelhead trout in Worthy Creek, Washington. Masters Thesis, Univ. of Wash.
LARSON, R. W. 1955. Annual report to Washington State Game Department. Unpublished.

LARSON, R. W., AND J. H. WARD. 1955. Management of steelhead trout in the State of Washington. Trans. Am. Fish. Soc., 84.
LOWRY, G. R. 1966. Production and food of cutthroat trout in three Oregon coastal streams. Tour of Wildlife Managmt. Vol. 30, No. 4.
MacMULLAN, R. A. 1954. The life and times of Michigan pheasants. Michigan Dept. of Conservation.
MAHER, F. P., AND P. A. LARKIN. 1954. Life history of the steelhead trout of the Chilliwack River, British Columbia. Trans. Am. Fish. Soc. 84.
MATTSON, C. R. 1962. Early life history of Willametter River spring chinook salmon. Special Report, Fish Comm. of Oregon.
McCONNELL, R. J., AND G. R. SNYDER. 1970. Occurrence of fish in the vicinity of proposed sites of two nuclear electric plants on the lower Columbia River. U. S. Bur. Comm. Fish., Biol. Lab., Seattle, Wash.
MEIGS, R. C., AND C. F. PAUTZKE. 1941. Additional notes on the life history of the Puget Sound steelhead. Wash. Dept. of Game.
MESSERSMITH, J. 1958. Food habits of smolt steelhead trout in the Alsea River, Oregon. Masters Thesis, Oregon State College.
MOORE, E., et al. 1934. A problem in trout stream management. Trans. Am. Fish. Soc. Vol. 64.
NEEDHAM, P. R. 1934a. Notes on the food of trout. Calif. Fish and Game. Vol. 92, No. 3.
NOBLE, R. 1972. Personal discussion on unpublished Minter Creek data.

OREGON STATE GAME COMMISSION. 1971. Fall chinook rehabilitation on the Alsea River. Federal Aid progress report.
PAUTZKE, C. F., AND R. C. MEIGS. 1940. Studies on the life history of the Puget Sound steelhead. Biol. Bull. No. 3, Wash. Dept. of Game.
REES, W. H. 1959. Effects of stream dredging on young silver salmon and bottom fauna. Res. Papers, Vol. 2, No. 2, Wash. Dept. of Fish.
REIMERS, P. E. 1968. Social behavior among juvenile fall chinook salmon. Jour. Fish. Res. Bd. of Canada, Vol. 25, No. 9.
REIMERS, P. E., AND R. E. LOEFFEL. 1967. The length of residence of juvenile fall chinook salmon in selected Columbia River tributaries. Res. Briefs, Ore. Fish. Comm., Vol. 13, No. 1.
RICH, W. H. AND H. B. HOLMES. 1929. Experiments in marking young chinook salmon on the Columbia River, 1916 to 1927. U. S. Bur. of Fish., Bull. 44, Doc. 1047.
RICH, W. H. 1925. Growth and degree of maturity of chinook salmon in the ocean. U. S. Bur. Fish., Bull. 41, Doc. 974.

