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Trends in Abundance of Hatchery and Wild Stocks of Pink Salmon in Kodiak Island, Cook Inlet, and Prince William Sound, Alaska

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Abstract

Trends in pink salmon (Oncorhynchus gorbuscha) abundance, production, and average weight of hatchery and wild stock catches, were examined for of Kodiak Island, Lower Cook Inlet, and Prince William Sound areas, 1960 to 1990. Wild pink salmon abundance was the sum of wild stock catches and escapements. Wild stock escapements were aerial survey index counts expanded by estimates of stream life, by area. Hatchery stock abundance was the sum of estimated contribution of hatchery stocks to catches and returns to the hatchery. Production estimates were based on hatchery stock returns from fry released at the hatchery and wild stock returns from parent escapement. Hatchery runs have increased greatly since the late 1970's and currently exceed wild stock runs. The total central Gulf of Alaska runs have increased and average weights of pink salmon have decreased since the early 1970's. There has been no recent decline in wild pink salmon runs in Kodiak or Cook Inlet; however, in Prince William Sound a marked decrease in wild stock runs has coincided with the increase in hatchery runs. Return per

spawner for wild stocks and survival of releases for hatchery stocks were similarly affected by ocean temperatures. The recent decline in Prince William Sound wild pink salmon runs is believed to be due lower wild stock escapement levels.

Introduction

Pink salmon (Oncorhynchus gorbuscha) have been produced in Alaskan hatcheries, since 1972. The Fisheries Rehabilitation, Enhancement, and Development (FRED) Division, Alaska Department of Fish and Game (ADF&G) was created by state legislation in 1971 following a period of very poor wild stock salmon returns throughout Alaska. FRED hatchery production of pink salmon was initiated in 1972, with the Kitoi Bay hatchery in the Kodiak Area, (Figure 1). The Tutka Lagoon hatchery in Lower Cook Inlet (LCI) and the Cannery Creek hatchery in Prince William Sound (PWS), were established by FRED, in 1976 and 1978, respectively. The Main Bay hatchery (PWS) produced pink salmon from 1980 through 1986, after which it was converted to a sockeye salmon production facility.

Two private non-profit hatchery corporations (PNP), the Prince William Sound Aquaculture Corporation (PWSAC) and the Valdez Fisheries Development Association (VFDA) also operate pink salmon hatcheries in the central Gulf of Alaska area. PWSAC manages the

Armin F. Koernig (AFK) and the W.F. Noerenberg (formerly Esther Island) hatcheries which began production in 1976 and 1986, respectively. VFDA operates the Solomon Gulch hatchery which began production in 1981.

The central Gulf of Alaska FRED Division pink salmon hatcheries have been or are in the process of being turned over to PNP's. The Cannery Creek hatchery was turned over to PWSAC in 1988. The Kodiak Regional Aquaculture Association (KRAA) took control of the Kitoi Bay hatchery in 1988, and the Cook Inlet Aquaculture Association (CIAA) will operate the Tutka Lagoon hatchery in 1991.

These pink salmon hatcheries are ocean ranching operations. Eggs are taken from returning broodstock, incubated at the hatchery, held for short periods in saltwater net pens and released into near shore rearing areas. The fry rear in nearshore and coastal waters and eventually migrate into the North Pacific Ocean. Hatchery and wild pink salmon are intermixed throughout their ocean residence. At maturity, 12 - 15 months after release, the adults return to the hatchery. Hatchery stocks are harvested along with wild pink salmon stocks in the near-terminal mixed-stocks fishing areas and as cost recovery in the hatchery terminal harvest areas.

Initially, hatchery production goals were modest compared to natural production. However, with continuous growth, the central

Gulf of Alaska pink salmon hatchery program has developed into the world's largest ocean ranching operation. In Prince William Sound the hatchery production has exceeded wild stock production every year since 1986 (Brady et al. 1991).

The majority of commercial fishermen have been vociferous supporters of the central Gulf of Alaska hatchery program. The program was designed to supplement wild stock production. Enabling legislation was promulgated to insure that sustainable wild stock production was not impacted by the hatcheries. The massive hatchery releases have been justified based on three assumptions: 1. The practice of holding and feeding all fry in net pens, then releasing them into the peak of the plankton bloom, eliminates or reduces the possibility of competition between hatchery and wild fry for prey resources in coastal rearing areas. 2. Prey resources in open ocean rearing areas is not limiting. 3. Commercial fisheries managers can successfully manage the mixed-stocks commercial and terminal hatchery fisheries for multiple objectives of wild stock escapement, hatchery brood stock, and facility cost recovery. This paper examines these assumptions with respect to trends in abundance, production, and size of hatchery and wild stocks of pink salmon in the Kodiak, Lower Cook Inlet, and Prince William Sound areas.

Methods

To gain insight into pink salmon hatchery/wild stock interactions, unpublished hatchery and wild stock adult return statistics were summarized for the years 1960 - 1990, by the Kodiak, Cook Inlet, and Prince William Sound commercial fishery management areas (Figure 1). Hatchery returns consist of the estimated hatchery contribution to commercial fishery catches, catches in the hatchery terminal harvest area used for cost recovery (i.e. fish sold by private hatchery operators to generate revenue for hatchery operations), fish used for broodstock, and any fish returning to the hatchery that were not used. Wild stock returns consist of estimated wild stock contribution to commercial catches, estimated wild stock contribution to cost recovery, and escapement to spawning streams. The data sources and methods are presented by management area.

Kodiak

Total catch numbers and delivery weights of pink salmon for the years 1960-1964 were taken from ADF&G, Division of Commercial Fisheries (DCF) annual reports, for the years 1965-1985 from Manthey et al. (1986), and for the years 1986-1990 from DCF fish ticket summary reports. Catches of hatchery fish were assumed to be the entire commercial catch in the terminal harvest area near the hatchery. No attempt was made to estimate the number of hatchery fish caught in other areas. Wild stock catches were total catches less hatchery catches.

Wild stock escapement estimates were determined from cumulated weir counts and expanded peak counts of live fish derived from aerial or foot surveys (Manthey et al. 1986; Dave Prokopowich, Alaska Department of Fish & Game, Division of Commercial Fisheries, 211 Mission Rd., Kodiak, AK., personal communication). Peak counts were expanded by a factor of 1.84 based on estimated stream life (Barrett et al. 1990). Escapements for streams not surveyed were interpolated from surveyed streams in the respective year, based on the historical, 1960-1990, average odd and even year escapement distribution among streams.

Estimates of the number of brood stock, excess, and cost recovery fish, for the Kitoi Bay hatchery, were taken from unpublished ADF&G FRED Division annual reports.

Cook Inlet

The Cook Inlet area includes both the Upper (north of Anchor Point) and the Lower (south of Anchor point) Cook Inlet areas. The fisheries in Upper and Lower Cook Inlet are managed separately and estimates of hatchery and wild pink salmon catches and escapements were summed for the two subareas to give the Cook Inlet total.

For Lower Cook Inlet, total pink salmon catches and delivery weights for years 1960-1989 were taken from Schroeder (1990) and for 1990 from DCF fish ticket summary reports. Catches of hatchery fish were taken to be the entire commercial catch in the terminal harvest area near the hatchery. No attempt was made to estimate the hatchery fish caught in other areas. Wild stock catches were total catches less the hatchery catches.

Wild stock escapement estimates for 1960 through 1989 were taken from Schroeder (1990). The 1990 estimates was based on preliminary surveys (Wes Bucher, Alaska Department of Fish & Game, Division of Commercial Fisheries, 3298 Douglas St., Homer, AK., personal communication). Wild pink salmon escapement estimates are based on cumulative weir counts or expanded peak counts of live fish from aerial surveys.

Estimates of the number of brood stock, excess, and cost recovery fish, for the Tutka Lagoon hatchery, were taken from unpublished ADF&G FRED Division annual reports.

There is no pink salmon hatchery production in the Upper Cook Inlet area. Wild stock pink salmon catches and delivery weights for years 1960-1989 were taken from Ruesch (1990) and for 1990 from DCF fish ticket summary reports. Very limited information is available in Upper Cook Inlet for wild stock pink salmon escapement. Estimates of pink salmon escapement made with side scan sonar, were available for the Susitna River (King and Davis 1989), for the years, 1976 - 1981 and 1984. Escapement in other years were estimated based on average rate of exploitation (53%) observed for the years where pink salmon escapement to the Susitna River were available.

Estimates of pink salmon abundance in Upper Cook Inlet were very conservative for recent years. Pink salmon escapement was not enumerated for many river systems in Upper Cook Inlet that support large runs of pink salmon. Further, the fishery does not target on pink salmon. The timing of Upper Cook Inlet pink salmon runs coincides with the more valuable and more abundant sockeye salmon (Oncorhynchus nerka). The gill nets used in the sockeye fishery do not efficiently capture pink salmon. Because of the increased abundance of Upper Cook Inlet sockeye, in recent years, there has been little interest in direct fishing for pink salmon.

Prince William Sound

Total catch numbers and delivery weights of pink salmon for the years 1960-1964 were taken from DCF annual reports, for years 1965-89 from Brady et al. (1991), and for 1990 from DCF fish ticket summary reports.

Wild pink salmon escapement was estimated by dividing cumulative spawner days, based on stream counts from aerial surveys, by the estimated stream residence time. Aerial survey data for years 1960-1964 were taken from Brady et al. (1987), for years 1965-89 from Brady et al. (1991), and 1990 data was unpublished (James Brady, Alaska Department of Fish and Game, Division of Commercial Fisheries, P.O. Box 669, Cordova, AK 99574-0669, personal communication). Preliminary estimates of stream residence time (Sam Sharr, Alaska Department of Fish and Game, Division of Commercial Fisheries, P.O. Box 669, Cordova, AK 99574-0669, personal communication) of 8.75 days was used for the Northern, Coghill, Northwest, Eshamy, Southwest, and Montague Districts, while a 17.5 day stream residence time was used for the Eastern and Southeastern Districts.

Catches of hatchery fish in mixed stock commercial fisheries, brood stock, and non-utilized excess fish, which originated from state operated hatcheries were taken from ADF&G, FRED Division annual reports to the Alaska Legislature. Catches of hatchery fish that originated from private hatcheries in mixed stock commercial fisheries, brood stock, cost recovery, and non-utilized excess fish, were taken from annual reports filed by each hatchery with ADF&G, FRED Division. Prior to 1987, the wild and hatchery fish contribution to the mixed stocks commercial fishery were based on the relative magnitude of returns to hatchery terminal areas and wild stock escapement levels. Estimates of hatchery catches from 1987 - 1990 were based on a coded wire tagging program (Geiger and Sharr, 1990; Peltz and Geiger, 1990).

Catches of wild stocks were taken to be the total mixed stock commercial harvest less the estimated hatchery contribution.

Environmental Data

A 31-year record (1959-1990) of monthly mean sea surface temperatures (°C) on a 5° by 5° grid from the North Pacific Ocean, (Scripps Institute of Oceanography) was used as an index of environmental conditions to relate to variation in average weight and production of pink salmon stocks in the central Gulf of Alaska area. Monthly temperature anomalies were calculated for each month and grid point by subtracting the respective mean sea surface temperature averaged over the 27 year period. The anomalies were averaged over an area (45°-55°N, 135°-160°W) which is thought to be the region inhabited by central Gulf of Alaska pink salmon (Takagi et al. 1981). Two temperature indices were used. The first (T_s) is the anomaly during the first four months at sea and is the average of the April - July temperature anomalies for the brood year (BY) +1. The second (T_o) is the anomaly during the ocean residence period and is the average of the temperature anomalies for the months April (BY+1) to July (BY+2).

The relative effect of temperature on hatchery and wild pink salmon population dynamics were compared for the Kodiak and Prince William Sound areas in order to determine the relative role of environment and hatchery/wild stock interactions in recent decline in PWS wild pink salmon.

Results

Trends in Abundance

Hatchery and wild pink salmon runs for 1960 - 1990 were summarized by area (Tables 1 - 3). The runs were combined for Kodiak, Cook Inlet, and Prince William Sound commercial fishery management areas to obtain the central Gulf of Alaska hatchery and wild stock runs (Table 4). Cook Inlet total pink salmon run strength (i.e. hatchery + wild stocks) has been relatively stable, averaging 2.78 million fish, during the period 1960 -1990. Because of the under-developed nature of the Upper Cook Inlet pink salmon fishery and limited escapement enumeration program, the Cook Inlet runs of pink salmon were likely under-estimated. Nevertheless, the Cook Inlet runs were substantially lower than the total pink salmon runs to Kodiak and Prince William Sound (Figure 2) which have averaged 14.03 and 12.44 million fish, respectively, during the period 1960-1990.

Pink salmon runs to Kodiak were cyclical with the even year runs larger than the odd year runs. There has been no obvious trend in Kodiak runs; although, they were at low levels during the period 1971 - 1975. Total Prince William Sound pink salmon runs were stable during the period 1960 - 1978, averaging 5.14 million fish. Since 1978, total pink salmon runs to Prince William Sound have been much higher averaging 24.1 million fish. This increase has been due to increases in both hatchery and wild stock runs. The trend in total run appears to be increasing since 1979. However the increasing trend is due entirely the large 1990 run.

The central Gulf of Alaska total pink salmon runs have been increasing since the early 1970's (Figure 3). There was a large increase in wild stock runs prior to the appearance of the hatchery runs (Figure 3). The wild stock runs have been decreasing since 1980; however, they are presently at levels comparable or exceeding those during the 1960's. This decrease has accompanied the large increases in hatchery runs. Hatchery stock runs have exceeded the wild stock runs since 1989 (Figure 3).

In Kodiak, estimates of hatchery fish intercepted in commercial fishing districts other than the district in the immediate vicinity of the Kitoi Bay hatchery have not been available. Therefore hatchery runs were likely underestimated and wild stock runs overestimated (Table 2). This most likely accounts for the inconsistent and generally low marine survival of fry released and low contribution of hatchery fish to Kodiak area commercial fisheries. The numbers of fry released in the Kodiak Area has been approximately one fifth of that released in Prince William Sound area. There does not appear to be a recent decreasing trend wild pink salmon runs in the Kodiak area.

