Effects of the ocean environment on the survival of Columbia River juvenile salmonids.
Research Plant to the Department of Energy, Bonneville Power Administration, Div. Fish/Wild
R. C. Francis, W. G. Pearcy, R. Brodeur, J. P. Fisher, and L. Stephens
Project number R/F-84 WSG-MR 89-8

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 1^82-1983 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.

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

GROUP	CODE	RUN	REL. MONTH	SIZE	COMMENTS
Releases near San Francisco Bay	SF1	Fall	July-Aug	20-58/lb	No inriver catch or escape. data
Releases near San Francisco Bay	SF2	Fall	Oct-Nov	4.5-20/lb	No inriver catch or escape. data
Iron Gate Hatchery (Klamath River)	IGH	Fall	Oct-Nov	7.2-11.0/lb	Complete data*
Trinity River California	TRF	Fall	Sept-Nov	7.0-16.9/lb	Complete data*
Trinity River California	TRS	Spring	Sept-Nov	7.0-13.6/lb	Ocean recoveries only
Chetko River Oregon	CHT	Fall	Sept-Nov	9.5-15.5/lb	No hatchery escape. data
Rogue River Oregon	RO	Spring	Sept-Oct	5.2-12.3/lb	Complete data
Anadromous, Inc. Coos Bay Oregon	ANAD	Spring	Aug-Sept	7.8-17.4/lb	Complete data
Elk River Oregon	ELK	Fall	Sept-Nov	9.3-15.8/lb	Complete data
Stayton Pond Tule Chin. Willamette R	STAY	Fall	April-June	53-88/lb	Pacific Salmon Comm. data
Bonniville Tule, Columbia River	BON	Fall	April-June	58-100/lb	Pacific Salmon Comm. data
Cowlitz Tule Chin. Columbia R.	COW	Fall	June-July	55-128/lb	Pacific Salmon Comm. data
Spring Creek Tule, Col. River	SPR	Fall	Mar-May	42-137/lb	Pacific Salmon Comm. data
Upriver Bright, Columbia River	URB	Fall	May-July	37-96/lb	Pacific Salmon Comm. data
Willamette River Spring Chinook	WILL	Spring	Nov-March	5-20/lb	Pacific Salmon Comm. data
Robertson 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 6= 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 recoveries 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