ROSE, J. H., AND A. H. ARP. Contribution of Columbia River hatcheries to harvest of 1962 brood fall chinook salmon. Bur. Comm. Fish. Col. River Prog. Office.
SALO, E. O. 1969. Final report for the period June 1, 1965 to September 30, 1968 - Estuarine ecology research project. Coll. of Fish., Univ. of Wash.
SALO, E. O., AND W. H. BAYLIFFE. 1958. Artificial and natural reproduction of silver salmon at Minter Creek, Washington. Res. Bull. No. 4. Wash. Dept. of Fish.
SENN, H., AND K. SATTERTHWAITE. 1971. Evaluation of 1966 brood coho released from eleven Puget Sound and two coastal hatcheries. State of Wash., Dept. of Fish.
SHEPHERD, D. 1928. The tricloptera of Waddell Creek and their relation to the food of the rainbow trout. Doctoral Thesis, Stanford Univ.
SHEPARD, M. F. 1972. Timing of adult steelhead migrations as influenced by flow and temperatures in four representative Washington streams. M. S. Thesis. Univ. of Wash.
SKEESICK, D. G. 1965. Catch, migration, growth and survival of stocked coastal cutthroat trout in Munsel Lake, Oregon. Fish. Res. Rpt. No. 2, Res. Division, Oregon State Game Commission.
SMOKER, W. A. 1955. Effects of stream flow and silver salmon production in western Washington. Ph.D. Thesis, Univ. of Wash.
----------. 1956. Effects of stream flow on steelhead production at Minter Creek, Washington. Unpublished data. Wash. Dept. of Fish.
STEIN, R. A. 1971. Social interaction between juvenile coho and fall chinook salmon in Sixes River, Oregon. Masters Thesis, Ore. State Collge.
SUMMER, F. H. 1962. Migration and growth of the coastal cutthroat trout in Tillamook County, Oregon. Trans. Am. Fish Soc., Vol. 91, No. 1.
SWARTZ, D. 1971. Summary - number and age composition of adult salmon and steelhead handled at Fish Commission of Oregon hatcheries in 1969 and 1970.
VINCENT, R. 1972. The catchable trout. Montana Outdoors May/June, 1972 issue.

WAGNER, H. H., R. L. WALLACE AND H. J. CAMPBELL. 1963. The seaward migration and return of hatchery - reared steelhead trout in the Alsea River, Oregon. Trans. Am. Fish. Soc. Vol. 92, No. 3.
WAGNER, H. H. 1967. A summary of investigations of the use of hatchery reared steelhead in the management of a sport fishery. Fish. Rpt. No. 5., Oregon State Game Comm.
----------. 1970. Progress in game and sport fishery research, 1963-1970. Oregon State Game Commission.
----------. 1971. The development of parr-smolt transformation in anadromous salmonids in relation to some environmental conditions. Fed. Aid Prog. Rpt., Ore. State Game Comm.
WASHINGTON STATE FISHERIES DEPARTMENT. Annual Reports for 1966, 1967, 1968, 1969, 1970 and 1971.
WATSON, R. E., AND T. C. HOFFMAN. 1968. Fish management progress report. Unpublished manuscript. Wash. Dept. of Game.
WENDLER, H. O., AND L. O. ROTHFUS. 1955. Grays River steelhead trout population study December 1954 through April 1955. State of Wash., Dept. of Fish. (Unpublished)
WOOD, J. W. 1968. Diseases of pacific salmon - their prevention and treatment. Wash. Dept. of Fish.

July 12, 1971

Appendix A

M E M O R A N D U M

TO: Cliff Millenbach, Chief - Fishery Management Division

FROM: Loyd Royal, Fisheries Research Coordinator

SUBJECT: Scale Samples as a Major Part of the Winter Steelhead Management Program

An essential part of fisheries management involves a practical knowledge of the numerical abundance of the population under control. Without this knowledge operational policies cannot be analyzed to determine the true relationship of these policies to the abundance or to the reproductive and survival capabilities of the stock.

In an attempt to increase the abundance of winter steelhead, substantial plantings of yearling steelhead in the 5 to 7 fish to the pound size category have been made for a number of years in most of the larger streams. Adult returns have been substantial as shown by numerous marking experiments as the practice appears to have a sound economic base.

The winter steelhead planting program required that the whole reproductive process be advanced and the growth of the young fish stimulated in order to produce fish of a size capable of smolting and emigrating successfully to its marine existence in one year instead of the two or three years required naturally. This advancement in the development of the young steelhead has resulted in the return of the hatchery adult earlier in the season, which is evident in Figure I, shown on the following page. December catches have increased remarkably in recent years while the March and April catches have remained the same even though they are known to include an unknown number of hatchery fish. If the latter figure were known, and subtracted from the catch of fish produced naturally, it is probably that the March and April catches would show a definite decline. The following table further illustrates the shifting predominance of the catch of winter steelhead to the earlier months.

