Quality and Behavior of Juvenile Salmonids in the Columbia River Estuary and Nearshore Ocean

Research Plan

Final Report

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Bonneville Power Administration
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U. S. Department of Commerce
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National Marine Fisheries Service
Northwest Fisheries Center
Coastal Zone & Estuarine Studies Division

University of Washington
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Oregon State University
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RESEARCH PLAN

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by

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INTRODUCTION

The Pacific salmon (Oncorhynchus spp.) and steelhead (O. mykiss) resources of the Columbia Basin have historically supported a large fishery with important economic and recreational benefits to the people of the Pacific Northwest. Over the past 50 years the economic value of these resources has remained relatively high largely due to the growing demand for high quality seafood and recreational fishing; however, the numbers of harvestable fish have greatly declined. This decline is generally attributed to the industrial and agricultural development of the Columbia Basin, and particularly the construction and operation of over 50 dams on the Columbia River and its tributaries.

Prior to hydroelectric power development on the Columbia River, streams throughout most of the 259,000 square mile Columbia River watershed were utilized by salmon and steelhead. Tributary streams making up the Columbia River network each produced their own unique stock of fish whose migration timetable was strongly influenced by the stream's environment and its distance from the ocean. Thus, time of entry of juvenile salmonids into the ocean ranged from April to November.

As dams were built for power production, over half of the watershed was made inaccessible to anadromous fish, and many stocks of salmon were lost forever. This loss of smolt production together with significant losses of juveniles passing through dams and reservoirs resulted in a major reduction in numbers of juvenile fish entering the ocean, and the once extensive runs of salmonids in the Columbia Basin started to decline.

As public hatcheries were constructed and put on line to help rebuild the declining runs, the periods of time during which fish were released often differed from the traditional times a particular stock migrated to the ocean. Such factors as need to decrease hatchery holding density, increasing mortalities from infectious disease, and assorted economic reasons frequently dictated release time. Biological readiness to migrate and historical time of migration were not always considered. This situation has the potential to not only force juvenile chinook salmon to the estuary and ocean environment before they are physiologically ready, but also may place migrating fish in the estuary or nearshore ocean when sub-optimum biological, physical, and chemical conditions may limit carrying capacity and early ocean survival.

In response to declining salmon runs, the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program has identified a "doubling of salmon and steelhead runs in the Basin" as one of its priority goals. To accomplish this the state and federal agencies and tribal organizations responsible for power, water, and fisheries management in the Basin have embarked on a large-scale program to evaluate a variety of means of enhancing salmonid production. Three areas that are receiving particular attention are hatchery effectiveness, natural production through habitat improvement, and downstream passage of juvenile salmonids at dams.

To date the majority of the research has focused on the riverine phase of the salmonid life cycle, and particularly the problems associated with passage of juvenile and adult salmon and steelhead around or through hydroelectric projects. While these efforts, which include evaluating the benefits of transportation of juveniles around dams and improved techniques of fish guidance through the safest routes of passage, have probably contributed to increasing the returns of steelhead and fall chinook salmon (*O. tshawytscha*), not all Columbia River stocks have fared as well. Of particular concern has been the continuing decline of spring chinook salmon stocks.

Although a multitude of factors, working alone and together, may be contributing to the failure of spring chinook salmon stocks to rebound, several are considered priority areas for research. For example, the high prevalence of infection with *Renibacterium salmoninarum*, the etiological agent of bacterial kidney disease (BKD), is believed to be responsible for significant morbidity and mortality in hatchery-reared spring chinook salmon, particularly during their transition to seawater. Furthermore, there are many unknowns regarding what constitutes "good smolt quality" at the time of hatchery release and the influence it has on migratory behavior and the ability to make the physiological transition to seawater. Finally, there is virtually no information on how biological, chemical, and physical factors in the estuarine and nearshore ocean environment influence smolt survival and ultimately contribution to the commercial and recreational fisheries.

In response to this limited understanding of the factors responsible for the continuing decline of spring chinook salmon in the Columbia River, this research plan was developed. The overall goal of the proposed research is to investigate and identify relationships among smolt quality (measured in the hatchery and after recovery in the estuary and nearshore ocean), environmental conditions in the estuary and nearshore ocean during smolt migration, and long-term survival (as measured by adult returns to the hatchery of origin and contributions to the recreational, commercial, and tribal fisheries). This research was specifically designed to be conducted concurrently with, and to complement and extend the information developed in, the BPA-funded project Smolt Quality Assessment of Spring Chinook Salmon.

BACKGROUND

Columbia River Estuary

The Columbia River estuary, which forms part of the boundary between Oregon and Washington, is biologically one of the most important and unique estuaries on the West Coast of the United States. Geographically, the estuary extends from the mouth of the Columbia River to River Kilometer (RKm) 75 at the eastern end of Puget Island near Jones Beach, Oregon. The estuary can be characterized as a drowned river mouth with delta islands in the upper portion. The major source of fresh water to the estuary is the Columbia River, the second largest river in the United States (Fox et al. 1984). Columbia River flows are typically highest during the spring and lowest during late summer and fall. Salinity intrusion in the estuary fluctuates considerably because of the relatively large freshwater flows and tidal changes. Vertical salinity gradients are present in portions of the estuary, with highest salinities occurring in deep water channels near the bottom (Neal 1972; McConnell et al. 1981). During low river flows (about 4,400 m^3/s), salinity intrusion is the greatest. Minimum bottom salinities in most of the lower 22 km of the estuary generally range from 0.5 to 15 ppt, with maximum salinities $\geq$30 ppt. During high river flows (about 8,800 m^3/s), minimum bottom salinities in the estuary may be near zero (Jay 1984).

The large inputs of fresh water to the Columbia River estuary and the subsequent low salinities have a dramatic influence on the ecology and species composition of the estuary. For example, the estuary has no saltmarshes, only brackishwater and freshwater marshes (Fox et al. 1984). Although much of the estuary presents a rather harsh environment in terms of changing salinities, it serves as an important feeding, rearing, spawning, or passage area for a variety of fish and shellfish species. Annually, millions of migrating juvenile Pacific salmon and steelhead use the estuary for passage to the ocean, rearing, and feeding (Dawley et al. 1979, 1981; McCabe et al. 1983, 1986). Various anadromous and marine fishes, such as American shad (Alosa sapidissima), longfin smelt (Spirinchus thaleichthys), English sole (Parophrys vetulus), starry flounder (Platichthys stellatus), Pacific herring (Clupea harengus pallasi), and northern anchovy (Engraulis mordax) also feed and rear in the estuary (Durkin et al. 1981; Bottom et al. 1984). Moreover, the commercially- and recreationally-valuable white sturgeon (*Acipenser transmontanus*) feeds heavily in the estuary during the spring and summer, particularly when northern anchovies are abundant (Muir et al. 1988). Finally, the estuary provides valuable habitat for Dungeness crabs (*Cancer magister*) (Emmett and Durkin 1985; McCabe et al. 1988).

Use of the Columbia River Estuary by Salmonids

Extensive use of estuaries by juvenile salmonids has been reported in several river systems in North America (Reimers 1973; Healey 1980; Levy and Northcote 1982; Myers and Horton 1982; Levings et al. 1986). McCabe et al. (1986) reported that subyearling chinook salmon use the Columbia River estuary, particularly intertidal areas, for feeding. The Columbia River estuary also has been shown to provide sanctuary for juvenile salmonids from predators (McCabe et al. 1983). Reimers (1973) found increasing adult return rates of chinook salmon in the Sixes River correlated with increasing length of juvenile residence in the estuary.

Despite the documented importance of estuaries in the life history of certain species and races of juvenile salmonids, the results of at least one published study suggests that juvenile salmonids use the Columbia River estuary to a lesser degree that juvenile salmonid use other west coast estuaries. Dawley et al. (1986) and McCabe (unpublished data, P.O. Box 155, Hammond, OR.), using a variety of sampling gear at numerous locations throughout the estuary found that salmonids migrating in spring and summer from upriver areas more than 150 km from the river mouth spent little time in the estuary. Measurement of juvenile salmonid migration rates from release sites to and through the estuary, showed an average decrease of 30% as they entered the estuary. All or most of this may be explained by decreased water velocities associated with tidal action. (Average migration rate at a river flow of 11,300 m^3/s was 5.0 km/h from Bonneville Dam to RKm 79 and 3.5 km/h from RKm 79 to RKm 22 [Blahm 1974]).

Yearling chinook salmon tend to use the Columbia River estuary less than other juvenile salmonids (Dawley et al. 1986). Movement rates indicate only a 5% decrease in travel time during passage through the estuary (20 km/d to the estuary vs 19 km/d through the estuary). The period of capture in the lower estuary was generally the same as the duration observed for the same groups in the uppermost reaches of the estuary at Jones Beach. Movement rates from the estuary to ocean sampling sites have yet to be defined.

Although the brief residency of yearling spring chinook salmon in the Columbia River estuary suggests they have only a limited exposure to ambient estuarine environmental conditions, it also suggests they have limited migratory flexibility as a means of avoiding adverse conditions in the estuary and nearshore ocean. Such a situation emphasizes the need to obtain a better understanding of the relationships among estuarine and nearshore conditions and long-term survival.

Smolt Quality

Public hatcheries in the Columbia Basin rear between 200 and 300 million salmonids each year for release in the Columbia River and its tributaries. Of this total, about 25 to 30 million are spring chinook salmon. Despite these large releases, hatchery contributions are generally believed to be, as a whole, far below their potential. This is particularly true for spring chinook salmon. One factor thought to be contributing to this low potential is poor smolt quality. Hatchery release strategies are often based on economic and logistic considerations rather than the biological readiness of juvenile salmonids to migrate downstream and successfully enter seawater. At most Columbia Basin hatcheries, information on the quality (e.g., physiological and developmental status, infectious diseases) of smolts prior to and at release is not routinely obtained, even though health and physiological status prior to release are known to affect migration rate and, potentially, early marine survival. Hence, groups of smolts released from hatcheries at inappropriate times may suffer large losses from predation, slow migration and osmoregulatory dysfunction.

The relationship between smolt quality and long-term survival of selected populations of hatchery-reared spring chinook salmon is currently being investigated in the BPA-funded Smolt Quality Assessment. The primary focus of this study is a 3-plus year monitoring program in which selected measures of smolt quality will be determined at six Columbia Basin hatcheries during a 3- to 4-month period prior to release. The study hatcheries are Willamette, Klickitat, Warm Springs, Leavenworth, Dworshak, and Rapid River. The measures of smolt quality to be determined include gill Na^+-K^+ ATPase, plasma T_4 and T_3, plasma insulin, plasma cortisol, plasma glucose, liver triglycerides, skin guanine, liver glycogen, tissue water content, plasma water content, plasma total protein, and selected blood electrolytes (e.g., Na^+, Cl^-, K^+). Moreover, selected hematological parameters will be measured (e.g., hematocrit, white blood cell count) and tests will be conducted to assess immunocompetence. Samples will also be collected for a seawater challenge assay. In addition to these measured parameters, information will be available on disease status from the Augmented Fish Health Monitoring Program.

The overall goal of the Smolt Quality Assessment is to develop a weighted, composite index of fish quality that can be used for real-time adjustments in rearing practices to increase hatchery effectiveness. Notwithstanding the rigor of the experimental approach and the high potential of this project in meeting the experimental objectives, like all research projects, there are some additional questions that could be addressed in a timely and cost-effective way in a companion study. The companion study would focus on continued monitoring of smolt quality in the study hatchery populations as the fish migrate through the estuary and into the Pacific Ocean. Little or no information exists on the physiological changes occurring as yearling spring chinook salmon make the transition to seawater. Moreover, if the numbers of fish released from the target hatchery populations are large enough (i.e., ca. 400,000), an estimate of relative smolt survival to the estuary can be made. This would be particularly important information for interpreting findings from the Smolt Quality Assessment in the event long-term survival (i.e., adult returns) are low for a particular hatchery population or treatment. Such information could be used to determine whether the fish survived to the estuary. Finally, although smolt quality may be an extremely important factor influencing long-term survival, additional factors such as environmental conditions in the estuary and nearshore ocean may play critical roles in early ocean survival and therefore also influence long-term survival. Clearly the ability to relate smolt quality to long-term survival can best be accomplished in the context of a more complete understanding of all the factors influencing survival.

OBJECTIVES

The overall goal of the present research is to investigate and identify relationships among smolt quality, migrational behavior, environmental conditions, and survival of juvenile spring chinook salmon in the Columbia River estuary and nearshore ocean. A logic tree for the proposed research is shown in Fig. 1. The research is designed to be conducted in parallel with, and to complement and extend the understanding of smolt quality obtained in, the BPA-funded Smolt Quality Assessment. This will be accomplished by collection and testing of outmigrant fish from the same

Quality and Behavior of Juvenile Spring Chinook Salmon in the Columbia River Estuary and Nearshore Ocean

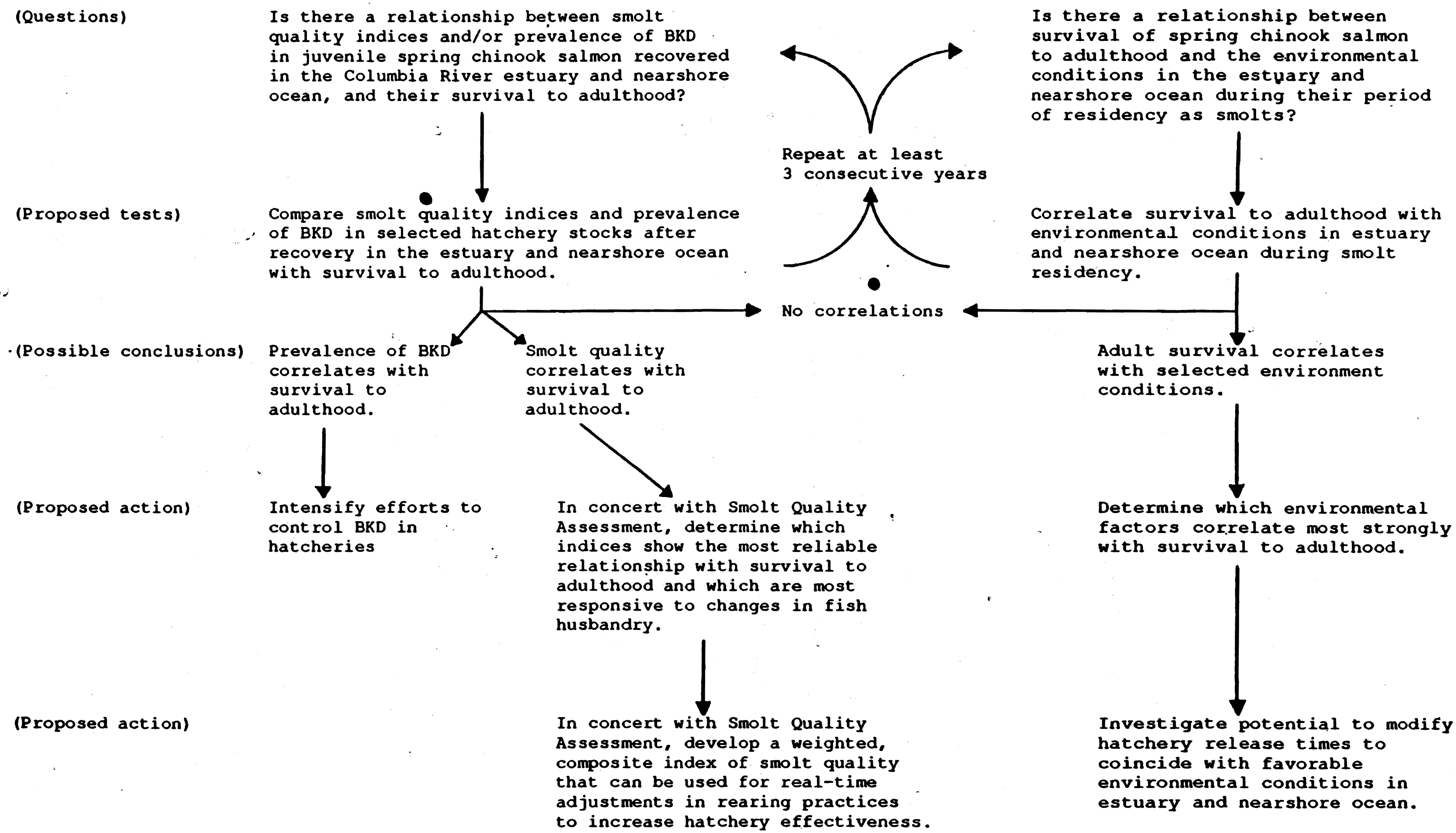

Figure 1.--Logic tree for research plan to investigate smolt quality, health, and behavior of juvenile spring chinook salmon in the Columbia River estuary and nearshore ocean.

populations/treatments under study in the Smolt Quality Assessment. Juvenile salmonids will be collected by beach and/or purse seine at two estuarine sampling stations, and in the nearshore ocean in and adjacent to the Columbia River plume. Physiological status of the target fish populations will be monitored by direct measurement of selected indices of smoltification, and by similar measurements made after transfer to, and short-term holding in, seawater. In addition, fish recovered at each of the sampling locations will be tested for BKD and stomachs will collected to determine stomach fullness and diet composition. As in the Smolt Quality Assessment, measures of smolt quality will be related to long-term survival based on returns of adults to the commercial, recreational, and tribal fisheries, and returns to the hatchery of origin. Research will also be initiated to examine relationships among selected estuarine environmental conditions, time of entry into seawater, and long-term survival.

Objective 1

Based on recapture percentages in the Columbia River estuary, estimate relative survival of selected stocks of juvenile spring chinook salmon tested in the Smolt Quality Assessment.

Null hypothesis (Ho): Relative survival of juvenile spring chinook salmon is not significantly different among hatchery populations or between hatchery treatments.

Corollary: If the null hypothesis is rejected, it is highly likely that survival to the estuary is different among hatchery populations or between hatchery treatments, and that these difference may be influenced by hatchery- or treatment-specific factors (e.g., physiological status, health, genetic background, rearing protocol, time and size at release, etc.).