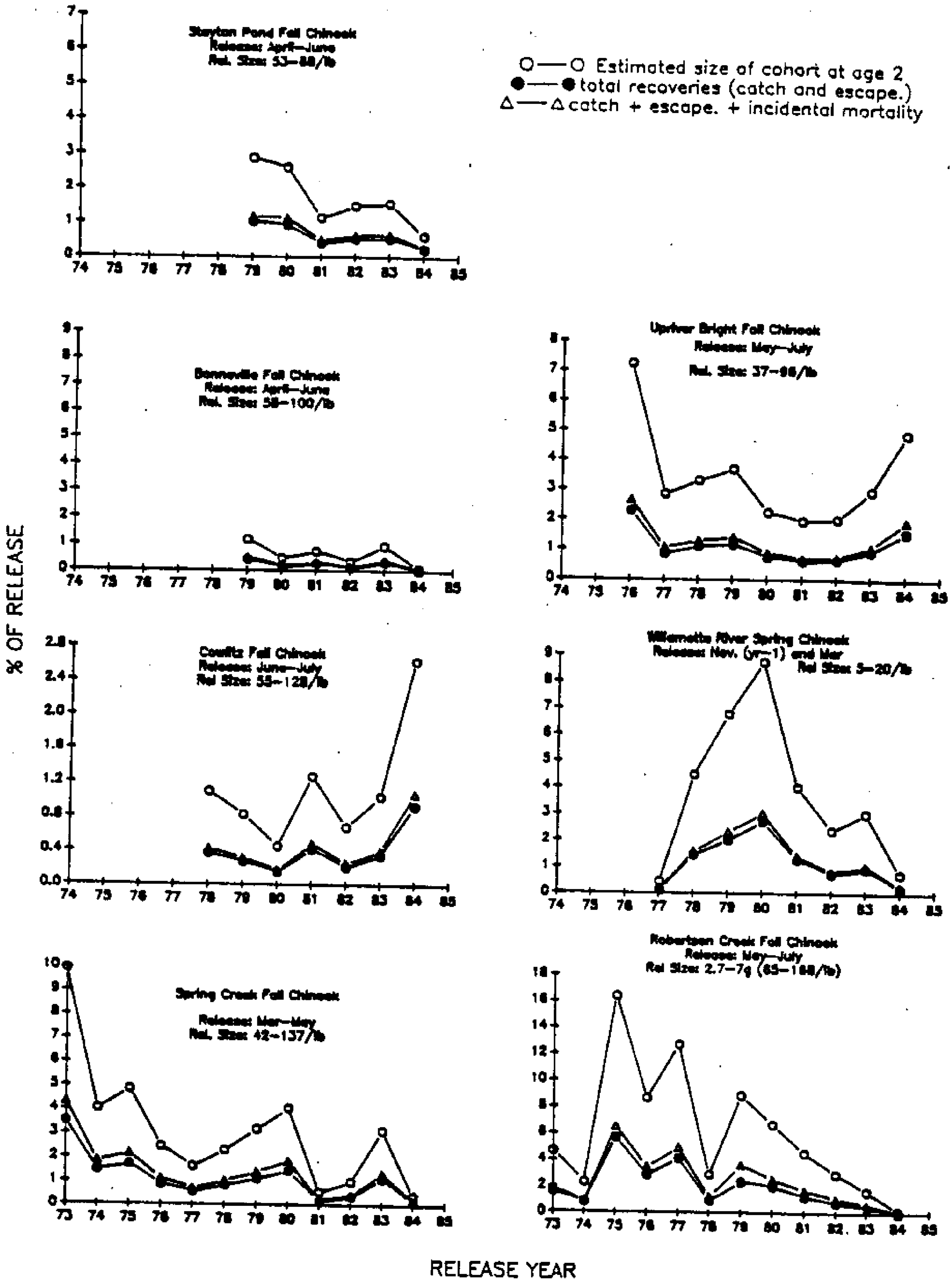


Fig. 1. Estimated survival to age 2 and total percentages of tagged fish recovered at all ages for Columbia River and Robertson Creek (B.C.) Hatchery groups of chinook salmon. Data source: Pacific Salmon Commission.

