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Salmon Population and Exploitation Modeling

by

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Alaska State Legislature
Senate Special Committee on Domestic and
International Commercial Fisheries

As part of the
Legislative Review of the Alaska Salmon Enhancement Program
Benefit-Cost Analysis

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Introduction

The objective of the salmon population and exploitation modeling was to project Alaska salmon production levels by region to the year 2021. For each region, projections were made of expected wild and enhanced production based on current facility capacity. Estimates of commercial salmon harvests are based on present fisheries management practices.

Background

In the early 1970s, the state of Alaska began a salmon enhancement and rehabilitation program through the Alaska Department of Fish and Game (ADF&G), Division of Fisheries Rehabilitation, Enhancement, and Development (FRED). Salmon production through enhancement efforts was to compensate for extremely low wild salmon returns in the 1970s.

The hatchery (or ocean ranching) component is the largest part of the enhancement program. There are two categories of hatcheries: 1) state hatcheries, which are state funded and operated by FRED, and 2) private non-profit (PNP) hatcheries. Private non-profit hatcheries include regional aquaculture association facilities, which can collect salmon enhancement tax receipts from fishermen in the region, and "mom and pop" operations working independently from the regional associations. The independent operations cannot collect enhancement taxes. All PNPs can sell cost-recovery harvest fish to pay for operating costs. They may apply for state enhancement loans through the Alaska Department of Commerce and Economic Development, Division of Investments.

During the past 20 years, the state of Alaska has invested extensively in hatcheries, providing capital construction costs and operating costs to state facilities and loans to PNPs. In addition, FRED provides administrative, technical, research, and planning support to PNP facilities. However, due to declining state revenues, the state has encouraged privatization of state-owned and operated facilities, primarily through contracts in which regional aquaculture associations operate state-owned facilities. Support to PNPs through FRED and salmon enhancement loans also has declined.

In general, the enhancement program has been very successful in producing salmon. Recent annual harvests from the hatchery program range from 15-23 million fish. It is now recognized that the early 1970s were years of low productivity for salmon and other fishes in the North Pacific Ocean. Productivity has increased since then, resulting in record salmon harvests in the 1980s. It is presently uncertain whether ocean productivity will remain high or cycle back to the lower level prevalent in the 1970s.

Enhancement Program Review

In May 1991 the Senate Special Committee on Domestic and International Commercial Fisheries initiated an extensive review of the Alaska salmon hatchery and enhancement program. The purpose of the overall study is to:

- 1) Review the history and legislative intent of the program.
- 2) Analyze the current status of the program.
- 3) Consider future options for the program ranging from fine tuning to possible redirection.

Part of the program review is an economic analysis. An economics study group was formed to address questions raised by the Committee, including:

- if the present levels of Alaska salmon harvest are over- or under-supplied from a world market perspective, and
- if increased enhanced salmon production will raise or lower prices, fishing revenues, and the total net benefits of Alaska's salmon fisheries.

A benefit-cost analysis is required to answer these two questions. My salmon population and exploitation modeling project is one part of this benefit-cost analysis. The results of the benefit-cost analysis are reported in Boyce et al. 1992.

Fisheries Modeled

To bound the modeling project, a subset of regions and species was selected by legislative and FRED representatives and the author to be intensively modeled:

Kodiak pink salmon
 Kodiak sockeye
 Cook Inlet sockeye
 Prince William Sound pink salmon
 Southeast Alaska chinook salmon

This set includes most of the enhanced salmon production harvested by commercial fleets (Figure 1). The models aggregate production over the region of interest. We agreed that the remainder of the commercial salmon population and exploitation estimates (the non-intensively modeled set) would be based on projections of state and PNP hatchery managers and ADF&G, Division of Commercial Fisheries historical records of wild-stock harvests. Only the intensively modeled fisheries are discussed in this report.

Modeling Methodology

The modeling effort followed the standard approach to estimating the catch of enhanced fish:

$$\text{Hatchery Catch} = \text{Fry released} * \text{Survival} * \text{Exploitation Rate}$$

Refinements were made to the model by estimating survival rates and variance from past releases, and by considering constraints on the exploitation rate imposed by mixed fisheries.

The flow chart (Figure 2) illustrates the steps involved in the simulation model. The first step was to estimate the model parameters from historical data. If there were insufficient data to quantify a relationship, the effect could not be included in the model. Thus, genetic effects were not included, even though they may potentially

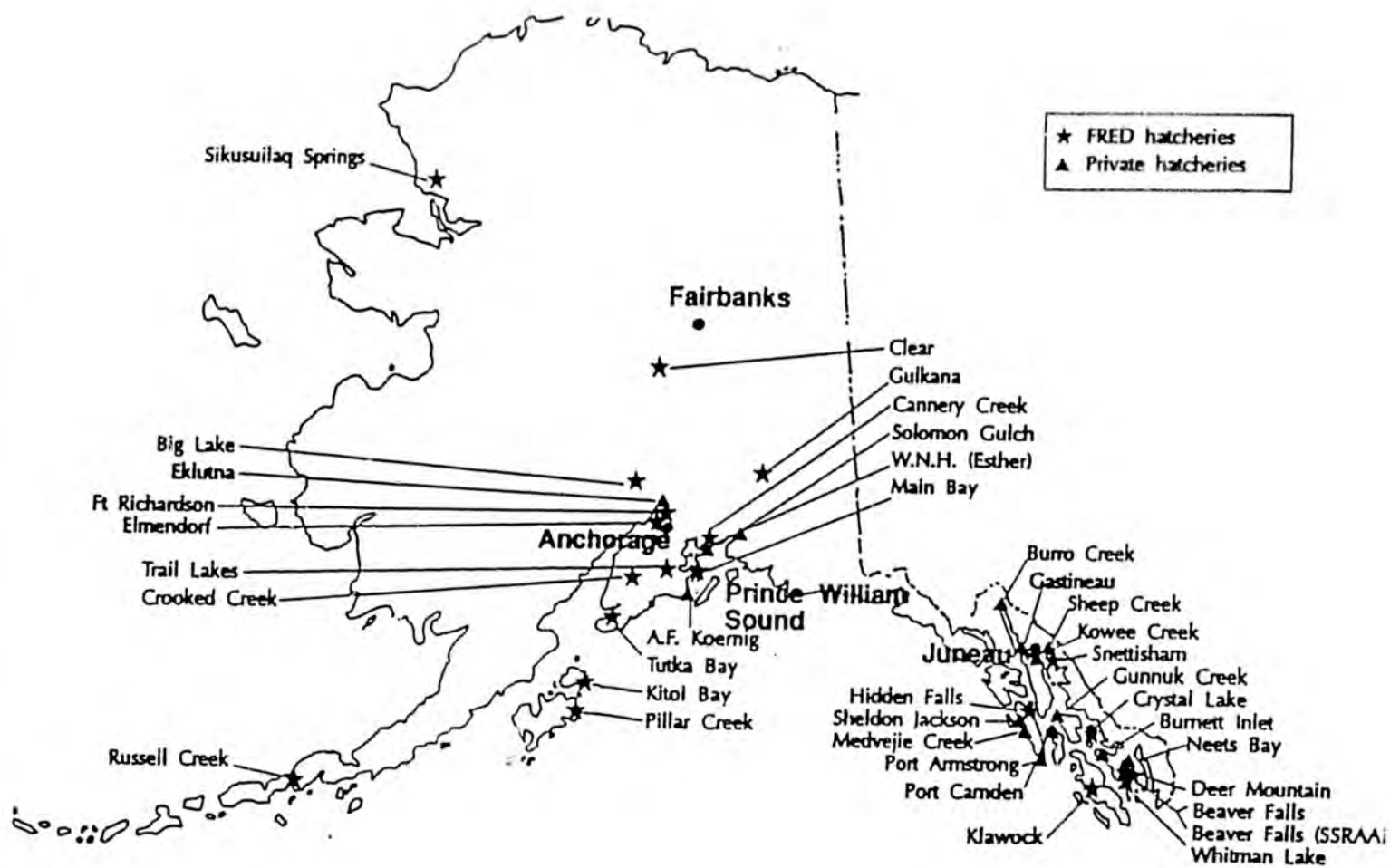


Figure 1. Locations of hatcheries in Alaska.

Salmon Simulation Model

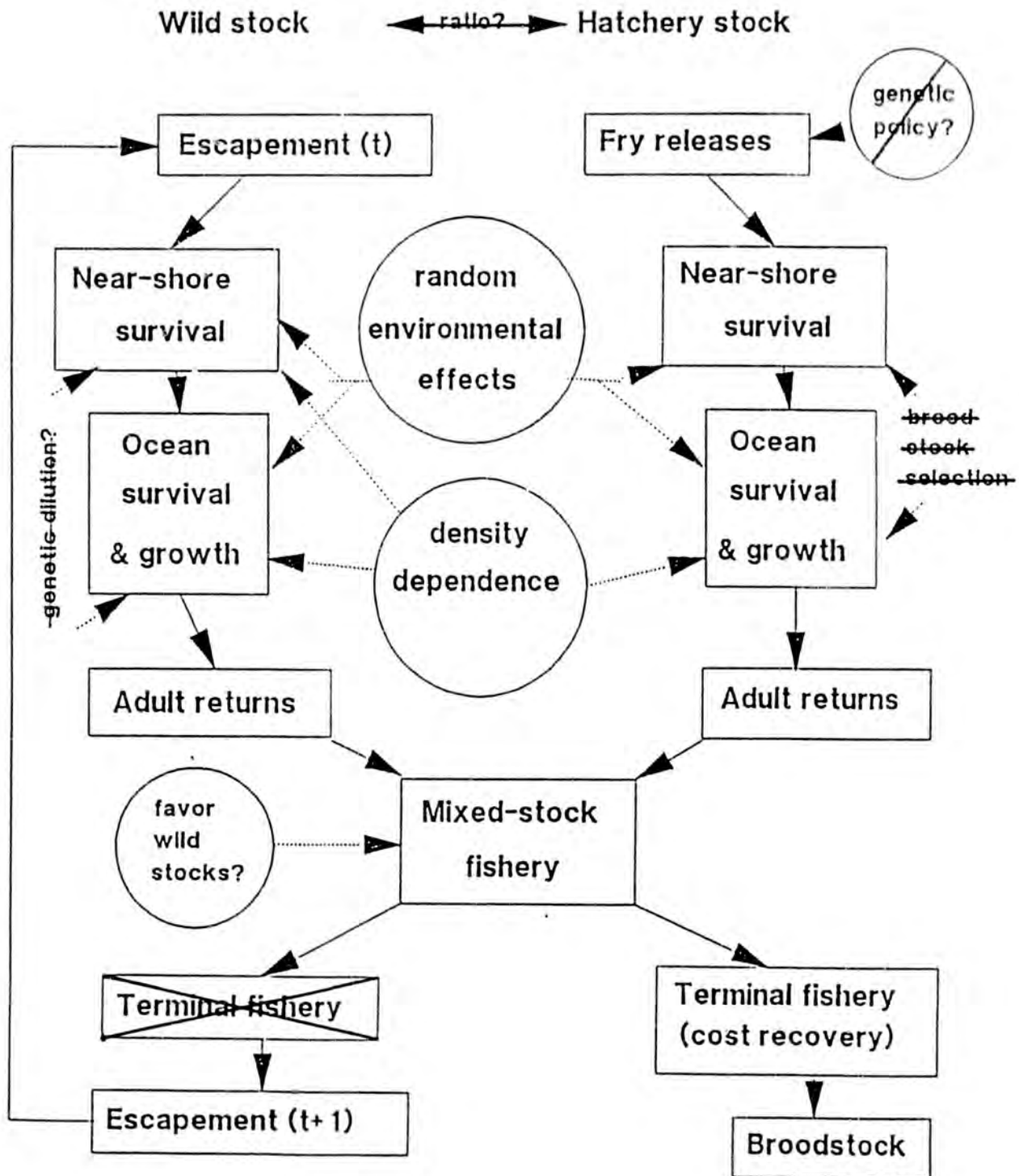


Figure 2. Flow chart of salmon simulation model. Components deleted with an "X" were considered in model development but not included in the final models.

affect salmon production. Initial attempts to intensively model the Prince William Sound chum salmon fishery and the Southeast Alaska coho salmon fishery were discontinued because of inadequate data.

Release data for enhanced stocks were obtained by surveying hatchery managers. This survey was conducted jointly by legislative and FRED effort. Survey results were provided to the author. Most of the survey results indicated that fry and smolt releases will change very little after the initial survey years. Although the hatchery managers' planning horizon is relatively short, investment decisions must be made with a longer planning horizon. In most cases, planned releases are the same as current releases. The exception was Cook Inlet sockeye salmon; hatchery operators there are planning significant production expansion.

Wild-stock recruitment and escapement data, future escapement targets, and mixed-fisheries management constraints were provided by ADF&G, Division of Commercial Fisheries.

Monte Carlo Simulations

The purpose of the simulations is not to *predict* catch in each year, but to *project* the most likely level of production and upper and lower confidence levels. In these Monte Carlo simulations, random variability was introduced into the survival rates to indicate the level of natural variability to expect around the median estimates. Mean survival rates and their variances were calculated from spawner-recruit data for wild stocks, and from historical release data for hatchery stocks. The inputs for the Monte Carlo simulations included enhanced fry and smolt releases, wild-stock escapements during the initialization years, and the escapement target for future years. Wild-stock preference was built into the exploitation sub-model such that the harvest rate of hatchery fish in the mixed-stock fishery was conditional on the escapement target for the wild stock. Excess hatchery fish were assumed to be harvested in the terminal areas. Broodstock requirements were backcalculated from projected fry and smolt releases, assuming a 50:50 sex ratio, average fecundities from literature, 10% more fish collected than required, and egg-to-release survivals as listed in the surveys. Initial simulation runs indicated that the return of hatchery fish would very seldom be less than brood stock requirements. Therefore it was assumed that the fry and smolt releases listed on the surveys would actually occur and not be constrained by adult return rates.

The simulation outputs were adult returns, divided into the various harvest and escapement boxes (Figure 2). One hundred stochastic replicates of the 30-year simulations were run. The 100 replicates were then sorted by total return for each year to obtain median, 10%, and 90% quantiles. The quantiles of the return distribution provide an empirical confidence interval around the median; 80% of the replicates lie between the 10% and 90% quantiles.

As part of the benefit-cost analysis public policy simulation, hatchery production was hypothetically altered to estimate how net benefits would change under different production scenarios. To develop accurate population and exploitation estimates for these simulations, the population models were run using the production scenarios listed below. Changes in production refer to numbers of returning adult salmon available for harvest by commercial fisheries. The first five changes were specified by the legislature. The sixth was added to compare enhanced production with increased wild salmon production through increased escapement targets. The

results of the latter scenario are referred to as the "management" option in the figures. Only the first five scenarios were included in the complete benefit-cost analysis.

Production Scenarios

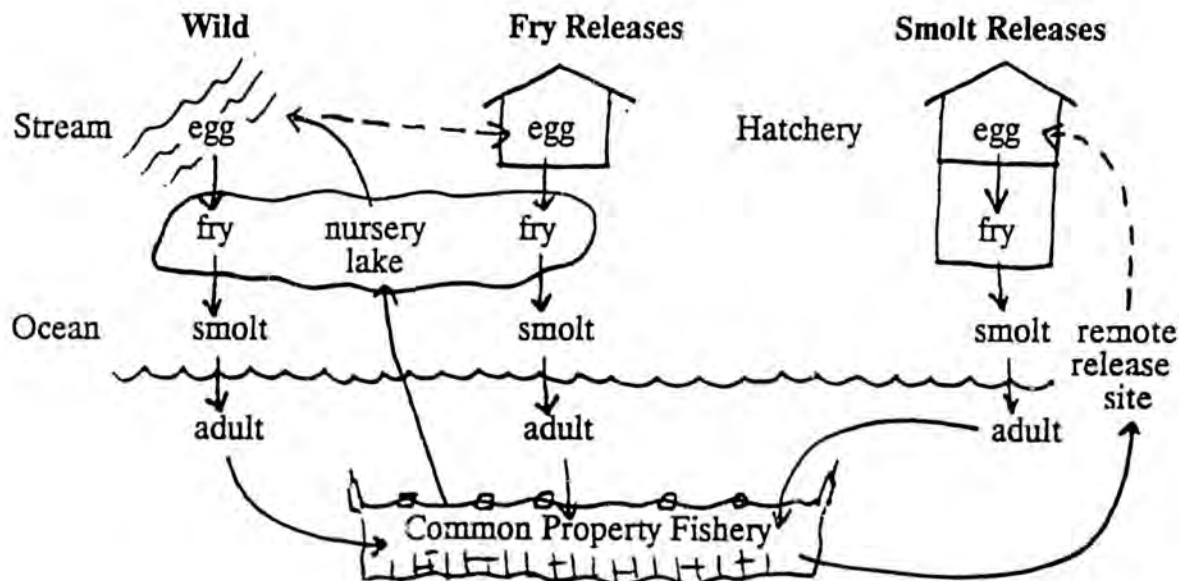
1. Hatchery production continues at current permitted levels (Base Case)
2. Hatchery production continues at planned (unconstrained) levels.
3. Hatchery production is eliminated (no egg take in 1993)
4. Hatchery production is increased 15% over the Base Case
5. Hatchery production is decreased 15% from the Base Case
6. Hatchery production is eliminated and escapement targets are increased.

