# Interannual Trends In Steelhead Abundance And In Ocean Conditions

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# BACKGROUND

## Ocean Distributions - Migrations

The oceanic range of steelhead originating from North America is vast. It covers almost the entire North Pacific Ocean north of about 41° N from North America to Asia (to at least 163° E) (Burgner et al. 1992)(Fig. 1). Consequently, steelhead salmon entering the ocean from rivers in Oregon, Washington and California are exposed to different ocean conditions during their migrations including those in local marine waters off the mouths of their home rivers and in coastal and oceanic waters in the subarctic North Pacific ocean thousands of miles away. Although year-class success may be often determined before or during the first few months of ocean life (see Pearcy 1992 for a review), under certain conditons (such as El Niño) adult mortality may have a strong negative impact on year-class strength (Johnson 1988). Thus, a search for potential environmental factors affecting survival of steelhead requires knowledge of the distribution of the fish during different phases of their life history.

High-seas recoveries of CWT fish and inland recoveries of fish tagged at sea (1956-1988) indicate that ocean distributions may differ for steelhead from different regions. Steelhead from British Columbia, coastal Washington and Puget Sound and the Columbia River basin were found in the Gulf of Alaska and in the western Pacific Ocean between 163°E and 180 (Fig. 2). However, steelhead from coastal Oregon and northern California rivers were only found east of 160°W (Fig. 2). Those from coastal Oregon rivers had a more northerly distribution (to about 56° N) than those from California streams (to about 53°N, Fig. 2) (Burgner et al 1992). Information on the distributions of coastal Oregon and California steelhead was entirely from fish tagged at sea and later recovered in streams. No CWT fish were released from coastal

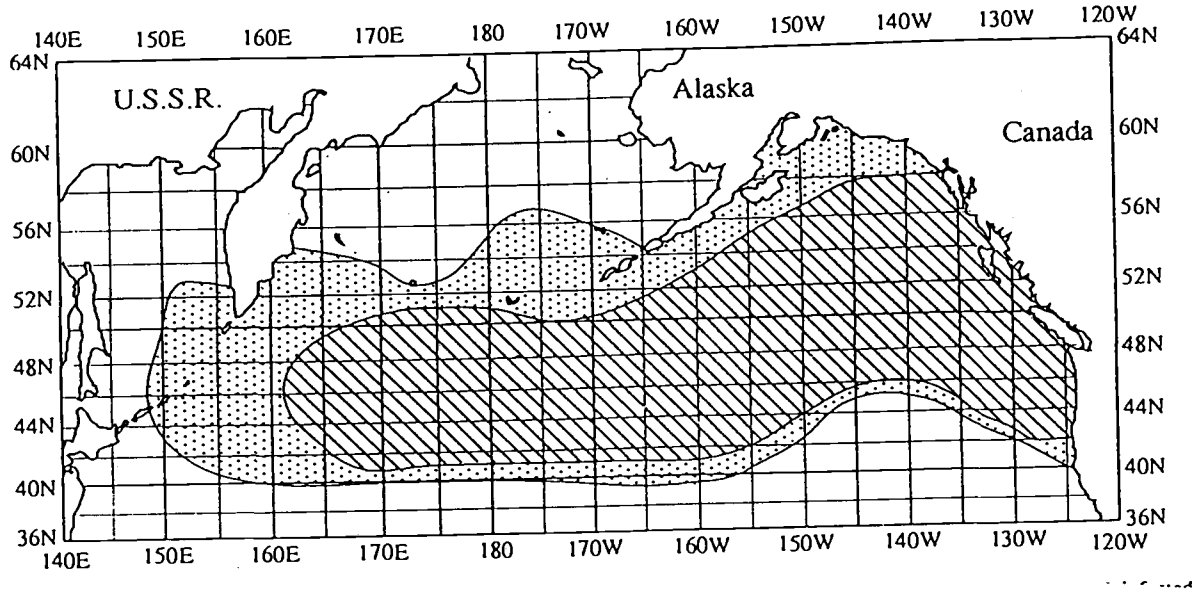



Figure 1. Known distribution of North American steelhead as determined from tag recoveries (slanted lines) within the total distribution of steelhead from research vessel data. (From Burgner et al. 1992)

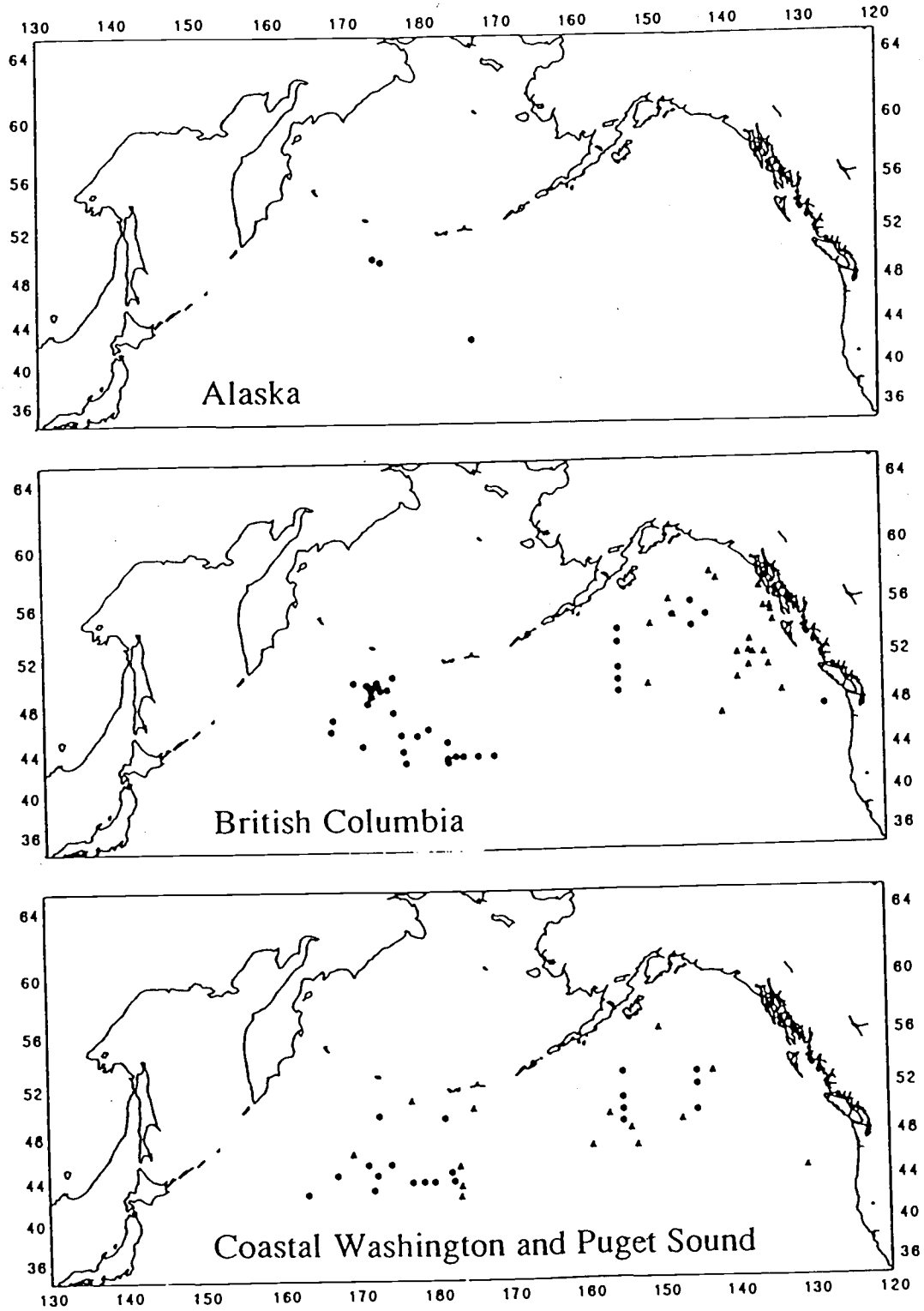



Figure 2. Distributions of steelhead originating in different areas determined from high-seas recoveries of CWT fish (filled circles) and from inland recoveries of fish tagged at sea (filled triangles). (From Burgner et al. 1992)

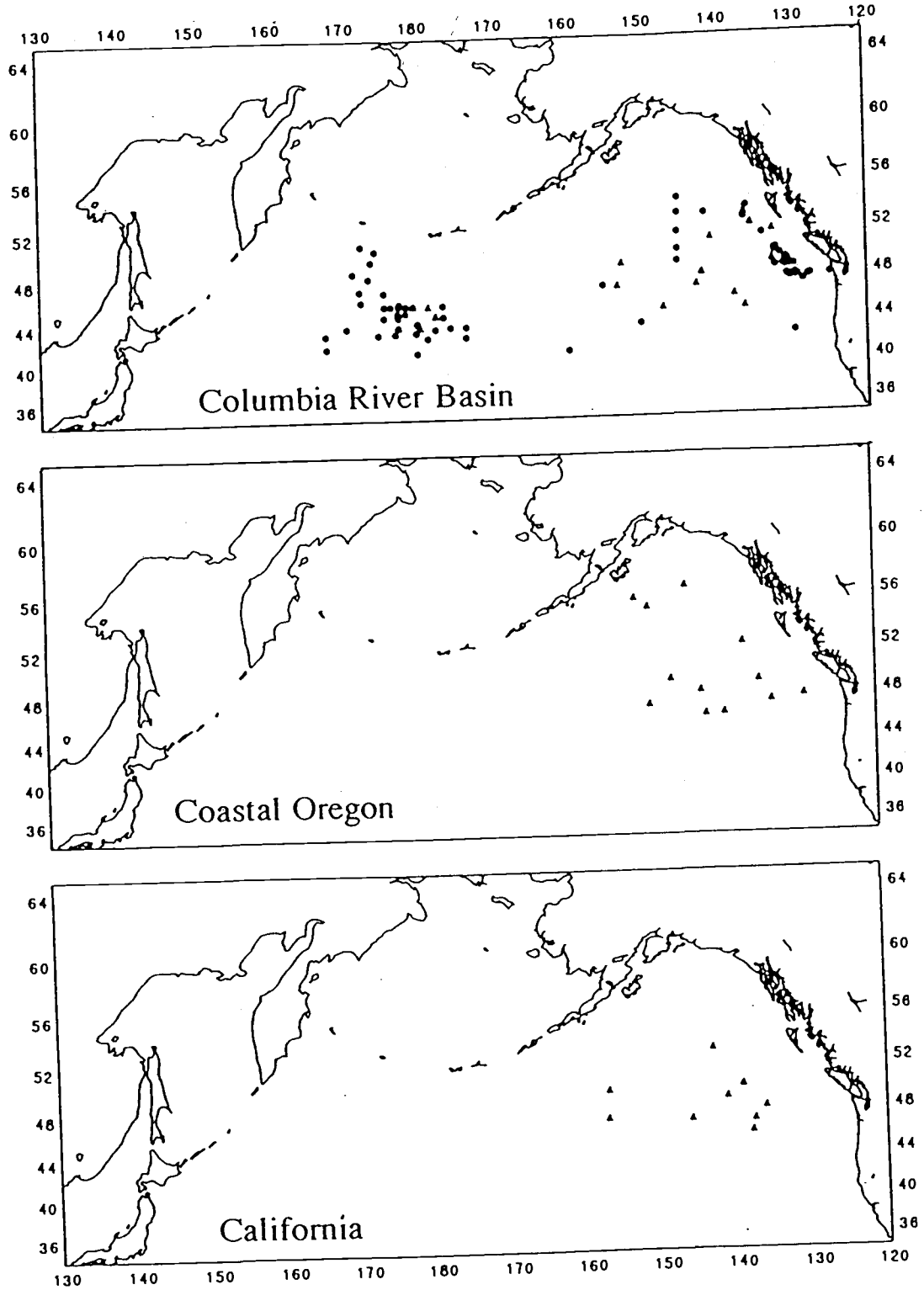



Figure 2 Cont.

Oregon rivers during the study period. Although over 1 million CWT steelhead from California rivers were released, none was recovered at sea (Burgner et al. 1992), suggesting limited migrations of this group into the northern sampling area. Summer steelhead from the Rogue River basin in southern Oregon, most of which have a "half-pounder" life history (smolts go to sea in the spring and return to the river that same fall, overwintering in freshwater before returning to sea the following year) likely do not undertake extensive ocean migrations, at least during their initial few months at sea (Pearcy et al. 1990, Light et al. 1989).

Unlike juvenile Pacific salmon, which generally remain in coastal waters during their first summer in the ocean (Hartt and Dell 1986, Pearcy and Fisher 1988), many steelhead apparently migrate directly offshore soon after entering the ocean. In sampling over many years with small-mesh purse seines in nearshore and offshore areas of the northeastern Pacific ocean, age _.0[1] steelhead were found in offshore waters as early as June and, in contrast to juvenile (age _.0) salmon, were more abundant in offshore waters than in inshore waters (Hartt and Dell 1986).

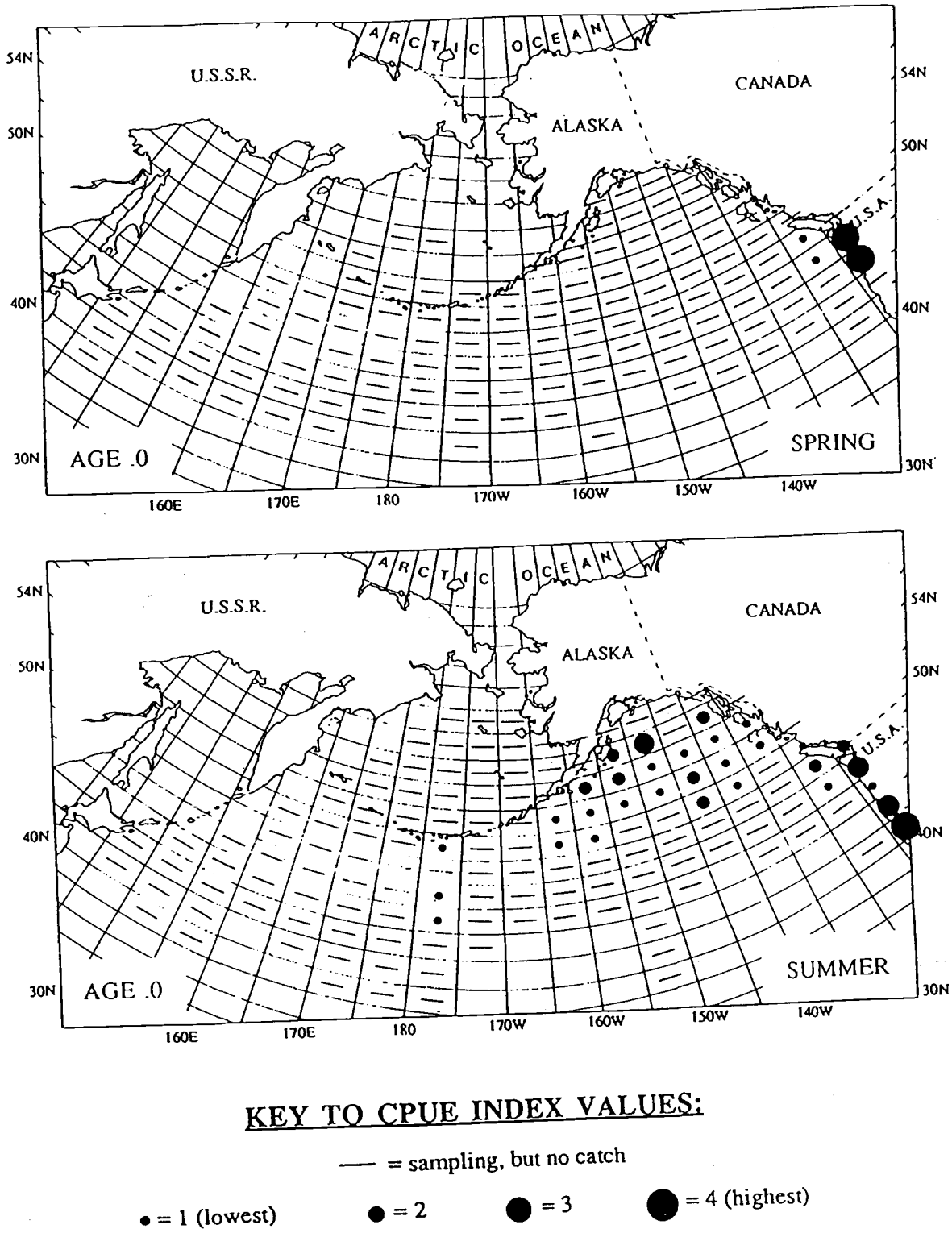
During sampling in May, June-July and August-September 1981-1985 along the coastal strip (inshore of 50 km) of Oregon and Washington, catch per unit effort (CPUE) of juvenile steelhead was often highest offshore of 37km, whereas CPUE of juvenile coho and chinook salmon was usually highest farther inshore (Pearcy and Fisher 1990). CPUE of steelhead was highest in May and June and decreased to 0 in September (Pearcy and Fisher 1990). A similar spatial and temporal pattern in catch of juvenile steelhead was found in other purse seine

[1] The number of winters spent in freshwater before the initial migration to the ocean precedes, and the number of winters spent in the ocean succeeds the period (Koo 1962).

sampling off northern Oregon and southern Washington in 1980 (Miller et al. 1983). The low abundance after June of juvenile steelhead off of Oregon and Washington suggests that most migrate out of the coastal strip soon after entering the ocean as smolts. This may not apply to southern Oregon and northern California stocks, since most sampling was north of Coos Bay.