Criteria for Rejecting Ho: The null hypothesis will be rejected if the relative survival is significantly different among populations or treatments by ANOVA ($P<0.05$). Significantly different groups will be identified by a multiple comparison test (e.g., S-N-K test).

Objective 2

Determine selected physiological parameters and prevalences of BKD in populations of spring chinook salmon tested in the Smolt Quality Assessment after recovery in the Columbia River estuary.

Null hypothesis (Ho): The physiological parameters or prevalence of BKD are not significantly different among hatchery populations or treatments.

Corollary: If the null hypothesis is rejected, it is highly likely that there are differences in physiological parameters or prevalences of BKD and that these differences may be related to hatchery- or treatment-specific factors.

Criteria for Rejecting Ho: The null hypothesis will be rejected if mean values or prevalences are significantly different among hatchery populations or treatments by ANOVA ($P<0.05$). Significantly different populations or treatments will be identified by a multiple comparison test.

Objective 3

Determine relative survival of juvenile spring chinook salmon from the hatchery populations or treatments under study in the Smolt Quality Assessment after a 7-day holding period in fresh water and seawater.

Null Hypothesis (Ho): Relative survival is not significantly different among hatchery populations or treatments.

Corollary: If the null hypothesis is rejected, it is highly likely that there are differences in relative survival and that these differences may be influenced by hatchery- or treatment-specific factors.

Criteria for Rejecting Ho: The null hypothesis will be rejected if survival is significantly different among hatchery populations or treatments by ANOVA ($P<0.05$). Populations or treatments which are significantly different will be identified by a multiple comparison test.

Objective 4

Determine selected physiological parameters and prevalence of BKD in populations of spring chinook salmon under study in the Smolt Quality Assessment during a 7-day holding period in fresh water and seawater following recovery at the upper estuarine sampling site.

Null Hypothesis (Ho): The physiological parameters or prevalence of BKD are not significantly different among hatchery populations or treatments.

Corollary: If the null hypothesis is rejected, then it is highly likely that there are differences in physiological parameters or prevalence of BKD and that these differences may be influenced by hatchery- or treatment-specific factors.

Criteria for Rejecting Ho: The null hypothesis will be rejected if the measured physiological parameters are significantly different by ANOVA ($P<0.05$). Hatchery populations or treatments that differ significantly will be identified by a multiple comparison test.

Objective 5

Determine selected physiological parameters and prevalence of BKD in populations of spring chinook salmon tested in the Smolt

Quality Assessment after recovery in the nearshore ocean in or adjacent to the Columbia River plume.

Null Hypothesis (Ho): The physiological parameters or prevalences of BKD are not significantly different among hatchery populations or treatments.

Corollary: If the null hypothesis is rejected, then it is highly likely that there are differences in physiological parameters or the prevalence of BKD and that these differences may be related to hatchery- or treatment-specific factors.

Criteria for Rejecting Ho: The null hypothesis will be rejected if the measured physiological parameters or prevalences of BKD are significantly different by ANOVA ($P<0.05$). Groups which differ significantly will be identified by a multiple comparison test.

Objective 6

Begin investigation of relationships among selected environmental parameters (e.g., salinity, temperature, current, turbidity, etc.) in the Columbia River estuary and nearshore ocean during smolt residency and long-term survival of selected populations of hatchery-reared spring chinook salmon tested in the Smolt Quality Assessment.

Null Hypothesis (Ho): There is no relationship among measured environmental parameters and long-term survival of spring chinook.

Corollary: If the null hypothesis is rejected, then it is highly likely that there is a relationship among environmental factors/conditions in the estuary and nearshore ocean, and long-term survival.

Criteria for Rejecting Ho: The null hypothesis will be rejected if significant correlations are detected by multivariate regression analysis ($P<0.05$).

Objective 7

Determine if single or multiple physiological parameters or prevalence of BKD measured in selected populations of juvenile spring chinook salmon tested in the Smolt Quality Assessment after recovery in the Columbia River estuary or nearshore ocean zone, or during a 7-day holding period in seawater, are different from the same parameter(s) or prevalence measured at the study hatchery prior to release.

Null Hypothesis (Ho): There is no significant difference between physiological parameters or prevalence of BKD when measured in the hatchery prior to release, or after recovery in the estuary or nearshore ocean or a 7-day holding period in seawater.

Corollary: If the null hypothesis is rejected, then it is highly likely that there are differences in physiological parameters or prevalence of BKD.

Criteria for Rejecting Ho: The null hypothesis will be rejected if mean values or prevalences are significantly different by ANOVA ($P<0.05$). Significantly different parameters or prevalences will be identified by a multiple comparison test.

Objective 8

Determine if single or multiple physiological parameters measured in selected populations of juvenile spring chinook salmon tested in the Smolt Quality Assessment Study after recovery in the Columbia River estuary or nearshore ocean zone, or during a 7-day holding period in seawater, are correlated with overall survival to adult stages.

Null Hypothesis (Ho): There is no significant correlation between measured physiological parameters and survival to adult stage among the study populations or treatments within or between years.

Corollary: If the null hypothesis is rejected, then measured physiological parameters may be related to long-term survival, and "high or low potential" stocks could be identified.

Criteria for Rejecting Ho: The null hypothesis will be rejected if a significant correlation ($P<0.05$) can be shown by regression analysis in consecutive years between adult returns and measured physiological parameters.

EXPERIMENTAL APPROACH

Outmigrant spring chinook salmon will be collected during 3 or more consecutive years between about 1 April and 15 July by beach and purse seine at two locations in the Columbia River estuary, and by purse seine in the nearshore ocean zone. The estuarine sampling will be conducted at Tongue Point (RKm 29) and Jones Beach (RKm 75) (Fig. 2). Tongue Point is at the upper extent of seawater intrusion in the Columbia River estuary and Jones Beach is physically the uppermost boundary of the estuary. A time series of data on juvenile spring chinook salmon migration past the Jones Beach site extending from 1978 to 1983 is available (Dawley et al. 1986).

Unlike the fixed-station sampling in the estuary, the ocean sampling will be conducted over a broad area in and adjacent to the Columbia River plume within about 8 km of the river bar. It is unlikely that large numbers of spring chinook salmon will be collected in the ocean, and hence a fixed-station approach would not provide the flexibility to make real-time adjustments in sampling

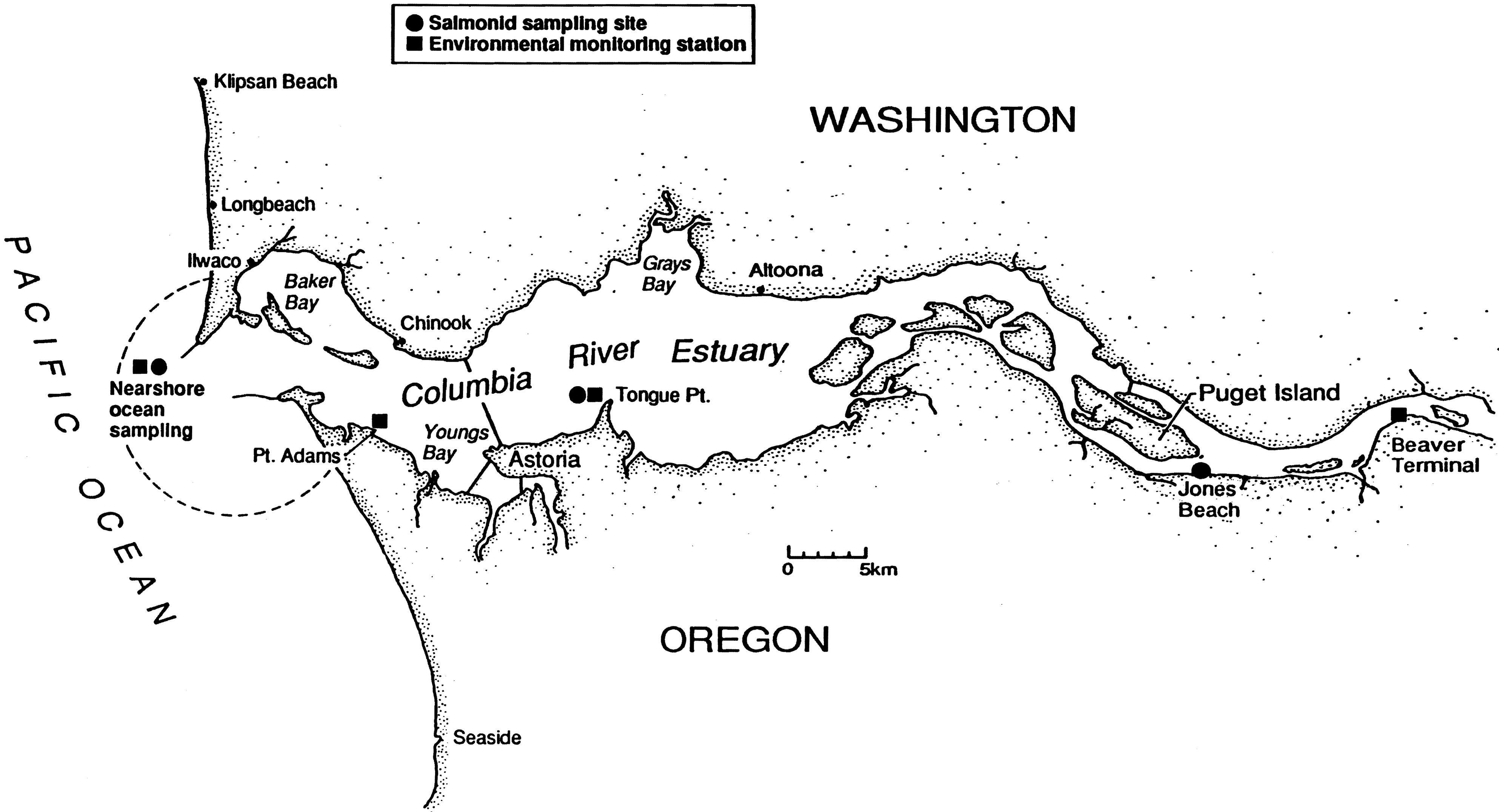

Figure 2.--Map showing locations of juvenile spring chinook salmon sampling stations and unmanned environmental monitoring stations in the Columbia River estuary and nearshore ocean.

required to obtain the largest possible numbers of fish. Moreover, rapid and dramatic shifts in weather and oceanographic conditions during the sampling period would likely limit sampling at selected locations, and every means of increasing the likelihood of collecting fish needs to be utilized.

The target fish will be from six Columbia Basin hatcheries and will be from the same populations/treatments tested in the BPA-funded Smolt Quality Assessment. Table 1 lists the study hatcheries, the numbers of spring chinook salmon to be released, the anticipated percentage recoveries of outmigrants in the estuary, and the expected adult production.

All yearling spring chinook salmon from the target hatcheries recaptured in the estuary and nearshore ocean will be weighed and measured, and their numbers recorded. The percentages recovered at the Jones Beach and Tongue Point sites will be used to estimate differences in relative survival to the estuary. The usefulness and validity of such estimates have been established and are discussed in detail in Dawley et al. (1986). In addition, samples of each hatchery population of fish will be collected at each of the three sampling locations for measurement of selected physiological parameters. The physiological parameters to be measured will included gill Na^+-K^+ ATPase, plasma Na^+, plasma T_4 and T_3. Fish will also be evaluated for morphological changes associated with smoltification. In addition, spleen and kidney samples will be collected from fish sampled at all locations to screen for the presence of antigens from, and hence exposure to, <u>Renibacterium</u>

Table 1. List of study hatcheries and numbers of yearly spring chinook salmon to be released in 1990. Also shown for each hatchery are ongoing hatchery effective experiments, and anticipated percent recoveries of juveniles in the Columbia River estuary and adult returns.

Size	Marks			Jones Beach			Tongue Point			Adults	
(no/lb)	Treatment	Rep.	Total	Date	%[a]	Total	Date	%[b]	Total	%	Total
Willamette Hatchery											
9	Mich.+O_2	6	180,000	15 Apr	0.23	414	23 Apr	0.12	216	1.7	3,060[a]
9	control	2	60,000	15 Apr	0.23	138	23 Apr	0.12	72	1.7	1,020
Klickitat Hatchery											
10	1wk riv accl	1	80,000	20 Apr	0.16	128	2 May	0.08	64	0.4	320
10	2wk riv accl	1	80,000	20 Apr	0.16	128	2 May	0.08	64	0.4	320
10	control	1	80,000	20 Apr	0.16	128	2 May	0.08	64	0.4	320
Warm Springs Hatchery											
12	high density	1	50,000	1 May	0.08	40	4 May	0.04	20	0.3	150
12	control	3	150,000	1 May	0.08	120	4 May	0.04	60	0.3	450
Leavenworth Hatchery											
15	US/Can index	3	240,000	25 May	0.09	216	28 May	0.05	120	0.25	600
		includes 50,000 branded									
Dworshak Hatchery											
7	Prod contrib	3	180,000	10 May	0.06	108	15 May	0.03	54	0.25	450
		includes 60,000 branded									
Rapid River Hatchery											
20	US/Can index	3	300,000	5 May	0.08	240	10 May	0.04	120	0.15	540
20	FPC smolt id	1	60,000	5 May	0.08	48	10 May	0.04	24	0.00	0

[a] Expanded to represent current efficiency levels--1.5 x catch rates from 1977 through 1983.
[b] One half of catch rate anticipated at Jones Beach.

salmoninarum. Further, stomach contents of the sampled fish will be analysed to determine diet composition and stomach fullness.

For determination of physiological parameters, three 15-fish samples collected at 1-week intervals will be taken at the upper estuarine station, while single 15-fish samples will be taken at the lower estuarine site and during the nearshore ocean sampling. In addition, a sample of up to 150 fish from selected populations will be collected at the upper estuarine site for extended holding. About 50 fish will be held in flowing river water at or near the Jones Beach site. An additional 100 fish will be transferred to a fish holding facility near the mouth of the Columbia River where 50 fish will be held in fresh water and 50 will be held in seawater. At intervals of 24, 72 and 168 hours after capture and transfer, 15-fish samples from each group will be sacrificed for the determination of same physiological parameters measured in the field sampling.

The mean and variance of each of the measured parameters will be determined. These data will be compared among hatcheries by ANOVA and, as appropriate, a multiple comparison test. All data will be stored for subsequent correlation analysis to investigate the relationships between individual or related physiological parameters and total contribution based on returns of marked adults to the commercial, recreational, and tribal fisheries, and to the hatchery of origin.

Estuarine and nearshore ocean environmental conditions will be monitored at each of the fish sampling locations (Jones Beach, Tongue Point, and nearshore ocean) and at three additional unmanned sites in the Columbia River estuary. These latter sites will be at existing tide-recording stations at Point Adams, Tongue Point, and Beaver Terminal (Fig. 1). Physical/chemical parameters to be monitored at the estuarine fish sampling sites include water temperature, salinity, turbidity, pH, dissolved oxygen, and current (direction and velocity). At the unmanned stations the parameters to be measured include tide level, current, temperature, salinity, and surface wind (direction and velocity). In conjunction with the nearshore ocean sampling, seawater temperature, salinity, and turbidity will be recorded. Additional biological parameters that could be measured include chlorophyll-a and zooplankton density. In the longterm, we anticipate that these data can be used to construct a multivariate model to identify relationships among estuarine environmental conditions, salmonid entry into seawater, and salmonid survival and contribution to the ocean fisheries.

A critical issue that needs to be addressed as this research plan is refined is that of the statistical precision desired in estimating differences in survival of juvenile spring chinook salmon among hatchery populations and hatchery treatments. The precision of such estimates, as well as the ability to meet the proposed estuarine and nearshore sampling goals, depends on the numbers of marked (coded wire tagged and cold branded) fish released. As indicated in Table 1, several of the study hatcheries are planning to release fish marked only with coded wire tags. Since the fish from the target hatcheries must be visually identified when recovered, as a minimum, all fish to be coded wire tagged should also be cold branded. This modification will result in the largest sample size possible within the existing hatchery release plans.

In addition to branding all tagged fish, consideration must also be given to increasing, where feasible, the total numbers of marked fish to be released from each of the study hatcheries. The differences in survival that will be detectable between treatments or hatcheries (within and between years) are summarized in Table 2. These differences were calculated using the equation of Cochran and Cox (1957) for sample size estimation using a critical value of $P<0.05$. It is clear from this summary that only very large differences in estimated relative survival will be detectable in between-treatment comparisons (21 to 37%). Equally clear is that only relatively large differences in estimated survival to the estuary used in between-hatchery and within-year comparison will be statistically distinguishable (i.e., 15% or larger).

Based on the above analysis, it is recommended that the following increases in numbers of marked fish be considered. These changes in numbers would allow detection of at least 15% differences in estimated survival in between-hatchery and between-year comparison.

1) Klickitat: additional 28,150 control/production fish
2) Leavenworth: additional 220,000 index/production fish
3) Rapid River: additional 176,000 index/production fish
4) Dworshak: additional 535,000 contribution/production fish
5) Willamette: no additional marked fish required

Table 2.--Anticipated precision of between-treatment, between-hatchery, and between-year comparisons ($P \leq 0.05$) of relative survival of selected groups of spring chinook salmon to the Columbia River estuary. Estimated differences were calculated according to Cochran and Cox (1957) and assume all coded wire tagged fish were also cold branded to allow visual identification. The between-hatchery and between-year comparisons could be made using all marked fish from a given hatchery only if no between treatment differences were detectable.

