Chum Salmon Supplementation: Bane or Boon?

Jim Ames and Kyle Adicks
Washington State Department of Fish and Wildlife
600 Capitol Way N. - Olympia, WA 98501-1091, USA

Abstract

The decline of a number of wild salmon populations in Washington State over the last two decades has caused salmon managers to increasingly employ hatchery supplementation to facilitate recovery of salmon stocks that are at risk of extinction. However, this practice has frequently been criticized as having unacceptable negative consequences on salmon populations, and has been described as a failed approach for recovering depleted populations. An early successful application of hatchery supplementation involved two wild summer chum salmon stocks in south Puget Sound. These stocks experienced a severe decline in the late 1970s, in part because of high harvest rates which were directed at hatchery coho salmon. Artificial production techniques were utilized to supplement the three largest spawning populations of summer chum in the region. The supplementation program operated from 1976 to 1991, contributing to summer chum runsizes that returned to and exceeded pre-decline abundance. Harvest rates were reduced in the early 1990s, and the two stocks are currently sustaining themselves without aid of supplementation. Average post-supplementation runsizes, now 2nd and 3rd generation natural origin recruits, are higher than average returns of the pre-decline years.

Introduction

In Washington State, the term Asupplementation@ is used to differentiate fish culture techniques used to assist recovery efforts for wild salmon populations from the more traditional hatchery programs intended to enhance fisheries. Supplementation for salmonids is generally defined as:

> A**The use of artificial propagation to maintain or increase natural production while maintaining the long term fitness of the target population, and keeping the ecological and genetic impacts to non-target populations within specified biological limits.@ (WDFW and PNPTT 2000)**

Inherent in this definition is the intent to discontinue the supplementation when the wild population has recovered.

The use of salmon culture to routinely assist the recovery of wild salmon populations is a relatively recent, and evolving, technique in salmonid population management. In Washington State the first wild stock supplementation efforts were generally begun in the late-1970s, with continuing applications of the approach in the 1980s and 1990s. Within a relatively short span of years, however, this management approach had already been declared a failure (Steward and Bjornn 1990, Waples 1991).

The early assessments that supplementation had Afailed@ were in part based on a broad assumption:

> A**... the general failure of supplementation to achieve management objectives is evident from the continued decline of wild stocks in some areas despite, and perhaps partly due to, increases in hatchery production...@ (Steward and Bjornn 1990).**

This conclusion overlooks several factors: 1) it treats supplementation and hatchery fishery enhancement programs together, 2) it does not consider the often overwhelming impacts of other factors for decline (e.g., over-harvest, habitat destruction, ecological interactions, and hydro-power related mortalities), and 3) it was too early to evaluate many supplementation projects.

The most frequently proposed standard of success for supplementation projects is: did the project successfully return the depressed wild salmon population to self-sustainability? (Miller et al. 1990, Waples et al. in press). This is a curious criterion because there is no reason to expect supplementation to lead to self-sustainability. The poor performance of a depressed salmonid population is caused by one or more negative factors affecting survival. If these negative influences on survival are not corrected, no amount of supplementation can achieve self-sustainability in a wild population. Authors who use Aself-sustainability@ as a measure of supplementation success nearly always also state that self-sustaining status is dependent on the correction of factors for decline.

Several authors have evaluated selected salmon supplementation projects in an attempt to determine if any have been successful in achieving self-sustaining populations. Waples et al. (in press) reported on their examination of 22 projects and summarized the results of the review of 26 projects by Miller et al. (1990):

> **AWe, like Miller et al. (1990), have not found any examples in which salmon supplementation has been used to help a natural population become self-sustaining.@**

Both papers include acknowledgments that there are potential reasons for this result other than project failure like: lack of evaluation, unpublished results, short time spans, lack of correction of factors for decline, and others. They also point out that success can be dependent on a variety of project specific factors: e.g., species of salmon, degree of hatchery intervention, similarity of supplemented fish to the local stock, freshwater residence time, and distance to the ocean.

