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HATCHERY AND WILD FISH PRODUCTION OF ANADROMOUS SALMON IN THE COLUMBIA RIVER BASIN

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ABSTRACT

Because of extensive hydroelectric development, the Columbia River Basin has been the site of the most extensive hatchery program for Pacific salmon (*Oncorhynchus* spp.) in North America. Wild salmonids have declined from former abundances between 8 and 16 million fish to under 2 million fish. Wild stocks have been eliminated above high dams, and in other regions of the basin wild stock abundance is as low as 1% of abundances 50 years ago.

Annual hatchery releases now number nearly 250 million juveniles, with a combined weight of over 4 million kg in 1988. Survival and adult production are estimated from coded-wire-tag data. Between 1971 and 1984, no consistent upward or downward trends in survival were apparent, although for most stocks the brood years 1982 and 1983 were exceptionally good. Adult production of fall chinook (*O. tshawytscha*) is estimated to have ranged between 280,000 and 2 million per brood year. Spring chinook adult production has ranged from 133,000 to 640,000. Adult production of coho (*O. kisutch*) has ranged from 200,000 to 2.25 million.

The dominant causes of the decline of wild stocks have been overexploitation, dams, and habitat loss. Artificial production has negatively impacted wild stocks through many mechanisms, including competition for space and food, predation by hatchery fish on wild stocks, genetic effects, hatchery fish causing premature emigration of wild fish, introduction of disease and parasites, robbing of wild stocks for hatchery brood stock, hatchery structures as barriers to wild fish passage, the timing of the water budget, and stimulation or maintenance of fishing pressure by hatchery production. Despite this long list of negative impacts, overexploitation, dams, and habitat loss are almost surely much more important in explaining the decline of wild stocks. However, now that wild stocks are severely depressed, the negative impacts of hatcheries will hinder recovery of wild stocks.

Hatcheries have impacted wild stocks primarily by making society believe that we could have intense fisheries, dams, and habitat loss, and have salmon by building hatcheries. The hatchery system on the Columbia has failed to mitigate or compensate for the hydroelectric system and other habitat loss; far fewer salmonids occur in the Columbia Basin now than before European exploitation. While lower river hatcheries have been successful at producing fish for aboriginal, recreational, and commercial exploitation, those hatcheries have not been able to rebuild or help maintain wild stocks.

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KEY WORDS

Columbia River, hatcheries, habitat loss, hydroelectric dams, mitigation, overexploitation, Pacific salmon, wild stocks

INTRODUCTION

To understand the interaction between wild and hatchery stocks, we must consider three essential ingredients: wild stocks, hatcheries, and biological studies on both. The Columbia River Basin (CRB) has all of these. Estimates indicate that between 5 and 50 million wild spawning fish returned to the Columbia each year in the beginning of this century. There are now at least 100 hatcheries or related facilities on the Columbia and its tributaries (Table 1, Fig. 1), and an enormous amount of research has been conducted on the Columbia. Each year at least $200 million are spent on fisheries-related activities in the Columbia, and there are hundreds of biologists working on Pacific salmon in the CRB.

In this paper, we first review the history of wild stocks on the Columbia, drawing from published papers and reports. We next summarize the history of hatchery releases, survival, and adult fish production from CRB hatcheries. For this analysis, we have assembled agency records and generated what we believe is now the most complete database available on Columbia hatchery release and survival data. Finally we review what is known about the interaction between wild and hatchery fish in the CRB. Again this is drawn from published papers and agency reports.

THE HISTORY OF WILD FISH PRODUCTION

PRE-EUROPEAN ABUNDANCE

Several authors have attempted to estimate the abundance of salmon on the Columbia prior to the development of the hydroelectric and hatchery systems. The data available have been number of fish canned or caught, dam counts since the advent of the fish ladders beginning with Bonneville Dam, and most recently actual escapement counts in some systems. For the period prior to European development of commercial fisheries, the only data are processor records and estimates of native peoples' catches.

While estimates of abundance range as high as 500 million fish (NWPPA 1985), the two most credible methods for assessing original abundance are Chapman (1986) who used catch data and estimates of exploitation rate and estimated about 8 million fish of all species, and the Pacific Fisheries Management Council (PFMC 1979), which used habitat availability to arrive at a figure of 6.2 million fish. The Northwest Power Planning Council (NWPPC 1986) adopted a range of 10-16 million fish. There is considerable uncertainty about these numbers of course, but for illustration, Chapman's (1986) estimates by species and race are presented in Table 2.

The Chapman and PFMC estimates are probably the most reliable for abundance in the early years of European exploitation, but they almost surely represent an underestimate of abundance prior to human exploitation. Craig and Hacker (1940) estimated aboriginal consumption in 1800 as 8.2×10^6 kg and the Northwest Power Planning Council estimated aboriginal consumption in the same period as 19×10^6 kg. These figures would translate to catches in numbers of fish of 1-2 10^6 fish, which would constitute an exploitation rate of perhaps 10-20%. Such an exploitation rate would have likely reduced or eliminated many unproductive substocks that occupied marginal habitats, so that by the time the catch records Chapman used began, the stocks were reduced well below their virgin abundances.

CATCH TRENDS PRIOR TO THE DAMS AND HATCHERIES

The catch records provide us with the best record of abundance in the early days of European exploitation. Figure 2 shows the catch history of chinook (*Oncorhynchus tshawytscha*) salmon from 1866 to 1986 (from McIsaac 1990). The reliability of such data as an indicator of total return depends on a constant exploitation fraction, and no harvest of Columbia River fish in fisheries outside of the Columbia. This is clearly a poor measure in the last 30 years because of development of ocean troll fisheries and severe in river restrictions on harvest. However, for the period 1866-1950, we believe the data are a good reflection of the decline in abundance for chinook salmon.

RECENT TRENDS IN ABUNDANCE

Coho (*O. kisutch*) salmon have always been most abundant in the lower river and are now confined almost exclusively to rivers below Bonneville Dam. Since 1950, the Oregon Department of Fish and Wildlife (ODFW) has maintained index sections of streams for counting wild spawning coho. Figure 3 shows the trends in wild coho abundance as indicated by ODFW index counts (ODFW 1990). Wild coho appear to now be at 1% of their abundance in 1950.

Among the best documented wild stocks are Snake River chinook salmon. Figure 4 shows the trends in escapement of Snake River fall chinook, and the Grand Ronde spring chinook stock (ODFW 1991a). Similar trends in wild stock escapements for other spring chinook stocks in the Snake River have been documented by Chapman et al. 1991.

THE HISTORY OF HATCHERY PRODUCTION

HATCHERY RELEASES

Anadromous salmonids are reared and released into the CRB at more than 100 state, federal, tribal, and privately operated hatcheries[1] (DeLarm and Smith 1990). In general, five state and federal agencies[2] are responsible for maintaining records on salmonid releases from these

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[1]For the purposes of this paper, "hatchery" is used to indicate true hatcheries, rearing ponds, and other facilities dedicated to production of anadromous salmonids.

[2]United States Fish and Wildlife Service (USFWS), Washington Department of Fisheries (WDF), Washington Department of Wildlife (WDW), Oregon Department of Fish and Wildlife (ODFW), and Idaho Department of Fish and Game (IDFG).

hatcheries. Despite recent attempts to coordinate and centralize hatchery rearing, tagging, and release data (e.g., through the Pacific States Marine Fisheries Commission [PSMFC] and Fish Passage Center [FPC]), no accurate historical record exists documenting total releases since 1975. With interest in enhancement activities at an all time high, and numerous questions being raised about the impacts of hatcheries, a complete picture of CRB hatchery practices is imperative.

In a series of reports (Wahle et al. 1975; Wahle and Smith 1979; Smith and Wahle 1981), coast-wide releases of hatchery-reared salmonids were summarized. Smith and Wahle (1981) noted that demand for copies of the reports was overwhelming, and the reports were in use by all U.S. and Canadian fisheries management agencies as well as by many researchers. However, those reports have not been updated recently, and the authors informed us that the original data no longer existed in computerized format. Our first objective, therefore, was to create a database of salmonid releases that included the entire range of complete records, and to make this database publicly available.

Since 1973, many of the CRB hatcheries have participated in the coded-wire-tag (CWT) program (see Johnson and Longwill 1991). One of the major purposes of this program is to determine survival rates of hatchery-reared salmonids. While counts of tagged fish, and those associated with tagged releases, annually number in the millions, large numbers of releases are not tagged. Records on the rearing, release, and capture history of tagged fish are relatively complete and are publicly available through the Regional Mark Processing Center of the PSMFC. Releases not associated with tag groups are not as well-documented. Our second objective was to estimate chinook and coho survival rates by hatchery for the entire CRB system. We accomplished this by combining the total release record we had compiled with survival rates calculated from CWT release groups.

Finally, our third objective was to analyze our data sets for trends in survival rates and suggest possible causes for variability in survival rates among species and hatcheries.

Assembly of Release Data

To assemble the complete release history for CRB anadromous salmonid releases, we first scoured the literature for available data. While some of the agencies published hatchery release data (e.g., in processed reports), we found it necessary to obtain the data directly from the agencies. As a minimum, we specified that individual release group records contain the following information: rearing hatchery, species, race, brood year, number released, weight of releases, release site, release date, and brood stock. With one major exception, the six agency data managers (USFWS hatcheries are managed by two field offices) were able to provide at least this much detail. The IDFG tracks release year instead of brood year, thus we developed an algorithm based on size at, and month of, release to back-calculate brood year. Two other databases completed the original data from which we worked: the Smith and Wahle report (1981), which we had rekeyed, gave us 1958-1975 brood year releases; and the FPC database, which incorporated most post-1985 releases. A total of 12 anadromous salmonid species/races have been reared in CRB hatcheries since 1960 (Table 3).

The time series provided to us differed greatly among the five agencies, both in content and historical completeness. Complicating matters is the fact that many hatcheries are co-operated by more than one agency, and transfer of releases between hatcheries or agencies, or both, is common. As a result, release records are duplicated frequently with accompanying discrepancies. As a general rule, the rearing agency records were used to resolve discrepancies. Where there was overlap with either the Smith and Wahle (1981) data or the FPC's database, agency-provided data were generally used. In many cases, however, judgment calls were required and, when necessary, the data managers were contacted for clarification.

In dealing with databases of this sort, unanticipated problems unfortunately will arise, particularly when examining older records in microscopic detail. Smith and Wahle (1981) found that release data prior to 1960 were difficult to obtain; in our case, we had problems with the period 1975-1980. Still, we believe the assembled database represents the most complete and accurate record of CRB hatchery reared salmonid releases.

CODED-WIRE-TAG ANALYSIS

The second step in our analysis was to estimate CRB system-wide survival rates of coho and chinook salmon. We relied upon the PSMFC's CWT database, which has been continually expanded and improved since the beginning of CWT releases in 1971. CWT releases groups are classified by rearing condition: P (production), E (experimental), B (both production and experimental), I (index), K (PSC Key Index stock), and O (other). In general, P, B, I, and K releases represent groups reared under standard hatchery conditions, and E releases denote special rearing conditions such as variation in food, length of rearing period or release site.

When a CWT fish is recovered—either in a fishery or at the hatchery—an expansion factor is employed to estimate total recoveries represented by that fish. These expansion factors are determined by the recovery agencies reflecting their sampling coverage. The PSMFC database contains both actual recovery and expanded numbers. Recoveries are contained in two separate, incompatible formats, one for recoveries prior to 1984, the other (newer format) for later recoveries. Both formats contain recoveries from the other time period but incompletely so. The new format, which is simpler to use, lacks WDF recovered fish from 1975-1983. To determine total recoveries of CWT releases, we used the new format and obtained raw recovery records from WDF to fill in missing data.