The Cook Inlet terminal hatchery harvest has reflected the hatchery catch. Most wild pink salmon streams are in Kamishak Bay, the outer coast areas, and in Upper Cook Inlet, which are distant from the Tutka Lagoon hatchery. Currently, hatchery runs are a moderate component of the pink salmon run in Cook Inlet. There does not appear to be a recent decreasing trend in the wild pink salmon runs in the Cook Inlet area.

An association between hatchery and wild stock runs is most apparent in the Prince William Sound area (Figure 4). There has been a decline in the wild stock runs since 1984, with recent levels comparable to the runs in the 1960's and early 1970's. The Gulfwide decline in wild stock runs was due entirely to declines in wild pink salmon runs in Prince William Sound. In Prince William Sound the hatchery runs have exceeded the wild stock runs every year, since 1985.

Trends in Wild and Hatchery Pink Salmon Population Dynamics

Cold ocean temperature conditions have had a negative effect on central Gulf of Alaska pink salmon abundance (Willette and Cooney 1991). Trends in ocean residence (T_o) and spring outmigration (T_s) temperature anomaly (Figure 5) parallels the central Gulf of Alaska pink salmon abundance with higher runs occurring during years of warm temperatures and lower runs occurring during years of cold temperatures during the period of ocean residence (Willette and Cooney 1991). Correlation between T_o and central Gulf of Alaska, Kodiak and Prince William Sound total run magnitude is 0.60, 0.28, and 0.63, ($n = 29$) respectively.

Ricker (1975) escapement-return models were fit by non-linear least squares to the Kodiak (Figure 6) and Prince William Sound (Figure 7) wild pink salmon data. There is an indication of density dependance in both data sets. Residuals expressed as the difference between the observed and predicted (based on the fitted Ricker model) natural logarithm of return per spawner were positively correlated with temperature anomaly for the spring of fry outmigration for Kodiak (Figure 8, ρ = 0.30, n=29) and for Prince William Sound (Figure 9, ρ = 0.49,n = 29). The effect of the cold temperature anomalies was much greater for Prince William Sound (Figure 9) than for Kodiak (Figure 8), during recent years since hatchery development. Recent brood years (except for 1981) where a negative T_s occurred (1981, 1984, 1986, and 1987) had lower return per spawner than expected based on the Ricker model (Figure 9).

Prince William Sound hatchery returns are strongly related to numbers of fry released (Figure 10). Marine survival of released fry has averaged 5.0 percent based on linear regression of return to fry released. Deviations from predicted return based on the average marine survival were positively correlated (ρ = 0.63, n = 29) with T_s (Figure 11). As with PWS wild stocks, recent brood years where a negative T_s occurred (1981, 1984, 1986, and 1987) had lower than expected hatchery returns based on average marine survival (Figure 11).

Trends in pink salmon escapement (Figure 12) and escapement anomalies (Figure 13, i.e. observed escapement - historical average escapement (1960 - 1990)) were examined for the Kodiak and Prince

William Sound area. Note that escapement anomalies for PWS were computed using pooled odd/even year averages while those for Kodiak were computed based on the average level for the respective odd and even cycle.

Pink salmon escapement levels were higher and more variable for Kodiak than for PWS. The higher variability reflects the cyclic nature of the Kodiak runs. Kodiak odd year escapements have increased greatly since the mid-1970's and escapement anomalies have been consistently high since 1976 (Figure 13). Recent Kodiak even year escapement levels have been comparable to the those achieved during the 1960's (Figure 13). The has been no observable trend in the Kodiak escapement levels since the late 1970's. The very large 1989 escapement was due to widespread closures of the Kodiak area commercial fishery due to presence of oil from the Exxon Valdez oil spill.

Prince William Sound escapement levels were lower and less variable than in Kodiak (Figure 12). The PWS pink salmon escapements were low from the mid-1960-s to the late-1970's. Escapements were high from 1979 - 1985. Except for the 1984 brood year which experienced cold weather, the 1977 - 1985 brood year returns were higher than expected based on the Ricker model (Figure 7). Since 1983 escapements have declined and since 1986 were comparable to the low levels observed before 1977 (Figure 13). The recent low escapement levels have occurred, despite consistently high runs produced from the high escapement brood years, 1977 - 1985.

Prince William Sound hatchery stock exploitation rate has increased rapidly since the brood stocks were established (Figure 14). Since 1980, the PWS hatchery stocks have been consistently exploited at rates greater than 90 percent. Brood stock needs have been met in face of these high exploitation rates and releases of fry have continued to increase.

For Kodiak and PWS wild stocks, exploitation rates have ranged widely and reflect the constant escapement policy under which the PWS commercial fishery has been managed. The exploitation rate was low (5 - 50%) during years of weak runs and high (70% - 85%) during years of strong runs. Note the low exploitation rates for 1989 were atypical and due to the inability to prosecute normal fisheries due to presence of oil from the Exxon Valdez oilspill. Wild stock exploitation rates were necessarily lower than hatchery stock exploitation rates.

The exploitation rate on PWS and Kodiak wild stocks were comparable prior to the establishment of the PWS hatchery broodstocks. However, since the late 1970's PWS wild pink salmon have generally been exploited at a higher level than Kodiak stocks (Figure 14). Since 1986, the exploitation rate on Prince William Sound wild pink salmon runs have been generally at the highest levels achieved. The 1988 and 1989 runs were an exception to this trend. The 1988 wild stock run was very weak and the 1989 fishery was atypical due to the oil spill. Recent low escapements of PWS wild pink salmon since 1986 were due to a combination of reduced returns and high exploitation rates.

Trends in Average Weight

Average weights of central Gulf of Alaska pink salmon have been decreasing since the early 1970's (Figure 15). There was a negative correlation (ρ = -0.651, n = 29) between average weight and central Gulf of Alaska pink salmon run magnitude (Figure 16). This suggests that pink salmon growth has been density dependant. The recent decreasing trend in average weight has occurred during a generally increasing trend in temperature anomaly (T_0) (Figure 5). Thus, the decreasing trend in average weight was due to increasing trend in run magnitude which, to some extent, has been due to increasing hatchery runs.

Discussion

There was little evidence for interaction of hatchery and wild stocks of pink salmon in the Kodiak and Cook Inlet areas. However, for Prince William Sound there has been a decline in wild stock runs coincident with the increase in hatchery runs which suggests some interaction of hatchery and wild stocks. In the following, we examine this observation with respect to the three potential wild stock - hatchery stock interactions: 1. competitive interaction during the early marine residence period, 2. reduced growth due to density dependent growth during the period of ocean residence, and 3. inability to manage mixed hatchery and wild stocks fisheries for wild stock escapement objectives in face of large hatchery runs.

The early marine phase has been identified as critical to marine survival and year-class strength (Parker 1968, Walters et al. 1978, Bax 1983). Pink salmon in Prince William Sound rear in nearshore areas during the spring and early summer months (Cooney et al. 1981, Sturdevant et al. 1991). Initially, pink salmon in Prince William Sound occur in the bay areas and feed on both epibenthic harpacticoid copepods and pelagic calanoid copepods. Pink salmon quickly leave the Bay areas (Cooney et al. 1981) and enter the corridor areas and feed on pelagic calanoid copepods (Cooney et al. 1981, Sturdevant et al. 1991). Similar behavior has been observed for pink salmon in Southeast Alaska (Landingham and Mothershead

1987, Mortensen et al. 1991), Washington (Kaczynski et al. 1973) and British Columbia (Godin 1981); however, pink salmon in these areas seem to have a more extended period of feeding on epibenthic prey in nearshore areas than in Prince William Sound. In all areas, pelagic prey items become dominant as pink salmon migrate out of the nearshore areas. Kaczynsky (1973) has speculated that prey resources in these nearshore areas are critical to pink salmon survival and Simenstad et al. (1980, 1982) have suggested that increasing the numbers of chum and pink fry in these areas by hatchery releases will result in depletion of epibenthic prey resources, shorter residence times, and higher mortalities.

High growth rates during the early marine period are characteristic of pink salmon (LaBrasseur and Parker 1971, Healey 1980). This high growth has been hypothesized to allow pink salmon to escape size selective predation (Parker 1971, Healey 1982, Hargreaves and LaBrasseur 1985). Further, a larger body size enables a more efficient utilization of pelagic zooplankton which have a more developed escape response than epibenthic prey (Volk et al. 1984). Handling times of zooplankton by juvenile chum salmon have been observed to decrease with increasing body size (Wissmar and Simenstad 1988). Juvenile chum salmon had lower growth efficiencies when fed pelagic calanoid copepods than when fed epibenthic hapacticoid copepods (Volk et al. 1984).

Higher pink salmon survival has been associated with higher ocean temperatures during the early marine period (Donnelly 1983, Quinn and Marshall 1989, Willette and Cooney 1991, Willette 1991). In Auke Bay, Southeast Alaska, both survival and growth for groups of CWT tagged pink salmon increased with increasing water temperature in nearshore zone at the time of entry (Mortensen et al. 1991). This could result from the direct bioenergetic effect of temperature on growth and survival by reducing gastric evacuation and maximum daily ration (Brett and Higgs 1970, Kepshire 1976). Temperature has a direct bioenergetic effect on growth provided prey densities are high enough so that maximum daily ration is effected solely by temperature (Brett 1979). Alternatively, the reduced growth and survival could the consequence of low prey densities which are correlated with temperature.

The effect of ocean temperatures on pink salmon population dynamics has been observed for wild pink salmon in the Prince William Sound and Kodiak areas. Here, deviations in natural logarithm of return per spawner increased with increasing spring temperature anomaly (Figure 8 and 9). However, the relationship was stronger for Prince William Sound area. For the recent years of high hatchery runs, production of both hatchery and wild stocks of Prince William Sound pink salmon was depressed during years when cold temperatures occur during the period of outmigration (Figure 9 and 11). In Kodiak where hatchery runs were smaller, there was no observable effect of temperature on recent pink salmon runs (Figure 8).

The implication of the differential effect of temperature on PWS and Kodiak pink salmon is unclear. Prey densities in PWS may be more affected by environmental conditions than in the Kodiak area. Thus, pink salmon in the PWS may be more vulnerable to environmental shocks than in other areas. With the increase in hatchery runs combined with the moderate wild stock runs, the present abundance of pink salmon in PWS may be closer to the nearshore carrying capacity than in other areas. On the other hand, sea surface temperatures in the Gulf of Alaska may be a better indicator of ocean temperatures near PWS than near Kodiak Island. Lastly, if the effect of temperature is bioenergetic (i.e. temperature is limiting the daily ration at high prey densities), then growth and mortality is not density dependent and increasing fry densities would have no effect on growth and survival.

The rearing of hatchery juveniles prior to their release may provide a competitive advantage to these stocks. If this were the case, then hatchery stocks would be less sensitive to prey resource depressions and temperatures in nearshore rearing areas than wild stocks. However, there does not appear to be any competitive interaction between hatchery and wild stocks in Prince William Sound because both runs have been similarly affected by ocean temperatures.

Density dependent growth as reflected in an inverse relationship between size at age and abundance, has been observed in Southeast Alaska pink salmon (Davidson and Vaughan 1941) and in Bristol Bay sockeye salmon (Rogers 1984, Eggers et al. 1984). A similar relationship was observed for central Gulf of Alaska pink salmon (Figure 15). Certainly increased hatchery runs in recent years have contributed to the increase abundance of pink salmon in the Gulf of Alaska. However, pink salmon from southeast Alaska to southern Alaska Peninsula occur in the central Gulf (Takagi et al. 1981). Stocks of pink salmon throughout the area have increased and incremental increase due to solely to hatchery runs may not be significant when the aggregate stocks from Southeast Alaska to the Alaska Peninsula are considered.

Because of underlying relationships between parent escapement and returns, trends in pink salmon runs have been related to trends in escapement level. In general, the management objective for wild pink salmon commercial fisheries in Prince William Sound has been to maintain an level of escapement that was within the range of historical levels. The same is true for Kodiak except the range was higher for even than for odd years.

Historical escapement objectives for Kodiak were to achieve a certain level of peak escapement counts for individual streams based on aerial surveys. These counts were not in units directly comparable to the total escapement levels in Table 2. The individual stream odd year and even year escapement count goals have been converted to total escapement levels (Barrett et al. 1990) for Kodiak. The odd year and even year escapement goals cumulated over streams are 4.7 and 8.8 million fish (Barrett et al. 1990), and higher than historical average level of 7.2 and 3.4 million fish, respectively. In general it has not been possible to achieve escapement goals for all streams because of the mixed stock nature of the fishery and between stream variability in production.

The recent Kodiak escapements, particularly for the odd years, have been higher than historical averages (Figure 13). These high escapements have been a consequence of market forces and the fleet's general lack of interest in fishing for the poorer quality pink salmon that are available late in the season. Without the late season effort the fishery has been unable to fully harvest available fish.

Prince William Sound pink salmon escapement levels were low from the mid-1960's through the mid-1970's (Figure 13). Escapement levels increased in the late-1970's. This increase was due to a combination of factors, including a different, more conservative, area manager, increased abundance, and inability to fully utilize the large runs due either to limited harvesting and processing capacity and/or the lack of interest in harvesting the poorer quality fish that were available late in the season.

Prince William Sound pink salmon escapements decreased following the 1985 run and have been below the historical average since 1986. The weak 1988 wild stock run contributed to this decline; however, escapements were low during the relatively strong 1987 and 1990 runs. There has been a divergence in wild stock exploitation rate between the Kodiak and Prince William Sound areas since the establishment of the hatchery runs in PWS (Figure 14). Prior to the recent period the Kodiak and PWS exploitation rates were quite similar; however, except for 1988 when the PWS run was weak, the wild stock exploitation rates have been much higher in PWS than in Kodiak.