Even the current attempts to evaluate most projects would seem to be somewhat premature. For example, Waples et al. (in press) review 22 supplementation projects with an average start date of 1984: 4 begun in the 1970s, 13 in the 1980s, and 5 started in the 1990s. Since by definition the subject salmon populations are depressed, it can potentially take a decade or more to re-build a population to the point that substantial numbers of spawners are utilizing the natural habitat. Population growth rates can also be largely controlled by the ability (or lack of ability) to correct major factors for decline. For a chinook, chum, or sockeye population made up primarily of 3, 4, and 5 year-old fish, a supplementation project begun in 1984 would not complete its first brood return until 1989, and would have only thirteen more complete brood returns by the year 2002. Under most circumstances, this likely would be insufficient time to re-build the population, correct factors for decline, evaluate the population performance, end the project, and evaluate the self-sustainability of the post-project wild population. The limited documentation of supplementation success to date may in part be because most projects are too recent in origin to evaluate.

In Washington State, supplementation is currently being utilized in situations where a salmon stock is at risk of extirpation and with species that are amenable to the available propagation techniques. Chum salmon are arguably one of the most suitable of the Pacific salmon to supplement. They have an extremely short juvenile freshwater residence time, typically spawn close to marine waters, and have been shown to be highly responsive to hatchery propagation techniques.

The successful supplementation of two southern Puget Sound summer chum salmon stocks (Hammersley Inlet and Case Inlet) that was conducted by the Washington Department of Fisheries (WDF; now Washington Department of Fish and Wildlife - WDFW) and the Squaxin Indian Tribe from 1976 through 1991 is discussed in this paper. The program is described in a variety of reports (Allen and Cowan 1977, Allen and Cowan 1979, Allen et al. 1980, Allen et al. 1981a, Allen et al. 1981b, WDFW and WWTIT 1994, Johnson et al. 1997). These summer chum projects were not included in the previously referenced reviews of salmon supplementation (Miller et al. 1990, Waples et al. in press).

This paper is not meant to be a defense of supplementation as a general salmon recovery approach; the subject is far too complicated to adequately address here. However, it is important to demonstrate that supplementation can be a valuable tool for recovering salmon populations in specific situations.

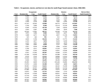
Background

Puget Sound hosts three chum salmon runs designated by timing: summer chum, which spawn in September and October; fall chum, which spawn primarily in November and December; and winter chum, which spawn from January through March (WDF et al. 1992). All three run segments are currently producing at high levels, a condition which contributed to the NOAA Fisheries (previously National Marine Fisheries Service) 1997 chum salmon status review assessment that the Puget Sound/Strait of Georgia chum salmon are Aat or near historic levels@ (Johnson et al. 1997). The current strength of the summer chum stocks originating in south Puget Sound, however, represents a major recovery from a period of very low escapements and runsizes that occurred from the late 1970s through the mid-1980s. This recovery was facilitated in part by supplementation projects on the three summer chum streams with the largest populations.

There are three distinct summer chum stocks located in central and south Puget Sound (WDF et al. 1992). The Blackjack Creek summer chum stock is the northernmost of the three stocks, spawning solely in a small stream tributary to Sinclair Inlet (central Puget Sound). The Hammersley Inlet and Case Inlet summer chum stocks spawn in streams flowing into south Puget Sound. The Hammersley Inlet stock occurs primarily in Johns Creek, with an extended distribution that utilizes adjacent Cranberry and Deer creeks. Case Inlet summer chum are represented by major spawning populations in Sherwood and Coulter creeks, and by a small number of spawners in nearby Rocky Creek (see Figure 1).

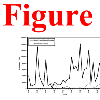
Figure 1

Table 1



South Puget Sound summer chum salmon have historically displayed robust, but highly variable abundance. For the nine year pre-decline period 1968 through 1976, summer chum runsizes generally ranged from 8,000 to 40,000 fish with larger returns each fourth year (highs of 132,000 in 1972 and 91,200 in 1976; Table 1). The pattern of large runsizes on a four year cycle is characteristic of Washington State=s summer chum salmon stocks, both in south Puget Sound and Hood Canal (Figure 2).