To estimate survival rates, we employed a Virtual Population Analysis (VPA) technique (Gulland 1965, Pope 1972, Hilborn and Walters 1992), which has become the standard stock assessment methodology used in managing Pacific salmonids. VPA reconstructs numbers at age of a cohort based on the total estimated catch and escapement. The terminal catch is added to the escapement of the oldest age group (generally age 6 for chinook and age 4 for coho) and then expanded by an age-specific natural mortality rate (Table 4). Subsequent cohort sizes are calculated in the same manner, always adding in the numbers surviving to the next older age group. We employed the following basic VPA algorithm:

$$N_t = \frac{N_{t+1} + (C_t + E_t)}{1 - M_t} \tag{1}$$

where N_t = number of fish alive at the beginning of age t,
C_t = catch of age to fish,
E_t = escapement of age t fish, and
M_t = natural mortality rate of age t fish.

Survival rate to age *t* is the ratio of the numbers surviving to age *t* divided by the cohort size at time of release:

$$\text{survival}_t = \frac{N_t}{N_{\text{released}}} \tag{2}$$

To standardize comparisons between hatcheries and brood years, we calculated, and report here, survival to age 2; i.e., the fraction of releases estimated to have survived to age 2.

To look at trends in species survival over time, we computed weighted survival averages for individual hatcheries by brood year; to examine system-wide performance we averaged across hatcheries. For individual hatcheries, if more than one tag-code group was released for a single brood year, the survivals were weighted by release size. To estimate annual survival rates, individual hatchery survival rates were averaged (weighted by total hatchery releases). Survival rates for hatchery/brood year combinations without tag-codes (and, therefore, no survival estimates) were assumed equal to the average for all other hatcheries during that brood year.

There was great variability in CWT release coverage by species, hatchery and brood year. Table 5 summarizes the number of tag-codes used in our analysis and the breakdown by release type. The largest number of CWT groups were released for fall chinook (1,027, brood years 1971-84), followed by coho (841, 1974-86), spring chinook (633, 1971-84) and summer chinook (56, 1974-84). To maximize the number of hatcheries and brood years represented by direct VPA estimates of survival, we utilized all tag-code groups. We found that survival estimates based solely on P, B, I, and K tag-code groups were virtually identical to estimates derived using all tag-codes. The proportion of hatchery releases represented by tag-code groups for each species was relatively low until the mid-1970s (Table 6). We defined a non-represented hatchery/brood year as a brood year for which no CWT groups were included among that hatchery's releases, thus providing no means of directly estimating survival and production via VPA analysis.

There are two weaknesses associated with this VPA technique. First is the critical importance of the assumed natural mortality rates. These rates, while widely used (e.g., by the PSC), are poorly determined and probably not constant over time, as we have assumed. Second, many salmon fisheries have associated with them a "shaker" mortality resulting from the catch and release of sub-legal fish. Some of these shakers presumably die and their numbers are not reported in catch statistics, thus resulting in underestimation of fishing mortality and cohort size. Ignoring the effect of shaker mortality, however, does not impact our results if we can assume that the rate of shaker mortality is the same for all tag-code groups. In this case, our survival rates should be interpreted as relative survival rates, useful for comparison between groups and examination of survival trends.

HATCHERY RELEASES HISTORY

Between 1960 and 1970, numerical releases of artificially reared anadromous salmonids (smolt stage and younger) rose steadily from 100 million to 200 million (Table 7, Fig. 5). Thereafter, release numbers remained relatively steady until 1987, when releases jumped to 250 million annually. A second measure of hatchery production is the weight of the releases. Total weight of salmonid releases has grown steadily, from 1.3 million pounds in 1960 to 9.8 million pounds in 1988 (Table 8, Fig. 6). This trend reflects a change in hatchery practice towards longer rearing periods and larger release sizes.

In terms of numbers, fall chinook salmon are the dominant species, averaging over 50% of total releases for the 1960-88 period. Since 1980, fall chinook brood year releases have ranged from 90 to 130 million. Other major release species are coho (35-66 million), spring chinook (29-44 million) and summer steelhead (*O. mykiss*, 11-20 million). Much smaller numbers of winter steelhead (1.0-4.8 million) and summer chinook (1.7-4.8 million) are also released. There have also been sporadic releases of several other anadromous salmonid species, including chum (*O. keta*) and sockeye (*O. nerka*) salmon.

The release picture by weight looks very different. Four species—coho, summer steelhead, fall and spring chinook—are presently released in roughly equal amounts. Through the 1960s and 70s, coho was the major species, with releases first topping 2 million pounds in 1969, a level at which they have remained up to the present. Spring and fall chinook releases have increased steadily from 300,000 pounds each in 1960 to 1 million pounds in the early 70s to their current releases of 2 million pounds. The most spectacular rise has been with summer steelhead, whose releases have grown from 70,000 pounds in 1960 to 2.8 million in 1988. Winter steelhead releases are presently in the 500,000 pound range, up from 150,000 pounds in 1960. Summer chinook, releases of which began in 1967, currently average 70,000 pounds annually.

While a large number of hatcheries rear and release anadromous salmonids, relatively few are responsible for the bulk of the releases (Table 9). A total of 63 hatcheries released 1960-88 brood year fall chinook; however, 75% of the releases came from just 11 hatcheries. The largest fall chinook hatchery, Spring Creek, has released as many as 27 million in a single year and nearly 500 million of the total release of 2.5 billion during the 1960-88 period.

HATCHERY SURVIVAL AND PRODUCTION

To examine hatchery performance, we analyzed returns from over 2,500 CWT groups. The species survival rates and adult production estimates are presented below for hatcheries, both on an individual and combined basis.

Fall Chinook

For brood years 1971 to 1984, 1,027 tag-code groups were released from 33 hatcheries. CWT coverage of hatchery/brood year releases was very low up to the 1976 brood year, but remained greater than 63% thereafter. Therefore, survival and production estimates of the earlier brood years are subject to greater error. Combined fall chinook survival of CRB hatchery releases ranged from 0.56% to 4.49% (Fig. 7). Survival rates showed no clear pattern in the early 70s, fluctuating between 2% and 4.5%. By 1977, survival rates had dropped to under 1%, where they remained up through the 1981 brood year. The 1982-84 brood years showed increased survival and had reached 3.5% in 1984.

We estimated adult production by using an adult equivalency (AE) rate of 0.5 for fish surviving to age 2. Thus, if 4% of releases survived to age 2, we estimated that 2% contributed to either catch or escapement. Multiplying adult equivalence by the release numbers previously generated gave us an estimate of adult production. As releases were relatively stable over the period of CWT data, the pattern in adult production is similar to that of survival rate (Fig. 7). Production peaked in 1974 at 2,055,052 fall chinook, and the least productive brood year was 1981 at 281,208 adults.

As with all species, hatcheries varied considerably in producing adult fall chinook. Survival rates for individual CWT groups ranged between 0.00% and 21.54%. Weighted averages for hatchery/brood years varied from 0.00% (South Santiam, 1977) to 17.17% (Grays River, 1974, but based on just 5,367 tagged smolts). Examination of long-term averages allows us to qualitatively separate the hatcheries into three groups on the basis of survival rates (Fig. 8). The best fall chinook hatcheries (e.g., Spring Creek, Bonneville and Priest Rapids) produce releases that have 2-4% survivals. The middle group of hatcheries (e.g., Little White Salmon, Cowlitz, and Stayton Pond) yielded 1-2% survivals and have performed well in recent years, while the lowest group of hatcheries (e.g., Elokomin, Klickitat, and Lower Kalama) have at best 1% survival of their releases.

There is no clear geographic pattern to which hatcheries produce more successful releases. Lower Columbia River hatcheries (below and up to Bonneville dam) placed in all three groups, as was the case for mid-Columbia River hatcheries. Only two fall chinook hatcheries are located on the upper Columbia (Lyons Ferry) and Snake river (Hagerman). According to our criteria, both of these hatcheries would place in the middle group.

Spring Chinook

There were substantially fewer spring chinook than fall chinook CWT releases, both in absolute terms and in coverage by hatchery/brood year. A total of 633 groups were released from 36 hatcheries for the 1971-84 brood years. CWT groups have generally represented about 50% of the total spring chinook releases. Brood years with poor coverage are 1971-73, 1979 and 1981. Individual CWT group survivals ranged from 0.00% to 16.23%, while weighted averages for hatchery/brood years were between 0.00% (9 occurrences) and 13.76% (Cowlitz, 1973).

CRB hatchery-reared spring chinook averaged 2% survival for the 1971-84 brood years (Fig. 9), ranging from a high of 3.04% (1977 brood year) to a low of 0.75% (1978 brood year). Survival rates showed no consistent trend over this time period. Adult production (using a 0.5 AE rate) peaked for the 1983 brood year at 643,099, and was lowest for 1978 at 133,322 fish.

Considerable disparity existed among spring chinook hatcheries in terms of release survival (Fig. 10). Hatcheries with consistently high survivals included Cowlitz, Willamette and Marion Forks. In the case of spring chinook, we considered survivals greater than 2% to be good. The next class of hatcheries (e.g., Carson, South Santiam and Eagle Creek) produced 1-2% survivals. The least successful spring chinook hatcheries produce virtually no fish; i.e., survival rates less than 0.1%. Most of the Snake River hatcheries (e.g., Rapid River and Sawtooth) and Upper Columbia hatcheries (e.g., Leavenworth) fall into this category. As a general rule, we found that lower river hatcheries performed much better than hatcheries upriver from the dams.

Summer Chinook

In relative terms, summer chinook contribute very little to CRB hatchery chinook production. There were a total of just 56 CWT groups released for the 1974-84 brood years from seven hatcheries. CWT coverage of hatchery/brood year combinations has been very uneven: greater than 80% for five brood years, less than 10% for four brood years.

Survival rates for summer chinook have been very poor over the entire time period covered, never topping 1% of total releases (Fig. 11). Performance has been especially poor since the 1977 brood year, with survivals at or below 0.3%. Adult production estimates reflect the poor survivals, with a high of 12,673 in 1975 and a low of just 55 adults in 1978. A cautionary note, however, for the 1978 brood year: only one hatchery released a CWT group that year; thus it may not be representative of all releases.

Just two hatcheries rear and release summer chinook with any regularity: Wells and McCall. Both hatcheries produced very low survival rates (<1% for all brood year releases since 1974).

Coho Salmon

Coho salmon have been consistently and intensively tagged since the 1974 brood year. A total of 841 tag groups have been released from 19 hatcheries. The range of survival rates for individual CWT releases was 0.00% to 42.47%, weighted hatchery/brood years from 0.08% (Grays River, 1974) to 17.70% (Sandy, 1983).

Survival rates for coho are generally higher than chinook rates (Fig. 12). The 1976 to 1982 brood years showed consistent survivals to age 2 of just over 3%. The 1983 brood year was an excellent producer, with survivals averaging 11.45%. The 1984 brood year dropped back to the 3% level, followed by increased survival for 1985 and 1986 broods at 7.76% and 8.42%, respectively. Adult production (0.5 AE) showed the same basic trend, though with somewhat greater variability reflecting release trends. The best production year was for the 1983 brood at 2.25 million adults, and the least productive was the 1974 brood year at 208,744. We did not attempt to classify coho hatcheries by success rate as no clear difference was apparent between most of the hatcheries: survival rates generally rose and fell together.

INTERACTION BETWEEN WILD AND HATCHERY FISH

The Columbia River has been the site of an enormous hatchery program and considerable effort to study and save wild fish. As a result, the Columbia provides a focus for many studies of the interaction between wild and hatchery fish. In this section we review what is known from the Columbia about this interaction.

The interaction between wild and hatchery fish can be broadly divided into two classes: direct biological interaction and human induced interaction. We review first the direct biological interactions and then examine human induced interaction.

