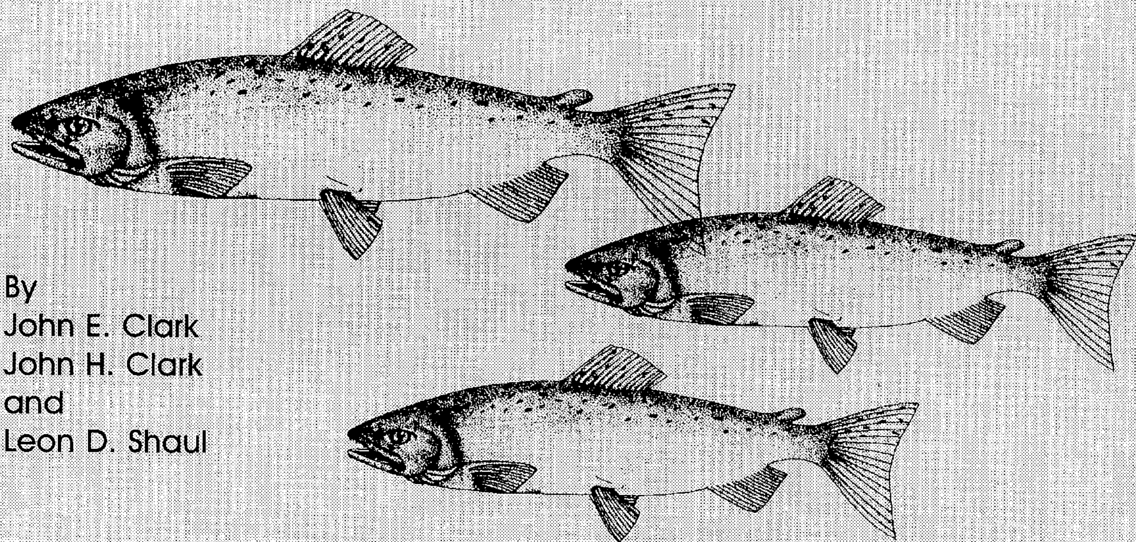
Escapement Goals for Coho Salmon Stocks Returning to Berners River, Auke Creek, Ford Arm Lake, and Hugh Smith Lake in Southeast Alaska



By
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Alaska Department of Fish and Game
Division of Commercial Fisheries Management and Development
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ABSTRACT

The age class composition, spawner abundance, and contributions to fisheries for four coho salmon *Oncorhynchus kisutch* stocks in Southeast Alaska have been monitored fairly continuously since the early 1980's by the Alaska Department of Fish and Game. These data were reviewed and summarized to develop brood tables for nine broods of coho salmon returning to the Berners River in Lynn Canal, ten broods of coho salmon returning to Auke Creek near Juneau, seven broods of coho salmon returning to Ford Arm Lake near Sitka, and eight broods of coho salmon returning to Hugh Smith Lake near Ketchikan. Paired data points consisting of estimated escapements and estimated total returns resulting from these escapements were used to develop spawner-recruit curves for each of the four stocks. Because of significant relationships (range of r^2 from 0.547 to 0.811) between residuals in the estimated spawner-recruit curves and deviations from average marine survivals for the Berners River, Ford Arm Lake, and Hugh Smith Lake stocks of coho salmon, adjusted spawner-recruit curves were developed for all four coho salmon stocks based upon smolt production estimates. These adjusted spawner-recruit curves were used to estimate optimum escapements for each of the four coho salmon stocks that result in maximum sustainable harvests as well as the range of escapements predicted to result in 90% or more of maximum sustainable harvests. Spawner-recruit curves adjusted to both low and high marine survivals were also developed for each of the four coho salmon stocks to better determine the effects assumed marine survivals have on estimates of optimum escapement. Based on these analyses, we recommend the Alaska Department of Fish and Game formally adopt the following escapement goal ranges:

Coho Salmon Stock	Escapement Goal	Escapement Goal Range
Berners River	6,300	4,000 - 9,200
Auke Creek	340	200 - 500
Ford Arm Lake	2,050	1,300 - 2,900
Hugh Smith Lake	770	500 - 1,100

Further, we recommend that this analysis be updated in about four years because many of the recent escapements (1990-1993) of coho salmon to the Berners River, Auke Creek, and Ford Arm Lake are greater than escapements used in this analysis. Returns from these escapements will be complete in four years and can be used to help better define production resulting from escapements larger than the upper range of the escapement goals we recommend herein. Also, variability in the spawner-recruit relationships and the maximum sustainable harvest escapement goals will be reduced with additional completed brood years.

KEY WORDS: coho salmon, *Oncorhynchus kisutch*, Southeast Alaska, brood tables, spawner-recruit, escapement goal, Berners River, Auke Creek, Ford Arm Lake, Hugh Smith Lake

INTRODUCTION

Coho salmon *Oncorhynchus kisutch* are an important component of the Southeast Alaska salmon harvest. Total estimated annual harvests have increased from a 10 year average of about 1.1 million fish during the 1970's, to an average of 2.0 million fish during the 1980's, and to 3.4 million fish from 1990 through 1993. The majority of harvest occurs in the troll fishery (57% of the total harvest since 1990) followed by drift gillnet (14%), purse seine (13%), hatchery cost recovery (6%), set gillnet (6%), sport (3%) and Annette Island Reserve (1%) catches. The annual ex-vessel value of the Southeast Alaska commercial coho salmon harvest has averaged more than $24 million during the 1990-1993 period.

The Southeast Alaska management area (Southeast Region) consists of two distinct parts, the Yakutat Area and the remainder of the Southeast Region from Cape Fairweather to Dixon Entrance. For the purposes of this report, Southeast Alaska will refer to all of the Southeast Region except the Yakutat Area. Spawner-recruit relationships have been generated for seven Yakutat area coho salmon stocks; the East Alsek-Doame, Akwe, Italio, Situk, Lost, Kaliakh, and Tsiu-Tsivat Rivers (Clark and Clark 1994). It was determined that recent escapements have tended to fluctuate around the optimum for four of the systems, to be below optimum for the East Alsek-Doame and Kaliakh river systems, and to be above optimum for the Italio River.

Development of escapement goals for other Southeast Alaska stocks will further understanding of the production potential of this species and provide management with improved guidelines for harvest control. The first step in this process is to evaluate the spawner-recruit relationships for the four index stocks of coho salmon in Southeast Alaska; Berners River, Auke Creek, Ford Arm Lake and Hugh Smith Lake stocks of coho salmon.

Habitat based escapement goals have been developed for coho salmon stocks in the State of Washington (Zillges 1977; Johnson 1986). Zillges presented formulas for computing escapement goals from stream length and width. However, an empirical method was chosen over a habitat based model for this analysis because we perceived the life history and habitat of Southeast Alaska coho salmon stocks to be, in general, more complex compared with Washington stocks. Also, while there was less baseline information on northern stocks of the type needed to develop habitat based escapement goals (e.g. egg to fry survival and rearing density estimates), there was a series of direct estimates of escapement and subsequent production for the four index stocks.

Analysis of the length distributional properties of juvenile coho salmon as conducted by Holtby et al. (1993) may provide an alternative method for evaluating spawner-recruit relationships and the status of some coho salmon stocks in Southeast Alaska. However, the method is still being validated for more southern coho salmon stocks. Before being adopted for stock assessment in northern areas, the technique needs to be evaluated for use where multiple age classes are present in the types of habitat available in Alaskan streams.

Management of coho salmon in Southeast Alaska is complicated by the large number of streams in the area that contain spawning stocks of coho salmon, the highly mixed stock nature of the fisheries, increasing hatchery production, and growing international considerations. Coho salmon spawn in more than 2,000 drainages in Southeast Alaska, including three major transboundary rivers (Alsek, Taku, and Stikine). Alaska hatchery-produced coho salmon are currently being released at more than 25 locations and hatchery coho salmon comprised over 17% of the common property catch in 1993. Coho salmon originating from sites as far south as Oregon have also been found in Southeast Alaska catches. Understanding the distribution and productivity of the assortment of stocks harvested in Southeast Alaska fisheries is necessary to effectively manage this resource.

Coho salmon smolt marking programs began in 1972 (Gray et al. 1978) to study the distribution and harvest of selected coho salmon stocks. Since 1976, 28 drainages have been studied by coded-wire tagging juvenile fish and recovering these tags from adult fish captured in fisheries and on the spawning grounds (Gray et al. 1986; Shaul et al. 1983; 1985; 1986; 1987; 1991). In general, these studies have found that most coho salmon stocks in most years are harvested at a modest rate of about 60%, although rates as high as 90% or as low as 20% have occurred. Further, most of these coho salmon stocks are widely distributed in Southeast Alaska fisheries. Marine survival varied from about 2% to almost 30% for various stocks and return years. Four of these systems (Berners River, Auke Creek, Ford Arm Lake, and Hugh Smith Lake) have been consistently monitored since the early 1980's and provide a time series of data that permits an analysis of the spawner-recruit relationships (Figure 1).

The purpose of this report is to summarize the available catch, escapement, and age composition data for the four coho salmon index stocks; to generate total returns, escapements, and exploitation rates by brood year; to estimate spawner-recruit relationships for these four stocks, accounting for the effect of marine survival; to recommend escapement goal ranges for these four stocks; and, to evaluate harvest strategies over the last decade in light of these escapement goals.

METHODS

Data Collection Methods

There are three stages in estimating the escapement and total return of Southeast Alaska coho salmon indicator stocks. In the first stage, juvenile fish (pre-smolts, or smolts) are captured either using smolt-weir traps (Auke Creek and Hugh Smith Lake) or baited wire-mesh minnow and box traps (Berners River and Ford Arm Lake). Adipose fins are removed and coded wire tags are inserted into the nose cartilage which identifies the origin of these fish (see Koerner (1977) for a complete description of the tagging methods).

The second stage is estimating the commercial and sport fishery catch of returning adult coho salmon from these indicator stocks. Commercial catches are sampled for coded wire tagged salmon by samplers stationed at fish processors and buying stations located throughout Southeast Alaska. Sport fishery catches are sampled by ADF&G personnel located at the major sport fishery boat launching areas and during local salmon fishing derby activities. When a coho salmon with a missing adipose fin is found, the head of the fish is removed and sent to the tag lab for coded-wire tag removal and processing. Methods used to estimate contributions to the various fisheries is detailed in Clark and Bernard (1987; in prep.). Catches of coho salmon from waters of Canada are also sampled by the Canadian Department of Fisheries and Oceans for coded wire tags (Kuhn et al. 1988).

The third stage is estimating the total adult escapement and the number of coded-wire tags in the escapement. Escapements are estimated by total counts, mark-recapture estimates, or extensive foot surveys (Shaul et al. 1991). Weirs are operated at Auke Creek, Ford Arm Lake, and Hugh Smith Lake. These weirs generally provide complete enumeration of escapements and coded wire tags returning to these systems. However, high water during some years at Hugh Smith Lake and at Ford Arm Lake, weirs allowed fish to pass uncounted, and mark-recapture estimates were used to either validate the weir counts or to account for the fish that passed upstream but were uncounted. The Berners River was annually surveyed intensively during the peak of the coho salmon return by the same observer from 1982-1993. Excellent visibility in the system and migratory characteristics of the stock suggest that most of the escapement is counted each year.

Age-length-sex samples are collected from the coho salmon escapements. A total of around 600 fish from each stock is annually sampled and samples are distributed throughout the run. Often 10% to 20% of the scales are unageable, resulting in 500 or more samples being used to estimate age composition of the returning coho salmon. Samples are either taken from a proportion of the daily escapements through the weirs or are obtained by beach seining schools of coho salmon on the spawning grounds (Berners River). More detailed discussion on methods used to collect and age scales are presented in regional stock composition technical publications (i.e. Wood and Van Alen, 1990).

Analytical Methods

Contributions of coho salmon from the four stocks to commercial and sport fisheries were calculated by expanding the estimated number of coded-wire tags in these fisheries by the tagged to total abundance ratio calculated in the escapements. Total catches of the four stocks in the fisheries were estimated by summing the contributions across all fisheries. The age compositions of the escapements were applied to the total escapement and total catch to yield estimates of catch and escapement by age class for each of the four stocks. Brood year returns were estimated by summing the appropriate age-specific catch and escapement estimates (for example, the adult returns corresponding to the 1985 escapement are the three year olds returning in 1988, the four year olds returning in 1989, etc.). The returns in some of the older age classes were projected for recent years. For example, the age 5 return of the Berners River stock in 1994 was forecast by dividing the total return of age 3 coho salmon in 1992 and age 4 coho salmon in 1993 by the average total proportion of the return which is comprised of these ages (0.96), and then multiplying the total estimated return by the average contribution of age five fish (0.04).

Survivals were based on the ratio of the number of coded wire tagged smolts that migrated into the marine environment to the estimated number of coded wire tags that returned in the following year. Projected survivals were the average of the last 5 survivals (i.e survivals from 1988/89 to 1992/93 were used to project the survival of 1993/94 returns).

Paired data sets consisting of the estimated escapements of coho salmon and the total returns produced from these escapements were used to develop spawner-recruit relationships by fitting these paired data sets with the following model:

$$R = S \exp[a(1-S/P_m)] \qquad (1)$$

where: R = estimated total return;
S = spawning escapement;
$\exp$ = base of the natural system of logarithms;
a = intrinsic rate of population increase in the absence of density-dependent limitations; and,
P_m = carrying capacity.

This model, commonly referred to as a Ricker recruitment curve (Ricker 1975), has two parameters, a and P_m, to estimate, given a series of spawner and recruitment observations. We assumed the errors were multiplicative (as is common when variables are counts), resulting in the log-transformed equation:

$$Ln(R/S) = a - a/P_m(S) + error. \qquad (2)$$

Linear regression procedures provided estimates of the intercept (a) and the slope (a/P_m) of the equation. The estimated number of spawners that produce the maximum number of recruits is:

$$S_{max} = P_m/a; \qquad (3)$$

and, the estimated number of spawners that produce the maximum harvestable surplus is estimated by iteratively solving the equation:

$$S_{msy} = (P_m/a \ \{1-\exp[-a(1-S_{msy}/P_m)]\}. \qquad (4)$$

Four spawner-recruitment relationships were developed for each of the four stocks. The first analysis was made using observed or estimated escapements and returns. Adjustments for marine survival were made for the other three spawner-recruit relationships. These adjustments were made by first dividing the estimated return of adults by age in each year by the estimated marine survival for that return. This yields an estimate of the number of smolts (by freshwater age) outmigrating in the previous year and removes the variability caused by changes in marine survival from the analysis. This value was then multiplied by the average marine survival over all years, the average marine survival of the four years with the lowest marine survivals (termed LOW marine survival) and the average marine survival of the four years with the highest marine survivals (termed HIGH marine survival). For example, the estimated survival of smolts emigrating from the Berners River in 1992 and returning in

1993 was 15.0%, and we estimated that 36,017 age 4 adult coho salmon returned in 1993, producing an estimate of 239,559 age 3 smolts that emigrated from the Berners River in 1992. If the marine survival had been average for the 1993 returns (i.e. 14.5%), the return would have been 33,960 age 4 adult coho salmon.

Once spawner-recruit relationships were calculated, a series of statistics were estimated including: (1) carrying capacity, or the point on the modeled spawner-recruit line where it intersects the replacement line; (2) the estimated escapement that produces the maximum recruits, or highest point on the curve; and, (3) the optimum escapement, or the point on the modeled spawner-recruit line where harvestable surplus is at a maximum. The fit of the curve is measured using the R^2 and mean squared error. The spawner-recruit relationships for the four index stocks of coho salmon using the average marine survival models were the models we chose to make recommendations concerning point escapement goal values for the four stocks. The range of escapements predicted to provide 90% or more of the maximum yield was also calculated for each of the four spawner-recruit relationships for each of the four index stocks of coho salmon and this range for the average survival models was used for our recommendations concerning target escapement goal ranges.

Variability and bias associated with the optimal escapement estimates were estimated using a bootstrap technique, similar to that used by McPherson (1990). The Ricker recruitment curve was fitted to the original data used in the analysis and a set of predicted values was calculated for each spawning escapement in the data set. Residuals were calculated as the difference in the natural log of the observed recruits per spawner and the predicted log of recruits per spawner. The residuals of the data set were randomly selected with replacement. Thus each bootstrap iteration contained the original escapements, but different recruits associated with these escapements, depending upon which error was randomly chosen for each paired observation. These computer-generated spawner and recruit data were then used to estimate new values for the parameters a and P_m and the corresponding optimum escapements. This procedure was repeated 4,001 times and the resulting optimum escapements were ordered from the smallest to largest. The 200th and 3,800th of these ordered estimates provided a 90% confidence interval and the 2,001st ordered estimate represented the median optimal escapement.

Marine survivals were assumed to be independent of parental abundance. Under this assumption, removal of the effect of marine survival was expected to improve the spawner-recruit relationship by removing random variability. This assumption is somewhat contrary to the arguments of Peterman (1978 & 1981) who found significant relationships between smolt abundance and marine survival in some populations. We did not have the data series necessary to fully evaluate this hypothesis for the Southeast Alaska coho salmon indicator stocks but adopted the assumption that, because of their relatively small population sizes, density dependence in the marine environment would have at most a minor influence on marine survival.

However, there is also a possibility that smolt survival is affected by parental abundance through influence in the freshwater environment. For example, if a large proportion of offspring from a low parental escapement reached the smolt size threshold at age 1, the marine survival of those smolts might be lower than for larger, older smolts resulting from a larger escapement that reared for additional years before migrating. This assumes that there is a survival advantage for larger smolts. However, Holtby et al. (1990) found no consistent survival advantage for larger smolts from Carnation Creek although larger smolts did survive better in years when marine survival was poor. To the extent that it occurs, an early marine survival advantage for larger smolts would likely be reduced after the first ocean season by a greater tendency of larger male smolts to return to the stream as jacks (Bilton et al. 1982). In order to test the assumption of independence, differences in marine survivals by age class were examined for Hugh Smith Lake smolts by comparing the freshwater age composition of smolts and corresponding adult returns the next year. Mean age of smolts and mean age of adults were calculated and a nonparametric sign test (Conover 1980) was used to test for a significant difference in mean age of smolts and returning adults.

Survival estimates for returns of coho salmon to Auke Creek and Hugh Smith Lake included the period from the time of smolt migration until adults returned the following year to the fisheries and escapements. Survival rates for the Ford Arm Lake stock of coho salmon also included a freshwater component. Pre-smolts were tagged at Ford Arm Lake in mid-summer and remained in the lake until the following spring before migrating to sea. We assumed that the vast majority of density dependent effects on survival occurred in the first year of residence in freshwater. This assumption was based on indications of very high mortality during the first year in residence and relatively stable abundance of age 1 and older pre-smolts. Estimates of pre-smolt survival were made for 1982-1990 returns of coho salmon to the Berners River. In 1989, smolt tagging was begun and pre-smolt tagging was discontinued. However, the same group of fish was tagged as pre-smolts in 1988 and as smolts in 1989. The survival rate for 1989 smolts was divided by the rate for the pre-smolts tagged in the previous summer. This mathematical result was used as an expansion factor that was then multiplied by pre-smolt survivals for 1982-1989 returns to obtain survival estimates for these earlier returns that could be compared and used with direct smolt survival estimates for the 1990-1993 returns.

RESULTS

The Berners River stock of coho salmon is the largest of the 4 stocks studied, with estimated total returns averaging almost 30,000 coho salmon since 1982 and ranging from 14,058 fish in 1987 to 49,198 fish in 1993 (Table 1). The estimated exploitation rates on the Berners River coho salmon stock also averaged the highest of the four stocks at 73%. Survival rates are similar to the other stocks studied, ranging from 6.5% to 24.8% and averaging 14.5%. The dominant age class is four-year-old fish, averaging 63% of the returning adults followed by age 3 fish averaging 33% of the return (Appendix Table 1).

The Auke Creek stock of coho salmon is the smallest of the four stocks studied, with estimated total returns averaging almost 1,200 coho salmon since 1980 and ranging from 756 fish in 1982 to 1,689 fish in 1985 (Table 2). The estimated exploitation rates on the Auke Creek stock of coho salmon averaged the lowest of the four stocks (40%) with Southeast Alaska fisheries taking 20% of the return in 1980 and 22% in 1992. Estimated survival rates averaged the highest of the stocks, ranging from 9.5% to 23.2% and averaging 17.1%. The dominant age class is four-year-old fish, averaging 68% of the returning adults followed by age 3 fish averaging 18% of the return (Appendix Table 2).