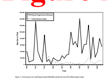
Figure 2



Two factors caused substantial changes in the management of Puget Sound salmon fisheries in the mid-1970s, tribal fishing rights and hatchery surpluses. A U.S. Federal Court ruling in 1974 affirmed the right of tribal fisheries to take half of the harvestable surplus of Puget Sound and coastal Washington salmon runs. One result of the ruling was that Puget Sound net fisheries were moved from mixed-stock to terminal fishing areas, in part to allow the allocation of the harvest shares for individual tribes in their usual and accustomed fishing areas. At the same time, fishery managers were attempting to find ways to harvest large returns of hatchery coho that were resulting in huge surplus escapements at various WDF hatcheries. Net fishery harvest rates were high for summer chum (1968-1976 mean 54%, range 13% to 77%), because fisheries were targeting hatchery coho stocks returning to Puget Sound (primarily in September and October).

A consequence of the high harvest rates during the 1970s was a steep decline in the escapements and subsequent runsizes of summer chum stocks in south Puget Sound and Hood Canal (Figure 2). Certainly other factors contributed to these declines (e.g., habitat loss, ecological interactions, and climate effects), however, harvest impacts had a major influence. WDF and the local Squaxin Indian Tribe recognized that the high harvest rates directed at south Puget Sound hatchery coho were excessive for the coincident wild summer chum stocks. In 1976, a program was begun to supplement the two summer chum stocks located in the region, with the result that subsequent south Puget Sound summer chum runsizes stabilized and then increased.

Figure 2



A different approach was taken with Hood Canal summer chum salmon. When local stocks suffered a steep decline in the late 1970s and early 1980s, no supplementation occurred. The Hood Canal summer chum stocks continued to decline and were ultimately listed as a Athreatened species@ in 1999 under the Endangered Species Act (ESA). Supplementation of Hood Canal summer chum salmon did not begin until 1992 and is discussed in two companion papers (see Johnson and Weller 2003 and Tynan et al. 2003, this volume).

Program Description

Because of concerns that the two south Puget Sound summer chum stocks would not be able to withstand existing harvest rates WDF, in cooperation with the Squaxin Tribe, began supplementation projects in 1976 for both the Hammersley and Case inlet stocks. Allen and Cowan (1978) documented the purpose of the WDF summer chum salmon supplementation program:

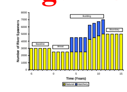
> **ATo supplement natural production in streams likely to be impacted by intensive harvesting of artificially produced stocks.@**

The artificial production techniques utilized varied from egg incubation boxes with unfed fry releases to the more traditional hatchery approach of rearing and releasing fed fry at a size of approximately 1 gram. The decision to supplement was to a degree pro-active, since the supplementation efforts began before an actual decline occurred.

The supplementation program for southern Puget Sound summer chum salmon was initiated 27 years ago, and was one of the earliest supplementation efforts in Washington State. Artificial production of summer chum occurred over a 16 year period (1976-1991 brood years), and the last age-4 fish resulting from supplementation returned in 1995. There have now been seven years of post-supplementation returns of south Puget Sound summer chum (12 years for Sherwood Creek), which represent 2nd and 3rd generation natural origin recruits (NOR). Only now is it possible to begin to assess the post-supplementation status of the affected stocks.

This evaluation of the south Puget Sound summer chum supplementation projects is based on the four stages of a successful salmon supplementation program as described by Pearsons (2002); termed Baseline, Brood, Building, and Boundary stages. The Baseline stage includes the return years with depressed abundance, which generated the need for some level of intervention (e.g., supplementation). The Baseline stage would be preceded by a pre-decline stage, presumably when the stock was abundant and was self-sustaining. The Brood stage commences with the collection of broodstock from the returning spawners to initiate supplementation, temporarily further depressing the magnitude of natural escapement. The Building stage begins as the artificially produced fish contribute to increasing stock abundance, and ends when freshwater carrying capacity is reached. The final Boundary stage is characterized by a stable, self-sustaining population of natural origin fish, and is achieved through the modification of factors for decline. Figure 3 shows a hypothetical representation of the four stages of a successful supplementation project.