Reasonably exact knowledge of annual catch of fish of hatchery origin and its continuing relationship to the catch of naturally produced steelhead is required if a study of population dynamics of the winter steelhead is to be undertaken. In fact, any basic attempt to maintain or increase either segment of the winter steelhead population in the future appears to depend upon the accumulation of this information. One method of obtaining these data would be the marking of all smolts planted in key streams with field checks of sufficient dimensions to obtain a statistically sound marked to unmarked ratio for each month. However, in marking experiments, fish are severely crowded and handled several times with accompanying fin mutilation which does not heal prior to planting. In addition, a significant reduction in the smolt to adult survival rate due to fin removal always accompanies such an operation which

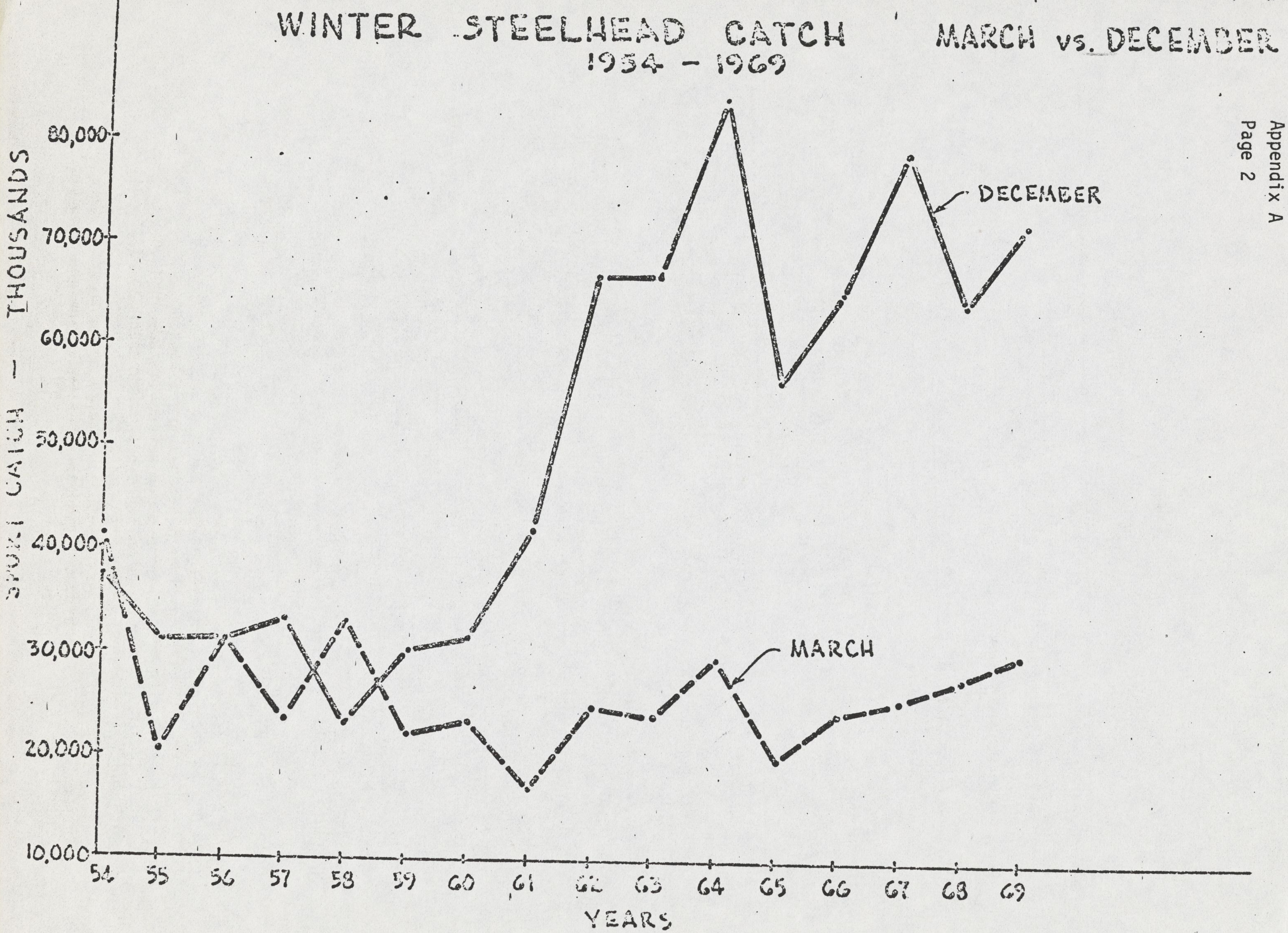

WINTER STEELHEAD CATCH MARCH vs. DECEMBER
1954 - 1969
SPORT CATCH — THOUSANDS
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
YEARS
DECEMBER
MARCH

TABLE I

CATCH OF WINTER STEELHEAD BY MONTH

Month	Years	Annual Average Catch	Difference
December	1954-61	33,208	
"	1962-69	70,239	+ 37,031
January	1954-61	40,473	
"	1962-69	61,540	+ 21,067
February	1954-61	29,622	
"	1962-69	40,906	+ 11,284
March	1954-61	27,544	
"	1962-69	26,781	- 763
April	1954-61	8,558	
"	1962-69	8,690	+ 132
		Total Difference	+ 68,751

tends to defeat the purpose of the rearing program and lessen its economic justification.

There is every reason to believe that the total marking program and the serious objections to it can be eliminated by the taking of adult scale samples during field checks which would be required in any case. A preliminary examination of 67 adult steelhead scale samples with accompanying otoliths taken this spring at the Cowlitz Hatchery, many of which were marked, indicates that hatchery and wild fish can be separated satisfactorily either by age, fresh-water circuli counts, or by otoliths. Reading mistakes occurred in 16% of the total scale sample