The next sections provide information on modeling methodology and results for the Cook Inlet sockeye, Prince William Sound pink, and Southeast Alaska chinook salmon fisheries. Results for Kodiak pink and sockeye salmon are not included in this report. Methods for Kodiak were the same as for Cook Inlet sockeye and Prince William Sound pink salmon. In fact, the Kodiak and Prince William Sound pink salmon simulations were combined in a single program.

Cook Inlet Sockeye Salmon

Considerable research has been conducted in Alaska on sockeye salmon dynamics. Cook Inlet is the region of Alaska producing the most enhanced sockeye. The Cook Inlet Regional Salmon Enhancement Plan projected a harvest of 1 million enhanced sockeye by the year 2000. Cook Inlet also supports large natural runs of sockeye. From 1968 through 1985, the median return of wild sockeye was 4 million fish. During a visit to Soldotna in May 1992, the author consulted limnologist Dana Schmidt and other ADG&G staff to obtain information needed for the Cook Inlet and Kodiak regions.

Figure 3. Sockeye salmon life history



Sockeye enhancement, consisting primarily of fry lake releases, fish passes, and lake fertilization has until recently been relatively "benign." This is for the most part because the enhanced stocks are from wild egg takes that are transported to nursery lakes and harvested with wild stocks rather than creating new, separate stocks. These enhancement methods, however, provide no mechanism for generating cost-recovery revenue because the fry releases do not return to a hatchery facility. For this reason, most of the initial sockeye fry enhancement in Cook Inlet was conducted by FRED. In contrast, smolts released directly into salt water return as adults to the release sites, where cost recovery harvests can be conducted. It is likely that remote smolt release will provide for cost-recovery sales harvest but it will also complicate management.

Spawner-Recruit Data

The escapement data include all surveyed streams in Upper Cook Inlet; data values streams not surveyed in a given year were interpolated. The return data include only the dominant age categories. The percentages of these age categories, calculated over all years, were used to project the age compositions in the simulation model.

Age	1.2	1.3	2.2	2.3
%	18.3	62.6	7.9	11.2

Escapement targets and returns have both increased since 1971 (Figure 4). I used an escapement target of 1.06 million in the simulations, the midrange of escapement goals for Upper Cook Inlet, inflated to include Lower Cook Inlet stocks. The fitted spawner-recruit curve is a straight line with a slope of 4.2 returning adults per spawner. There is relatively little scatter in the data point around the straight line, compared with typical spawner-recruit data. It is uncertain what level of escapement will lead to diminishing returns per spawner. One possible reason for this linear relationship is that the return data contain a small but unknown number of hatchery released sockeye salmon, which cannot presently be distinguished from the wild sockeye. Based on the estimated survival of past releases, the hatchery contribution to these return data is at most 1 million and probably much less in most years. The 1992 return of approximately 10 million adult salmon, primarily from the 1987 escapement of 2.3 million, will indicate the degree of density-dependent survival for Cook Inlet sockeye. In addition, the 1989 escapement, also 2.3 million, will test whether such high returns are sustainable.

Sockeye life-stage survivals are summarized in Figure 5 from Koenings and Kyle (1991). Lake Tustumena, in particular, has been the site of fry tagging and smolt enumeration (Kyle 1992).

Residuals from log survival rates were used to estimate the variance of the random deviations in survival (Figure 6). The residuals from the combined Cook Inlet spawner-recruit data (Figure 4) have an increasing trend which reflects the increased productivity since the 1970s. The data for fry and smolt releases are all from Lake Tustumena (Kyle 1992). Deviations in survival for the different life stages are not in phase, nor does the variance in survival decrease for partial life stages, compared with the entire life span. This lack of coherence could indicate compensatory survival during the smolt-adult stage, or imprecision in measuring smolt abundance.

Upper Cook Inlet Sockeye Salmon (data labels are brood years)

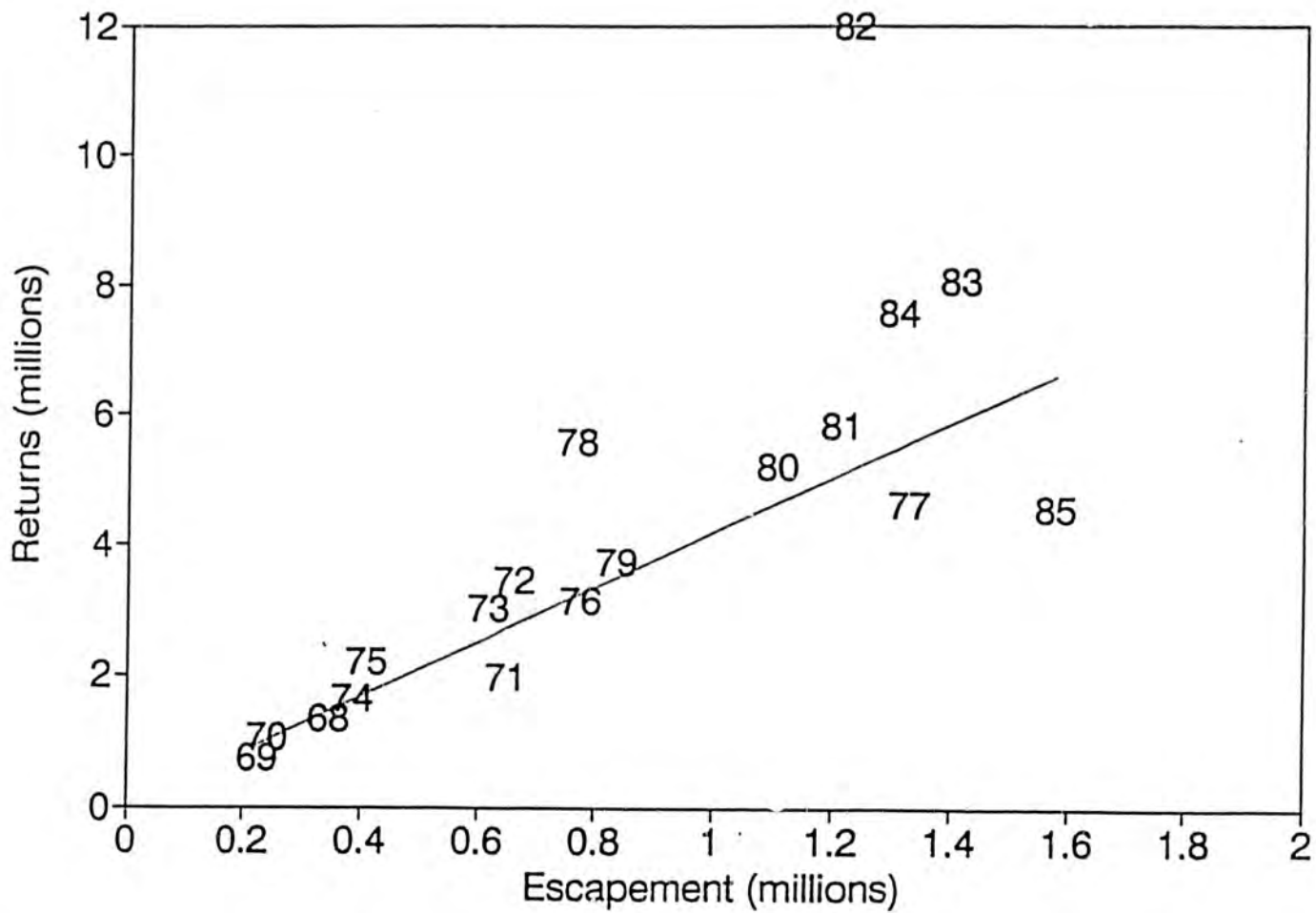


Figure 4. Upper Cook Inlet sockeye salmon spawner-recruit data.

***Sockeye Salmon Life-Stage Survivals at Rearing
Limitation Based on Euphotic Volume (EV)***

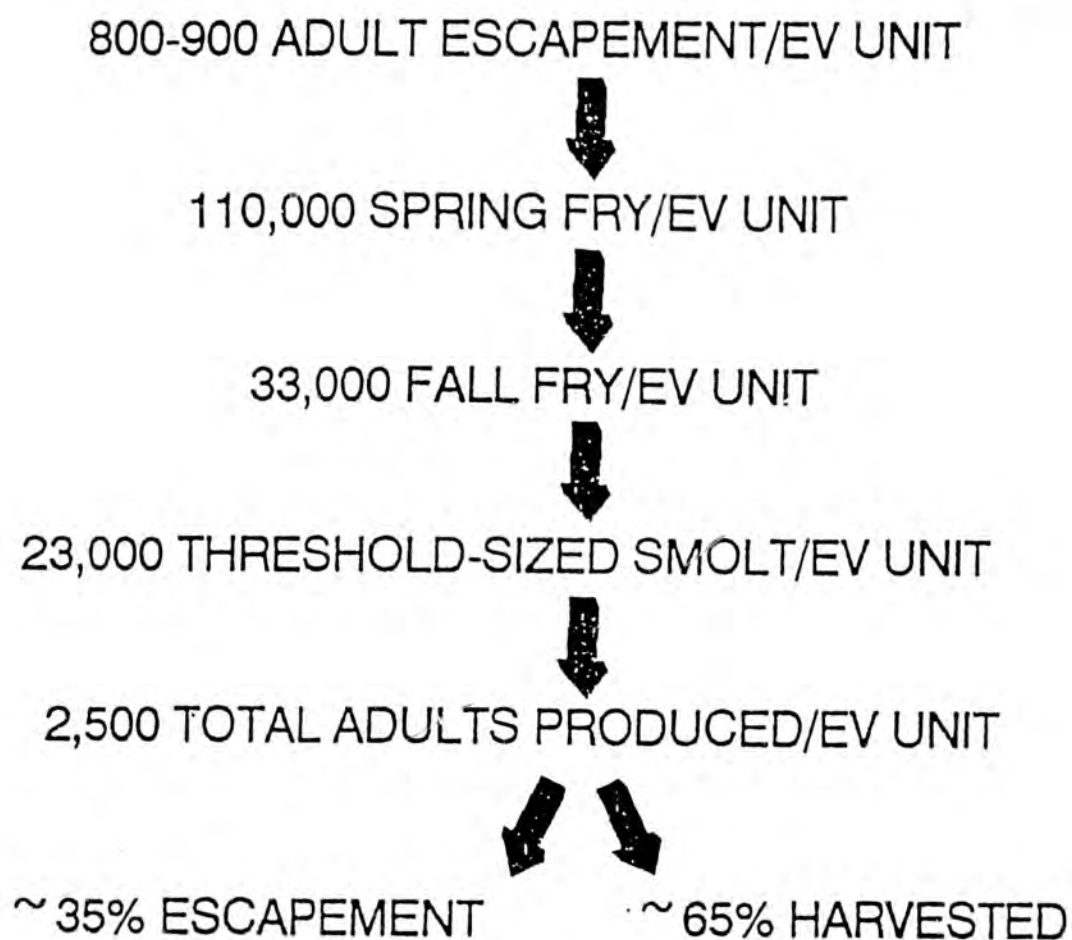


Figure 5. Sockeye salmon survival by life stage (from Koenings and Kyle 1991).

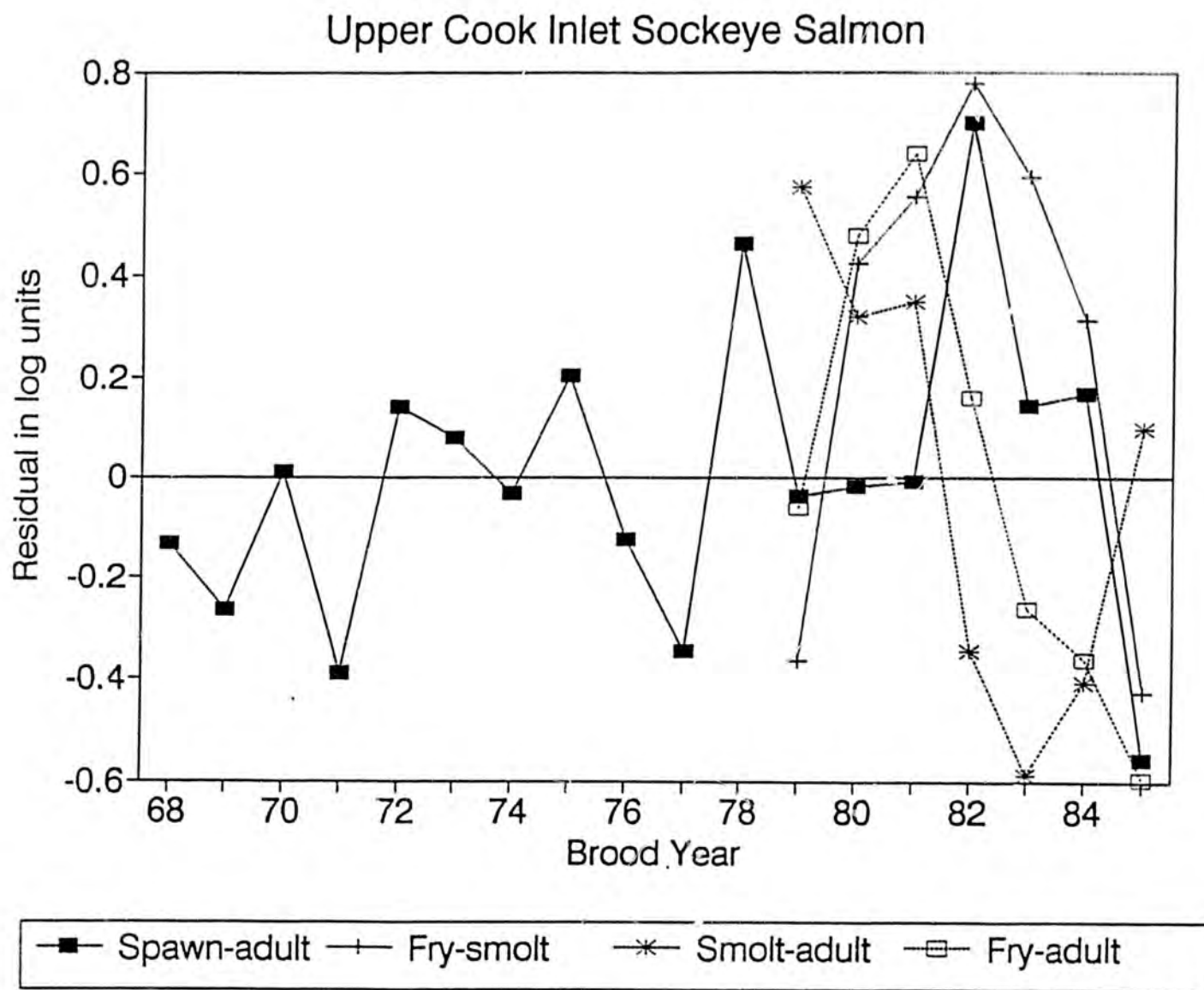


Figure 6. Residual deviations from mean log survival rates.

Cook Inlet Sockeye Releases

Fry are released into about a dozen lakes. Figure 7 shows historic fry releases as well as current, planned, and the 15% increase and decrease production scenarios. Changes in production are assumed to begin with the 1993 egg take and thus the 1994 releases. Planned releases would be almost double the currently permitted levels. In the simulations, I used a fry-adult survival rate of 2.2%.

Smolt releases are the latest trend in sockeye salmon enhancement (Figure 8). Smolts are being released both at age-0 and age-1. Four facilities plan to release a total of over 5 million sockeye smolts. The smolt-adult survival rate used in the simulations was 15.1%.