Between-Treatment Comparisons

Hatchery	Recovery	n_1	n_2	Percent difference
Willamette	0.0035	60,000	180,000	21
Klickitat	0.0024	80,000	80,000	27
Warm Springs	0.0012	150,000	50,000	37

Between-Hatchery and Between-Year Comparisons

$Hatchery_1$	$Hatchery_2$	Recovery	n_1	n_2	Percent difference
Willamette	Willamette	0.0035	240,000	240,000	13 year vs year
Willamette	Klickitat	0.0035	240,000	240,000	13
Willamette	Warm Springs	0.0035	240,000	200,000	14
Willamette	Leavenworth	0.0035	240,000	240,000	13
Willamette	Rapid River	0.0035	240,000	360,000	12
Willamette	Dworshak	0.0035	240,000	180,000	14
Klickitat	Klickitat	0.0024	240,000	240,000	16 year vs year
Klickitat	Warm Springs	0.0024	240,000	200,000	17
Klickitat	Leavenworth	0.0024	240,000	240,000	16
Klickitat	Rapid River	0.0024	240,000	360,000	14
Klickitat	Dworshak	0.0024	240,000	180,000	17
Leavenworth	Leavenworth	0.0014	240,000	240,000	20 year vs year
Leavenworth	Warm Springs	0.0014	240,000	200,000	21
Leavenworth	Rapid River	0.0014	240,000	360,000	19
Leavenworth	Dworshak	0.0014	240,000	180,000	22
Warm Springs	Warm Springs	0.0012	200,000	200,000	24
Warm Springs	Rapid River	0.0012	200,000	360,000	21
Warm Springs	Dworshak	0.0012	200,000	180,000	25
Rapid River	Rapid River	0.0012	360,000	360,000	18 year vs year
Rapid River	Dworshak	0.0012	360,000	180,000	22
Dworshak	Dworshak	0.0009	180,000	180,000	29 year vs year

6) Warm Springs: additional 336,000 control/production fish

(Note: The increased numbers of fish recommended for each hatchery are dependent on the indicated increases at all the hatcheries. If logistical or other constraints prevent the marking of additional fish at any one hatchery, the recommended numbers at the remaining hatcheries will need to be revised.)

The following is a summary of the proposed research plan in the format of specific tasks and subtasks:

Objectives 1,2,7,and 8

TASK 1 Collect outmigrant spring chinook salmon at two locations in the Columbia River estuary (an upper and lower station) using beach and/or purse seine.

TASK 1.1 Enumerate outmigrants from each of the study populations and treatments; estimate relative survival based on recovery of branded fish.

TASK 1.2 Weigh and measure fish; sacrifice and collect blood, tissue and stomach samples for measurement of selected physiological parameters, testing to estimate prevalence of BKD, and stomach contents analysis.

TASK 1.2.1 Measure gill Na^+-K^+ ATPase according to Zaugg (1982), plasma T3 and T4 according to Dickhoff et al.

(1982), serum Na^+, liver glycogen, and hematocrit. N = 15 fish per sample.

TASK 1.2.2 Determine morphological changes associated with degree of smoltification using the procedure of Winans and Nishioka (1987). N = 15 fish per sample.

TASK 1.2.3 Estimate prevalence of BKD using the enzyme-linked immunosorbent assay of Pascho and Mulcahy (1987) to detect soluble antigen(s) of *Renibacterium salmoninarum* in kidney and spleen tissue. N = 15 fish per sample.

TASK 1.2.4 Determine stomach fullness (Terry 1977) and taxonomic composition of stomach contents.

Objectives 3,4,7 and 8

TASK 2 Collect outmigrant yearling spring chinook salmon at an upper Columbia River estuary site; from selected hatchery populations or treatments tested in the Smolt Quality Assessment hold about 50 fish at the site of recapture at Jones Beach in river water and transfer about 100 to a lower estuary holding facility for holding in fresh water and seawater.

TASK 2.1 Record percent survival in each group after 24, 72, and 168 hours.

TASK 2.2 Sacrifice 15 fish from each group and collect blood and tissue samples for measurement of selected physiological parameters and estimates of prevalence of BKD after 24, 72, and 168 hours.

TASK 2.2.1 Measure gill Na^+-K^+ ATPase according to Zaugg (1982), plasma T3 and T4 according to Dickhoff et al. (1982), serum Na^+, liver glycogen, and hematocrit. N = 15 fish per sample.

TASK 2.2.2 Determine morphological changes associated with degree of smoltification using the procedure of Winans and Nishioka (1987). N = 15 fish per sample.

TASK 2.2.3 Estimate prevalence of BKD using the enzyme-link immunosorbent assay of Pascho and Mulcahy (1987) to detect soluble antigen(s) of *Renibacterium salmoninarum* in kidney and splenic tissue. N = 15 fish per sample.

Objectives 5,7 and 8

TASK 3 Collect outmigrant juvenile spring chinook salmon in the nearshore ocean in and adjacent to the Columbia River plume.

TASK 3.1 Enumerate, weigh, and measure juvenile spring chinook salmon from each of the study populations or treatments.

TASK 3.2 Sacrifice up to 15 fish per group and collect blood, tissue, and stomach samples for measurement of selected physiological parameters, estimation of prevalence of BKD, and stomach contents analysis.

TASK 3.2.1 Measure gill Na^+-K^+ ATPase according to Zaugg (1982), plasma T3 and T4 according to Dickhoff et al. (1982), serum Na^+, and hematocrit. N = 15 fish per sample.

TASK 3.2.2 Determine morphological changes associated with degree of smoltification using the procedure of Winans and Nishoika (1987). N = 15 fish per sample.

TASK 2.2.3 Estimate prevalence of BKD using the enzyme-linked immunosorbent assay of Pascho and Mulcahy (1987) to detect soluble antigen(s) of *Renibacterium salmoninarum* in kidney and spleen tissue. N = 15 fish per sample.

TASK 2.2.4 Determine stomach fullness (Terry 1977) and taxonomic composition of stomach contents.

Objective 6

TASK 4 Monitor selected environmental parameters at each sampling location and at three additional unmanned stations in the Columbia

River estuary (Point Adams [RKm 5], Tongue Point [RKm 29], Beaver Terminal [RKm 79]).

TASK 4.1 Measure water temperature, salinity, turbidity, dissolved oxygen concentration, pH and current (velocity and direction) during sampling at each of estuarine collection sites.

TASK 4.2 Record water temperature, salinity, tide level, current, and surface wind direction and velocity at the unmanned estuarine stations.

TASK 4.3 Record seawater temperature, salinity, and turbidity during sampling at each nearshore ocean sampling site. (Additional meaningful biological parameters that could be measured include chlorophyll-a and density of zooplankton).

Objectives 1 through 8

TASK 5 Assemble and store data.

TASK 5.1 Assemble and store data from estuarine and nearshore sampling.

TASK 5.2 Assemble and store data on estuarine environmental parameters/conditions.

TASK 5.3 Assemble and store data on adult returns to the commercial, recreational, and tribal fisheries, and hatchery of origin of all study populations of spring chinook salmon.

Objectives 1 through 8

TASK 6 Analyze data and prepare required administrative reports and manuscripts for publication in peer-reviewed literature.

ANTICIPATED BENEFITS

This research plan is designed to generate important new information on the influence of smolt quality and estuarine and nearshore ocean environmental factors on long-term survival of spring chinook salmon. It is anticipated that this new information can be used by hatchery, river, and ocean fisheries managers to better predict and enhance the production of spring chinook salmon in the Columbia River and its tributaries. It is important to note, however, that the potential of these data to identify factors contributing to long-term survival will come only after multiple years of study and after trends in adult production at the target hatcheries can be related to smolt quality and environmental conditions at the time of entry into seawater. One year of data may provide insight into differences in relative survival (based on estuarine recapture) between treatment groups at an individual hatchery; however, comparisons among hatcheries in a single year will not be particularly meaningful. It is anticipated that trends in hatchery production can be related to the measured parameters only after 3 to 5 years of continuous data collection. In addition, since results of the physiological testing conducted in the estuary and nearshore ocean must be evaluated in the context of similar testing at the target hatcheries prior to and at the time of release, it is essential that this research be conducted concurrently with the Smolt Quality Assessment.

One of the most important products of this research will be new data on smolt quality (based on selected physiological parameters and prevalence of BKD) in stocks of spring chinook salmon as they enter and pass through the Columbia River estuary and enter the ocean phase of their life cycle. Such information, taken together with similar data collected on the same stocks and treatment groups of spring chinook salmon prior to and at the time of hatchery release (obtained in the Smolt Quality Assessment) will provide the most complete picture of smolt quality obtained to date. The ability to relate these data to long-term survival based on returns to the hatcheries of origin, and contributions to the commercial, recreational, and tribal fisheries offer several potential benefits. For example, knowledge of how smolt quality relates to adult production could be used to identify hatchery stocks or brood years of "high or low potential." This information could be used in the estimation of adult returns 1 to 3 years before a particular stock returns, and hence provide a means for better managing and allocating this important ocean and river fishery.

In addition to using smolt quality to identify hatchery stocks, treatments, or brood-years more likely to survive to adulthood, a better understanding of smolt quality and its relation to long-term survival offers the potential to increase overall survival. Previous studies have suggested the ability to control, and to a limited extent manipulate, selected physiological parameters associated with smoltification (and hence readiness to migrate) by rearing practices such as modified photoperiods, diets, and holding densities. Therefore, the potential exists to enhance production of harvestable adults through the use of hatchery rearing strategies or practices that correlate with higher returns.

The estimates of relative survival of the target hatchery populations and treatment groups to the Columbia River estuary will be another important product of this research, particularly in the interpretation of findings in the Smolt Quality Assessment. These data will allow preliminary assessments of the relationships among smolt quality and prevalence of BKD (as measured at the hatcheries prior to and at time of release) and short-term river survival. Moreover, in hatchery stocks or treatments where poor ocean survival and small group numbers lead to poor adult returns, the estimates of estuarine survival would be critical in determining whether the juveniles survived to the estuary.

Another major benefit of this research will be the development of the first multi-year data base of environmental conditions in the Columbia River estuary and nearshore ocean, in and adjacent to the plume. Such a data base is a prerequisite for developing a better understanding of the influence of estuarine and nearshore environmental factors on early ocean survival of spring chinook salmon. Data collected on estuarine and particularly nearshore environmental conditions during the period of seawater entry can be related to adult survival.

The importance of these types of data for better salmon harvest management was highlighted recently by the Pacific Fisheries Management Council. The Council placed "long- and short-term relationships between ocean environmental conditions and fluctuations in abundance and maturation of chinook and coho salmon" as one of its highest priority research needs. The Council cited the substantial predictive errors in forecasts of salmonid year-class abundance based on previous year returns, and apparent large scale multi-stock fluctuations in abundance as a continuing obstacle in the timely and effective management of the west coast salmon fishery.

To summarize, this research program has the potential to add substantially to the knowledge of relationships among smolt quality, estuarine and nearshore environmental conditions, and adult production of spring chinook salmon. This knowledge should substantially increase the ability to estimate year-class strength and hence better manage the existing stocks. More importantly, it has the potential to identify factors (physiological and environmental) influencing the numbers of harvestable adults. Control and manipulation of these factors affords the greatest potential for increasing the contribution of spring chinook salmon to the Columbia Basin salmonid resource.

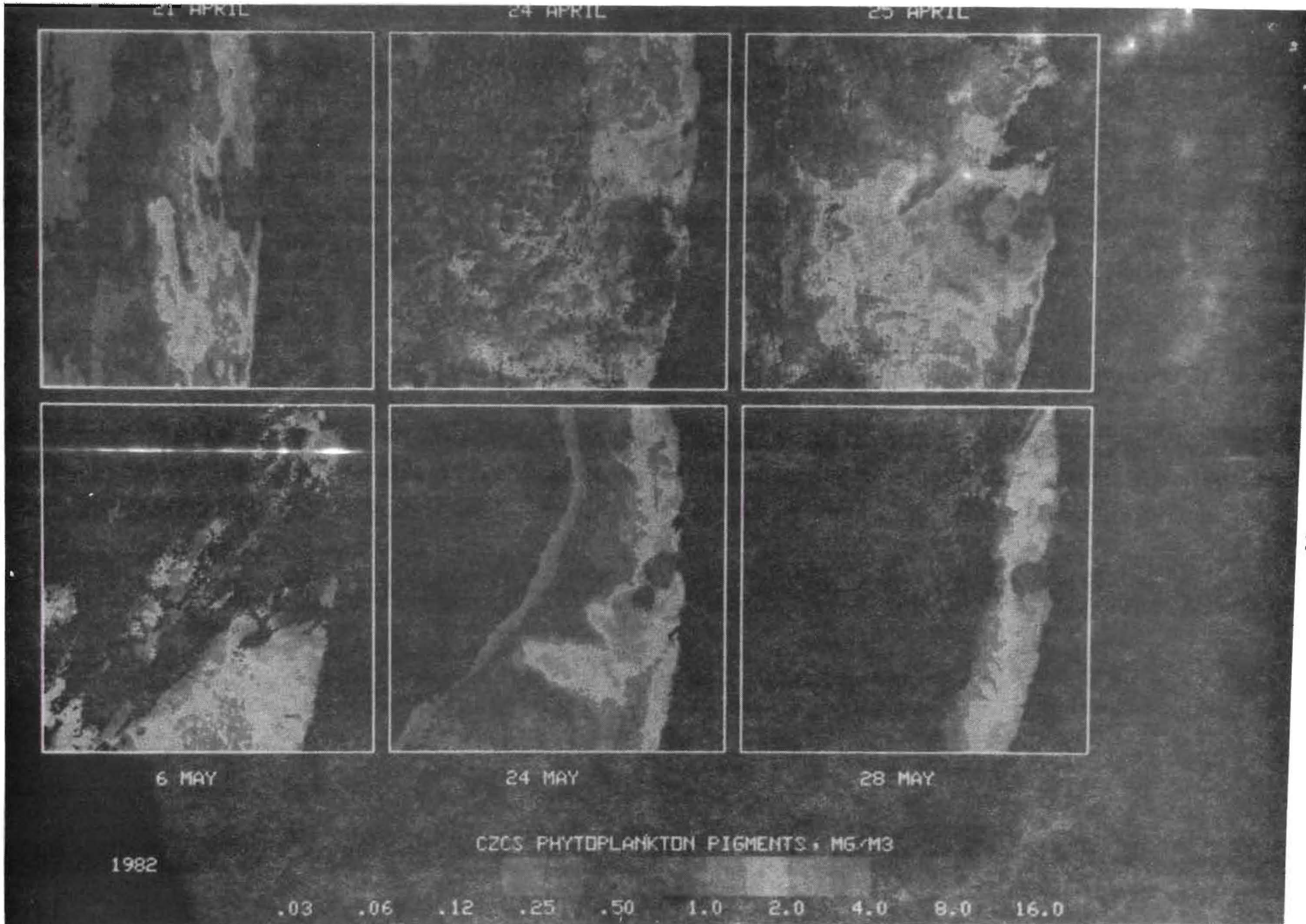

Figure 3. Time series of CZCS images illustrating changes in the Columbia River plume during spring transition in 1982. Colors indicate increasing phytoplankton pigment concentrations: Purples (<0.1 mg m^3), blues (0.1-0.4), greens (0.4-1.5), yellow and oranges (1.5-4.0), reds (>4.0). From Fiedler and Laurs, in rev.

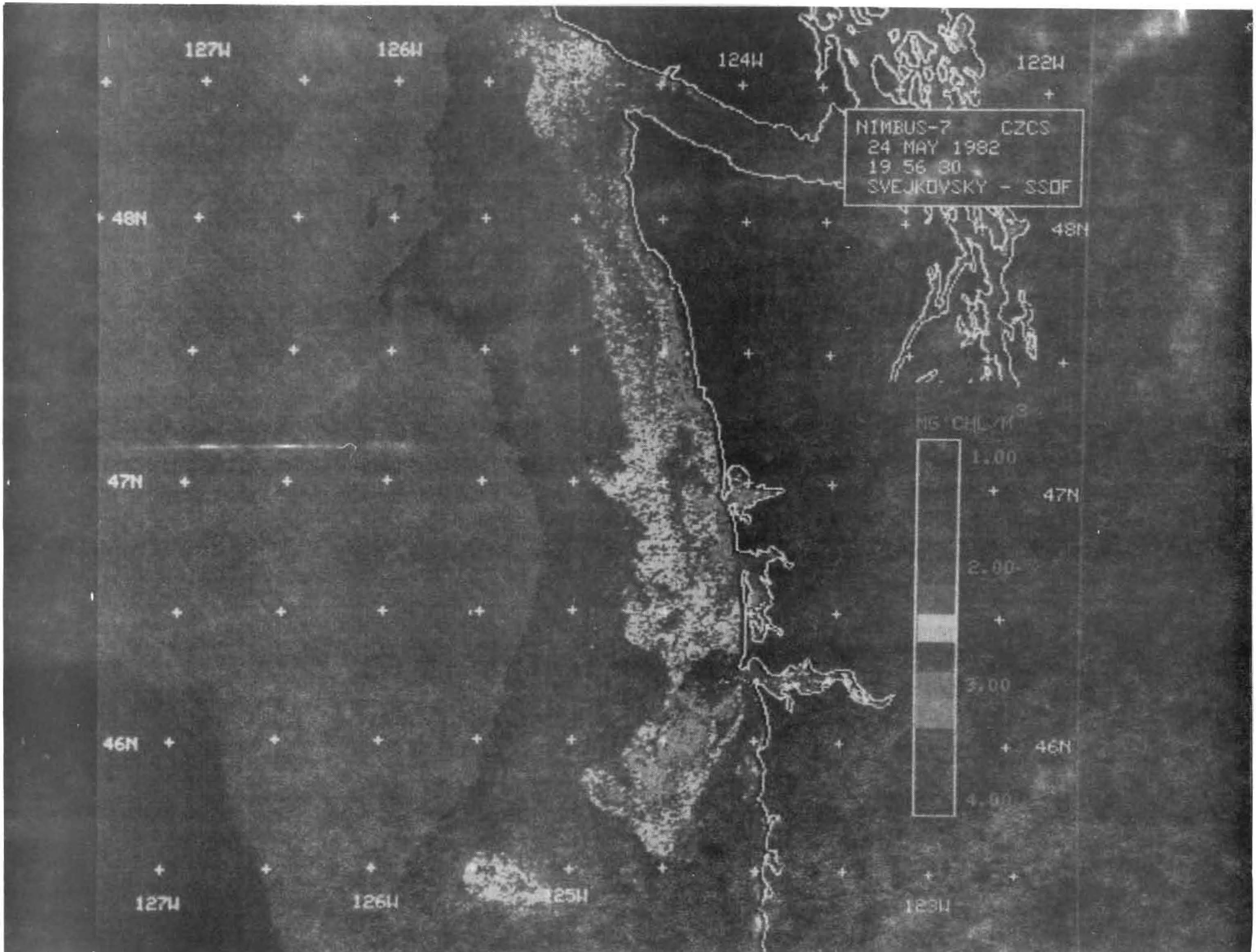

Figure 4. CZCS image observed in late May 1982 showing nearshore oceanic region between central Oregon and

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RESEARCH PLAN

Effects of the Ocean Environment on the Survival of
Columbia River Juvenile Salmonids:

by

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CONTENTS

INTRODUCTION

One of the major goals of the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program is to "double salmon and steelhead runs in the basin." In order to do this, the agencies responsible for power, water and fish management in the basin have embarked on a massive program to evaluate the potential for enhanced salmonid production. Three areas that are being carefully studied are (1) downstream passage of juvenile salmonids through or around power projects, (2) improved hatchery effectiveness, and (3) improved natural production of salmonids through habitat improvements.