but further discussion with the reader, Rich Kolb, indicated that part, if not all of these mistakes, could be eliminated in reading scales alone. To assure the reader of a basic reading reference, a permanent scale sample representing one hundred 5-7 to the pound hatchery smolts, and one hundred smolts of wild origin, should be secured next spring (1972) without fail. (See later discussion on scale sampling procedure). Three or four impression copies should be made and filed in a safe place since it may be impossible in a few more years to obtain smolts guaranteed to be of natural origin. Several experienced biologists of this Department and of the Oregon Game Commission are in agreement with the undersigned on this important subject, namely, that scale samples provide the simplest answer for providing a statistical breakdown of the origin of the sports catch.

An age analysis of scales from 1,542 wild downstream migrating winter steelhead in the Alsea River in Oregon revealed that 5% were age 1/, 82% age 2/, and 13% age 3/. By contrast, few hatchery fish returning to the Alsea River showed a second fresh-water annulus (50 out of 16,808 adult fish). A sample of Alsea adults of hatchery origin revealed that 4.6% were Jacks or age 1/, 89.9% were three-year-olds or 1/2's, and 5.5% were four-year-olds or 1/3's. This sample has been generally corroborated by other data in the literature. These data not only show that hatchery and wild fish can be separated by fresh-water circuli counts but by age as well. They also verify that hatchery fish do not survive when they do not migrate to sea immediately upon release.

In order to collect the necessary information on the hatchery-wild fish ratio in the catch by months, it is requested that 200 scale samples be secured during the winter steelhead season on ten key, high producing streams. A certain percentage or number must be taken each month with the number required based on the average expected catch for that month. On the following page, Table II lists the selected streams and the number of scale samples required for each month involved.