It has been difficult for managers to assess the strength of wild stock runs with the large number of hatchery fish present in the mixed stocks commercial fishing areas. In PWS, hatchery and wild stocks use the same migratory passages, and have considerable overlap in run timing (Geiger et al. 1991). Early run strength assessment in the entry corridor areas of PWS has been based on fishery performance. Because of the high quality of the early fish and industry pressure to continue fishing in the corridor areas when catches have been high, weak to moderate wild stocks runs have been generally heavily exploited whenever the hatchery runs have been strong. The reverse situation has occurred during the strong 1984 and 1985 PWS wild stock runs, where hatchery runs were heavily exploited to the extent that returns to terminal hatchery harvest areas were not sufficient to meet cost recovery objectives (Geiger et al. 1991)

In summary, the declining wild pink salmon runs in PWS appear to be the result of lower escapement levels. These lower escapements were a consequence of the heavy exploitation of weak to moderate wild stock runs by mixed hatchery and wild stock commercial fisheries. Managers have not reduced wild pink salmon exploitation rates in the presence of the strong hatchery runs sufficient to maintain wild stock escapement at the levels the were prior to the establishment of hatchery runs. This has resulted from the combined effect of the hatchery fish and a weak implementation of the fixed escapement goal policy, where the focus is maintaining a minimum escapement (based on the historical minimum levels) rather managing for the maximum sustainable yield (MSY) escapement levels which are in the range of the levels achieved during the late-1970's to mid-1980's.

Managers must be able to assess the strength of wild stock early in the season, and be able to curtail fishing in the entry corridor areas during years of weak wild stock runs. The in-season assessment of hatchery and wild stock run strength requires an expensive in-season hatchery/wild stock identification program using coded wire tags (Geiger 1989) or [illegible] alternative mass marking method (Volk et al. 1990). The [illegible] PWS CWT program is on the order of a million dollars per [illegible] roughly doubles the costs of the fishery management system. Support for the program has been fragmentary, and the costs of the CWT program is not a permanent budget item in the ADF&G Prince William Sound fishery management system (Geiger et al 1991).

The amount of brood stock required to maintain fry releases is a low percentage of the run, hatchery stocks can be easily maintained during years of low production. Since minimum wild stock escapement levels are a relatively large fraction of the run during weak runs, it is more difficult to maintain wild stocks during years of low production. This difficulty is greatly exacerbated by the presence of large numbers of hatchery fish in the mixed stocks fisheries. In PWS managers have generally been unable to do this in the presence of strong hatchery runs. Further declines in PWS wild pink salmon runs will likely occur unless the management system is further developed.

There has been an increase in the total pink salmon runs to Prince William Sound with the development of the hatchery runs; however, the increase over that baseline wild stock runs of the early 1980's has been only a small fraction of the increase in the hatchery runs

(Figure 4). Please note that the evidence presented here suggests that the size of the PWS and Kodiak wild runs have been largely determined by escapement level. It is possible that the high wild stock runs during the early 1980's is the coincidence of the higher escapements and a short term episode of favorable environmental conditions. It may be possible to achieve a sustainable level of hatchery and wild stock runs that is greater than the wild stock baseline during the early 1980's; however, the evidence presented here suggests that this will be possible only if a management system is developed that can maintain wild stock escapements levels at those achieved during the early 1980's.

Intensive fishery management systems on wild salmon stocks, that enable the accurate implement[illegible] of constant escapement management objectives are ext[illegible] effective (Royce 1989, Eggers 1991). The annual cost[illegible]e Alaska Department of Fish and Game program, of which [illegible] half is used to manage commercial fisheries, during the years 1977 - 1985 was between 5 and 10 percent of the ex-vessel value of catch from fisheries under State of Alaska jurisdiction, (Kruse 1988).

Because of the inherent variability in wild salmon runs, catches at times may be quite low. The 1988 wild pink salmon run in PWS was quite weak. The 1988 catch was large relative to historical levels and was almost entirely hatchery fish. Without the large 1988 hatchery run in PWS, a serious economic hardship would have occurred.

However, the production from hatchery systems is extremely expensive. The projected FY-92 operational and debt service costs for the PNP facilities in Prince William Sound (Anon. 1991A, 1991B) is $13.7 million. This represents the ex-vessel value of 12.7 million pink salmon (Anon. 1991A) which is 30% of the projected 1991 harvest of pink salmon in Prince William Sound (Geiger and Savikko 1991). A detailed examination of the relative costs and benefits of the PWS hatchery system is beyond the scope of the paper. However, if the wild stock runs are overfished with the development of the hatcheries the cost effectiveness of the Prince William Sound hatcheries is significantly reduced. In view of the high cost of the hatchery operations relative to the costs of the mixed stocks commercial fishery management system, a parallel investment in an expanded mixed stock fishery management system that would enable managers to meet dual objectives of protecting wild stocks and hatchery cost recovery/brood stock needs, would seem to be cost effective.

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Table 1. Prince William Sound area pink salmon hatchery runs (millions of fish), wild stock runs (millions of fish), total runs millions of fish), mean weight (kg), and total run biomass (millions of kg).

	Hatchery Runs							Wild Runs						
			Harvest											
Year	No. Hatcheries	Fry Released Year - 1	Mixed Stocks Commercial	Cost Recovery	Brood Stock	Hatchery Run	Survival (%)	Catch	Escapement	Wild Run	Total Run	Percent Hatchery	Mean Weight (kg)	Total Run Biomass
1960								1.8	2.1	3.8	3.8	0.0%		
1961								2.3	3.2	5.6	5.6	0.0%		
1962								6.7	3.1	9.7	9.7	0.0%	1.4	13.1
1963								5.3	1.9	7.3	7.3	0.0%	1.7	12.5
1964								4.2	2.8	6.9	6.9	0.0%	1.8	12.2
1965								2.5	1.4	3.9	3.9	0.0%	1.5	5.8
1966								2.7	2.1	4.8	4.8	0.0%	1.7	8.2
1967								2.6	1.2	3.8	3.8	0.0%	2.0	7.7
1968								2.5	1.8	4.2	4.2	0.0%	1.6	6.8
1969								4.8	0.6	5.4	5.4	0.0%	1.8	9.8
1970								2.7	1.4	4.2	4.2	0.0%	1.8	7.5
1971								7.3	1.7	9.0	9.0	0.0%	1.6	14.6
1972								0.1	0.9	0.9	0.9	0.0%	1.9	1.8
1973								1.9	2.0	3.9	3.9	0.0%	1.8	7.0
1974								0.4	1.6	2.0	2.0	0.0%	2.1	4.3
1975								4.5	1.9	6.4	6.4	0.0%	1.6	10.3
1976								3.0	1.3	4.3	4.3	0.0%	1.9	8.1
1977	1	1.0	0.0	0.0	0.1	0.1	7.9%	4.5	1.9	6.4	6.5	1.2%	2.0	13.2
1978	1	11.0	0.0	0.1	0.1	0.3	2.4%	2.8	1.8	4.6	4.9	5.3%	1.6	7.9
1979	1	17.0	0.3	0.2	0.2	0.7	4.3%	15.1	3.1	18.2	18.9	3.8%	1.6	30.6
1980	2	25.6	1.1	0.3	0.3	1.7	6.7%	12.3	2.5	14.8	16.6	10.3%	1.5	25.3
1981	2	22.5	1.4	0.7	0.4	2.5	11.2%	17.9	2.5	20.3	22.8	11.0%	1.9	43.2
1982	3	87.1	4.3	1.4	0.6	6.2	7.1%	14.6	3.5	18.0	24.3	25.6%	1.6	38.2
1983	4	120.3	3.7	0.7	0.5	4.9	4.0%	9.6	3.2	12.8	17.7	27.5%	1.4	25.5
1984	4	140.8	3.6	0.4	0.4	4.4	3.1%	18.0	6.1	24.1	28.5	15.4%	1.6	46.2
1985	4	158.2	6.7	1.2	0.4	8.3	5.2%	17.3	3.8	21.1	29.4	28.2%	1.5	45.0
1986	4	220.6	5.9	0.9	0.4	7.2	3.3%	4.6	1.4	6.0	13.2	54.4%	1.4	17.8
1987	5	290.6	14.0	2.7	1.0	17.7	6.1%	12.1	2.1	14.2	31.9	55.5%	1.6	50.2
1988	5	296.5	8.9	1.6	0.9	11.5	3.9%	0.7	1.4	2.1	13.6	84.2%	1.6	21.4
1989	4	531.8	13.0	7.8	1.1	21.9	4.1%	0.8	1.9	2.7	24.6	89.1%	1.6	38.8
1990	5	518.1	25.2	6.7	1.2	33.1	6.4%	11.7	1.9	13.6	46.6	70.9%	1.4	63.0

Table 2. Kodiak area pink salmon hatchery runs (millions of fish), wild stock runs (millions of fish), total runs millions of fish), mean weight (kg), and total run biomass (millions of kg).

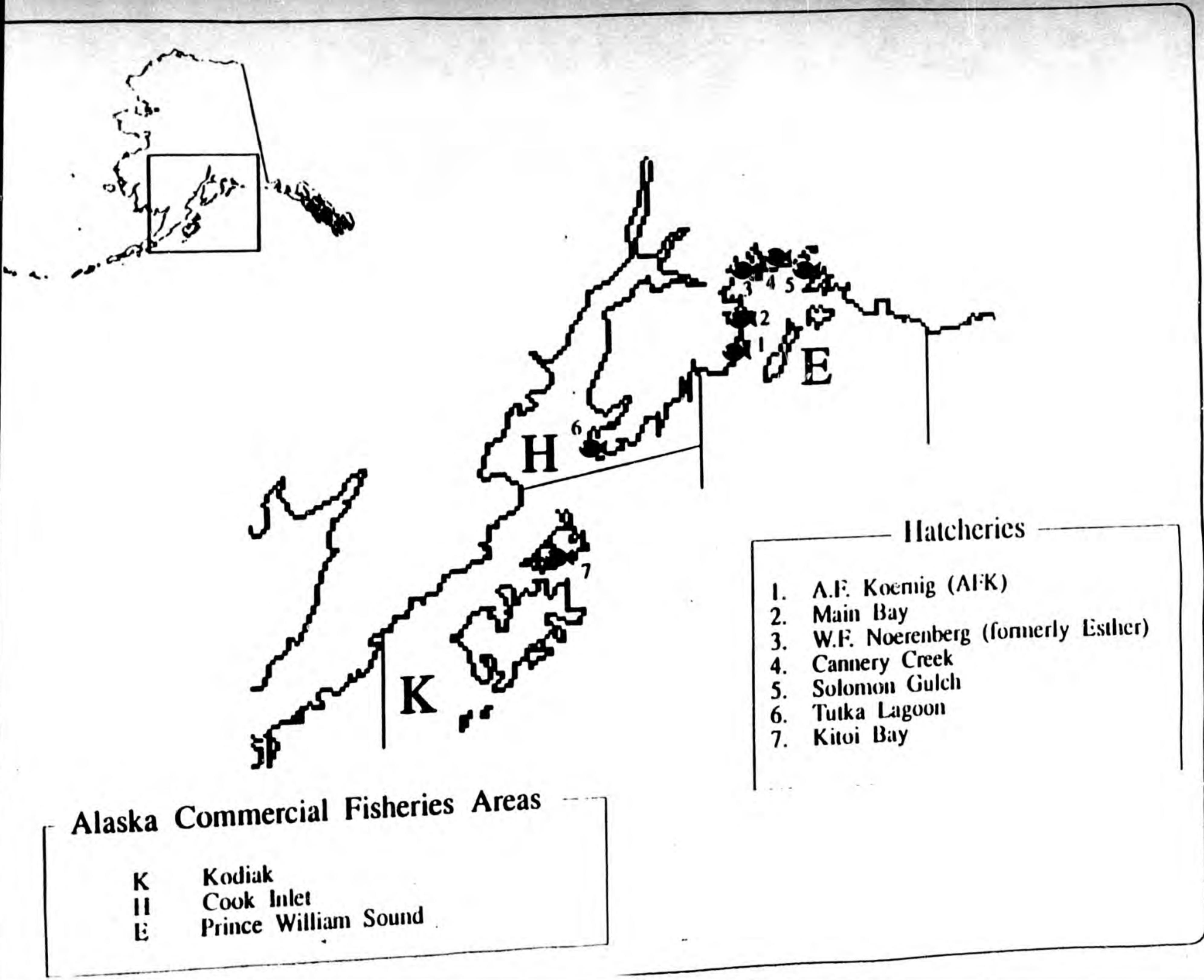
	Hatchery Runs							Wild Runs						
			Harvest											
Year	No. Hatcheries	Fry Released Year - 1	Mixed Stocks Commercial	Cost Recovery	Brood Stock	Hatchery Run	Survival (%)	Catch	Escapement	Wild Run	Total Run	Percent Hatchery	Mean Weight (kg)	Total Run Biomass
1960								6.7	6.9	13.5	13.5	0.0%		
1961								3.9	1.4	5.3	5.3	0.0%		
1962								14.2	9.1	23.2	23.2	0.0%	1.4	31.4
1963								5.5	2.6	8.0	8.0	0.0%	1.5	11.9
1964								11.9	7.0	18.8	18.8	0.0%	1.5	28.0
1965								2.9	2.0	4.9	4.9	0.0%	1.7	8.4
1966								10.8	7.7	18.5	18.5	0.0%	1.8	32.4
1967								0.2	2.2	2.4	2.4	0.0%	1.9	4.6
1968								8.8	7.7	16.5	16.5	0.0%	1.5	25.3
1969								12.5	3.1	15.6	15.6	0.0%	1.8	28.6
1970								12.0	7.8	19.8	19.8	0.0%	1.6	32.4
1971								4.3	2.3	6.6	6.6	0.0%	1.7	11.5
1972								2.5	3.8	6.2	6.2	0.0%	1.6	10.3
1973								0.5	1.2	1.7	1.7	0.0%	1.8	3.1
1974	1	0.5	0.0	0.0	0.01	0.0	2.9%	2.6	4.2	6.8	6.8	0.2%	1.9	13.1
1975	1	0.4	0.0	0.0	0.01	0.0	3.3%	2.9	2.3	5.2	5.2	0.3%	1.9	10.0
1976	1	1.2	0.0	0.0	0.01	0.0	1.0%	11.1	6.7	17.8	17.8	0.1%	1.8	32.3
1977	1	2.5	0.0	0.0	0.03	0.0	1.1%	6.3	4.3	10.6	10.6	0.3%	1.9	19.7
1978	1	4.7	0.0	0.0	0.03	0.0	0.9%	15.0	8.3	23.3	23.3	0.2%	1.7	39.1
1979	1	17.3	0.2	0.0	0.06	0.2	1.3%	11.1	5.7	16.8	17.1	1.3%	1.7	28.9
1980	1	17.4	0.3	0.0	0.08	0.4	2.1%	17.0	10.0	27.0	27.4	1.3%	1.5	40.6
1981	1	22.5	1.2	0.0	0.13	1.3	5.7%	9.2	5.8	15.0	16.3	7.9%	1.7	28.3
1982	1	26.1	0.2	0.0	0.14	0.3	1.2%	7.9	7.8	15.7	16.0	2.0%	1.6	25.7
1983	1	48.9	0.1	0.0	0.15	0.3	0.6%	4.5	3.9	8.4	8.7	3.2%	1.6	13.9
1984	1	72.1	0.3	0.0	0.15	0.4	0.6%	10.6	6.8	17.4	17.8	2.4%	1.7	30.6
1985	1	87.3	3.4	0.0	0.19	3.6	4.2%	3.9	5.7	9.6	13.2	27.5%	1.6	21.7
1986	1	75.4	0.3	0.0	0.17	0.5	0.7%	11.5	7.2	18.6	19.1	2.7%	1.6	31.5
1987	1	98.1	0.9	0.2	0.15	1.2	1.2%	4.0	4.9	8.9	10.1	12.0%	1.6	16.4
1988	1	90.5	0.3	0.3	0.14	0.7	0.8%	14.0	6.1	20.1	20.8	3.6%	1.7	35.4
1989	1	95.9	0.0	6.6	1.13	7.7	8.0%	0.2	21.1	21.3	29.0	26.5%	1.3	38.8
1990	1	82.1	0.5	0.0	0.19	0.7	0.9%	5.4	8.2	13.6	14.3	5.1%	1.4	20.5