With respect to item (2), the Northwest Power Planning Council emphasized the importance of improving the effectiveness of hatcheries through the release of better-quality smolts. Work is currently under way to test physiological condition and follow the physiological development of spring chinook salmon produced over a three-year period at four hatcheries in the basin. Different treatments will collectively produce an array of spring chinook smolt populations which may differ in age, gene pool, size, health, and physiological development. Data on physiological condition will ultimately be correlated with overall survival of released groups, based on the analysis of coded wire tag recoveries of juveniles in the estuary and nearshore ocean, and of adults in the fisheries and upon return to the hatcheries.

There is considerable evidence (Pearcy 1984; Nickelson 1986; Bottom, et al., 1986) that changes in the ocean environment have a major influence in effecting changes in overall smolt to adult survival of salmonids throughout their range. In order to evaluate the effects of hatchery conditions, reflected through the sampling of smolt physiology, on subsequent survival one should be able to remove any effects of changes in ocean conditions on survival over the time period sampled. We have therefore performed pilot studies to identify key environmental variables which appear to correlate with marine survival of West Coast salmonids. We have evaluated both the space and the time scales of critical environmental influences on survival of stocks ranging from British Columbia to California.

To be more specific, four main tasks have been accomplished in this part of the overall preliminary research project.

1. Examination of survival histories, by ocean entry year, of spring chinook salmon produced in Columbia River hatcheries, as well as those produced by selected hatchery systems ranging from California to coastal Oregon and British Columbia.

2. Compilation of time series of environmental variables that may affect the ocean survival of salmon.

3. Correlation of survival and environmental time series to determine the spatial and interannual dimensions of responses of salmonid production (survival) to major environmental keys. In particular, we explored whether Columbia River salmonid survival responds primarily to localized or to larger-scale regional or to global environmental keys.

4. Formulation of a conceptual survival model for Columbia River salmonids with particular emphasis on environmental conditions occurring during the early ocean phase of the life history.

BACKGROUND RESULTS

Trends in Survival of Chinook Salmon

We compared between-brood trends in survival of chinook salmon released from hatcheries in different areas from northern California to the west coast of Vancouver Island. Similar between-brood patterns in survival for fish released in different river systems or different geographic areas would be evidence for large-scale weather or ocean conditions affecting survival over a wide area.

Survival of release groups of coded-wire tagged (CWT) fish were examined since accurate catch and escapement data were available for these tag groups. Those hatcheries and stocks for which complete time series of releases of tagged fish were available from

1979 to 1984 are presented in Table 1. Unfortunately, long time series were generally not available for tagged fish. As an index of survival for coastal California and Oregon groups we used the total recoveries (at all ages) of a tag group in ocean and freshwater fisheries and in returns to hatcheries divided by the total release of fish in the tag group. For several Columbia River and the Robertson Creek, B. C., stocks data from a cohort analysis of these groups produced by the Chinook Technical Committee of the Pacific Salmon Commission (H. Schaller, Columbia River Inter-Tribal Fish. Comm., 975 S. E. Sandy Boulevard, Portland, OR 97214, pers. commun.) were used to evaluate survival. For these groups both estimated survival to age 2 as well as total catch, escapement and incidental fishing mortalities were used to estimate survival. Total recoveries at all ages should be a relative index of survival between broods if the age distribution of fish in the fisheries and in freshwater escapement is also fairly constant between broods. Trends in estimated survival between broods to age 2 from cohort analyses agreed quite well with between-brood trends in total recoveries of tags for six Columbia River stocks and the Rogue River stock, indicating that using total recoveries is probably a valid method for comparing survival between broods for most groups (see Fig. 1).

When several tag groups represented a brood, an average survival index was calculated for the brood, with each tag group having equal weight (except for the data from the Pacific Salmon Commission where a different weighting procedure was used). Between-year comparisons of survival were made within hatchery or stock groups for fish released at a similar size and at about the same time of year. Most of the CWT recovery data were obtained from a data base maintained by the Pacific Marine Fisheries Commission (Regional Mark Processing Center, Pacific Marine Fisheries Commission, 2000 S. W. First Avenue, Portland, OR 97201). Other data were obtained from state and federal fisheries agencies and from the Chinook Technical Committee of the Pacific Salmon Commission. The data presented in this report should be considered preliminary.

Fall and spring chinook salmon released at a large size from late summer through early winter in northern California and southern Oregon had strikingly similar trends in survival. Survival was usually highest among fish released in 1984 and lowest or next to lowest among fish released in 1982 (Fig. 2, Table 2). Survival trends were similar for fish released in widely separated river systems, suggesting that survival in these years was affected by weather or ocean conditions influencing a wide area. Those fish released in the fall of 1982 entered the ocean during the 1982-1983 El Nino. During the first three months of 1983, downwelling was the strongest of any year from 1979 to 1984 (Mason and Bakun 1986). With the exception of fish from Elk River hatchery, these stocks from northern California and southern Oregon are thought to spend their entire lives in local waters (Nicholas and Hankin 1988).

In contrast to California and southern Oregon stocks, no consistent trends in survival were apparent for fall or spring chinook salmon released in the Columbia River system and from the Robertson Creek Hatchery, B.C., usually at small sizes (Fig. 1, Table 3). Survival trends for two stocks (Cowlitz fall and upriver bright fall chinook salmon) were similar to the trend for southern Oregon and California stocks: High survival for fish released in 1984 and low survival for fish released in 1982. It is interesting to note that these are the latest released of the Columbia River chinook for which adequate tag data were available. However, survival among the other Columbia River and the Robertson Creek groups was lower in 1984 than in other years.

The difference in survival trends between Columbia River-Robertson Creek chinook released from May through August, and California-coastal Oregon chinook released later in the year from July through December may be related to different timing of ocean entry. Dawley, et al. (1986), found that downstream migration rates of subyearling chinook in the Columbia River were rapid with only slight slowing in the lower estuary. They concluded that subyearling chinook did not rear in the Columbia River estuary for extended periods. Peak migration of subyearling chinook past river kilometer 75 occurred in June and July. Upriver bright fall chinook salmon released far upstream at Priest Rapids spawning channel (rkm 640) generally passed river kilometer 75 within 1-1.5 months of release (Dawley, et al., 1985). In addition, small subyearling chinook were collected in nearshore areas of the ocean from May through September (Dawley, et al, 1981). Thus subyearling chinook released in the Columbia River from May through August probably entered the ocean earlier than coastal California and Oregon groups released later from August through December. Timing of ocean entry may therefore explain poor survival of fall chinook in 1984 from most northern hatcheries. Conditions in the ocean late in 1984 or early in 1985 may have promoted high survival, but conditions for survival were apparently not as good for fish entering the ocean earlier in 1984.

- Preliminary data on catches of fish through age 3 (incomplete cohort) show significant increases in survival for fall chinook released in spring and summer 1985 from Stayton Pond and Bonneville hatcheries over survival rates of fish released in spring and summer of 1984.

Few long time series were available for coastal Oregon chinook salmon originating north of Elk River; however, unlike the southern stocks, none of these groups, which are known to be more migratory, had exceptionally high survival among fish released in 1984.

Summaries of survival rate estimates for mid-Columbia River spring chinook (Raymond 1988), Columbia River fall chinook (Fresh, et al., 1987), and OPI coho (Nickelson 1986) are also given in Figure 3.

Two trends are apparent from these survival estimates. First, a major decline in survival occurred in the mid-1970s (around 1976) for Columbia River stocks entering the ocean in the spring and summer of the year (coho, spring chinook). This decline has persisted for nearly a decade. Second, incomplete cohort data indicate a major increase in survival may have occurred over a broad range of the coast in 1984 for stocks (both fall and spring chinook) released in the second half of the year, and in 1985 for stocks (fall and spring chinook, coho) released in the first half of the year. One would expect that both of these effects were stimulated by large-scale environmental events.

Trends in the Ocean Environment

Between 1976-1977 and the present, significant warming has occurred in the ocean environment of the North Pacific (Fig. 4) (McLain 1984; Norton, et al., 1985) impacting fisheries production from California to Alaska. For example, in 1977, Alaska salmon production jumped to high levels not seen for decades. Figure 5 shows the time of the spring transition (calculated from Bakun upwelling indices) at 48 deg. N, 45 deg. N, and 42 deg. N. In 1976 (at 48 deg. N and 45 deg. N), and in 1977 (at 42 deg. N), major changes in the coastal ocean environment occurred: Weaker upwelling and later spring transition (by 20-30 days) off Washington, Oregon, and California occurred in the decade 1977-1986, in comparison with the decade 1967-1976.

	Mean Spring Transition Date	
	1967-76	1977-86
48 deg. N	17 Apr	16 May
45 deg. N	13 Apr	15 May
42 deg. N	4 Apr	23 Apr

These changes were accompanied by warmer ocean temperatures (Fig. 4). In 1985, the year of enhanced regional salmonid production, upwelling intensity was higher than any year 1983-1987 (Fisher and Pearcy 1988, unpubl.) and the spring transition was relatively early, particularly in the south.

Influence of Ocean Environment on Coastal Salmonid Production

In this section, we speculate how major environmental shifts might have affected coastal salmonids, and to be more specific, which oceanic factors or conditions are favorable for early ocean survival of West Coast salmonids.

We hypothesize that the ocean environment influences salmonid production from the Columbia River in several ways. First, survival is favorable if ocean entry occurs after the spring transition and prior to the fall transition. Timing of the spring transition and cumulative upwelling volume are correlated, but the relationship is clearly non-linear (Fig. 6).

Second, we hypothesize that survival is favorable when the percentage of cool subarctic water is high in the coastal zone. The mechanisms for cross-shelf transport of subarctic waters from the California Current are uncertain, but during northern El Ninos, warm waters are advected onshore (downwelling), the thermocline is depressed, and upwelling is ineffective. Bottom (1986) hypothesizes that during such years the subarctic boundary and high abundances of zooplankton retreat to the north (Fig. 7). These two hypotheses are closely related.

One more physical factor which certainly could have a major impact on Columbia River salmonid production is river flow. Figure 8 shows maximum, minimum, and mean annual flows (1,000 m^3/sec) for both the Columbia River and the Fraser River. The major difference between the two systems occurs in peak flow, a factor which has a major influence on sedimentation in the estuary and spring outmigration. Peak flow in the Columbia declined steadily during the 1960s and 1970s, while it remained fairly constant in the Fraser. Figure 9 shows monthly Columbia River flows from 1950 to 1978. The spring peak declined beginning in 1975. During May and June 1985, Fisher and Pearcy (1985) caught 113 juvenile chinook and 34 juvenile coho salmon with coded wire tags from Columbia River hatcheries in purse seines off Oregon and Washington. During this good survival year most of the chinook were caught within 10 km north or south of the Columbia River, suggesting that they were associated with the Columbia River plume. The volume and distribution of the Columbia River plume needs to be considered when trying to understand physical effects on the survival of Columbia River salmonids.

Finally, one factor that may play an important role in determining the survival of coastal salmonids is the number of smolts entering the nearshore ocean. For coho, the debate has been joined for years. McGie (1984) suggested that density-dependent mortality occurred in times of unfavorable oceanic conditions. Nickelson (1986), in a reanalysis of the data, concluded that marine survival of coho smolts that migrated into the OPI area was density independent. The crux of the disagreement seems to rest on whether one assumes mixing in the nearshore ocean of wild and hatchery coho. Fresh, et al. (1987), suggest that survival of hatchery and wild fall chinook in the Columbia River is density dependent. In the late 1960s and early 1970s, survival certainly dropped when smolt production increased (Fig. 3). Figure 10 shows estimated OPI coho survival for hatchery and wild fish separately as a function of total smolts produced and plotted separately for strong upwelling and weak upwelling during the period of smolt outmigration. Taking these estimates at face value one might surmise that smolt density affects survival of both hatchery and wild fish under unfavorable environmental conditions but not under favorable environmental conditions. Furthermore, it appears that hatchery fish are much more severely affected under unfavorable environmental conditions than wild fish. This tends to partially corroborate the recent work of Peterson and Black (1988), who hypothesize that individuals previously stressed (e.g., hatchery fish) may be more susceptible to subsequent density-dependent mortality following an additional physical stress (e.g., unfavorable early ocean environment).

To summarize, there is evidence that Columbia River salmonid production responds to large-scale regional or global environmental factors. The major shifts in North Pacific salmonid production in the ;mid-1970s--increases at the northern extremes of the range (e.g., West Coast)--and the coherent spike of increased coastal production for coastal salmonids entering the ocean in fall 1984 and spring 1985 seem to bear this out.

Our conceptual model of Columbia River salmonid production is driven by:

(a) The timing of the spring and fall nearshore ocean transitions and the intensity of coastal upwelling in the spring and summer.

(b) Coastal circulation and the input of subarctic water on the continental shelf.

(c) The timing and magnitude of Columbia River peak flow and the structure of the Columbia River plume.

(d) The timing, magnitude, and dynamics of the entry of hatchery and wild smolts into the highly variable nearshore ocean environment.

OBJECTIVES

It is quite clear in our minds that survival of Columbia River salmonids is strongly influenced by both abiotic and biotic conditions occurring at the time of the entry of juveniles into the ocean. Environmental driving variables appear to affect salmonid stocks from California to Alaska and occur on both annual and decadal time scales. In addition, depending on environmental conditions, the number of fish released into the ocean could affect Columbia River salmonid survival. Recent cooling in the northern hemisphere indicates that a reversal of the trend evidenced in the mid-1970s may now be occurring. Therefore, any experiments now being conducted which require estimates of survival to adult for their evaluation must take into account the effects of conditions occurring at the time of ocean entry in order to be evaluated in a meaningful and unbiased fashion.

Much of what is proposed herein is a continuation and refinement of what was started in this preliminary study. In particular, we propose the following objectives to future study.

Objective 1. Construct and update time series of survival of chinook salmon from Columbia River hatcheries as well as other hatcheries from California, Oregon, Washington, and British Columbia. Data from 1985 and on release years will be particularly important for clarifying our conceptual model. This set of estimates must be comprehensive both over time and space. Of particular importance are the development of coastwide comparable and unbiased estimates of survival of wild chinook and coho salmon. At the present time, these estimates, when available, are highly variable.

Objective 2. Correlate interannual trends in survival among geographic regions, stocks, smolt outmigration timing, and ocean migration patterns. These correlations will help to determine if, over the relevant time frame for the smolt physiology experiments currently being supported by BPA, major changes in survival occurred on a large-scale regional basis. Chinook stocks, similar to those being experimented on, will be monitored from California to British Columbia.

Objective 3. Correlate trends in survival with environmental variables such as upwelling intensity, spring-fall transition dates, Columbia River flow and plume structure, and smolt releases. These correlations will advance research attempting to uncover biophysical mechanisms occurring in the oceans which have major impacts on the survival of juvenile salmonids and resultant production of adult salmonids to the Columbia River system, partly managed by BPA.

Objective 4. Relate interannual trends in survival with size at age and time of ocean entry of age groups within and among stocks to elucidate variations in growth rates that may be correlated with regional ocean conditions and interactions among stocks. Of particular importance here is the attempt to join together bottom up field and experimental work on juvenile salmonids and their early ocean environment conducted during the early 1980s with the top ;down correlative approach carried out under Objectives 1-3 above over a much longer time period (1960 to present).

Objective 5. Integrate our understanding of the early ocean survival dynamics of Columbia River chinook salmon into a numerical simulation model which takes into account biotic and abiotic factors. This model will explore management alternatives (hatchery release strategies, harvest management options), which attempt to achieve the stated objectives and goals of the NPPC Columbia River Basin Fish and Wildlife Program. Specific management alternatives to be addressed are:

(a) Hatchery release strategies which reflect variations in carrying capacity of the early ocean environment.

(b) Hatchery release strategies which do not limit survival of wild salmonids.

(c) Harvest strategies which effectively utilize adult enhancements resulting from the Plan while not limiting production in other parts of the system.

Objective 6. In collaboration with the Southwest Fisheries Center, National Marine Fisheries Service, explore the possibility of using satellite imagery to determine optimal time of release of chinook salmon smolts from Columbia River hatcheries (see Appendix I). Of particular importance will be the integration of satellite imagery data with the intensive field data collected by OSU during the early 1980s. It will provide the synoptic views of the surface ocean environment that simply cannot be provided by at-sea sampling. In addition, the at-sea sampling, although discrete in time, will provide important ground truth for the satellite information.

EXPERIMENTAL APPROACH

The experimental approach is fairly completely described under Objectives. Much of the work is a refinement and extension in time of the work described in Background Results. Particular attention will be paid to the survival time series of the chinook salmon stocks being studied in the ongoing physiology studies. No field sampling will be undertaken under the proposed study. However, it must be emphasized that in order to attribute either ocean environment or, for that matter, smolt physiology effects to resultant survival to adult for these stocks, tagging must be both comprehensive and representative so that survival from release to adult can be accurately and precisely estimated. These issues are addressed in the accompanying research plan by Schiewe, et al.