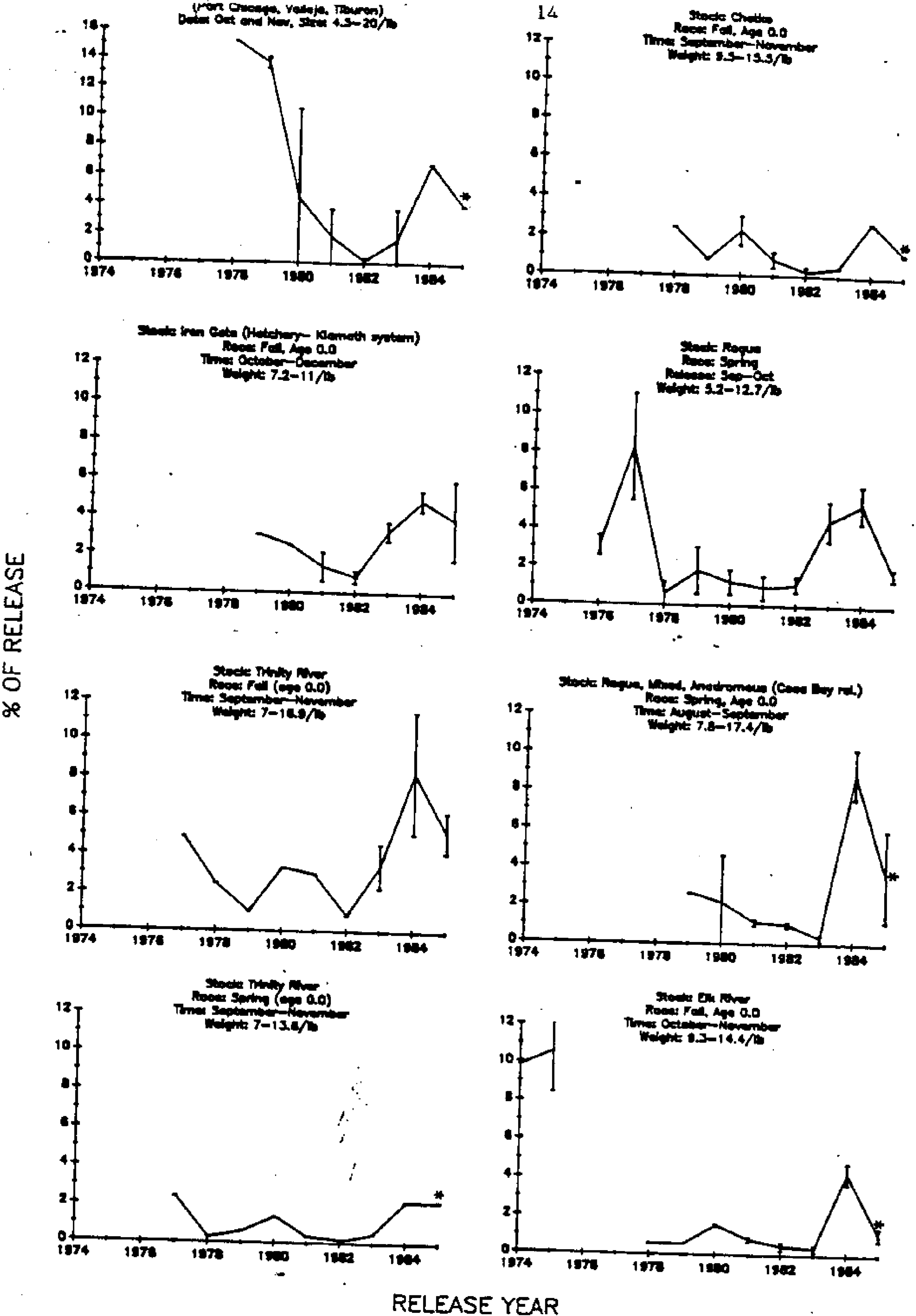
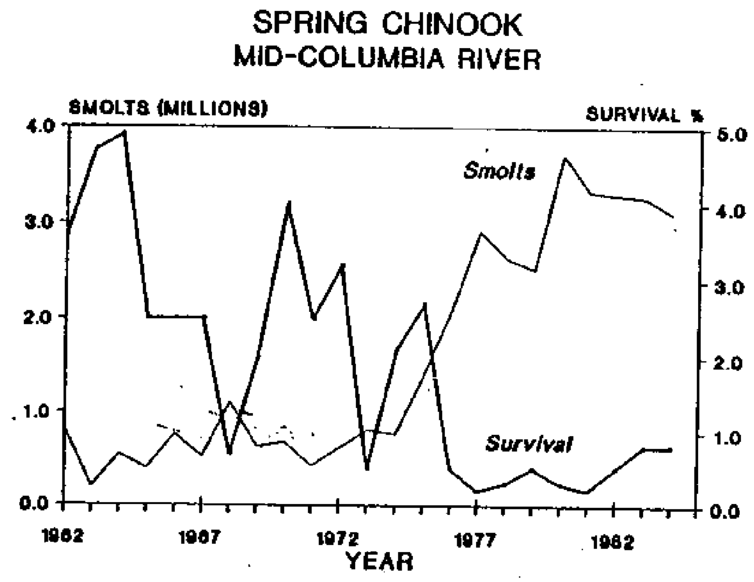
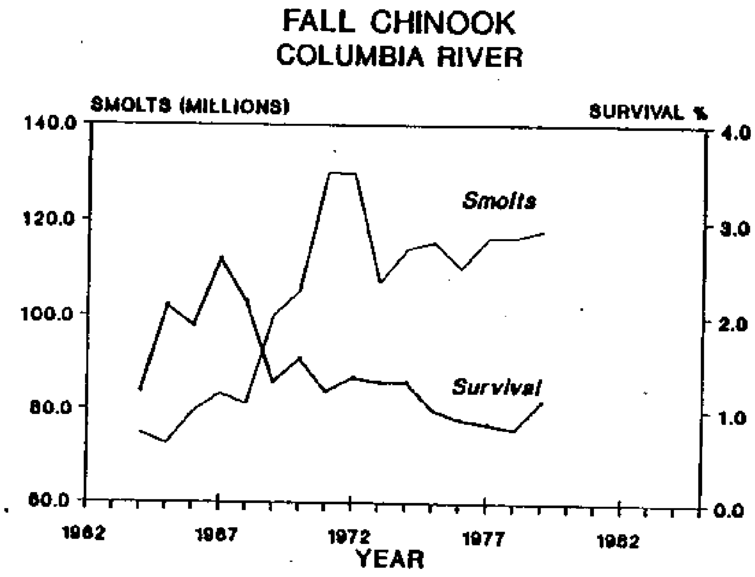