COMPETITION FOR SPACE AND FOOD

It has been widely observed that releasing hatchery-raised juvenile salmonids into natural habitat decreases the survival of existing natural spawning populations (Snow 1974, Thuember 1975, Vincent 1975, 1987, Bjornn 1978, McMullin 1982, Solazzi et al. 1983, Nickelson et al. 1986, Kennedy and Strange 1986, Petrosky and Bjornn 1988). Steward and Bjornn (1990) provide an extensive review of the mechanisms responsible and the associated literature. Competition for space and food in freshwater, and competition for food during downstream migration and in the early ocean life have all been discussed. While competition for space and food in freshwater would normally be minimal for hatchery releases in the mainstem and large tributaries, the practice of supplementation (releasing hatchery production into tributaries) has been widespread in many parts of the Columbia, and it is suspected (ODFW 1991b) to have been a factor in the decline of wild coho populations in the lower river.

Studying the mechanisms of competition during downstream migration or early ocean life is more difficult (competition for food and space during downstream migration has not been documented to our knowledge). Considerable evidence suggests density-dependent ocean survival for coho (McGie 1981, 1984; Nickelson 1986; Emlen et al. 1990); if this density dependence does exist, then the large hatchery releases of the last 3 decades have certainly had a negative impact on the wild stocks.

HATCHERY RELEASES AS PREDATORS

Many hatchery fish, particularly coho, spring chinook, and steelhead, are released at sizes large enough to prey upon wild fry. However, we know of no documentation of significant predation on wild stocks by hatchery stocks.

GENETIC EFFECTS

There is little question that hatchery practice through transfers, brood stock selection, and straying have altered the genetic structure of wild populations throughout the Columbia. The recent National Marine Fisheries Service (NMFS) ruling on the proposed listing of lower river coho as a threatened or endangered species found that lower river coho were genetically indistinguishable from the homogeneous hatchery stocks (ODFW 1991b). Similar dilution has occurred in chinook salmon (ODFW 1991a). Few if any stocks in the Columbia have been unaffected by genetic impacts of the hatchery system (see Goodman 1990 for a more detailed review).

Determining the impact of such changes on wild fish survival is difficult. Documentation indicates that hatchery fish, when spawning in wild streams, have poorer survival than wild fish (Leider et al. 1986), but it is difficult to determine how widespread this impact has been on wild fish throughout the Columbia basin.

PREMATURE EMIGRATION

Steward and Bjornn (1990) review a number of papers (Kuehn and Schumacher 1957, Hansen et al. 1984, and Hillman and Mullan 1989) that suggest that hatchery-released smolts induce wild fish to join them in seaward migration. If so, this may adversely impact wild fish that have not reached proper levels of smoltification.

DISEASE AND PARASITES

The disease resistance of wild fish has been eroded by crosses with hatchery fish (ODFW 1991b). Hatcheries throughout the Columbia have been plagued by disease problems (Goodman 1990), and these diseases have undoubtedly been transmitted to wild fish. For instance, Chapman et al. (1991) suggest that Snake River chinook salmon are heavily infected with bacterial kidney disease (BKD) as a result of large-scale hatchery programs on the Snake.

STIMULATION OF PREDATOR POPULATIONS

Frequent suggestions have been made that hatchery releases have led to the buildup of predator populations, either through aggregation or population increases. While there is great concern that predators, particularly squawfish (*Ptychocheilus oregonensis*), have increased in Columbia River reservoirs, and perhaps in the estuary as well, we know of no evidence that this has been a response to hatchery production.

ROBBING FOR BROOD STOCK

The most direct human-induced impact of hatchery programs on wild fish is direct takes of wild fish for hatchery brood stock. This has been a cause of the decline in wild stocks for coho (ODFW 1991b) and chinook (ODFW 1991a). In some cases, where hatchery survival has been poor, the taking of brood stock has continued until the wild stock is almost completely eliminated

(Chapman et al. 1991), at which point hatchery staff have had to rely on brood stock transfers from other areas, thus leading to genetic dilution of local stock structure.

Hatchery Structures as Barriers

A second direct impact of hatchery programs is to block access of wild spawning fish to sections of spawning or rearing habitat by the construction of hatchery structures. This has occurred for coho (ODFW 1991b) and chinook (ODFW 1991a).

Increases in Fishing Pressure

A major cause of the decline of wild stocks of coho and chinook has been fishing pressure from ocean and in-river fisheries. Since these fisheries now target primarily on hatchery fish, and without the hatcheries these fisheries would almost certainly have closed, the hatcheries have certainly aggravated the decline of wild stocks by mixed stock fishing (ODFW 1991b). One could argue, of course, that in fact the hatcheries have buffered the wild stocks from the fishing pressure, and that without the hatcheries the harvest rate on wild stocks would have been higher. We do not believe this is a credible argument, since the exploitation rate is primarily a function of the amount of fishing effort, and in the absence of hatchery stocks almost all fisheries directed on Columbia River stocks would have ceased to be economically viable. Thus, we see mixed-stock fishing as probably the most important impact of hatchery stocks on wild fish. Indeed, ODFW (1991b) has shown that the decline of wild lower river coho can be attributed almost exclusively to exploitation pressure, and the increase in exploitation pressure coincided with early success of hatchery released coho.

Timing of the Water Budget

A major part of current management practice on the Columbia is the "water budget" water released in the spring to help speed juvenile fish on their downward migration. The water budget is currently timed to benefit the majority of downstream migrating fish, which means hatchery fish. The timing of the majority of water budget releases is in fact earlier than would be optimal for wild stocks.

The Mitigation Myth

The history of dam construction, water withdrawals, and habitat degradation on the Columbia has been dominated by what we call the *Mitigation Myth* —that is the belief that you can have dams, logging, irrigation, grazing, etc., and have fish by using hatcheries. The very heart of the Columbia River hatchery program has been the concepts of mitigation and compensation—replacing what has been lost, or will be lost in wild fish production by building hatcheries. The *Mitigation Myth* has made possible the current dam system and other environmental impacts that have been dominant factors in the decline of wild stocks. If society had realized that the construction of the hydroelectric system would have meant the loss of salmon on the Snake River, for instance, it is quite possible the four mainstem Snake River dams would not have been built.

DISCUSSION

The main purpose of the hatchery program in the CRB is to compensate for lost fish production due to the hydroelectric system. In this it has been partially successful; CRB stocks contribute to ocean catch, particularly of coho and fall chinook, and some in-river fisheries remain. However, today's salmon runs on the Columbia are at best 25% of the historic runs, and taken in the aggregate the hatchery program has largely failed to compensate for the hydroelectric system. The failure of compensation is most dramatic for up-river users of the salmon. Since almost all adults produced by hatcheries return to lower-river hatcheries, the benefits of the hatchery system now accrue primarily to ocean fisheries and river mouth fisheries. There is little if any harvestable surplus on the Snake or upper Columbia rivers.

The wild stocks on the Columbia have declined as the size of the hatchery program increased, but the available evidence indicates that hatcheries have not been a major cause of the wild stock decline, except in that promises from hatcheries delayed the needed regulation on ocean and in-river fisheries and permitted further habitat loss from the hydroelectric system and other sources. There is wide agreement that the dominant cause of decline of wild stocks has been overharvesting, habitat loss, and passage mortality. Nonetheless, hatcheries clearly have had a generally detrimental effect on the wild stocks. In some places, these detrimental effects may be dramatic, but more commonly they are much more subtle than overharvesting, habitat loss, and passage mortality. As a generalization, one can say that as hatchery programs have increased in a basin of the river wild stocks have declined, but in both the Hanford Reach and Lewis River, there are reasonably healthy wild stocks in the presence of significant hatchery production.

It is discouraging to reflect on how little we can say with confidence about the impact of hatchery and wild stocks on the Columbia. Partly this results from the historical assumption that hatchery production had to be good—put more fish in the creek and you will get more back. Only in the last 10 years has serious energy has been devoted to studies of wild and hatchery interaction. Very little planned experimentation on wild\hatchery interaction has been planned; most of our studies involve merely monitoring of unplanned hatchery programs. If we want to understand how to obtain an optimum mix of wild and hatchery production from the Columbia, specifically planned experiments are needed.

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Table 1. Columbia River Basin hatcheries and related facilities participating in rearing of anadromous salmonids, 1960-88. Hatchery number identifies location in Figure 1.

No.	Hatchery/Facility	State
1	Grays River	WA
2	Sea Resources	WA
3	Weyco Pond	WA
4	Big Creek	OR
5	Gnat Creek	OR
6	Klaskanine	OR
7	Clatsop Econ. Dev. Comm.	OR
8	Klaskanine Pond, SF	OR
9	Beaver Creek	WA
10	Elokomin	WA
11	Germany Creek	WA
12	Trojan Rearing Ponds	OR
13	Abernathy SCDC NFH	WA
14	Alder Creek Pond	WA
15	Toutle Salmon	WA
16	Wallace Pond	WA
17	Olequa Creek	WA
18	Cowlitz Salmon	WA
18	Cowlitz Trout	WA
19	Stone Pond	WA
20	Mossy Rock	WA
21	Swofford Pond	WA
22	Toutle River Trap	WA
23	Deer Springs	WA
24	Kalama Falls	WA
25	Lower Kalama Salmon	WA
26	Coweeman Rearing Pond	WA
27	Gobar Rearing Pond	WA
28	Powerline Ponds	WA
29	Lewis River Salmon	WA
30	Merwin	WA
31	Speelyai Salmon	WA
32	Carson NFH	WA
33	Klineline Net Pens	WA
34	Washougal Salmon	WA
35	Willard NFH	WA
36	Salmon Creek Coop	WA
37	Big White Salmon Pond	WA
38	Little White Salmon NFH	WA
39	Spring Creek NFH	WA
40	Northwestern	WA
41	Drano Lake pens	WA
42	Goldendale	WA
43	Klickitat	WA
44	Sandy	OR
45	Skamania	WA
46	Vancouver Hatchery	WA
47	Aumsville Ponds	OR
48	Salem Pond	OR
49	Marion Forks	OR
50	Roaring River	OR
51	Stayton Pond	OR
52	South Santiam	OR
53	Leaburg	OR
54	McKenzie River	OR
55	Dexter Rearing Pond	OR
56	Willamette	OR
57	Eagle Creek NFH	OR
58	Clackamas	OR
59	Bonneville	OR
60	Wahkeena Pond	OR
61	Cascade	OR
62	Herman Creeks Ponds	OR
63	Oxbow Herman	OR
64	Hood River	OR
65	Rock Creek Pens	WA
66	Oak Springs	OR
67	Pelton Ladder	OR
68	Warm Springs NFH	OR
69	Round Butte	OR
70	Metolius	OR
71	Wizard Falls	OR
72	Social Security Pens	OR
73	Irrigon	OR
74	Bonifer Pond	OR
75	Minthorn Pond	OR
76	Ringold Springs Rearing Pond	WA
76	Ringold Springs Salmon Pond	WA
77	Pasco Rearing Ponds	WA
78	Naches	WA
79	Yakima Net Pens	WA
80	Nelson Springs Raceway	WA
81	Yakima Trout	WA
82	Nile Springs Pond	WA
83	Priest Rapids	WA
84	Columbia Basin	WA
85	Cle Elum Ponds	WA
86	Leavenworth NFH	WA
87	Rocky Reach	WA
88	Turtle Rock Pond	WA
89	Eastbank	WA
90	Entiat NFH	WA
91	Wells Salmon	WA
91	Wells Trout	WA
92	Chelan PUD	WA
93	Washburn Island	WA
94	Winthrop NFH	WA
95	Sandpoint	ID
96	Mullan	ID
97	Lyons Ferry Salmon	WA
97	Lyons Ferry Trout	WA
98	Curl Lake	WA
99	Dayton Pond	WA
100	Tucannon Hatchery	WA
101	Sweetwater	ID
102	Dworshak NFH	ID
103	Clearwater	ID
104	Kooksia NFH	ID
105	Crooked River	ID
106	Red River Satellite	ID
107	Indian	ID
108	Powell Satellite Facility	MT
109	Cottonwood Pond	WA
110	Lookingglass	OR
111	Big Canyon Acclimation Pond	OR
112	Wallowa	OR
113	Little Sheep Creek Acclim. Pond	OR
114	Imnaha	OR
115	Oxbow Dam Hatchery	OR
116	Rapid River	ID
117	McCall	ID
118	Hayden Creek	ID
119	Pahsimeroi Ponds	ID
120	Mackay	ID
121	Sawtooth	ID
122	Hayspur	ID
123	Niagara Springs	ID
124	Magic Valley	ID
125	Hagerman NFH	ID
126	American Falls	ID

Table 2. Estimates of pre-exploitation abundance of different Columbia River salmon. Data are the lower estimate from Chapman (1986). Chapman's upper estimates were at most 25% higher.