Results

Figure 9 shows commercial catch from current releases and wild stocks with 10%, median, 90% levels, and the actual 1992 catch. The range between the 10 and 90 percent levels is approximately 1-2 million fish from the median estimate. Projected catches are initially high because of high escapements in the late 1980s. Escapement was 2.3 million in 1987 and again in 1989. In the model, escapement is maintained at the target of 1.06 million, so there are approximately half as many fish returning. It appears that high catches in the 1990s are realistic--the model predicted exactly the 1992 catch.

Commercial Catch Estimates for Production Scenarios

Planned increases in hatchery fry and smolt releases add about 1 million returning adult salmon to be harvested by the common property commercial fishery by the year 2000 (Figure 10). Eliminating hatchery production reduces catches by approximately 1/2 million annually. Doubling the escapement target to 2 million results in an initial decrease of 1 million salmon annually (a total reduction in harvests of 4 million sockeye over the four year period 1993-1996). This increased escapement would result in an eventual annual payoff of 3.5 million sockeye salmon. The management option exceeds harvest levels of planned sockeye enhancement by approximately 2.5 million annually. The prospect of such high catches may be overoptimistic if possibility of brood-year interactions occur. There is evidence that strong year-classes may decrease the survival of following cohorts by heavy grazing of zooplankton populations in the nursery lakes (Koenings and Kyle 1991). Lake rearing capacity may therefore set upper bounds on escapement targets and fry stocking densities.

Terminal sockeye harvests will increase with increases in smolt production (Figure 11). If hatcheries close, there would be a short burst of terminal catch followed by declines. The number of sockeye harvested in the terminal areas is about two orders of magnitude lower than the number harvested in the common property fishery. It would be very difficult for managers to ensure that this relatively small number of smolt-released sockeye was available for cost-recovery harvest. Thus, sockeye smolt releases will further complicate fisheries management in Cook Inlet, which is already adversarial.

Cook Inlet Sockeye Salmon

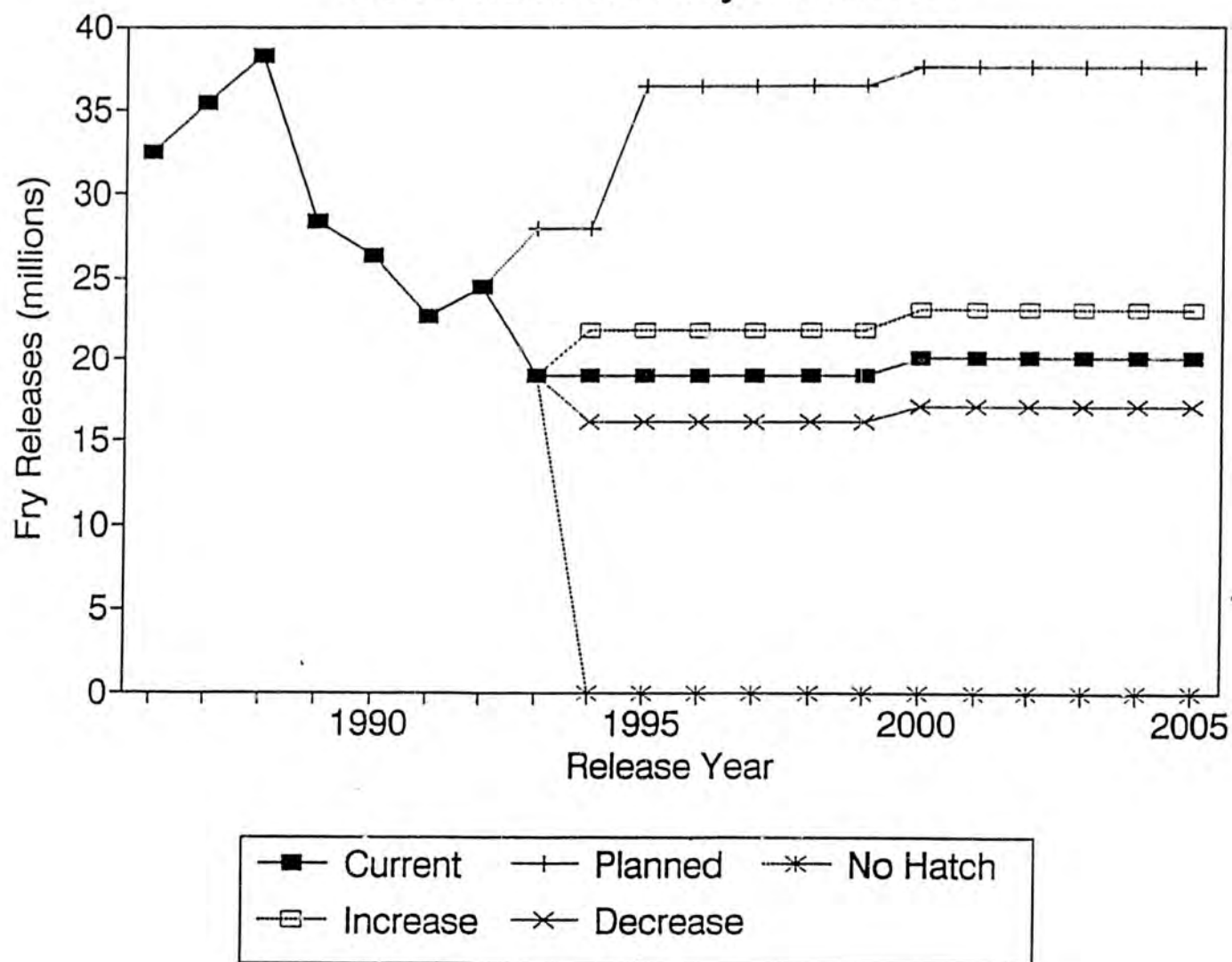


Figure 7. Cook Inlet sockeye salmon fry releases. "Current" releases are actual releases until 1991 and projected releases starting in 1992.

Cook Inlet Sockeye Salmon

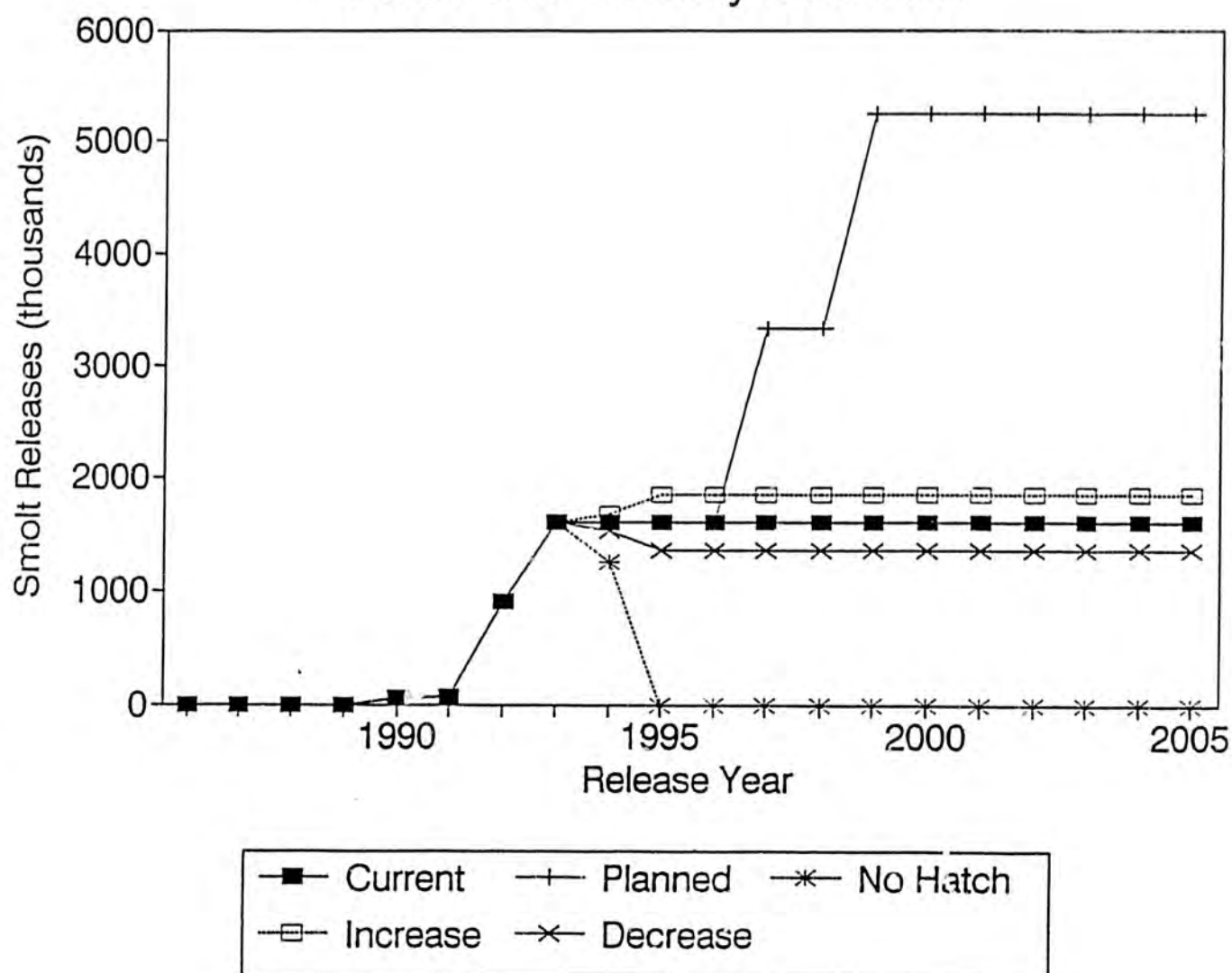


Figure 8. Cook Inlet sockeye salmon smolt releases. "Current" releases are actual releases until 1991 and projected releases starting in 1992.

Figure 9. Projected commercial catches of Cook Inlet sockeye salmon. The solid line is the median or 50% quantile of 100 replicates. The broken lines are the 10% and 90% quantiles of the distributions of catch each year.

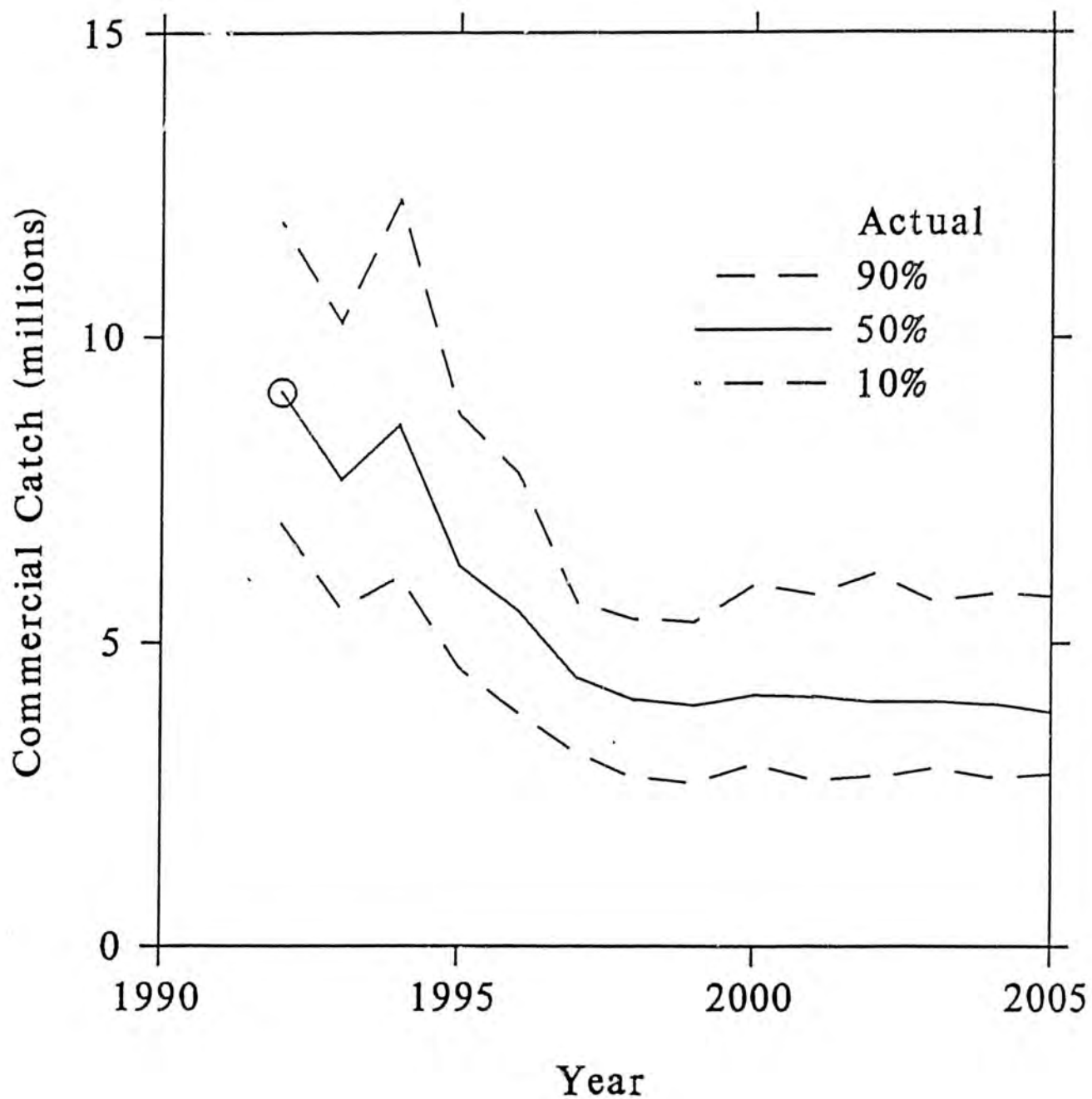


Figure 10. Projected common-property catches of Cook Inlet sockeye salmon for four production scenarios: Current releases, Planned releases, No hatchery releases, and a doubling of the escapement target ("Manage").