Very rapid ocean migrations of marked juvenile steelhead have been reported. A fin-clipped steelhead released in the Alsea River, Oregon in April was caught south of Kodiak Island five months later. It had travelled at least 1200 nmi at a net rate of at least 8-10 nmi/d (Hartt and Dell 1986). Pearcy and Masuda (1982) caught a Snake river summer steelhead at 145° W, 886 nmi from the mouth of the Columbia River about two months after the fish entered the ocean. Its average speed of migration was at least 13 nmi/d.

Burgner et al. (1992) analyzed steelhead catch data from United States, Soviet Union, Japanese and Canadian research vessels fishing purse seines, gillnets and longlines in the North Pacific Ocean caught in different seasons between 1955 and 1990. Based on the CPUE of steelhead in different areas they concluded that migration of steelhead (all ocean age groups) was generally northward and westward in the spring and summer and southward and eastward in the autumn and winter. In the summer of their first year in the ocean (age _.0) steelhead were found both in coastal areas from northern California to British Columbia and offshore throughout most of the Gulf of Alaska (Burgner et al. 1992, Fig. 3). By the spring and summer of their second year in the ocean (age _.1) steelhead were much more abundant in far offshore areas between 45 and 52°N in the eastern Pacific and between 42 and 50° N in the western Pacific than in nearshore areas (Fig. 4). Age _.2 and older steelhead were also generally more abundant in offshore than nearshore areas (Burgner et al. 1992). An exception is the area south of the




**KEY TO CPUE INDEX VALUES:**

— = sampling, but no catch

• = 1 (lowest) ● = 2 ● = 3 ● = 4 (highest)

Figure 3. Distribution of age _.0 steelhead in spring (March - May) and summer (June - August). (From Burgner et al. 1992)

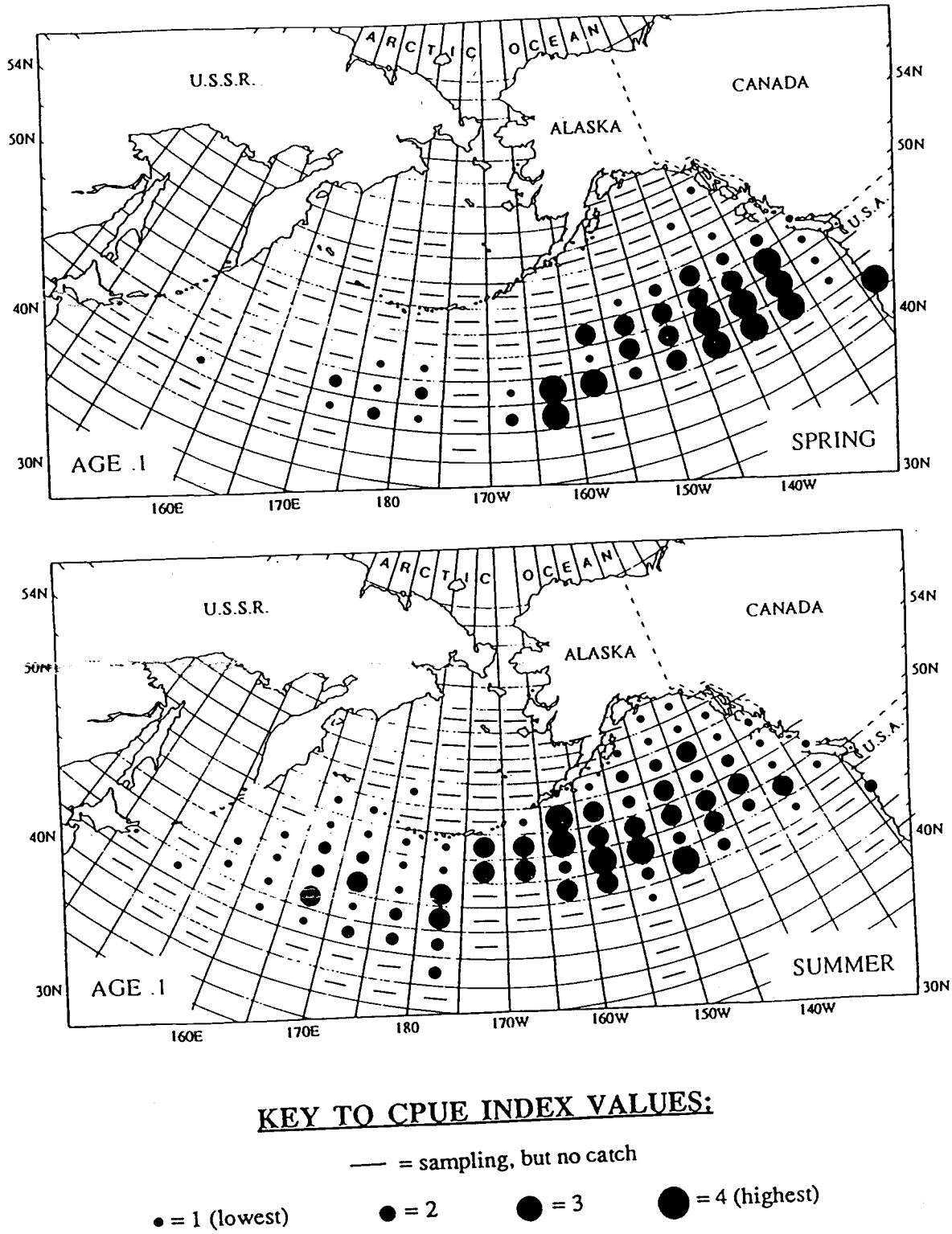



Figure 4. Distribution of age _.1 steehead in spring and summer. (From Burgner et al. 1992)

Alaska Peninsula and the Aleutian Islands where steelhead are abundant in nearshore waters (Fig. 4, Burgner et al. 1992).

Oceanography

As shown in Fig. 1, steelhead inhabit vast regions of the subarctic Pacific Ocean. A general review of the oceanography of the northeast Pacific Ocean is therefore relevant. Between about 40 and 50°N water flows from the western Pacific near Japan toward the west coast of North America (Fig. 5). This current, the northern part of which is called the "Subarctic Current" and the southern part of which is call the "Westwind Drift" is in an area of mixing of cold, low salinity, high nutrient subarctic water to the north and warmer, higher salinity, lower nutrient Central Pacific water to the south (Favorite et al. 1976, Dodimead et al. 1963). As the current approaches the west coast of North America it splits several hundred kilometers offshore into the Alaska Current, which flows north along the eastern Gulf of Alaska, and the California Current, which flows south along Oregon and California (Ware and Thomson 1991, Favorite et al. 1976).

The Northeast Pacific Ocean has been divided into four domains, each with different oceanographic characteristics (Ware and McFarlane 1989)(1-4 in Fig. 5). The area off Washington, Oregon and California, inshore of the California current is known as the Upwelling Domain (Ware and McFarlane 1989)( 3 in Fig. 5). During the spring and summer months in this domain winds generally blow from the north or northwest. This produces a southward flowing current along the shelf, and as the surface waters are pushed to the south by the northerly winds, some of the water also moves offshore due to the earth's rotation (offshore

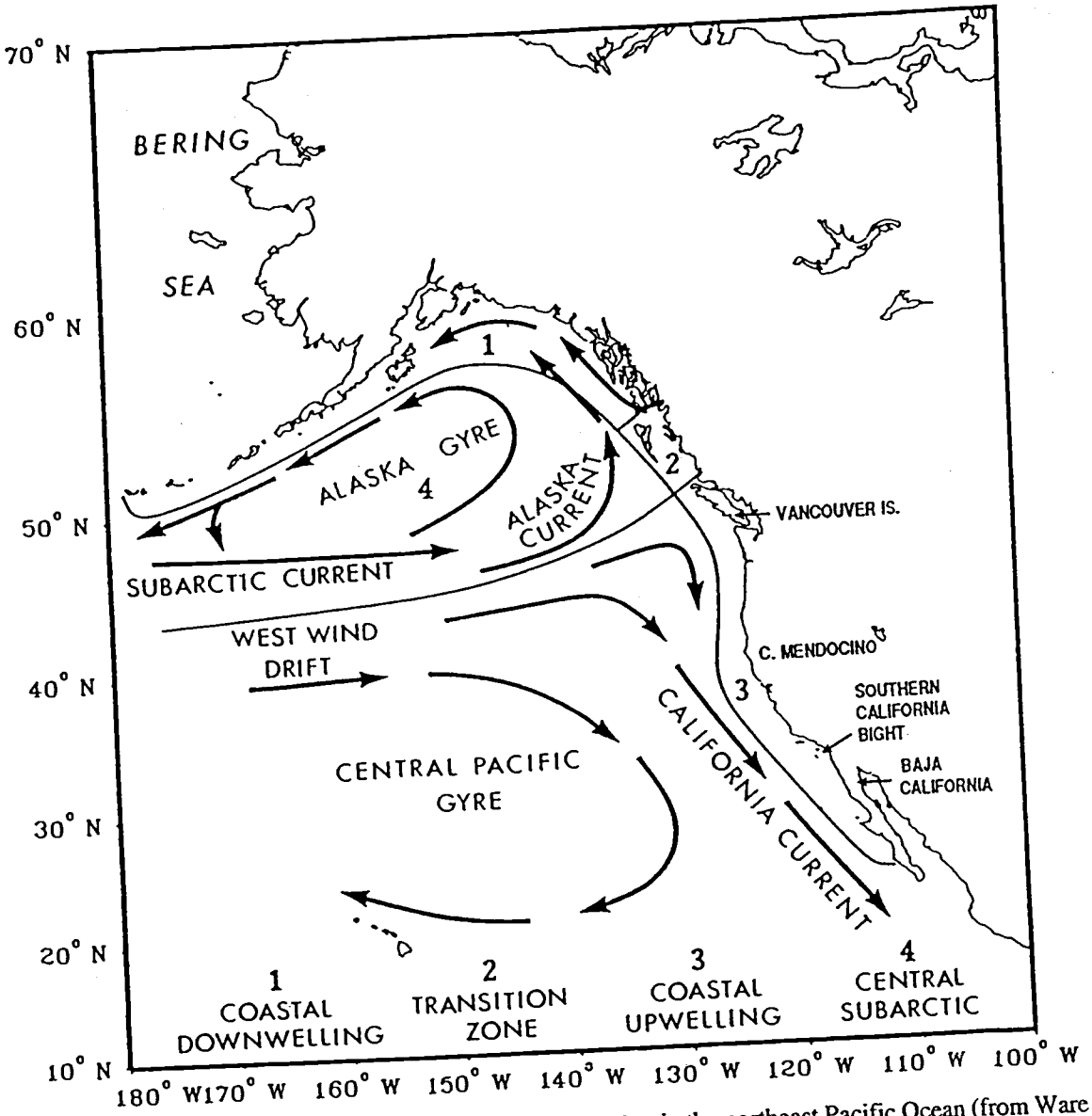



FIG. 1. Fisheries production domains and general circulation in the northeast Pacific Ocean (from Ware and McFarlane 1989). Some key place names mentioned in the text are shown.

Figure 5. The northeast Pacific Ocean showing currents and fisheries production domains. (From Ware and McFarlane 1989)

Ekman transport). The water that has moved offshore is usually replaced by cold, nutrient-rich water that wells up from below the theromocline into the surface layers next to the coast (Landry et al. 1989). This process is called upwelling (Fig. 6). Episodes of upwelling greatly increase the productivity of the coastal ocean in the upwelling domain by bringing nutrient-rich water into the euphotic zone near the surface where it promotes growth of phytoplankton, zooplankton and larger animals. In the northern part of the Upwelling Domain the winds reverse in the winter and blow from the south. These southerly winds cause onshore movement of water. As this onshore moving water approaches the coast it sinks (downwelling) (Fig. 6).

The central area of the Gulf of Alaska is known as the Central Subarctic Domain (Ware and McFarlane 1989) (4 in Fig. 5). During most of the year winds and currents flow counter-clockwise around the Gulf of Alaska. This causes oceanic upwelling of nutrient-rich water in the center of the gyre and onshore flow (Brodeur and Ware 1992, Cooney 1993). As water approaches the coast it sinks. Because of this, the coastal area in the Gulf of Alaska is known as the Downwelling Domain (Ware and McFarlane 1989) (1 in Fig. 5).

Both the Coastal Upwelling Domain, off Washington, Oregon and California, and the Downwelling Domain, around the edge of the Gulf of Alaska are very productive areas, producing many millions of tons of fish each year. (Pollock, cod, sablefish, rockfish in the Downwelling Domain; Hake, anchovy, sardine, pacific mackerel in the Upwelling Domain; Ware and McFarlane 1989). Although the overall production in the Central Subarctic Domain is not as high as in the two coastal domains, it is a very important feeding area for several species of salmonids, and biomass of salmonids in the Central Subarctic Domain is very high (Ware and McFarlane 1989, Pearcy, in press).