The Ford Arm Lake stock of coho salmon is the second largest of the four stocks studied, with estimated total returns averaging 6,200 coho salmon since 1982 and ranging from 3,229 fish in 1987 to 12,673 fish in 1993 (Table 3). The estimated exploitation rates on the Ford Arm Lake stock of coho salmon averaged 57%, ranging from 44% in 1982 to 69% in 1983. Estimated survival rates of pre-smolts ranged from 4.4% in 1987 to 22.0% in 1993 and averaged 10.8%. The dominant age class is four-year-old fish, contributing to an average of 56% of the return. However, age 5 returns make up a substantial portion of the return, averaging 35% of the returning adults (Appendix Table 3).

The Hugh Smith Lake stock of coho salmon is the second smallest of the four stocks studied, with estimated total returns averaging almost 3,700 coho salmon since 1984 and ranging from 1,530 fish in 1988 to 5,731 fish in 1991 (Table 4). The estimated exploitation rates on the Hugh Smith Lake stock of coho salmon averaged 69%, ranging from 52% in 1987 to 81% in 1993. Estimated survival rates ranged from 4.2% in 1988 to 21.0% in 1992 and averaged 12.8% since 1984. The dominant age class is four-year-old fish, contributing to an average of 62% of the return. Age 5 returns make up the next largest percent of the return, averaging 26% of the returning adults (Appendix Table 4).

We estimated escapements and returns for nine brood years from the Berners River stock of coho salmon, 1979 and 1982-1989 (Table 5). Brood year exploitation rates ranged from 65.8% to 86.9% and averaged 73.0%. The escapements and returns from these nine broods have almost a 5-fold range in magnitude. The escapements ranged from 1,752 fish to 9,840 fish and averaged 5,005 fish. The returns from these nine brood years ranged from 9,600 to 58,811 fish and averaged 29,343 fish.

We estimated escapements and returns for ten brood years from the Auke Creek stock of coho salmon, 1980-1989 (Table 6). Brood year exploitation rates ranged from 25.0% to 55.2% and averaged 42.8%. The escapements and returns from these ten broods have only a 2-fold range in magnitude. The escapements ranged from 447 fish to 942 fish and averaged 646 fish. The returns from these ten brood years ranged from 822 to 2,032 fish and averaged 1,311 fish.

We estimated escapements and returns for seven brood years from the Ford Arm Lake stock of coho salmon, 1982-1983 and 1985-1989 (Table 7). Escapements in 1984 were not counted. Brood year exploitation rates ranged from 50.9% to 66.7% and averaged 58.9%. As was found with the Auke Creek escapements, those of Ford Arm Lake have only a 2-fold range in magnitude. However, the returns have about a 4-fold range. The escapements ranged from 1,546 fish to 3,028 fish and averaged 2,196 fish. The returns from these seven brood years ranged from 2,921 to 12,283 fish and averaged 7,105 fish.

We estimated escapements and returns for eight brood years from the Hugh Smith Lake stock of coho salmon, 1982-1989 (Table 8). Brood year exploitation rates ranged from 57.3% to 81.1% and averaged 71.4%. Escapements to Hugh Smith Lake have a 5-fold range in magnitude, while returns have about a 4-fold range. The escapements ranged from 424 fish to 2,144 fish and averaged 1,223 fish. The returns from these eight brood years ranged from 1,411 to 6,781 fish and averaged 3,768 fish.

When returns to Berners River were adjusted for average marine survival, the range in total returns decreased. Total returns ranged from 13,207 fish to 48,570 fish and averaged 29,238 fish when returns were adjusted to average survival (Table 9). When returns were adjusted to low survival, total returns ranged from 8,038 fish to 29,559 fish and averaged 17,794 fish (Table 10); and when returns were adjusted to high survival, total returns ranged from 19,213 fish to 70,659 fish and averaged 42,534 fish (Table 11).

When returns to Auke Creek were adjusted for average marine survival, there was only a small change in the relative range of total returns. Total returns ranged from 825 fish to 2,047 fish and averaged 1,182 fish when returns were adjusted to average survival (Table 12). When returns were adjusted to low survival, total returns ranged from 532 fish to 1,320 fish and averaged 762 fish (Table 13); and when returns were adjusted to high survival, total returns ranged from 1,082 fish to 2,686 fish and averaged 1,550 fish (Table 14).

When returns to Ford Arm Lake were adjusted for average marine survival, there was a very small change in the relative range of total returns. Total returns ranged from 5,198 fish to 7,527 fish and averaged 6,486 fish when returns were adjusted to average survival (Table 15). When returns were adjusted to low survival, total returns ranged from 3,119 fish to 4,516 fish and averaged 3,891 fish (Table 16); and when returns were adjusted to high survival, total returns ranged from 7,579 fish to 10,975 fish and averaged 9,456 fish (Table 17).

When returns to Hugh Smith Lake were adjusted for average marine survival, the range in total returns decreased. Total returns ranged from 2,823 fish to 4,863 fish and averaged 3,571 fish when returns were adjusted to average survival (Table 18). When returns were adjusted to low survival, total returns ranged from 1,644 fish to 2,832 fish and averaged 2,080 fish (Table 19); and when returns were adjusted to high survival, total returns ranged from 4,110 fish to 7,078 fish and averaged 5,198 fish (Table 20).

Results of the spawner-recruit analysis are summarized in Table 21 and are presented graphically in Figures 2 - 17. There was a substantial improvement in the spawner-recruit relationships for the Ford Arm Lake and Hugh Smith Lake stocks of coho salmon when adjustments were made for average marine survival. The R^2 values increased from 0.027 to 0.561 for the Ford Arm Lake stock of coho salmon and from 0.662 to 0.859 for the Hugh Smith Lake stock of coho salmon. There was a small improvement in the spawner-recruit relationship for the Berners River stock of coho salmon, with the R^2 value increasing from 0.531 to 0.588 (the mean square error decreased from 0.293 to 0.106) and a small decline in the spawner-recruit relationship for the Auke Creek stock of coho salmon, with the R^2 value decreasing from 0.081 to 0.079. Because the returns for low and high survival assumptions are essentially scalar multiples of the average survival assumption, R^2 and MSE values for these analyses are the same as those for the average survival assumptions. Estimates for optimum escapement differ with differing survival assumptions, but these differences are relatively small.

Use of smolt production instead of adult production (accounting for marine survival) results in a substantial increase in estimated optimum escapement for the Berners River stock of coho salmon, increasing this estimate from 4,440 to 6,302 fish. Conversely, use of smolt production procedures results in a relatively large decrease in optimum escapement for the Ford Arm Lake stock of coho salmon (from 3,687 to 2,057 fish). There were moderate increases in optimum escapement estimates for the Auke Creek stock of coho salmon (from 316 to 341 fish) and the Hugh Smith Lake stock of coho salmon (from 692 to 768 fish) when smolt production procedures were used instead of adult production procedures. If future average marine survivals are higher than past average survivals, the estimated optimum escapements for all four stocks will increase slightly (as will the total abundance and catch); whereas, a lower than expected survival will tend to somewhat decrease the optimum escapements.

The Berners River and Hugh Smith Lake stocks of coho salmon tended to have the highest and similar Ricker a parameter estimates (or the intrinsic rate of growth), with the estimates for these parameters under average survival assumptions being 2.49 and 2.47, respectively. This translates into an estimated production of 12 adults per spawner under average survival conditions with no density-dependent limitations. The Ford Arm Lake and Auke Creek stocks of coho salmon had corresponding estimates of the Ricker a parameter of 1.82 and 1.93, respectively; equaling an estimated production of 6 and 7 adults per spawner under average survival conditions with no density-dependent limitations.

The results of the bootstrapping analysis are summarized in Table 22. The median optimum escapement estimates were very similar to the regression estimates of optimal escapement for all four coho salmon stocks. Confidence limits improved when production was adjusted by average marine survivals for the Berners River, Ford Arm Lake and Hugh Smith Lake stocks of coho salmon, and varied for the Auke Creek stock of coho salmon. The range in the 90% confidence limits was 96%, 66%, 115%, and 37% of the median for the average marine survival cases for the Berners River, Auke Creek, Ford Arm Lake and Hugh Smith Lake stocks of coho salmon, respectively.

The 90% of maximum yield ranges are entirely dependent on the shape of the curve and do not account for any of the variability in the spawner-recruit data. The bootstrap 90% quantiles of median escapement producing MSY reflect the variability in estimating the spawner-recruit relationship. Thus these bounds about the MSY escapement are two very different quantities, both of which could be considered when determining an escapement goal range. Future analyses should combine these two elements by bootstrapping the range of escapements that result in 90% of MSY instead of the point estimates. However, without this integrated, we recommend using the 90% of MSY range, conditional on this range being comparable with the corresponding bootstrap quantiles. The unadjusted analysis of the 90% of maximum yield ranges are much smaller than the corresponding bootstrap ranges (Table 23). However, the bootstrap estimates and ranges of the adjusted production under average marine survival conditions are comparable to the regression estimates and the 90% of maximum yield ranges. The range in the 90% of maximum yield values was 83%, 88%, 78%, and 78% of the median for the average marine survival cases for the Berners River, Auke Creek, Ford Arm Lake and Hugh Smith Lake stocks of coho salmon, respectively.

Over one-half of the escapements, by brood year and stock, were estimated to be above the optimum ranges while 12% were estimated to be below the optimum ranges and 34% were estimated to be within the optimum ranges (Table 24 and Figure 18). Ford Arm Lake escapements of coho salmon have been within the optimum range the most (escapements from 8 of the last 11 years and 3 of the last 5 years were within the range). Berners River coho salmon escapements were below range 5 of the last 13 years, but are well above the range in the last 4 years. The coho salmon stock of Auke Creek is usually over-escaped, with 12 of the last 14 escapements being greater than the optimum range.

The results of the comparison of the freshwater age composition of the outmigrating smolts and the returning adults from the Hugh Smith Lake stock of coho salmon are presented in Table 26. The average fish spends about three years in freshwater (from egg through the smolt life stages), with the average freshwater residence time ranging from 3.0 to 3.3 years for outmigrating smolts and ranging from 3.0 to 3.5 years for returning adults. The returning adults tended to be slightly older (average difference in freshwater residence time is 0.094 years with a standard deviation of 0.135 years). This difference is significant using a nonparametric sign test ($p = 0.04$). However, the small difference in freshwater age composition (and thus survival) of the smolts and returning adults would likely have no substantial effect on the survival used in the adjusted spawner-recruit analysis.

DISCUSSION

Escapements were estimated that, under average marine survival conditions we have witnessed over the last 10 to 12 years, will produce the maximum sustainable yield (MSY). Ranges in escapement goals were estimated, based on the range of escapements that were predicted to produce 90% or more of the MSY. The escapement goals and escapement goal ranges we recommend are as follows:

Coho Salmon Stock	Escapement Goal	Escapement Goal Range
Berners River	6,300	4,000 - 9,200
Auke Creek	340	200 - 500
Ford Arm Lake	2,050	1,300 - 2,900
Hugh Smith Lake	770	500 - 1,100

If escapement goals are met consistently, the resulting expected exploitation rates in the fisheries under average marine survival conditions would range from 68% for the Ford Arm Lake stock of coho salmon to 81% for the coho salmon stocks of Berners River and Hugh Smith Lake. In an attempt to rebuild many of the natural stocks in Georgia Straight, British Columbia, Canada, coho salmon harvest rates for Canadian fisheries are targeted between 65% and 70%, although recent exploitation rates have been about 10% above these target rates (Kadowaki 1993). Total harvest rates on remaining natural stocks of coho salmon in Washington and Oregon have also been high, resulting in failure to achieve most of the escapement goals. Management of Washington and Oregon coho salmon stocks is difficult due to interception of stocks in British Columbia troll fisheries, excessive hatchery impacts, and allocation limitations (Hayman and More 1993; Jacobs and Nicholas 1993).

Establishing a hatchery indicator stock program would improve estimation of harvest rates on stocks from areas in Southeast Alaska not currently represented by these four indicator stocks. Analysis to estimate harvest rates for various hatchery stocks of coho salmon by Southeast Alaska fisheries is currently underway.

Spawner-recruit analysis for the four long-term indicator stocks of coho salmon in Southeast Alaska would benefit from a larger range of observed escapements. This is particularly true for the Ford Arm Lake and Auke Creek stocks where parental abundance has only varied about two-fold. All of the 1990-1993 escapements of coho salmon to the Berners River were greater than any of the escapements used in this analysis and should better define production from large escapements. The 1992 Auke Creek escapement of coho salmon and the 1992 and 1993 Ford Arm Lake escapements of coho salmon were also greater than escapements used in this analysis and will help confirm the spawner-recruit relationships under very high escapement levels. A revised spawner-recruit analysis conducted four years from now could put these high escapements to use in better defining MSY. However, substantial uncertainty will remain for these stocks regarding production from low escapement levels. Although the predicted optimum escapement to Auke Creek is 340 spawners, the lowest observed escapement was 447 spawners. The lowest observed escapements to Ford Arm Lake of 1,546 and 1,694 spawners produced returns adjusted for average marine survival that were well within the range of other brood years suggesting that the optimum escapement of 2,050 predicted by the Ricker curve may be high. Estimated optimum harvest rates for Auke Creek (70.6%) and Ford Arm Lake (68.1%) under average marine survival conditions are estimated to be lower than for Berners River (81.4%) and Hugh Smith Lake (81.0%) which have been more heavily exploited and have observations at lower escapement levels. Ricker a parameter estimates are also higher at 2.47 to 2.49 for the more heavily exploited stocks compared with 1.82 to 1.93 for the lesser exploited stocks.

Additional low escapement observations would be useful for the Auke Creek and Ford Arm Lake stocks of coho salmon. Such low escapements are unlikely to occur naturally in the short-term because of the stability of the freshwater environment in these lake systems and because nearly all of the harvest of these stocks occurs in highly mixed-stock fisheries with relatively stable exploitation rates. Low escapements could be obtained by following the adaptive management approach suggested by Smith and Walters (1981) whereby the number of spawners allowed past the weirs would be limited.

In this analysis, it was assumed that escapements from individual brood years had an independent effect on subsequent adult production (i.e. that there was no density-dependent interaction among brood years). However, the fact that smolt production of northern coho salmon stocks results from two and in some cases three major contributing brood years, suggests that density dependence could occur across brood years during the period of freshwater residence. For example, competition from an above average population of age 1 pre-smolts might reduce the growth of age 0 fish thereby reducing their survival and subsequent contribution to the smolt migration the following spring. This hypothesis has fundamental implications for fishery management strategy. Therefore, we believe that an investigation of this topic should be undertaken when the data series are more developed.

There is still substantial uncertainty in aging of northern coho salmon. Very preliminary results from a study being conducted on known age coho salmon stocked into Auke Lake suggests that age 1 smolts may be under-represented in age samples from that system before 1993 (Craig Farrington, ADF&G, personal communication). Because of the importance of accurate aging, we believe that this research should be continued to completion and that guidelines should be developed for more accurate and consistent aging of coho salmon. Depending upon the results, it may be advisable to re-age historical scale collections before conducting an updated spawner-recruit analysis of the four long-term indicator coho salmon stocks four years from now so that production results from recent escapements and improved estimates of age composition are both included in the revised spawner-recruit analysis.

The four systems used in this study represent a very limited cross section of the geographic distribution and habitat types of coho salmon producing systems in Southeast Alaska (Table 27). Coho salmon stocks are distributed throughout Southeast Alaska among four basic habitat types: (1) large river systems, primarily in mainland valleys; (2) small to medium streams without lakes; (3) lake systems; and, (4) interior tributaries of certain U.S. - Canada transboundary rivers. The systems included in this study represent only four of the seven major stock groupings in Southeast Alaska and only two of the four habitat types. Three of the four ADF&G long-term indicator coho salmon stocks are lake stocks which are characterized by medium production levels, widely distributed freshwater ages and a stable freshwater environment. The Berners River stock of coho salmon is the only stock being used to represent mainland river systems.

There are currently no on-the-grounds coho salmon stock productivity studies underway in small or medium stream systems in Southeast Alaska. A program to assess the total run in the Taku River (a large U.S. - Canada transboundary system) is currently being developed by Sport Fish Division of ADF&G. Because of small population sizes and the volatile nature of flows in small non-lake systems, development of spawner-recruit relationships from total run reconstruction is dependent upon various assumptions. Based upon preliminary results from southern British Columbia streams (Holtby et al. 1993), analysis of the distributional properties of fork-length of coho salmon fry shows some potential to be a useful and cost-effective method for setting escapement goals for coho salmon in small to medium streams in which most rearing habitat occurs in flowing water.

Limited run reconstruction studies have been conducted in two upper Taku River tributaries, the Nahlin and Tatsamenie rivers (Shaul 1989 and 1992). Survival rates of pre-smolts from four experiments with coho salmon in upper Taku River tributaries were consistently less than one-half of the average obtained for coastal stocks of coho salmon in Southeast Alaska, suggesting that these interior coho salmon stocks may be less productive and unable to sustain high exploitation rates. Information on the status of coho salmon stocks in the upper Skeena River watershed (Kadowaki 1988) suggests that interior coho salmon stocks in the Skeena River may also be less productive than coastal stocks. Although interior coho salmon stocks, in total, are very limited in occurrence and probably support a very limited proportion of the coho salmon harvest in Southeast Alaska, we support continued long-term research on stock productivity in these systems that will lead to better determination of escapement needs for these stocks.

RECOMMENDATIONS

Preserving long-term stock assessment programs should continue to be one of the highest priorities for the Alaska Department of Fish and Game. These programs provide information on the basic biology of the resource which is often poorly understood due to the lack of long-term programs coast-wide. These programs also provide a continuing time series of data used to forecast abundance and understand the causes of abundance fluctuations, allow for comparisons of year-to-year abundance and overall status of the resource, and help improve in-season management. Because of the 2 to 6 year life span of salmon, many years of data are necessary to monitor the spawning abundance and subsequent returns of a few cohorts, and omission of a single year of data can compromise many years of data included in an otherwise valid analysis.

We recommend that in addition to maintaining the current wild indicator stock projects at the Berners River, Auke Creek, Ford Arm Lake, and Hugh Smith Lake, additional wild indicator stocks be identified for long-term stock assessment monitoring. Table 27 provides a survey of the geographic and habitat based groups of coho salmon stocks contributing to the harvests of coho salmon in Southeast Alaska and where the four existing long-term stock assessment projects fit within these groups. Of the 24 groups, only 4 (17%) are currently represented by long-term indicator stock monitoring projects. The most outstanding need is for a stock monitoring program in the Yakutat area. This was also a recommendation made by Clark and Clark (1994). Other notable wild stock monitoring needs are in the central inside and southern outside areas, and in small to medium sized stream habitats. The program begun by Sport Fish Division on the Taku River could be converted into a long-term stock assessment program and it is our recommendation that ADF&G continue this coho salmon work in the Taku River over the long-term.

We recommend that the following escapement goals be formally adopted by the Alaska Department of Fish and Game:

Coho Salmon Stock	Escapement Goal	Escapement Goal Range
Berners River	6,300	4,000 - 9,200
Auke Creek	340	200 - 500
Ford Arm Lake	2,050	1,300 - 2,900
Hugh Smith Lake	770	500 - 1,100

We recommend that these escapement goals be reexamined in four years. The returns from the 1990-1993 escapements, many of which are much greater than escapements used in this analysis, will be complete at that time and will help to better define production resulting from escapements much larger than the upper range of our recommended escapement goals. Variability in the spawner-recruit relationship and MSY escapement goals will also be reduced with additional completed brood years. Further, it is recommended that a more extensive statistical analysis be conducted on the data and a summary analysis be developed for the Southeast Alaska region as a whole. This analysis would consider such factors as measurement error in escapement estimates (Walters and Ludwig 1981; Ludwig and Walters 1981; Fuller 1987), time series effects such as density effects between brood years, differences in survival between different ages; autocorrelation of the residuals (Walters 1985), and, environmental effects.

It is recommended that a hatchery indicator stock program be established. Such a program, if carefully implemented and overseen by ADF&G, would improve estimates of the distributions, harvest rates, survivals, and other attributes of established wild stock monitoring programs, provide data for stocks not currently represented by these indicator stocks, increase the accuracy of in-season stock assessment programs, and help extend the historic database.