Species	Abundance
Coho	500,000
Summer Chinook	2,000,000
Fall Chinook	1,250,000
Spring Chinook	500,000
Sockeye	2,253,000
Steelhead	449,000
Chum	449,000

Table 3. Anadromous salmonid species reared at CRB hatcheries since 1960.

Species	Brood years
Fall Chinook	1960-88
Spring Chinook	1960-88
Summer Chinook	1960-88
Coho	1960-88
Summer Steelhead	1960-88
Winter Steelhead	1960-88
Chum	1960-87
Sockeye	1960-68,80-84
Cherry	1971
Masu	1971
Pink	1973
Searun cutthroat	1960-75,79-88

Table 4. Age-specific natural mortality rates used in VPA reconstruction of cohort survival.

Age	Chinook	Coho
2	.4	.5
3	.3	.5
4	.2	
5	.1	
6		

Table 5. Summary of CWT group releases for chinook and coho. Chinook releases are for brood years 1971-84, coho releases for 1974-86.

	Release type							
Species	P	E	B	I	K	O	U	Total
Fall chinook	264	85	26	69	75	12	396	1027
Spring chinook	83	19	96	19	0	8	108	633
Summer chinook	17	19	0	0	0	0	20	56
Coho	152	357	32	63	1	20	16	841

Table 6. Percent of hatchery/brood year releases for which survival rates and production estimates are represented by at least one CWT release.

Brood year	Fall chinook	Spring chinook	Summer chinook	Coho
1971	17.9	18.5		
1972	35.0	8.3		
1973	32.4	3.3		
1974	38.1	64.9	66.7	53.9
1975	27.6	73.7	94.9	25.9
1976	81.6	53.4	81.3	22.9
1977	93.4	72.4	82.8	34.7
1978	91.6	47.2	3.8	48.7
1979	96.3	29.9	9.7	25.2
1980	97.6	59.9	4.4	65.2
1981	95.8	32.5	6.2	66.6
1982	63.2	49.4	15.3	66.1
1983	69.9	52.1	90.7	63.7
1984	75.1	77.4	99.6	73.2
1985				58.5
1986				60.5

Table 7. Total numbers of anadromous salmonids released into the Columbia River Basin, brood years 1960-88.

Brood Year	Fall Chinook	Coho	Spring Chinook	Summer Steelhead	Winter Steelhead	Summer Chinook	Other Anadromous	Total
1960	53,061,327	12,524,088	5,108,010	564,421	1,693,831	0	3,100,535	**76,052,212**
1961	58,763,486	30,842,486	5,962,052	1,067,487	2,069,349	0	2,950,101	**101,654,961**
1962	62,862,966	40,081,387	11,851,344	1,012,160	1,887,105	0	4,936,396	**122,631,358**
1963	72,911,939	28,136,776	18,715,380	1,202,707	1,458,454	0	4,432,286	**126,857,542**
1964	71,584,008	40,496,794	18,904,718	1,435,606	1,996,410	0	747,638	**135,165,174**
1965	53,466,379	45,742,001	16,171,513	1,872,234	2,145,184	0	972,277	**120,369,588**
1966	86,764,210	42,670,866	11,673,019	3,706,901	1,864,451	0	788,566	**147,468,013**
1967	83,254,893	51,426,928	14,541,677	7,489,497	1,898,929	2,138,378	483,995	**161,234,297**
1968	69,322,206	43,649,496	17,461,685	7,050,707	2,106,863	2,121,276	557,279	**142,269,512**
1969	93,008,752	49,471,208	22,196,595	12,844,003	2,932,063	4,249,277	565,636	**185,267,534**
1970	94,016,519	67,302,514	33,243,407	10,320,105	2,786,901	2,184,527	487,220	**210,341,193**
1971	100,517,262	64,238,786	31,827,824	8,278,293	2,598,830	2,604,903	853,655	**210,919,553**
1972	99,467,326	48,804,001	31,712,145	14,799,182	2,871,734	2,312,635	936,314	**200,903,337**
1973	93,694,024	49,805,429	30,376,154	18,274,249	2,577,555	2,777,837	936,270	**198,441,518**
1974	91,558,812	39,460,826	36,355,443	9,413,772	2,418,246	2,339,732	321,523	**181,868,354**
1975	110,574,072	34,374,228	32,604,197	8,697,357	2,432,206	4,478,714	1,509,533	**194,670,307**
1976	61,690,290	42,881,019	20,914,750	5,523,297	342,709	2,342,889	37,448	**133,732,402**
1977	98,484,480	31,609,880	32,105,025	8,968,530	1,024,607	1,687,097	221,292	**174,100,911**
1978	107,806,757	46,942,357	35,471,385	18,247,319	1,648,701	3,119,548	1,558,319	**214,794,386**
1979	99,979,661	47,092,611	32,277,899	16,278,411	1,696,051	2,573,389	1,926,059	**201,824,081**
1980	103,424,188	66,194,676	36,307,154	11,265,780	1,589,165	2,793,066	450,951	**222,024,980**
1981	99,774,718	37,812,508	29,331,931	17,915,760	3,557,736	2,986,230	1,051,036	**192,429,919**
1982	100,025,245	49,692,583	39,055,088	11,689,508	2,245,673	1,758,583	866,935	**205,333,615**
1983	103,286,089	38,860,731	44,198,390	18,192,432	3,636,424	2,256,900	1,124,612	**211,555,578**
1984	77,710,927	58,726,003	34,510,576	13,589,006	2,843,570	2,807,288	2,572,751	**192,760,121**
1985	90,280,325	44,433,869	40,766,050	18,037,728	2,853,051	3,580,483	897,562	**200,849,068**
1986	93,986,865	46,055,193	38,650,161	18,540,306	3,374,583	3,615,464	580,224	**204,802,796**
1987	132,101,323	35,930,043	33,468,430	19,739,905	2,852,842	4,798,520	512,740	**229,403,803**
1988	132,619,333	43,447,821	44,762,506	20,121,287	4,752,979	4,406,287	323,393	**250,433,606**
Total	**2,595,998,382**	**1,278,707,108**	**800,524,508**	**306,137,950**	**68,156,202**	**63,933,023**	**36,702,546**	**5,150,159,719**

Table 8. Total weight (in pounds) of anadromous salmonids released into the Columbia River Basin, brood years 1960-88.

Brood Year	Coho	Spring Chinook	Summer Steelhead	Fall Chinook	Winter Steelhead	Summer Chinook	Other Anadromous	Total
1960	508,604	182,033	71,868	322,858	134,673	0	73,839	**1,293,875**
1961	837,359	222,628	68,524	291,013	170,103	0	45,587	**1,635,214**
1962	1,001,976	428,889	128,826	349,493	143,226	0	71,145	**2,123,555**
1963	1,091,409	415,100	154,351	415,514	173,531	0	86,922	**2,336,827**
1964	1,195,537	488,519	162,900	379,315	233,015	0	69,988	**2,529,274**
1965	1,368,923	559,174	208,853	456,109	220,974	0	33,594	**2,847,627**
1966	1,190,689	600,417	383,568	536,939	206,869	0	53,314	**2,971,796**
1967	1,796,040	778,773	722,237	716,648	194,824	13,625	64,347	**4,286,494**
1968	1,675,028	954,622	812,961	687,071	209,012	20,230	73,162	**4,432,086**
1969	2,062,075	1,289,611	1,393,187	914,816	292,912	35,617	85,556	**6,073,774**
1970	2,336,431	1,385,772	1,090,712	740,666	255,315	37,024	88,721	**5,934,641**
1971	2,218,718	1,823,244	1,062,540	1,045,251	283,509	42,643	40,764	**6,516,669**
1972	2,096,492	1,381,021	866,080	1,108,860	379,918	34,323	69,394	**5,936,088**
1973	2,366,999	1,433,440	1,457,112	1,273,255	280,912	57,759	52,720	**6,922,197**
1974	1,945,180	2,031,522	1,134,925	1,076,626	268,772	84,634	61,947	**6,603,606**
1975	1,589,020	1,413,898	1,146,875	1,382,026	342,073	71,057	74,165	**6,019,114**
1976	2,227,849	1,343,453	532,538	751,246	39,928	129,183	8,804	**5,033,001**
1977	1,651,767	1,556,367	653,325	1,425,926	159,370	71,762	425	**5,518,942**
1978	2,030,914	1,770,021	820,770	1,381,780	140,780	94,656	31,179	**6,270,100**
1979	2,197,401	1,812,325	1,144,124	1,324,405	157,608	52,302	33,748	**6,721,913**
1980	1,754,304	1,779,137	1,164,162	1,474,434	158,267	80,475	14,474	**6,425,253**
1981	1,847,222	1,734,938	1,863,710	1,298,644	531,620	80,997	30,531	**7,387,662**
1982	2,170,504	2,246,951	1,057,143	1,390,848	180,150	62,448	28,943	**7,136,987**
1983	1,918,279	2,089,779	1,948,553	1,751,151	401,464	79,828	61,119	**8,250,173**
1984	2,447,728	1,864,291	1,913,664	1,442,381	447,908	74,712	62,374	**8,253,058**
1985	1,973,103	2,156,689	1,949,932	1,686,586	448,847	133,339	78,117	**8,426,613**
1986	1,927,109	2,253,471	2,396,047	1,526,654	568,059	199,868	71,207	**8,942,415**
1987	1,848,284	1,608,792	2,781,773	1,938,573	436,021	161,636	75,043	**8,850,122**
1988	2,257,472	1,924,269	2,700,089	1,936,258	807,028	159,566	79,068	**9,863,750**
Total	**51,532,416**	**39,529,146**	**31,791,349**	**31,025,346**	**8,266,688**	**1,777,684**	**1,620,197**	**165,542,826**

Table 9. Total hatcheries and number of hatcheries producing 75% of total releases for the major artificially reared anadromous salmonid species, 1960-1988 brood years.