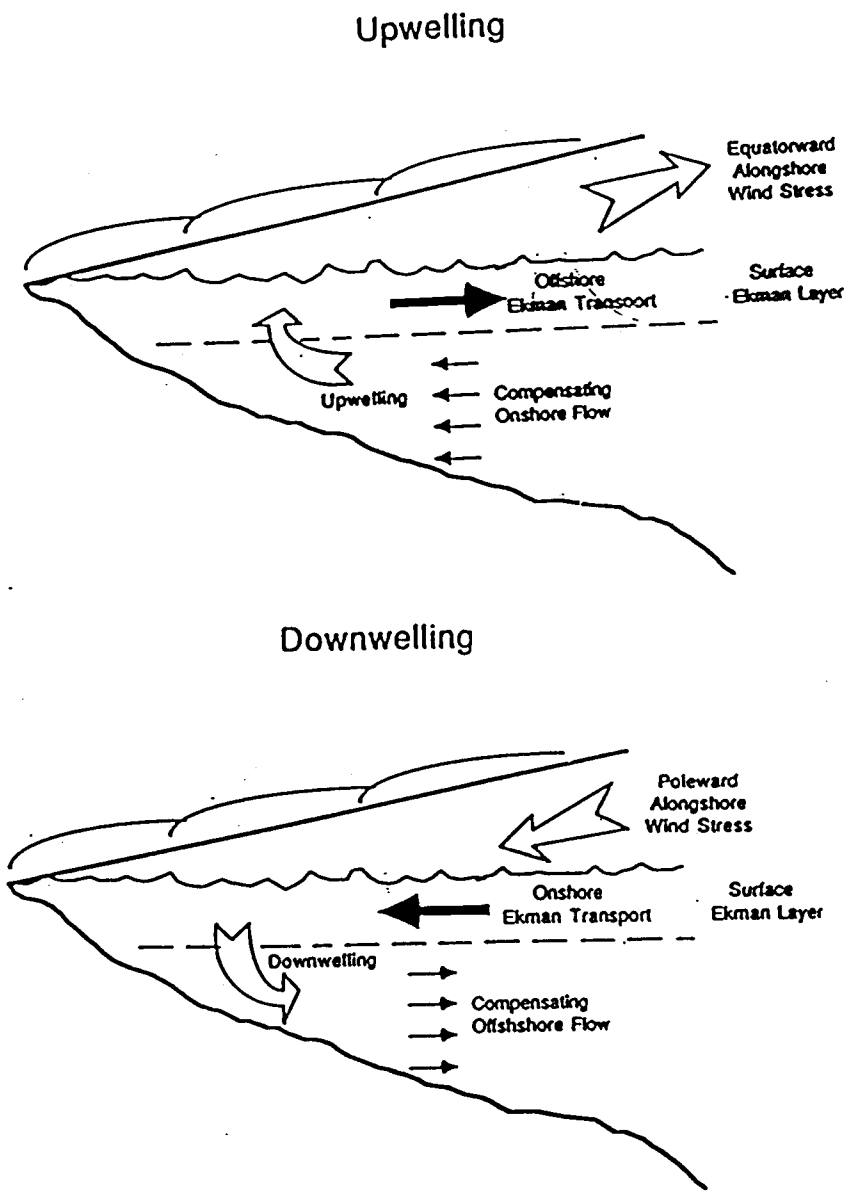


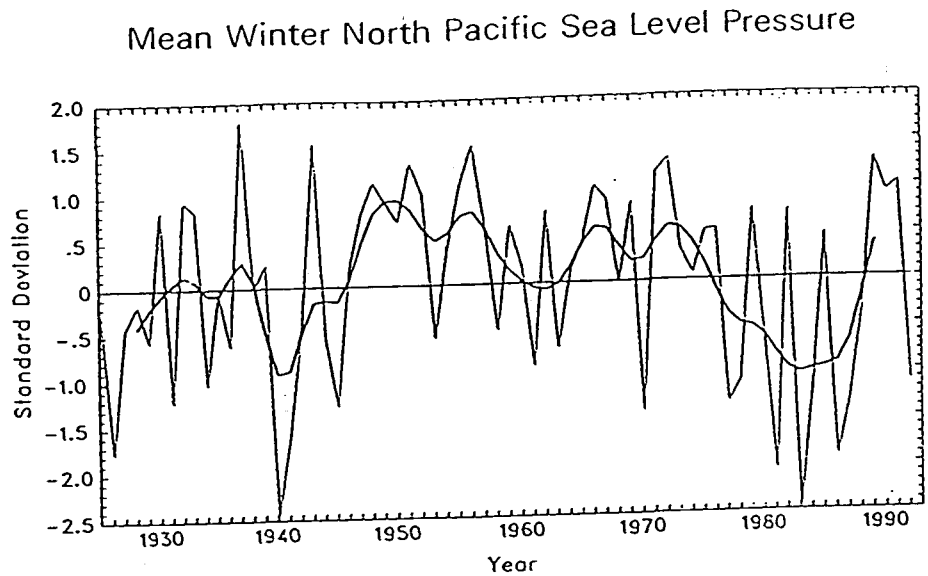

Figure 6. Diagramatic of upwelling and downwelling.

Climatic Changes

Some remarkable changes have occurred in the ocean climate of the North Pacific Ocean during the past 20 years that have affected the production of salmonids. In 1976-1977 the ocean/atmosphere regime changed from one that favored salmonids in the California Current system to one that favored high production of salmonids in the Gulf of Alaska and the Central Subarctic Domain. This climate change was associated with a deepening of the Aleutian Low (Fig. 7), strong cyclonic circulation in the Gulf of Alaska, intensification of the Alaska Current and advection of relatively warm air and water into the Gulf of Alaska. Upwelling in the Subarctic Gyre may have also increased. All these factors resulted in very favorable conditions for production of salmonids in Alaska, and records catches were made during the 1980s and early 1990s (Fig. 8) (Pearcy 1992; Beamish and Bouillon 1993; Hare and Francis in press). During this same period, advection of cool, nutrient-rich subarctic water southward in the California Current probably decreased (Chelton and Davis 1982, Chelton et al. 1982), and a prolonged series of El Niño events (Fig. 7), high sea levels and sea surface temperatures occurred along the coast of North America. Steelhead smolts migrating through coastal waters of Oregon may have been adversely affected by these climatic changes, but maturing fish in oceanic waters of the subarctic Pacific may have benefited from the good conditions there.

## METHODS

We examined time series of run sizes and return rates of summer and winter run steelhead originating in different river systems from northern California to British Columbia. Similar trends in abundance and survival of steelhead from different river systems would suggest



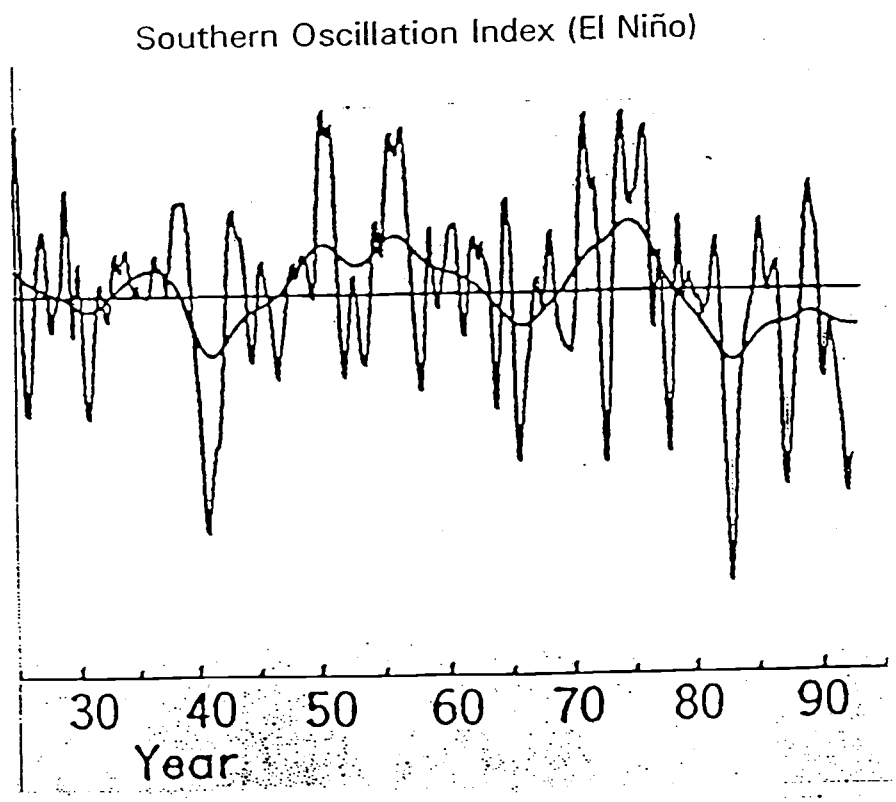
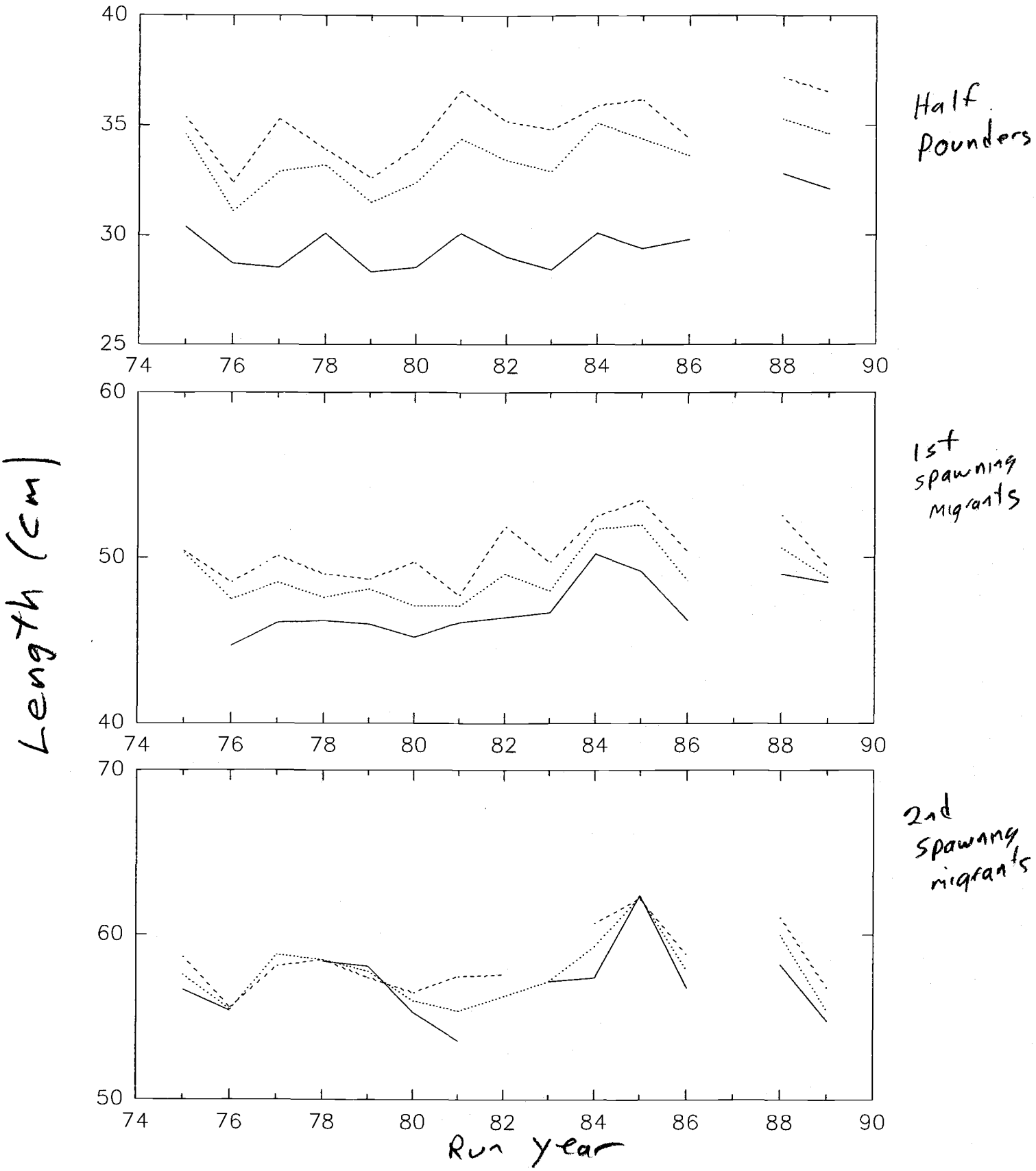




Figure 7. The North Pacific Pressure index and the Southern Oscillation Index for different years. Intense low pressure in the winter over the North Pacific Ocean (intense Aleutian Low) is indicated by large negative values of the North Pacific Pressure Index. El Niños are indicated by large negative values in the SOI. Both interannual values and smoothed long-term trends are shown. (From Trenberth and Hurrell in press)

Mean Size of fish at Huntley Park



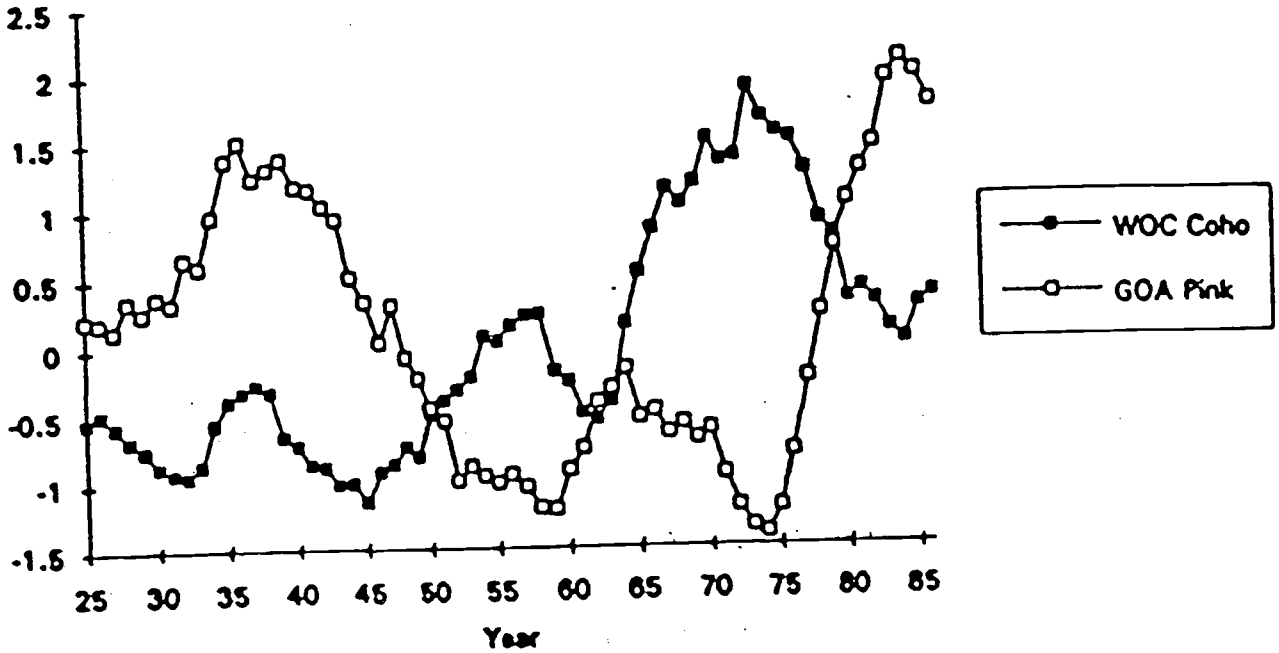



Figure 8. Catch of pink salmon in the Gulf of Alaska and coho salmon off Oregon and Washington in different year. (From Francis and Sibley 1991)

that survival of these fish was strongly influenced by large-scale climatic or oceanographic factors. Since the number of hatchery smolts released influences the number of returning adults, whenever possible we examined time series of return rates (adults/smolts). This was possible for summer-run steelhead in the Rogue, Umpqua, Siletz and Columbia Rivers and for winter-run steelhead in the Alsea River Oregon and several rivers on the Washington Coast and Puget Sound. (Data for these last two areas were from Cooper and Johnson 1992).

We examined return rates of Rogue River hatchery summer steelhead to Cole Rivers Hatchery one year and two years following release (Mike Evenson, ODFW, unpublished data). To estimate return rate of Umpqua summer steelhead we divided total estimated run of hatchery fish (McGie unpublished) by the total number of Umpqua River hatchery smolts released in the prior two years. (Umpqua summer steelhead return to spawn mainly as 1-salt or 2-salt fish, ie. one or two years following the release year; Peterson 1979, Kenastan unpubl.). Return rates of summer steelhead in the Columbia River between 1979 and 1992 were estimated by dividing the estimated total summer steelhead run (WDFW and ODFW 1994, their table 61) by the total number of summer steelhead smolts released two and three years before the run year[2]. The run of summer steelhead in the Columbia River is a mixture of mainly 1-, 2- and 3- salt fish (Kenastan unpubl., Lindsey unpubl.). The run included both wild and hatchery fish, so dividing by smolt releases did not give a true return rate for hatchery fish, but rather a correction for the effect of changing hatchery smolt releases on total return. Time series of abundance and survival of chinook and coho salmon orginating in the area from coastal Washington to northern

[2] Data on smolt releases from the Pacific States Marine Fisheries commission release data base (releases associated with CWTs plus releases not associated with tags)

California were examined for similarities with trends in abundance of steelhead. Similar trends in these different species would suggest that common environmental factors are influencing their survival.

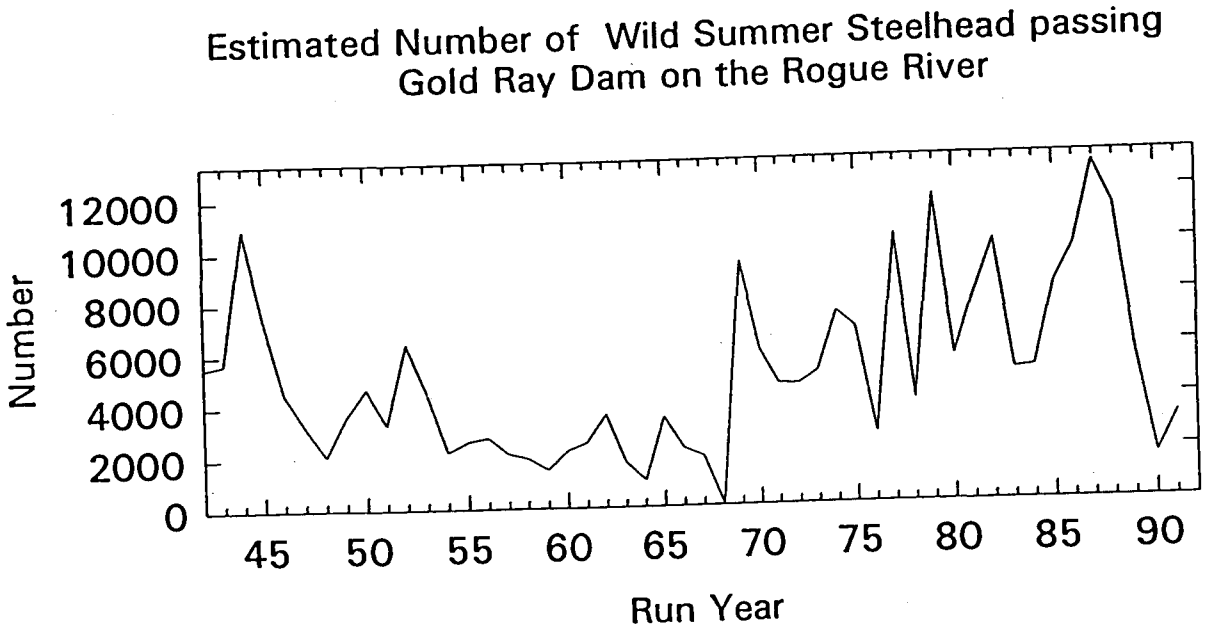
## RESULTS

### Trends in run-sizes and return rates of steelhead

#### *Summer Steelhead*

Interannual trends in run sizes, return rates of hatchery fish and sports catches of summer steelhead from southern Oregon to northern British Columbia were quite similar in the decade from the early 1980s to early 1990s. This suggests that during this period large scale climatic conditions may have had an important impact on the survival of these fish.