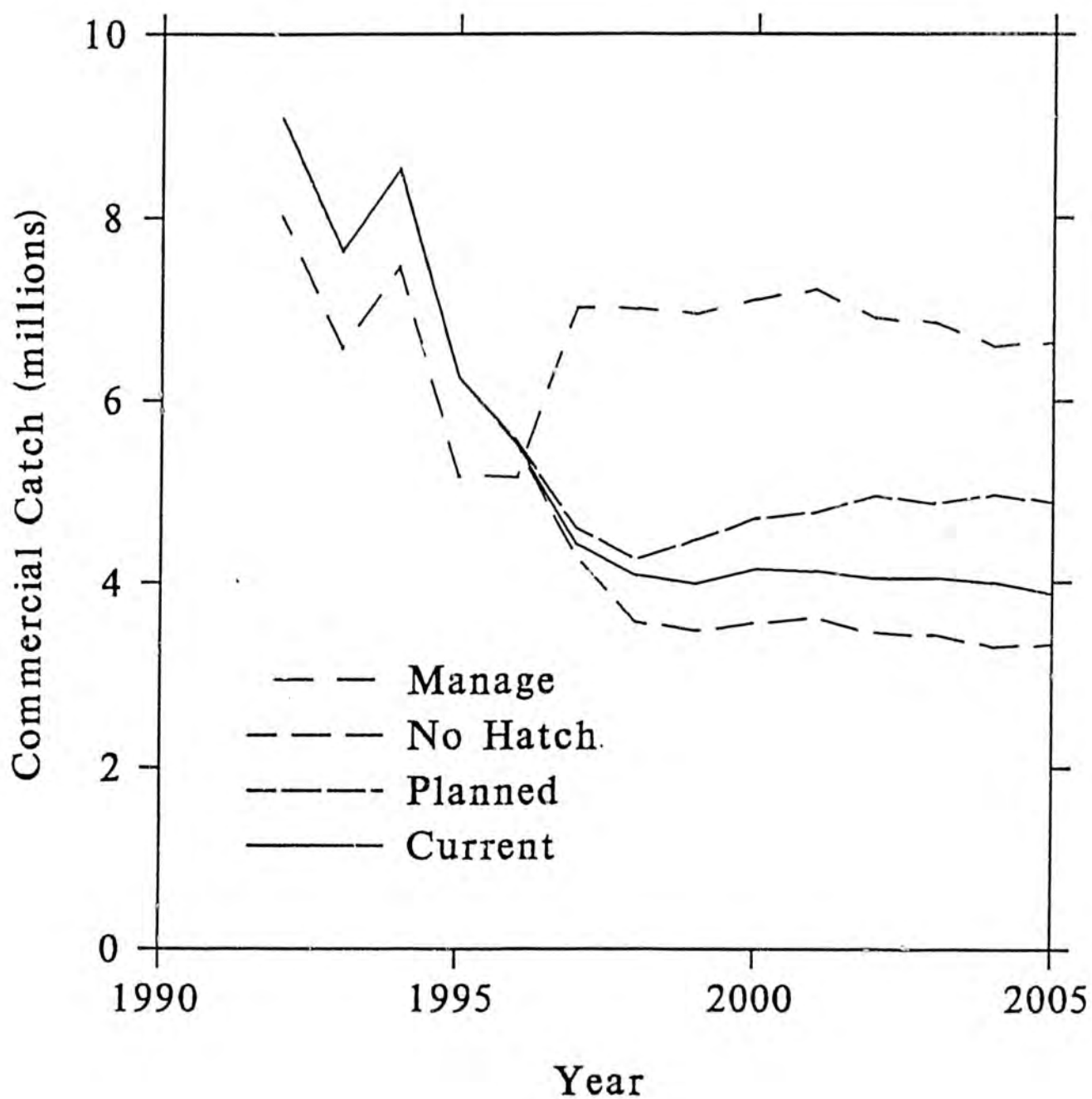
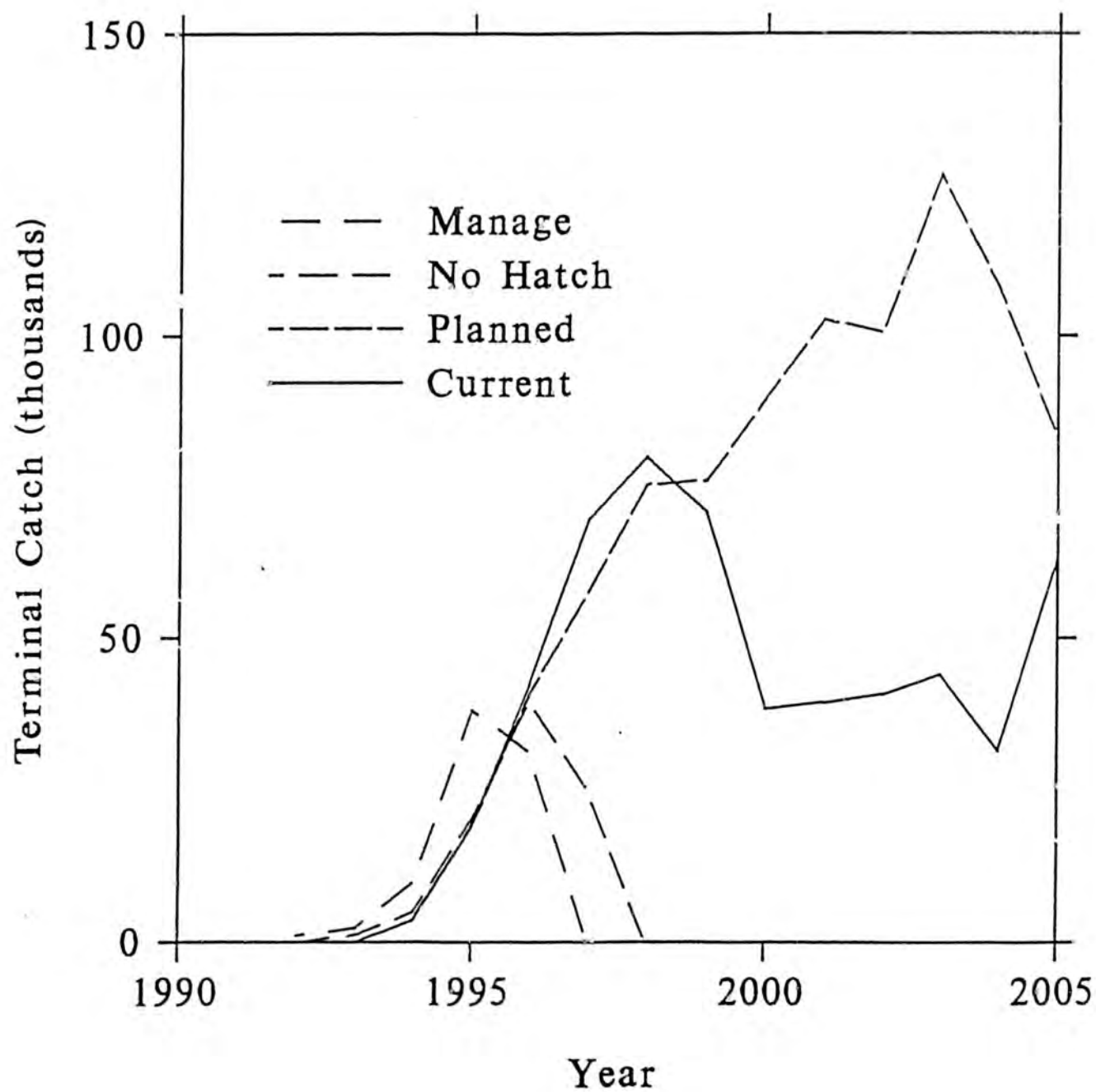


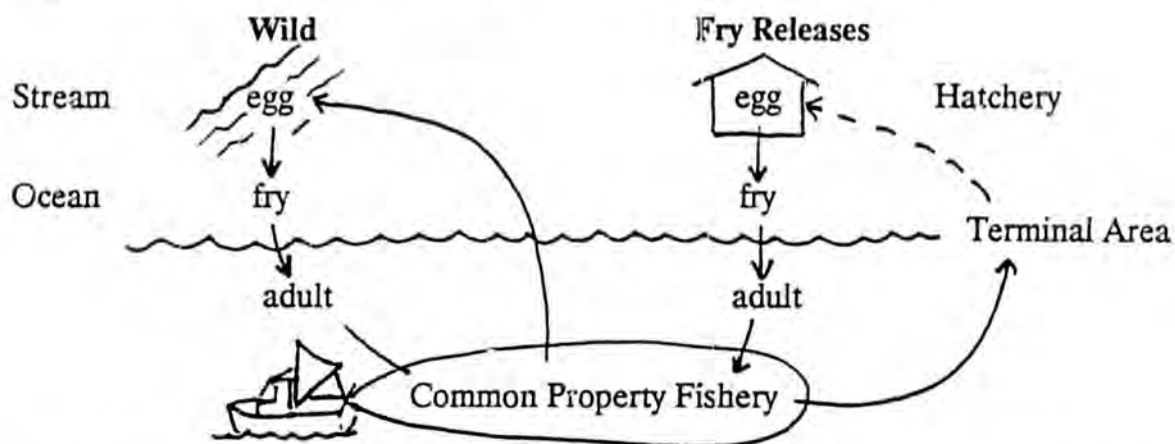
Figure 11. Projected terminal-area catches of Cook Inlet sockeye salmon for four production scenarios: Current releases, Planned releases, No hatchery releases, and a doubling of the escapement target ("Manage").



Prince William Sound Pink Salmon

My pink salmon model is based on a 1991 paper by Eggers et al. entitled, "Trends in abundance of hatchery and wild stocks of pink salmon in Cook Inlet, Prince William Sound, and Kodiak, Alaska." The relationships described in this paper were used to simulate salmon abundance in the future.

Figure 12. Pink salmon life history



For Prince William Sound there exist the perennial problems of trying to optimize the escapement of wild and hatchery fish in the common property fishery. In the model simulations, the harvest rate is conditioned on the strength of the wild stock.

Spawner-Recruit Data

In general, increased escapement has brought greater returns of adult pink salmon with the exception of 1984 (Figure 13). The Ricker curve passes through the center of the data, which fall into two clusters—good years and bad years. The Ricker curve gives fairly conservative predictions of adult returns. The present escapement target is about 1.5 million; the apparent optimum is 5 million.

Hatchery survival rates have averaged 5% (Figure 14). There is not yet evidence of density-dependent survival, but the low return of the 1990 releases is a break from the linear relationship that prevailed up to now.

Deviations in survival rates are correlated between 1) Prince William Sound hatchery and wild pink salmon and 2) Prince William Sound hatchery and Kodiak hatchery survival (Figure 15). The covariance and autocorrelation structure illustrated in Figure 15 was programmed into the model simulations.

Average body weight appears to decrease as a function of the combined run of Kodiak and Prince William Sound pink salmon (Figure 16). However, there is plenty of scatter because the weights were derived from fish ticket data, not measurements of individual fish. This body weight relationship was modeled with a log-log function so that body weight decreases asymptotically with changing run size.

Fry releases were initiated in 1976, and jumped to over 1/2 million in 1988 (Figure 17). Current Prince William Sound fry production capacity is 650 million. Planned capacity is approximately 700 million. It does not appear that releases will reach the 1 billion level.

Prince William Sound Wild Pink Salmon (data labels are brood years)

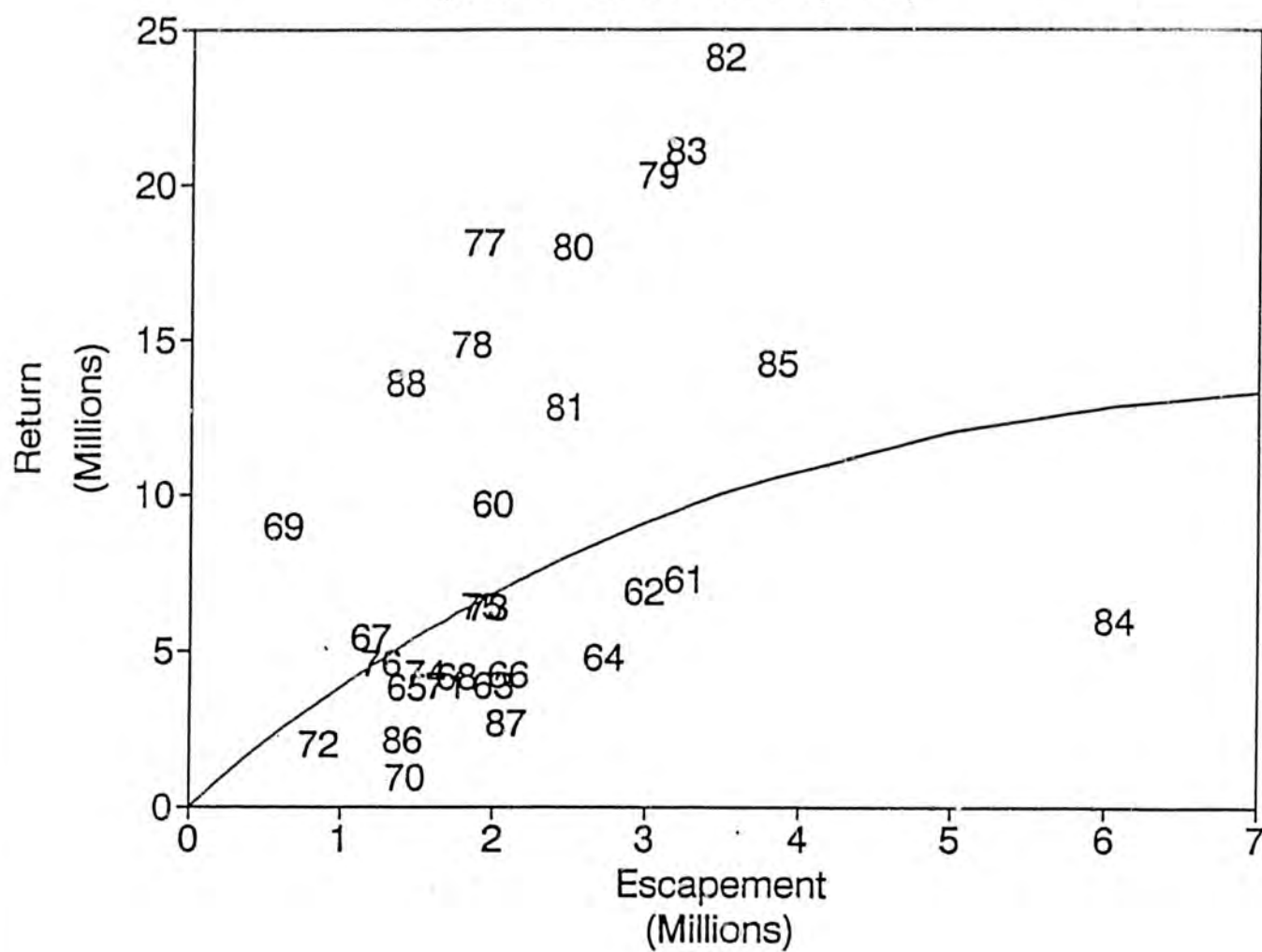


Figure 13. Prince William Sound wild pink salmon spawner-recruit data, and fitted Ricker curve.

PWS Hatchery Pink Salmon (data labels are brood years)

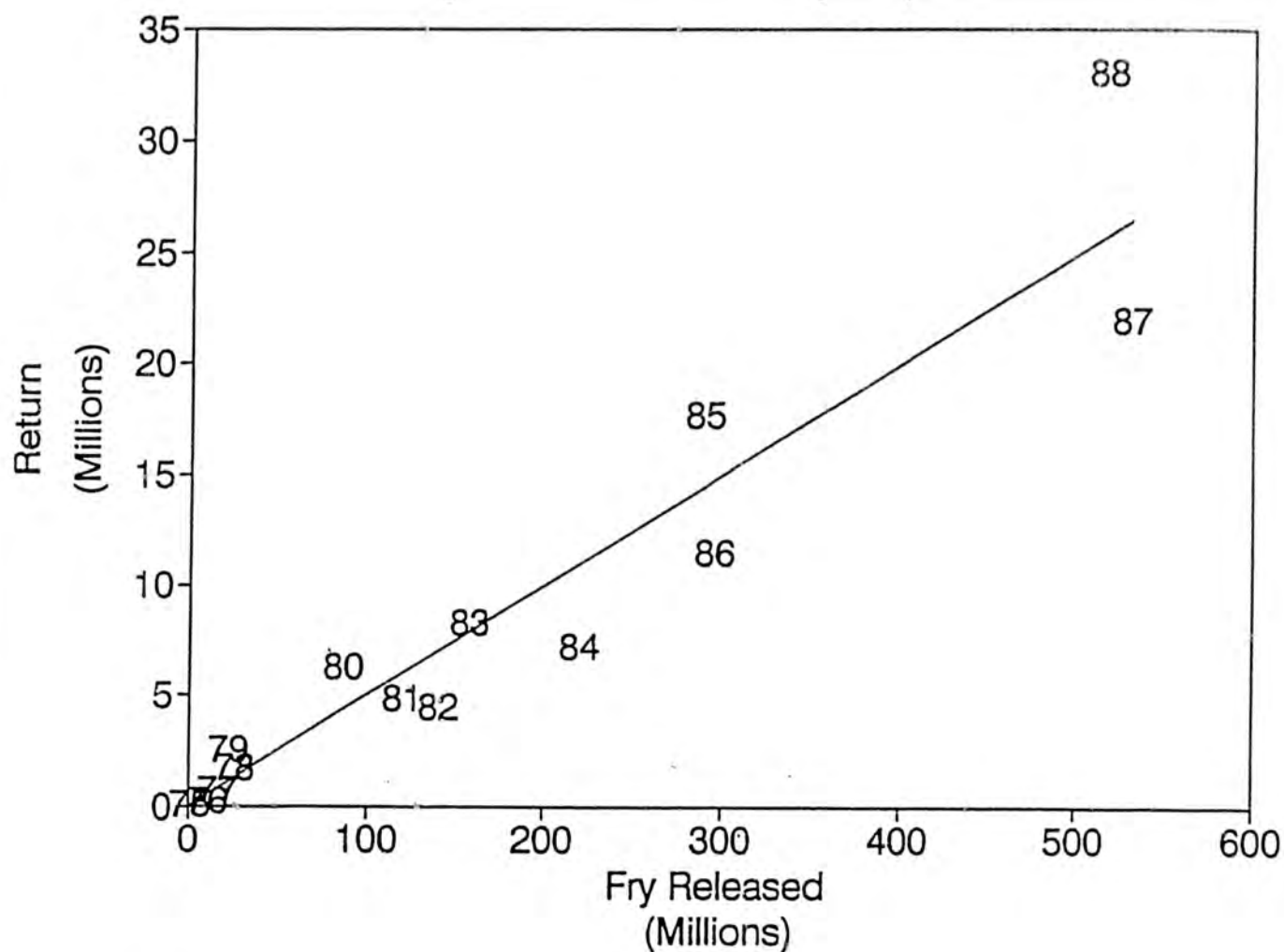


Figure 14. Prince William Sound hatchery pink salmon release-return data, and linear fit.