Fig. 2. Mean percentages of CWT chinook salmon recovered in ocean and river fisheries and returning to hatcheries at all ages from releases from hatcheries in California and southern Oregon. When several tag groups represent a brood, the average percent recovered (each group given equal weight) is plotted.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





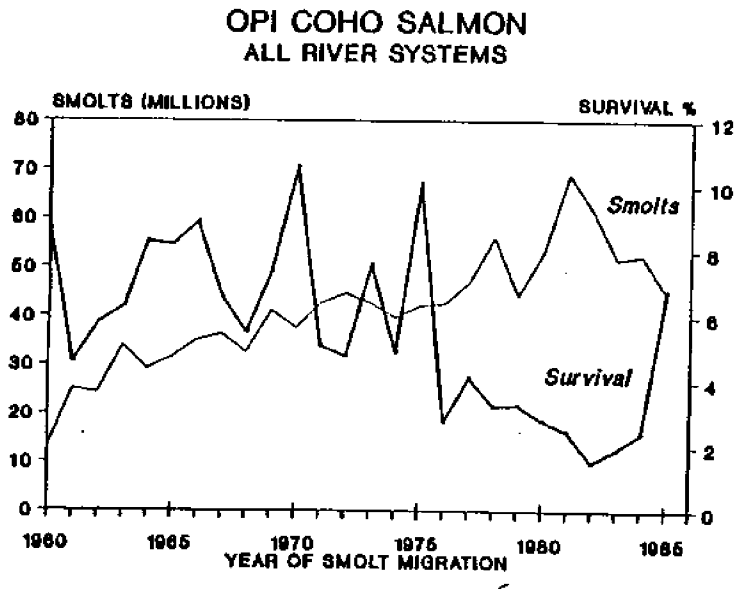


Fig. 3. Numbers of smolts released and percent adult survival for mid-Columbia spring chinook (Raymond 1988), Columbia River fall chinook (Fresh, et al., 1987), and OPI coho (Nickelson 1986).