Run of summer steelhead in the Rogue, Umpqua and Columbia Rivers peaked between the years 1984 and 1987 (Figs. 9-12). Year of peak run differed, ranging from 1984 for wild summer steelhead in the Umpqua River (Fig. 9) to 1987 for hatchery summer steelhead in the Rogue and Umpqua Rivers (Figs. 10 and 11). For all groups, however, run size was high for at least two or three consecutive years between 1984 and 1988. Run size was low both before (1982 to 1984, depending on the group) and after (between 1990 to 1992) the peak in the mid-late 1980s (Figs 9-12). The low runs in the early 1990s were among the lowest during the times series. Although total run of summer steelhead in the Columbia River in the early 1990s was not especially low, return rate (adults/smolts) was very low in these years (Fig. 12).



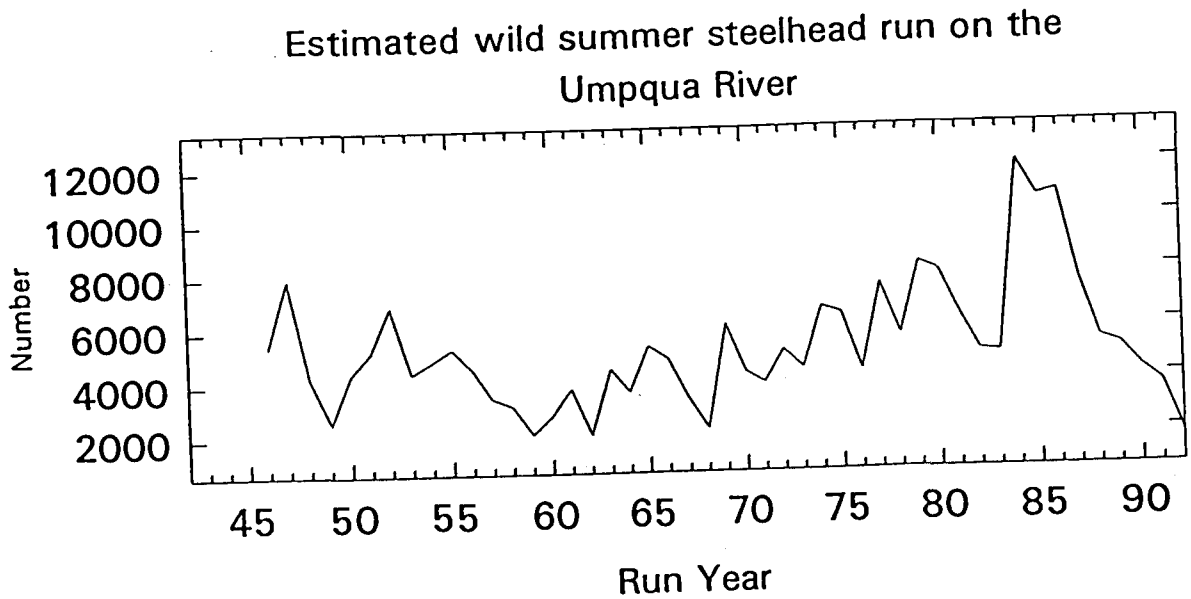
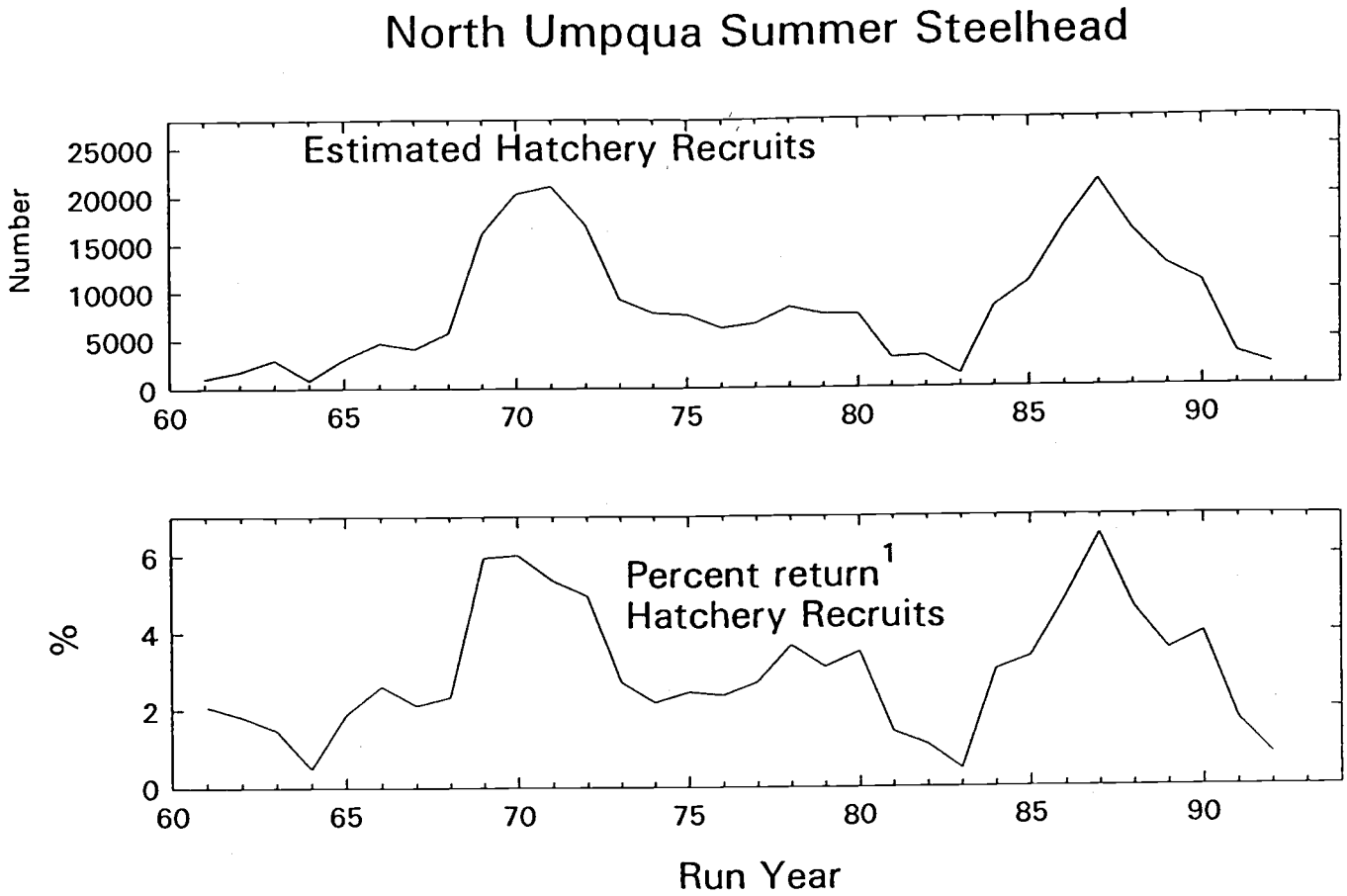




Figure 9. Estimated number of wild summer steelhead passing Gold Ray Dam on the Rogue River (data from ODFW 1994) and wild summer steelhead run on the Umpqua River in different years(data from McGie, unpublished).




[1]( Run estimate / smolts released the prior two years)*100

Figure 10. Estimated total hatchery summer steelhead run (recruits) in the Umpqua River and run divided by hatchery smolt releases in the prior two years (data From McGie, unpublished manuscript)

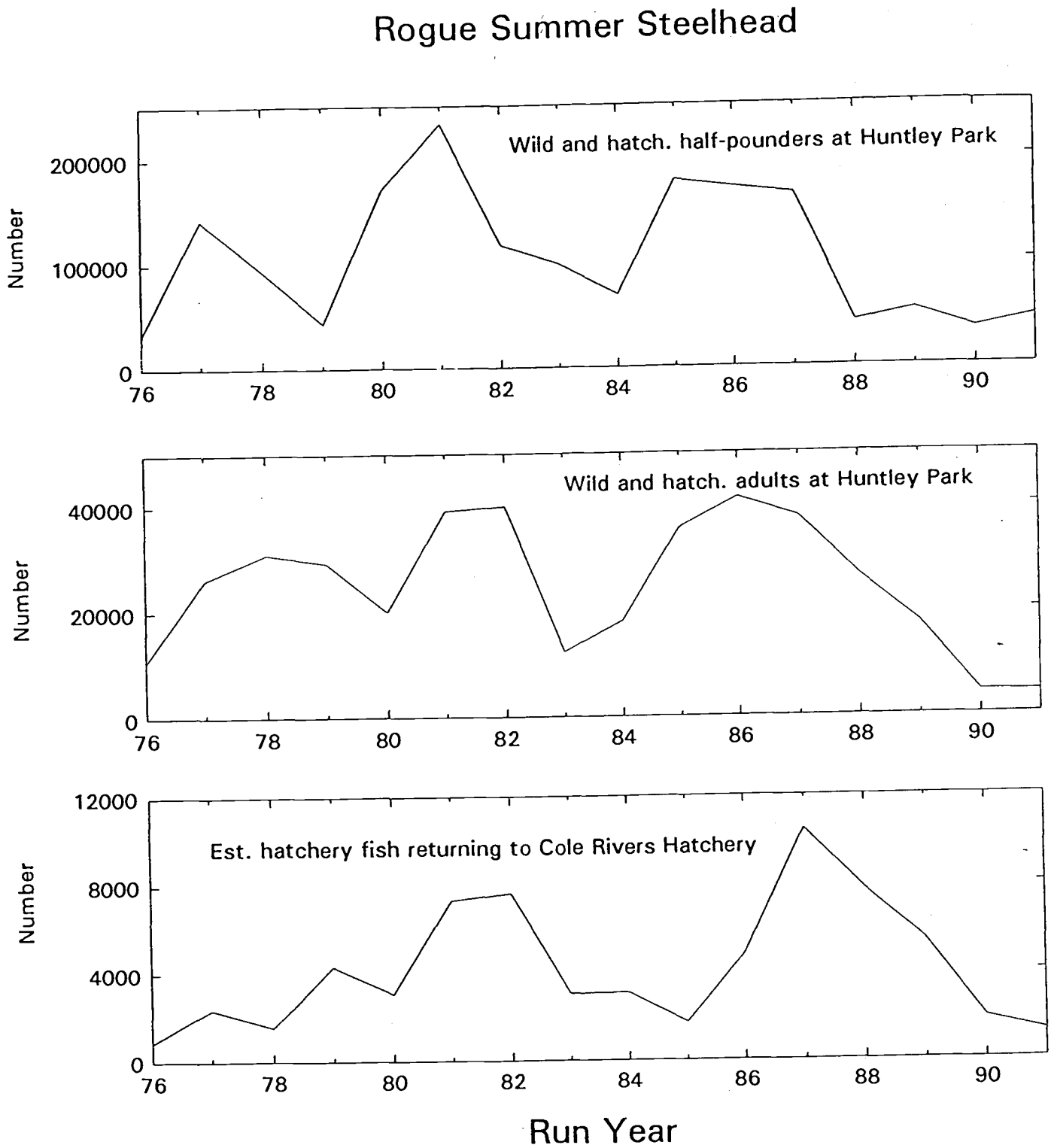



Figure 11. Estimated half-pounder and adult summer steelhead run at Huntley park near the mouth of the Rogue River (wild and hatchery fish combined) and estimated number of hatchery fish returning to Cole Rivers Hatchery in different years. (Data from ODFW 1994)