	Total hatcheries (and rearing facilities)	Hatcheries producing 75% of total releases
Fall Chinook	63	11
Spring Chinook	76	13
Summer Chinook	15	2
Coho	53	13
Summer Steelhead	73	11
Winter Steelhead	30	5

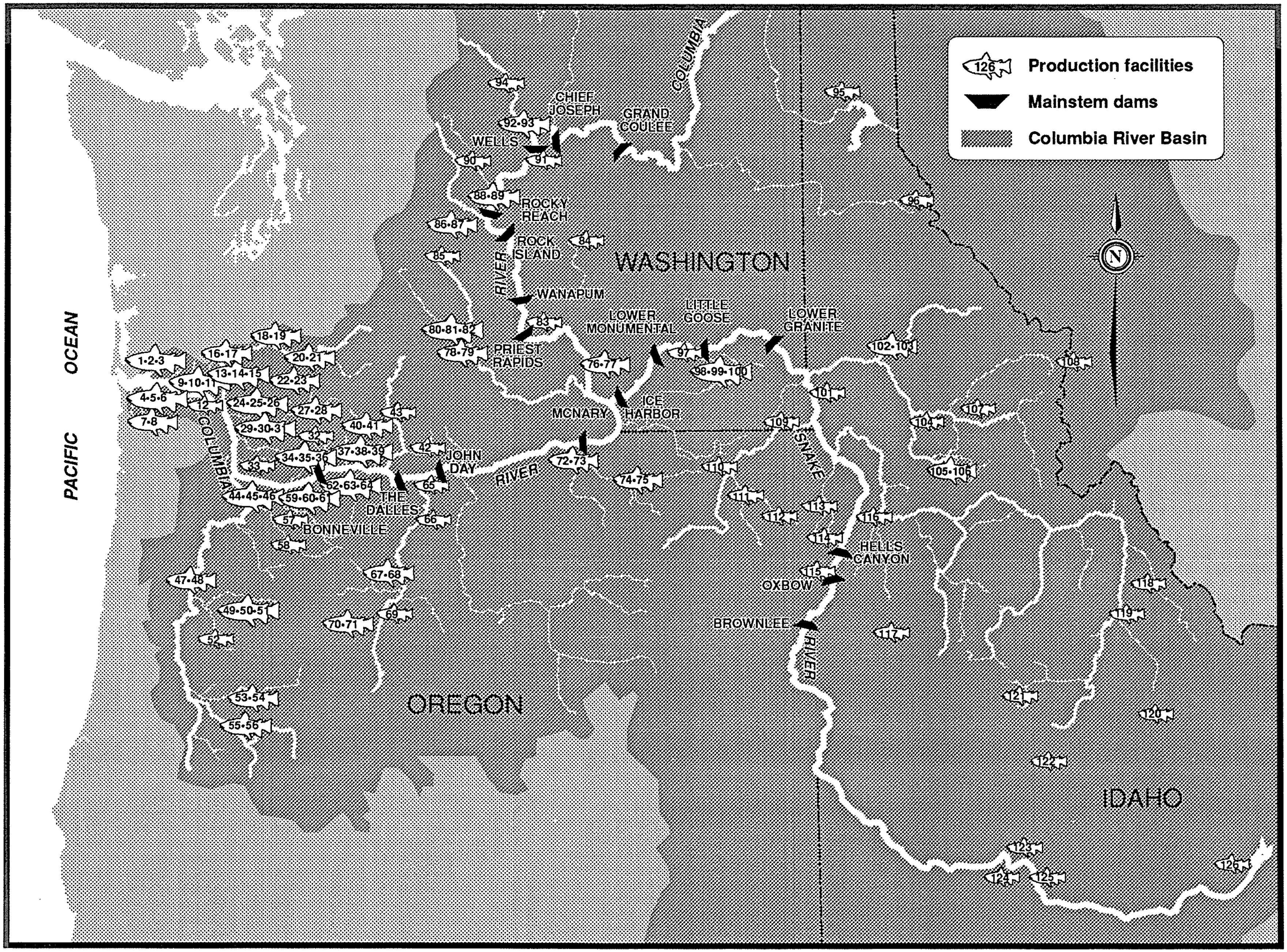


Figure 1. The Columbia River Basin and location of anadromous salmonid hatcheries and associated rearing facilities.

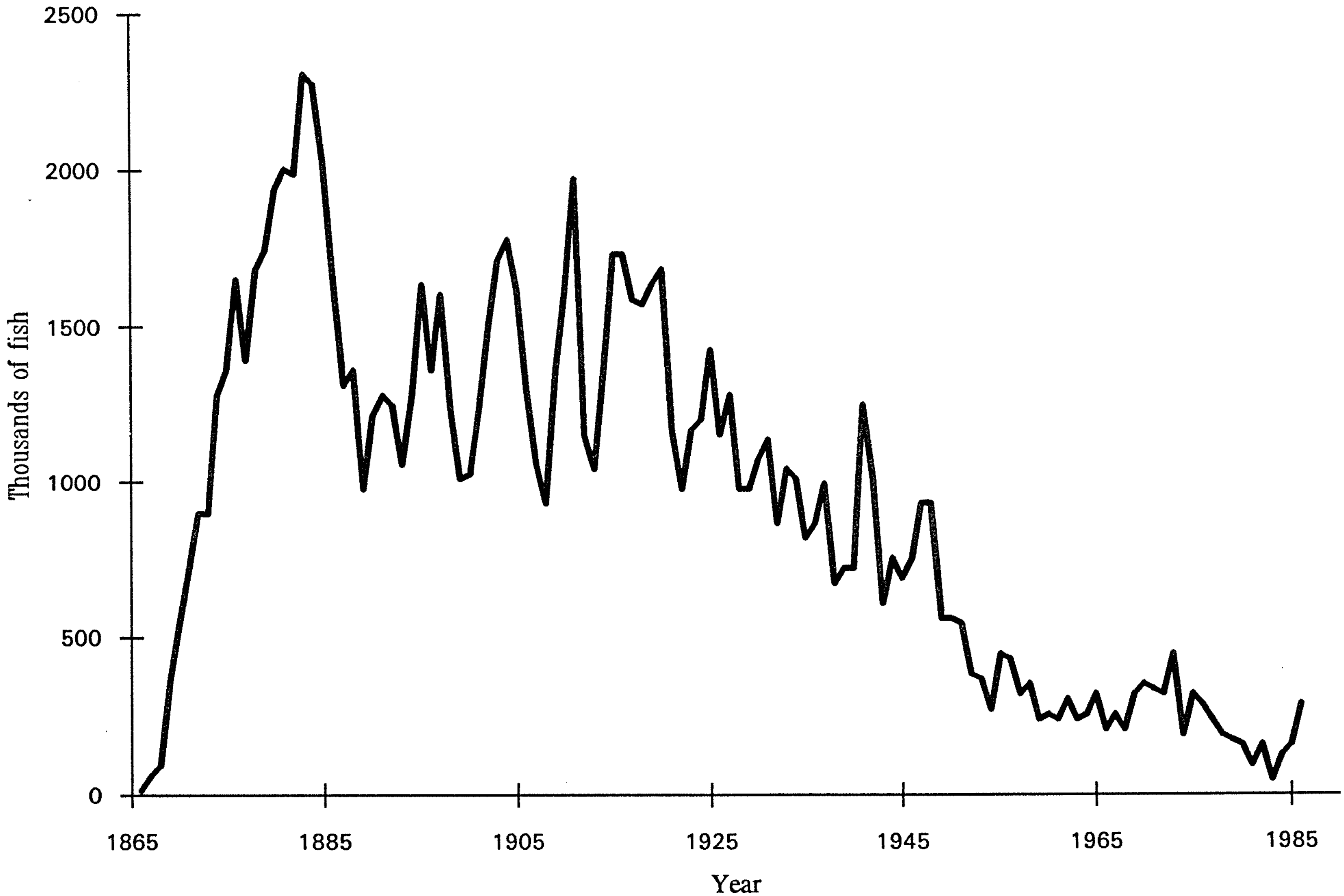


Figure 2. Commercial landings of chinook salmon on the Columbia River from 1966-1986 (from McIsaac 1990).

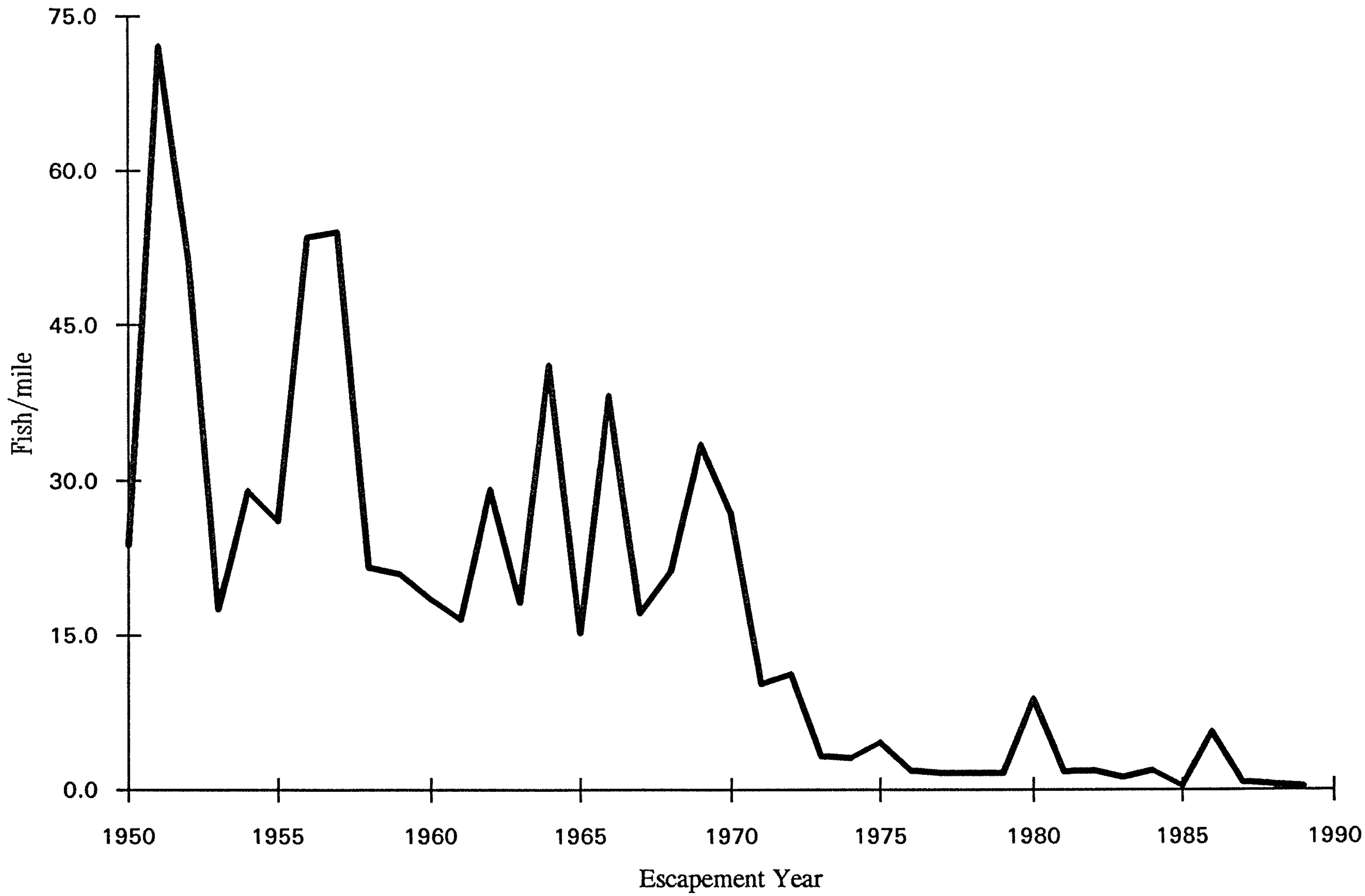
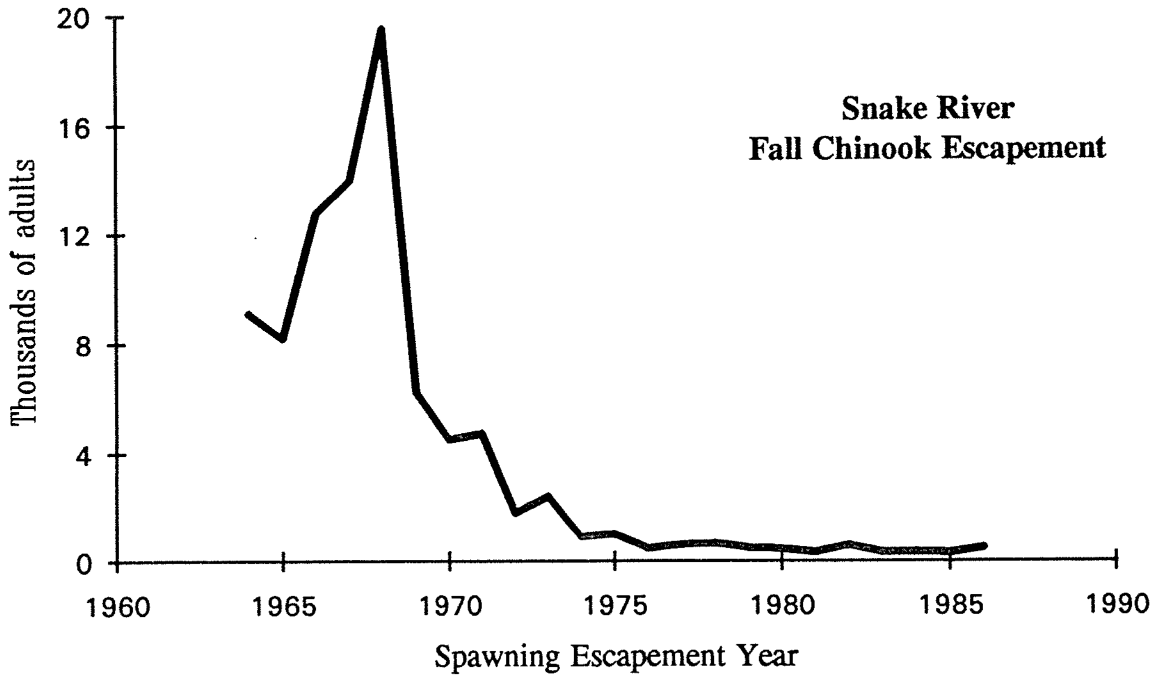


Figure 3. Trend in wild coho escapements as indicated by ODFW index counts, 1950-1989 (from ODFW 1990).