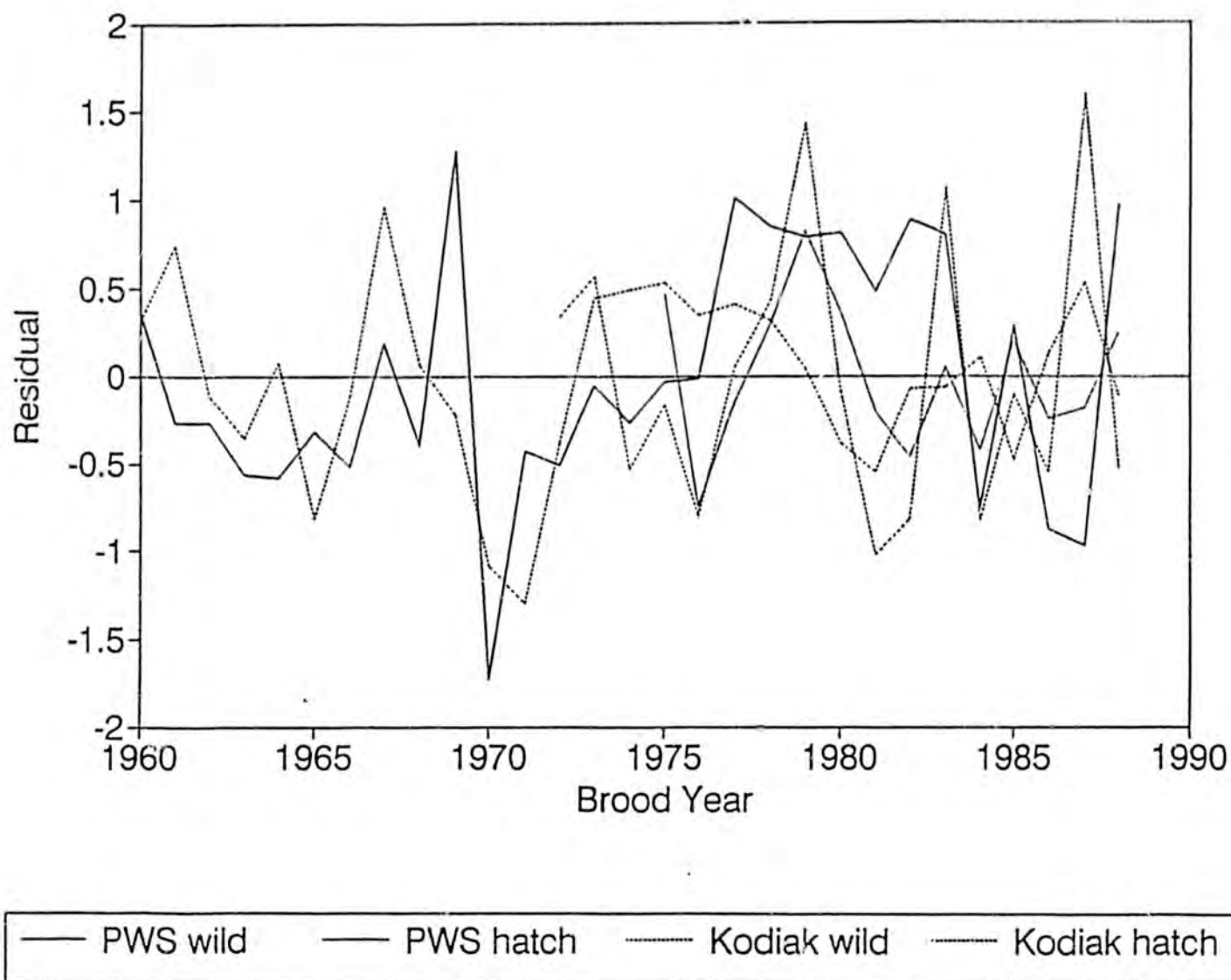


Figure 15. Residual deviations from log survival rates for Kodiak and Prince William Sound pink salmon. The wild salmon residuals are from spawner-recruit data (e.g. Fig. 13); the hatchery data are from release-return data (e.g. Fig. 14)

PWS and Kodiak Pink Salmon

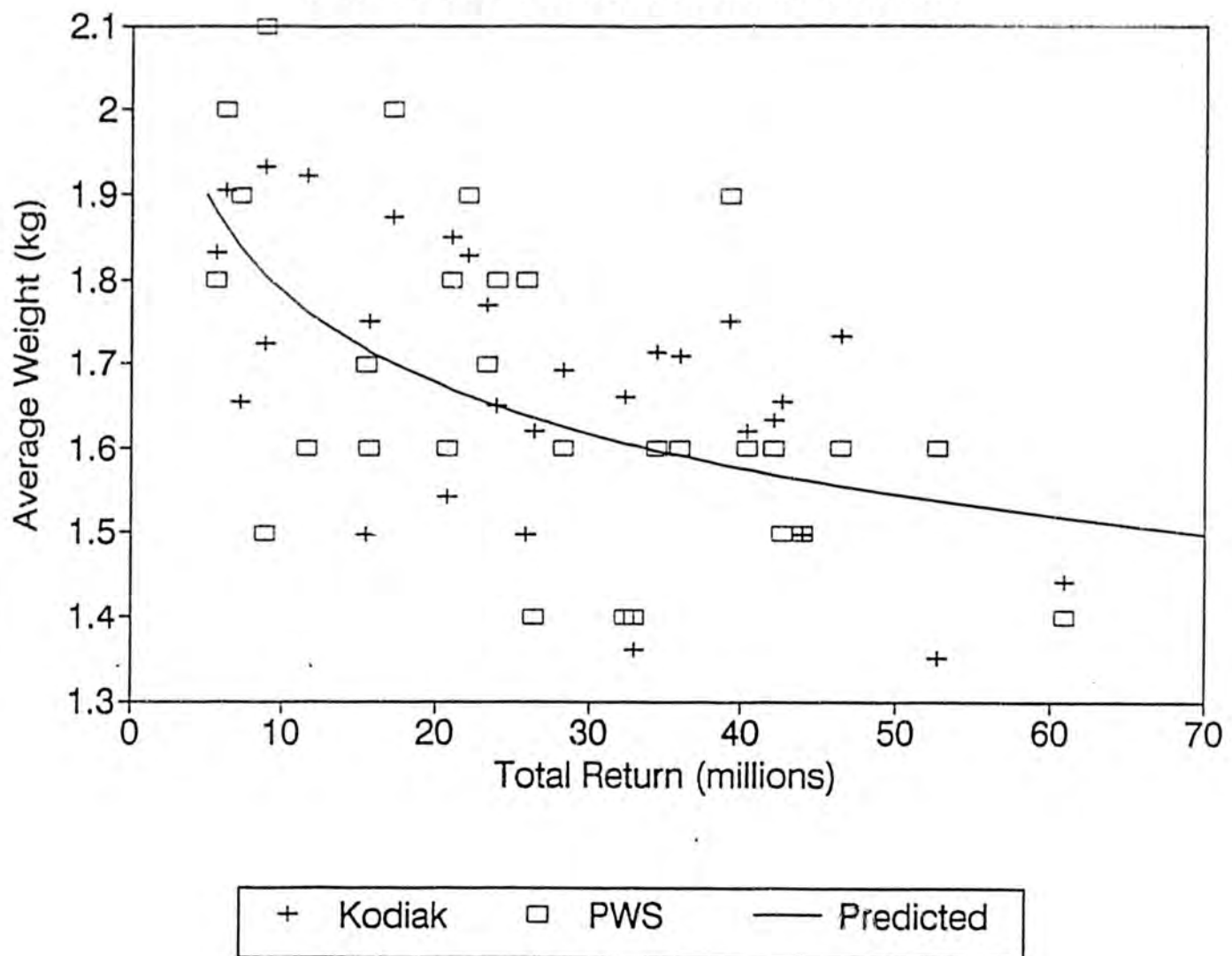


Figure 16. Average weight of Prince William Sound and Kodiak pink salmon, and a fitted log-log relationship.

Prince William Sound Pink Salmon

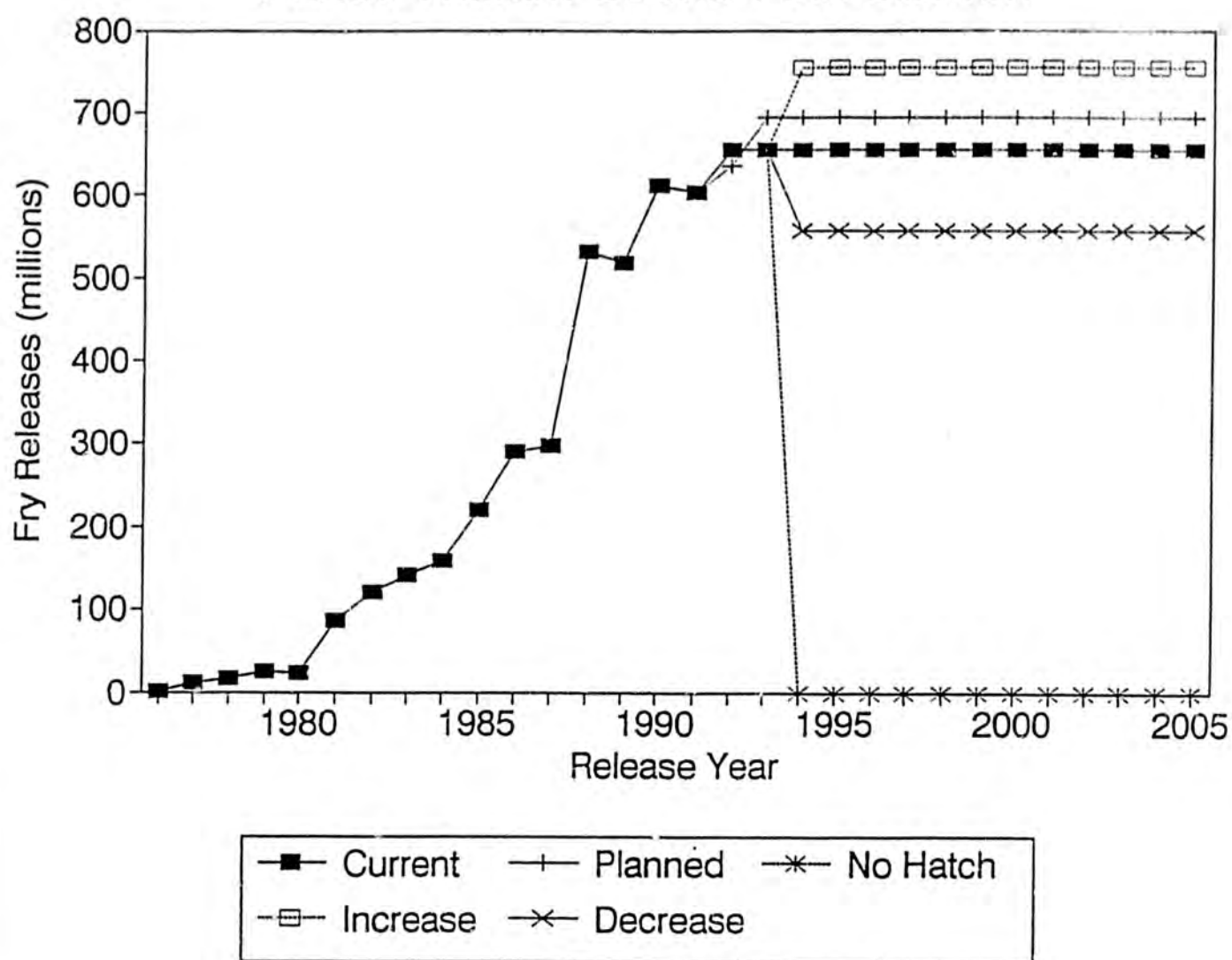


Figure 17. Prince William Sound pink salmon fry releases. "Current" releases are actual releases until 1991 and projected releases starting in 1992.

Results

Total annual adult returns of hatchery and wild salmon are projected at approximately 40 million, which is consistent with the 1990-91 returns (Figure 18). Eighty percent of the model realizations fall between the upper and lower broken lines. Actual 1992 adult returns were only approximately 10 million fish, a value below even the 10% quantile projection. The survival rate experienced by the 1990 year-class appears to be on the very low end of the range of historical survival rates.

Common property catch is highly variable because, if the wild stock return is weak, the fishery is closed, resulting in a lower harvest of hatchery stocks (Figure 19). This pattern is apparent for the Current and Increase cases. In these cases, the extra fish are harvested in the hatchery terminal areas where the enhanced stocks are no longer mixed with wild stocks. In the case of decreased production, median catches are more constant across years. If hatcheries are eliminated the wild stocks produce a median catch of about 4 million annually. If the escapement goal were raised to 5 million (the "Manage" scenario), an annual catch of 7.5 million could be obtained. This is still a small fraction of the harvest level with hatchery production.

Terminal cost recovery harvests are equal in magnitude to common property harvest. As fry releases increase, more of the salmon must be caught in terminal areas to protect wild stocks. The simulated management is only an approximation of actual pink salmon management. In practice it has not been possible to completely curtail the harvest of wild stocks when the runs are less than the escapement target. Some wild pink salmon are harvested even in the designated terminal areas (Hal Gieger, ADF&G, pers. comm.). At this point in time, the wild runs could only be built up to an escapement level of 5 million by leaving some hatchery fish unharvested.

Southeast Alaska Chinook Salmon

The chinook salmon model was the most challenging to construct because of the more complex life history and the trans-boundary nature of the fisheries. Alaska hatchery chinook salmon are caught along with other hatchery and wild chinook stocks mainly from British Columbia, Washington and Oregon. The abundance of these other stocks (referred to here as non-Alaska hatchery chinook) in southeast Alaska waters was projected with an existing coastwide chinook salmon model. Abundance indices for the years 1979-2005 were provided by John Carlile (ADFG, Douglas, AK). For this reason, projections of southeast Alaska chinook catch end in 2005.

Figure 18. Prince William Sound wild and hatchery pink salmon returns. The solid line indicates actual returns until 1991 and projected median returns starting in 1992. The broken lines are the 10% and 90% quantiles of the distributions of 100 replicates.

Prince William Sound Pink Salmon

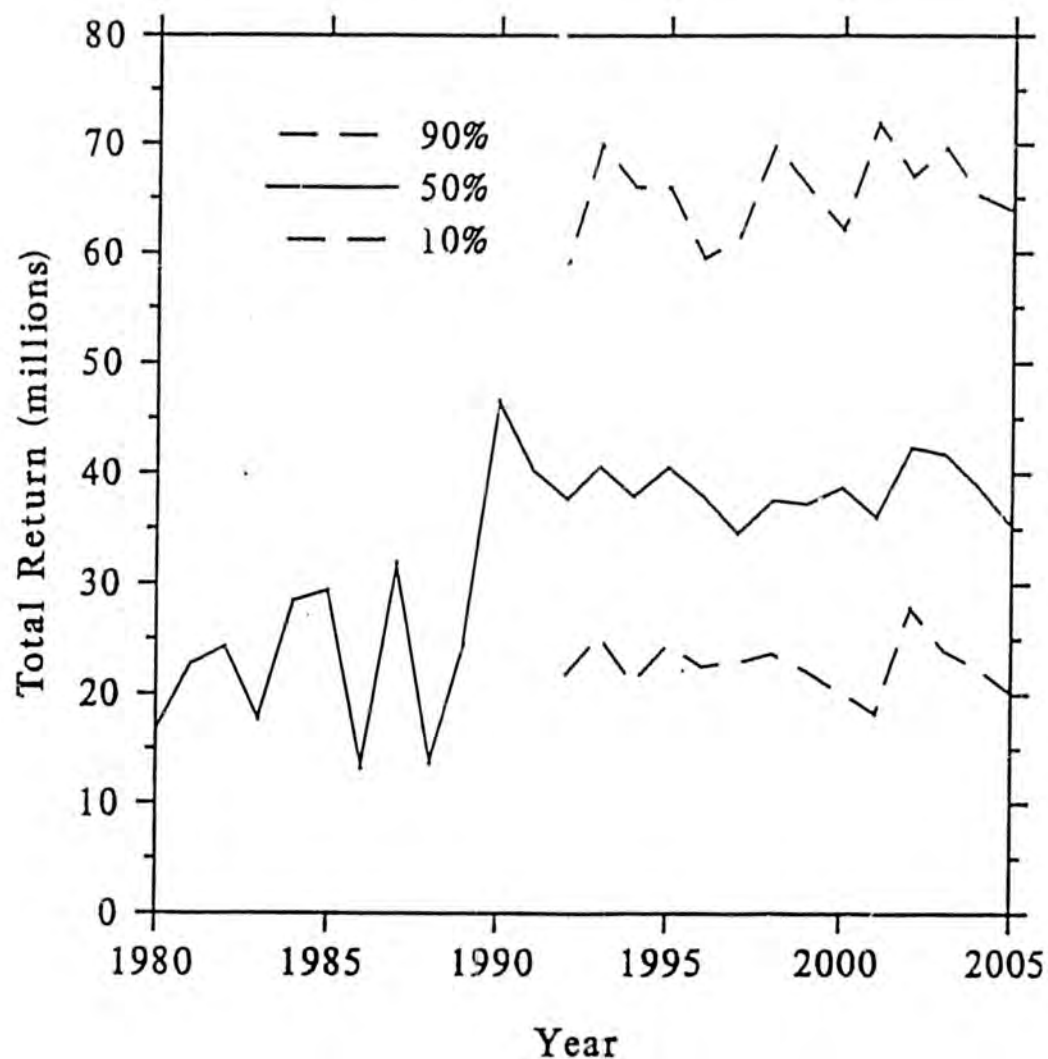


Figure 19. Projected common-property and terminal area catches of Prince William Sound pink salmon for five production scenarios: Current releases, 15% Increase, 15% Decrease, No hatchery releases, and increasing the escapement target to 5 million ("Manage").