Figure 3



The inherent variability of summer chum runsizes, particularly the periodic extreme high annual values, causes problems in characterizing average abundances (runsize and escapement). This paper presents average abundance values calculated for the varying number of years included in each of the various stages of the supplementation projects. Arithmetic means are presented in the text, followed by geometric means (GM) in parentheses. Each of these means may be affected by the number of cycle years included in the individual calculations, however, the geometric means tend to discount high values (most often cycle years). Another problem for the analysis of the supplemented populations is that the hatchery fish were not marked, and it is not possible to develop separate abundance estimates for the wild and supplemented contributions to returns. As a result, all abundance numbers presented in the report include the combined wild and artificially produced fish for the years of supplementation returns.

The small Blackjack Creek stock does not enter the same suite of fisheries as the south Puget Sound fish and did not display the same downward trend, presumably because the stock experienced lower average harvest rates (39%) from 1968 through 1979. Accordingly, the remainder of this report will focus on the two south Puget Sound summer chum stocks, and the Blackjack Creek stock (which was not supplemented) is not included in abundance numbers.

Table 1

Table 2

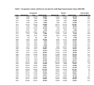
Annual runsize and escapement data for the two south Puget Sound summer chum stocks are presented in Table 1, and average runsizes during the various stages of supplementation are presented in Table 2. All escapement numbers presented in this report include both natural spawners and the adult fish removed from the streams for broodstocking.

Pre-decline

The south Puget Sound summer chum had an average pre-decline (1968-1976) runsize of 40,600 (GM = 25,100) fish. Average runsize for the Hammersley Inlet summer chum stock during the pre-decline years was 21,400 (GM = 11,800) fish, with a range of 2,929 to 64,775 fish. Case Inlet summer chum had pre-decline average runsizes of 19,200 (GM = 12,100) fish, ranging from a low of 2,500 to a high return of 67,200 fish.

Decline (Baseline/Brood Stages)
The two stocks in south Puget Sound, Hammersley and Case inlets, are harvested in gauntlet fisheries as they return though Puget Sound, and were subjected to consistently high harvest rates throughout the pre-decline and decline (Baseline/Brood stages) periods (Table 1). Harvest rates for south Puget Sound summer chum returns averaged 54% from 1968 through 1976 (pre-decline), and averaged 56% from 1977 through 1979 (decline) (Table 1). Although average harvest rates are similar for the pre-decline and decline periods, four of the six years immediately preceding the decline period (1971, 1972, 1973, and 1976) experienced higher harvest rates, averaging 70% (range 58-77%).

Table 1



The summer chum period of decline (Baseline and Brood stages combined) is very short, represented by just 3 years (1977-1979). Because of the inherent variability in wild salmonid abundances, it would typically take one or more generations of low returns for mangers to determine that a substantial population decline had occurred. In such a case, the Baseline stage would likely span a period of 4 or more years, and would then be followed by the Brood stage when supplementation egg takes and juvenile releases would begin. The summer chum effort was quite different, with supplementation beginning in 1976, a year before the Baseline/Brood stage, followed by the beginning of the Building stage just 4 years later, in 1980, with both age-3 and age-4 summer chum from two supplementation projects (Johns and Sherwood creeks) contributing to runsizes. Because of the early initiation of supplementation, the Baseline and Brood stages overlap, and last for only 3 years.

In 1979, the return of south Puget Sound summer chum reached a low of 1,700 fish, with a total escapement of only 990 spawners (down from a high of 32,100 spawners in 1972). The decline period averaged runsizes of just 9,100 (GM = 6,400) fish, compared to annual runsizes averaging 40,700 (GM = 25,100) fish during the 1968 through 1976 pre-decline period.

Runsize and escapement levels for the Hammersley Inlet and Case Inlet summer chum stocks are shown in Figures 4 and 5. During the 1977 through 1979 decline period (Baseline/Brood stage), Hammersley Inlet summer chum experienced average runsizes of only 3,700 (GM = 2,900) fish, ranging from a low of 911 to a high return of 5,293 fish. Average runsize for the Case Inlet summer chum stock during the decline years (1977-1979) was 5,400 (GM = 3,300) fish, with a range of 797 to 11,136 fish.