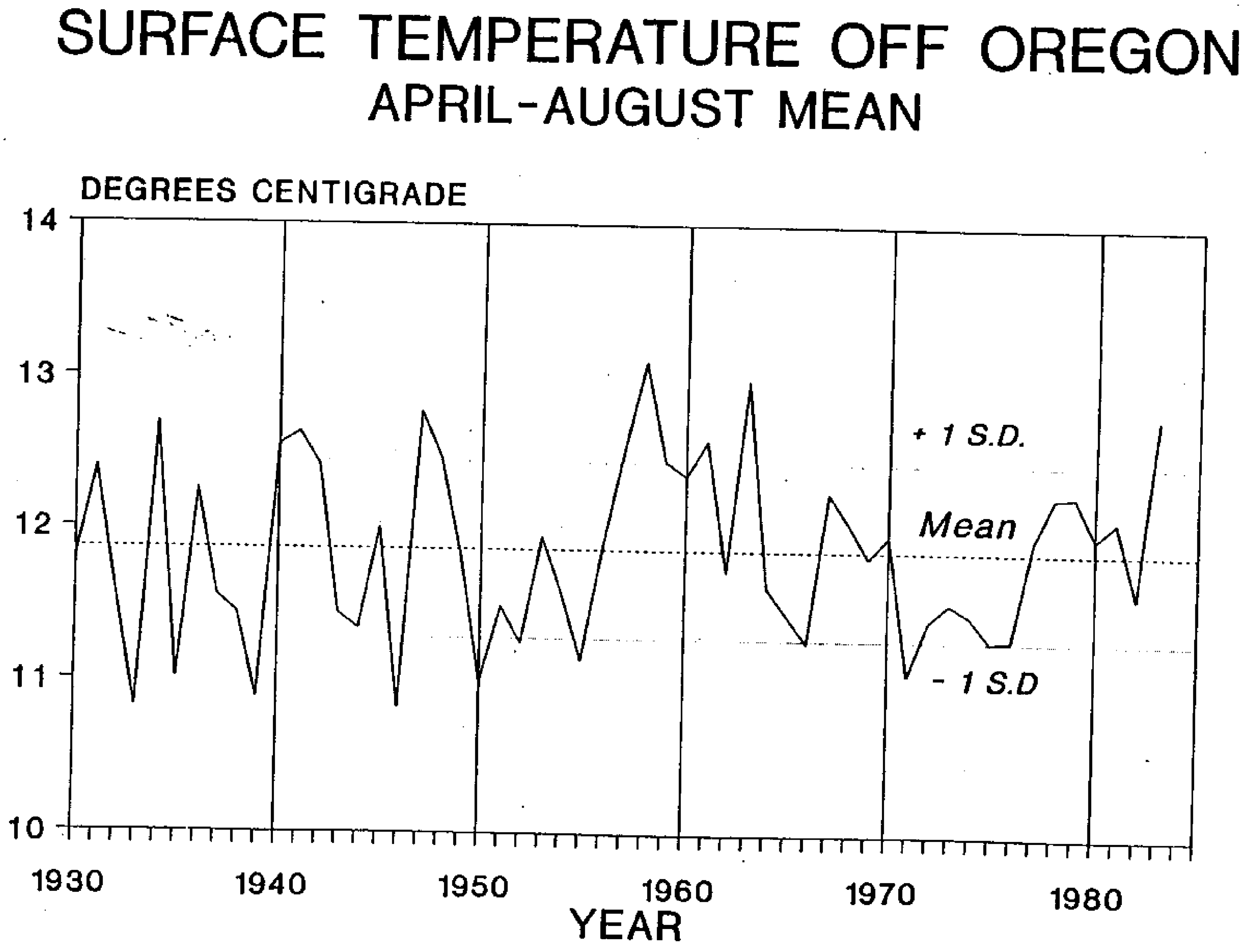


Fig. 4. Sea-surface temperature off Oregon, 1930-1983. Marsden square data provided by A. Hollowed, NMFS, Seattle.