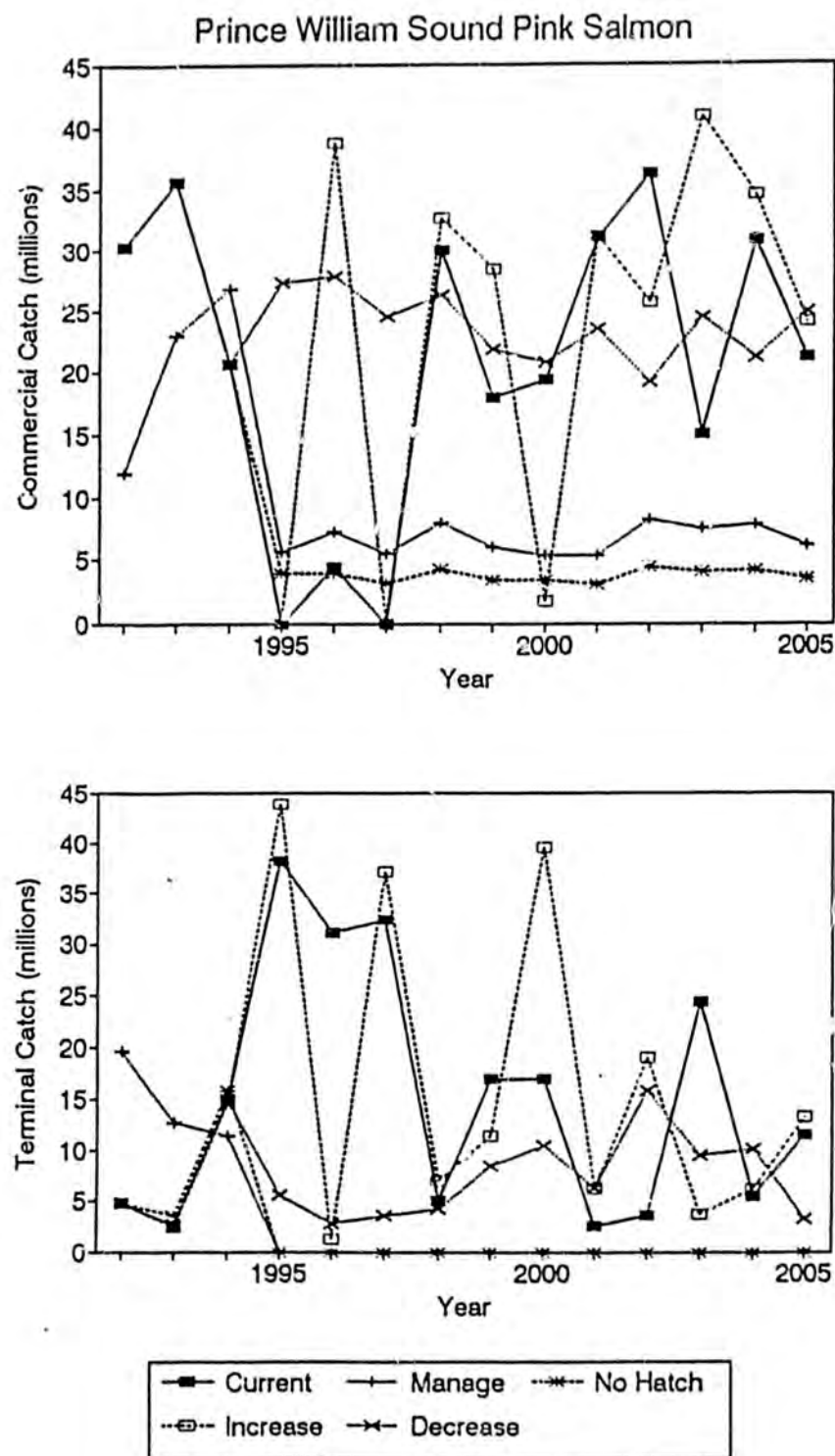
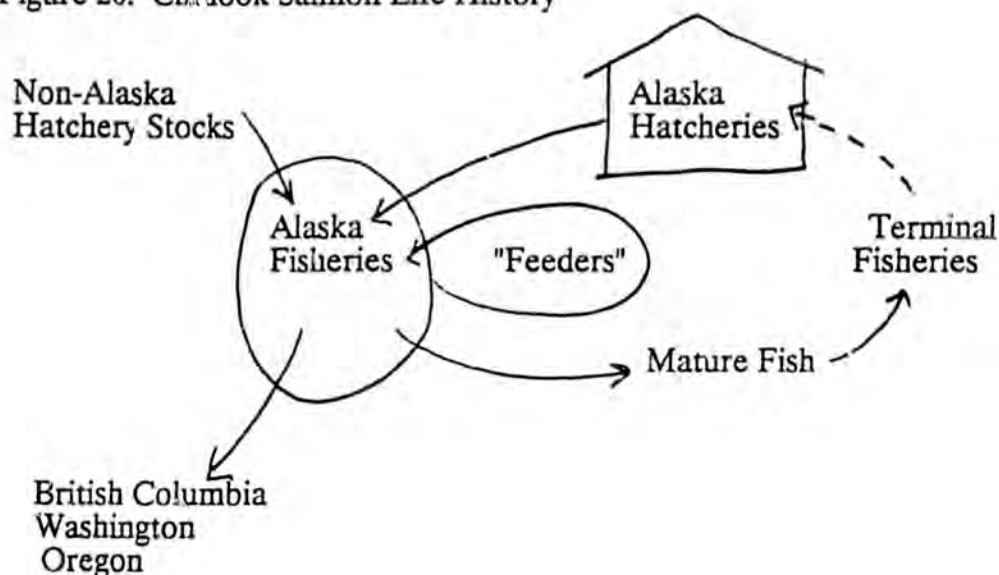


Figure 20. Chinook Salmon Life History



Fisheries Management

The chinook salmon fishery is governed by the US-Canada Pacific Salmon Treaty. Provisions of the treaty include a quota of chinook salmon, to be caught in waters adjacent to southeast Alaska, of 263,000 non-AK hatchery fish. This quota applies to all commercial gear types and user groups. Alaska hatchery fish can be taken in addition to the quota provided that their contribution is estimated in-season from coded-wire tags (CWT). This Alaska hatchery "add on" is calculated as the lower 90% confidence interval of the estimated hatchery contribution. The original plan was to produce 100,000 harvestable chinook salmon adults for the troll fishery (McGee et al. 1991). Under treaty stipulation, even if the hatchery fish are produced, they may not be harvestable if the treaty quota is exceeded.

The treaty quota of 263,000 chinook was allocated by the Alaska Board of Fish in March 1992. On a percentage basis the allocation was 77% troll, 16% sport and 7% net fisheries. Each gear group can supplement its catch of treaty fish according to its hatchery contribution rate. The hatchery contribution rate depends on the production of AK-hatchery chinook (P_H) and the abundance of non-AK hatchery chinook (P_N).

$$\frac{CH_g}{CN_g} = a_g + b_g \frac{P_H}{P_N}$$

$$CN_g = A_g Q$$

$$CH_g = [a_g + b_g \frac{P_H}{P_N}] A_g Q$$

where:

g = gear type

CH = Alaska hatchery catch

CN = Non-Alaska hatchery catch

a, b = parameters

A_g = gear allocation

Q = Treaty Quota

Hatchery contribution rates have increased as hatchery production increased (Figure 21). The sport fishery has the highest hatchery catch ratio, because the effort is in inside waters where the hatchery chinook congregate. The troll fleet has the lowest contribution because much of its effort is in outside waters where there are more non-Alaska hatchery fish and it is more difficult for the fleet to target the hatchery fish. Chinook are caught mainly as bycatch in seine and gillnet fisheries.

Southeast Alaska Chinook Salmon

AK-hatchery-catch/Non-AK-hatchery-catch

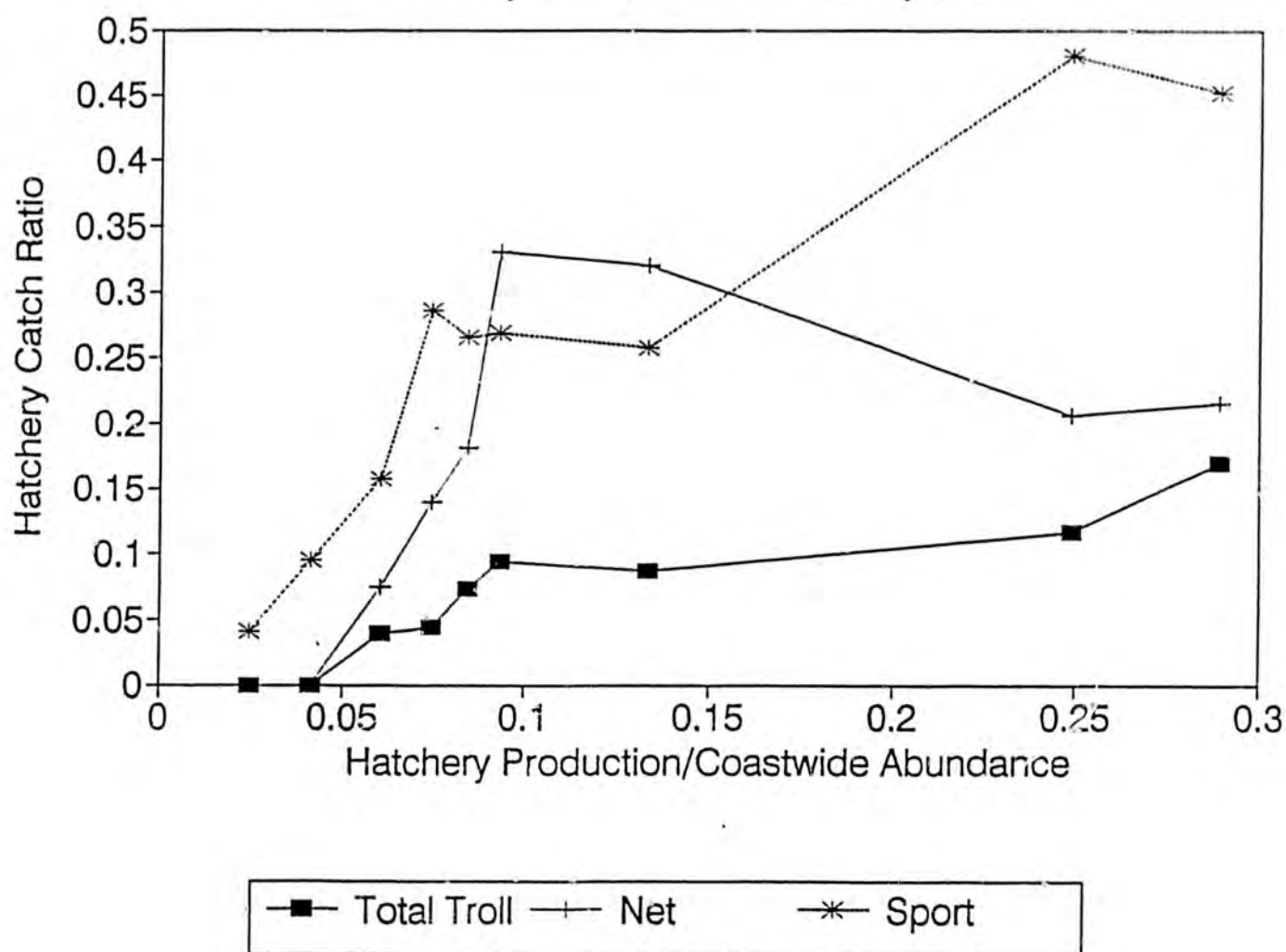


Figure 21. Contribution rates of Alaska hatchery chinook salmon to the Southeast Alaska chinook fishery. The ordinate is the ratio of Alaska hatchery chinook to non-Alaska chinook in the commercial catch.

Linear regressions were fit to the data in Figure 21 to estimate the parameters a and b . Given the coastwise abundance index and hatchery production, hatchery contribution rate can be calculated for each fishery. In using these relationships I am assuming that future fisheries will be conducted in the same fashion as in the past nine years. Hatchery production is estimated from releases and marine survival rates. A mean marine survival rate and variance are required for the stochastic simulation.

Marine Survival of Chinook Salmon was estimated from coded-wire tag data. I compiled data from 128 tag lots from 11 hatcheries and 10 release years to examine factors affecting marine survival rates. General linear models were then fitted with the response variable being log survival. The variables--size at release, hatchery, and release year--are apparently all significant with a total r^2 of 0.78.

The simulation model included only the hatchery and release year effects because the future sizes at release are not known. The survival model is:

$$S_{hy} = M * L_h * T_y * R_{hy}$$

where

h is hatchery

y is year

M is the grand mean survival rate

L is a constant hatchery effect

T is a random, shared, year effect

R is a random effect not shared by hatcheries

The grand mean survival rate was 1.82%. The year effects suggest a temporal pattern (Figure 22). Hatcheries are plotted in rank order according to the estimated hatchery effects (Figure 23). Adding the constant back into the hatchery effects, the mean marine survival rate of each hatchery was calculated with year effects removed (Figure 24).

Chinook Salmon Releases

Smolt releases increase and become constant after 1995 (Figure 25). This production is a doubling from the 1988 levels. Most chinook spend 3 or 4 years at sea, so we are just beginning to see the returns from the large releases. The coastwise index is also increasing, although the rise is exaggerated in Figure 25. This makes it harder to catch the Alaska hatchery fish without overrunning the treaty quota.

Results

For all gear types, total catch is expected to increase as the large releases begin to return (Figure 26). The total 1991 catch was slightly overestimated by the model.

The troll harvest is expected to increase to about 300 thousand fish annually (Figure 27). Without hatchery production, the treaty harvest is approximately 200 thousand. The trollers are estimated to receive about 100 thousand additional chinook by 1996 under current production scenarios. In general, two hatchery chinook are required for the trollers to catch one. The 1991 troll catch was well predicted by the model.

Figure 22. Year effects ($\log[T_y]$) on Chinook smolt survival as estimated with the linearized version of the survival model.