Figure 4

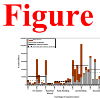
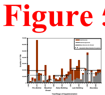
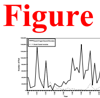


Figure 5



Supplementation (Building Stage)
During supplementation, the overall annual returns of summer chum salmon to south Puget Sound stabilized and then increased to levels higher than the pre-decline years. Average runsize for south Puget Sound summer chum during the Building stage of supplementation (1980-1995) was 47,200 (GM = 36,800), up from 9,100 (GM = 6,400) fish during the Baseline/Brood period, and higher than the pre-decline average of 40,700 (GM = 25,100) as well. Runsizes increased through the Building stage, peaking in 1992 at over 140,000 (Figure 2). This increase occurred even though harvest rates on both stocks continued to be high throughout most of the Building stage (Table 1), averaging 50% from 1980 through 1995.

Figure 2



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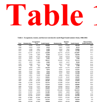

<u>Hammersley Inlet</u>
The Hammersley Inlet stock spawns primarily in the lower reaches of Johns Creek. There are also substantial numbers of summer chum spawning in the nearby Cranberry and Deer creeks,

which are both within 2.8 kilometers of Johns Creek. The escapements of summer chum to Cranberry and Deer creeks vary in concert with the Johns Creek population, and the spawners in the three streams are considered to be a single population. The supplementation of summer chum occurred primarily in Johns Creek (with two releases in Cranberry Creek), but it is probable that fish resulting from the hatchery production spawned in all three streams.

The WDF Johns Creek (or Shelton) Hatchery began operation in 1978, although Johns Creek summer chum supplementation began two years earlier. Broodstock were collected at Johns Creek from 1976 to 1991, and great care was taken to collect eggs from the entire temporal range of spawning (pers. comm. Tim Tynan, NMFS). During the years that adult returns included supplementation fish, broodstock collections were from a random mix of natural origin and artificial origin spawners. Resulting fry releases at Johns Creek averaged over 1,500,000 per year (Table 3), making it the largest of the south Puget Sound summer chum projects. Fish were released as fed fry (averaging ~1.25 grams/fish) for all broods except 1977 and 1992, when unfed fry (~0.3 grams/fish) were released. Fry were reared on-site, and at two out-of-basin hatcheries for several years. Fish were reared and released at Johns Creek Hatchery by the Squaxin Tribe for two broods, 1983 and 1986, through a cooperative agreement with WDF. All summer chum released were of Johns Creek origin, although some Johns Creek eggs were taken to other streams for release.

Table 3

Table 3. Total numbers and average size at release for summer chum releases from south Puget Sound supplementation projects.

Brood	Johns Creek		Cranberry Creek		Sherwood Creek		Coulter Creek	
year	Number	grams/fish	Number	grams/fish	Number	grams/fish	Number	grams/fish
1976	3,719,121	0.93	1,800,000	0.38	500,000	0.38		
1977	205,825	0.28			175,000	0.43		
1978	680,678	0.83			438,000	0.36		
1979	287,340	1.06			32,500	1.75	32,500	1.82
1980	665,000	0.98			977,845	0.36	1,510,147	1.23
1981	1,003,606	1.21					518,630	1.21
1982	2,212,900	1.25	951,658	0.36	869,186	0.39	1,136,900	1.01
1983	1,230,800	1.38					2,227,600	1.21
1984	1,140,000	1.16			460,815	0.40	2,097,000	1.23
1985	2,500,800	1.57			451,255	0.39	1,367,000	1.21
1986	1,835,000	1.40			757,000	0.40	1,382,800	1.30
1987	2,100,000	1.18					1,159,300	1.30
1988	1,975,000	1.01					1,230,600	1.02
1989	1,956,300	2.45					1,150,000	1.19
1990	1,958,900	1.04					1,153,500	1.35
1991	1,382,700	0.30					1,152,000	0.45