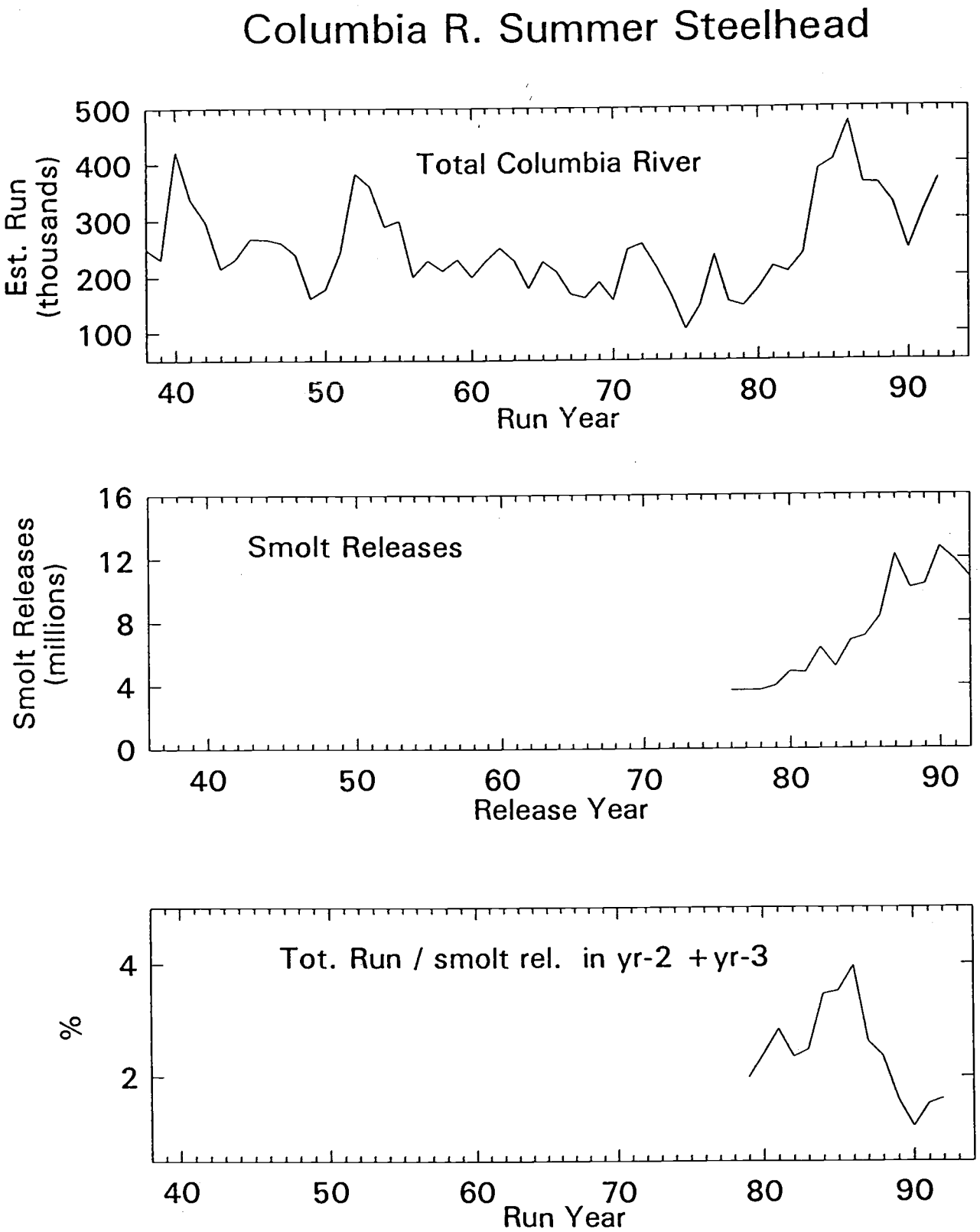
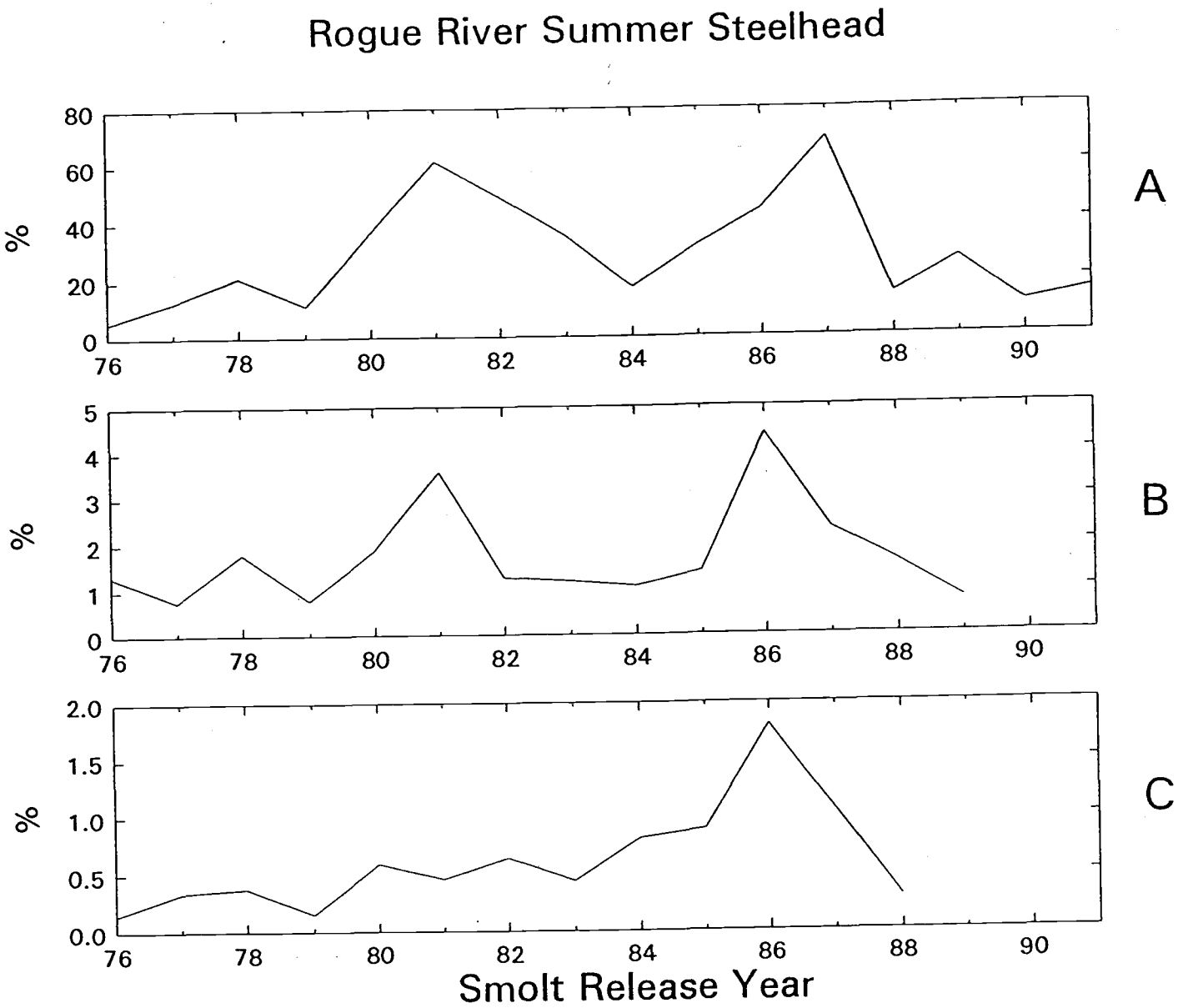



Figure 12. Estimated minimum run of summer steelhead in the Columbia River (data from WDFW and ODFW 1994), total releases of summer steelhead smolts (see footnote 2) and estimated run divided by smolt releases two and three years prior to the run year.

Return rates (survival) of Rogue River hatchery summer steelhead released in 1986 were very high one year (1987) and two years (1988) following release (Fig. 13). Return rates the year following release of fish released from 1982 through 1985 and in 1989 were low. Although fish released in 1981 returned at high rates as half-pounders in 1981 and as first spawning migrants or 1-salts in 1982, they returned at a relatively low rate in 1983 (Fig. 13). This suggests that mortality during the second year in the ocean may have been high for this year-class. This probably was the result of the 1982-1983 El Niño.

Only a short time series of run sizes and return rates were available for summer steelhead in the Siletz River. Run sizes and return rates of summer steelhead in the Siletz River did not fit the pattern seen for summer steelhead in the other river systems. The largest runs in the Siletz River occurred in 1981 and 1984 and highest return rate was for smolts released in 1984 (Fig. 14).

Interannual trends in sports catch of steelhead (summer and winter runs combined) in four British Columbia Rivers was quite similar to that found for run sizes and return rates of summer steelhead in Oregon and the Columbia River. Low catches in the late 1970s and early 1980s in British Columbia were followed by much higher catches in the mid to late 1980s and declining catches in the early 1990s (Fig. 15). Noteworthy are the very similar catch trends in widely separated river systems. However, the decline in catches in British Columbia occurred later than the decline in run sizes of Oregon summer steelhead: large catches of steelhead in British Columbia occurred as late as 1989. It is unclear if the large increase in sports catch in British Columbia in the 1980s was do to increased survival of fish, increased release of smolts (Fig. 16), increased fishing effort or a combination of these factors.




A: (Estimated run of hatchery half pounders at Huntley Park/ smolts)*100

B: Mean % of fin marked smolts returning to Cole Rivers Hatch. one year following release

C: Mean % of fin marked smolts returning to Cole Rivers Hatch two years following release

Figure 13. Estimated run of hatchery half-pounders near the mouth of the Rogue River at Huntley Park (A, data from ODFW 1994) and % of fin-marked smolts returning to Cole Rivers Hatchery one (B) and two (C) years following release (data from Evenson, unpubl.).

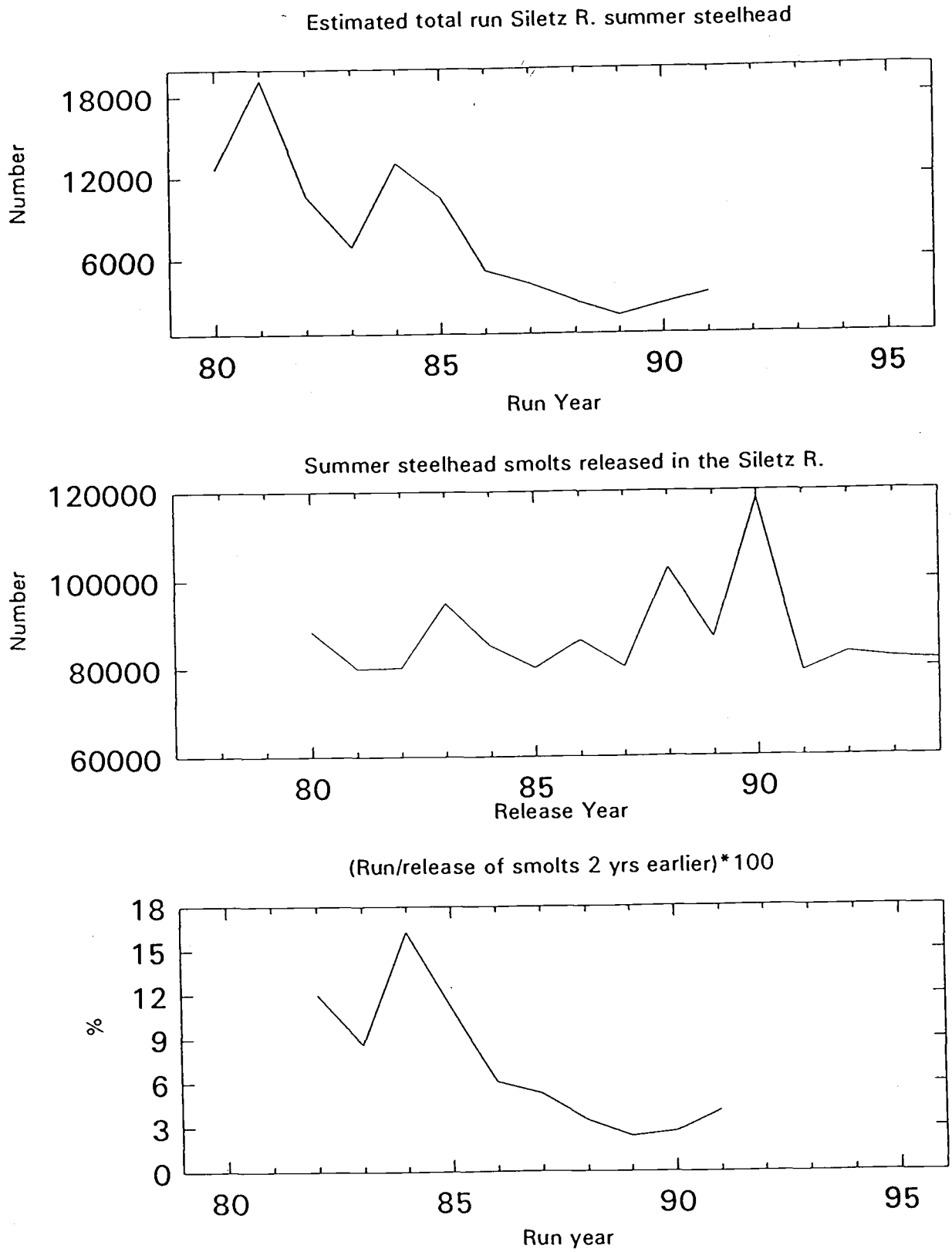
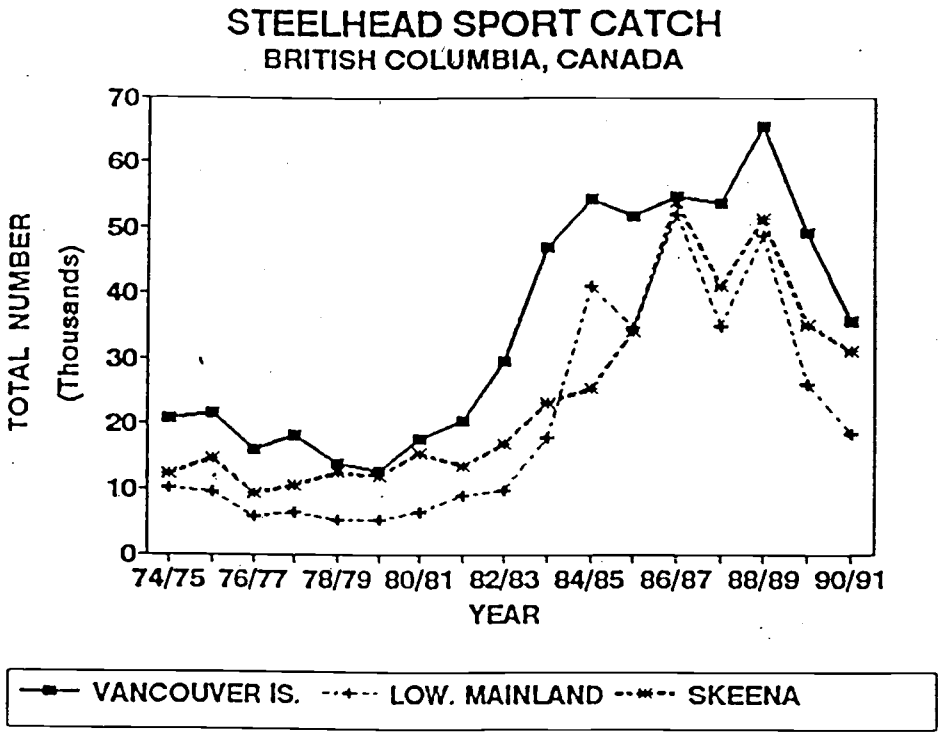



Figure 14. Estimated run of Siletz R. summer steelhead, numbers of smolts released and run divided by the numbers of smolts released two years prior to the run year.



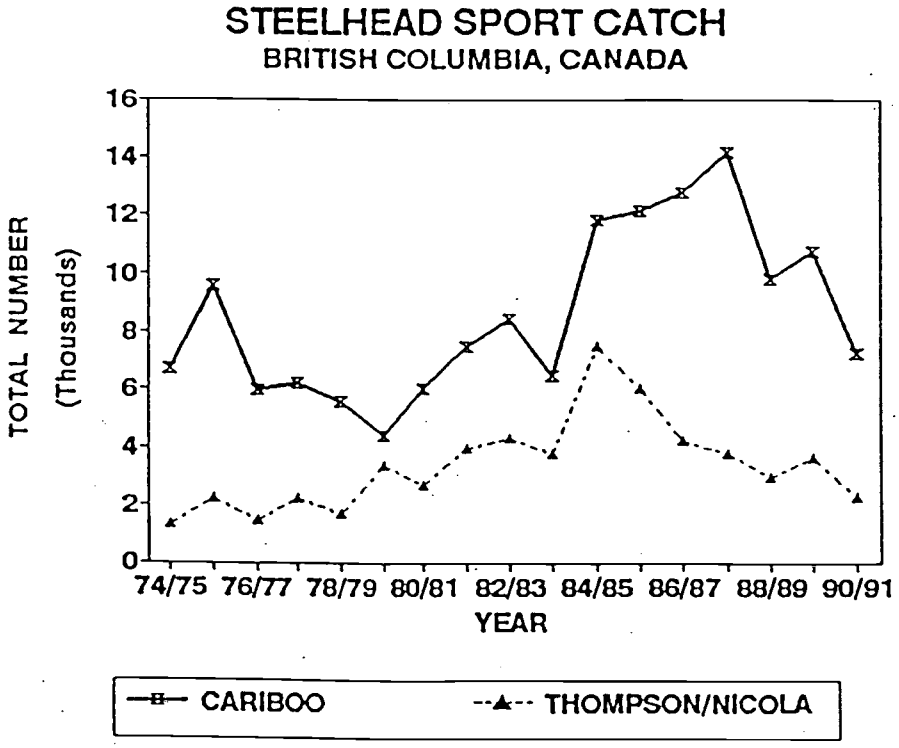




Figure 15. Steelhead sports catch in British Columbia in different years (From Cooper and Johnson 1992).