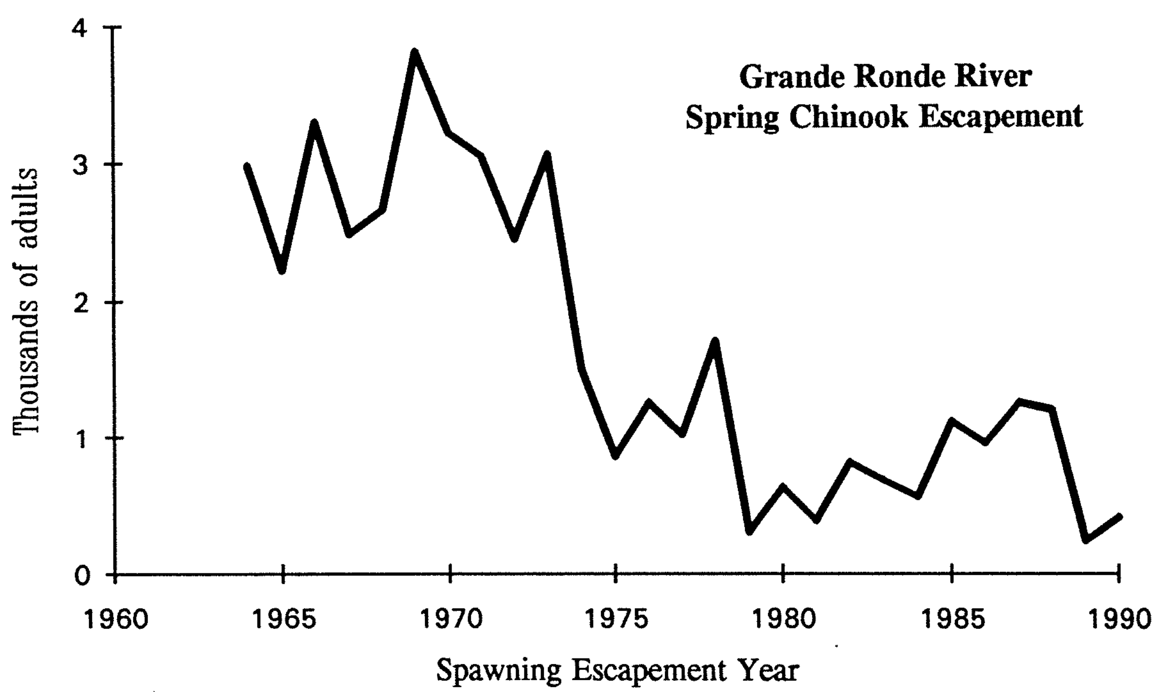


Figure 4. Trends in wild stock escapements for Snake River fall chinook and Grande Ronde spring chinook. Data from ODFW (1991a).

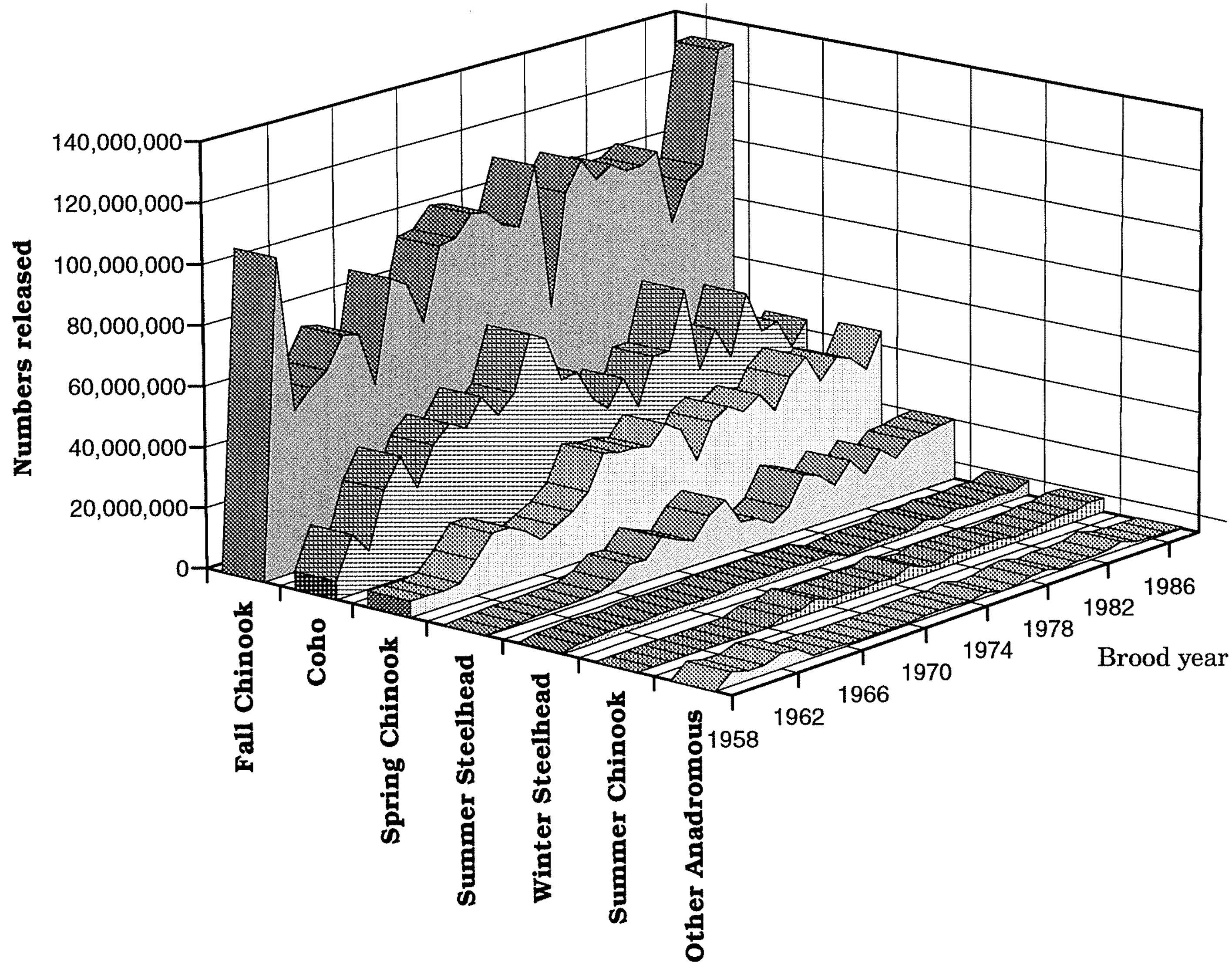


Figure 5. Trend in total numerical releases of Columbia River Basin hatchery-reared anadromous salmonids, 1960-1988 brood years.

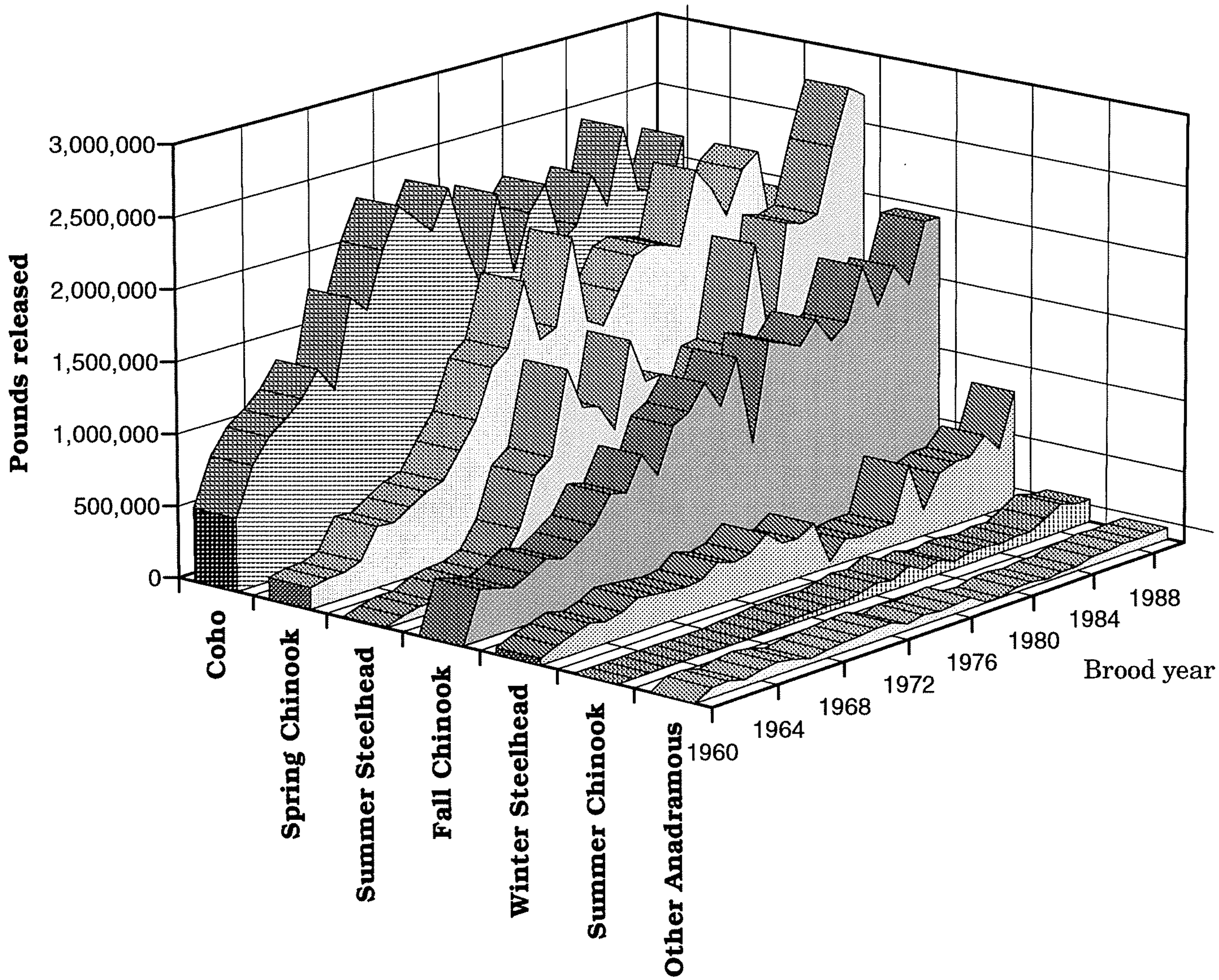


Figure 6. Trend in total weight of releases of Columbia River Basin hatchery-reared anadromous salmonids, 1960-1988 brood years.