Cranberry Creek was selected by the Squaxin Tribe and WDF as the site for a summer chum egg incubation box program to be operated by tribal staff (similar to the WDF Sherwood Creek project in Case Inlet). Summer chum releases occurred in only two years, although the site was used in other years for incubating eggs for other hatcheries, and for release of fall chum into Cranberry Creek. For the 1976 brood, summer chum eggs taken at Johns Creek Hatchery were loaded into egg boxes at Cranberry Creek, with the resulting release estimated at 1,800,000 of unfed fry (0.38 grams/fish). Summer chum eggs were not again available for the project until a weir was installed in 1980, to trap the returning 4 year-old fish from the 1976 brood release. Although 210,300 eggs were taken at Cranberry Creek that year (Allen et al. 1981b), vandalism to the site resulted in 100% loss before release. A second group of Johns Creek summer chum eggs were brought to the egg incubation boxes for the 1982 brood, resulting in a release of 951,658 unfed fry (0.36 grams/fish).

The Hammersley Inlet stock runsize stabilized during the early 1980s, and returned to pre-decline levels by 1988. Average runsize for the Building stage (1980-1995) was 30,000 (GM = 20,300) fish, which was higher than the pre-decline average of 21,400 (GM = 11,800) fish). Runsizes and escapements for all three creeks contributing to the stock increased across the period, peaking in 1992 with a return of over 105,000 summer chum.

<u>Case Inlet</u>

There are two major spawning populations of summer chum in Case Inlet; utilizing Sherwood and Coulter creeks. The nearby Rocky Creek receives very small numbers of spawners. Each of the three spawning streams is within approximately 4 kilometers of one of the other streams. Genetic screening of the Sherwood and Coulter creeks summer chum showed that the two populations are genetically dissimilar, suggesting some degree of reproductive isolation (Phelps et al. 1995). Separate supplementation projects were implemented on both Sherwood and Coulter creeks, using local broodstocks. No supplementation occurred at Rocky Creek because of the very small population size and limited habitat.

Supplementation was initiated for Sherwood Creek summer chum in 1976 (Allen and Cowan 1977). Broodstock were collected at Sherwood from 1976 to 1980, in 1982, and from 1984 through 1986. Like Johns Creek, all egg takes represented the entire duration of spawning, and included randomly mixed natural and hatchery origin fish. In most years, eggs were eyed away from Sherwood Creek, and brought back for final incubation in egg boxes and were volitionally released as unfed fry. In 1979, eggs were hatched and reared away from Sherwood Creek, and were returned for release as fed fry. Coulter Creek origin eggs made up a portion (36%) of the total Sherwood egg box releases for the 1978 brood (Allen et al. 1980). Numbers and size (grams/fish) of fry released are summarized in Table 3.

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Coulter Creek Hatchery began operation in 1979. Summer chum adults were trapped for broodstock at Coulter Creek from 1979 to 1991. On at least two occasions eggs from another stream were reared and released at Coulter Creek: Sherwood Creek (1980 brood), and Johns Creek (1982 brood). Releases for all broods were fed fry, with the exception of 1990 and 1991, when portions of the fish were released as unfed fry (0.3-0.4 grams/fish). Supplementation fry releases averaged around 1,200,000 fish annually at Coulter Creek (Table 3).

Analysis of the Case Inlet recovery is complicated by the different start and end times of the two projects, and because of differences in culture techniques employed. The average runsize for Case Inlet during the Building stage (1980-1995) was 17,200 (GM = 14,300) summer chum, well above the Baseline/Brood stage, but still below the pre-decline average of 19,200 (GM = 12,100) fish. This result is somewhat deceptive, since only the relatively modest Sherwood Creek supplementation returns contributed during the early years of the Building stage, while the larger Coulter Creek returns occurred later. The late building stage runsizes averaged 22,900 (GM = 19,900) fish, which exceeds the pre-decline level.