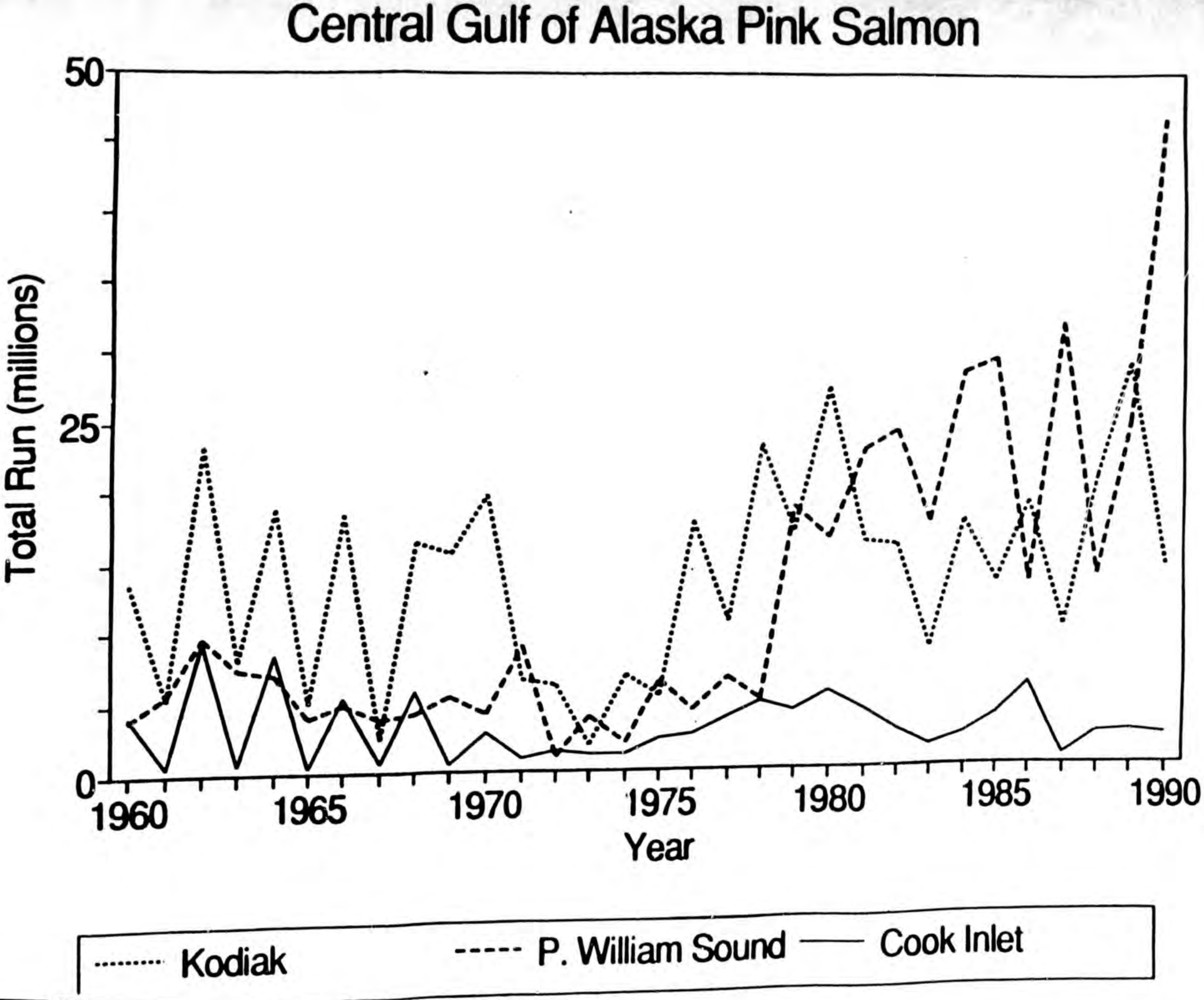
Table 3. Cook Inlet area pink salmon hatchery runs (millions of fish), wild stock runs (millions of fish), total runs millions of fish), mean weight (kg), and total run biomass (millions of kg).

	Hatchery Runs							Wild Runs						
			Harvest											
Year	No. Hatcheries	Fry Released Year - 1	Mixed Stocks Commercial	Cost Recovery	Brood Stock	Hatchery Run	Survival (%)	Catch	Escapement	Wild Run	Total Run	Percent Hatchery	Mean Weight (kg)	Total Run Biomass
1960								2.0	2.0	4.1	4.1	0.0%	1.4	5.8
1961								0.3	0.2	0.5	0.5	0.0%	2.0	1.0
1962								5.0	4.3	9.3	9.3	0.0%	1.4	13.4
1963								0.2	0.3	0.5	0.5	0.0%	1.5	0.8
1964								4.3	4.2	8.4	8.4	0.0%	1.6	13.3
1965								0.1	0.2	0.3	0.3	0.0%	1.6	0.5
1966								2.6	2.7	5.3	5.3	0.0%	1.6	8.6
1967								0.4	0.2	0.6	0.6	0.0%	1.8	1.0
1968								2.9	2.9	5.7	5.7	0.0%	1.4	7.7
1969								0.2	0.2	0.4	0.4	0.0%	1.8	0.7
1970								1.5	1.2	2.8	2.8	0.0%	1.8	4.9
1971								0.4	0.4	0.9	0.9	0.0%	1.6	1.4
1972								0.7	0.8	1.4	1.4	0.0%	1.9	2.8
1973								0.6	0.6	1.2	1.2	0.0%	1.8	2.1
1974								0.5	0.6	1.2	1.2	0.0%	2.1	2.4
1975								1.4	0.8	2.2	2.2	0.0%	1.7	3.7
1976								1.4	1.1	2.5	2.5	0.0%	2.0	4.9
1977								1.8	2.0	3.8	3.8	0.0%	1.8	6.8
1978	1	4.2	0.1	0.0	0.03	0.2	3.6%	1.9	2.7	4.6	4.8	3.2%	1.8	8.7
1979	1	4.9	0.3	0.0	0.03	0.4	7.6%	2.7	1.0	3.7	4.1	9.0%	1.6	6.5
1980	1	9.4	0.3	0.0	0.04	0.3	3.5%	2.3	2.8	5.2	5.5	6.0%	1.6	9.0
1981	1	6.3	1.0	0.0	0.05	1.0	16.2%	2.4	0.7	3.1	4.1	24.6%	1.7	6.9
1982	1	9.8	0.2	0.0	0.06	0.2	2.5%	1.1	1.3	2.4	2.6	9.3%	1.7	4.4
1983	1	15.3	0.6	0.0	0.06	0.7	4.4%	0.3	0.4	0.8	1.4	46.2%	1.4	2.0
1984	1	14.7	0.2	0.0	0.05	0.3	1.9%	1.0	0.8	1.8	2.1	13.5%	1.8	3.8
1985	1	19.6	0.5	0.0	0.05	0.5	2.7%	1.6	1.5	3.1	3.6	14.5%	1.6	5.8
1986	1	23.5	0.4	0.0	0.05	0.4	1.8%	2.3	3.2	5.4	5.9	7.2%	1.7	9.9
1987	1	23.1	0.1	0.0	0.03	0.1	0.3%	0.2	0.3	0.6	0.6	12.5%	1.6	1.0
1988	1	23.5	0.8	0.0	0.07	0.9	3.7%	0.5	0.7	1.2	2.1	41.3%	1.8	3.7
1989	1	15.0	0.9	0.0	0.06	0.9	6.1%	0.5	1.0	1.5	2.4	38.3%	1.4	3.4
1990	1	36.1	0.2	0.0	0.10	0.3	0.7%	0.8	1.0	1.8	2.1	12.4%	1.6	3.3

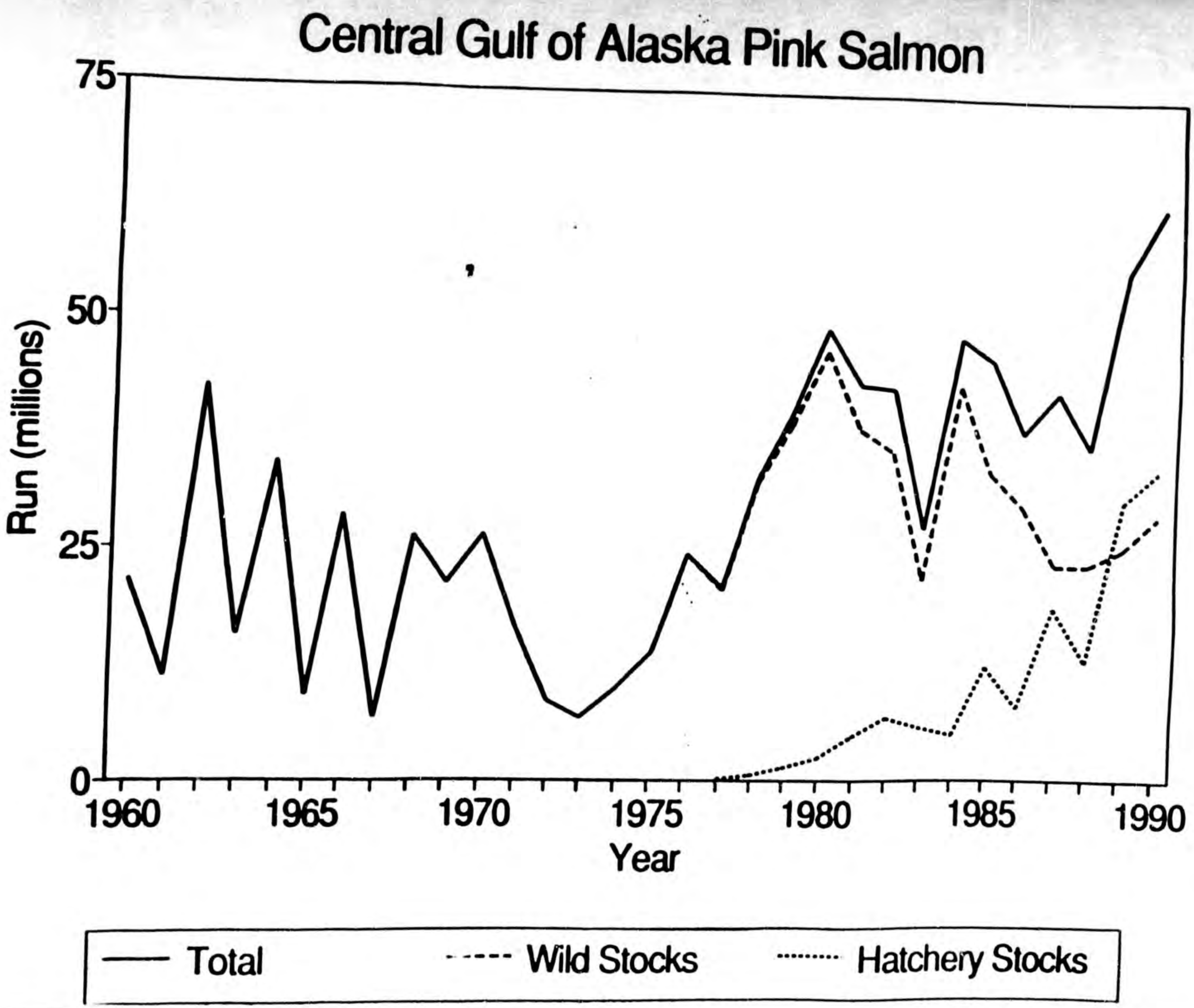
Table 4. Central Gulf of Alaska area pink salmon hatchery runs (millions of fish), wild stock runs (millions of fish), total runs millions of fish), mean weight (kg), and total run biomass (millions of kg).