In taking scales, a scrape of about 6-8 scales should be taken directly below any part of the dorsal fin between the 2nd and 5th row above the lateral line. The location of the scrape is most important and the above instruction must be complied with since the number of circuli in the fresh-water growth area varies between the tail and head sections of the fish and between the dorsal fin and the lateral line. Since scales are highly deciduous in the smolt stage, a scrape from each side of each adult fish is required to lessen the probability of collecting regenerated scales and guarantee the usuability of each sample.

Coin envelopes should be supplied and the scale sample inserted by simply wiping the knife blade of any pocket knife with the scraped scales in one side of the coin envelope. Each of the two samples for each adult fish should be wiped off in opposite sides of the same envelope. Seal the envelope and re-cored the date, river origin, total length, and any mark if present. Samples should be sent to the Regional Supervisor on a routine basis who will forward the month's sample to the Chief, Fisheries Management Division, Olympia, Washington.

The obtaining of each month's sample quota is absolutely essential to the practicality of the program. Since weather is an important item, it is strongly suggested tha an attempt be made to obtain each month's quota during the first half of the month. Failure to follow through and secure samples for each month means that the whole year's program has failed for the stream being sampled. The Regional Supervisor concerned should be held responsible for the fulfillment of the sampling program and should request direct assistance if his organization appears unable to meet these important needs of the basic winter steelhead management program. There should be no acceptable excuse for failure to complete the program except under most unusual weather conditions when the catch will be greatly reduced.

Scale samples can be secured in the easiest manner possible but under no circumstances should they be taken from adult returns to hatcheries or rearing pond release sites. They may be secured from properly instructed guides or from the Indian fishery except that the guide samples must be taken in the approved manner, otherwise, they are useless. Scales secured from Indian fish taken at the mouth of the Puyallup or on the Chehalis Reservation are satisfactory. Samples can be taken also from any confiscated fish caught illegally in the lower parts of any of the streams involved. Any samples available in November can be considered part of the December quota.

TABLE II

SELECTED KEY STREAMS AND SAMPLE SIZE

Sample Month	Samish	Skagit*	Stilla-guamish	Snohomish Skykomish	Green*	Puyallup*	Chehalis	Hump-tulips	Sol Duc	Cowlitz
Dec.	70	60	80	70	70	80	80	80	75	70
Jan.	50	50	50	60	50	40	40	50	45	30
Feb.	40	40	40	45	40	30	50	40	45	30
March	40	35	30	30	40	35	25	30	20	50
April	--	20	--	--	--	20	--	--	15	20

* Skagit to Rockport

* Green below Kummer Bridge

* Puyallup (Not White River)

It is suggested, also, that some individual in the central office be held responsible for the success of the program through periodic contacts with the Regional Supervisors. Back-up assistance could be provided in the field if necessary, but should be avoided except as a last resort.

Yours very truly,

Loyd A. Royal
Fisheries Research Coordinator

LAR/wb

cc - Jack Ayerst
Bob Meigs

April 1, 1971

Appendix B

M E M O R A N D U M

TO: Cliff Millenbach

FROM: Loyd A. Royal

SUBJECT: Quality of Steelhead Smolts

In the separation of the variables affecting the ultimate adult steelhead survival rate, fish quality obviously is one of the primary factors involved. Presently, the quality of the smolts being released is a matter of limited local knowledge at the hatchery source. Suitable quality records have not been defined nor apparently have adequate records been kept for assessing quality as an isolated variable in its effect on the smolt to adult survival rate. How to fully assess the quality of a fish in terms of its ability to survive has yet to be established but experienced pathologists acting in a multidiscipline capacity have set up certain criteria to be followed subject to improvement if found necessary at a later date.

It is suggested that a record keeping system be established for the central office files as a part of the Fisheries Management operation and that it be inaugurated as soon as possible; further, that past hatchery records be examined as to the possibility of extending the quality history of fish plantings for earlier years to facilitate application of the data.