ANTICIPATED BENEFITS

If done correctly, this research program should allow an accurate assessment of certain aspects of smolt quality and early ocean environment on Columbia River adult salmonid production. These results will be invaluable to the development of an understanding of the achievability of the heretofore untested salmonid production goals of the Columbia River Basin Fish and Wildlife Program.

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TABLES

Table 1. Groups for which between-brood comparisons of survival were made.

GROUP	CODE	RUN	REL. MONTH	SIZE	COMMENTS
eleases near San Francisco Bay	SF1	Fall	July-Aug	20-58/lb	No inriver catch or escape. data
eleases near San Francisco Bay	SF2	Fall	Oct-Nov	4.5-20/lb	No inriver catch or escape. data
ron Gate Hatchery (Klamath River)	IGH	Fall	Oct-Nov	7.2-11.0/lb	Complete data*
rinity River California	TRF	Fall	Sept-Nov	7.0-16.9/lb	Complete data*
rinity River California	TRS	Spring	Sept-Nov	7.0-13.6/lb	Ocean recoveries only
hetko River Oregon	CHT	Fall	Sept-Nov	9.5-15.5/lb	No hatchery escape. data
ogue River Oregon	RO	Spring	Sept-Oct	5.2-12.3/lb	Complete data
nedromous, Inc. Coos Bay Oregon	ANAD	Spring	Aug-Sept	7.8-17.4/lb	Complete data
lk River Oregon	ELK	Fall	Sept-Nov	9.3-15.8/lb	Complete data
tayton Pond Tule Chin. Willamette R	STAY	Fall	April-June	53-88/lb	Pacific Salmon Comm. data
onniville Tule, Columbia River	BON	Fall	April-June	58-100/lb	Pacific Salmon Comm. data
owlitz Tule Chin. Columbia R.	COW	Fall	June-July	55-128/lb	Pacific Salmon Comm. data
pring Creek Tule, Col. River	SPR	Fall	Mar-May	42-137/lb	Pacific Salmon Comm. data
priver Bright, Columbia River	URB	Fall	May-July	37-96/lb	Pacific Salmon Comm. data
illamette River Spring Chinook	WILL	Spring	Nov-March	5-20/lb	Pacific Salmon Comm. data
obertson Creek Hatchery, B.C.	ROB	Fall	May-July	65-168/lb	Pacific Salmon Comm. data

Recovery data for Klamath River system fall chinook supplied by A. Barracco, California Dept. Fish and Game, 1701 Nimbus Rd., Suite B, Rancho Cordova, CA 95670

Table 2. Between-year rank order of survival of chinook salmon released between July and December, 1979 and 1984 at a large average size (4.5-20/lb) at different hatcheries in northern California and southern Oregon. 1= highest survival and 6= lowest survival. (Hatchery group codes are explained in Table 1 and the actual precent recovery of tags are shown in Figure 1).

	Hatchery or stock group								
Release Yr	SF1	SF2	IGH	TRF	TRS	CHT	RO	ANAD	ELK
1979	3	1	3	5	3	3	3	2	4
1980	1	3	4	4	2	2	4	3	3
1981	2	4	5	2	5	4	6	4	2
1982	5	6	6	6	6	6	5	5	5
1983	6	5	2	3	4	5	2	6	6
1984	4	2	1	1	1	1	1	1	1

Table 3. Between-year rank order of survival of chinook salmon released between 1979 and 1984 in the Columbia River system and at Robertson Creek Hatchery, B.C. 1= highest survival and 5= lowest survival. Except for Willamette (WILL) spring chinook these groups were released as subyearling between May and August (Hatchery group codes are explained in Table 1 and percent reccoveries are shown in Figure 2).

	Hatchery or stock group						
Release Yr	STAY	BON	COW	SPR	URB	WILL	ROB
1979	1	1	4	2	2	2	2
1980	2	4	6	1	4	1	3
1981	5	3	2	5	6	3	1
1982	4	5	5	4	5	5	4
1983	3	2	3	3	3	4	5
1984	6	6	1	6	1	6	6

FIGURES

Figure Captions

Figure 1. Estimated survival to age 2 and total percentages of tagged fish recovered at all ages for Columbia River and Robertson Creek (B.C.) Hatchery groups of chinook salmon. Data source: Pacific Salmon Commission

Figure 2. Mean percentages of CWT chinook salmon recovered in ocean and river fisheries and returning to hatcheries at all ages from releases from hatcheries in California and southern Oregon. When several tag groups represent a brood, the average percent recovered (each group given equal weight) is plotted. Error bars are plus or minus 95% confidence limits. Asterisk indicates recoveries through age 3 only.

Figure 3. Numbers of smolts released and percent adult survival for mid-Columbia spring chinook (Raymond 1988), Columbia River fall chinook (Fresh, et al., 1987), and OPI coho (Nickelson 1986).

Figure 4. Sea-surface temperature off Oregon, 1930-1983. Marsden square data provided by A. Hollowed, NMFS, Seattle.

Figure 5. Spring transition dates at 48 deg. N, 45 deg. N, and 42 deg. N, 1967-1987.

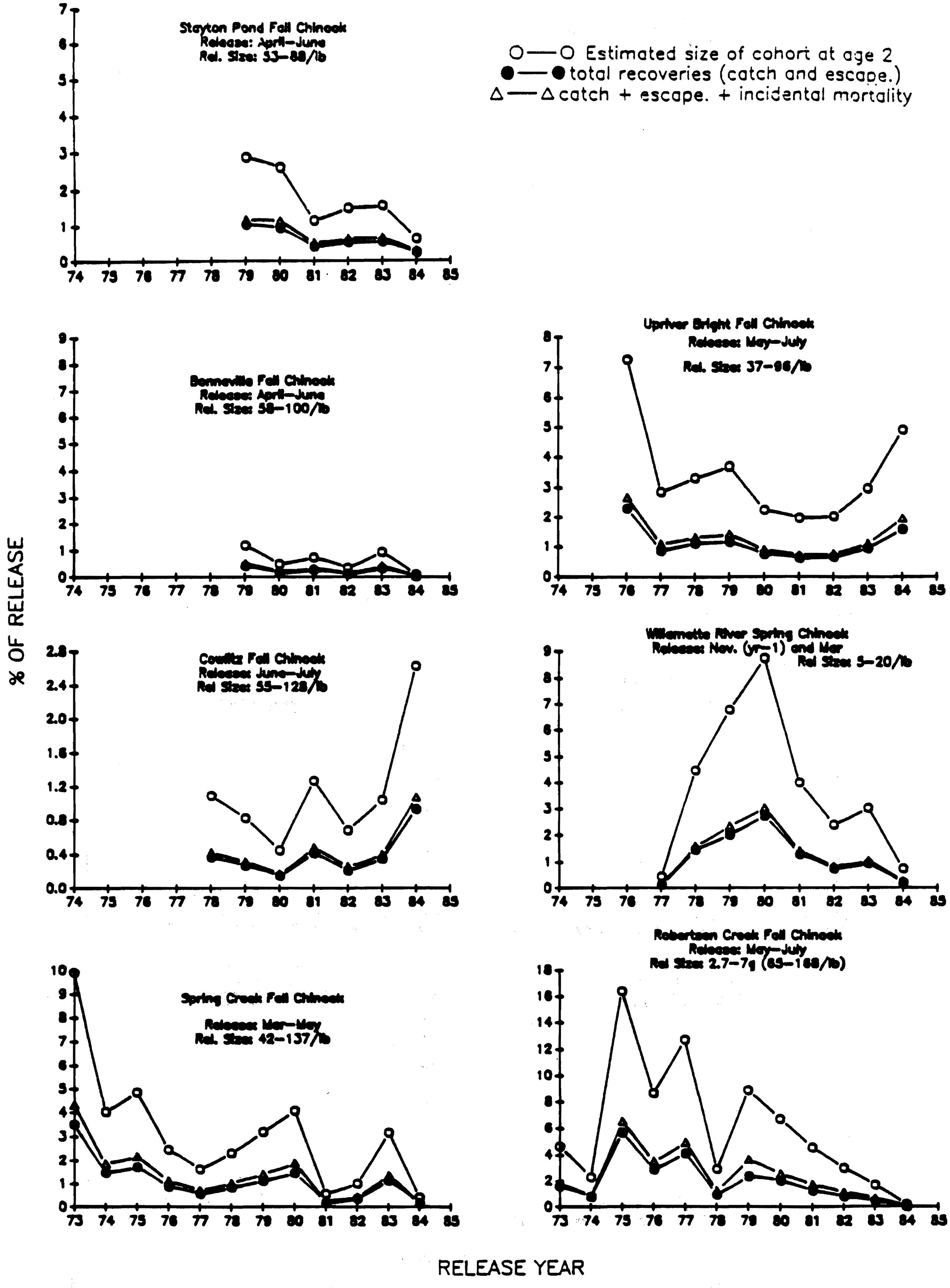
Figure 6. Cumulative March-September upwelling volume vs. transition date at 45 deg. N.

Figure 7. Schematic diagram of the area affected by shifting of the subarctic boundary.

Figure 8. Maximum, minimum and mean annual flows for Columbia River and Fraser River, 1951-1979.

Figure 9. Monthly Columbia River flows, 1950-1978.

Figure 10. Estimated OPI coho survival for hatchery and wild fish vs. total smolts for weak and strong upwelling years.



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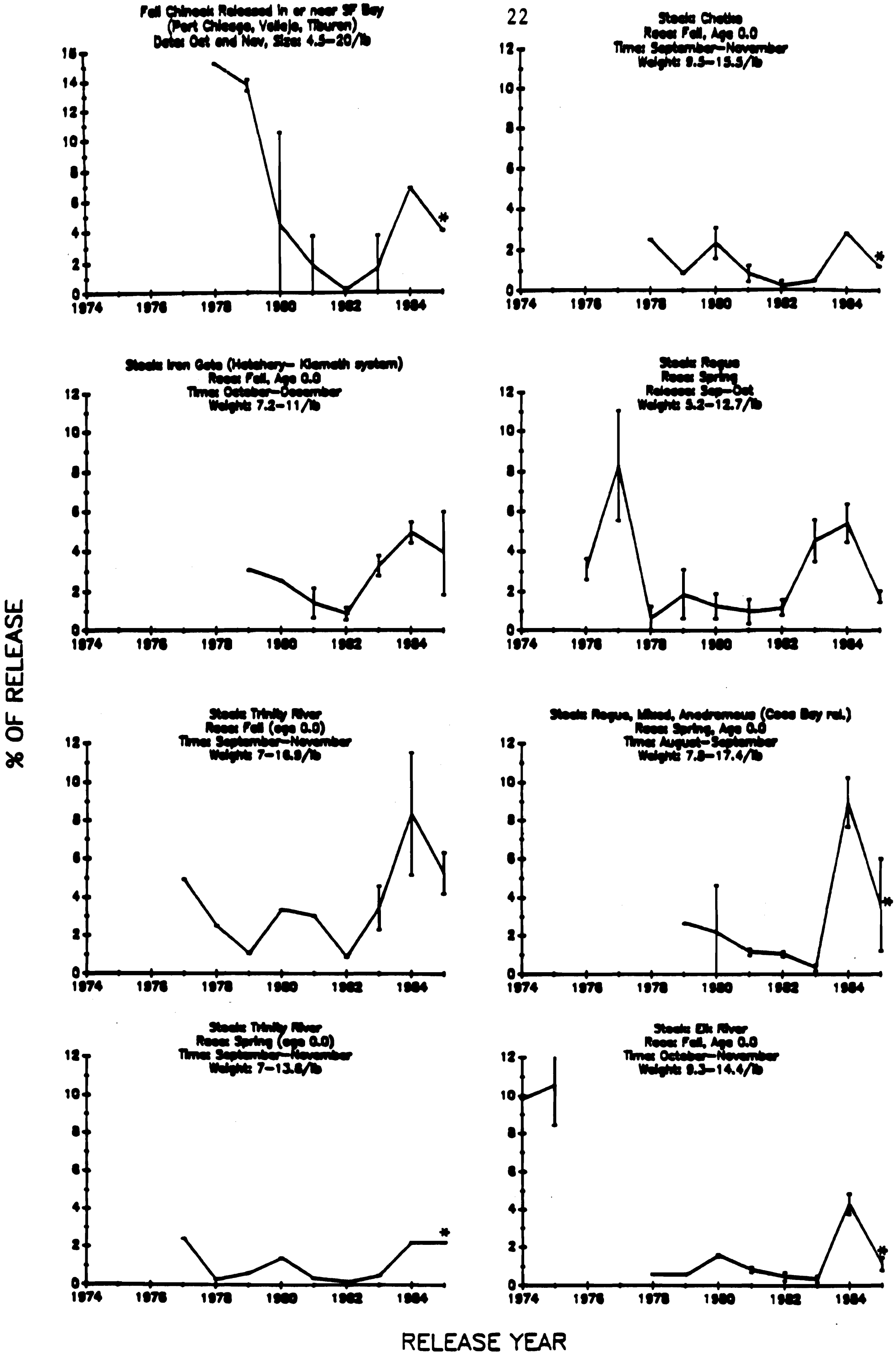
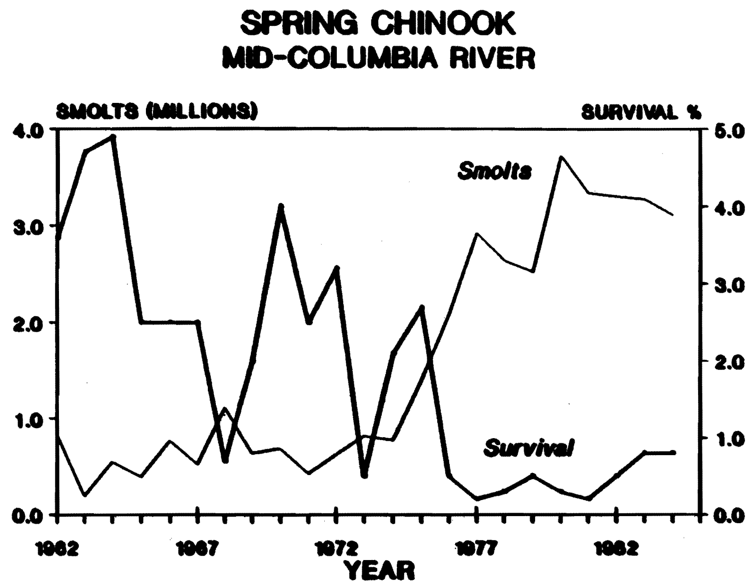
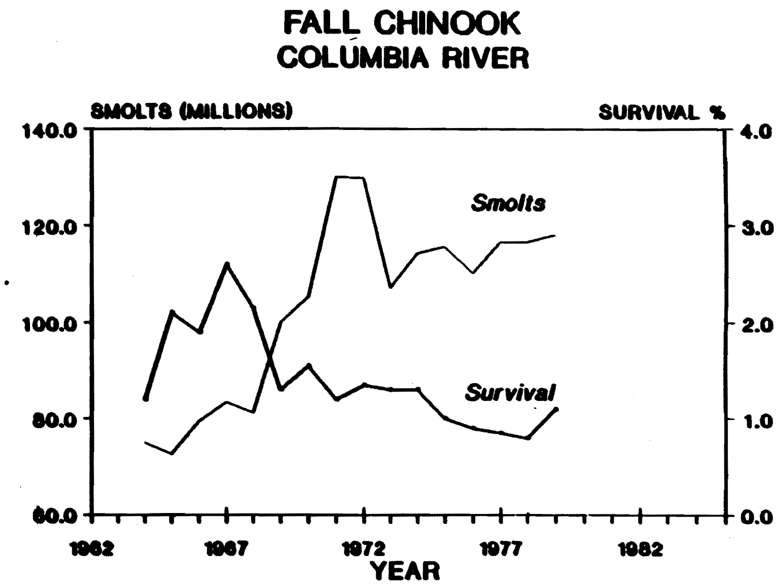
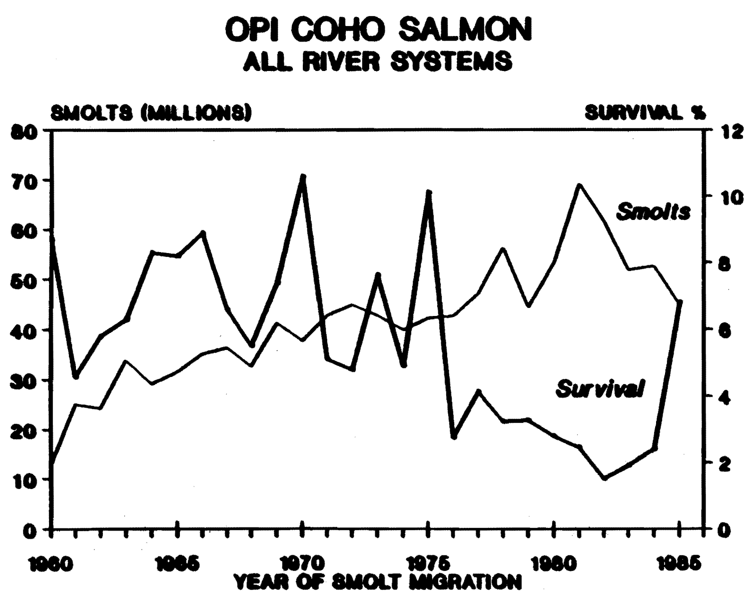


Fig. 2. Mean percentages of CWT chinook salmon recovered in ocean and river fisheries and returning to hatcheries at all ages from releases from hatcheries in California and southern Oregon. When several tag groups represent a brood, the average percent recovered (each group given equal weight) is plotted. Error bars are ±95% confidence limits. Asterisk indicates recoveries through age 3 only.