LITERATURE CITED

Bilton, H. T., D. F. Alderdice, and J. T. Schnute. 1982. Influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity. Canadian Journal of Fisheries and Aquatic Sciences 39: 426-447.

Clark, J. E. and D. R. Bernard. 1987. A compound multivariate binomial-hypergeometric distribution describing coded microwire tag recovery from commercial salmon catches in Southeastern Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Information Leaflet No. 261. Juneau, Alaska.

Clark, J. H. and J. E. Clark. 1994. Escapement goals for Yakutat Area coho salmon stocks. Regional Information Report No. 1J94-14. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska.

Conover, W. J. 1980. Practical nonparametric statistics 2nd Ed. John Wiley & Sons, New York. 493 pp.

Gray, P. L., K. R. Florey, J. F. Koerner, and R. A. Marriott. 1978. Coho salmon (*Oncorhynchus kisutch*) fluorescent pigment mark-recovery program for the Taku, Berners, and Chilkat Rivers in Southeastern Alaska (1972-1984). Alaska Department of Fish and Game, Division of Commercial Fisheries, Information Leaflet No. 176. Juneau, Alaska.

Gray, P. L., J. F. Koerner, and R. A. Marriott. 1986. Rearing coho salmon (*Oncorhynchus kisutch*) of 16 Southeastern Alaska watersheds. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report No. 173. Juneau, Alaska.

Hayman, R. and R. Moore. 1993. Management strategies for coho originating in Washington. Abstract In Proceedings of the 1992 coho workshop, Nanaimo, British Columbia, May 26-28, 1992. Canada Department of Fisheries and Oceans, Nanaimo, British Columbia.

Holtby, L. B., B. C. Andersen, and R. K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 47: 2,181-2,194.

Holtby, L. B., T. Hammond, R. Kadowaki, K. Simpson, and B. Finnegan. 1993. Using distributional properties of juvenile fork length to assess stock status of Georgia Strait coho and the productive potential of streams. Abstract In Proceedings of the 1992 coho workshop, Nanaimo, British Columbia, May 26-28, 1992. Canada Department of Fisheries and Oceans, Nanaimo, British Columbia.

Jacobs, S. E. and J. W. Nicholas. 1993. Contemporary management of Oregon's coho salmon stocks. Abstract In Proceedings of the 1992 coho workshop, Nanaimo, British Columbia, May 26-28, 1992. Canada Department of Fisheries and Oceans, Nanaimo, British Columbia.

Johnson, R. 1986. Assessment of the Skagit River system's coho rearing potential. Washington Department of Fisheries, Technical Report 95, Olympia, Washington.

Kadowaki, R. K. 1988. Stock assessment of early run Skeena River coho salmon and recommendations for management. Canadian Technical Report in Fisheries and Aquatic Sciences Number 1638, Nanaimo, British Columbia.

Kadowaki, R. 1993. Coho management in British Columbia. Abstract In Proceedings of the 1992 coho workshop, Nanaimo, British Columbia, May 26-28, 1992. Canada Department of Fisheries and Oceans, Nanaimo, British Columbia.

Koerner, J. F. 1977. The use of the coded wire tag injector under remote field conditions. Alaska Department of Fish and Game, Division of Commercial Fisheries Informational Leaflet No. 172. Juneau, Alaska.

Kuhn, B. R., L. Lapi, and J. M. Hamer. 1988. An introduction to the Canadian database on marked Pacific salmonids. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1,649.

Ludwig, D. and C. J. Walters. 1981. Measurement errors and uncertainty in parameter estimates for stock and recruitment. Canadian Journal of Fisheries and Aquatic Sciences 38:711-720.

McPherson, S. A. 1990. An In-Season Management System for Sockeye Salmon Returns to Lynn Canal, Southeast Alaska. MS Thesis, University of Alaska, Fairbanks. 158 pp.

Peterman, R. M. 1978. Testing for density-dependent marine survival in pacific salmonids. Journal of the Fisheries Research Board of Canada 35: 1,434-1,450.

Peterman, R. M. 1981. Form of random variation in salmon smolt-to-adult relations and its influence on production estimates. Canadian Journal of Fisheries and Aquatic Sciences 38: 1,113-1,119.

Ricker, W. E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin of the Fisheries Research Board of Canada No. 191. 382 pp.

Schmidt, A. E. 1985. Status of selected coho salmon stocks in Southeast Alaska. Alaska Department of Fish and Game, Sport Fish Division. Annual Report for 1984 - 1985. Project G-11-D, Volume No. 26. Douglas, Alaska.

Schmidt, A. E. 1986. Status of selected coho salmon stocks in Southeast Alaska. Alaska Department of Fish and Game, Sport Fish Division. Annual Report 1985-1986. Project F-10-1, Volume No. 27. Douglas, Alaska.

Schmidt, A. E. 1987. Coho salmon studies in Southeast Alaska. Alaska Department of Fish and Game, Sport Fish Division. Fishery Data Series No. 18. Juneau, Alaska.

Shaul, L. D., P. L. Gray, and J. F. Koerner. 1983. Coded wire tagging of wild coho (*Oncorhynchus kisutch*) stocks in Southeastern Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries. Technical Report for 1981-1982. Project AFC-67-1. Juneau, Alaska.

Shaul, L. D., P. L. Gray, and J. F. Koerner. 1985. Coded wire tagging of wild coho (*Oncorhynchus kisutch*) stocks in Southeastern Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries. Technical Data Report No. 140. Juneau, Alaska.

Shaul, L. D., P. L. Gray, and J. F. Koerner. 1986. Coded wire tagging of wild coho (*Oncorhynchus kisutch*) stocks in Southeastern Alaska 1983 - 1984. Alaska Department of Fish and Game, Division of Commercial Fisheries. Technical Data Report No. 192. Juneau, Alaska.

Shaul, L. D., P. L. Gray, and J. F. Koerner. 1987. Coded wire tagging of wild coho (*Oncorhynchus kisutch*) stocks in Southeastern Alaska 1984 - 1985. Alaska Department of Fish and Game, Division of Commercial Fisheries. Technical Data Report No. 218. Juneau, Alaska.

Shaul, L. D. 1989. Taku River coho salmon investigations, 1988. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 1J89-33, Douglas, Alaska.

Shaul, L. D., P. L. Gray, and J. F. Koerner. 1991. Coded wire tag estimates of abundance, harvest, and survival rates of selected coho salmon stocks in Southeast Alaska 1981 - 1986. Alaska Department of Fish and Game, Division of Commercial Fisheries. Fishery Research Bulletin No. 91-05. Juneau, Alaska.

Shaul, L. D. 1992. Taku River coho salmon investigations, 1990. Manuscript Report. Alaska Department of Fish and Game, Commercial Fisheries Division, Douglas, Alaska.

Smith, A. D. M. and C. J. Walters. 1981. Adoptive management of stock-recruitment systems. Canadian Journal of Fisheries and Aquatic Sciences 38: 690-703.

Walters, C. J. and D. Ludwig, 1981. Effects of measurement errors on the assessment of stock-recruitment relationships. Canadian Journal of Fisheries and Aquatic Sciences 38: 704-710.

Walters, C. J. 1985. Bias in the estimation of functional relationships from time series data. Canadian Journal of Fisheries and Aquatic Sciences 42: 1033-1037.

Wood, D. S. and B. W. Van Alen. 1990. Abundance, age, sex, and size of coho salmon catches and escapements in Southeast Alaska in 1986. Alaska Department of Fish and Game, Division of Commercial Fisheries. Technical Data Report No. 90-01. Juneau, Alaska.

Zillges, G. 1977. Methodology of determining Puget Sound coho escapement goals, escapement estimates, 1977 pre-season run size, prediction and in-season run assessment. Washington Department of Fisheries, technical Report No. 28. Olympia, Washington.

Table 1. Berners River returns of coho salmon by year of return.

Year	Estimated Escapement	Estim. Catch	Estim. Total Return	Estimated Annual Exploit. Rate	Estim. Marine Survival	Estimated Return by Age: Age 3	Age 4	Age 5	Age 6
1979	3,460	-	-	-	-	-	-	-	-
1980	-	-	-	-	-	-	-	-	-
1981	-	-	-	-	-	-	-	-	-
1982	7,505	23,455	30,960	75.8%	6.5%	8,886	19,642	2,432	0
1983	9,840	24,196	34,036	71.1%	15.0%	7,332	22,101	4,335	268
1984	2,825	-	-	-	10.7%[a]	-	-	-	-
1985	6,169	18,078	24,247	74.6%	13.3%	8,172	14,454	1,486	135
1986	1,752	22,883	24,635	92.9%	11.4%	5,298	17,483	1,854	0
1987	3,260	10,798	14,058	76.8%	7.8%	1,694	12,086	278	0
1988	2,724	12,248	14,972	81.8%	11.6%	7,596	7,281	95	0
1989	7,509	12,179	19,688	61.9%	9.6%	5,804	13,259	625	0
1990	11,050	22,764	33,814	67.3%	20.2%	18,063	15,245	506	0
1991	11,530	21,629	35,159	67.2%	24.8%	12,829	21,906	424	0
1992	15,300	30,558	45,858	66.6%	24.3%	21,485	23,948	425	0
1993	15,670	33,528	49,198	68.1%	15.0%	12,717	36,017	464	0
Average Marine Survival					14.5%[b]				

[a] This data point was estimated as the average listed for the years 1982, 1983, and 1985 through 1989.

[b] Average survival listed above does not include the estimated 1984 data point.

Table 2. Auke Creek returns of coho salmon by year of return.

Year	Estimated Escapement	Estim. Catch	Estim. Total Return	Estimated Annual Exploit. Rate	Estim. Marine Survival	Estimated[a] Return by Age: Age 3	Age 4	Age 5	Age 6+
1980	698	179	877	20.4%	9.5%	-	-	-	-
1981	647	344	991	34.7%	8.9%	-	-	-	-
1982	447	309	756	40.9%	11.6%	297	392	68	0
1983	694	540	1,234	43.8%	16.8%	342	886	6	0
1984	651	500	1,151	43.4%	14.9%	111	979	60	0
1985	942	747	1,689	44.2%	20.4%	69	798	671	151
1986	453	513	966	53.1%	16.4%	104	669	179	14
1987	668	509	1,177	43.2%	19.7%	153	665	316	44
1988	756	435	1,191	36.5%	17.3%	31	678	433	49
1989	502	637	1,139	55.9%	14.2%	329	790	19	0
1990	697	772	1,469	52.6%	20.9%	307	1,162	0	0
1991	804	341	1,145	29.8%	22.8%	269	876	0	0
1992	1,020	294	1,314	22.4%	23.0%	368	920	26	0
1993	859	729	1,588	45.9%	23.2%	145	1,391	52	0
Average Marine Survival					17.1%				

[a] Coho salmon aged older than 6 years only occurred in the 1985 return when it was estimated that 12 of 1,689 returning fish were 7 year olds.

Table 3. Ford Arm Lake returns of coho salmon by year of return.

Year	Estimated Escapement	Estim. Catch	Estim. Total Return	Estimated Annual Exploit. Rate	Estim. Marine Survival	Estimated Return by Age: Age 3	Age 4	Age 5	Age 6	Age 7
1982	2,662	2,054	4,716	43.6%	6.0%	-	-	-	-	-
1983	1,944	4,343	6,287	69.1%	9.5%	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-
1985	2,324	2,438	4,762	51.2%	12.3%	169	1,264	2,234	948	147
1986	1,546	2,562	4,108	62.4%	8.8%	491	2,444	1,078	96	0
1987	1,694	1,535	3,229	47.5%	4.4%	149	1,150	1,744	181	6
1988	3,028	2,933	5,961	49.2%	6.7%	528	4,137	1,245	50	0
1989	2,177	3,962	6,139	64.5%	13.3%	326	3,622	2,155	36	0
1990	2,190	3,087	5,277	58.5%	9.4%	415	3,627	1,235	0	0
1991	2,761	3,262	6,023	54.2%	10.8%	258	4,237	1,504	24	0
1992	3,847	5,456	9,303	58.6%	15.0%	100	5,598	3,517	88	0
1993	4,202	8,471	12,673	66.8%	22.0%	78	6,485	5,947	163	0
Average Marine Survival					10.8%					

Table 4. Hugh Smith Lake returns of coho salmon by year of return.

Year	Estimated Escapement	Estim. Catch	Estim. Total Return	Estimated Annual Exploit. Rate	Estim. Marine Survival	Estimated Return by Age: Age 3	Age 4	Age 5	Age 6	Age 7
1982	2,144	-	-	-	-	-	-	-	-	-
1983	1,490	-	-	-	-	-	-	-	-	-
1984	1,408	2,602	4,010	64.9%	7.7%	-	-	-	-	-
1985	903	1,509	2,412	62.6%	7.5%	296	1,171	870	74	0
1986	1,783	2,691	4,474	60.1%	19.0%	470	2,441	1,379	184	0
1987	1,118	1,226	2,344	52.3%	10.7%	157	1,522	622	36	6
1988	513	1,017	1,530	66.5%	4.2%	117	619	677	92	25
1989	424	2,000	2,424	82.5%	10.4%	388	1,400	635	0	0
1990	870	3,723	4,593	81.1%	17.3%	865	2,754	974	0	0
1991	1,826	3,905	5,731	68.1%	17.4%	457	4,727	526	21	0
1992	1,426	3,463	4,889	70.8%	21.0%	214	3,489	1,156	30	0
1993	830	3,438	4,268	80.6%	13.0%	267	3,392	591	19	0
Average Marine Survival					12.8%					

Table 5. Returns of coho salmon to the Berners River by brood year.

Brood Year	Estimated Escapement	Estimated Catch	Estimated Total Return	Exploitation Rate for Brood	Return by Age: Age 3	Age 4	Age 5	Age 6
1979	3,460	22,545	31,793	72.4%	8,886	22,102	670[a]	135
1982	7,505	22,546	25,933	86.9%	8,172	17,483	278	0
1983	9,840	14,282	17,479	81.7%	5,298	12,086	95	0
1984	2,825	7,644	9,600	79.6%	1,694	7,281	625	0
1985	6,169	14,757	21,361	69.1%	7,596	13,259	506	0
1986	1,752	14,138	21,473	65.8%	5,804	15,245	424	0
1987	3,260	27,166	40,394	67.3%	18,063	21,906	425	0
1988	2,724	24,896	37,241	66.9%	12,829	23,948	464	0
1989	7,509	38,862	58,811	67.6%	24,485	36,017	1,309[b]	0

[a] The age 5 return in 1984 was estimated by dividing the total return of age 3, 4, and 6 coho by the average total proportion of the return which is comprised of these ages (0.959) and multiplying the total estimated return by the average contribution of age 5 fish (0.04).

[b] This data point is a projection. The age 5 return in 1994 was estimated by dividing the total return of age 3, 4, and 6 coho by the average total proportion of the return which is comprised of these ages (0.959) and multiplying the total estimated return by the average contribution of age f fish (0.04). For adjusted returns provided on later tables, marine survival for coho at sea between 1993 and 1994 was projected at 18.8%.

Table 6. Returns of coho salmon to Auke Creek by brood year.

Brood Year	Estimated Escapement	Estimated Catch	Estimated Total Return	Exploitation Rate for Brood	Return by Age: Age 3	Age 4	Age 5	Age 6+
1980	698	879	2,006	43.8%	342	979	671	14
1981	647	515	1,132	45.5%	111	798	179	44
1982	447	541	1,104	49.0%	69	669	316	49
1983	694	501	1,201	41.7%	104	665	433	0
1984	651	324	850	38.2%	153	678	19	0
1985	942	453	822	55.2%	31	790	0	0
1986	453	795	1,491	53.3%	329	1,162	0	0
1987	668	428	1,210	35.4%	307	876	26	1[a]
1988	756	310	1,261	25.0%	269	920	52[a]	19[a]
1989	502	721	2,032	41.0%	368	1,391[a]	242[a]	31[a]

[a] These cohort estimates are projected; see Table 5 for estimation procedures.

Table 7. Returns of coho salmon to Ford Arm Lake by brood year.

Brood Year	Estimated Escapement	Estimated Catch	Estimated Total Return	Exploitation Rate for Brood	Return by Age: Age 3	Age 4	Age 5	Age 6	Age 7
1982	2,662	2,464	4,407	55.9%	169	2,444	1,744	50	0
1983	1,944	1,488	2,921	50.9%	491	1,150	1,245	36	0
1984	-	-	-	-	-	-	-	-	-
1985	2,324	3,333	5,409	61.6%	528	3,622	1,235	24	0
1986	1,546	3,198	5,544	57.7%	326	3,627	1,504	88	0
1987	1,694	4,709	8,363	56.5%	415	4,237	3,517	163	30[a]
1988	3,028	7,398	12,283	62.7%	258	5,598	5,947	435[a]	45[a]
1989	2,177	4,394	10,804	66.7%	100	6,485	3,796[a]	383[a]	39[a]

[a] These cohort estimates are projected; see Table 5 for estimation procedures.

Table 8. Returns of coho salmon to Hugh Smith Lake by brood year.

Brood Year	Estimated Escapement	Estimated Catch	Estimated Total Return	Exploitation Rate for Brood	Return by Age: Age 3	Age 4	Age 5	Age 6	Age 6
1982	2,144	2,040	3,452	59.1%	296	2,441	622	92	0
1983	1,490	1,529	2,669	57.3%	470	1,522	677	0	0
1984	1,408	1,018	1,411	72.1%	157	619	635	0	0
1985	903	2,037	2,512	81.1%	117	1,400	974	21	0
1986	1,783	2,932	3,698	79.3%	388	2,754	526	30	0
1987	1,118	4,756	6,781	70.3%	865	4,727	1,156	19	14[a]
1988	513	3,258	4,629	71.8%	457	3,489	591	83[a]	10[a]
1989	424	2,884	4,992	80.0%	214	3,392	1,286[a]	90[a]	11[a]

[a] These cohort estimates are projected; see Table 5 for estimation procedures.

Table 9. Total returns of coho salmon to the Berners River by brood year adjusted to average marine survival conditions (estimated total returns adjusted to average marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6	Estimated Total Return Adjusted for AVERAGE Marine Survival
1979	3,460	19,935	21,372	906	148	42,361
1982	7,505	8,939	22,254	516	0	31,710
1983	9,840	6,744	22,439	118	0	29,301
1984	2,825	3,145	9,121	941	0	13,207
1985	6,169	9,516	19,958	363	0	29,837
1986	1,752	8,736	10,938	247	0	19,921
1987	3,260	12,959	12,792	253	0	26,004
1988	2,724	7,491	14,289	448	0	22,228
1989	7,509	12,820	34,742	1,009	0	48,570

[a] Estimated returns were developed by taking smolt production estimates and dividing these estimates by 14.5%, the average marine survival estimate listed on Table 1. Smolt production was estimated by dividing the estimated adult return of coho salmon at age by the estimated marine survival for that cohort listed on Table 1 {for example, 36,017 age 4 adult coho were estimated to have returned in 1993 (see Table 1), and these fish were recruited from the 1989 escapement (see Table 5); marine survival of coho smolt emigrating in 1992 and returning in 1993 was estimated at 15.0% (see Table 1); and hence, the number of smolt emigrating from the Berners River in 1992 and returning in 1993 as four year olds is estimated to have been 239,559 fish; under average survival conditions (14.5%), a smolt emigration of 239,559 fish would be expected to produce a recruitment of 33,960 adults as listed above}.

Table 10. Total returns of coho salmon to the Berners River by brood year adjusted to low marine survival conditions (estimated total returns adjusted to low (8.8%) marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6	Estimated Total Return Adjusted for LOW Marine Survival
1979	3,460	12,132	13,007	551	90	25,780
1982	7,505	5,440	13,544	314	0	19,298
1983	9,840	4,104	13,656	72	0	17,832
1984	2,825	1,914	5,551	573	0	8,038
1985	6,169	5,791	12,146	221	0	18,158
1986	1,752	5,316	6,656	151	0	12,123
1987	3,260	7,887	7,785	154	0	15,826
1988	2,724	4,559	8,696	272	0	13,528
1989	7,509	7,802	21,143	614	0	29,559

[a] Estimated returns were developed by taking smolt production estimates and dividing these estimates by 8.8%. This is the average marine survival for the four years (1982, 1986, 1987, and 1989) with the lowest documented marine survival of the 11 years of available data (see Table 1). See Table 9 for example of the other calculation procedures.