	Hatchery Runs							Wild Runs						
			Harvest											
Year	No. Hatcheries	Fry Released Year - 1	Mixed Stocks Commercial	Cost Recovery	Brood Stock	Hatchery Run	Survival (%)	Catch	Escapement	Wild Run	Total Run	Percent Hatchery	Mean Weight (kg)	Total Run Biomass
1960								10.5	10.9	21.5	21.5	0.0%		
1961								6.6	4.7	11.3	11.3	0.0%		
1962								25.9	16.5	42.4	42.4	0.0%	1.4	57.6
1963								11.0	4.7	15.8	15.8	0.0%	1.6	25.1
1964								20.4	14.0	'1.3	34.3	0.0%	1.6	53.5
1965								5.5	3.6	9.1	9.1	0.0%	1.6	14.7
1966								16.0	12.5	28.6	28.6	0.0%	1.7	49.3
1967								3.2	3.6	6.8	6.8	0.0%	2.0	13.3
1968								14.1	12.4	26.5	26.5	0.0%	1.5	40.8
1969								17.5	3.9	21.4	21.4	0.0%	1.8	39.1
1970								16.3	10.4	26.7	26.7	0.0%	1.7	44.7
1971								12.1	4.4	16.5	16.5	0.0%	1.7	27.5
1972								3.2	5.4	8.6	8.6	0.0%	1.7	14.5
1973								3.1	3.7	6.8	6.8	0.0%	1.8	12.3
1974	1	0.5	0.0	0.0	0.01	0.0	2.9%	3.6	6.4	10.0	10.0	0.1%	2.0	19.6
1975	1	0.4	0.0	0.0	0.01	0.0	3.3%	8.8	5.0	13.8	13.8	0.1%	1.7	24.0
1976	1	1.2	0.0	0.0	0.01	0.0	1.0%	15.5	9.1	24.6	24.6	0.1%	1.8	44.9
1977	2	3.5	0.0	0.0	0.08	0.1	3.0%	12.6	8.2	20.9	21.0	0.5%	1.9	39.9
1978	3	20.0	0.1	0.1	0.20	0.5	2.3%	19.7	12.8	32.5	33.0	1.4%	1.7	54.9
1979	3	39.1	0.8	0.2	0.29	1.3	3.4%	28.9	9.8	38.7	40.0	3.3%	1.6	66.0
1980	4	52.4	1.7	0.3	0.39	2.4	4.6%	31.7	15.3	47.0	49.4	4.9%	1.5	74.1
1981	4	51.3	3.6	0.7	0.56	4.8	9.4%	29.4	9.0	38.4	43.2	11.1%	1.8	78.3
1982	5	123.0	4.7	1.4	0.77	6.8	5.5%	23.6	12.6	36.1	42.9	15.8%	1.6	68.0
1983	6	184.5	4.5	0.7	0.67	5.8	3.1%	14.4	7.6	22.0	27.8	20.9%	1.5	41.4
1984	6	227.6	4.1	0.4	0.56	5.1	2.2%	29.7	13.6	43.3	48.4	10.5%	1.7	80.2
1985	6	265.1	10.6	1.2	0.64	12.4	4.7%	22.7	11.1	33.8	46.3	26.9%	1.6	72.4
1986	6	319.5	6.6	0.9	0.63	8.1	2.5%	18.4	11.7	30.1	38.2	21.3%	1.5	58.3
1987	7	411.7	15.0	2.9	1.15	19.0	4.6%	16.4	7.3	23.6	42.6	44.5%	1.6	67.6
1988	7	410.6	10.0	2.0	1.13	13.1	3.2%	15.2	8.3	23.5	36.6	35.8%	1.6	60.0
1989	6	642.7	13.9	14.4	2.30	30.5	4.8%	1.4	24.0	25.4	56.0	54.6%	1.4	81.0
1990	7	636.3	25.9	6.7	1.45	34.1	5.4%	18.0	11.1	29.0	63.1	54.0%	1.4	86.3

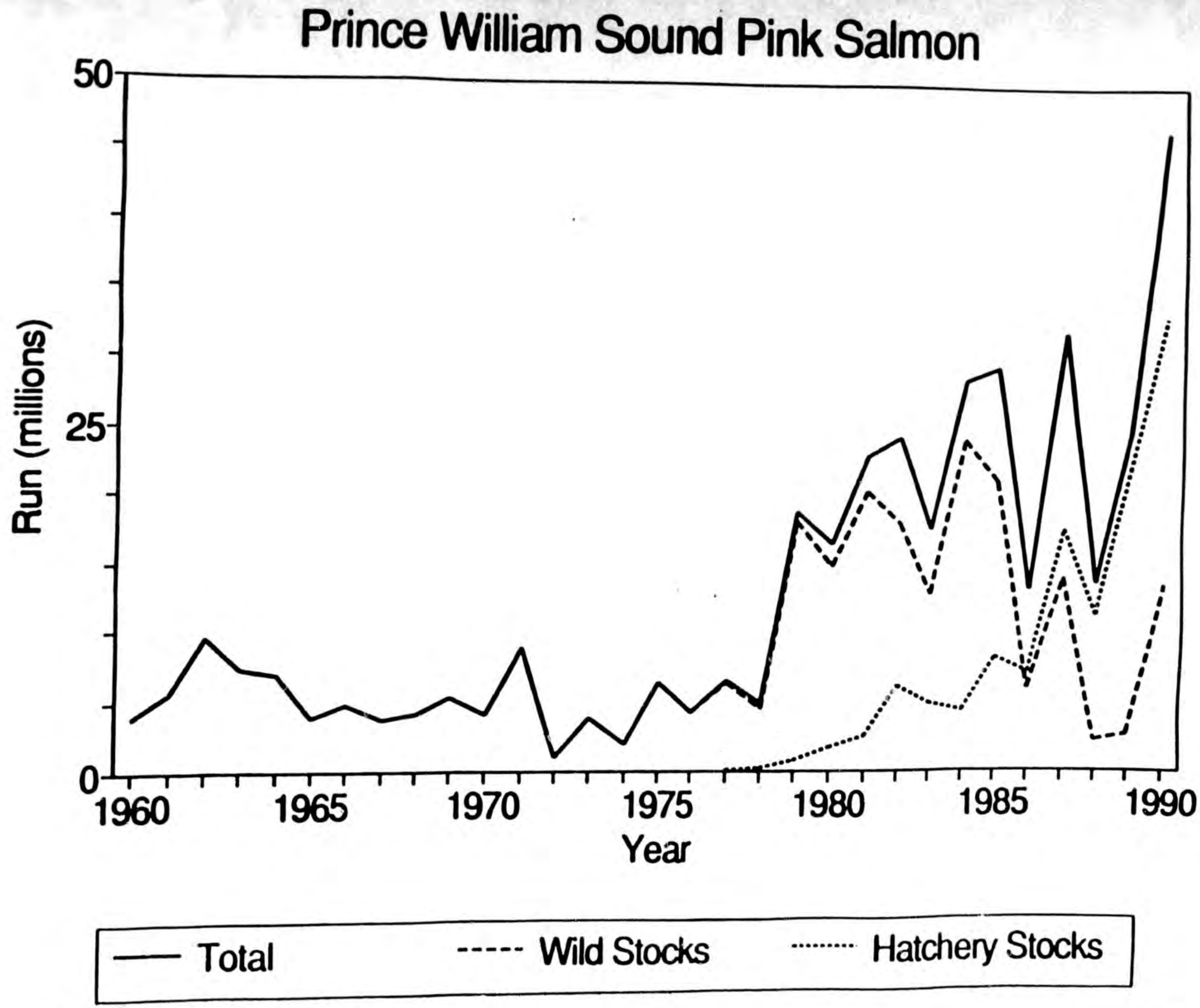

H
K
E
1
2
3
4
5
6
7
Hatcheries
1. A.F. Koernig (AFK)
2. Main Bay
3. W.F. Noerenberg (formerly Esther)
4. Cannery Creek
5. Solomon Gulch
6. Tutka Lagoon
7. Kitoi Bay
Alaska Commercial Fisheries Areas
K Kodiak
H Cook Inlet
E Prince William Sound

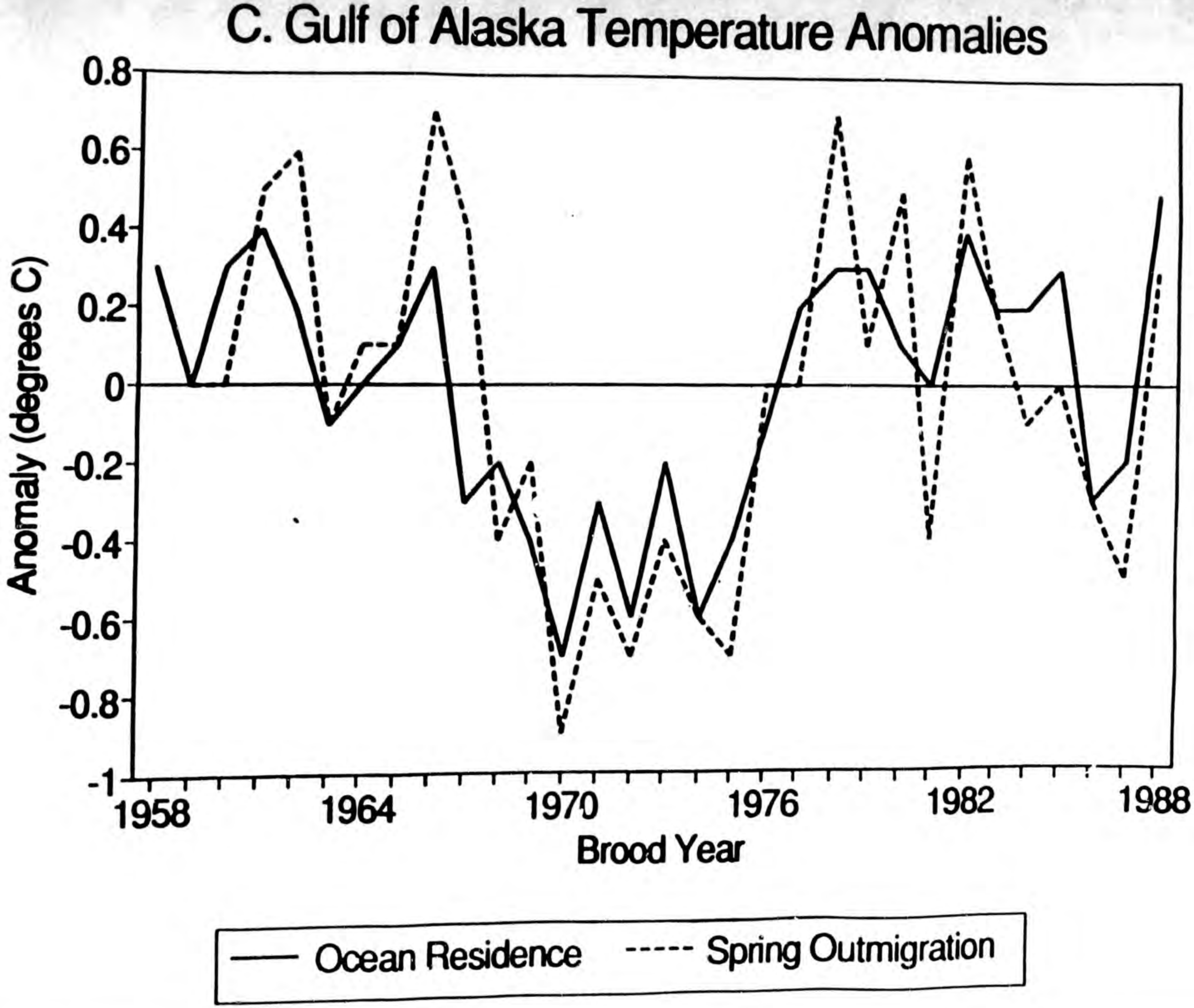


Central Gulf of Alaska Pink Salmon
Total Run (millions)
50
25
0
1960
1965
1970
1975
1980
1985
1990
Year
Kodiak
P. William Sound
Cook Inlet