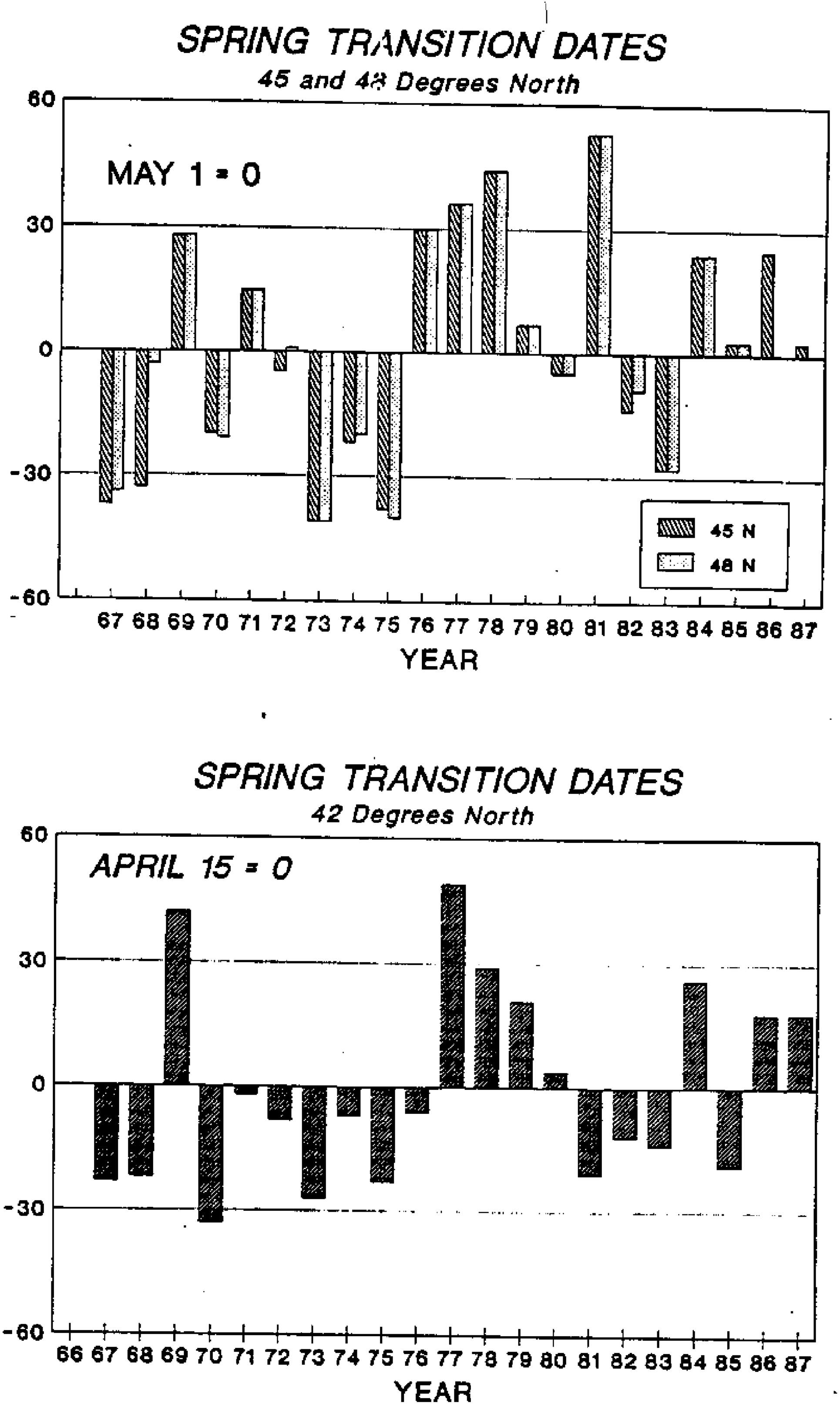


Fig. 5. Spring transition dates at 48°N, 45°N, and 42°N, 1967-1987.