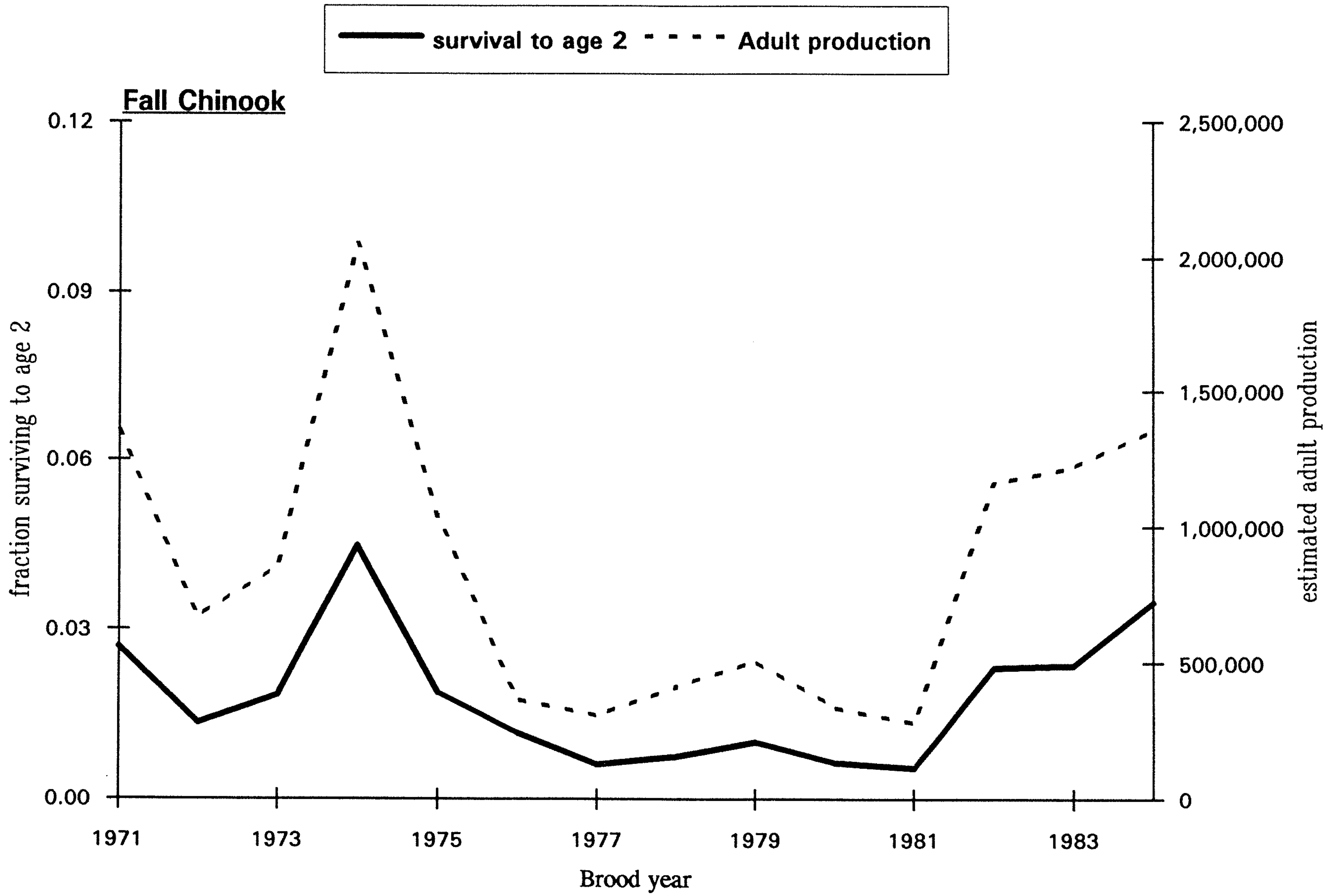


Figure 7. Trends in survival (to age 2) and adult production (catch plus escapement) of CRB hatchery-reared fall chinook. Survival estimates based on virtual population analysis of CWT releases.

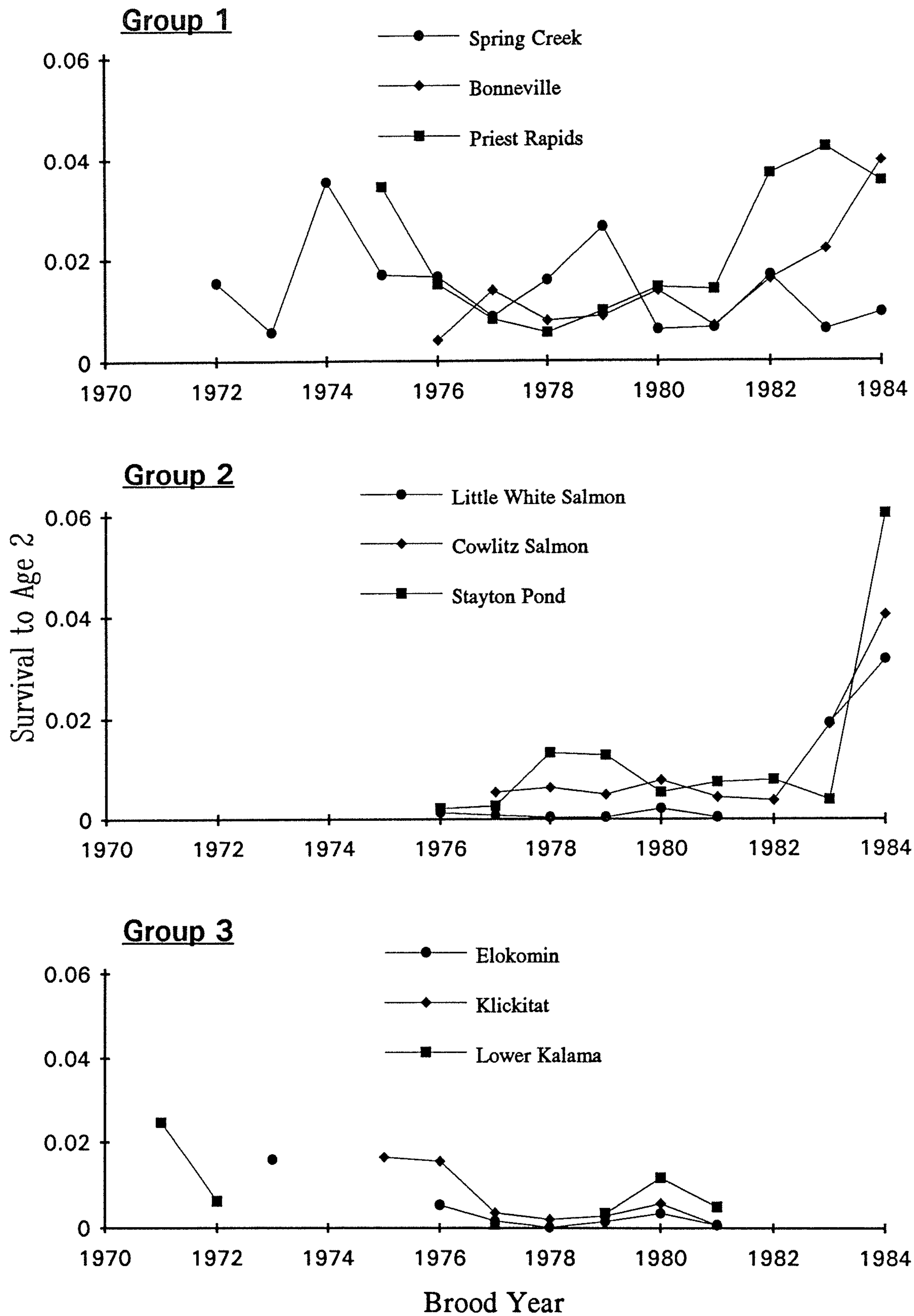


Figure 8. Qualitative grouping of CRB fall chinook hatcheries by survival rates (to age 2).

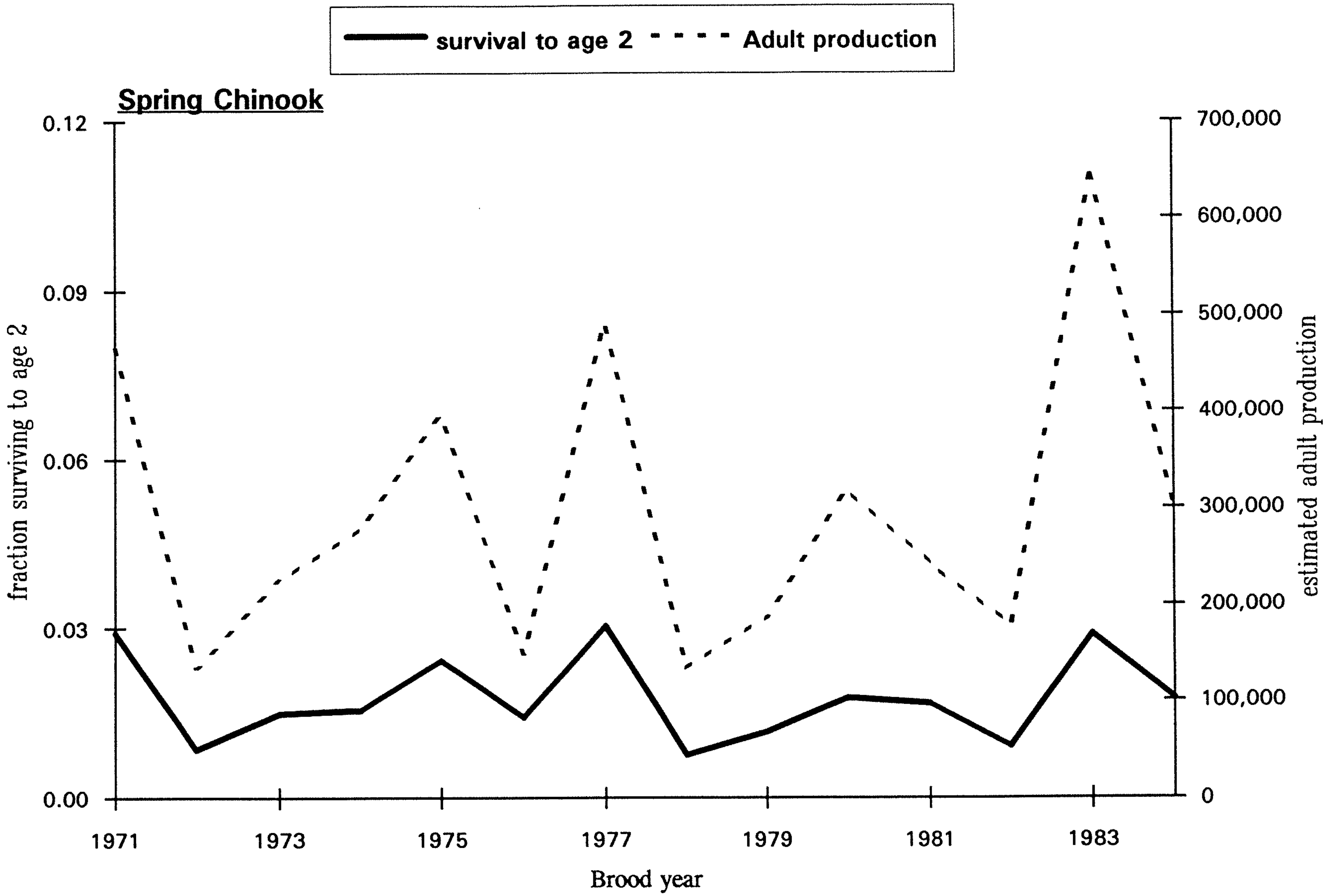


Figure 9. Trends in survival (to age 2) and adult production (catch plus escapement) of CRB hatchery-reared spring chinook. Survival estimates based on virtual population analysis of CWT releases.