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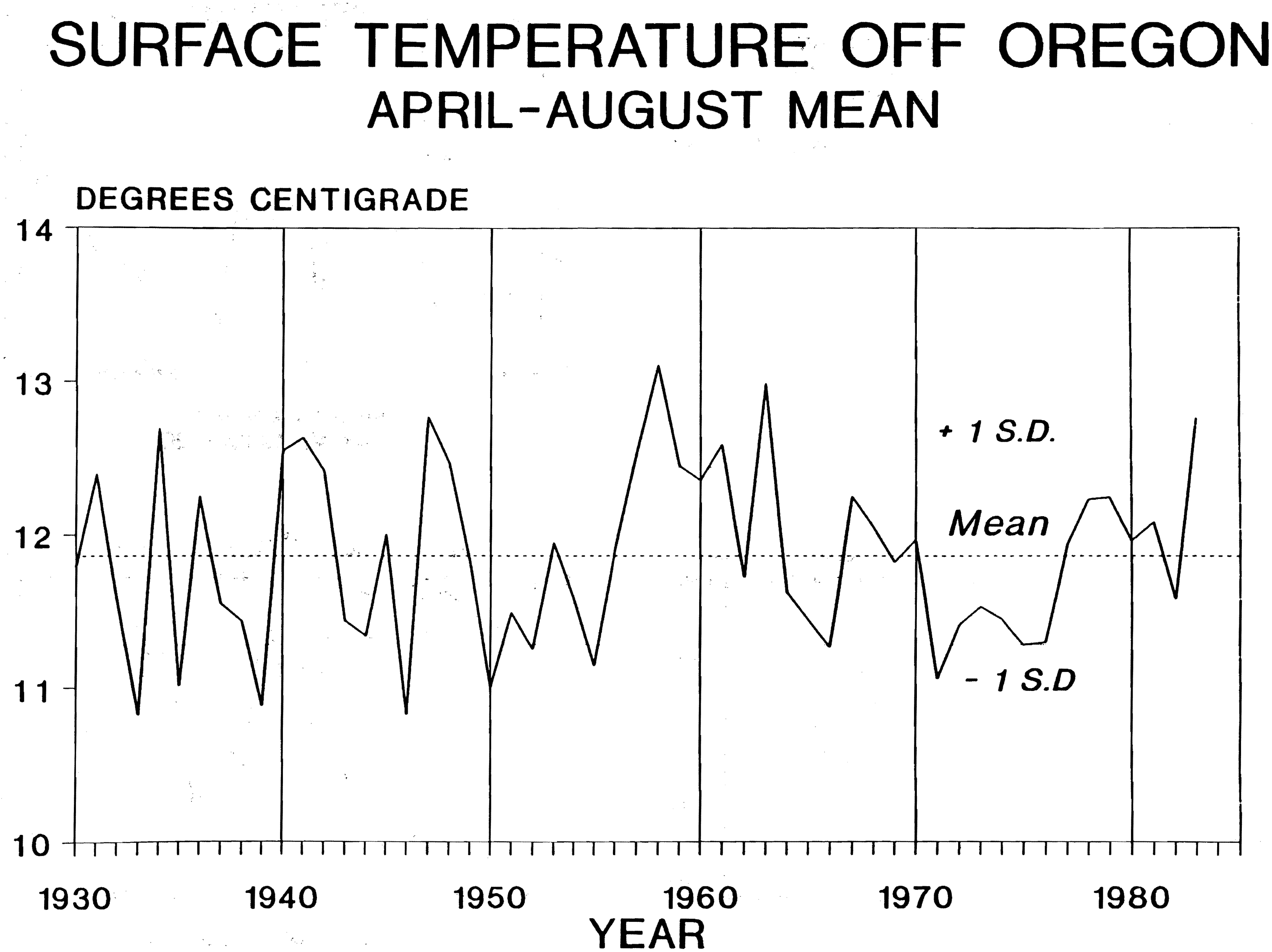

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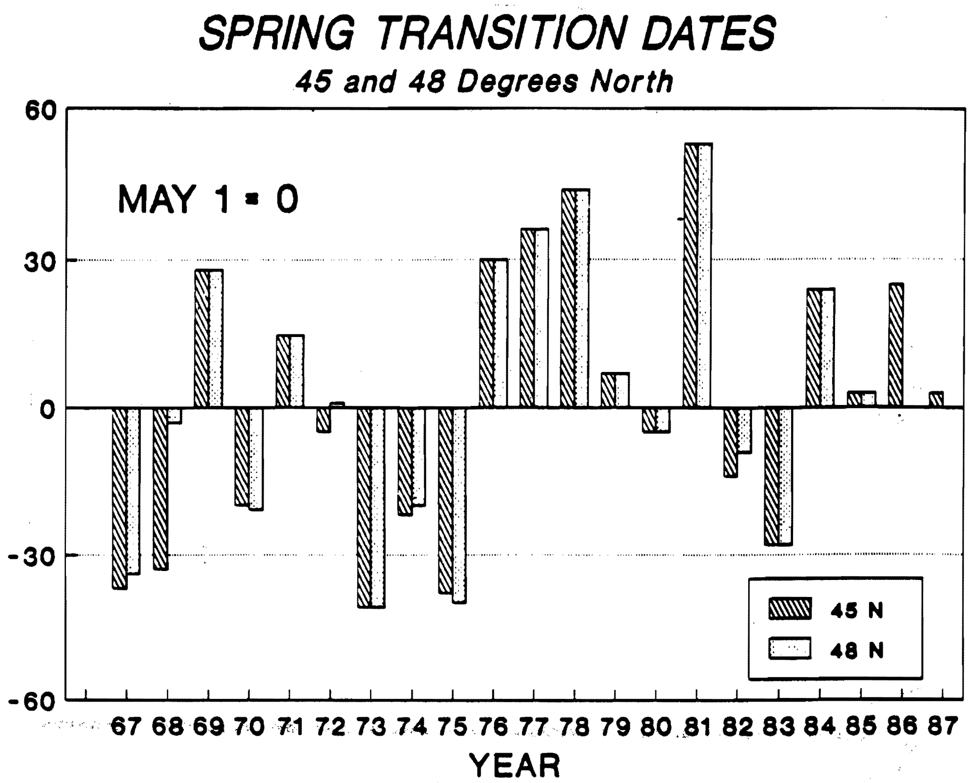


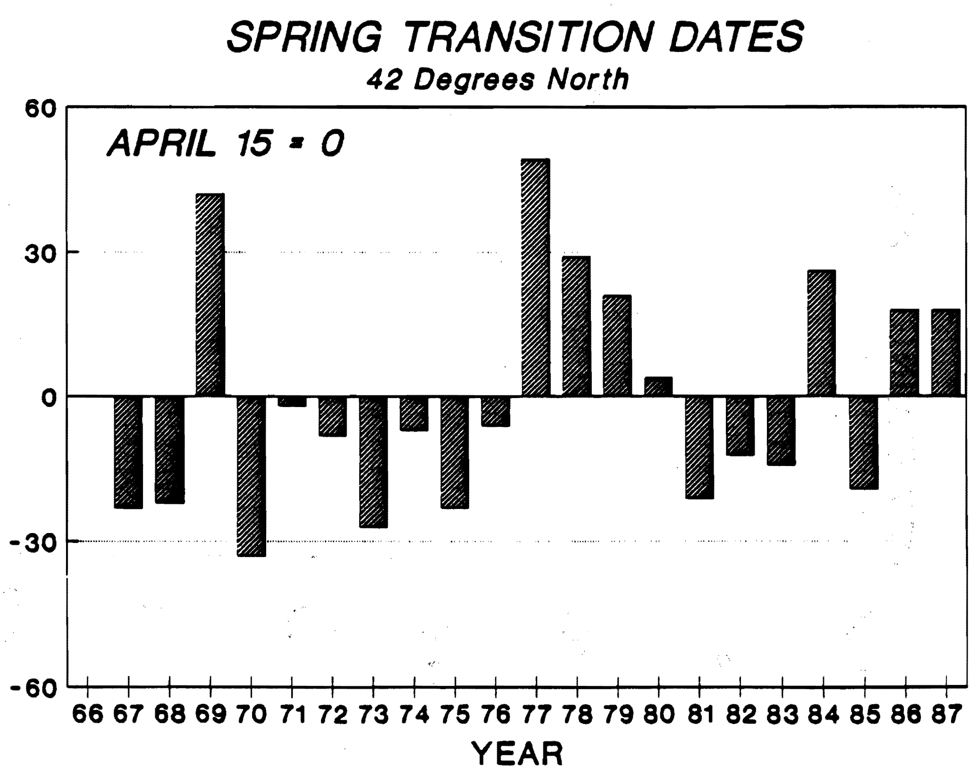


Fig. 5. Spring transition dates at 48°N, 45°N, and 42°N, 1967-1987.

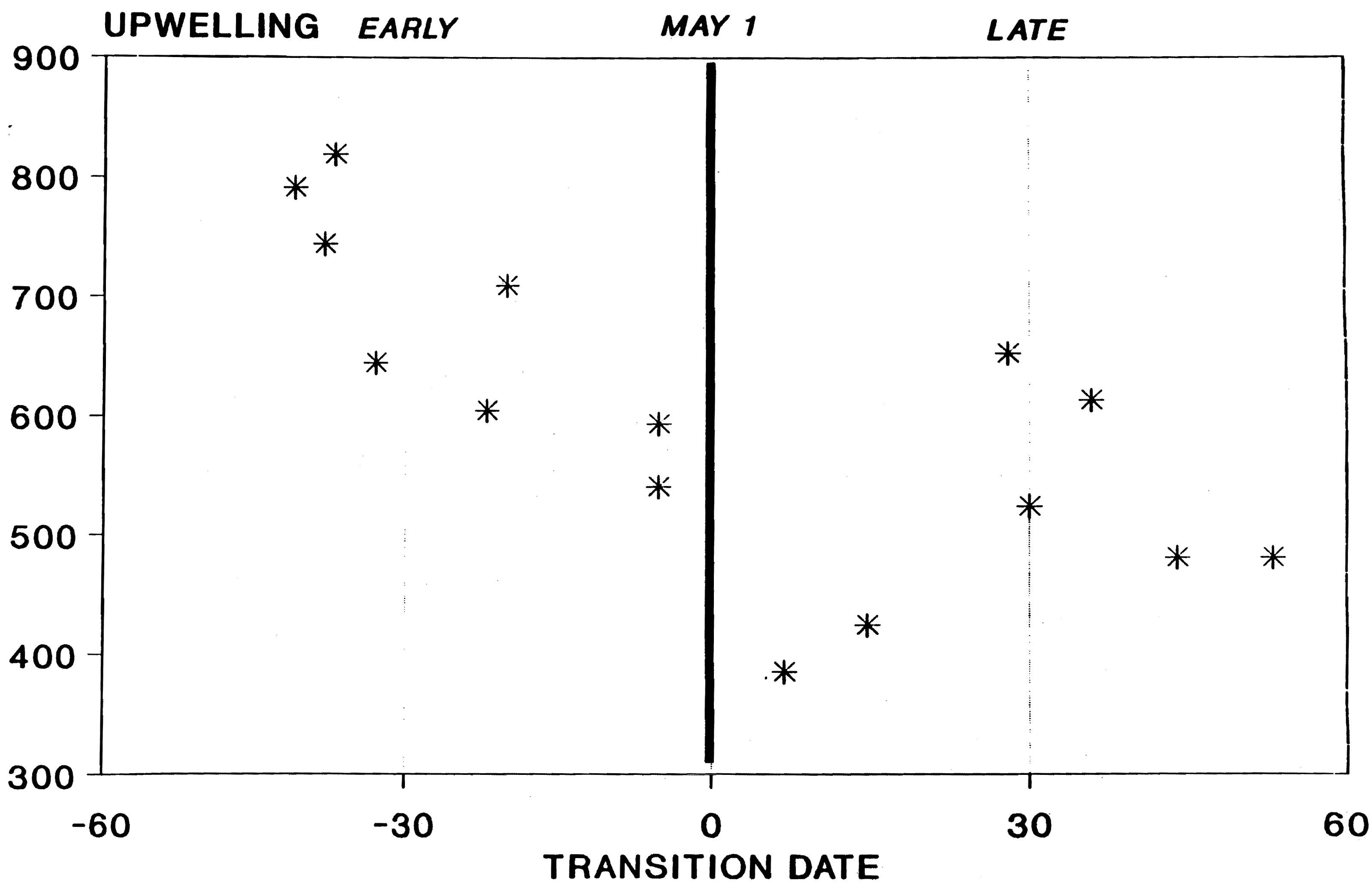


Fig. 6. Cumulative March-September upwelling volume vs. transition date at 45°N.

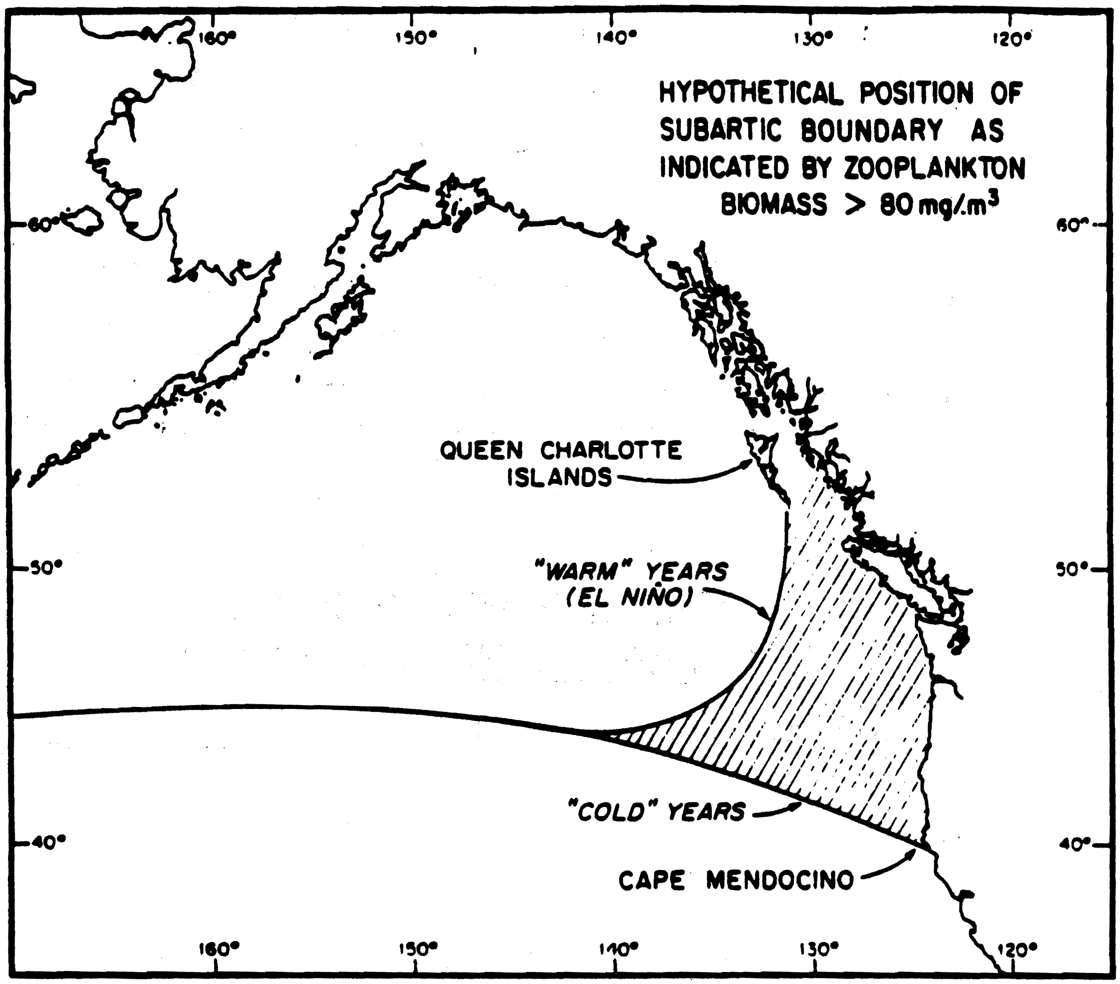
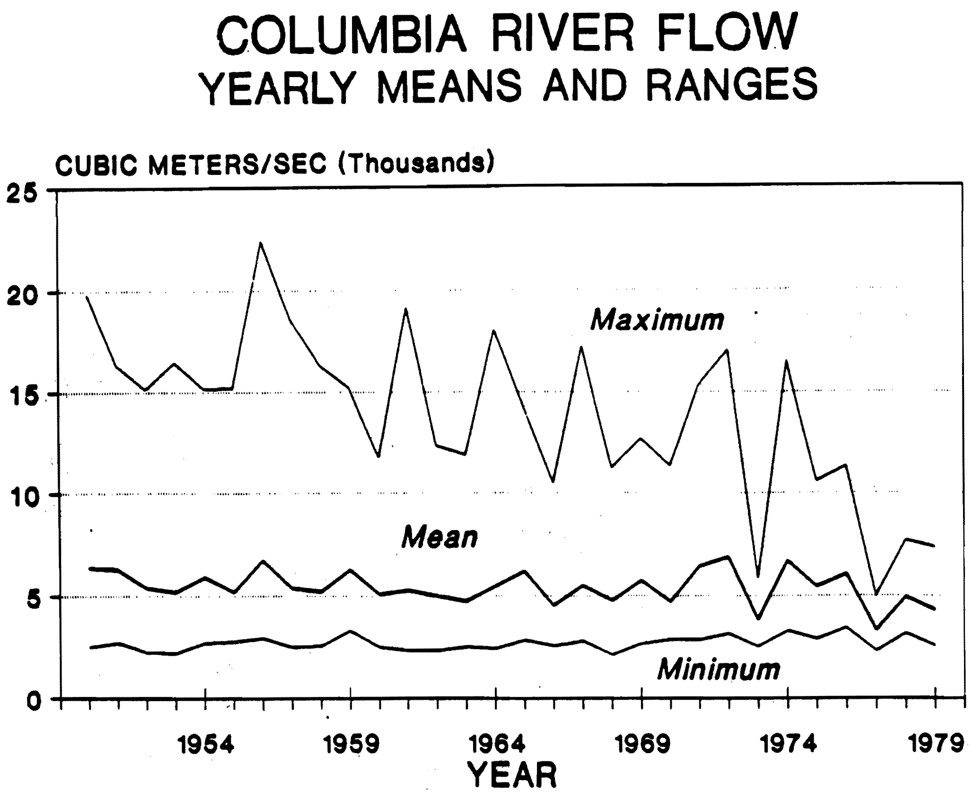
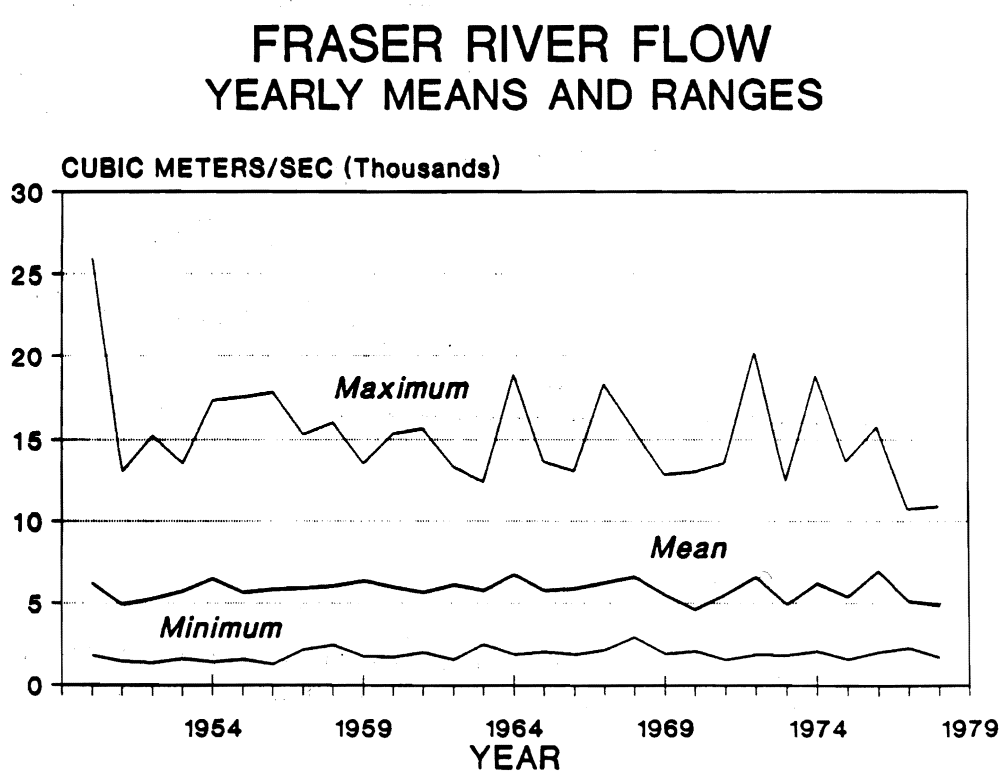