In order for a system of quality control and proper record keeping to be effective, it is strongly suggested that a properly trained pathologist experienced in dietetics, diagnosis, and treatment of fish pathogens and parasites, be assigned to the hatchery division with full responsibility to advise each hatchery superintendent in respect to the adequacy of diets, pathology, and aid him in providing the records required for isolating quality as a measurable variant in the production of adult steelhead.

Certain weaknesses in an initial organization of any new program will become apparent as experience is gained. The "Check List of Steelhead Migrant Condition", prepared earlier by your office, appears adequate with the exception that it might be more effective for later analysis if a report was issued to the hatchery superintendent in respect to each pond of fish, rather than by lots.

Since the check list, by itself, would not be adequate for proper definition of fish quality in the planted fish, it might be better if the check lists were retained by the hatchery superintendent. Later, after the fish were planted, the same information could be consolidated with other pertinent data on a special report for central files. A suggested form for the latter report is submitted herewith for your careful consideration as to its practicality in providing the required information relating to fish quality.

Loyd A. Royal
Fisheries Research Coordinator

LAR/wb

Attachment

CHECKLIST OF STEELHEAD MIGRANT CONDITION

Station______________________________ Supt.______________________________

Date______________________________ Pond No.______________________________

Winter Steelhead_____ Size_____/lb
Summer Steelhead_____ Size_____/lb

Type of Pond______________________________
____

Total Steelhead in Pond__________________ Mortality During Past Month:

No.____________ %________________

1. Physical Appearance of Fish

Normal__________ At Surface __________
Sluggish__________ Facing Water Current__________
Flashing__________ Gasping for Air__________
Jumping__________ Crowding Water Inlet__________

Other:____

2. Body Surface

Normal__________ Bluish or Grayish Film__________
Silvery__________ Dark__________
Tail Banded__________ Lesions__________

Parasites found: Describe: (None, few, light, heavy)

____

____

____

3. Fins

Normal__________ Bloodshot__________ Eroded__________

4. Gills

Normal__________ Swollen__________ Eroded__________
Abnormal Mucous__________ Clubbed__________
Color of Gills: Deep red______ Pale red______ Pink______ White______
Parasites found: Describe: (None, few, light, heavy)

____

____

____

Checklist of Steelhead Migrant Condition
Continued - Page 2

5. Eyes

Normal____________ Opaque_________ Spot in Lens___________

6. Body Cavity

Normal____________ Fluid Present______________
Normal____________ Light____________ Heavy_______________

7. Intestinal tract

Normal____________ Empty___________ Food Present_________
Yellow____________ Reddish_________

Roundworms________ Tapeworms________

Parasites found: Describe: (None, few, light, heavy)

____

____

____

8. Liver

Normal______ Red______ Yellow________ Brown_________ Pale ________
Marbled_____ Spotty________ Cysts_________

Gall Bladder bile: Greenish-yellow________ Clear_______ Bluish_____

9. Kidney

Normal_____________ Pinpoint spots________ Bloody__________

10. Spleen

Red_______ Black-red_________ Pale _______ Enlarged______

Treatment recommended:____

____

____

Treatment accomplished: (Give date, concentrations and treatment description)

____

____

____

Date of last treatment:_____________________________________

Side (1)

Washington State Department of Game

Steelhead Trout **Planting History**

Name of Stream Stocked ____________________
Planting Location ____________________
Hatchery Source ____________________
Broodstock Source ____________________
Relative Stream Flow Conditions ____________________
Tank Temperature ____________________
Stream Temperature ____________________

Species (W.R. Sthd., S.R. Sthd.) ____________________
Brood Year ____________________
Planting Date ____________________
Planting Time ____________________
No. Planted ____________________
No. Fish Per Lb. ____________________

Side (2)

Pathogenic History:

Date Total Stock Rec'd ________ Total No. Rec'd ________ Size ________ /lb
Source of Planted Fish ________ Pond No. ____ Total No. in Pond ________
Total Mortality in Source Pond ________ % Mortality ________
Dates of Treatment:
Date ________ Treatment ____________________
Reason ____________________
Date ________ Treatment ____________________
Reason ____________________
Date ________ Treatment ____________________
Reason ____________________

Abnormalities Relating to Condition at or Prior to Planting as Reported by Pathologist:

1. Date of Inspection ________
2. Physical Appearance ____________________
3. Body Surface Appearance ________ Parasites ________
4. Fins ____________________
5. Gills (condition) ____________________
   (parasites) ____________________
6. Eyes ____________________
7. Body Cavity ____________________
8. Intestinal Tract (condition & parasites) ____________________
9. Liver ____________________
10. Kidney ____________________
11. Spleen ____________________

Checklist of Steelhead Migrant Condition
Continued - Page 3

Remarks: (May be continued on back page)

____

____

____

____

____

Water Condition: Clear________ Turbid__________

Temperature:________________________

D. O. at Pond Outlet:________________________

pH________________________

Examination conducted by:________________________

December 13, 1971

Appendix C

M E M O R A N D U M

TO: Cliff Millenbach, Chief, Fishery Management Division

FROM: Loyd A. Royal, Fisheries Research Coordinator

SUBJECT: Summer Run Steelhead in Puget Sound and Coastal Rivers

In summarizing the life history of the summer run steelhead as a basis for later consideration in examining fish cultural activities, the undersigned was impressed by the lack of available knowledge on the coastal summer runs. Little information is available on the size of the populations in earlier years; whether or not small populations have become extinct or marginal in numbers, and the variance, if any, in spawning time, spawning areas, spawning environment, and fresh-water life history, from that of the winter steelhead.

It is suggested that the regional biologists carefully assemble all available information on native summer run populations as itemized above, in the coastal areas of western Washington and file a report at their convenience during the next year. Apparently few native populations remain which have not been mixed with hatchery plantings of Washougal stock and in a few years all of the native populations may be similarly affected.

The fresh-water life history of the native summer-run stocks in the coastal area may be somewhat different from that of the winter steelhead, especially in the period of stream habitat prior to smolting. Knowledge of the latter can best be obtained from scales of native summer and native winter run fish from the same stream, hence, it is suggested that a scale sample be taken in the approved manner from not less than 25 adults of each group inhabiting the same stream. A larger sample is preferable, if possible to obtain, to enhance the statistical value of any differences observed in the two samples.

It is recognized that the above request for scales may turn out to be more academic than practical but in view of the obvious negative difference in the survival rate of hatchery raised summer run smolts when released in Puget Sound streams compared with that of summer-run releases on lower Columbia tributaries or with winter run releases, additional information is required to attempt an assessment of the cause, or causes, for that difference.

The Washington State Fisheries Department reports that even with modern fish cultural practices they are unable to successfully transplant Columbia River chinook salmon to streams in the Puget Sound and Coastal districts. Continued failure to successfully transplant Green River chinook stock to coastal streams or the tributaries of the lower Columbia is reported also, although cross fertilization of Nemah River native chinook stocks with Green River hatchery stock apparently has proven quite successful on the basis of adult returns to the Nemah Hatchery.

While the survival rate of reared smolts of Washougal brood stock has been eminently satisfactory when planted in tributaries of the lower Columbia, survival rates from plantings of these fish in Puget Sound streams is considerably lower, raising a serious question involving the economic practicability of the program.

It is suggested that the genetic reaction of the Washougal brood stock to the environment of the Puget Sound streams and their related estuaries may inhibit survival where a cultured native stock of Puget Sound summer-run steelhead may react more positively. The above situation is not true in the case of winter steelhead since South Tacoma stock appears to have a fairly satisfactory survival rate when planted in the tributaries of the lower Columbia. However, the summer run steelhead of the coastal areas appear to be more sensitive to its fresh-water environment so an experimental attempt to develop a local brood stock for fish cultural purposes appears warranted in the light of the current low rate of survival. Lacking a practical method of developing a local brood stock source, it is suggested that eggs be obtained from adults returning from plants of Washougal stock in hopes that a continuation of this practice might develop a more pliable brood stock having a higher rate of adult survival from reared smolts.