Table 11. Total returns of coho salmon to the Berners River by brood year adjusted to high marine survival conditions (estimated total returns adjusted to high (21.1%) marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6	Estimated Total Return Adjusted for HIGH Marine Survival
1979	3,460	29,000	31,092	1,318	215	61,625
1982	7,505	13,005	32,375	751	0	46,130
1983	9,840	9,810	32,643	172	0	42,626
1984	2,825	4,575	13,269	1,369	0	19,213
1985	6,169	13,844	29,034	528	0	43,405
1986	1,752	12,708	15,912	360	0	28,980
1987	3,260	18,853	18,609	369	0	37,830
1988	2,724	10,898	20,787	651	0	32,336
1989	7,509	18,649	50,541	1,468	0	70,659

[a] Estimated returns were developed by taking smolt production estimates and dividing these estimates by 21.1%. This is the average marine survival for the four years (1990, 1991, 1992, and 1993) with the highest documented marine survival of the 11 years of available data (see Table 1). See Table 9 for example of the other calculation procedures.

Table 12. Total returns of coho salmon to Auke Creek by brood year adjusted to average marine survival conditions (estimated total returns adjusted to average marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6+	Estimated Total Return Adjusted for AVERAGE Marine Survival
1980	698	347	1,123	562	15	2,047
1981	647	128	669	187	38	1,021
1982	447	58	697	275	48	1,078
1983	694	108	577	427	0	1,112
1984	651	133	669	23	0	825
1985	942	31	955	0	0	985
1986	453	398	953	0	0	1,350
1987	668	252	657	20	1	929
1988	756	202	685	39	16	942
1989	502	274	1,027	199	25	1,526

[a] Estimated returns developed by taking smolt production estimates and dividing these estimates by 17.1%, the average marine survival estimate listed on Table 2 (see Table 9 for example of the procedure).

Table 13. Total returns of coho salmon to Auke Creek by brood year adjusted to low marine survival conditions (estimated total returns adjusted to low (11.0%) marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6+	Estimated Total Return Adjusted for LOW Marine Survival
1980	698	224	724	363	9	1,320
1981	647	82	431	120	24	658
1982	447	38	449	177	31	695
1983	694	70	372	275	0	717
1984	651	85	431	15	0	532
1985	942	20	615	0	0	635
1986	453	256	614	0	0	871
1987	668	162	423	13	0	599
1988	756	130	442	25	10	607
1989	502	177	662	129	17	984

[a] Estimated returns were developed by taking smolt production estimates and dividing these estimates by 11.0%. This is the average marine survival for the four years (1980, 1981, 1982, and 1989) with the lowest documented marine survival of the 14 years of available data (see Table 2). See Table 9 for example of the other calculation procedures.

Table 14. Total returns of coho salmon to Auke Creek by brood year adjusted to high marine survival conditions (estimated total returns adjusted to high (22.4) marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6+	Estimated Total Return Adjusted for HIGH Marine Survival
1980	698	456	1,473	738	19	2,686
1981	647	168	878	245	50	1,340
1982	447	76	914	360	64	1,415
1983	694	142	758	560	0	1,459
1984	651	174	878	31	0	1,082
1985	942	40	1,252	0	0	1,293
1986	453	522	1,250	0	0	1,772
1987	668	331	862	26	1	1,219
1988	756	265	899	51	21	1,236
1989	502	360	1,348	262	33	2,002

[a] Estimated returns were developed by taking smolt production estimates and dividing these estimates by 22.4%. This is the average marine survival for the four years (1990, 1991, 1992, and 1993) with the highest documented marine survival of the 14 years of available data (see Table 2). See Table 9 for example of the other calculation procedures.

Table 15. Total returns of coho salmon to Ford Arm Lake by brood year adjusted to average marine survival conditions (estimated total returns adjusted to average marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6	Age 7	Estimated Total Return Adjusted for AVERAGE Marine Survival
1982	2,662	148	2,996	4,280	81	0	7,505
1983	1,944	602	2,822	1,998	29	0	5,451
1984	-	-	-	-	-	-	-
1985	2,324	848	2,919	1,407	24	0	5,198
1986	1,546	263	4,133	1,499	63	0	5,958
1987	1,694	473	4,224	2,515	79	23	7,315
1988	3,028	257	4,002	2,902	331	34	7,527
1989	2,177	72	3,165	2,889	292	30	6,447

[a] Estimated returns developed by taking smolt production estimates and dividing these estimates by 10.8%, the average marine survival estimate listed on Table 3 (see Table 9 for example of the procedure).

Table 16. Total returns of coho salmon to Ford Arm Lake by brood year adjusted to low marine survival conditions (estimated total returns adjusted to low (6.5%) marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6	Age 7	Estimated Total Return Adjusted for LOW Marine Survival
1982	2,662	89	1,797	2,568	48	0	4,502
1983	1,944	361	1,693	1,199	18	0	3,270
1984	-	-	-	-	-	-	-
1985	2,324	509	1,751	844	14	0	3,119
1986	1,546	158	2,479	900	38	0	3,574
1987	1,694	284	2,534	1,509	48	14	4,388
1988	3,028	154	2,401	1,741	199	20	4,516
1989	2,177	43	1,899	1,733	175	18	3,868

[a] Estimated returns were developed by taking smolt production estimates and dividing these estimates by 6.5%. This is the average marine survival for the four years (1982, 1986, 1987, and 1988) with the lowest documented marine survival of the 11 years of available data (see Table 3). See Table 9 for example of the other calculation procedures.

Table 17. Total returns of coho salmon to Ford Arm Lake by brood year adjusted to high marine survival conditions (estimated total returns adjusted to high (15.7%) marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6	Age 7	Estimated Total Return Adjusted for HIGH Marine Survival
1982	2,662	216	4,369	6,240	118	0	10,942
1983	1,944	877	4,114	2,913	43	0	7,947
1984	-	-	-	-	-	-	-
1985	2,324	1,236	4,256	2,052	35	0	7,579
1986	1,546	383	6,026	2,186	91	0	8,686
1987	1,694	690	6,159	3,666	116	34	10,665
1988	3,028	375	5,835	4,231	483	50	10,975
1989	2,177	104	4,614	4,213	425	44	9,400

[a] Estimated returns were developed by taking smolt production estimates and dividing these estimates by 15.7%. This is the average marine survival for the four years (1985, 1989, 1992, and 1993) with the highest documented marine survival of the 11 years of available data (see Table 3). See Table 9 for example of the other calculation procedures.

Table 18. Total returns of coho salmon to Hugh Smith Lake by brood year adjusted to average marine survival conditions (estimated total returns adjusted to average marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6	Age 7	Estimated Total Return Adjusted for AVERAGE Marine Survival
1982	2,144	506	1,644	745	279	0	3,174
1983	1,490	316	1,822	2,056	0	0	4,194
1984	1,408	188	1,878	784	0	0	2,850
1985	903	355	1,729	724	15	0	2,823
1986	1,783	479	2,047	388	18	0	2,932
1987	1,118	643	3,482	707	19	12	4,863
1988	513	337	2,134	583	67	8	3,129
1989	424	131	3,348	1,043	73	9	4,604

[a] Estimated returns developed by taking smolt production estimates and dividing these estimates by 12.8%, the average marine survival estimate listed on Table 4 (see Table 9 for example of the procedure).

Table 19. Total returns of coho salmon to Hugh Smith Lake by brood year adjusted to low marine survival conditions (estimated total returns adjusted to low (7.5%) marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6	Age 7	Estimated Total Return Adjusted for LOW Marine Survival
1982	2,144	294	957	434	163	0	1,848
1983	1,490	184	1,061	1,197	0	0	2,442
1984	1,408	109	1,094	457	0	0	1,660
1985	903	207	1,007	422	9	0	1,644
1986	1,783	279	1,192	226	11	0	1,707
1987	1,118	374	2,028	412	11	7	2,832
1988	513	196	1,243	339	39	5	1,822
1989	424	76	1,949	608	42	5	2,681

[a] Estimated returns were developed by taking smolt production estimates and dividing these estimates by 7.5%. This is the average marine survival for the four years (1984, 1985, 1988, and 1989) with the lowest documented marine survival of the 10 years of available data (see Table 4). See Table 9 for example of the other calculation procedures.

Table 20. Total returns of coho salmon to Hugh Smith Lake by brood year adjusted to high marine survival conditions (estimated total returns adjusted to high (18.7%) marine survival conditions).[a]

Brood Year	Estimated Adult Escapement	Estimated Recruitment for Fish Returning at Age: Age 3	Age 4	Age 5	Age 6	Age 7	Estimated Total Return Adjusted for HIGH Marine Survival
1982	2,144	736	2,393	1,084	406	0	4,620
1983	1,490	461	2,652	2,992	0	0	6,105
1984	1,408	274	2,734	1,142	0	0	4,149
1985	903	517	2,516	1,054	22	0	4,110
1986	1,783	698	2,979	564	27	0	4,268
1987	1,118	936	5,069	1,030	27	17	7,078
1988	513	490	3,107	849	98	12	4,555
1989	424	191	4,873	1,519	106	12	6,701

[a] Estimated returns were developed by taking smolt production estimates and dividing these estimates by 18.7%. This is the average marine survival for the four years (1986, 1990, 1991, and 1992) with the highest documented marine survival of the 10 years of available data (see Table 4). See Table 9 for example of the other calculation procedures.

Table 21. Estimated spawner-recruit parameters for four coho salmon stocks using unadjusted and adjusted recruitment data sets.[a]

Coho Salmon Stock	Model	Sample Size n	Ricker a	Carrying Capacity	R^2	MSE	Escapement @ Prod. Maximum	Optimum Escapement Estimate
Berners	Unadjusted	9	2.75924	14,387	0.531	0.2933	5,214	4,440
Berners	Adj. AVERAGE	9	2.49389	19,316	0.588	0.1056	7,745	6,302
Berners	Adj. LOW	9	1.99728	15,469	0.588	0.1056	7,745	5,584
Berners	Adj. HIGH	9	2.86872	22,219	0.588	0.1056	7,745	6,701
Auke	Unadjusted	10	2.27399	927	0.652	0.0814	408	316
Auke	Adj. AVERAGE	10	1.92911	932	0.578	0.0792	483	341
Auke	Adj. LOW	10	1.49093	720	0.578	0.0793	483	286
Auke	Adj. HIGH	10	2.20083	1,063	0.578	0.0792	483	368
Ford Arm	Unadjusted	7	1.43326	9,179	0.027	0.2958	6,409	3,687
Ford Arm	Adj. AVERAGE	7	1.82491	5,508	0.561	0.0286	3,018	2,057
Ford Arm	Adj. LOW	7	1.31372	3,967	0.561	0.0285	3,019	1,628
Ford Arm	Adj. HIGH	7	2.20180	6,648	0.561	0.0286	3,019	2,303
Hugh S.	Unadjusted	8	2.63570	2,185	0.662	0.3119	829	692
Hugh S.	Adj. AVERAGE	8	2.46857	2,341	0.859	0.0766	948	768
Hugh S.	Adj. LOW	8	1.92793	1,828	0.859	0.0766	948	669
Hugh S.	Adj. HIGH	8	2.84404	2,697	0.859	0.0766	948	818

[a] Model refers to whether unadjusted or adjusted estimates of total returns were used. Adjusted models are either average (based on the average of all marine survival estimates), low (based on the average of the four lowest marine survival estimates), or high (based on the average of the four highest marine survival estimates). Sample size is the number of paired escapement-total return data points that were included in the analysis. Carrying capacity is the modeled escapement level that is equal to the replacement line. MSE is the mean square error of the regression. Escapement at production maximum is the escapement level that produces the maximum modeled total return.

Table 22. Estimated spawner-recruit parameters based on regressions and bootstrap statistics for four coho salmon stocks with unadjusted and adjusted recruitment estimates.[a]

Coho Salmon Stock	Model	Sample Size	R^2	Regression Estimate of Optimum Escapement	Bootstrap Statistics: Median Optimum Escapement	Lower 90% Bound	Upper 90% Bound
Berners	Unadjusted	9	0.531	4,440	4,470	3,082	8,271
Berners	Adj. AVERAGE	9	0.588	6,302	6,252	4,514	10,525
Berners	Adj. LOW	9	0.588	5,584	5,586	4,116	9,157
Berners	Adj. HIGH	9	0.588	6,701	6,671	4,725	11,652
Auke	Unadjusted	10	0.652	316	315	259	427
Auke	Adj. AVERAGE	10	0.578	341	337	274	495
Auke	Adj. LOW	10	0.578	286	283	249	361
Auke	Adj. HIGH	10	0.578	368	366	286	579
Ford Arm	Unadjusted	7	0.027	3,687	1,474	0	10,415
Ford Arm	Adj. AVERAGE	7	0.561	2,057	2,059	1,473	3,844
Ford Arm	Adj. LOW	7	0.561	1,628	1,643	1,265	2,605
Ford Arm	Adj. HIGH	7	0.561	2,303	2,305	1,587	4,440
Hugh S.	Unadjusted	8	0.662	692	693	525	1,011
Hugh S.	Adj. AVERAGE	8	0.859	768	766	651	937
Hugh S.	Adj. LOW	8	0.859	669	666	585	786
Hugh S.	Adj. HIGH	8	0.859	818	818	683	1,011

[a] Model refers to whether unadjusted or adjusted estimates of total returns were used. Adjusted models are either average (based on the average of all marine survival estimates), low (based on the average of the four lowest marine survival estimates), or high (based on the average of the four highest marine survival estimates). Sample size is the number of paired escapement-total return data points. Optimum escapement estimates were calculated from the spawner-recruit regressions. The bootstrap median and 90% confidence bounds for each model were taken from the set of optimum escapements calculated from a set of 4,001 bootstrap runs conducted for each of the models.

Table 23. Optimum escapement estimates and lower and upper escapements that are estimated to produce 90% of the maximum yield based on regressions of the spawner-recruit relationships along with estimates of median optimum escapements with 90% confidence bounds when recruitment errors were bootstrapped for four coho salmon stocks.[a]

		Regression Estimates:			Bootstrap Statistics When Recruitment Residuals Are Included:		
			Escapements Where Yield is 90% of Maximum:				
Coho Salmon Stock	Model	Estimate of Optimum Escapement	Lower Bound	Upper Bound	Median Optimum Escapement	Lower 90% Bound	Upper 90% Bound
Berners	Unadjusted	4,440	2,800	6,500	4,470	3,082	8,271
Berners	Adj. AVERAGE	6,302	4,000	9,200	6,252	4,514	10,525
Berners	Adj. LOW	5,584	3,500	8,000	5,586	4,116	9,157
Berners	Adj. HIGH	6,701	4,200	9,900	6,671	4,725	11,652
Auke	Unadjusted	316	200	500	315	259	427
Auke	Adj. AVERAGE	341	200	500	337	274	495
Auke	Adj. LOW	286	200	400	283	249	361
Auke	Adj. HIGH	368	200	500	366	286	579
Ford Arm	Unadjusted	3,687	2,400	5,200	1,474	0	10,415
Ford Arm	Adj. AVERAGE	2,057	1,300	2,900	2,059	1,473	3,844
Ford Arm	Adj. LOW	1,628	1,100	2,300	1,643	1,265	2,605
Ford Arm	Adj. HIGH	2,303	1,500	3,300	2,305	1,587	4,440
Hugh S.	Unadjusted	692	400	1,000	693	525	1,011
Hugh S.	Adj. AVERAGE	768	500	1,100	766	651	937
Hugh S.	Adj. LOW	669	400	1,000	666	585	786
Hugh S.	Adj. HIGH	818	500	1,200	818	683	1,011

[a] Model refers to whether unadjusted or adjusted estimates of total returns were used. Adjusted models are either average (based on the average of all marine survival estimates), low (based on the average of the four lowest marine survival estimates), or high (based on the average of the four highest marine survival estimates). Optimum escapement estimates were calculated from the spawner-recruit regressions. The range of escapements expected to produce 90% or more of the maximum yield were calculated from the spawner-recruit regressions. The bootstrap medians and 90% confidence bounds for each model were taken from the set of optimum escapements calculated from a set of 4,001 bootstrap runs conducted for each of the models. Recruitment residuals from the spawner-recruitment relationship were used to generate errors for column 6, 7, and 8 for each model. Escapement bounds estimated to produce 90% of maximum yield were rounded to the nearest 100.

Table 24. Recommended escapement goal ranges for four coho salmon stocks with the number and percentage of times that monitored escapement was within the range since escapements have been monitored.

Coho Salmon Stock	Recommended Escapement Range	Number of Years Escapement Monitored	No. of Years Escapement Was: Below: Range: No.	%	Within: Range: No.	%	Above: Range: No.	%	No. of Years Since 1989 That Escapement Was Within Range: No.	%
Berners	4,000-9,200	13	5	38%	3	24%	5	38%	1	20%
Auke	200-500	14	0	0%	2	14%	12	86%	0	0%
Ford Arm	1,300-2,900	11	0	0%	8	73%	3	27%	3	60%
Hugh Smith	500-1,100	12	1	8%	4	34%	7	58%	2	40%
Totals		50	6	12%	17	34%	27	54%	6	30%

Table 25. Estimates of harvest rates for four coho salmon stocks at maximum sustained yield and at 90% bounds of maximum sustained yield.[a]

Coho Salmon Stock	Model	Estimated Optimum Escapement	Escapements Where Yield is 90% of Maximum: Lower	Upper	Estimated Harvest Rate When Escapement is at: Optimum	Lower 90% MSY	Upper 90% MSY
Berners	Unadjusted	4,440	2,800	6,500	85.2%	89.2%	78.0%
Berners	Adj. AVERAGE	6,302	4,000	9,200	81.4%	86.2%	72.9%
Berners	Adj. LOW	5,584	3,500	8,000	72.1%	78.7%	61.9%
Berners	Adj. HIGH	6,701	4,200	9,900	86.5%	90.2%	79.6%
Auke	Unadjusted	316	200	500	77.6%	83.2%	64.9%
Auke	Adj. AVERAGE	341	200	500	70.6%	78.0%	59.1%
Auke	Adj. LOW	286	200	400	59.3%	65.9%	48.5%
Auke	Adj. HIGH	368	200	500	76.3%	83.2%	68.8%
Ford Arm	Unadjusted	3,687	2,400	5,200	57.6%	65.3%	46.3%
Ford Arm	Adj. AVERAGE	2,057	1,300	2,900	68.1%	75.2%	57.9%
Ford Arm	Adj. LOW	1,628	1,100	2,300	53.9%	61.3%	42.4%
Ford Arm	Adj. HIGH	2,303	1,500	3,300	76.3%	81.2%	67.0%
Hugh Smith	Unadjusted	692	400	1,000	83.5%	88.4%	76.0%
Hugh Smith	Adj. AVERAGE	768	500	1,100	81.0%	85.6%	73.0%
Hugh Smith	Adj. LOW	669	400	1,000	70.5%	77.8%	58.2%
Hugh Smith	Adj. HIGH	818	500	1,200	86.2%	90.1%	79.4%

[a] Model refers to whether the unadjusted or adjusted estimates of total returns were used. Adjusted models are either average (based on the average of all marine survival estimates), low (based on the average of the four lowest marine survival estimates), or high (based on the average of the four highest marine survival estimates).

Table 26. Comparison of smolt freshwater age composition with returning adult freshwater age composition for the Hugh Smith Lake stock of coho salmon.