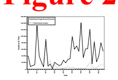
Sherwood Creek showed the least dramatic increase in runsize of the three projects during its period of supplemented returns (1980-1990), with an average runsize of only 5,000 (GM = 4,500) fish, compared to the Baseline/Brood average of 4,100 (GM = 2,400) summer chum. Supplementation at Sherwood would be expected to have had the smallest impact of the three major projects on runsize for several reasons. First, the project functioned as an egg incubation box project with volitional release of unfed fry for most of its duration, and it is known that releases of chum salmon as unfed fry results in substantially lower survival rates than releases of fish reared to a ~1 gram size. Second, the Sherwood project was the shortest in duration and released significantly fewer fish than the other two projects. Over the duration of the projects, the total number of fish released at Sherwood was only 19% of the Johns Creek total and 29% of Coulter Creek totals. Although Sherwood summer chum did not see dramatic increases, runsize did show a steady upward trend during supplementation.

While Sherwood supplementation had a positive but limited effect on Case Inlet runsize, the Coulter Creek project had a dramatic effect. For Coulter Creek, the period when supplementation fish were returning extended from 1983 through 1995. Average Coulter Creek runsize for that period was 14,000 (GM = 11,000) fish, much higher than the pre-decline and Baseline/Brood stage averages of 5,600 (GM = 3,200) and 1,200 (GM = 800) fish respectively. This recovery took place rapidly, with runsize returning to near pre-decline levels within five years of initiation of supplementation. The total runsize of Coulter Creek summer chum peaked in 1988 at 31,500 fish.

Post-supplementation (Boundary Stage)
The post-supplementation period (Boundary stage) is defined in large part by the return of a population to natural origin recruitment. The first post-supplementation return dominated by natural origin recruits was 1996, and the runsize of south Puget Sound summer chum in that year (121,300 fish) was near pre-decline highs. Available scale data show that age-3 and -4 fish made up 99.5% of returning summer chum in 1996, and the last supplementation fish (age-5, 1991 brood year) would have made an inconsequential contribution to total recruitment.

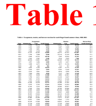
Post-supplementation summer chum runsizes decreased from the high levels experienced during the late Building stage (from 1988 through 1995), when returns averaged 73,200 (GM = 67,700) fish. A decrease would be expected if the late Building stage supplemented runsizes had exceeded levels sustainable by available habitat. However, the Boundary stage runsize average is still higher than pre-decline levels. Total south Puget Sound summer chum returns averaged 40,700 (GM = 25,100) fish from 1968 through 1976 (pre-decline),and averaged 59,800 (GM = 48,700) fish from 1996 through 2002 (post-supplementation). The post-supplementation averages are moderated somewhat by low values in 1997 and 1999 (Figure 2). South Puget Sound ***fall*** chum runsizes showed similar lows in those years, suggesting that broad based environmental factors probably impacted both groups of chum salmon.

Figure 2



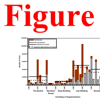
Harvest management regulations were recently modified for all-citizens fisheries targeting coho in central Puget Sound, where most of the south Puget Sound summer chum harvest typically occurs. From 1988 to 1992, there was an average of 9 days per year open to all-citizen commercial net fisheries during the primary summer chum migration period (September 10 to October 11) in the primary Puget Sound summer chum harvest zone (Seattle/Tacoma area). Since 1993, no gillnet and/or purse seine fishing has occurred in this area prior to October 11. These changes in fishery management were expressly designed to protect depressed wild coho stocks, and coincidentally contributed to a rapid drop in summer chum harvest rates. The average summer chum harvest rate dropped from 50% for 1988 through 1995, to 14% for 1996 through 2002 (Table 1).

Table 1



Hammersley Inlet
The 1996 return to Hammersley Inlet was the first post-supplementation year dominated by natural origin recruits. Runsize peaked at 74,000 summer chum in 1996, and averaged 40,300 (GM = 32,800) fish through the boundary period, in spite of lows in 1997 and 1999 (Figure 4). This average was well above both the Baseline/Brood average value of 3,700 (GM = 2,900) fish and the pre-decline runsize average of 21,400 (GM = 11,800) summer chum. As mentioned previously, this pattern of high and low runsizes is similar to that seen for south Puget Sound fall chum runsizes since 1996.