Fig. 7. Schematic diagram of the area affected by shifting of the subarctic boundary. From Fulton and LeBrasseur (1985).





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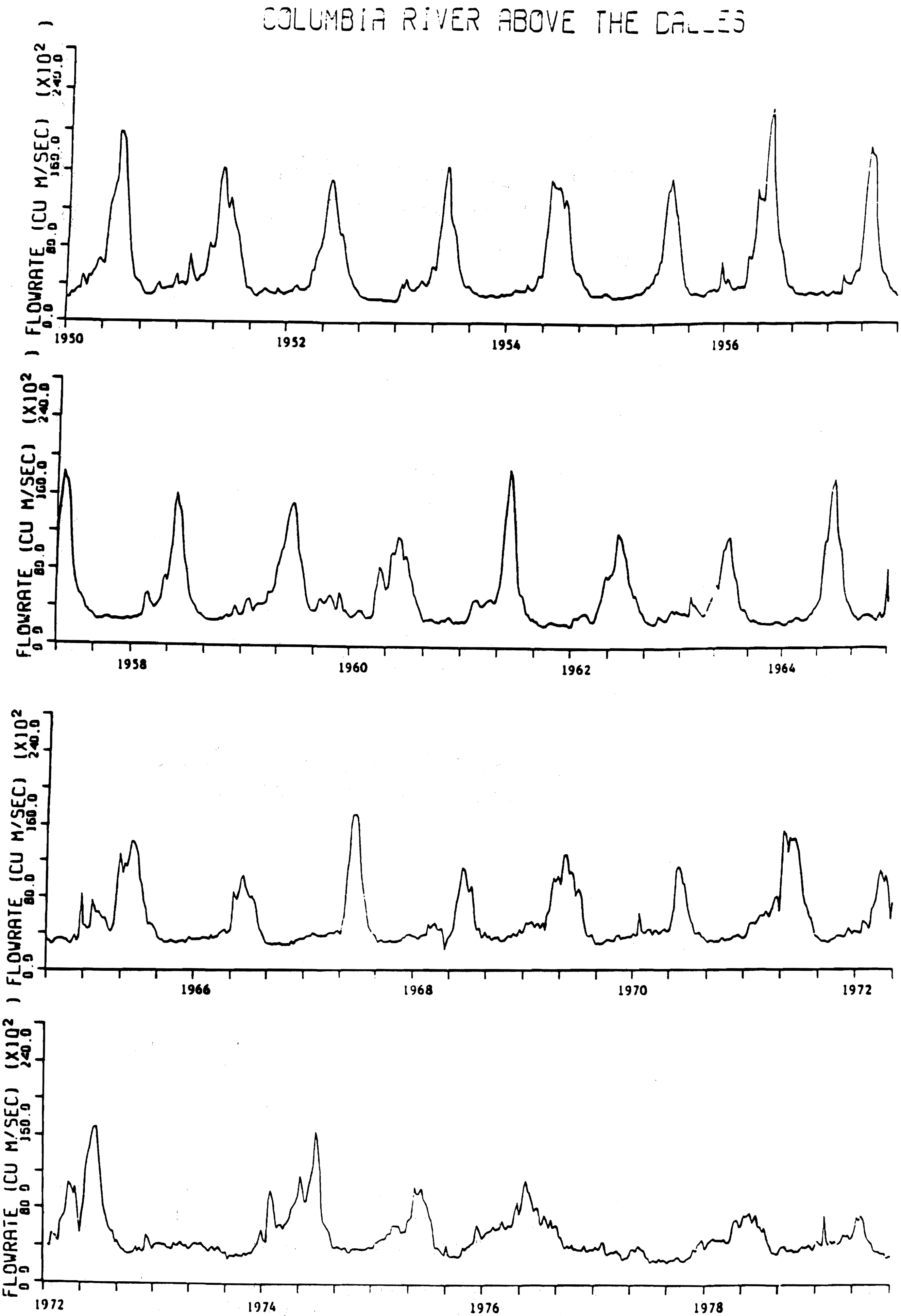
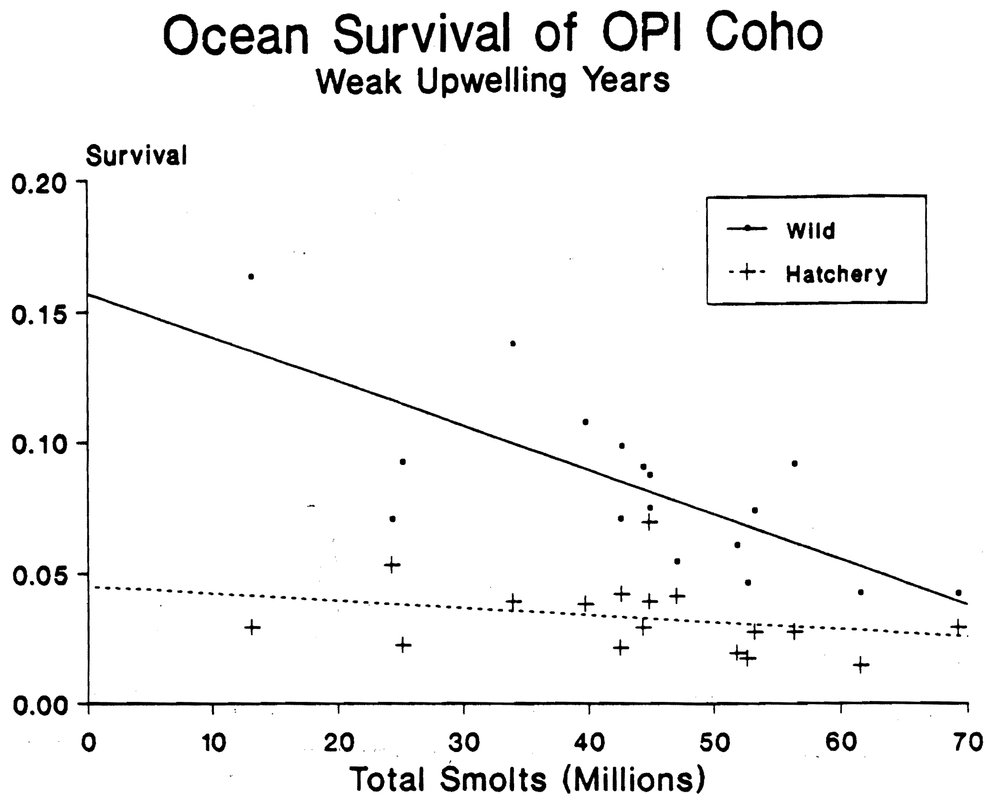


Fig. 9 Monthly Columbia River flows, 1950-1978.



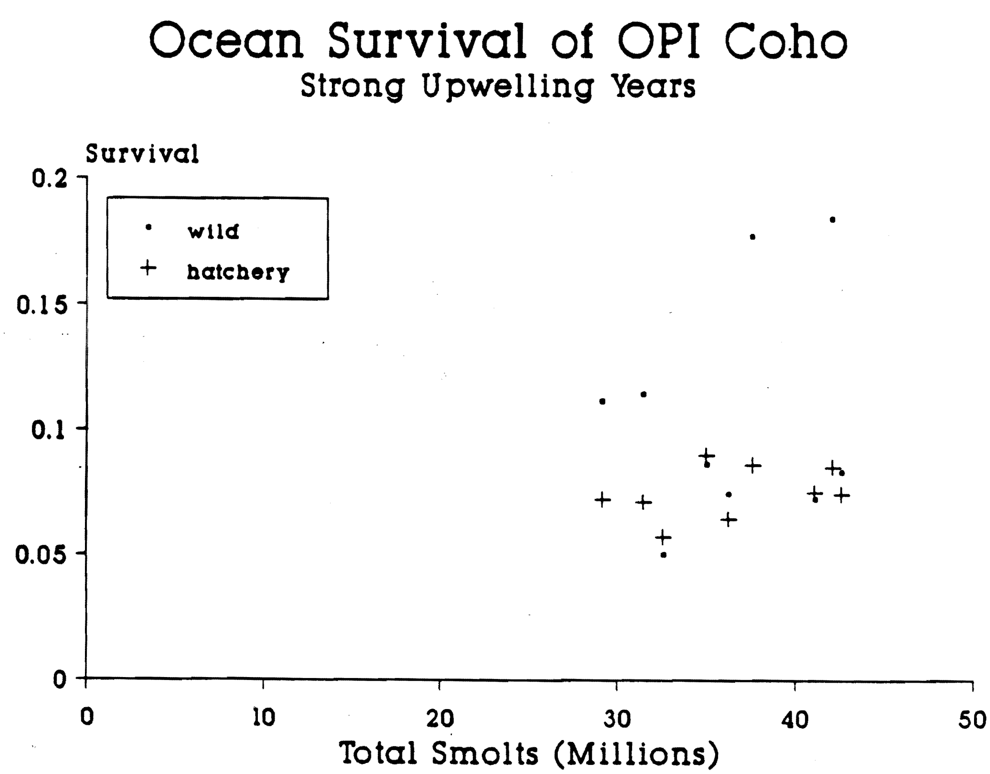


Fig. 10. Estimated OPI coho survival for hatchery and wild fish vs. total smolts for weak and strong upwelling years.

APPENDIX I

USE OF SATELLITE IMAGERY TO DETERMINE OPTIMAL TIME OF RELEASE OF CHINOOK SALMON SMOLTS FROM COLUMBIA RIVER HATCHERIES TO IMPROVE SURVIVAL AND RECRUITMENT TO FISHERIES

This element of the proposed investigation will evaluate the use of satellite imagery to optimize the timing of releasing chinook salmon smolts from hatcheries on the Columbia River to correspond with ocean environmental conditions favorable for their survival. Increasing the survival and subsequent contribution of salmon released from hatcheries to commercial and recreational fisheries can have significant economic benefit. Up to 90% of the salmon caught in the waters off the Columbia River are released from hatcheries on the Columbia River. About 60% of the salmon caught in other areas off Oregon are from salmon released from hatcheries on other coastal rivers and streams.

While hatchery produced salmon contribute most of the fish which are harvested, the percentage of released fish that are caught is very low, e.g. only about 2% for Columbia River hatcheries. About 98 % of salmon that are released by the Columbia River hatcheries suffer mortality. A major part of the mortality is believed to occur in the ocean soon after the smolts arrive there subsequent to their release from the hatcheries.

This research will test the hypothesis that the survival of young chinook salmon released from Columbia River hatcheries is related to variations in characteristics and interactions of the Columbia River plume in the ocean off the Pacific Northwest and coastal upwelling. The goal of the research is to ascertain if satellite imagery can be used to determine when ocean conditions are favorable for young salmon so that the release of the smolts from hatcheries may be timed for optimal survival. Even modest increases in survival could result in substantial increases in salmon available for harvest and have significant, measurable economic benefits.

The investigation will utilize information collected during 1979 - 1990 including (1) the numbers of chinook smolts released from Columbia River hatcheries,(2) numbers of hatchery released fish that were caught by commercial and recreational fishermen, and other fishery statistics, (3) information on Columbia River flow, (4) spatial and temporal variations of the Columbia River plume, (5) indices of coastal upwelling, (6) coastal wind observations, and (7) data collected on juvenile salmon research cruises conducted by OSU during 1981 - 1985.

Ocean color measurements made by the CZCS aboard the NIMBUS-7 satellite and ocean surface temperature measurements made by AVHRR sensors aboard polar-orbiting NOAA satellites will be used to determine variations in the Columbia River plume and coastal upwelling. Figure 1 shows generalized winter and summer surface salinity distributions in the Columbia River plume region (from Barnes et al, 1979), with superimposed boxes to indicate proposed coverage of satellite imagery. Schematic drawings of the basic forms of the Columbia River plume based on satellite imagery and a time-series of CZCS ocean color images during late-April - May 1982, given in Figures 2 and 3, respectively (from Fiedler and Laurs, in review) show that there are pronounced variations in plume structure and that dramatic changes can occur over a short time. Figure 4 is a CZCS ocean color image observed in late-May 1982 for the region along the Pacific Northwest coast from central Oregon to Vancouver Island, B.C. In addition to the Columbia River plume, several other oceanic features are apparent in the nearshore regime, e.g. outflow from bays, upwelled water, eddies, etc., which may have impact on the survival of salmon smolts.

An important task of the research will to be develop quantitative estimates of the Columbia River plume, including its orientation relative to the coast and its areal extent. Relationships between these estimates and winds will be examined. We believe that a set of "indices" may be derived from the winds which can be used to estimate characteristics of the Columbia River plume at important specific times, such as the period when smolts from a given hatchery release are estimated to have entered the ocean, when no satellite data are available. Figure 5 shows a time-series or wind vectors calculated from observations made off the Columbia River (from Fiedler and Laurs, in review).

Additional environmental data to be used in the proposed study include Columbia River outflow at the river mouth, the Bakun upwelling index and other estimates of ocean transport, and buoy and ship oceanographic observations.

Relationships will be examined between variations in the Columbia River plume and related oceanic process in the nearshore regime and variations in survival of chinook smolts released from Columbia River hatcheries. These relationships will be examined in collaboration with other investigators in the proposed project responsible for the analysis of hatchery, biological and fishery data for Chinook salmon released from Columbia River hatcheries.