PART 1; Age Composition of Hugh Smith Lake Coho Salmon based Upon Smolt:

	Freshwater Residence Time of Smolt in Years					Average
Year	2	3	4	5	6	Age
1984	12.3%	52.4%	34.6%	0.7%	0.0%	3.238
1985	17.9%	60.9%	21.2%	0.0%	0.0%	3.032
1986	16.0%	58.5%	25.5%	0.0%	0.0%	3.095
1987	5.8%	61.5%	32.7%	0.0%	0.0%	3.270
1988	16.1%	71.2%	12.5%	0.1%	0.0%	2.967
1989	26.0%	49.6%	21.1%	3.0%	0.3%	3.019
1990	4.7%	73.4%	19.8%	2.0%	0.2%	3.197
1991	8.7%	67.4%	21.9%	1.9%	0.0%	3.171
1992	15.0%	74.2%	10.6%	0.2%	0.0%	2.960
Average	13.6%	63.2%	22.2%	0.9%	0.1%	3.105

PART 2; Age Composition of Hugh Smith Lake Coho Salmon based Upon Adults:

	Freshwater Residence Time of Adults in Years:					Average	Change from
	2	3	4	5	6	Age	Smolt
1985	12.3%	48.6%	36.1%	3.1%	0.0%	3.299	0.062
1986	10.5%	54.6%	30.8%	4.1%	0.0%	3.285	0.253
1987	6.7%	64.9%	26.5%	1.5%	0.3%	3.237	0.142
1988	7.7%	40.4%	44.3%	6.0%	1.6%	3.536	0.266
1989	16.0%	57.8%	26.2%	0.0%	0.0%	3.102	0.135
1990	18.8%	60.0%	21.2%	0.0%	0.0%	3.024	0.005
1991	8.0%	82.5%	9.2%	0.4%	0.0%	3.019	-0.177
1992	4.4%	71.4%	23.6%	0.6%	0.0%	3.205	0.034
1993	6.3%	79.5%	13.8%	0.4%	0.0%	3.085	0.125
Average	10.1%	62.2%	25.8%	1.8%	0.2%	3.199	0.094
Std. Dev.							0.135

Table 27. Listing of long-term indicator stocks of coho salmon compared with geographic stock groupings and types of coho salmon producing systems found in Southeast Alaska and the U.S - Canada transboundary rivers.

Geographic Grouping	Small to Medium Streams	Lake Systems	Large Rivers	Interior Tributaries of U.S. - Canada Transboundary Rivers
Yakutat	X	X	X	X
Central Outside & Intermediate	X	Ford Arm L.		
Stephens Passage	X	Auke Lake	X	
Taku River			X	X
Lynn Canal	X	X	Berners R.	
Central Inside	X	X	X	X
Southern Outside	X	X		
Southern Inside	X	Hugh Smith L.	X	X

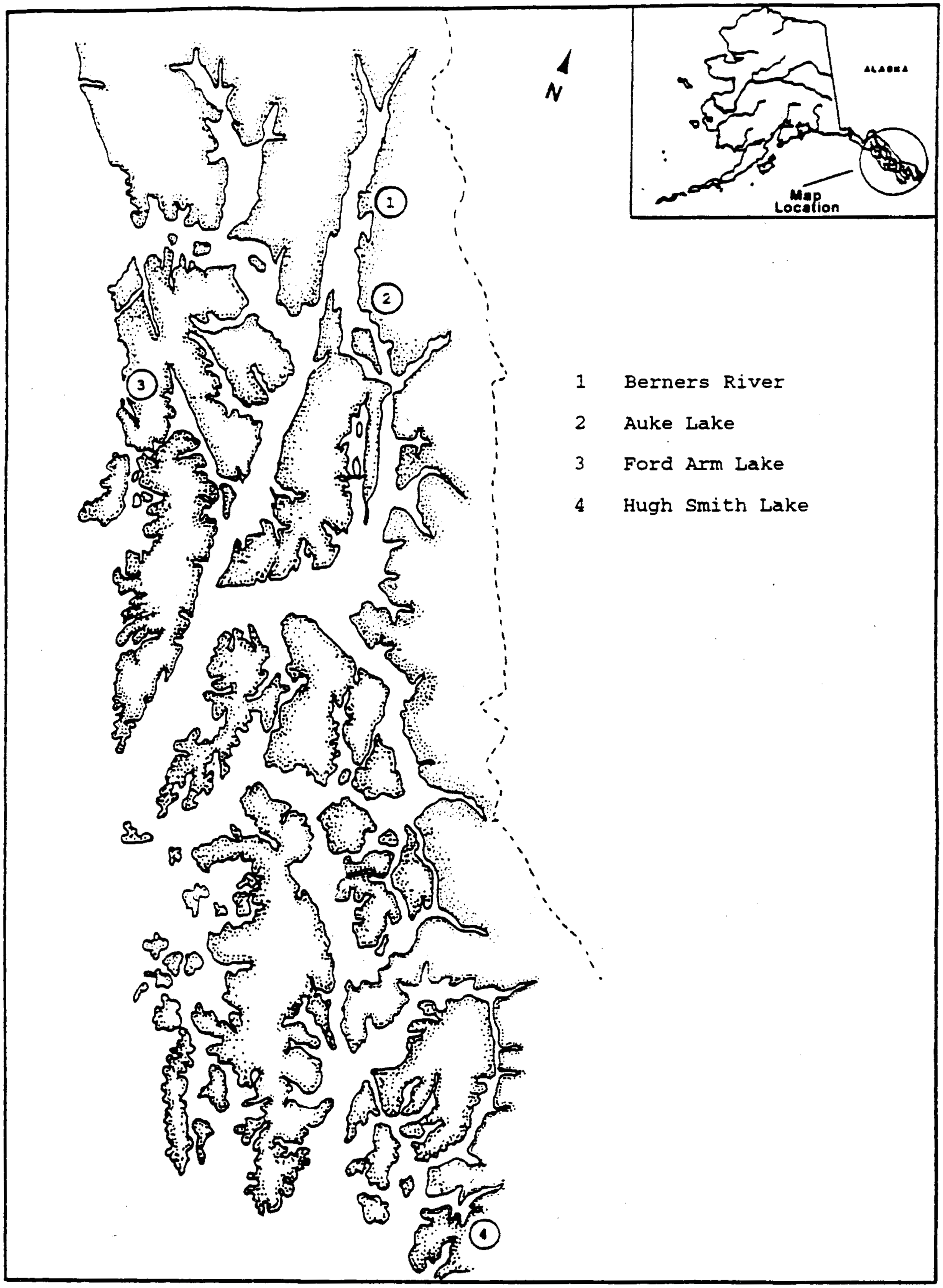


Figure 1. Map of Southeastern Alaska showing the locations of the Berners River, Auke Creek, Ford Arm Lake, and Hugh Smith Lake.

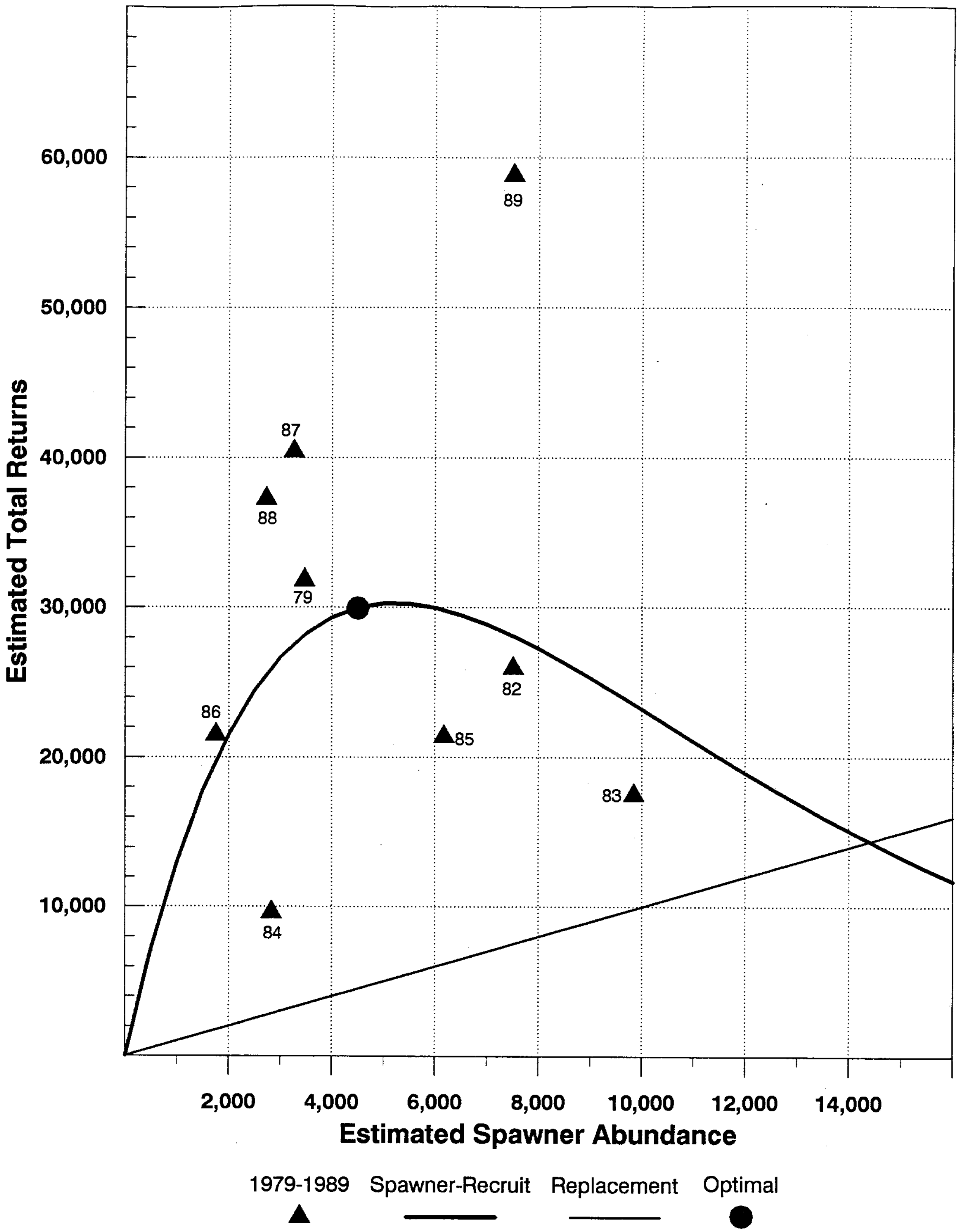


Figure 2. Spawner-recruit relationship for Berners River coho salmon using unadjusted total returns.

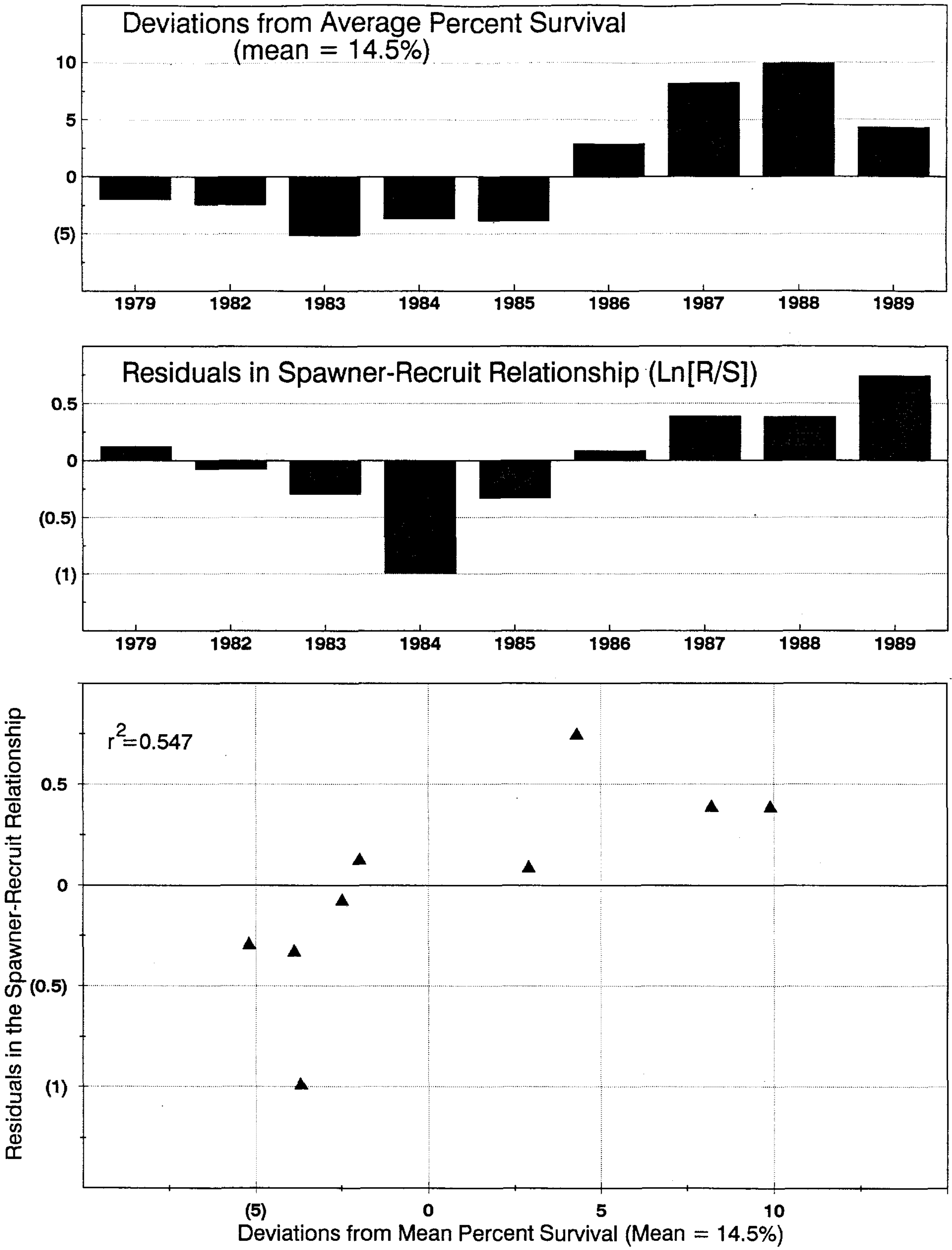


Figure 3. Deviations from average marine survival and residuals in the spawner-recruit relationship for Berners River coho salmon.

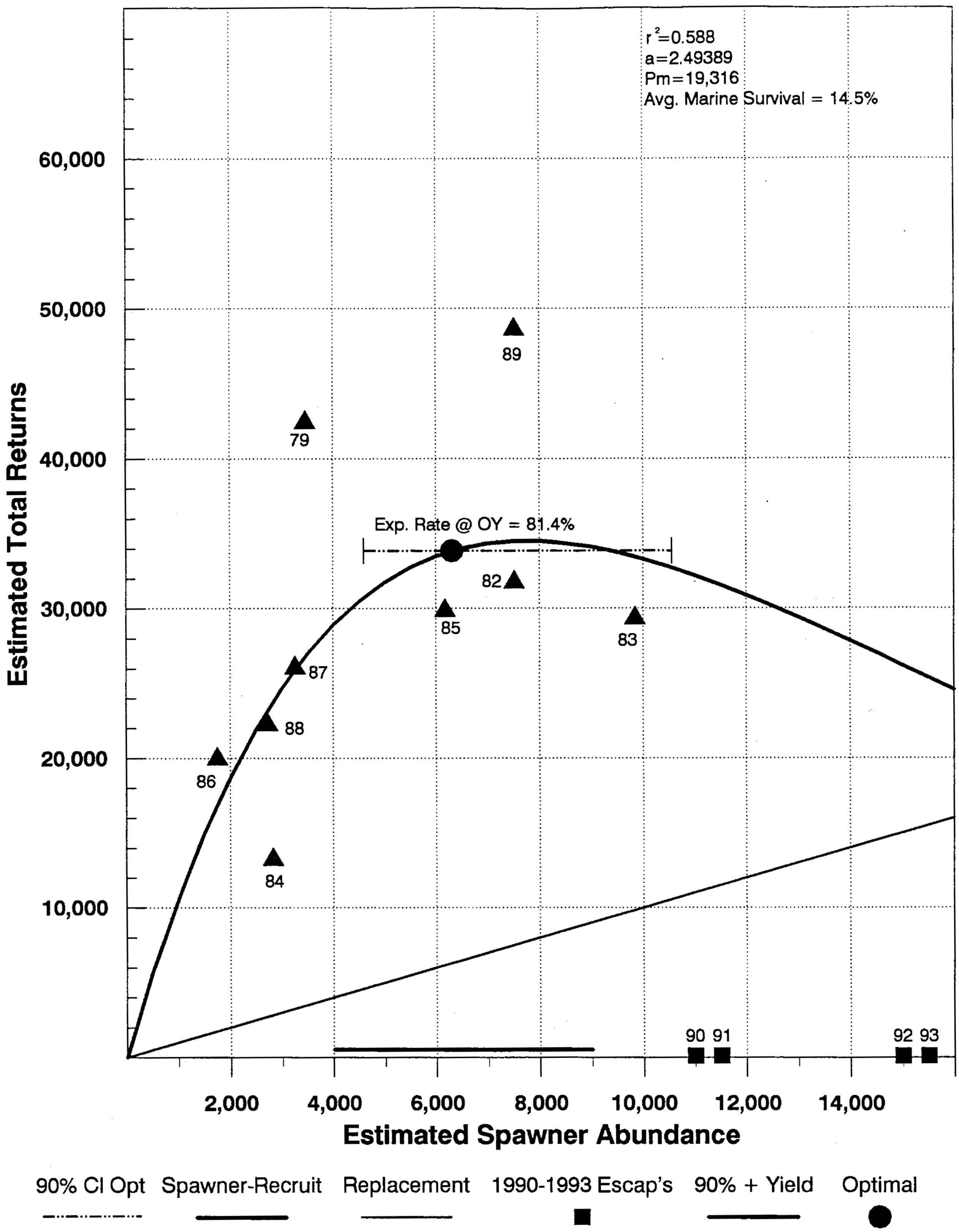
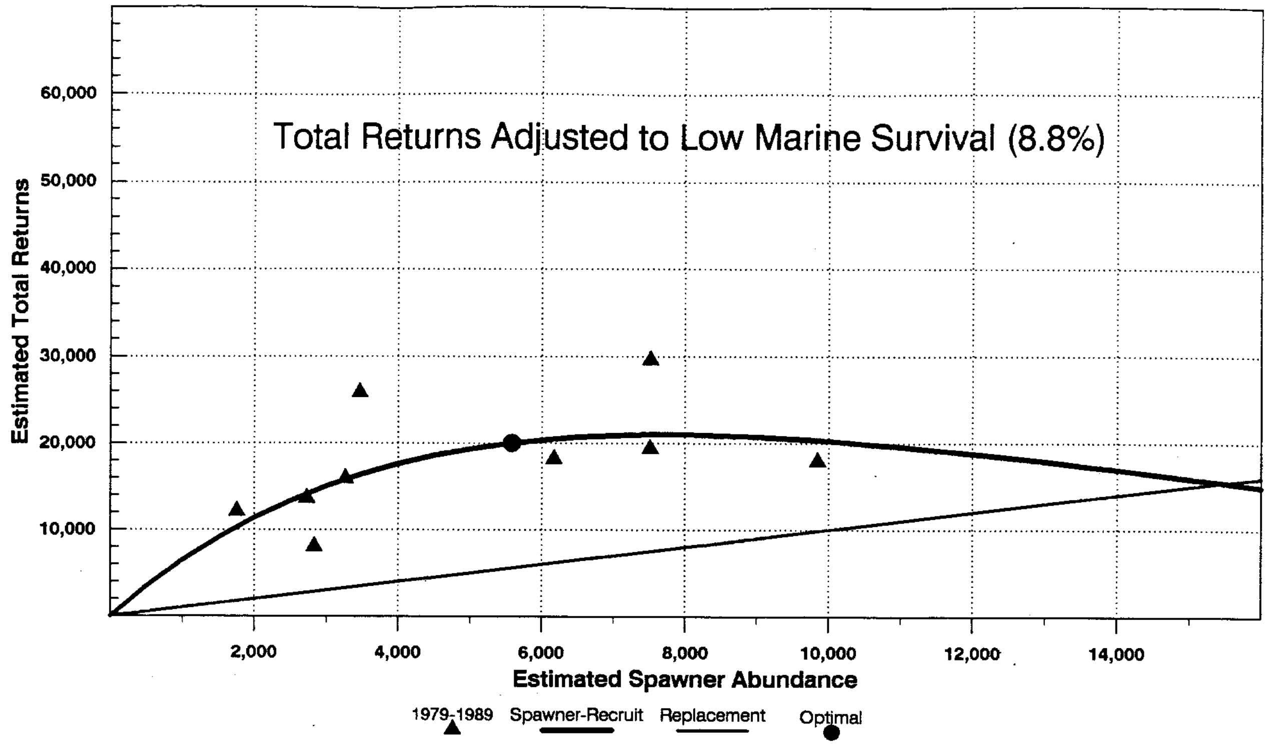


Figure 4. Spawner-recruit relationship for Berners River coho salmon using total returns adjusted to average marine survival conditions.