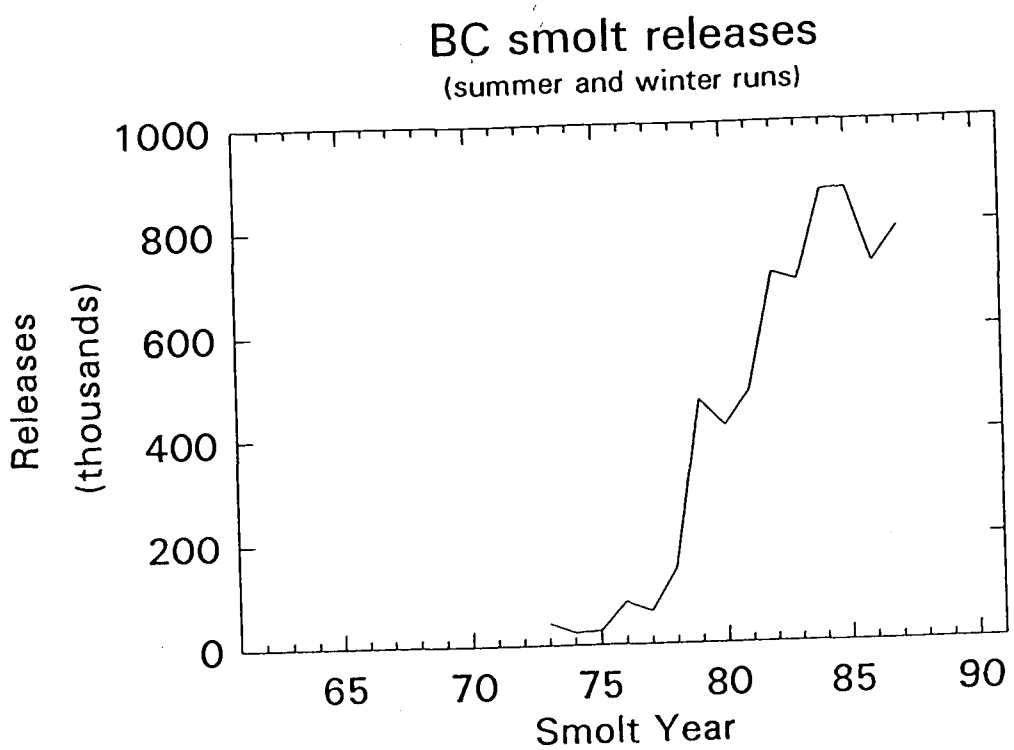
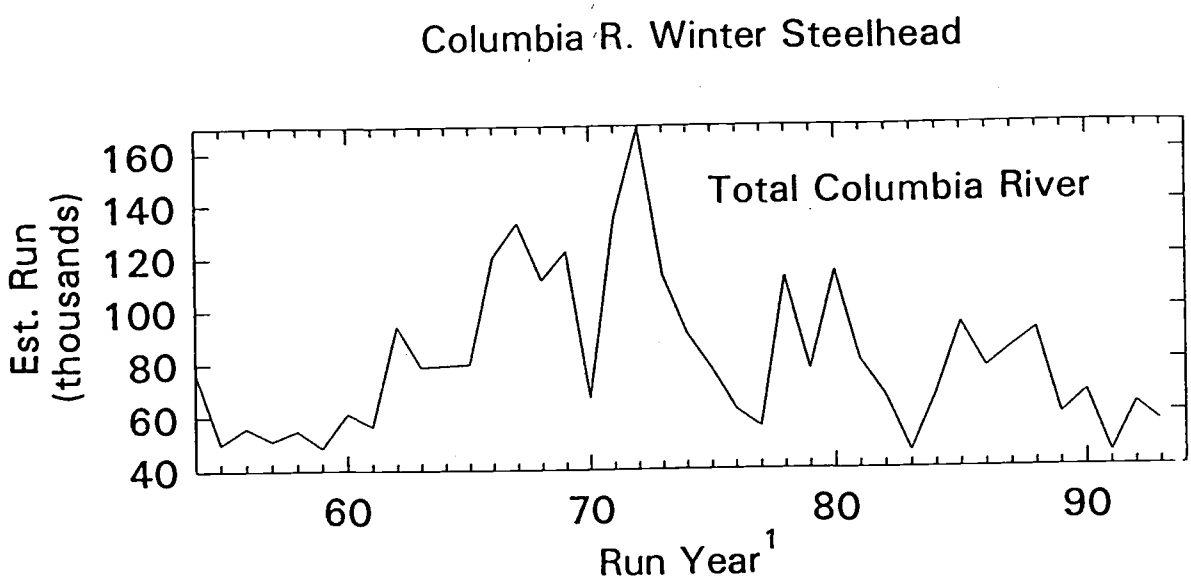



Figure 16. Release of summer and winter hatchery smolts from British Columbia hatcheries in different years. (Data from Burgner et al. 1992)

*Winter Steelhead*

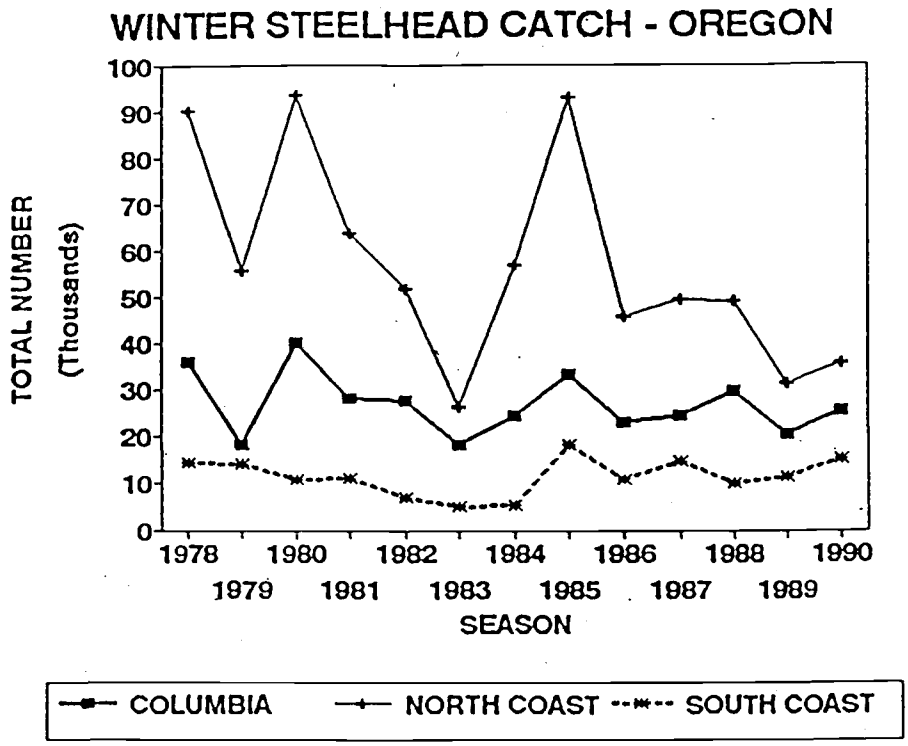
Interannual trends in estimated runs, catch and return rates of winter steelhead originating in widely separated river systems were somewhat similar during the period from the late 1970s to the early 1990s. The estimated total run in the Columbia River (Fig. 17), catch in the Columbia River, along the northern Oregon coast and in Washington (mainly in the Columbia River ) (Fig. 18), and return rates of 2-salt hatchery fish to Puget Sound, coastal Washington Rivers and the Alsea River, Oregon (Fig. 19) were all moderately high in the late 1970s, fell to very low levels in 1983, rose sharply to moderately high levels in 1985 then declined to a very low level in 1991. The return rate of winter steelhead in the Alsea River fell precipitously following the peak in 1985 and remained low from 1986 through 1991 (Fig. 19). Decrease in return rate of winter steelhead from coastal Washington and Puget Sound (Fig. 19) and in the Columbia River run (Fig. 17) was less rapid, with relatively high return rates or runs as late as 1988. In fact, large runs in some coastal Washington and Puget Sound Rivers occurred as late as 1989 (Fig 20). A common feature of most of these time series, however, was a peak in abundance sometime in the mid-late 1980s, with much lower abundance both before (usually in 1983) and after (in 1991).

In summary, several stocks of summer and winter steelhead from widely separated river systems had fairly similar interannual trends in abundance between the early 1980s and early 1990s. Low abundance sometime between 1980 and 1985 was followed by a large increase in abundance in the mid to late 1980s, usually lasting for at least two or three years. The peak abundance in the mid to late 1980s was followed by a decline to very low abundances in the early 1990s.




[1] example: the 69-70 run year is labelled 70

Figure 17. Estimated run of winter steelhead in the Columbia River in different years. (data from WDFW and ODFW 1994)



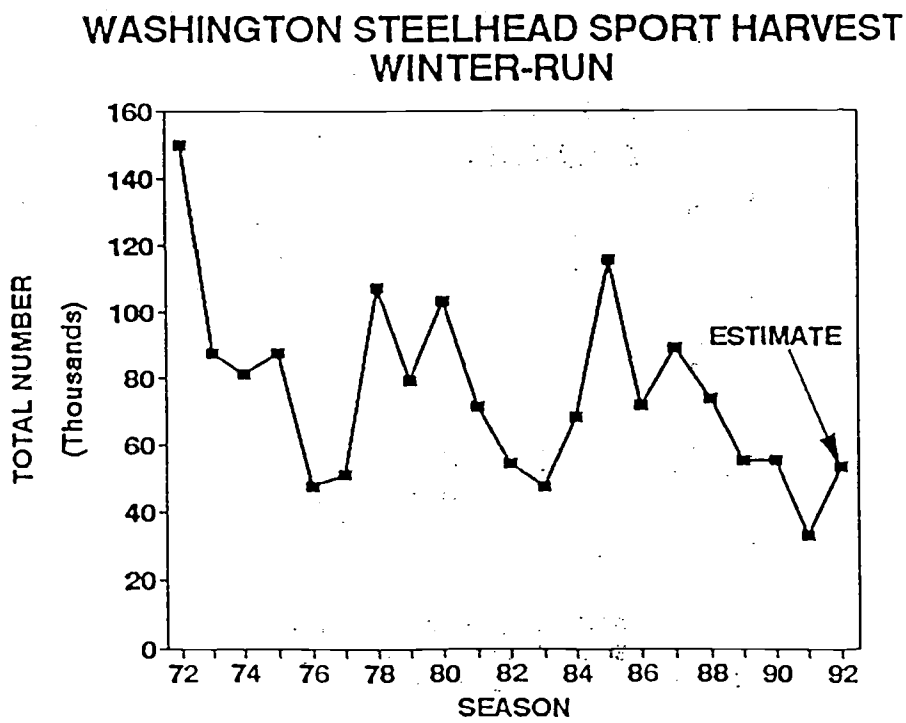




Figure 18. Winter steelhead catch in Oregon and Washington in different years (From Cooper and Johnson 1992).

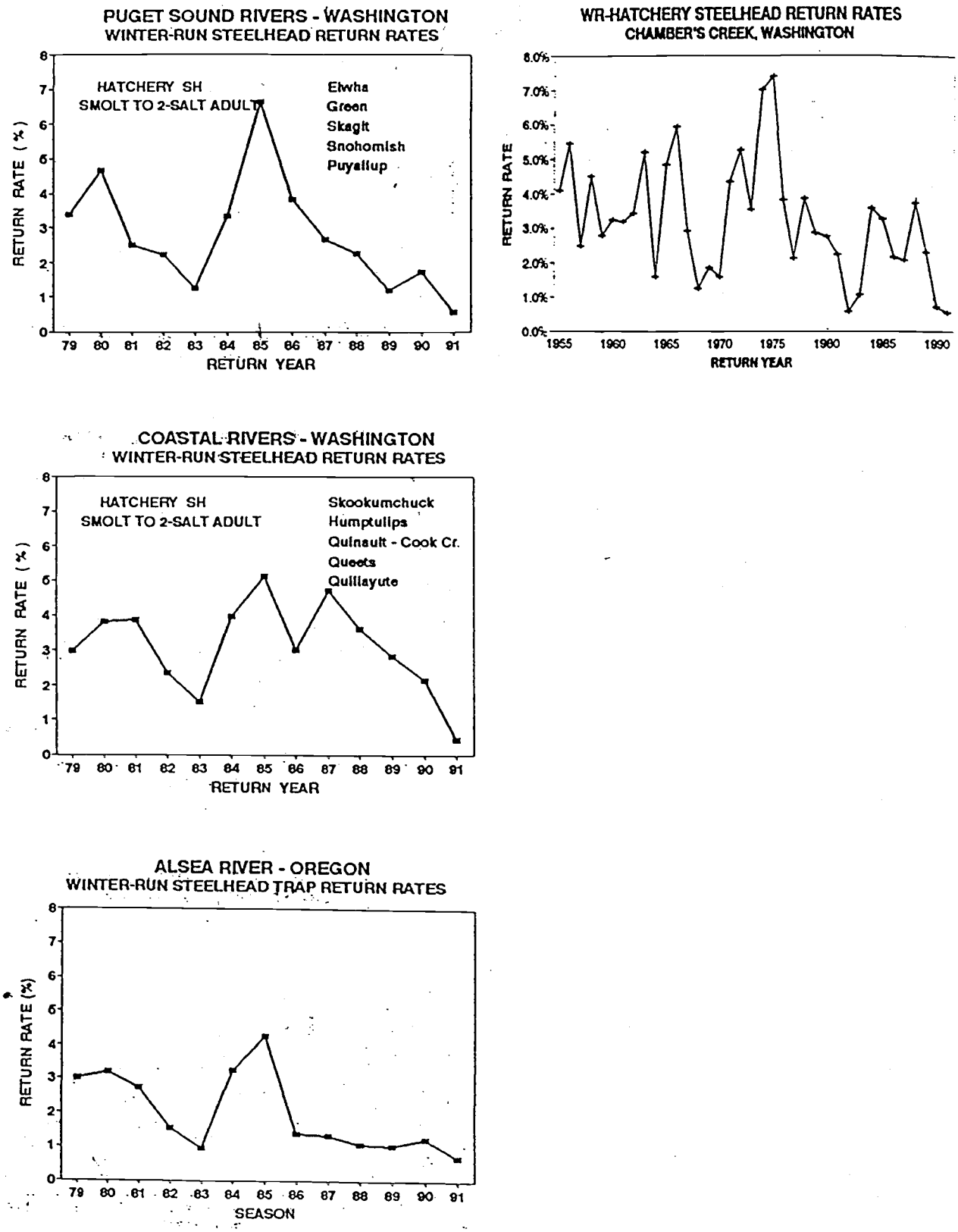
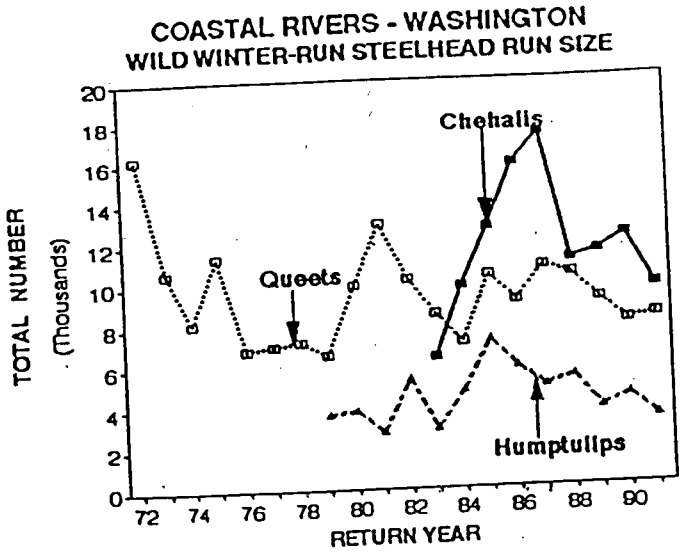
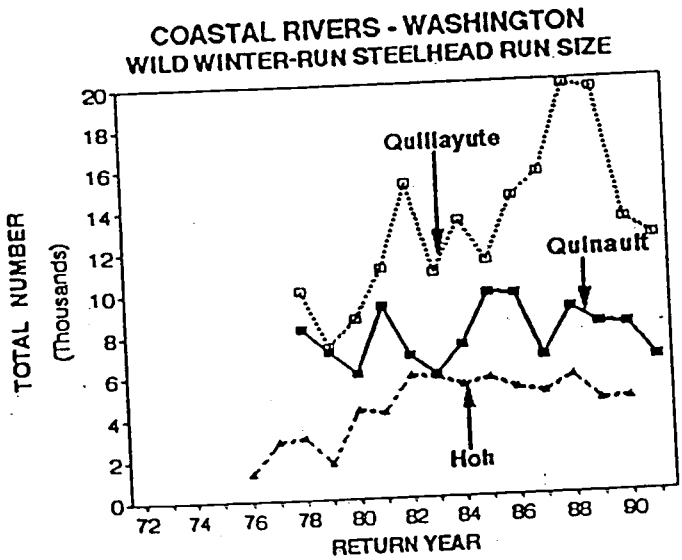



Figure 19. Return rates 2-salt winter steelhead to different Washington Rivers and the Alsea River, Oregon. (From Cooper and Johnson 1992).



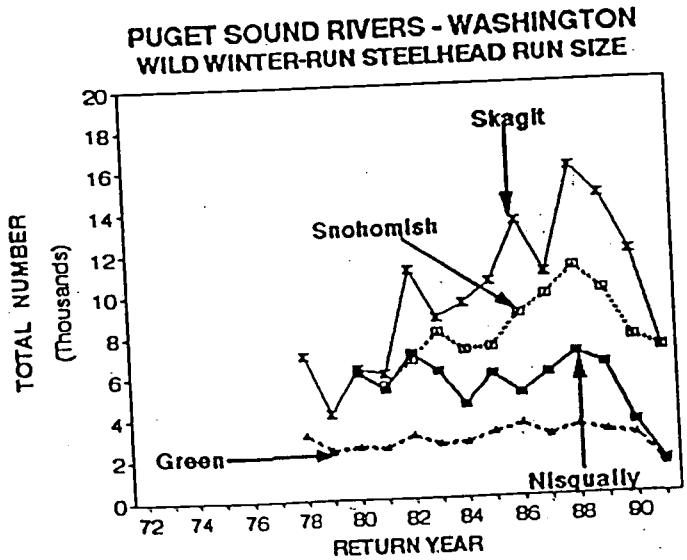




Figure 20. Run sizes of winter steelhead in different Washington rivers in different years (From Cooper and Johnson 1992).