Year Effects on Smolt Survival

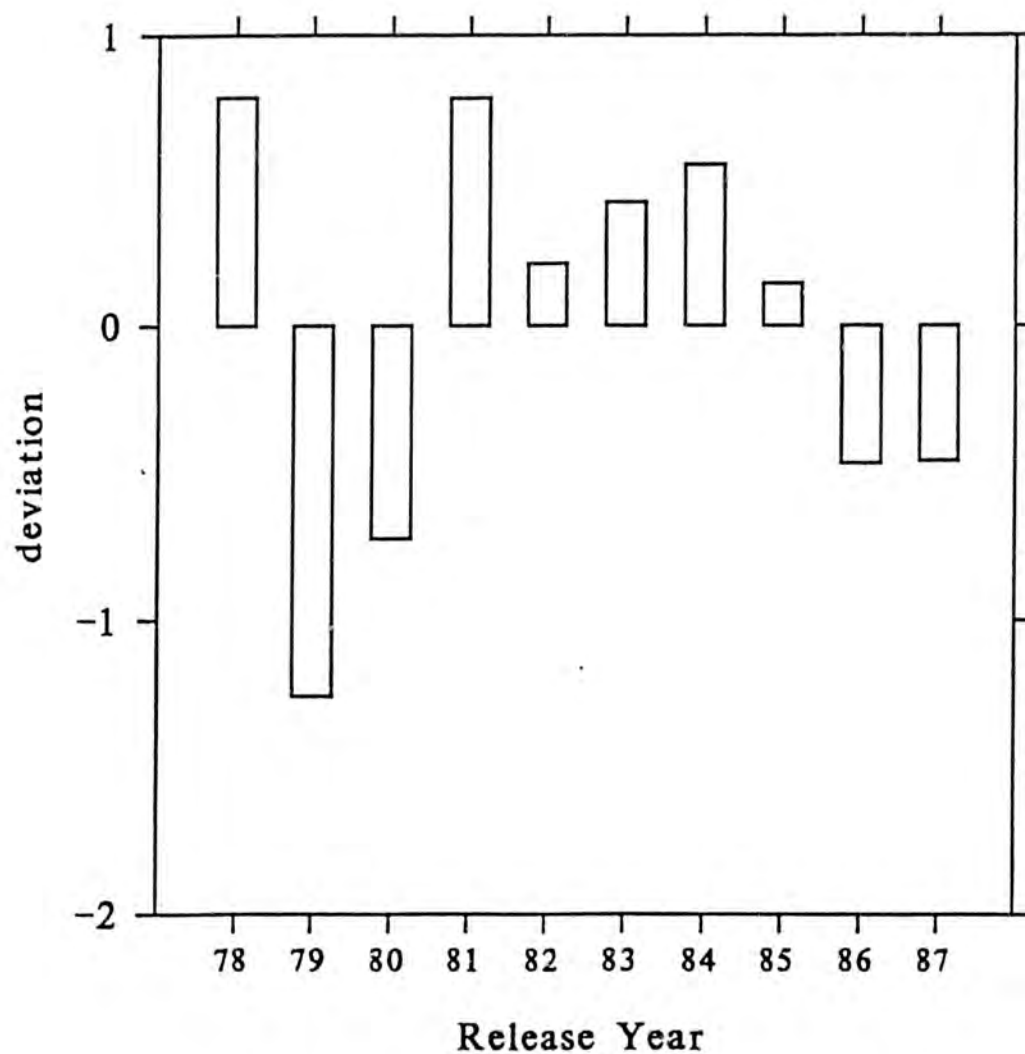


Figure 23. Location effects ($\log[L_h]$) on chinook smolt survival as estimated with the linearized version of the survival model. The hatcheries are Hidden Falls (HF), Sheldon Jackson (SJ), Snettisham (SN), Medvejie (MJ), Deer Mountain (DM), Crystal Lake (CL), Little Port Walter (LP), Neets Bay (NB), Earl West Cove (EW), Carroll Inlet (CI), and Whitman Lake (WL).

Location Effects on Smolt Survival

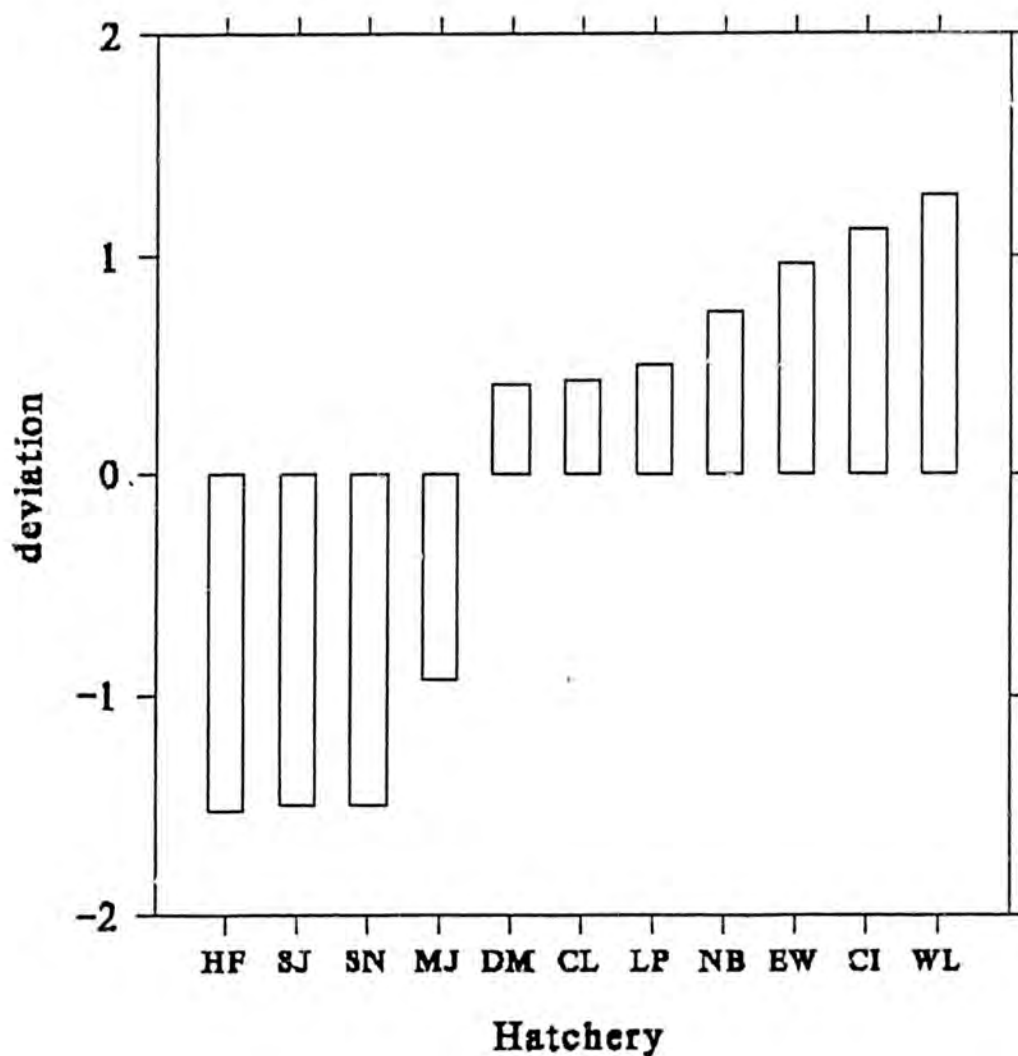
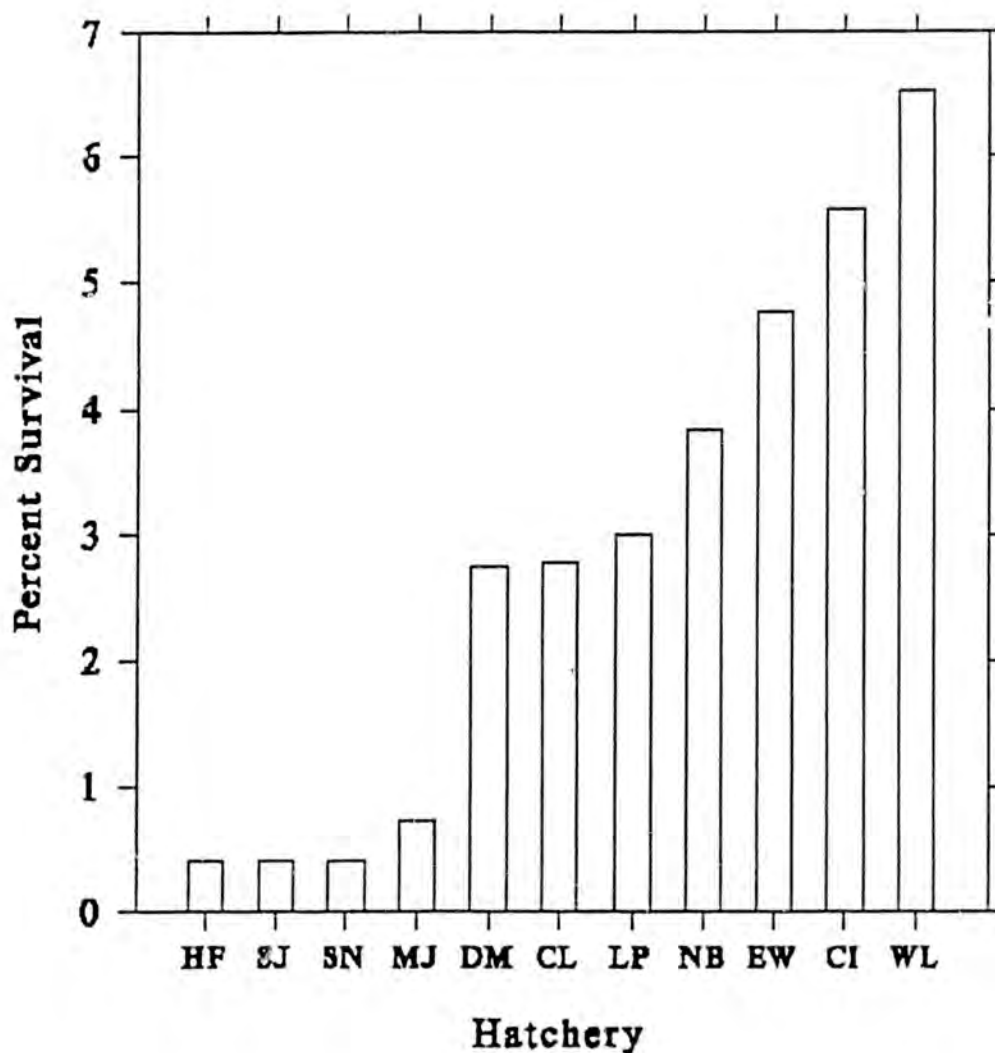


Figure 24. Marine survival rates ($M \cdot L_h$) of chinook smolts as estimated with the linearized version of the survival model. The hatcheries are Hidden Falls (HF), Sheldon Jackson (SJ), Snettisham (SN), Medvejie (MJ), Deer Mountain (DM), Crystal Lake (CL), Little Port Walter (LP), Neets Bay (NB), Earl West Cove (EW), Carroll Inlet (CI), and Whitman Lake (WL).

Smolt Marine Survival



Southeast Alaska Chinook Salmon

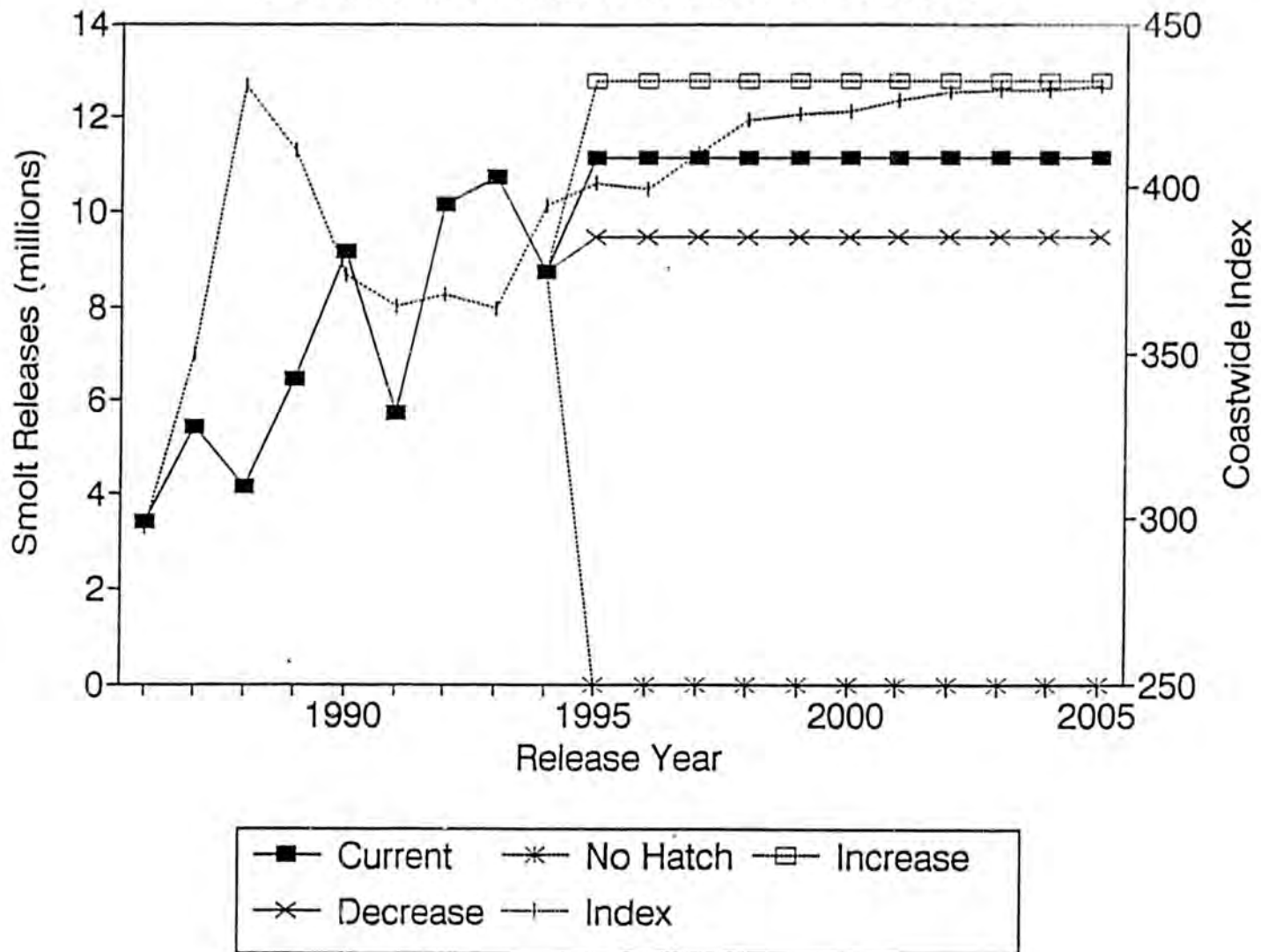


Figure 25. Southeast Alaska chinook salmon smolt releases. "Current" releases are actual releases until 1991 and projected releases starting in 1992. The index of non-Alaska hatchery chinook salmon in the waters of southeast Alaska is plotted for comparison.

Southeast Alaska Chinook Salmon Total Catch of All Gear

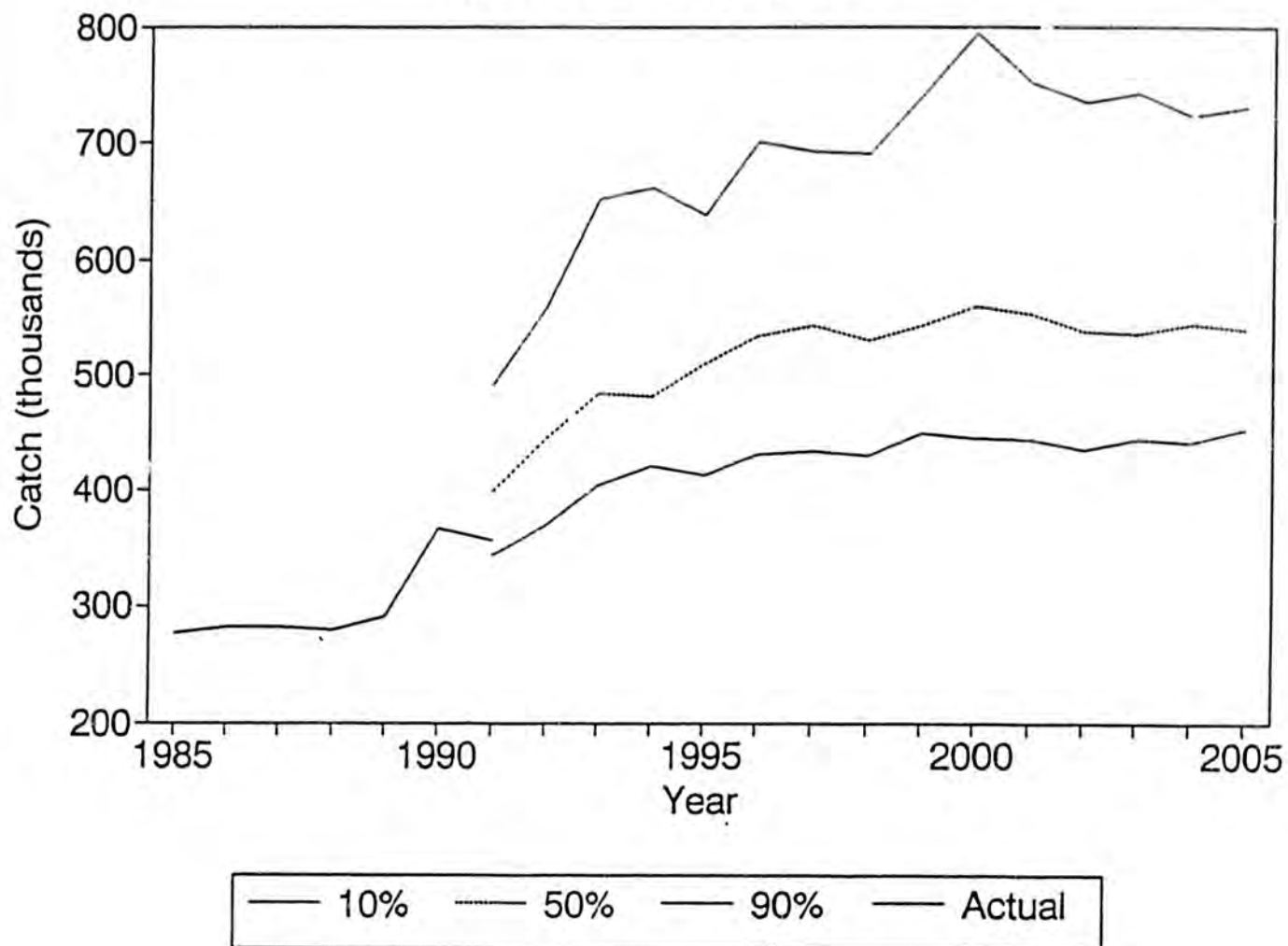


Figure 26. Actual and projected commercial catches of chinook salmon in southeast Alaska. The percentages indicate the distributions of 100 replicate simulations.