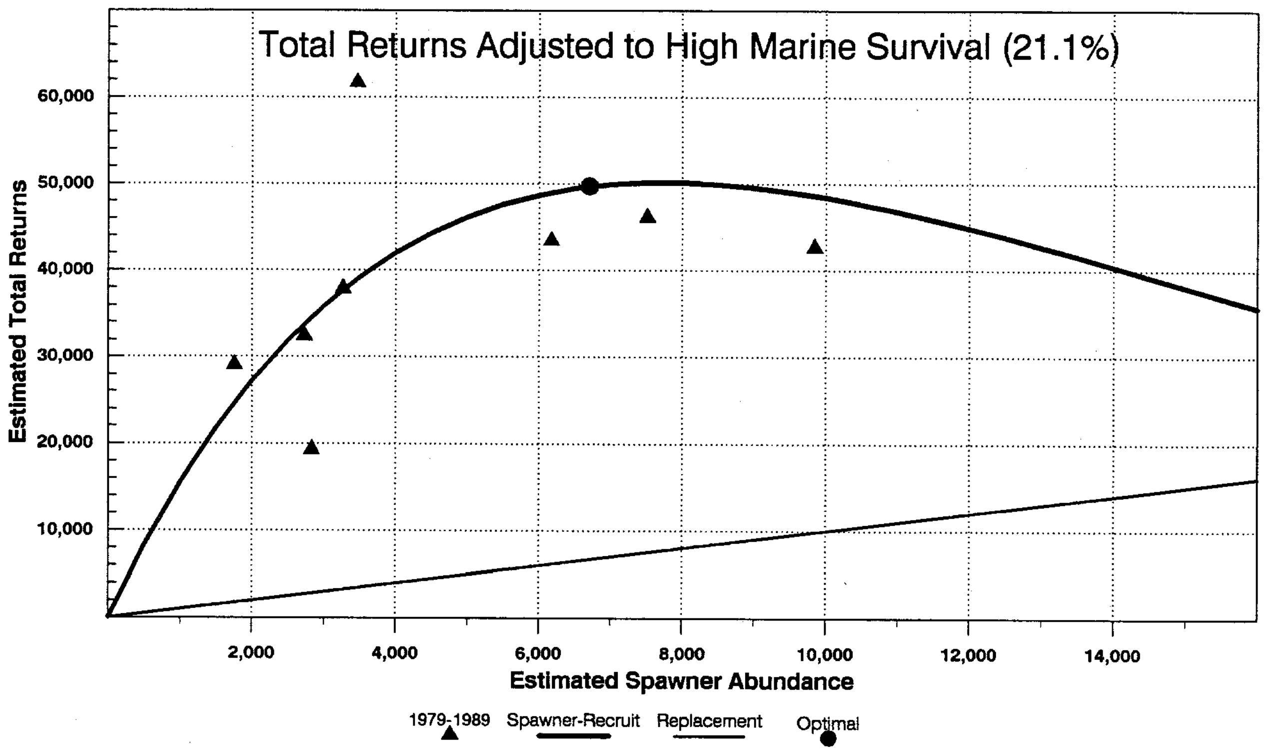


Figure 5. Spawner-recruit relationship for Berners River coho salmon using total returns adjusted to low and high marine survival conditions.

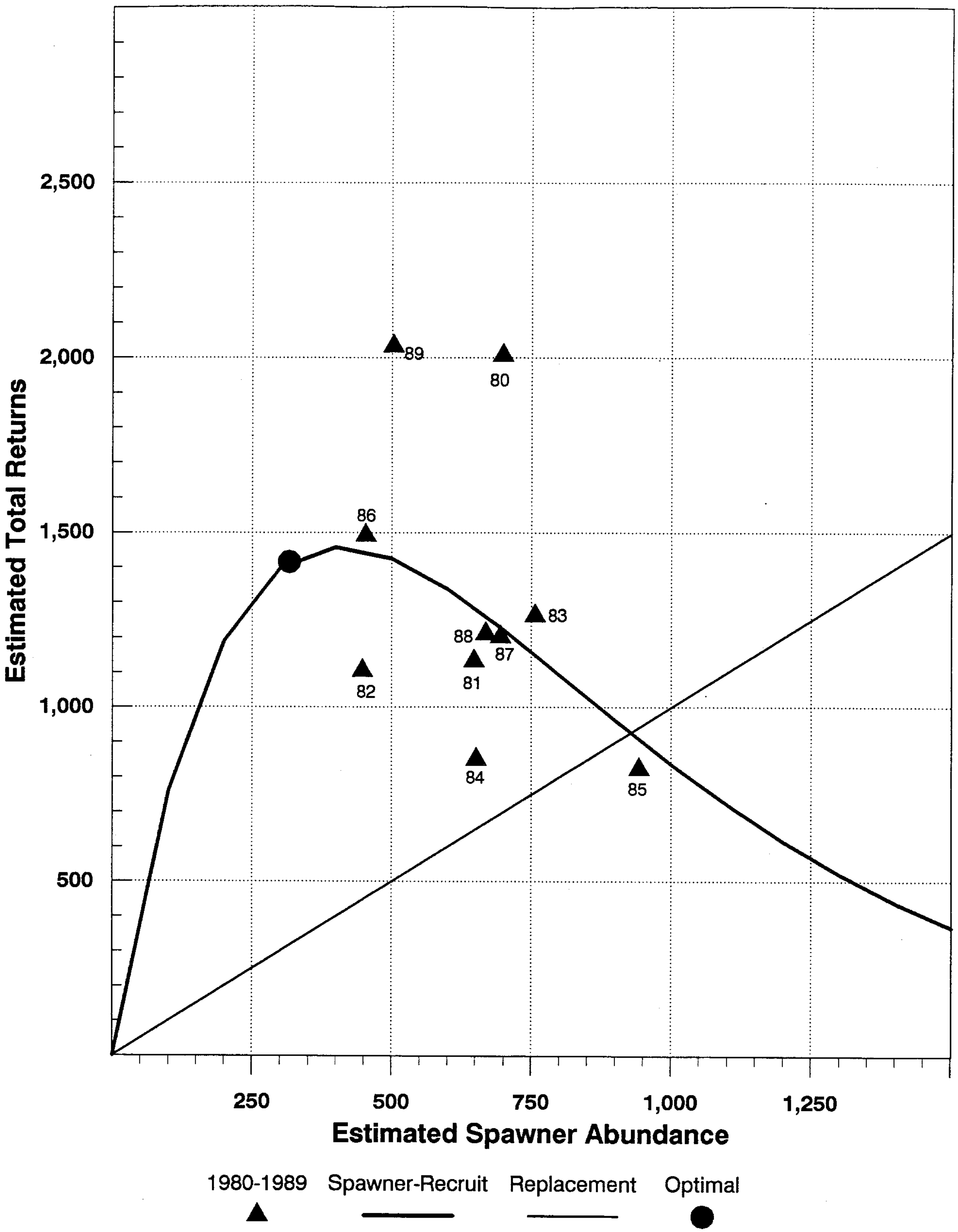


Figure 6. Spawner-recruit relationship for Auke Creek coho salmon using unadjusted total returns.

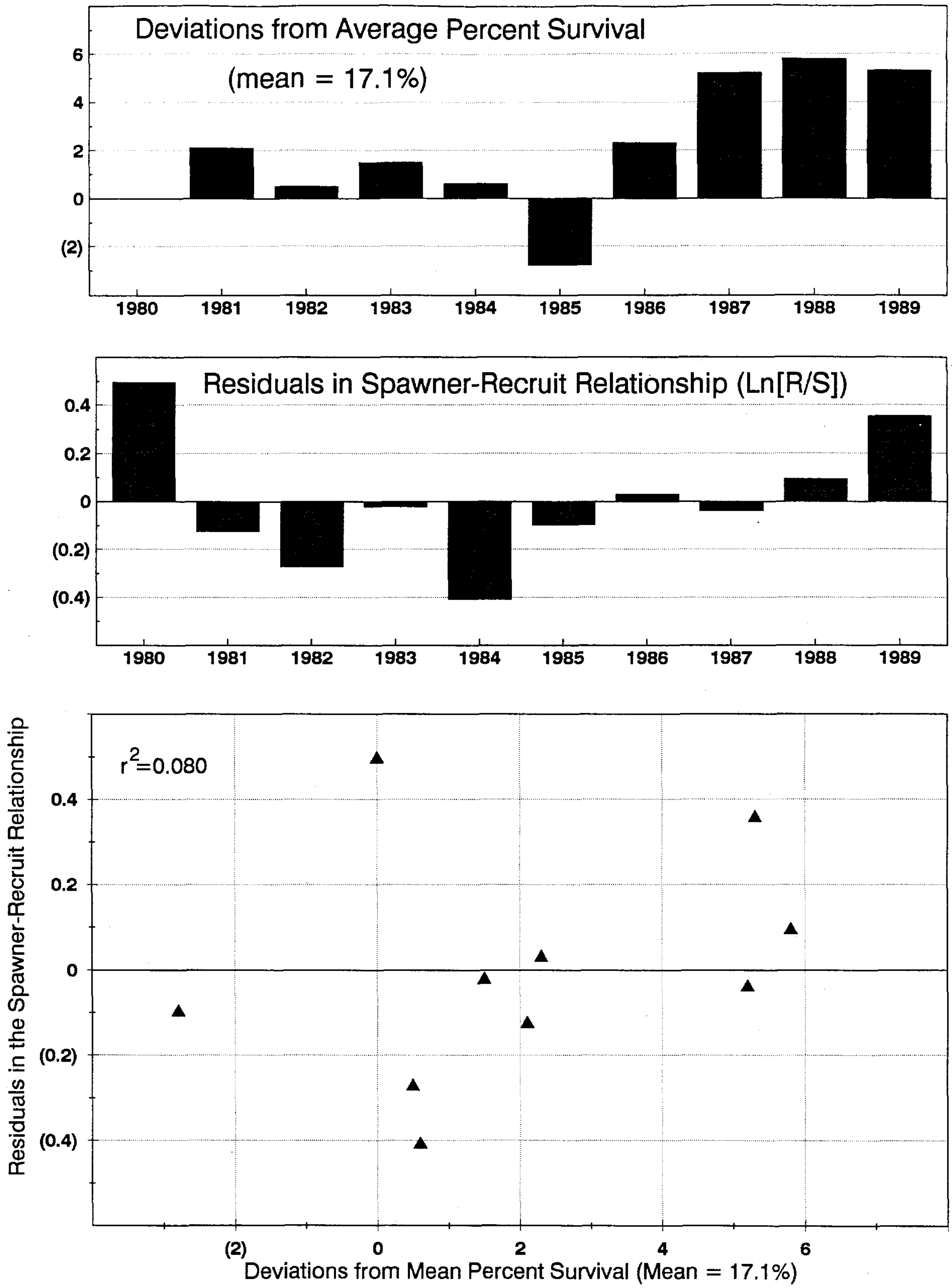


Figure 7. Deviations from average marine survival and residuals in the spawner-recruit relationship for Auke Creek coho salmon.

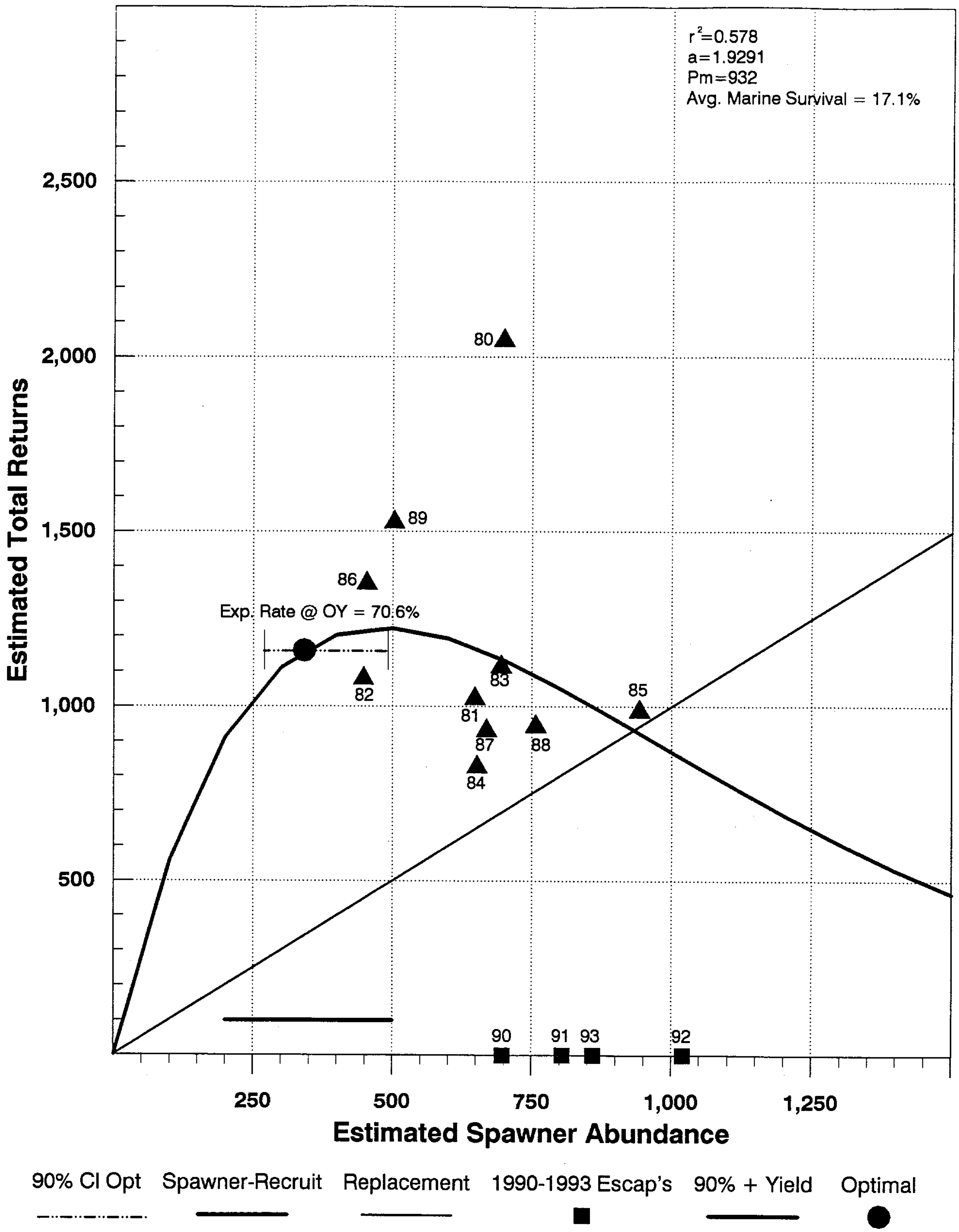


Figure 8. Spawner-recruit relationship for Auke Creek coho salmon using total returns adjusted to average marine survival conditions.

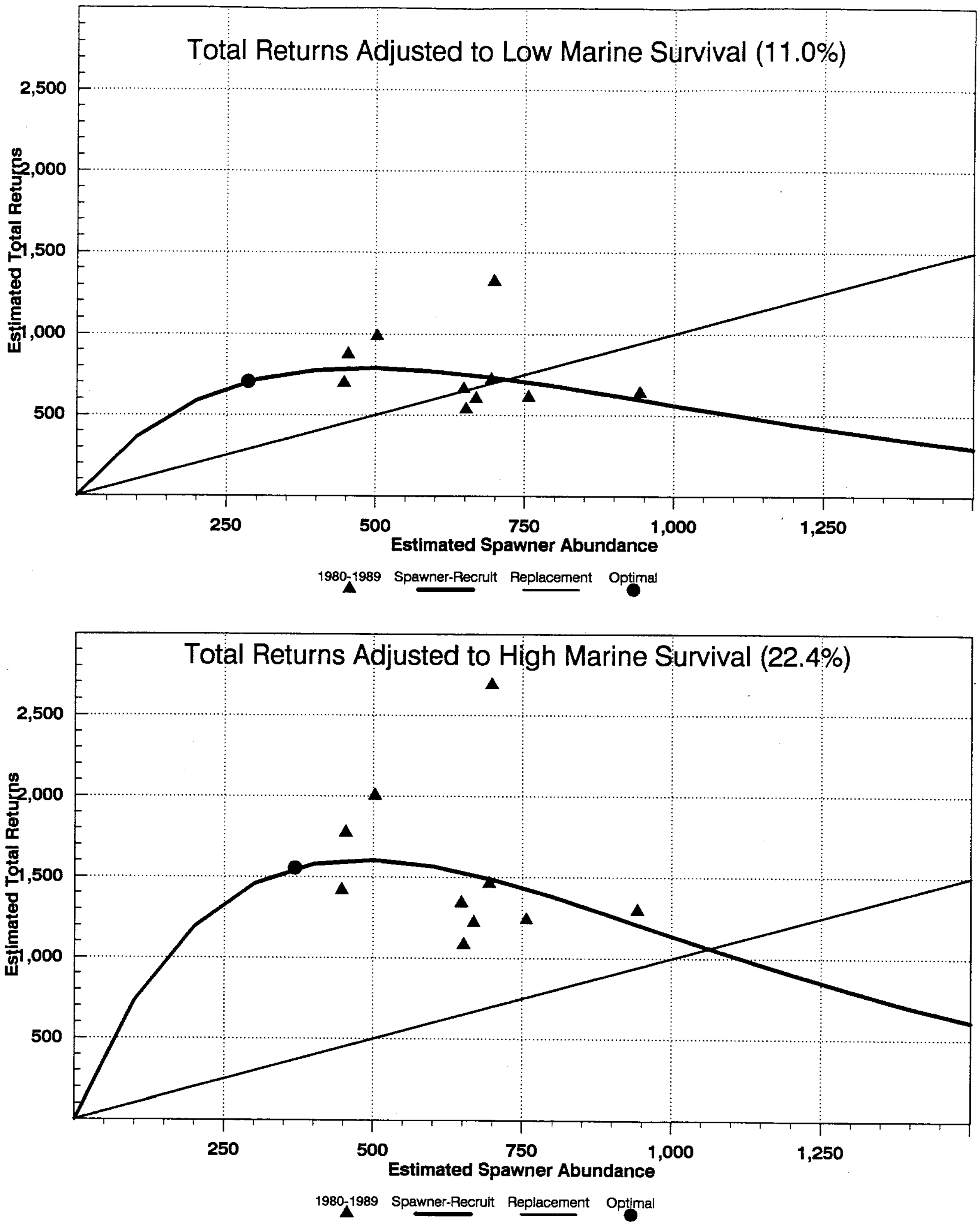


Figure 9. Spawner-recruit relationship for Auke Creek coho salmon using total returns adjusted to low and high marine survival conditions.