*Abundance trends of other salmonids*

Fall chinook salmon originating from northern California through coastal Washington all showed a strong peak in abundance sometime between 1986 and 1989 (Fig. 21). This peak was preceded by very low abundances in 1983 and 1984, and followed by very low abundance in 1991 and 1992. As was the case for summer steelhead, abundances of fall chinook salmon in the mid-late 1980's were the highest for at least two decades.

Total percent recovery (catch plus escapement) through age 6 of CWT groups of chinook salmon indicate that survival of groups released as smolts in 1984 and in some cases 1985 and 1986 was very high relative to survival of other year classes (Fig. 22-24). Survival was also fairly high for Rogue River spring and Klamath River fall chinook salmon released in fall 1983 (Fig. 23). Interannual trends in survival of coho salmon in the Oregon Production Index area from southern Washington to northern California had one characteristic in common with internnaual trends in abundance of steelhead and chinook salmon. Like these other species, a period of two or three years of poor survival in the early 1980s was followed by generally better survival in the mid to late 1980s (survival was good for four of six year-classes between 1985 and 1990). The moderate survival in the mid-late 1980s was followed by very poor survival in the early 1990s (Fig. 25).

## DISCUSSION

Cooper and Johnson (1992) reported similar trends in the steelhead abundance in Washington and along the Pacific coast of North America, often with low abundances during the

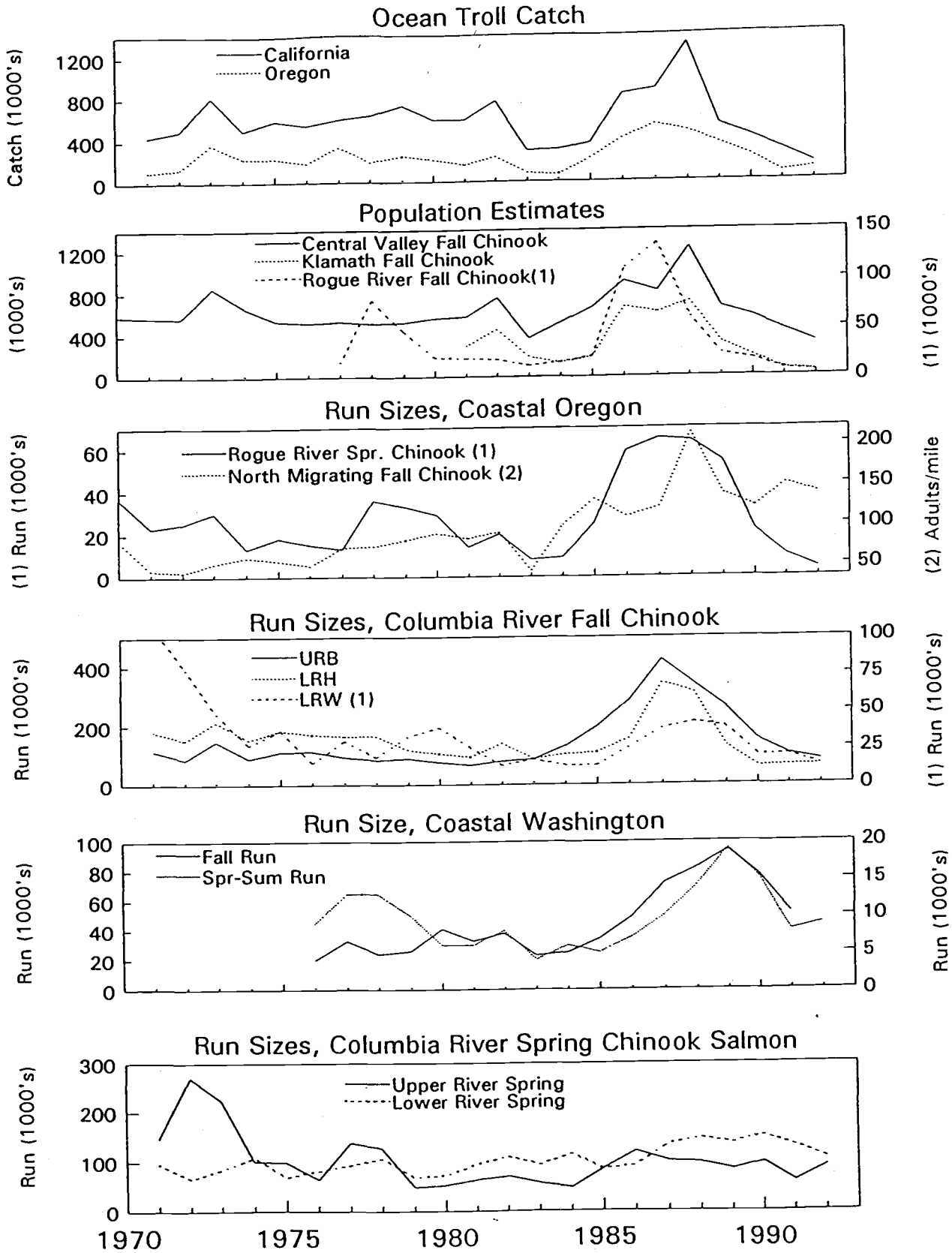



Figure 21. Ocean catch, population estimates and run sizes in different years for fall and spring chinook salmon stocks from northern California, coastal Oregon, the Columbia River and coastal Washington. (From Fisher and Pearcy, unpubl. manuscript)

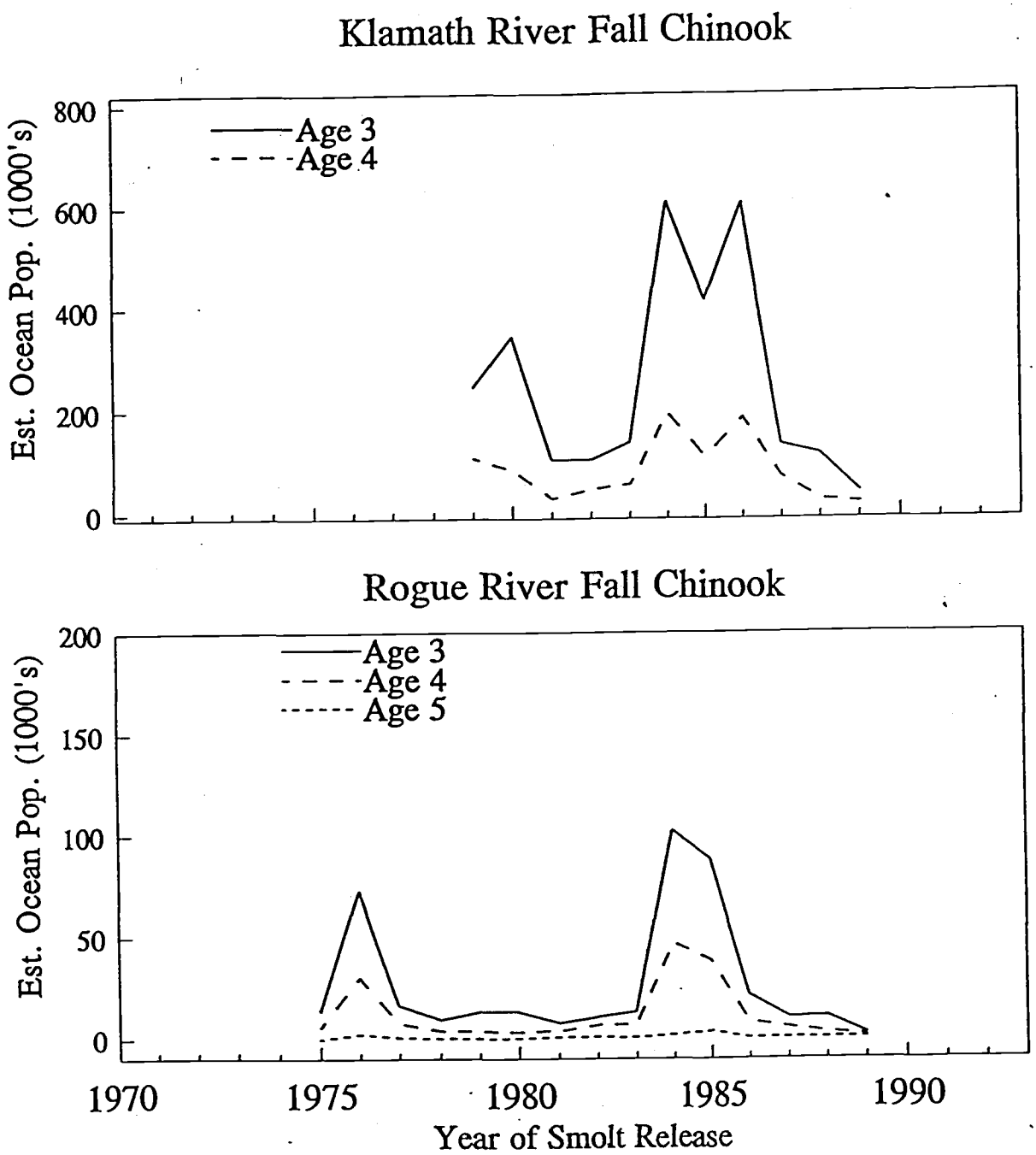



Figure 22. Estimated ocean populations of different age-classes of Klamath River and Rogue River fall chinook salmon vs. smolt release year. (From Fisher and Pearcy, unpubl. manuscript)

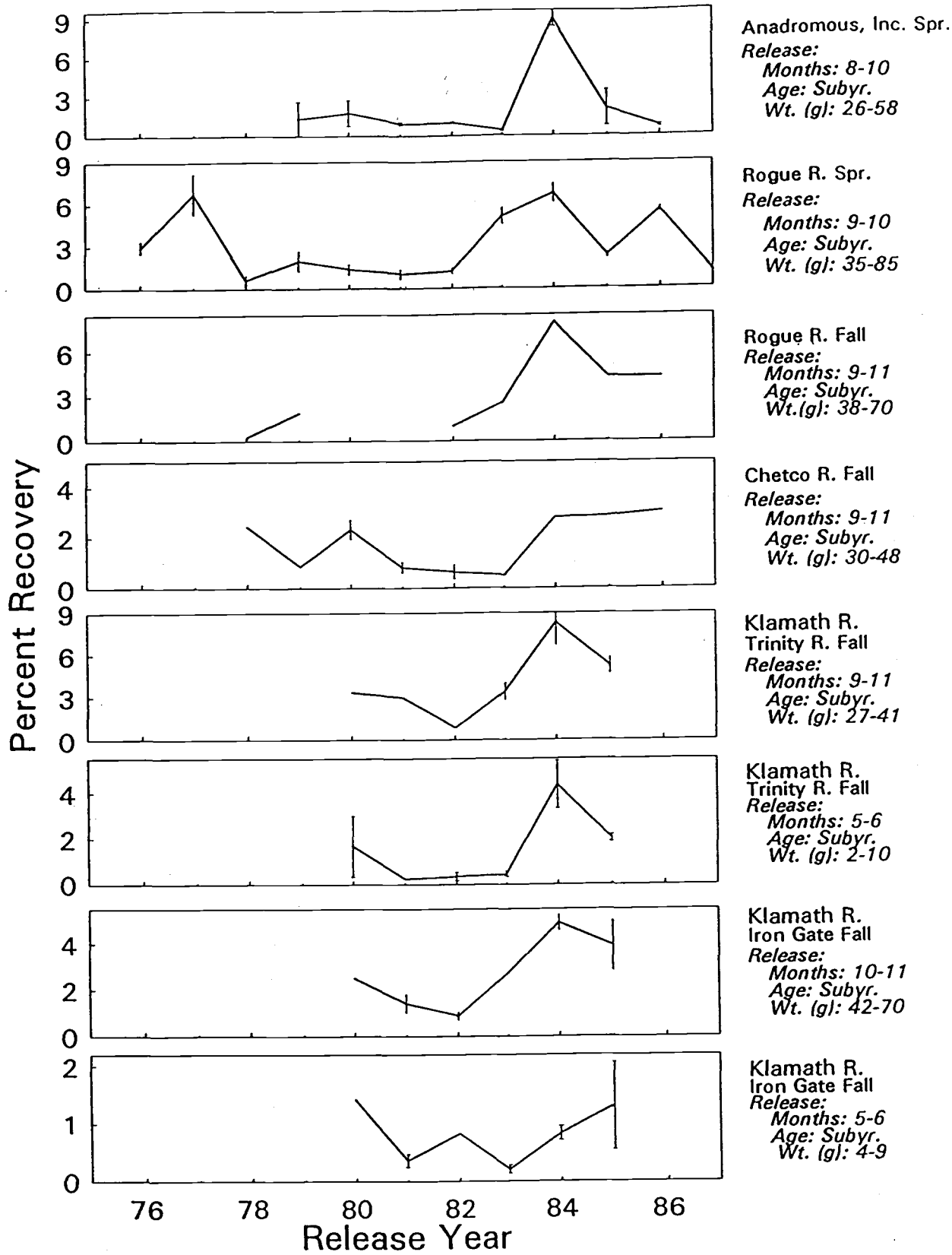



Figure 23. Percent recovery (ocean catch plus freshwater escapement) through age 6 of CWT chinook salmon from northern California and southern Oregon river systems vs smolt release year. (From Fisher and Pearcy, unpubl. manuscript)

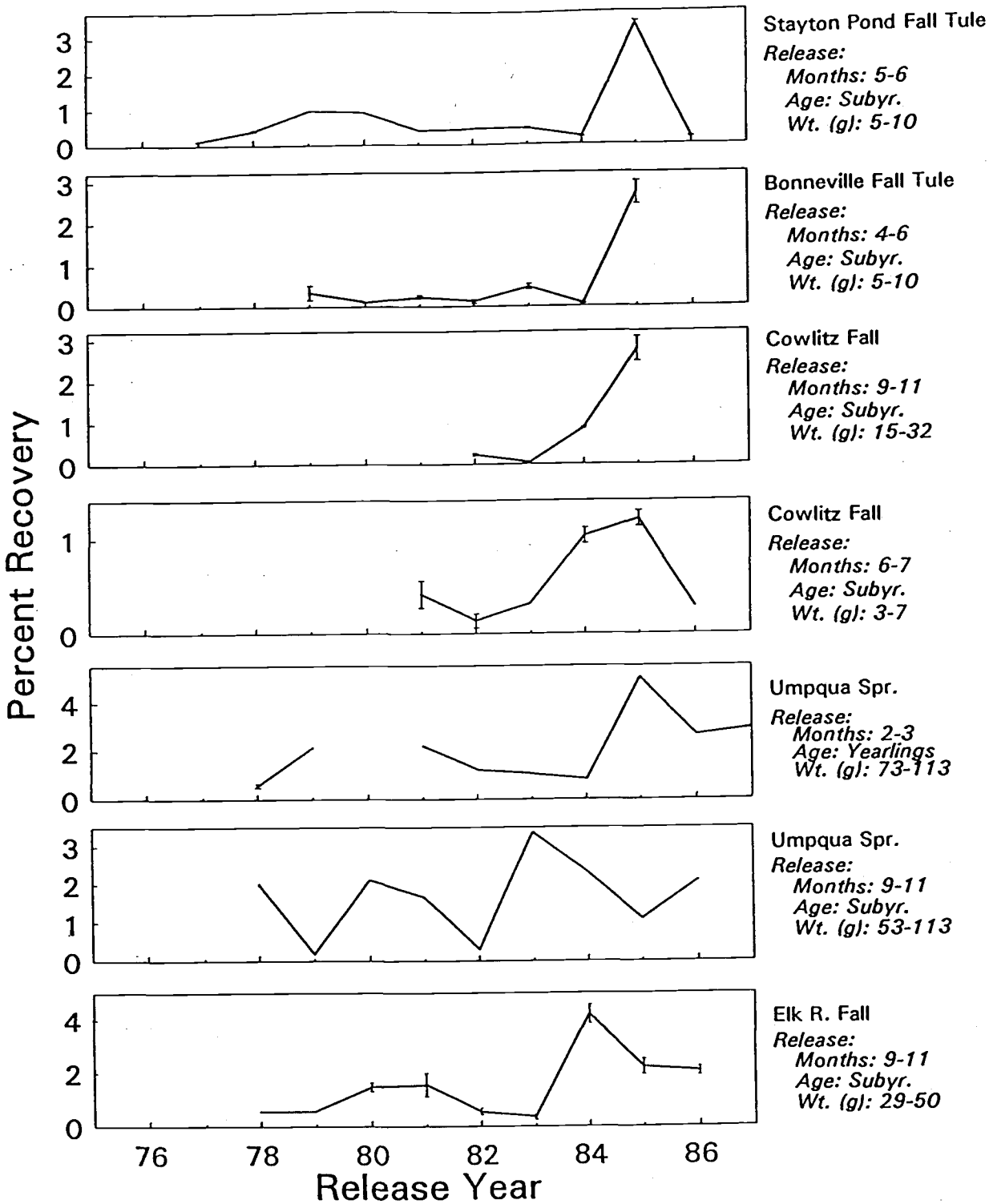



Figure 24. Percent recovery (ocean catch plus freshwater escapement) through age 6 of CWT chinook salmon from coastal Oregon rivers and the Columbia River vs. smolt release year. (From Fisher and Pearcy, unpubl. manuscript)