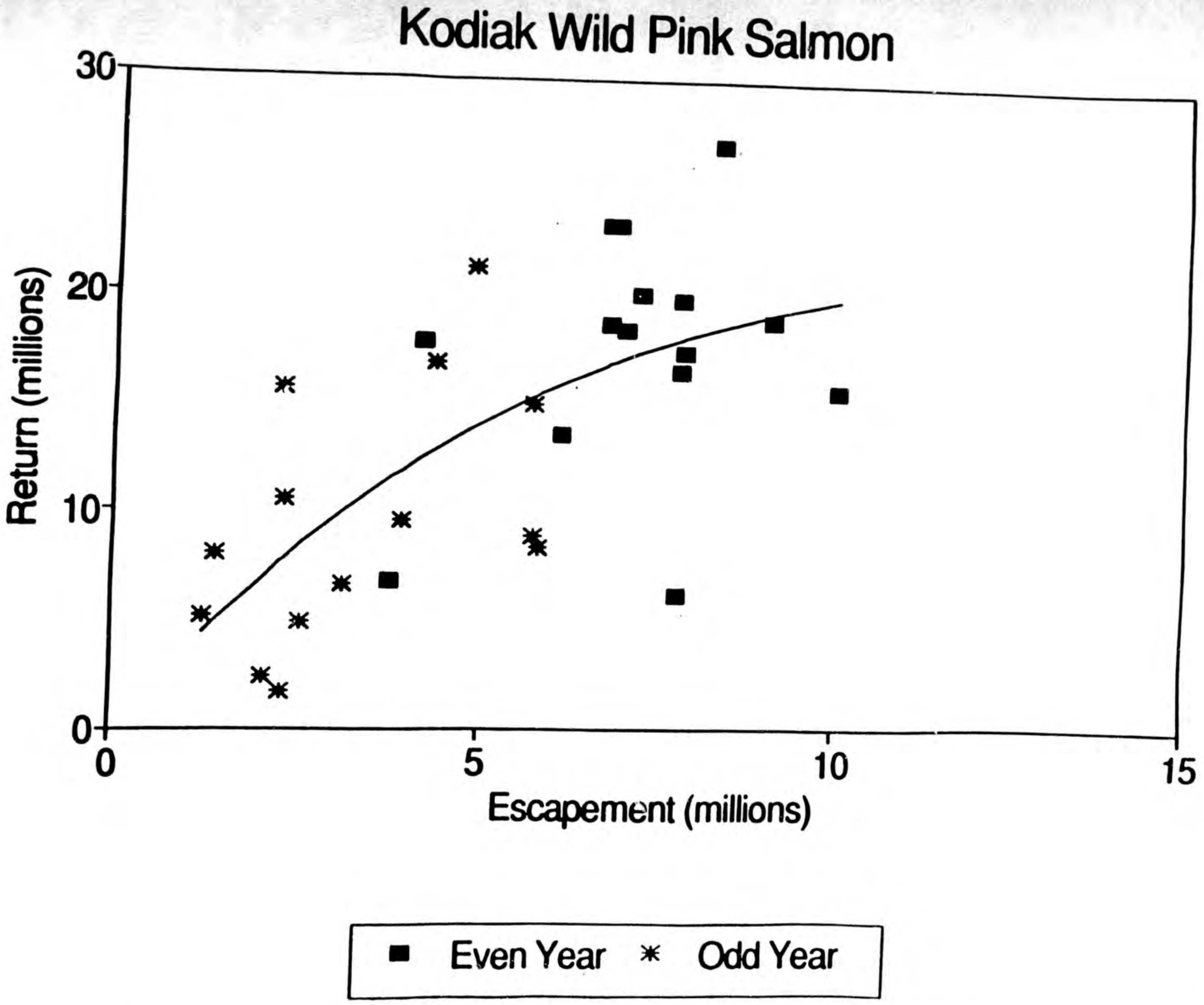


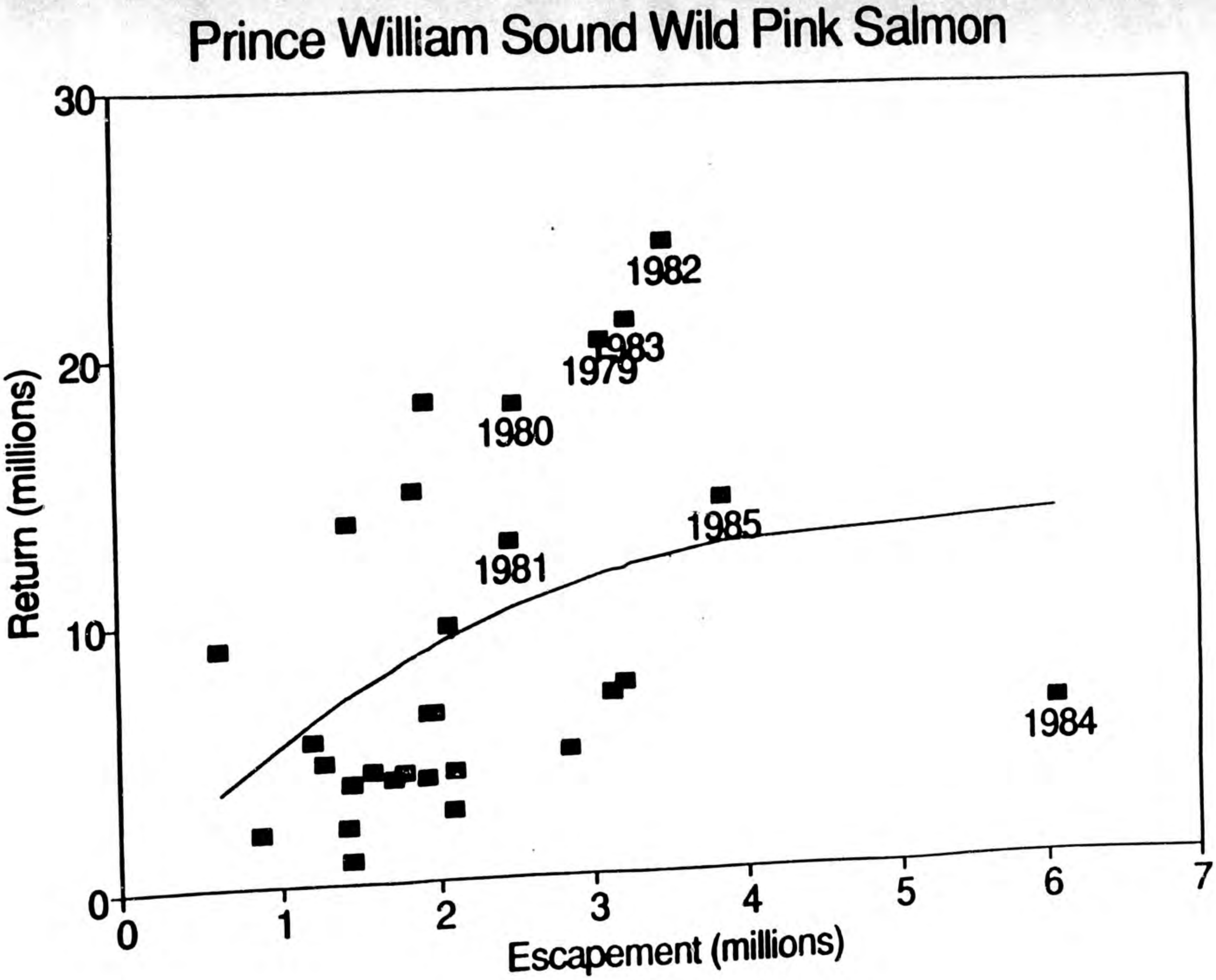
Central Gulf of Alaska Pink Salmon
Run (millions)
75
50
25
0
1960
1965
1970
1975
1980
1985
1990
Year
Total
Wild Stocks
Hatchery Stocks

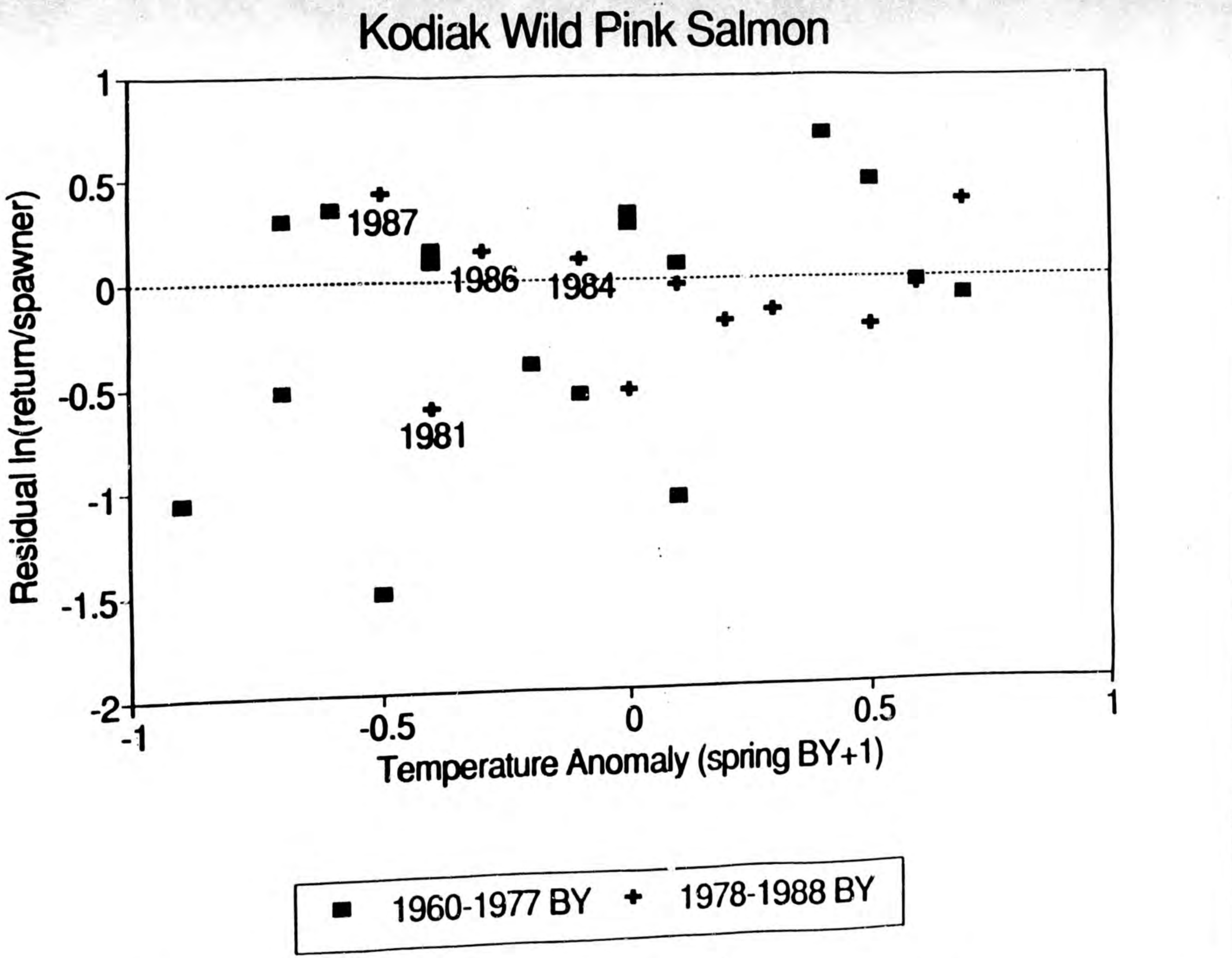

Prince William Sound Pink Salmon
50
25
0
Run (millions)
1960
1965
1970
1975
1980
1985
1990
Year
Total
Wild Stocks
Hatchery Stocks