Southeast Alaska Chinook Salmon Total Troll

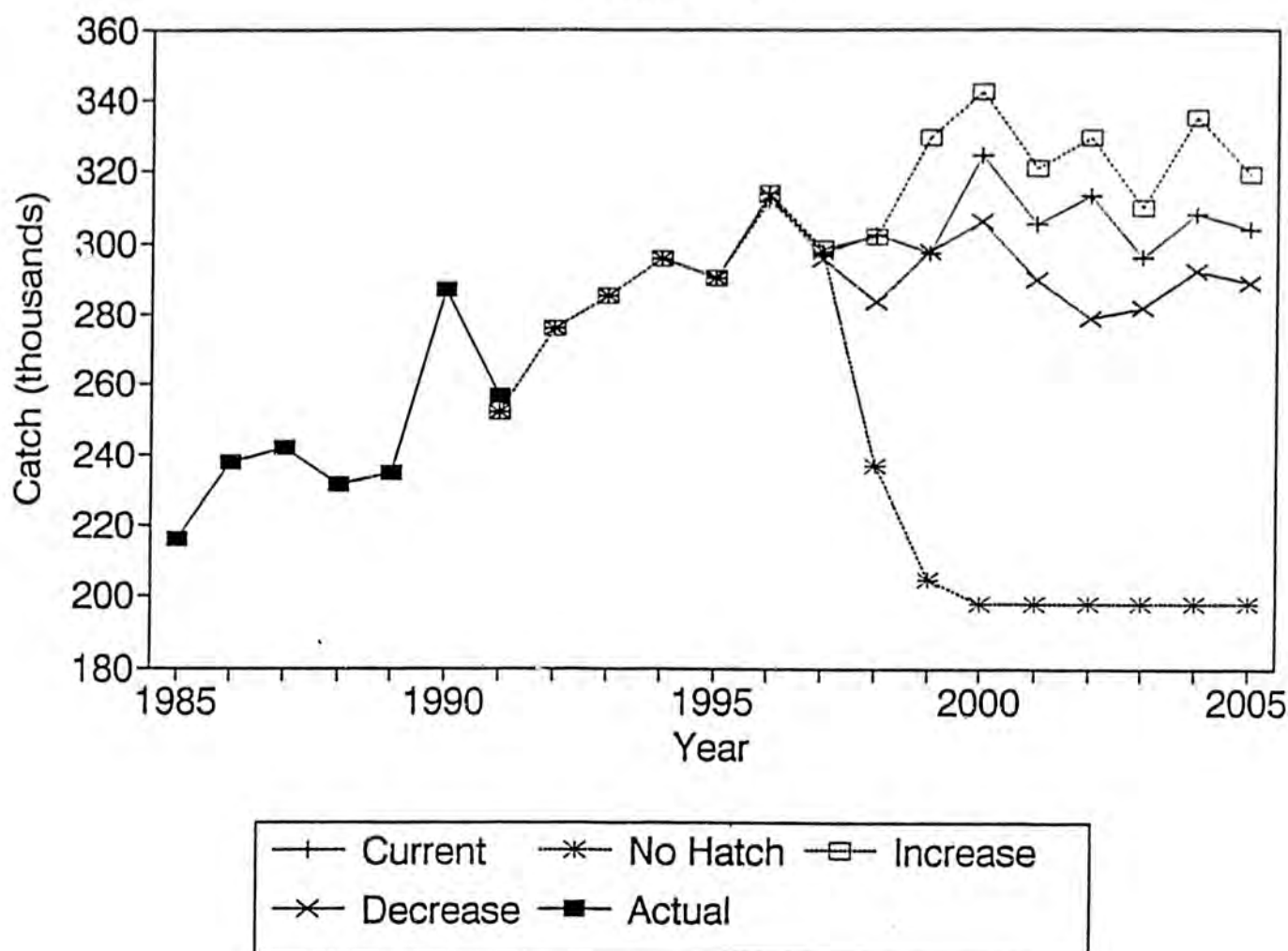


Figure 27. Actual and projected troll catches of chinook salmon in southeast Alaska for four production scenarios: Current releases, No hatchery releases, 15% Increase, and 15% Decrease in smolt releases.

Sport harvests are estimated to increase to 100 thousand by 1995 (Figure 28). Without hatchery production the sport fishing treaty allocation is 40 thousand. The model over-estimated the 1991 sport harvest. Terminal cost-recovery harvest is also estimated to increase to 100 thousand (Figure 29).

Conclusions

Alaska's hatchery program has been very successful in producing salmon. If survival rates continue to be high, we can expect lots more hatchery fish in the future. While lower than hatchery managers' estimates, these simulation results are, if anything, overly optimistic, for the following reasons.

Some oceanographers predict a return to the colder temperatures prevalent in the 1970s. If temperatures decrease, and if salmon production also decreases, realized salmon production may be closer to the lower 10% quantiles than to the median projections. Preliminary estimates of 1993 salmon returns indicate low survival of pink and chinook salmon. However, it should be remembered that my model projects the most likely level of salmon returns, not the exact number each year. Thus, deviations from the median projections are expected.

For most of the species/area combinations, projected catches appear to be realistic extensions of historical catches. The exception is southeast Alaska chinook salmon for which the model appears to over-predict catches. Smolt releases increased rapidly during the last decade and we are just beginning to experience returns from these releases. Thus, it is too early to tell whether such high levels of chinook production are realistic.

The abundance of wild stocks has increased dramatically since inception of Alaska's salmon enhancement program, because of favorable environmental conditions and more intensive management. There are still some wild stocks, such as Prince William Sound pink salmon and southeast Alaska chinook salmon, that could benefit from even more aggressive management to promote rebuilding.

Given a wild-stock preference mandated by the Alaska senate and the US-Canada Pacific Salmon Treaty, increases in hatchery production will increasingly have to be harvested by user groups in terminal areas.

Privatization of hatcheries creates a need for cost-recovery harvests, making fisheries management more costly and contentious.

In some regions, substantial yield increases are attainable by increasing the escapement targets of wild salmon stocks. In Cook Inlet it appears that an increase in sockeye production equal to the production of enhanced sockeye could be obtained by increasing the escapement targets. In Prince William Sound, increased escapement of wild pink salmon is desirable but difficult to achieve. At best, production of wild pink salmon could not equal the high level of hatchery production.

Maximizing yield is not the only important management objective. There is also a need to minimize the variance of yield to develop markets for Alaska salmon. Depending on the economics (see Boyce et al. 1992) lower escapement targets and hatchery releases may be desirable.

Southeast Alaska Chinook Salmon Total Sport Catch

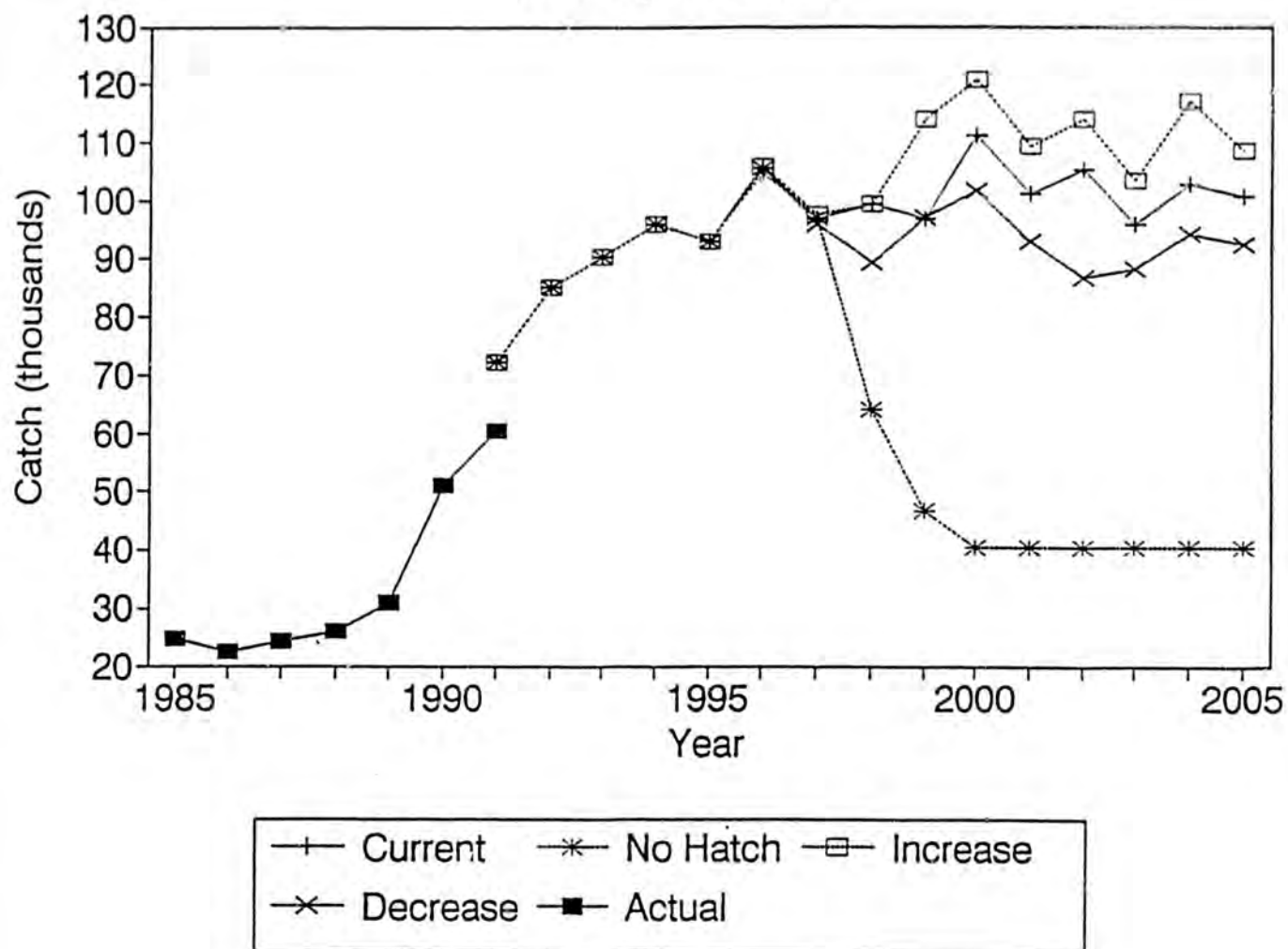


Figure 28. Actual and projected sport catches of chinook salmon in southeast Alaska for four production scenarios: Current releases, No hatchery releases, 15% Increase, and 15% Decrease in smolt releases.

Southeast Alaska Chinook Salmon Total Terminal Catch

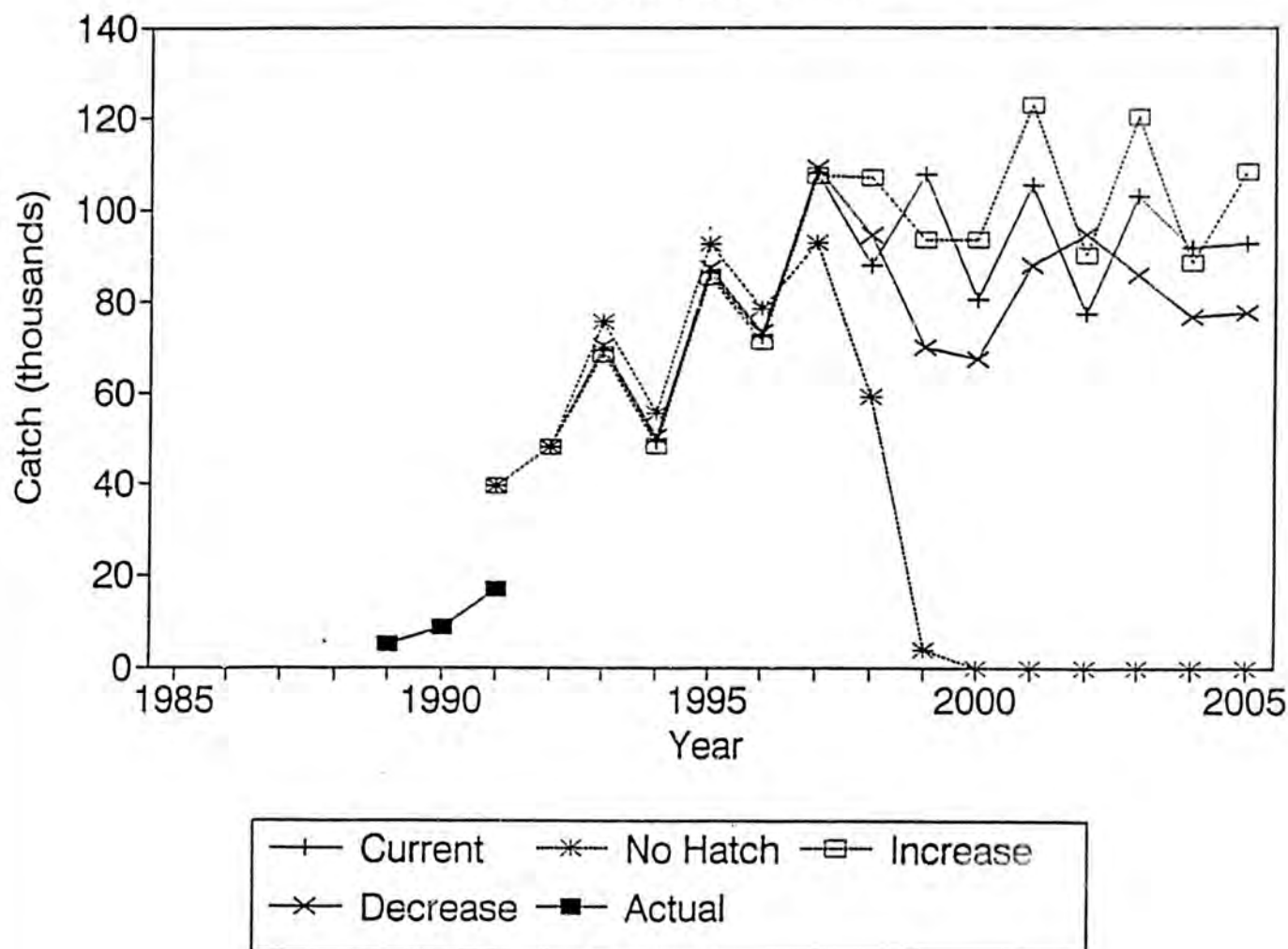


Figure 29. Actual and projected terminal catches of chinook salmon in southeast Alaska for four production scenarios: Current releases, No hatchery releases, 15% Increase, and 15% Decrease in smolt releases.

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