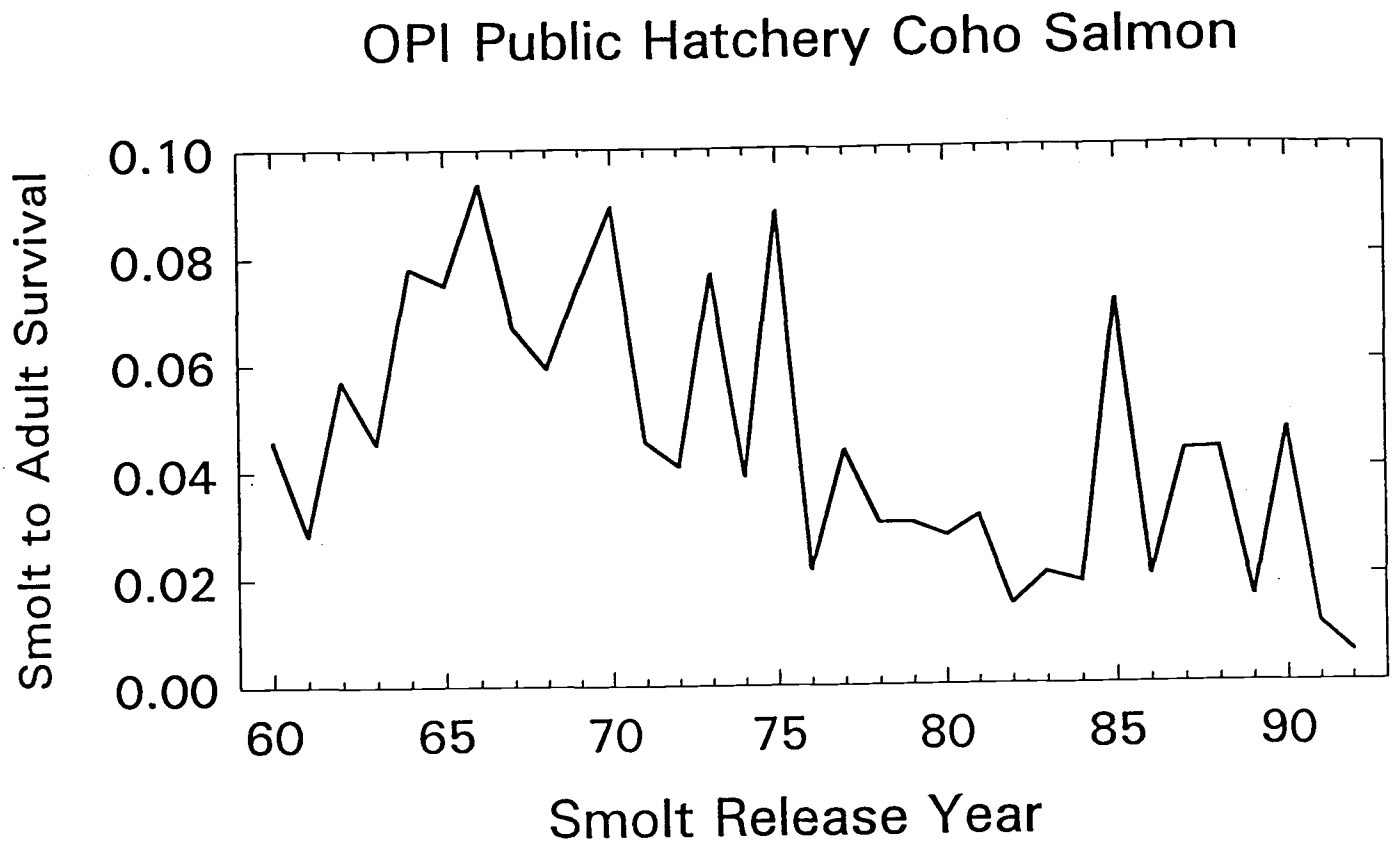



Figure 25. Smolt to adult survival of coho in the Oregon Production Index area vs smolt release year.

early 1980s, a peak during the 1985-88 run year, followed by a decline into the 1990s. Because survival trends were similar for hatchery and wild runs, and becasue hatchery steelhead use freshwater habitats only during downstream migration as smolts, they concluded that the ocean environment was a major factor in the recent decline of steelhead along the Pacific coast.

Cooper and Johnson (1992) reviewed potential causes for changes in steelhead abundance. These included:

1. Trends in escapement of wild steelhead,
2. Variations in hatchery smolt production,
3. High seas driftnet fisheries,
4. Predation,
5. Competition, and
6. Ocean environment.

They concluded that a combination of factors contributed to the low steelhead returns after the late 1980s and hypothesized low productivity in the Gulf of Alaska during the 1988-1989 steelhead smolt years, competition for food because of increased runs of salmon, and the high seas driftnet fishery for squid each contributed to low returns in 1990-91. However, as they point out, the evidence for causal connections between these factors, either singly or in combination, and trends in steelhead abundance is weak.

We beleive that recent changes in the abundance and survival of steelhead may be the result of three major interrelated processes: El Niño events, coastal conditions, and large-scale

fluctuations of ocean climate. The 1982-83 El Nino was the most intense El Nino of the century (Cane 1983). It had dramatic impacts on salmonids along the Pacific Northwest, resulting in poor survival of both smolts and adult salmon and in poor growth of returning adults (Johnson 1988; Pearcy and Schoener 1987). Steelhead and chinook and coho salmon smolts migrating to the ocean during these years produced weak runs of adults one to three years later (Figs. 9-25). This El Niño was asssociated with high sea level during the winter 1982-1983 (Fig. 26), and high ocean tempertures and weak upwelling (Fig. 27) during the spring and summer of 1983 along the coast of the Pacific Northwest.

Following this big El Niño, winter sea level decreased, and there were several years, like 1985, of anti-El Niño conditions with a positive SOI (Fig. 7). Good survival of salmonids during these years of relatively low coastal sea level (but weak coastal upwelling) could have been favored by increased southward flow of subarctic water into the California Current with high nutrient and zooplankton concentrations (Chelton and Davis 1982, Chelton et al. 1982). During this period the production of salmonids in the Gulf of Alaska was high, indicating favorable conditions in oceanic waters. Steelhead and fall chinook and coho salmon abundances rose to high levels during one or more years during this 1984-1987 period (Figs. 9-25). Favorable ocean conditions along the coast presumably resulted in good feeding conditions for migrating smolts during this period. Predation on steelhead smolts by migratory fishes, such as Pacific mackerel, jack mackerel and Pacific hake, which invade Oregon waters during warm El Niño periods, was probably reduced during this period of the mid 1980s. In addition, predatory bird and mammal populations along the coast may have declined during the 1982-83 El Niño (Graybill and Hodder 1985, Hodder and Graybill 1985, Bayer 1986a,b, Wilson 1991,

Takekawa et al. 1990, Bodkin and Jameson 1991, Trillmich et al. 1991).

These few years of favorable coastal conditions along the Washington - Oregon coast occurred during the period when the Aleutian Low generally was deep (long term trend in Fig. 7), circulation in the Subarctic Gyre was strong and sea temperatures were warm in the Gulf of Alaska and the Central Subarctic Domain. This resulted in favorable ocean conditions and high production of salmonids in this northern region (Fig. 8). Steelhead and some stocks of chinook salmon migrating into this region presumably also had good growth and survival.

This period of high abundance of steelhead and chinook salmon was followed by a decline during the late 1980s and early 1990s. This decline was correlated with increased sea level and warm ocean temperatures along the Pacific Northwest coast (Figs. 26 and 27), and a weakened Aleutian Low in the North Pacific, followed by the El Niño event of 1991-1993 (Fig. 7). Although this weak but prolonged El Niño did not appear to affect salmon abundances in Alaska, it may have had a negative effect on Oregon-California steelhead and chinook and coho salmon with southerly oceanic distributions relative to northern stocks. Polovina et al. (1994) concluded that climatic change that occurred in the late 1980s corresponded to declines in the productivity of the open ocean region north of Hawaii.

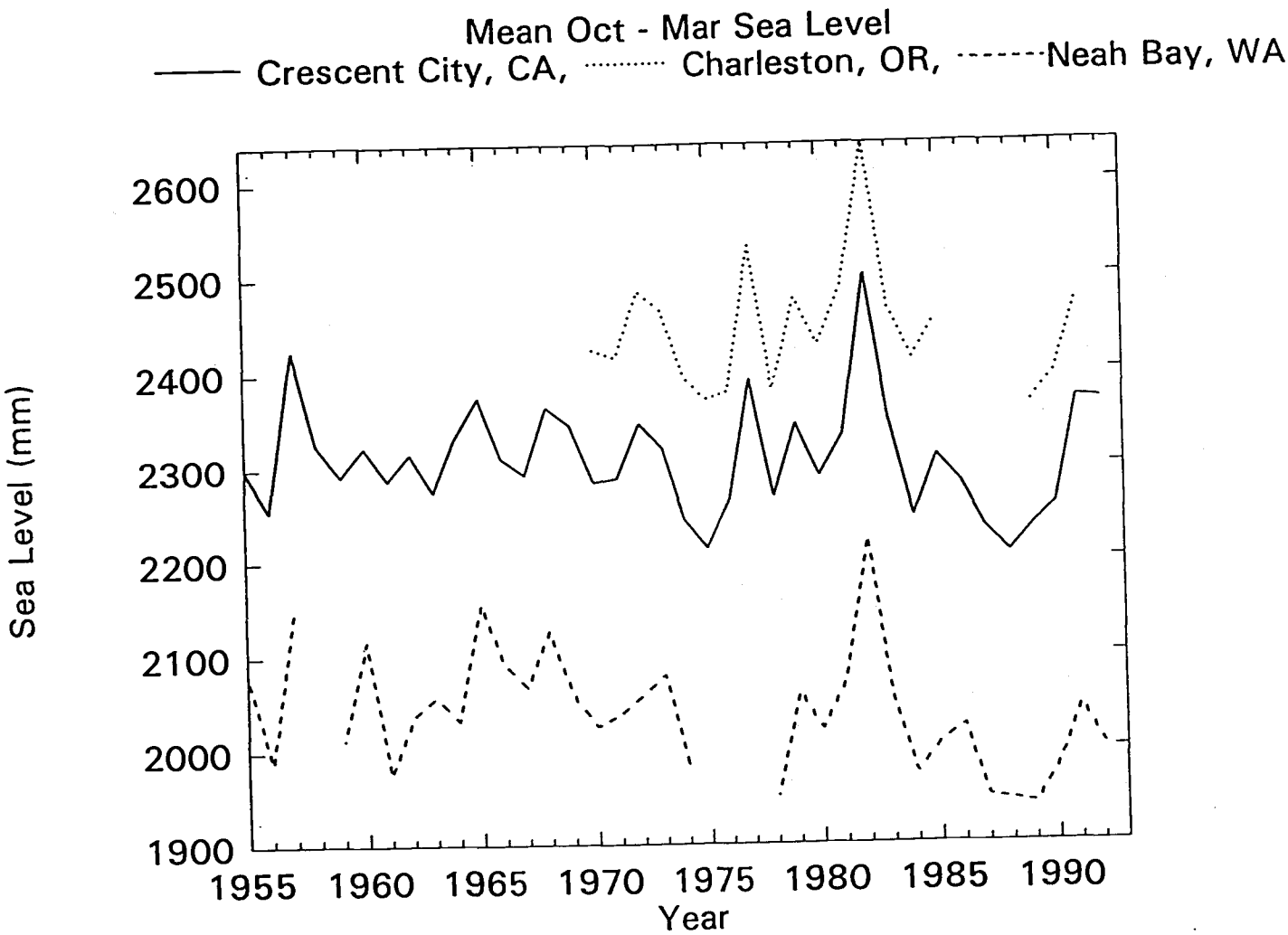



Figure 26. Mean sea level at three coastal stations.

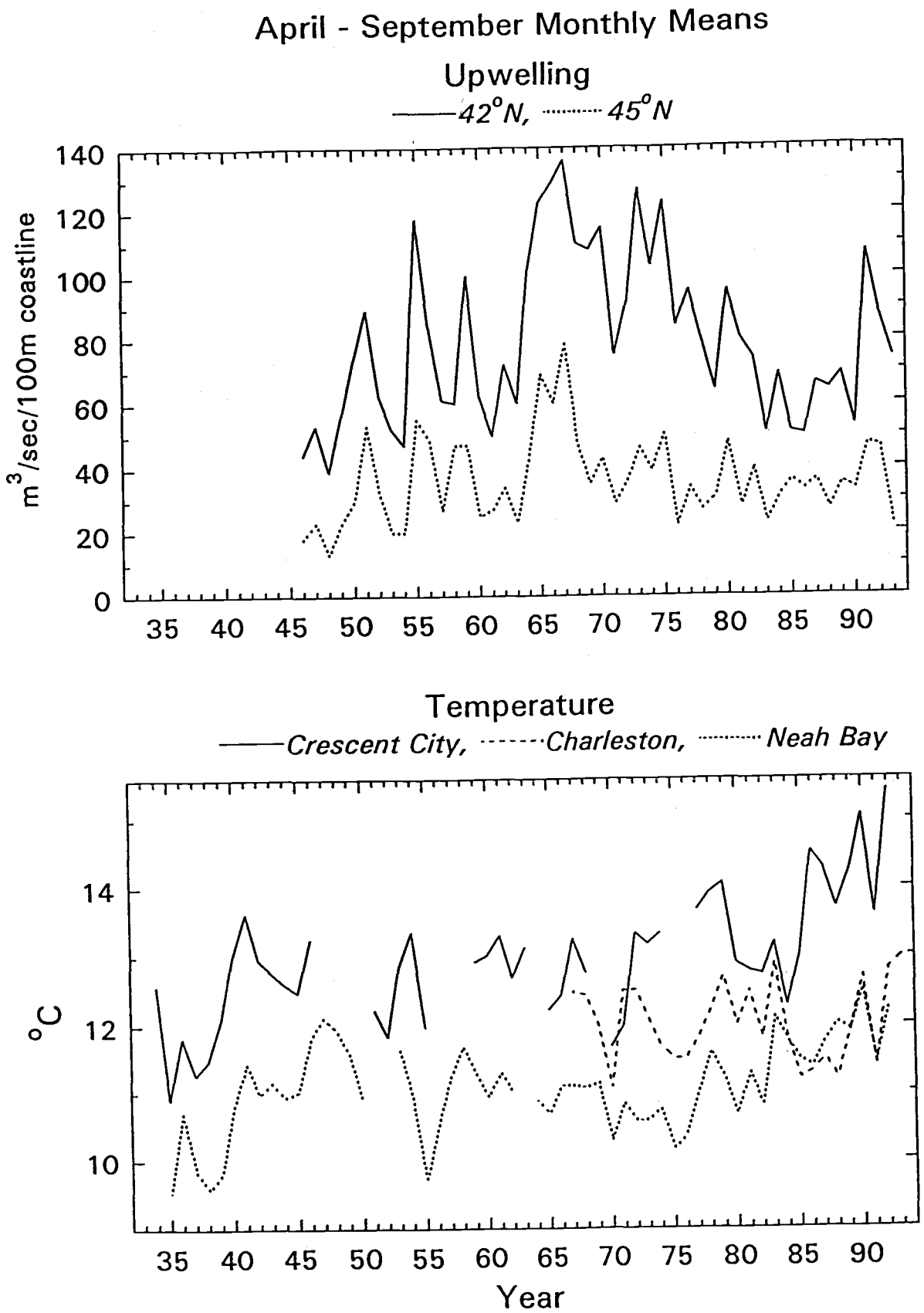



Figure 27. Mean spring-summer upwelling at 42°N and 45°N and sea-surface temperature at three coastal stations.

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