Very truly yours,

Loyd A. Royal

LAR/wb

January 7, 1972

Appendix D

M E M O R A N D U M

TO: Cliff Millenbach, Chief, Fishery Management Division

FROM: Loyd A. Royal, Fisheries Research Coordinator

SUBJECT: Time, Size and Age of Wild Steelhead Smolts

Data on the referenced subject is required for consideration on a number of steelhead management problems.

Time of migration is associated with delimiting the planting time of hatchery smolts in anticipation of a maximum survival rate. While some information is available which indicates a consistency in the time of major migration between streams, viz; April 25 to May 20, Ward and Larson report delayed migrations in certain streams having a glacial source. The biologist for each region in western Washington should type his streams into two types (probably glacial and non-glacial) and obtain an approximation of time of migration in the lower river representative of each type by a method of sampling sufficient to provide such approximation. It is assumed temporarily that a weeking sample, not to exceed 20 fish, taken by hook and line from the same favorable fishing location under similar water conditions, should prove adequate if associated with hours of fishing time for each sample.

A scale sample and total length measurement from each fish taken, when associated later with smolt length and age determinations from adult scales taken from the same river, will provide information on survival rates and the maturity age classification of the individual year classes of smolts. Total length data will provide a better assessment of the size of smolts, which should be produced in the hatchery to aid in obtaining maximum survival rates and to avoid residualism. It is suggested that the rivers selected for sampling should include streams which have already been delegated as key streams for the annual collection of adult scales.

The above data should have some value in the design of any program which may appear to have a possibility of producing larger adults either through selective breeding or through the production of smolts which will not return as adults until they have spent three years at sea.

Currently, an opinion prevails that the number of larger adult steelhead is declining in abundance. If this is true, the abundance of wild steelhead is declining. On the other hand, the percentage rather than the number of larger steelhead may be declining because the hatchery fish which are now a major part of runs may not be producing as many large steelhead as the naturally produced fish. The referenced data should provide a basis for defining just what is going on from year to year.

There appears to be good reasons for concluding that the 10-inch minimum size limit may not be accomplishing its intended purpose, while at the same time preventing the use of major stream systems as recreational fishing areas during the summer months. The delineation of the smolt migration by time and by river types might permit the setting of a minimum closed season for the protection of smolts while still permitting the possible harvest of residualized or resident steelhead and cutthroat after the smolt migration is essentially over.

Sampling should commence about the first week in April and continue as long as a significant number of smolts are present. It is most important that delayed migration, if any, be identified in time and composition. It is recognized that hatchery smolts will appear in the catch after the spring releases start but scale samples and marks should provide a means for separating wild and hatchery smolts.

In concluding the above, reference is made to a previous note that 100 total length frequencies be obtained from a random sample of hatchery fish during the spring of 1972. It is suggested further, that these be obtained for all rearing stations and separate samples be obtained where both ponds and raceways are used. The samples should be identified by reported hatchery weights, viz; 6/# or 5/#.

Very truly yours,

Loyd A. Royal
Fisheries Research Coordinator

LAR/wb

STATE OF WASHINGTON

THE DEPARTMENT OF GAME

Dec. 6, 1983

Dr. Behnke,

Thanks for your prompt reply to my query on your revised trout monograph. If possible, please put me on your mailing list for receipt of same.

Our 1982 progress reports were mailed out (?) many months ago. You are on our mailing list and should have received a copy. Sorry if you didn't. The 1983 report is now in preparation and should be available early next year. Will send you a copy at that time.

Best regards,

Steve Leider

4435 Independence Lane
Longview, WA. 98632