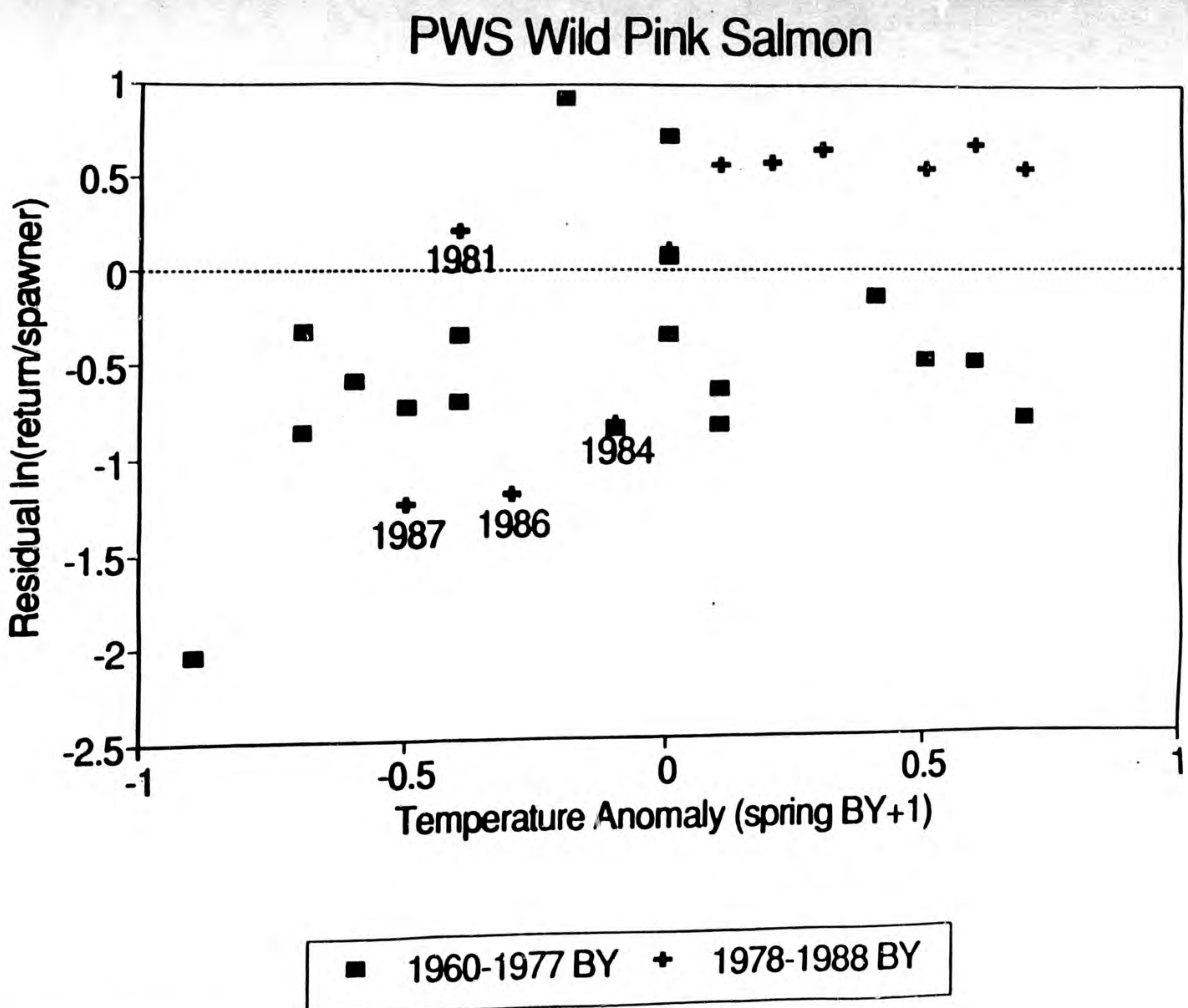


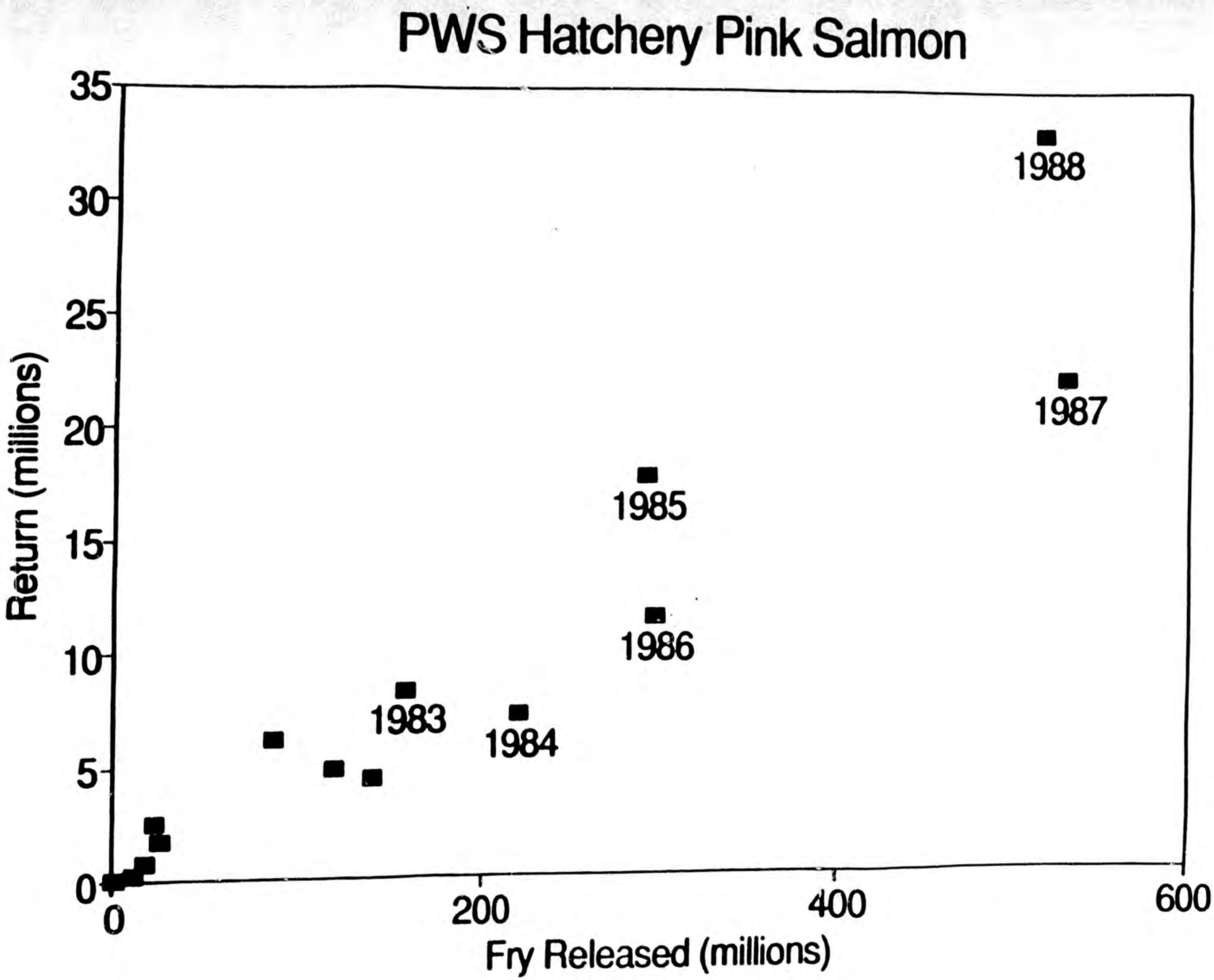
C. Gulf of Alaska Temperature Anomalies
Anomaly (degrees C)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
1958
1964
1970
1976
1982
1988
Brood Year
Ocean Residence
Spring Outmigration


Kodiak Wild Pink Salmon
Return (millions)
30
20
10
0
0
5
10
15
Escapement (millions)
Even Year
Odd Year

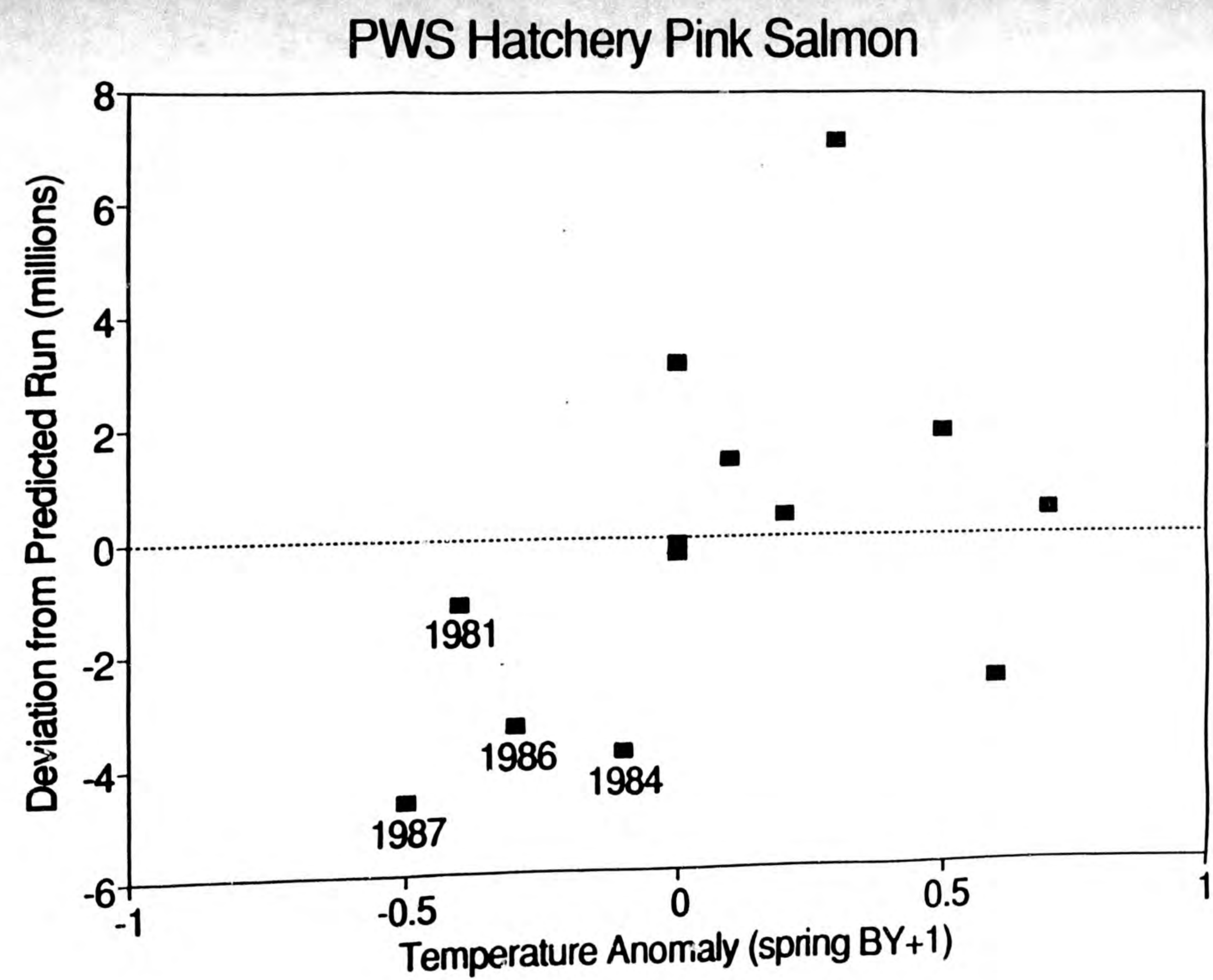

Prince William Sound Wild Pink Salmon
Return (millions)
Escapement (millions)
0
10
20
30
0
1
2
3
4
5
6
7
1982
1983
1979
1980
1985
1981
1984

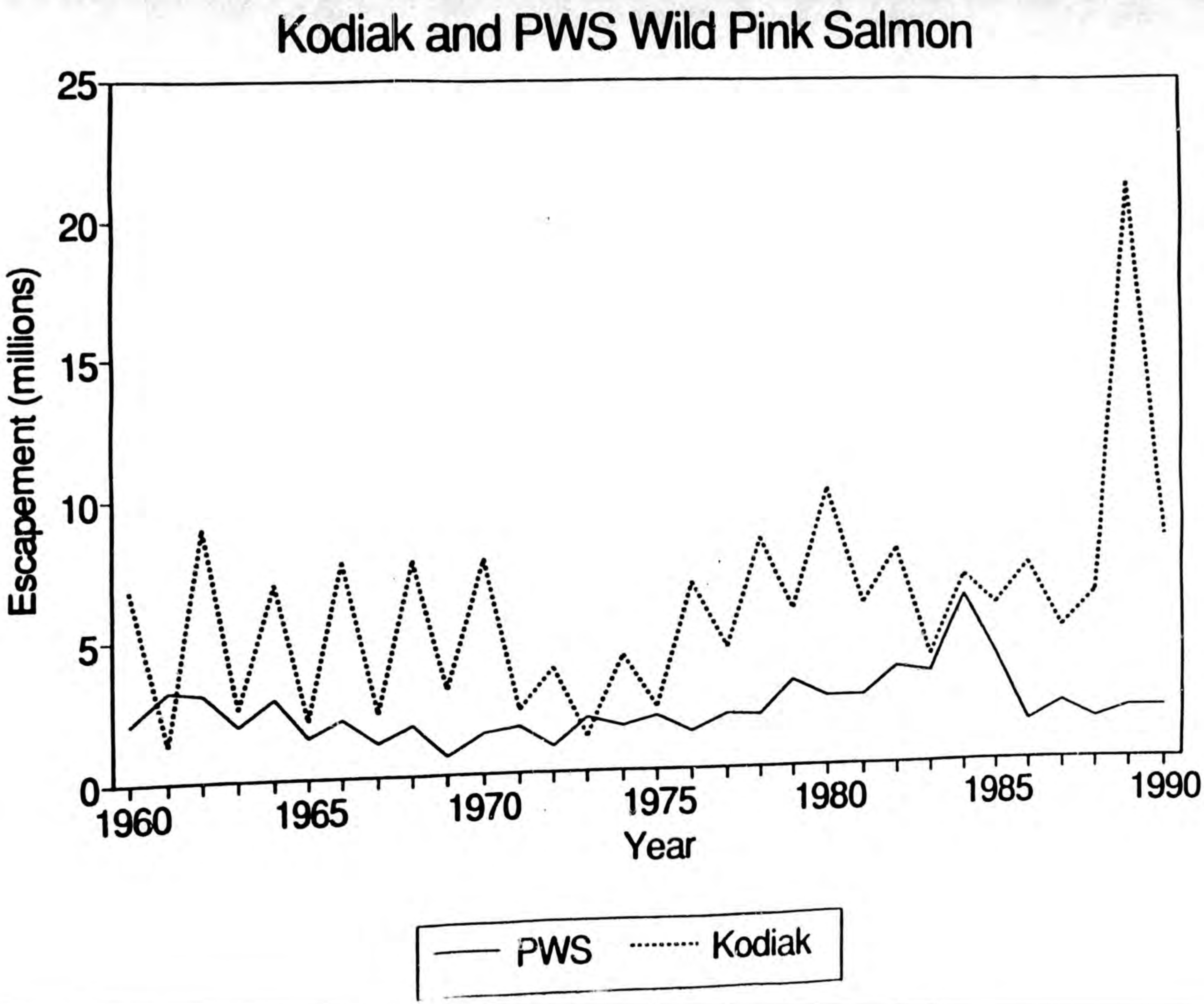

Kodiak Wild Pink Salmon
Residual ln(return/spawner)
1
0.5
0
-0.5
-1
-1.5
-2
-1
-0.5
0
0.5
1
Temperature Anomaly (spring BY+1)
1987
1986
1984
1981
1960-1977 BY
1978-1988 BY

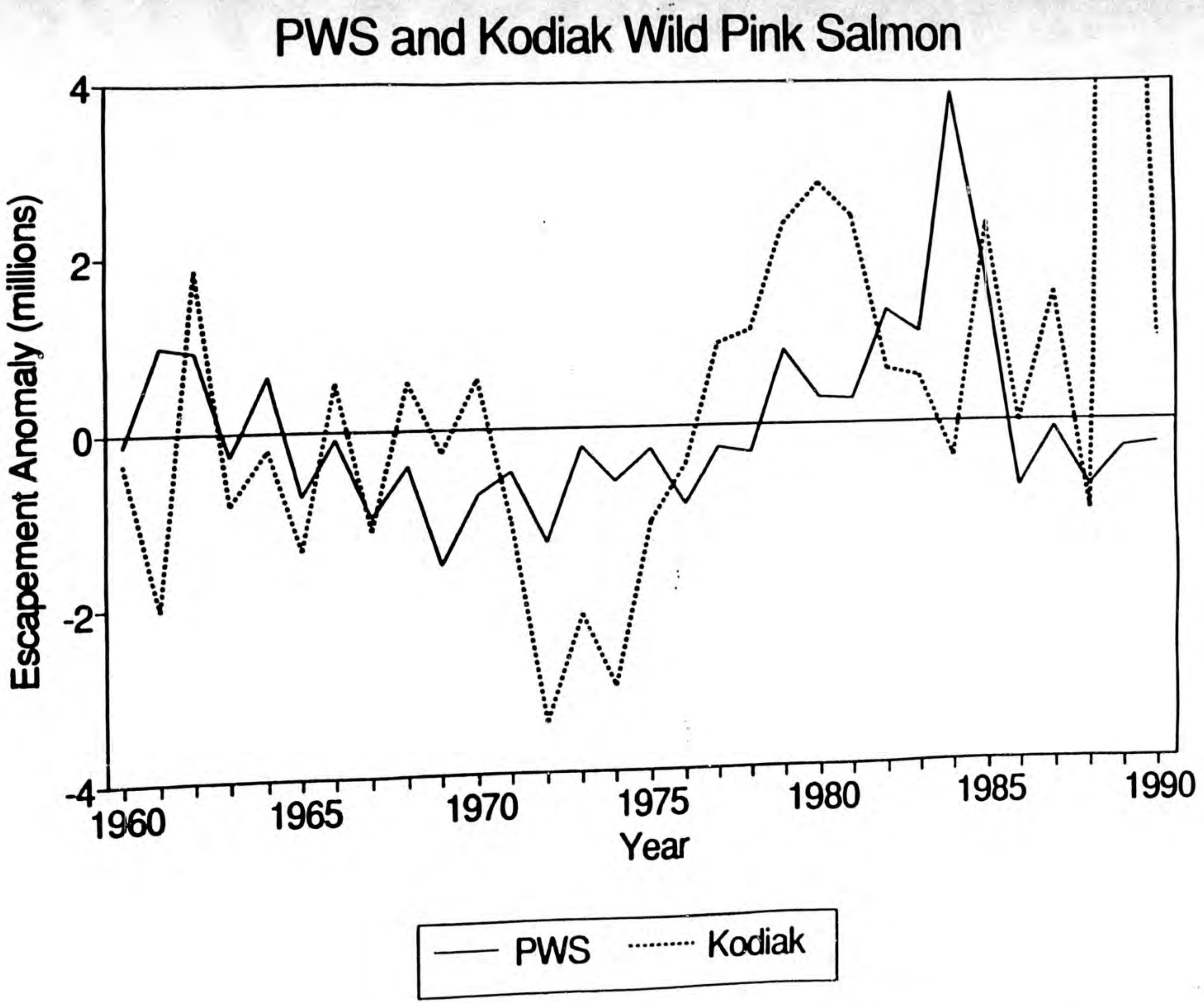

PWS Wild Pink Salmon
Residual ln(return/spawner)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-1
-0.5
0
0.5
1
Temperature Anomaly (spring BY+1)
1981
1984
1987
1986
1960-1977 BY
1978-1988 BY