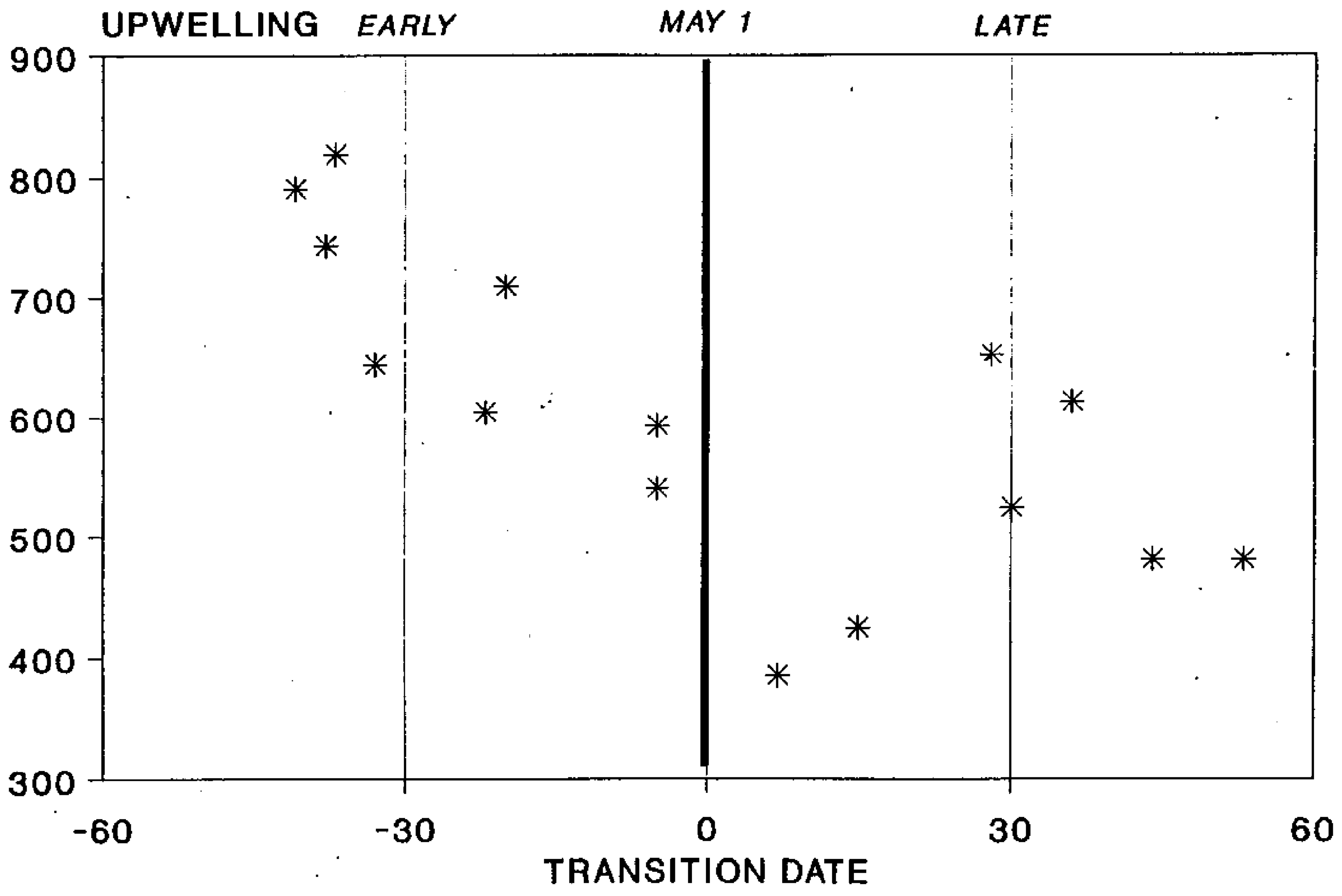


Fig. 6. Cumulative March-September upwelling volume vs. transition date at 45°N.

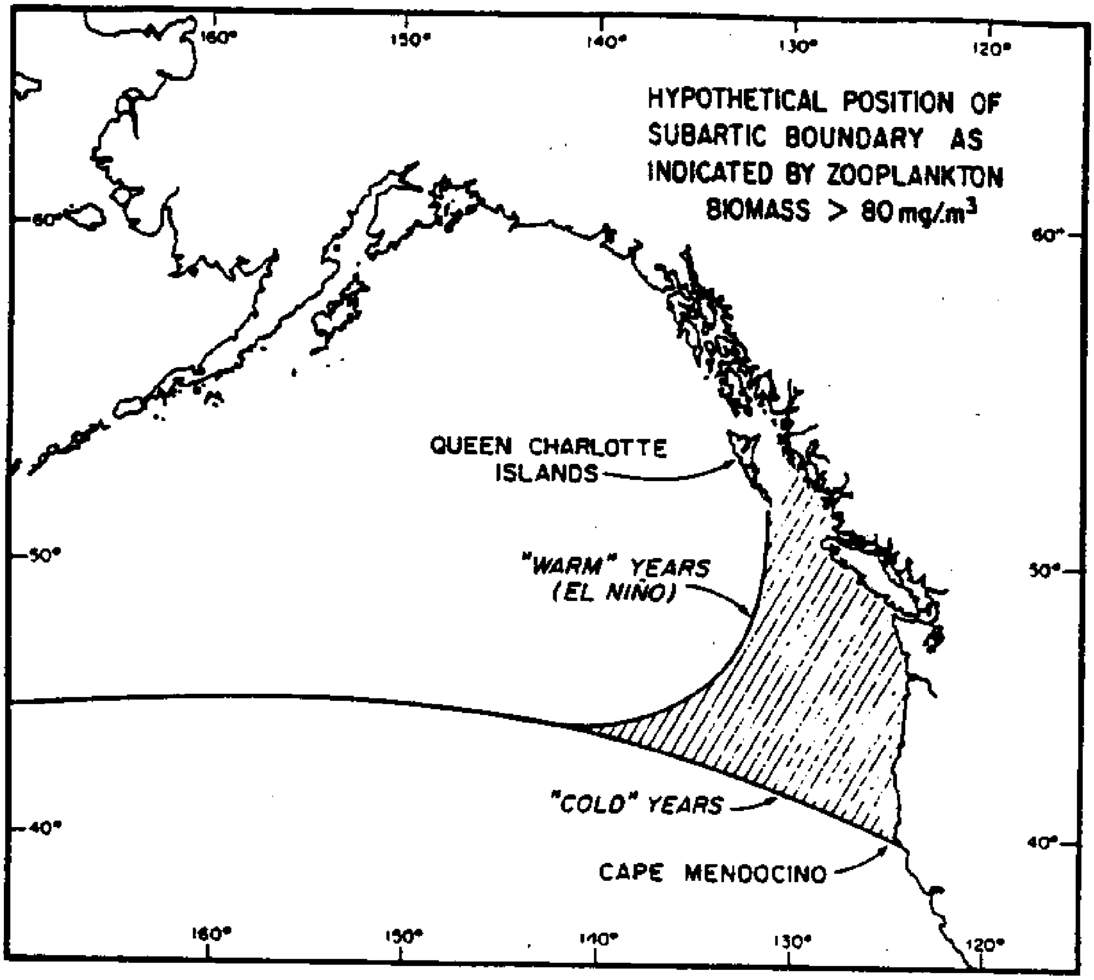


Fig. 7. Schematic diagram of the area affected by shifting of the subarctic boundary. From Fulton and LeBrasseur (1985).