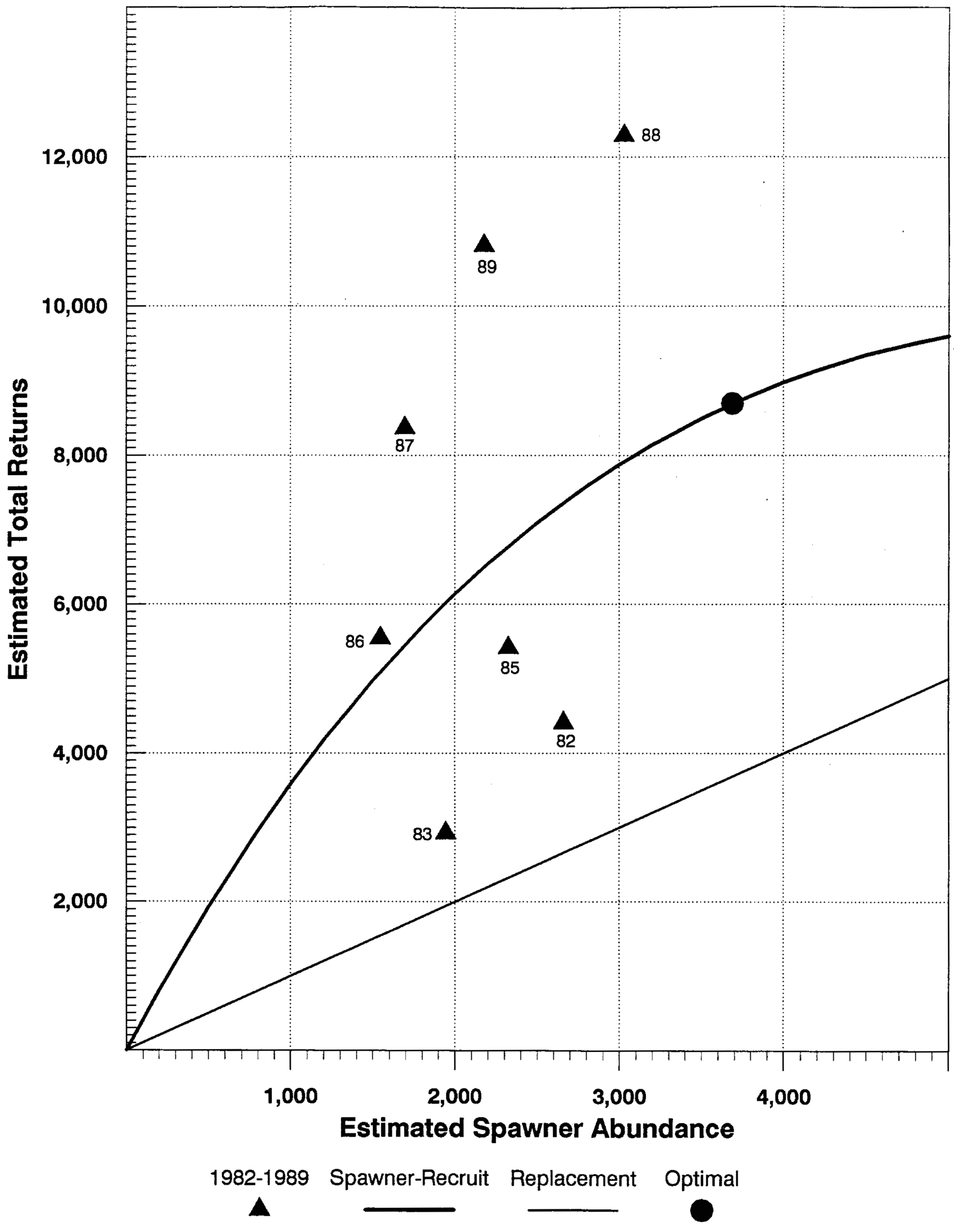


Figure 10. Spawner-recruit relationship for Ford Arm Lake coho salmon using unadjusted total returns.

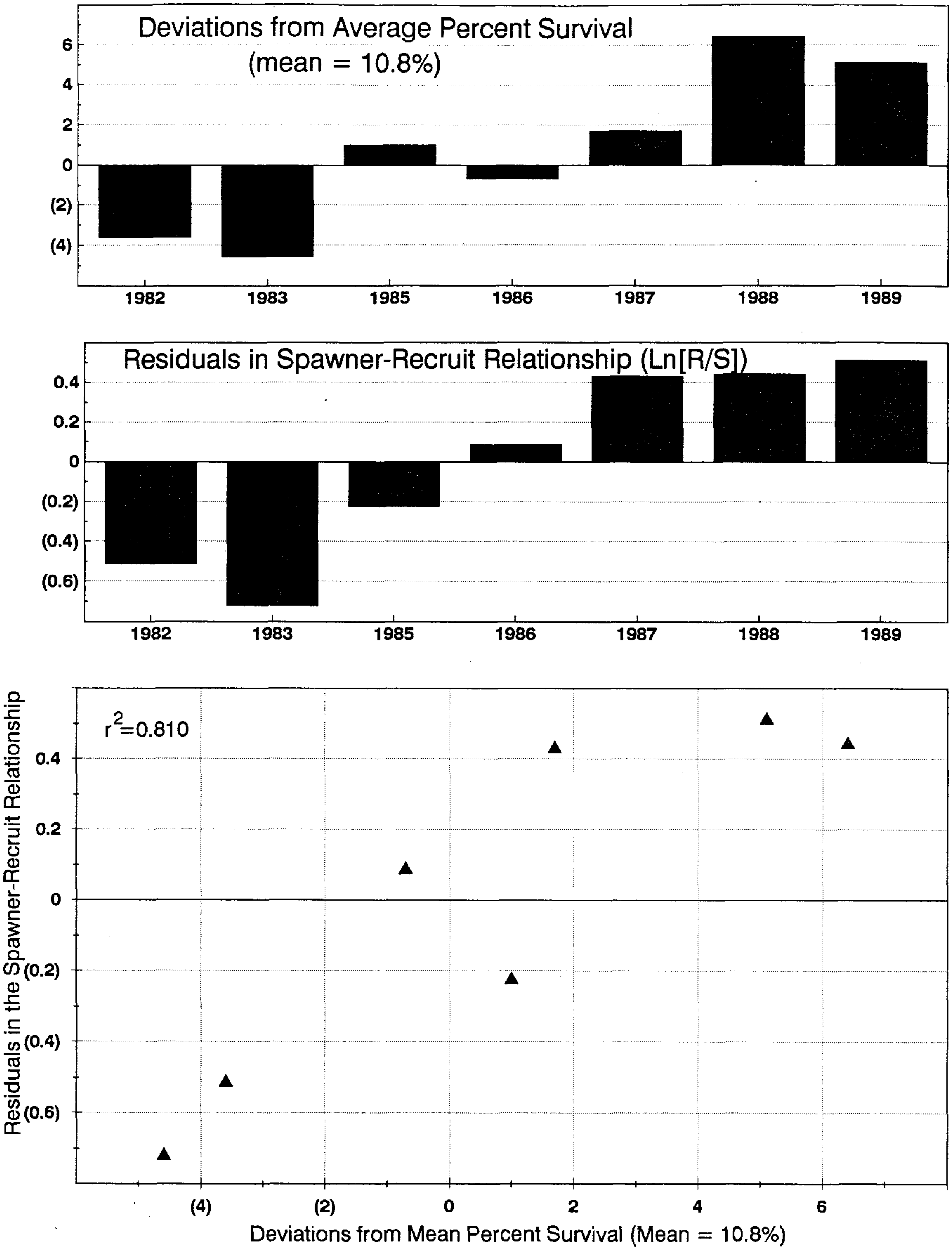


Figure 11. Deviations from average marine survival and residuals in the spawner-recruit relationship for Ford Arm Lake coho salmon.

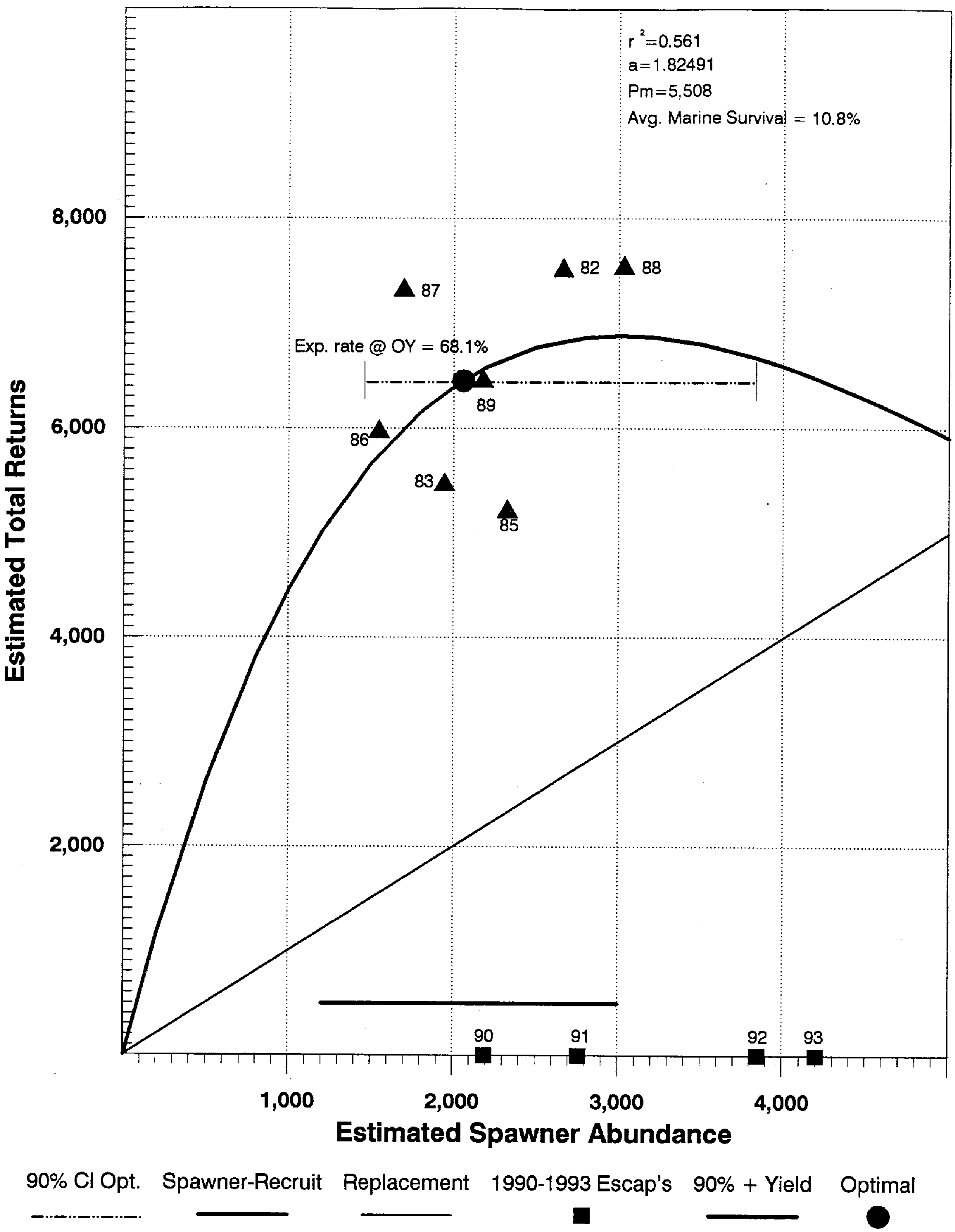


Figure 12. Spawner-recruit relationship for Ford Arm Lake coho salmon using total returns adjusted to average marine survival conditions.

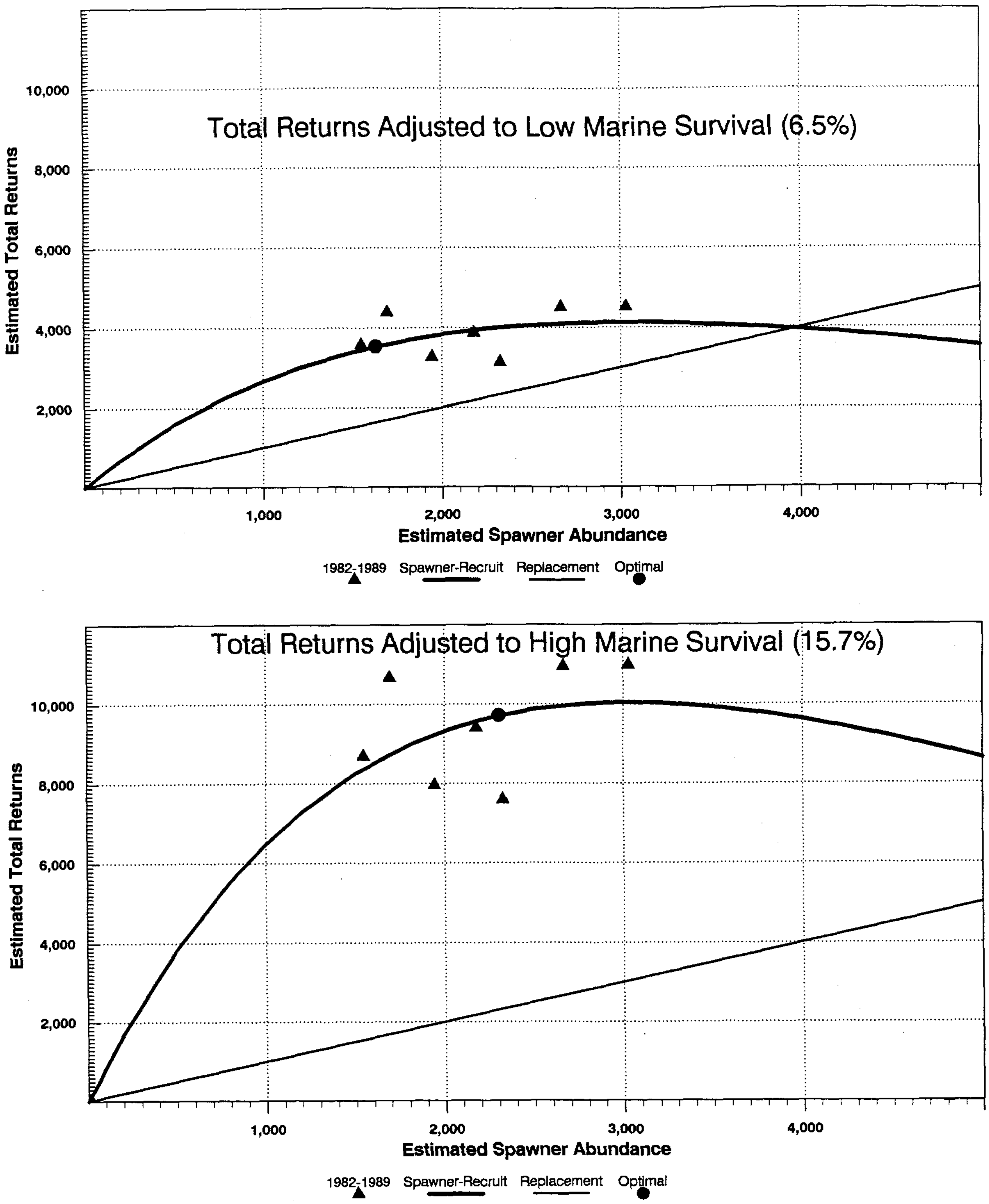


Figure 13. Spawner-recruit relationship for Ford Arm Lake coho salmon using total returns adjusted to low and high marine survival conditions.

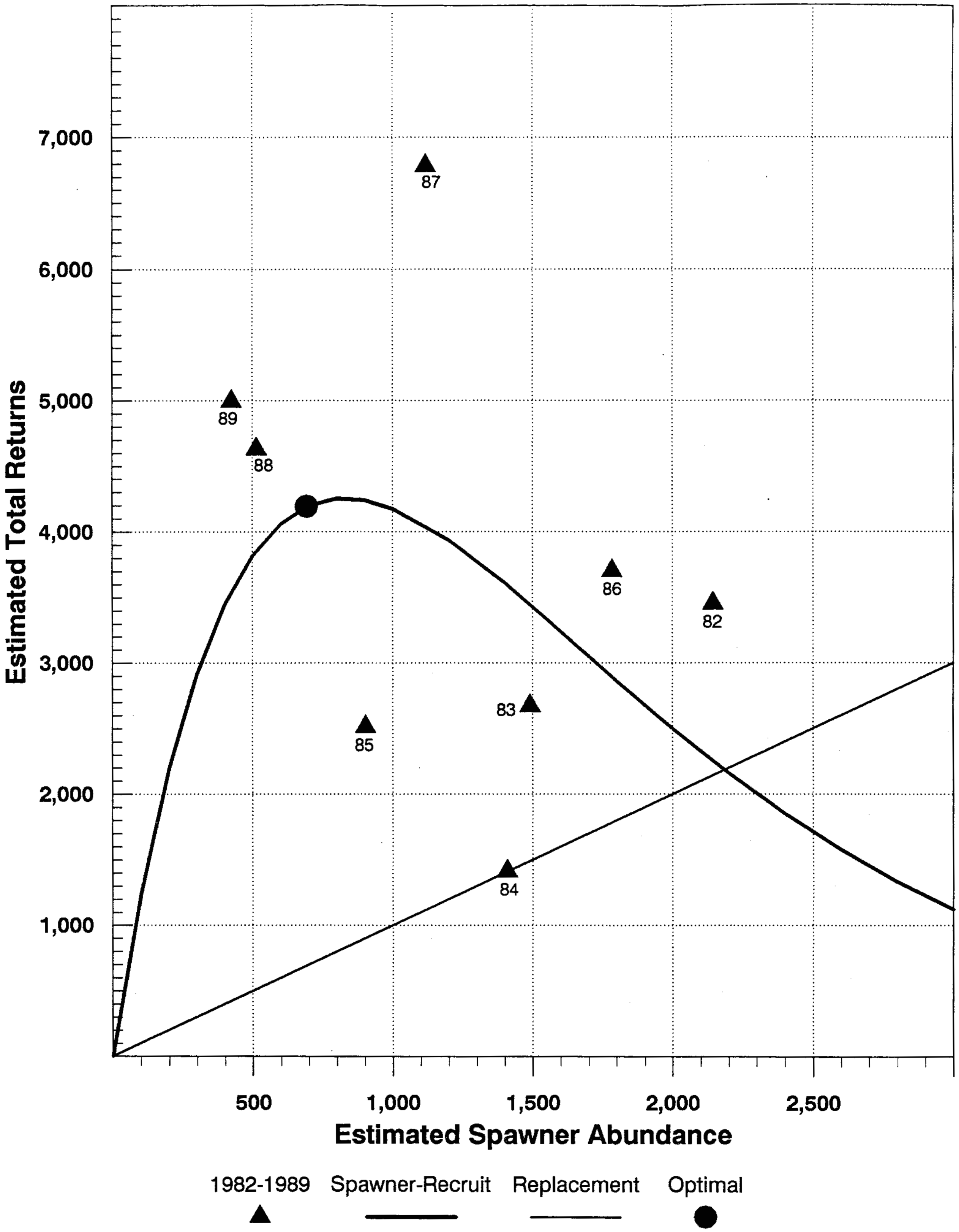


Figure 14. Spawner-recruit relationship for Hugh Smith Lake coho salmon using unadjusted total returns.

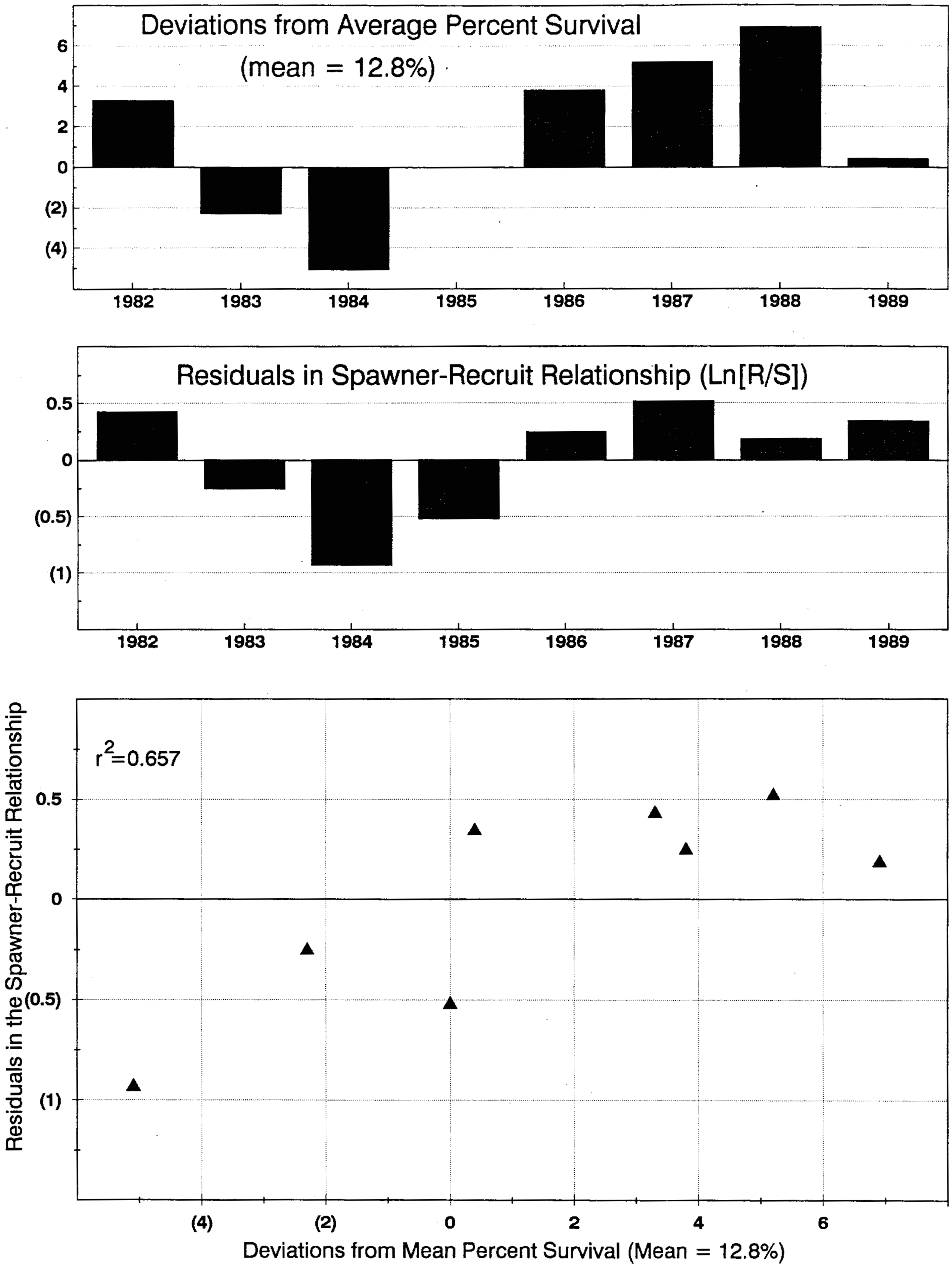


Figure 15. Deviations from average marine survival and residuals in the spawner-recruit relationship for Hugh Smith Lake coho salmon.