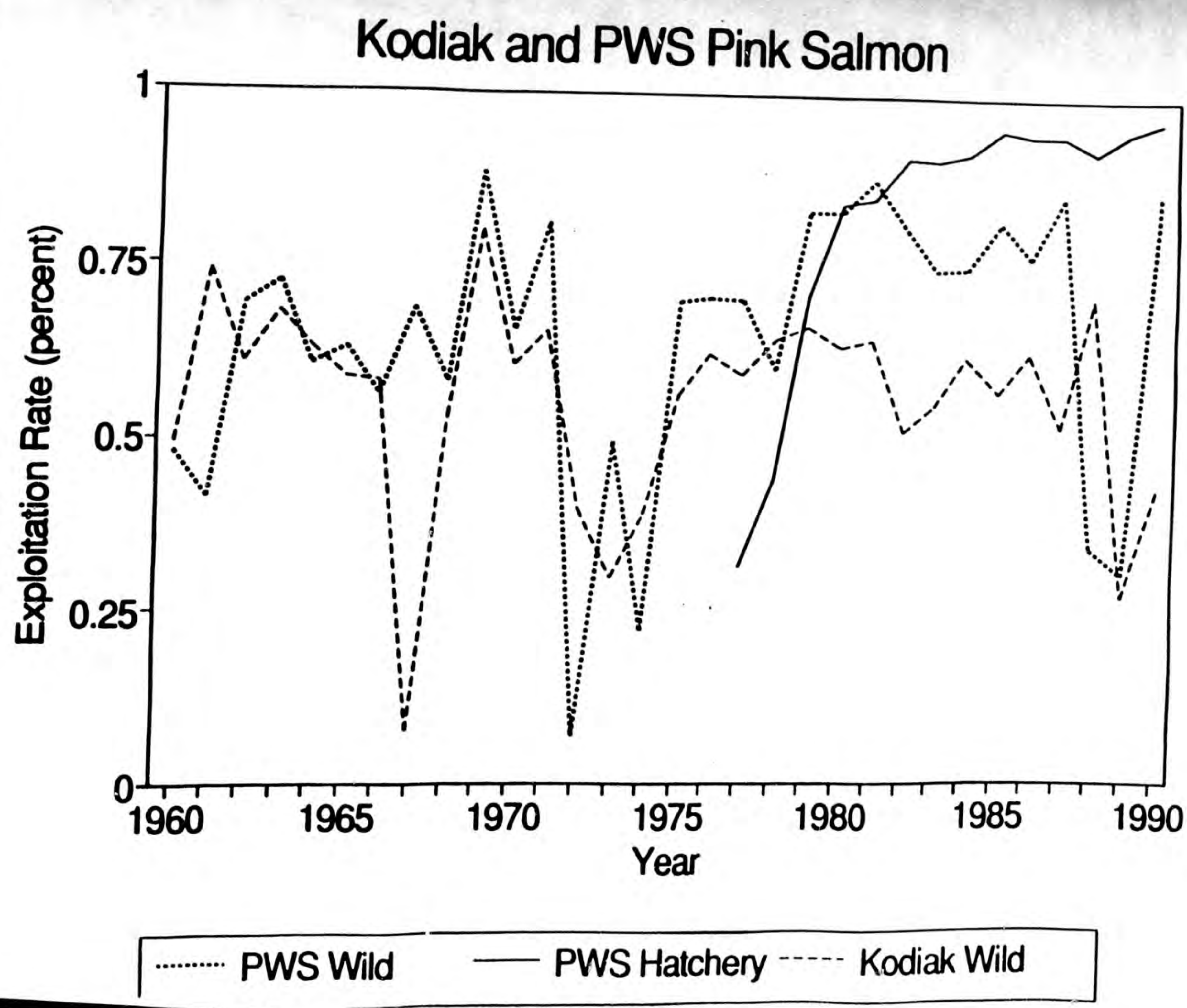


PWS Hatchery Pink Salmon
Return (millions)
35
30
25
20
15
10
5
0
0
200
400
600
Fry Released (millions)
1988
1987
1985
1986
1983
1984

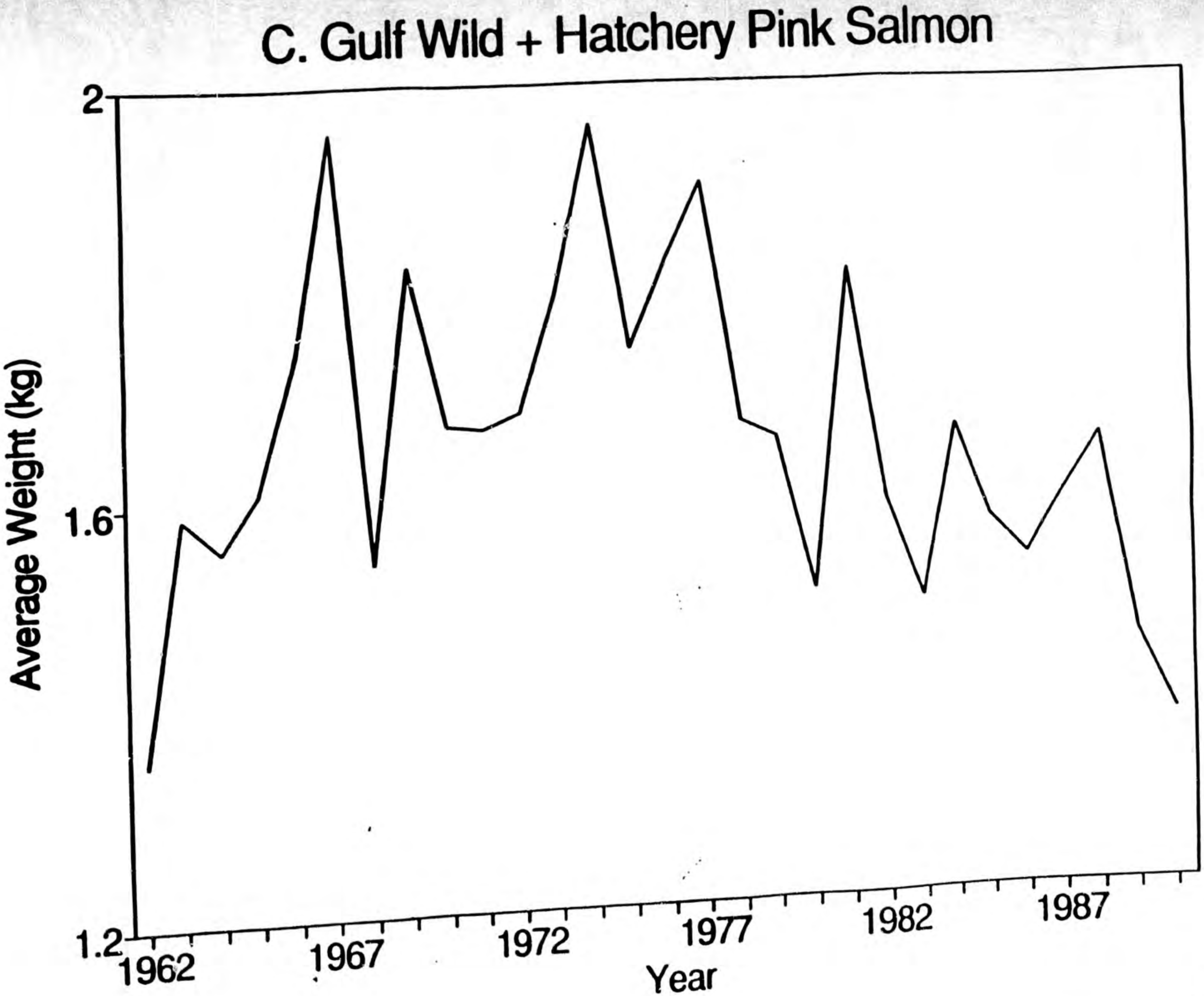

PWS Hatchery Pink Salmon
Deviation from Predicted Run (millions)
8
6
4
2
0
-2
-4
-6
-1
-0.5
0
0.5
1
1981
1986
1984
1987
Temperature Anomaly (spring BY+1)

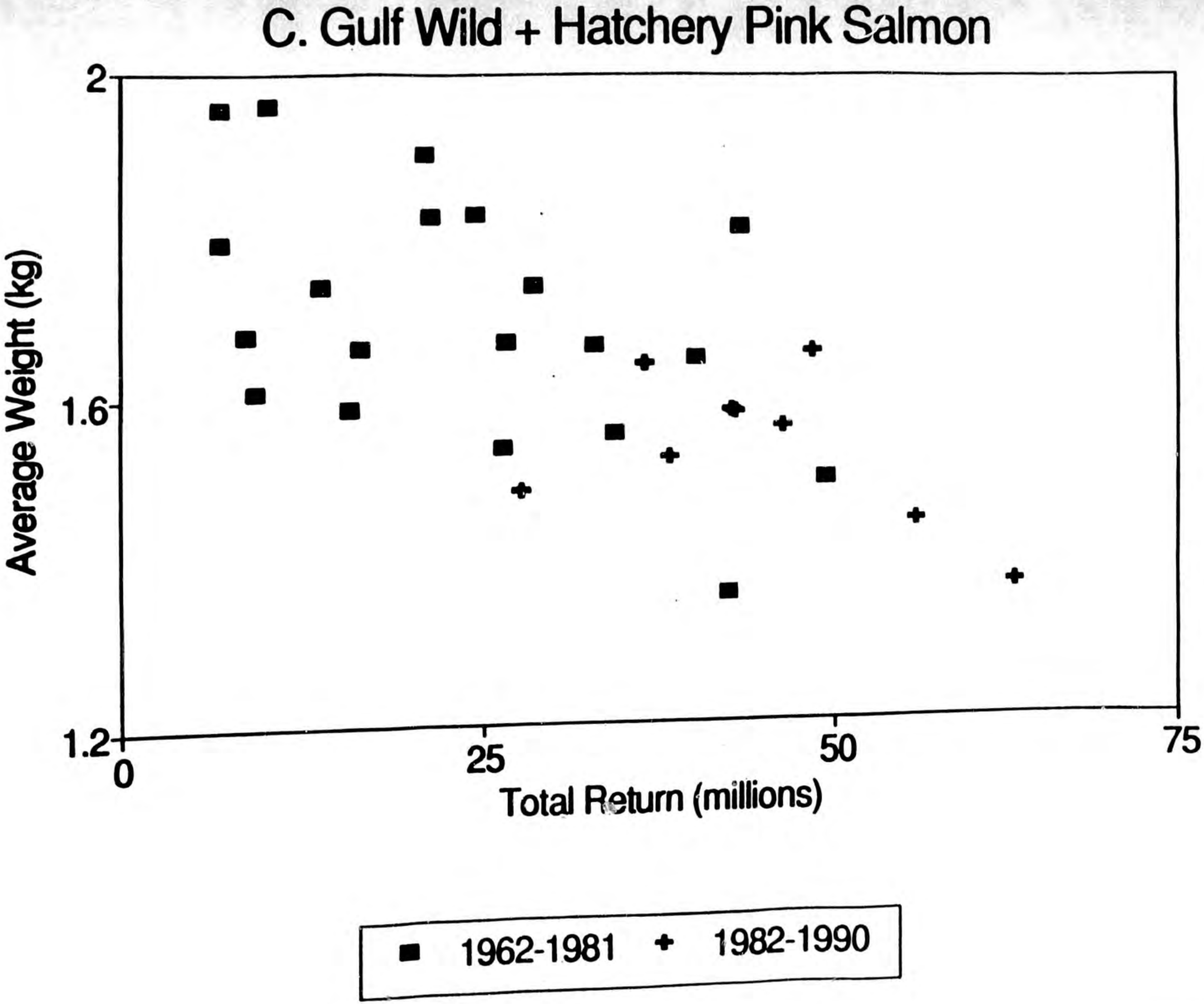

Kodiak and PWS Wild Pink Salmon
Escapement (millions)
0
5
10
15
20
25
1960
1965
1970
1975
1980
1985
1990
Year
PWS
Kodiak


PWS and Kodiak Wild Pink Salmon
Escapement Anomaly (millions)
4
2
0
-2
-4
1960
1965
1970
1975
1980
1985
1990
Year
PWS
Kodiak



Kodiak and PWS Pink Salmon
Exploitation Rate (percent)
1
0.75
0.5
0.25
0
1960
1965
1970
1975
1980
1985
1990
Year
PWS Wild
PWS Hatchery
Kodiak Wild


C. Gulf Wild + Hatchery Pink Salmon
2
1.6
1.2
Average Weight (kg)
1962
1967
1972
1977
1982
1987
Year


C. Gulf Wild + Hatchery Pink Salmon
Average Weight (kg)
2
1.6
1.2
0
25
50
75
Total Return (millions)
1962-1981
1982-1990