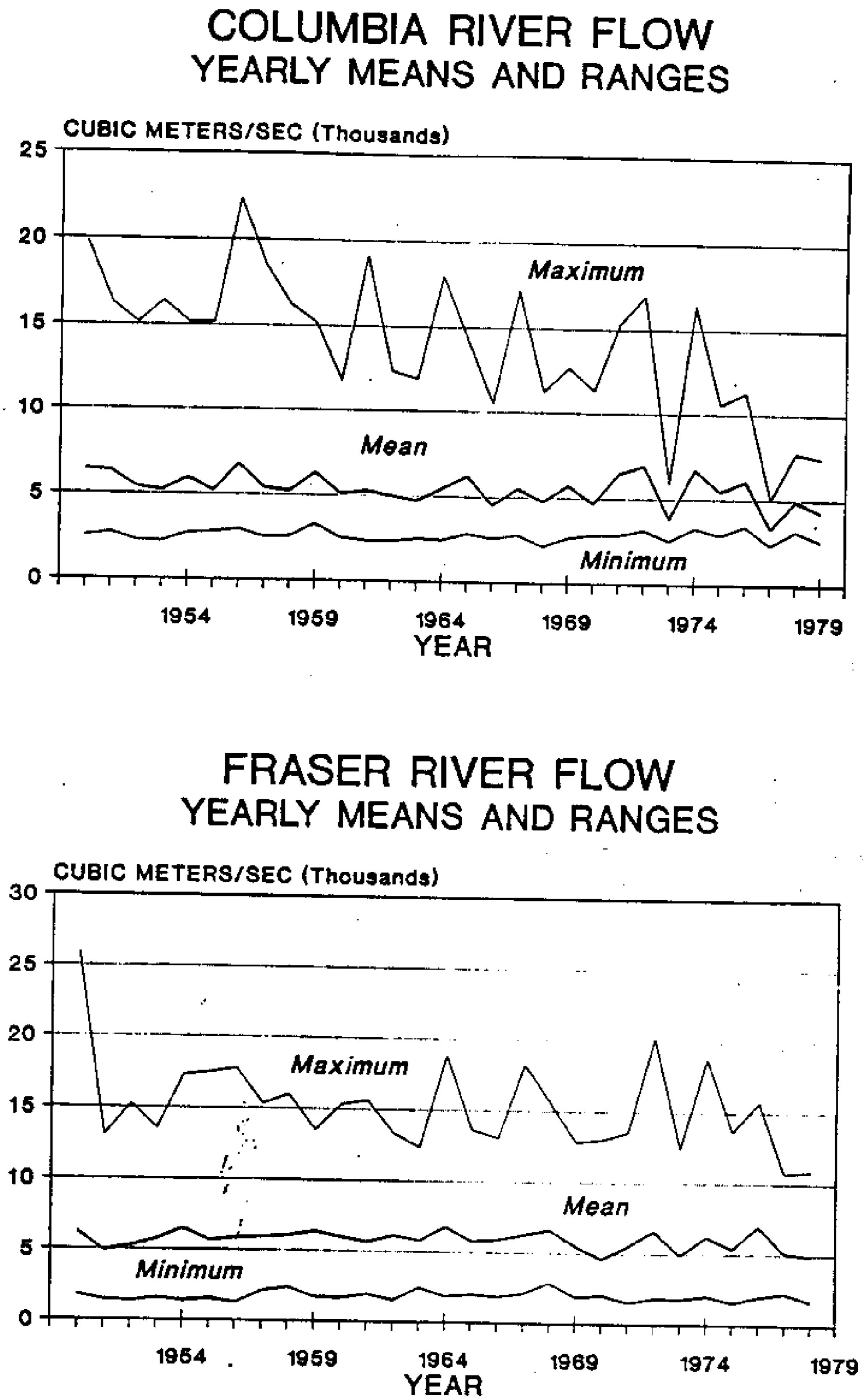


Fig. 8. Maximum, minimum, and mean annual flows for Columbia River and Fraser River, 1951-1979.