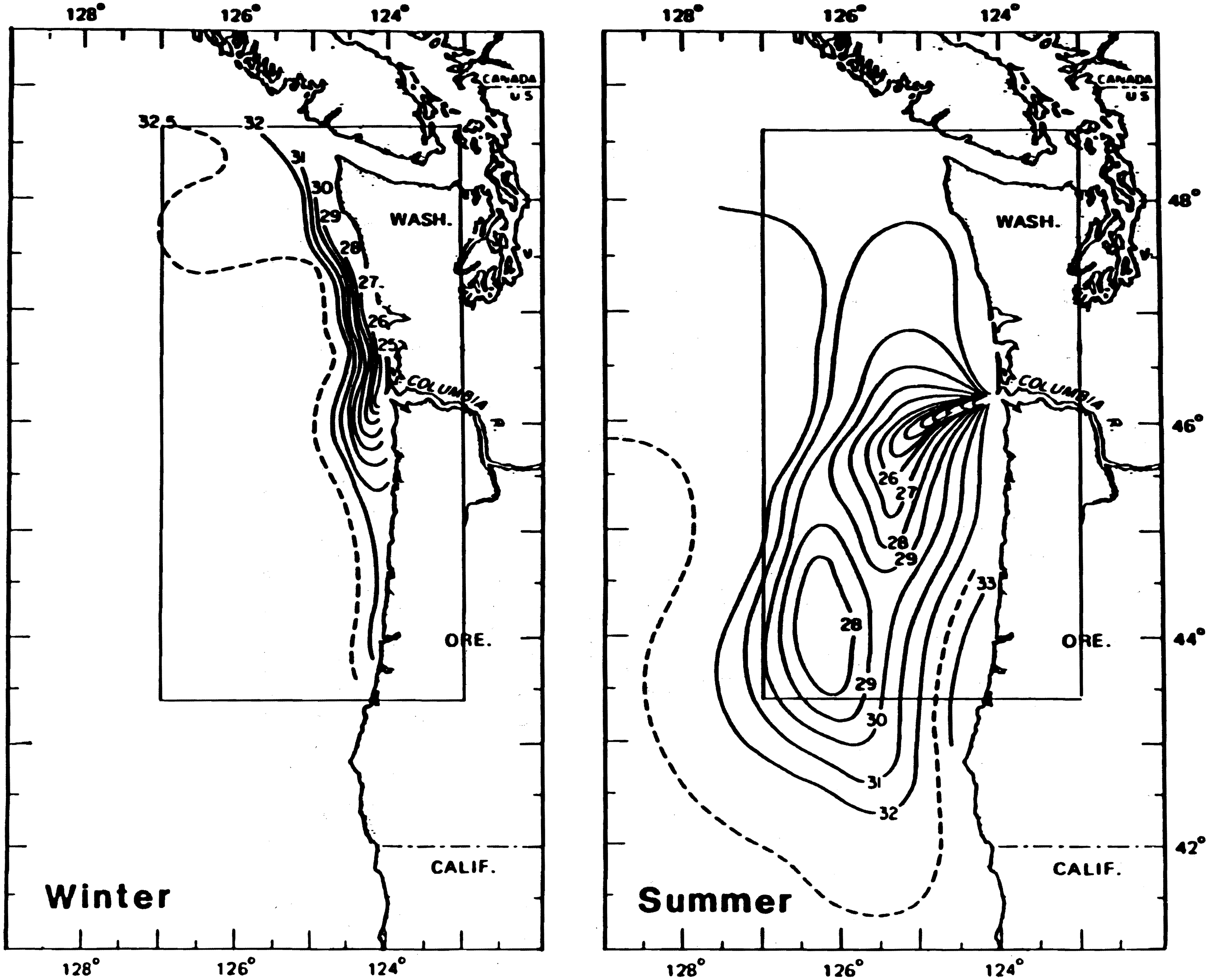


Figure 1. Generalized winter and summer surface salinity distributions in the Columbia River plume region (from Barnes et al., 1972, In The Columbia River Estuary and Adjacent Ocean Waters: Bioenvironmental Studies, ed. A.T. Pruter and D.L. Alverson) and superimposed boxes showing proposed coverage of satellite imagery.

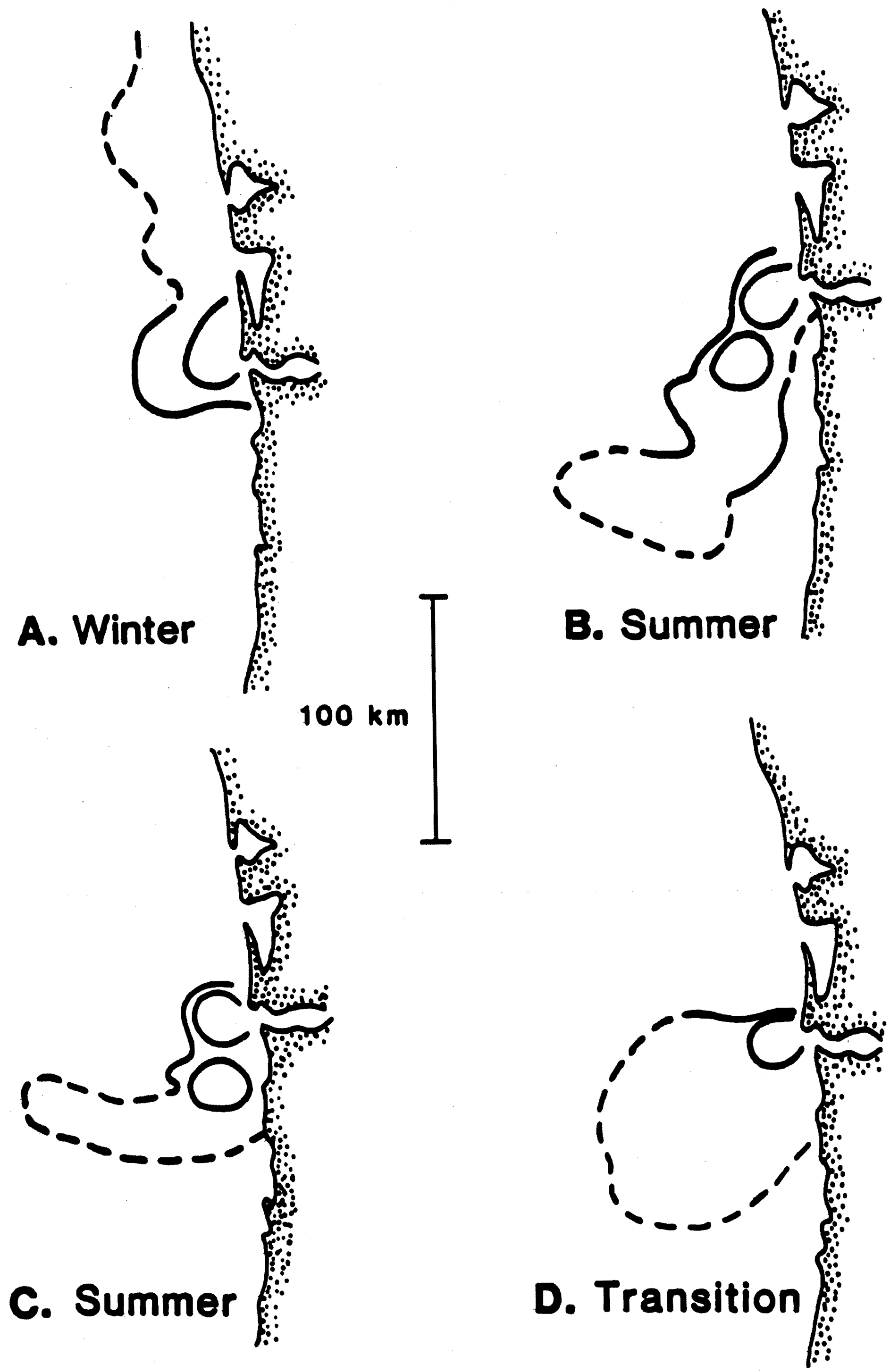


Figure 2. Schematic drawings of basic forms of the Columbia River plume based on ocean color and temperature satellite measurements. Solid lines represent strong color and/or temperature boundaries, dashed lines represent weaker boundaries

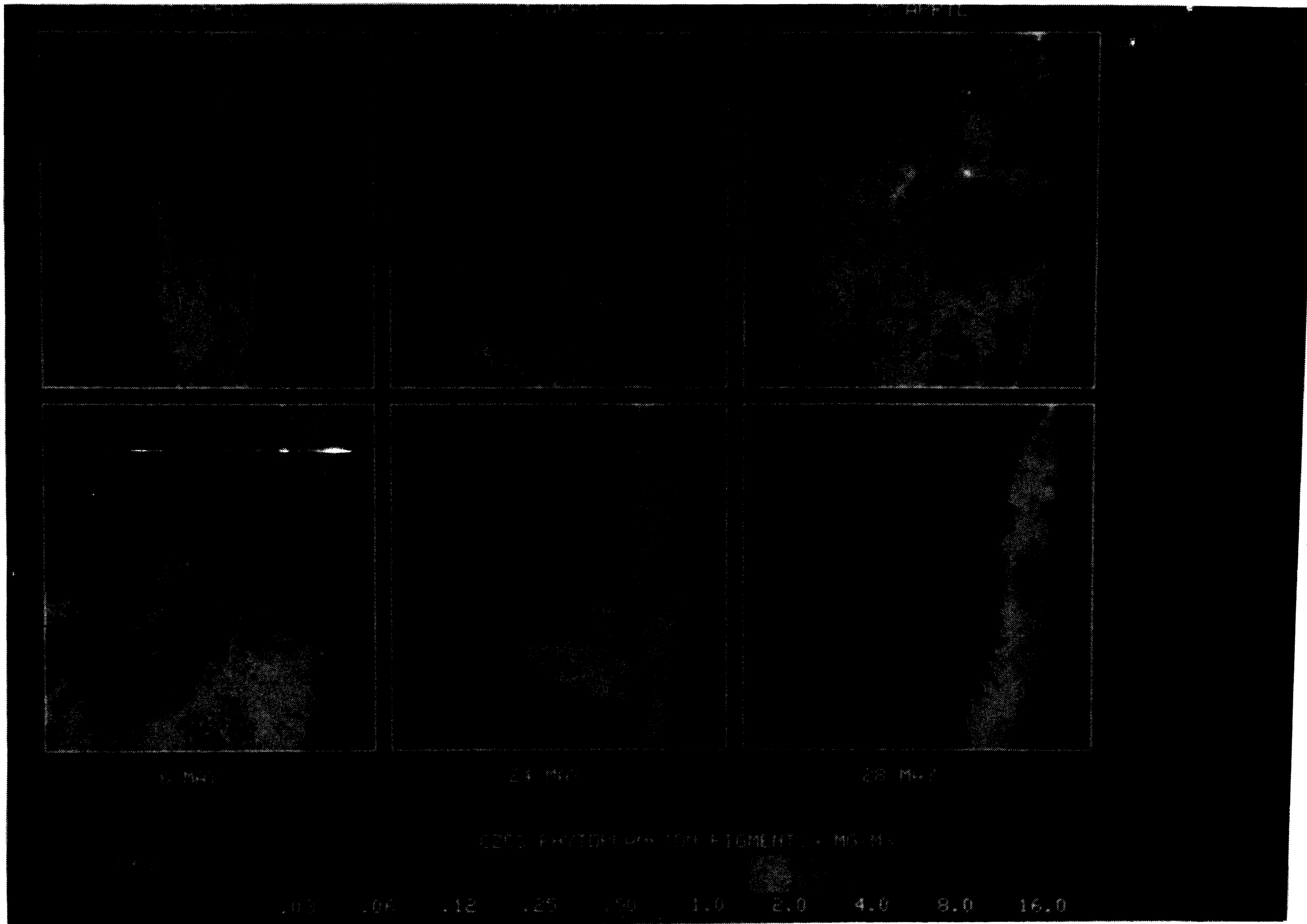


Figure 3. Time series of CZCS images illustrating changes in the Columbia River plume during spring transition in 1982. Colors indicate increasing phytoplankton pigment concentrations: Purples (<0.1 mg m^3), blues (0.1-0.4), greens (0.4-1.5), yellow and oranges (1.5-4.0), reds (>4.0). From Fiedler and Laurs, in rev.

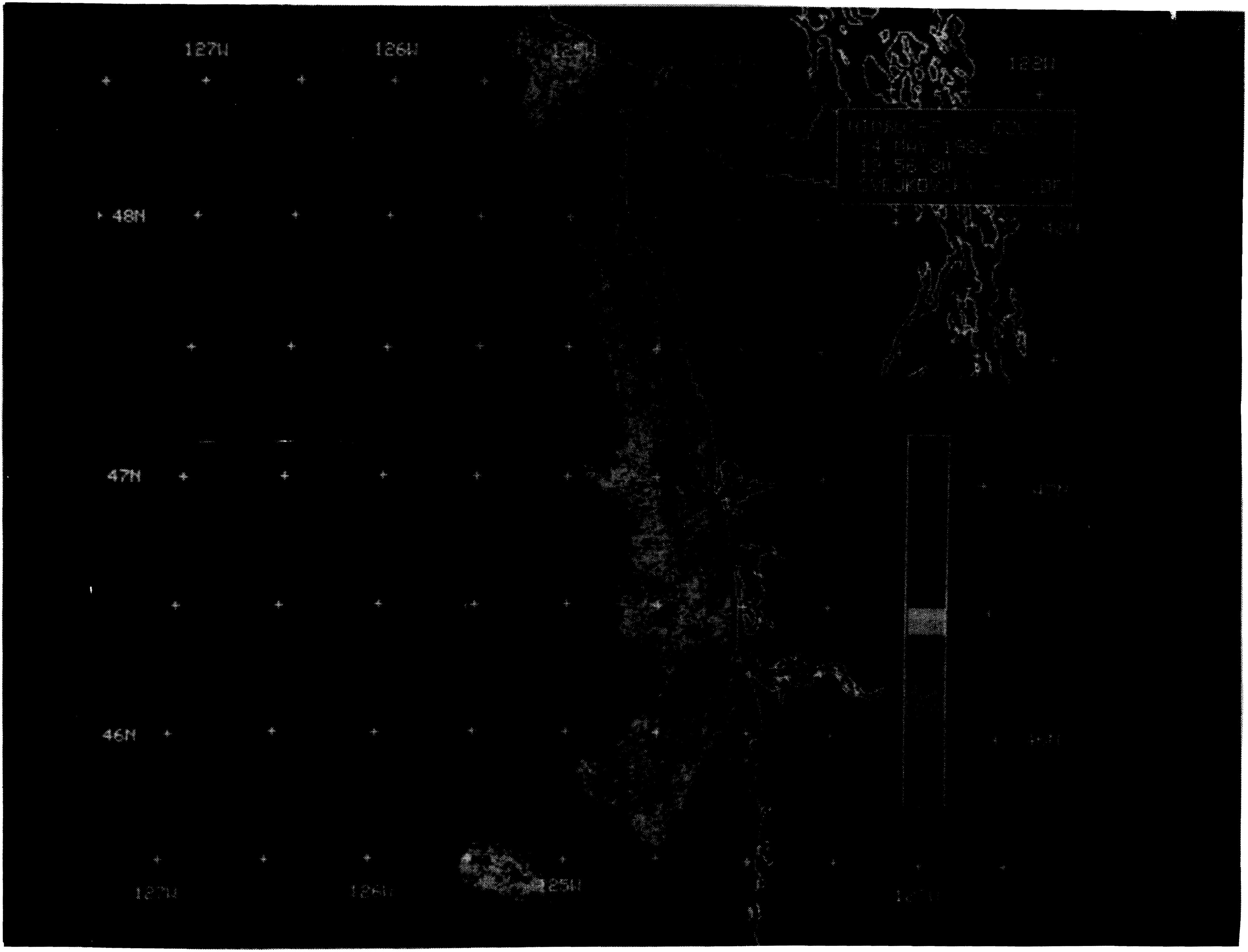


Figure 4. CZCS image observed in late May 1982 showing nearshore oceanic region between central Oregon and

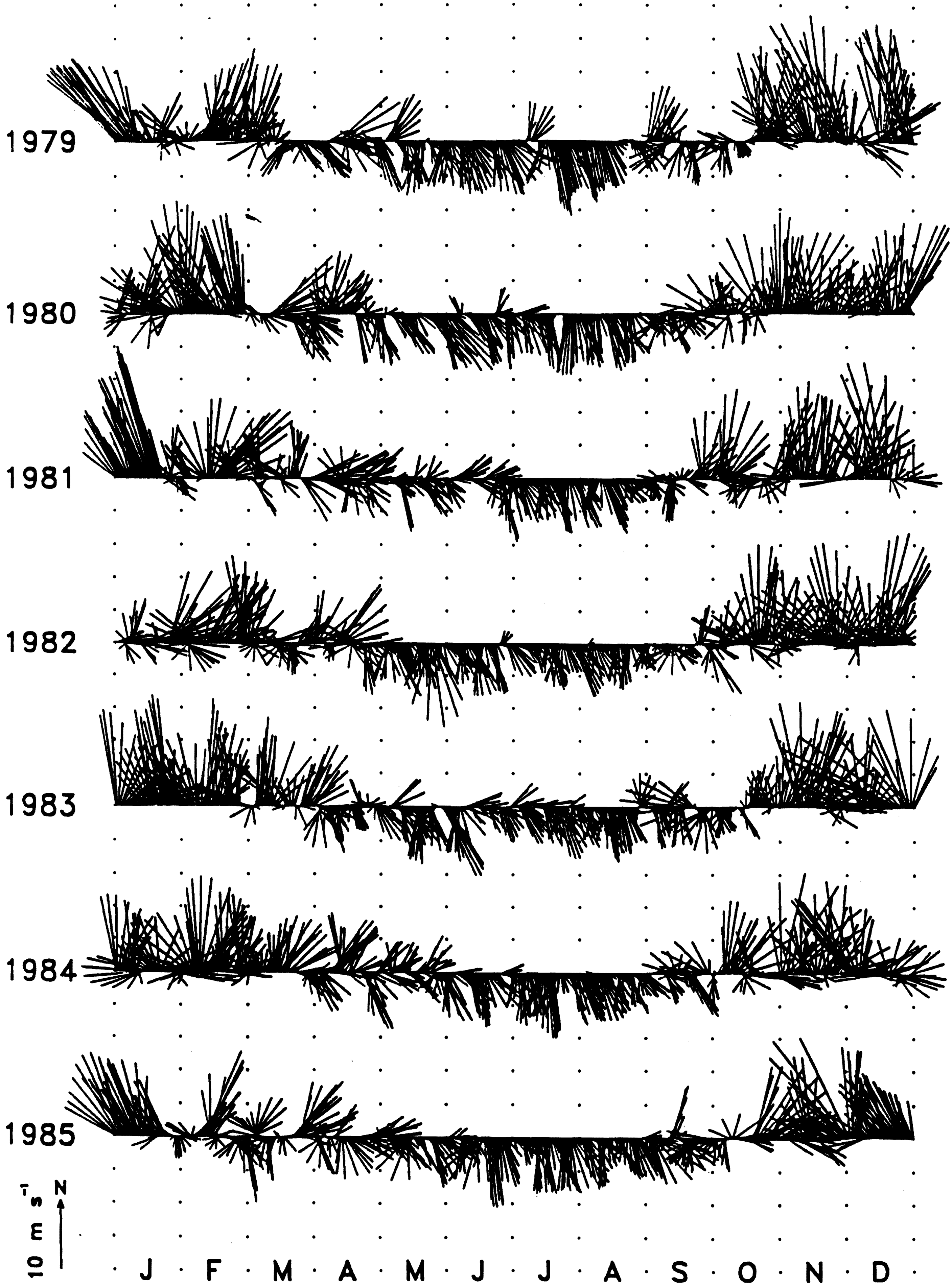


Figure 5. Time series of calculated wind vectors (smoothed 12-hour means) at 46°N 124.5°W (from Fiedler and Laurs, in review).