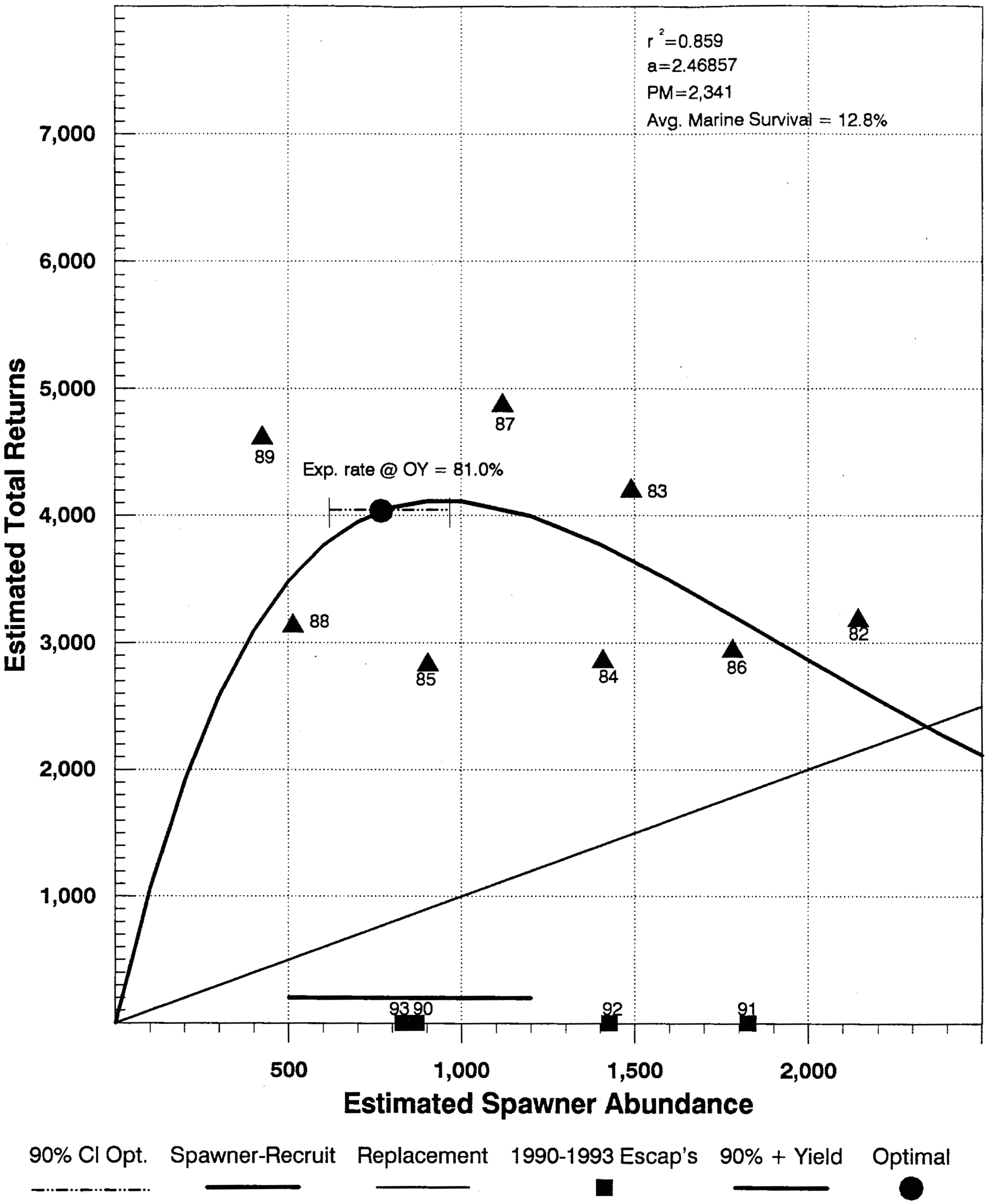


Figure 16. Spawner-recruit relationship for Hugh Smith Lake coho salmon using total returns adjusted to average marine survival conditions.

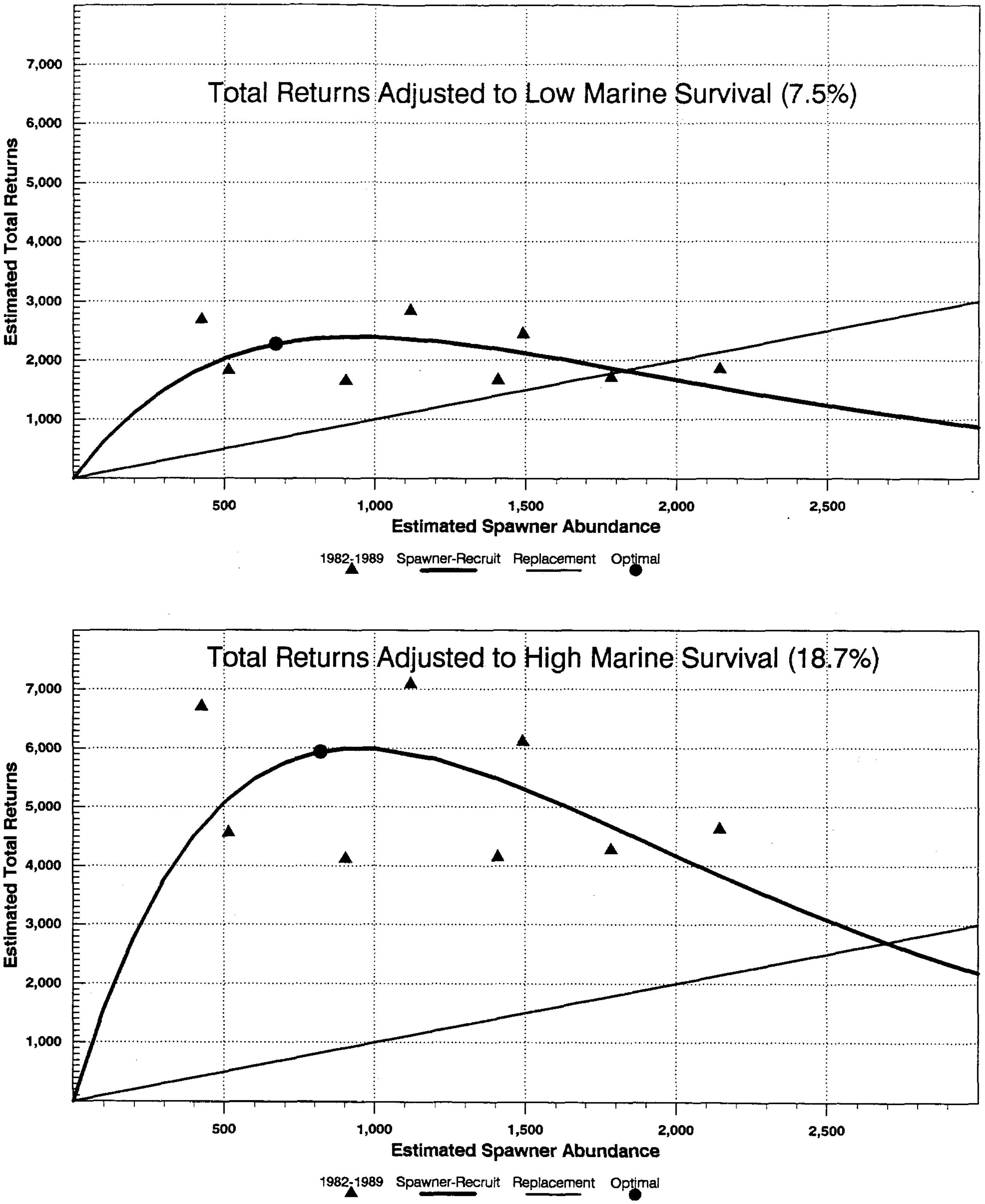


Figure 17. Spawner-recruit relationship for Hugh Smith Lake coho salmon using total returns adjusted to low and high marine survival conditions.

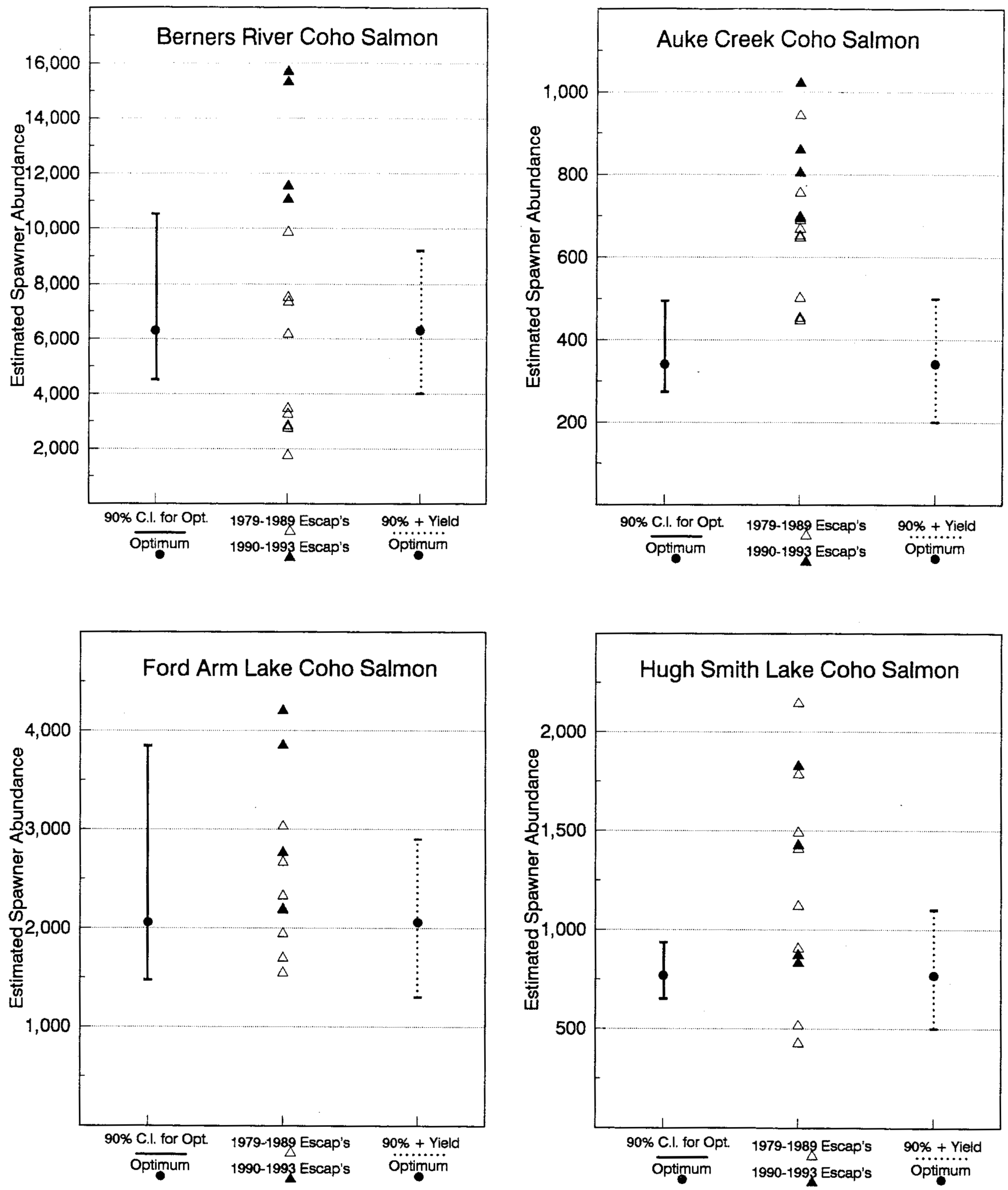


Figure 18. Comparison of coho salmon escapements to those ranges calculated to represent the 90% confidence interval for the optimum and to represent 90% or more of the maximum yield for four stocks.

APPENDIX TABLES

Appendix Table 1. Estimated age composition of coho salmon returning to the Berners River, 1982-1993.

PART 1; Age Composition of Berners River Coho Salmon (No. of sampled fish):

	Number of Fish Sampled by Age				Total
Return Year	Age 3	Age 4	Age 5	Age 6	Number of Fish Sampled
1982	95	210	26	0	331
1983	137	413	81	5	636
1984	-	-	-	-	0
1985	121	214	22	2	359
1986	60	198	21	0	279
1987	67	478	11	0	556
1988	241	231	3	0	475
1989	130	297	14	0	441
1990	250	211	7	0	468
1991	212	362	7	0	581
1992	253	282	5	0	540
1993	137	388	5	0	530

PART 2; Age Composition of Berners River Coho Salmon as Percent of Total Run:

	Estimated Percent Age Composition				
Return Year	Age 3	Age 4	Age 5	Age 6	Total
1982	28.7%	63.4%	7.9%	0.0%	100.0%
1983	21.5%	64.9%	12.7%	0.8%	100.0%
1984	-	-	-	-	100.0%
1985	33.7%	59.6%	6.1%	0.6%	100.0%
1986	21.5%	71.0%	7.5%	0.0%	100.0%
1987	12.1%	86.0%	2.0%	0.0%	100.0%
1988	50.7%	48.6%	0.6%	0.0%	100.0%
1989	29.5%	67.3%	3.2%	0.0%	100.0%
1990	53.4%	45.1%	1.5%	0.0%	100.0%
1991	36.5%	62.3%	1.2%	0.0%	100.0%
1992	46.9%	52.2%	0.9%	0.0%	100.0%
1993	25.8%	73.2%	0.9%	0.0%	100.0%
Averages	32.8%	63.1%	4.1%	0.1%	100.0%

Appendix Table 2. Estimated age composition of coho salmon returning to Auke Creek, 1982-1993.

PART 1; Age Composition of Auke Creek Coho Salmon (No. of sampled fish):

	Number of Fish Sampled by Age					Total
Return Year	Age 3	Age 4	Age 5	Age 6	Age 7	Number of Fish Sampled
1982	66	87	15	0	0	168
1983	106	275	2	0	0	383
1984	37	325	20	0	0	382
1985	6	69	58	12	1	146
1986	22	142	38	3	0	205
1987	14	61	29	4	0	108
1988	7	152	97	11	0	267
1989	187	449	11	0	0	647
1990	32	121	0	0	0	153
1991	36	117	0	0	0	153
1992	70	175	5	0	0	250
1993	36	345	13	0	0	394

PART 2; Age Composition of Auke Creek Coho Salmon as Percent of Total Run:

	Estimated Percent Age Composition					
Return Year	Age 3	Age 4	Age 5	Age 6	Age 7	Total
1982	39.3%	51.8%	8.9%	0.0%	0.0%	100.0%
1983	27.7%	71.8%	0.5%	0.0%	0.0%	100.0%
1984	9.7%	85.1%	5.2%	0.0%	0.0%	100.0%
1985	4.1%	47.3%	39.7%	8.2%	0.7%	100.0%
1986	10.7%	69.3%	18.5%	1.5%	0.0%	100.0%
1987	13.0%	56.5%	26.9%	3.7%	0.0%	100.0%
1988	2.6%	56.9%	36.3%	4.1%	0.0%	100.0%
1989	28.9%	69.4%	1.7%	0.0%	0.0%	100.0%
1990	20.9%	79.1%	0.0%	0.0%	0.0%	100.0%
1991	23.5%	76.5%	0.0%	0.0%	0.0%	100.0%
1992	28.0%	70.0%	2.0%	0.0%	0.0%	100.0%
1993	9.1%	87.6%	3.3%	0.0%	0.0%	100.0%
Averages	18.1%	68.4%	11.9%	1.5%	0.1%	100.0%

Appendix Table 3. Estimated age composition of coho salmon returning to Ford Arm Lake, 1985-1993.

PART 1; Age Composition of Ford Arm Lake Coho Salmon (No. of sampled fish):

	Number of Fish Sampled by Age					Total
Return Year	Age 3	Age 4	Age 5	Age 6	Age 7	Number of Fish Sampled
1985	15	112	198	84	13	422
1986	51	254	112	10	0	427
1987	23	178	270	28	1	500
1988	42	329	99	4	0	474
1989	18	200	119	2	0	339
1990	37	323	110	0	0	470
1991	107	1,758	624	10	0	2,499
1992	32	1,789	1,124	28	0	2,973
1993	25	2,073	1,901	52	0	4,051

PART 2; Age Composition of Ford Arm Lake Coho Salmon as Percent of Total Run:

	Estimated Percent Age Composition					
Return Year	Age 3	Age 4	Age 5	Age 6	Age 7	Total
1985	3.6%	26.5%	46.9%	19.9%	3.1%	100.0%
1986	11.9%	59.5%	26.2%	2.3%	0.0%	100.0%
1987	4.6%	35.6%	54.0%	5.6%	0.2%	100.0%
1988	8.9%	69.4%	20.9%	0.8%	0.0%	100.0%
1989	5.3%	59.0%	35.1%	0.6%	0.0%	100.0%
1990	7.9%	68.7%	23.4%	0.0%	0.0%	100.0%
1991	4.3%	70.3%	25.0%	0.4%	0.0%	100.0%
1992	1.1%	60.2%	37.8%	0.9%	0.0%	100.0%
1993	0.6%	51.2%	46.9%	1.3%	0.0%	100.0%
Averages	5.3%	55.6%	35.1%	3.5%	0.0%	100.0%

Appendix Table 4. Estimated age composition of coho salmon returning to Hugh Smith Lake, 1985-1993.

PART 1; Age Composition of Hugh Smith Lake Coho Salmon (No. of sampled fish):

	Number of Fish Sampled by Age					Total
Return Year	Age 3	Age 4	Age 5	Age 6	Age 7	Number of Fish Sampled
1985	64	253	188	16	0	521
1986	46	239	135	18	0	438
1987	26	252	103	6	1	388
1988	14	74	81	11	3	183
1989	33	119	54	0	0	206
1990	87	277	98	0	0	462
1991	132	1,365	152	6	0	1,655
1992	43	700	232	6	0	981
1993	28	356	62	2	0	448

PART 2; Age Composition of Hugh Smith Lake Coho Salmon as Percent of Total Run:

	Estimated Percent Age Composition					
Return Year	Age 3	Age 4	Age 5	Age 6	Age 7	Total
1985	12.3%	48.6%	36.1%	3.1%	0.0%	100.0%
1986	10.5%	54.6%	30.8%	4.1%	0.0%	100.0%
1987	6.7%	64.9%	26.5%	1.5%	0.3%	100.0%
1988	7.7%	40.4%	44.3%	6.0%	1.6%	100.0%
1989	16.0%	57.8%	26.2%	0.0%	0.0%	100.0%
1990	18.8%	60.0%	21.2%	0.0%	0.0%	100.0%
1991	8.0%	82.5%	9.2%	0.4%	0.0%	100.0%
1992	4.4%	71.4%	23.6%	0.6%	0.0%	100.0%
1993	6.3%	79.5%	13.8%	0.4%	0.0%	100.0%
Averages	10.1%	62.2%	25.8%	1.8%	0.0%	100.0%

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