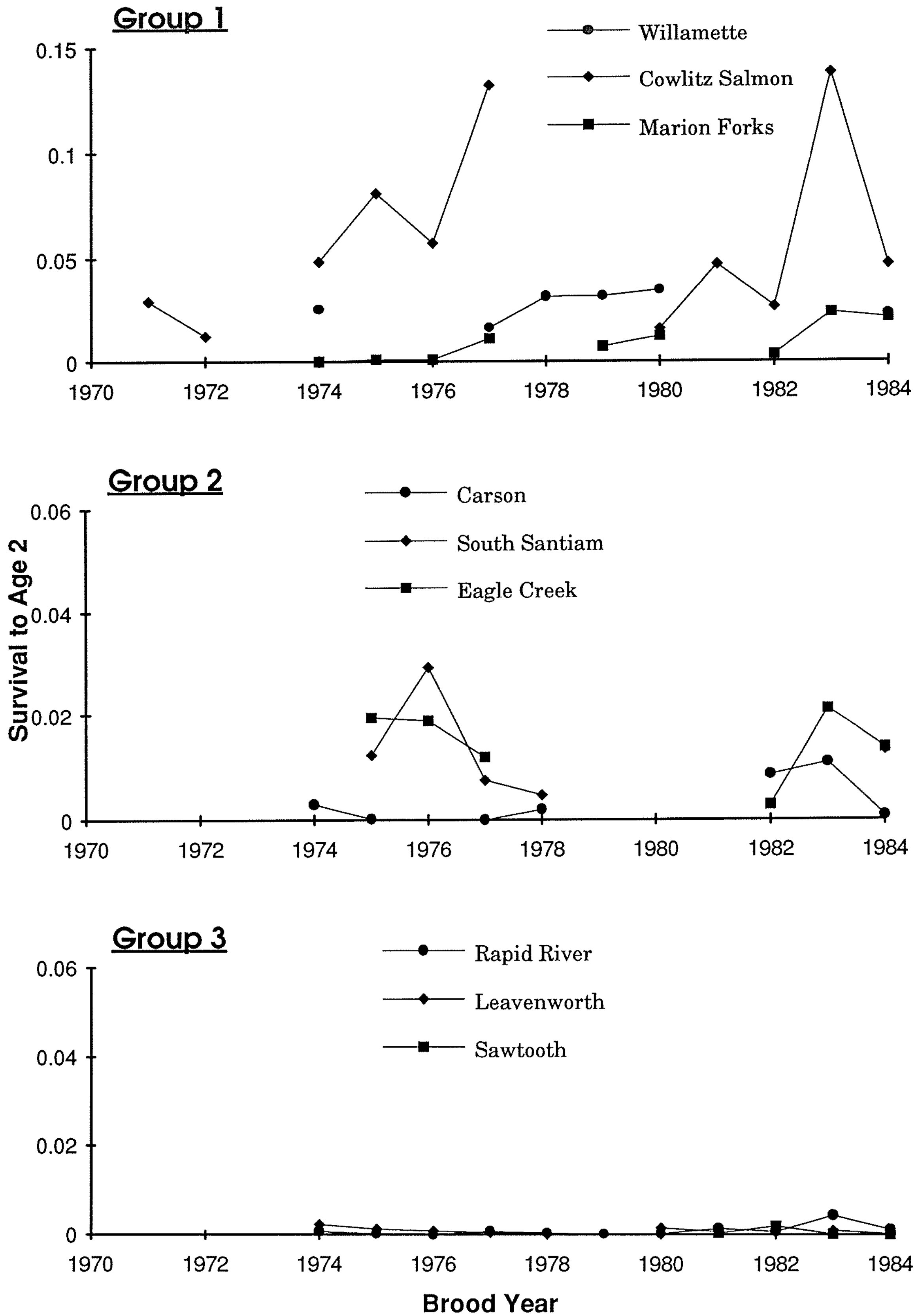


Figure 10. Qualitative grouping of CRB spring chinook hatcheries by survival rates (to age 2). Note different survival scale for Group 1 hatcheries.

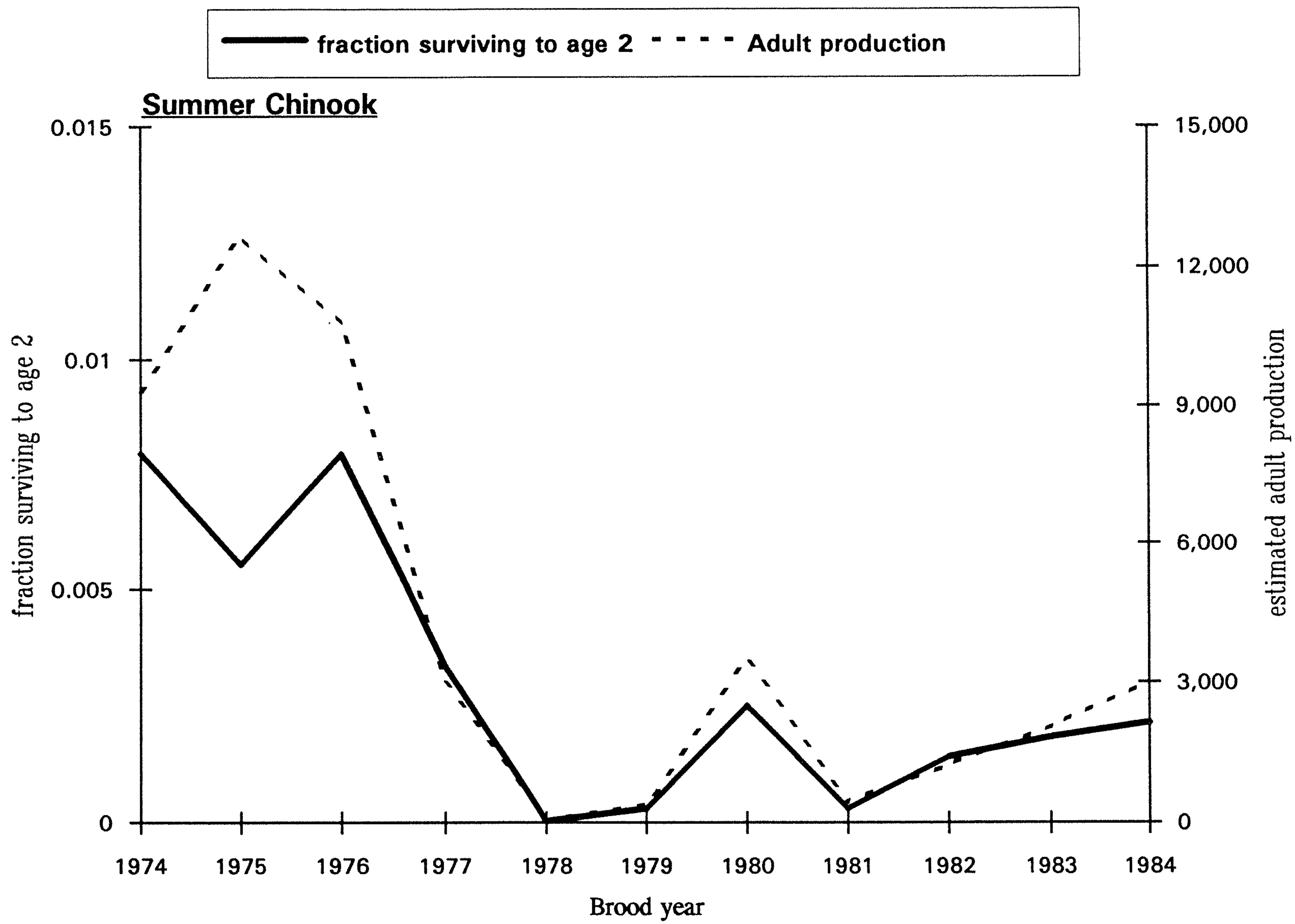


Figure 11. Trends in survival (to age 2) and adult production (catch plus escapement) of CRB hatchery-reared summer chinook. Survival estimates based on virtual population analysis of CWT releases.

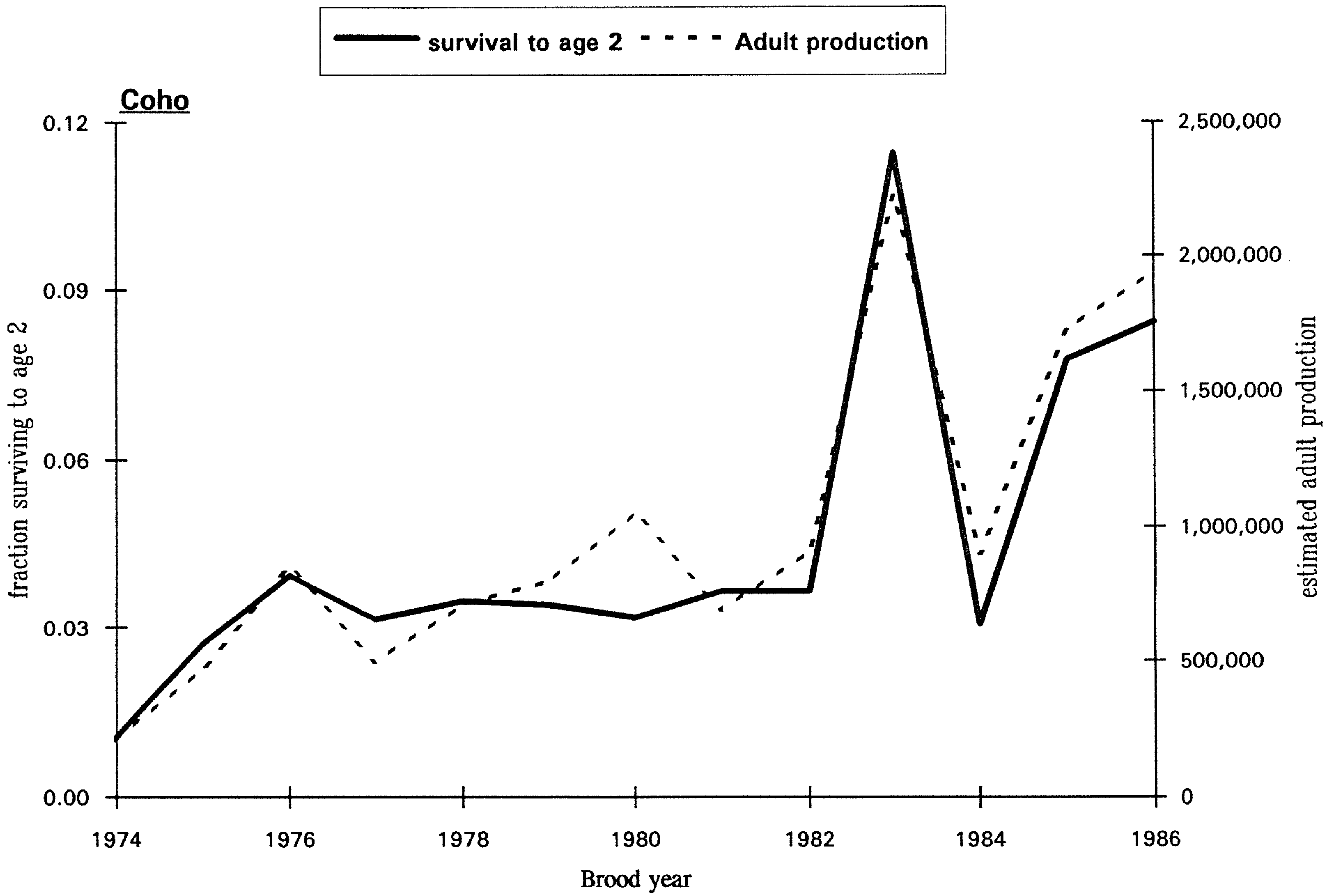


Figure 12. Trends in survival (to age 2) and adult production (catch plus escapement) of CRB hatchery-reared coho salmon. Survival estimates based on virtual population analysis of CWT releases.