Figure 4

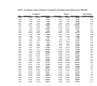


Case Inlet
Supplementation at Sherwood Creek ended earlier than the other projects (1986), meaning that any long-term effects of supplementation have had the longest time to appear. Sherwood Creek runsize averaged 7,900 (GM = 6,500) summer chum from 1991 to 2002 (post-supplementation years), above the baseline average of 4,100 (GM = 2,400) fish, but below the pre-decline average

of 13,100 (GM = 7,900) fish. While Sherwood runsizes have yet to return to pre-decline levels, runsize has demonstrated a gradual increasing trend, even though high harvest rates persisted until 1992 (Table 1). Although Sherwood runsizes were low in 1997 and 1999 (1,000 and 4,700 fish respectively), the 2000 runsize (12,800) was the largest to occur since supplementation began, and represented 2nd and 3rd generation NORs. Sherwood Creek is the only supplementation stream where runsizes have continued to increase post-supplementation, probably because the population is still below carrying capacity and the current low harvest rates are allowing continued growth

Coulter Creek runsize showed the quickest recovery of the three supplemented populations. Runsize returned to near pre-decline levels within 5 years of the initiation of supplementation. Like Johns Creek, the 1996 return to Coulter Creek was the first post-supplementation year dominated by NORs, and the runsize of 35,600 summer chum was the largest on record. In spite of a low of 700 fish in 1997, the boundary period average runsize of 10,900 (GM = 6,500) is well above the pre-decline average of 5,600 (GM = 3,200) fish, and the Baseline stage average of 1,200 fish.

Table 1

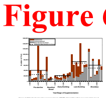


As a whole, Case Inlet runsize averaged 19,500 (GM = 14,100) summer chum during the boundary period, very close to the pre-decline average of 19,200 (GM = 12,100), but well above the baseline average of 5,400 (GM = 3,300) fish. This average includes an extremely low runsize in 1997 (1,700), a low which was also experienced by south Puget Sound fall chum stocks.

Discussion

The chronology of south Puget Sound summer chum salmon supplementation (Figure 6) mirrors the four stages of a successful supplementation program as described by Pearsons (2002). The four stages were preceded by a pre-decline period (1968-1976) when south Puget Sound summer chum had an average runsize of 40,600 (GM = 25,100) fish. The Baseline/Brood stage for summer chum (1977-1979) had an average return of 9,100 (GM = 6,400) fish, defining the low point of abundance. The Building stage was represented by the 1980 through 1995 returns, and was characterized by a period of modest increases (1980 through 1987 returns averaged 21,300 (GM = 20,000) fish), followed by robust returns (1988 through 1995 returns averaged 73,200 (GM = 67,700) fish). During the Boundary stage (post-supplementation; 1996-2002), runsizes averaged 59,800 (GM = 48,700) fish.

Figure 6



The last summer chum originating from supplementation projects returned to Sherwood Creek in 1990, and to Johns and Coulter creeks in 1995. The post-supplementation (Boundary stage) fish are now in their second or third generation of natural origin recruitment (the last 7-12 return years), without any evidence of negative consequences from the prior supplementation. The Boundary stage average abundance of 59,800 (GM = 48,700) south Puget Sound summer chum salmon is 47% (GM = 94%) higher than the pre-decline average abundance of 40,600 (GM = 25,100) fish. The Hammersley Inlet stock has increased 88% (GM = 178%) and the Case Inlet stock is 2% (GM = 17%) higher. It is not known if the two summer chum stocks are now at full carrying capacity, because not all factors for decline have been addressed. However, the performance of these stocks as natural origin recruits over the last seven post-supplementation years is strong evidence of successful recovery.

It should be pointed out that the successful supplementation of south Puget Sound summer chum was accomplished using the artificial production approaches of the late 1970s and 1980s. By that time period WDF salmon culture protocols had greatly improved over earlier years, and particular care was taken to select representative broodstock for all projects. However, not all culture techniques used were as sensitive to wild stock protection issues as present hatchery practices, and the methods used were not as rigorous as the supplementation approaches now used to assist the recovery of ESA listed chum salmon stocks (Tynan et al. 2003, this volume, WDFW and PNPTT 2000). It is certain that current approaches to supplementation will have a reduced chance of deleterious consequences for target stocks.

Did the supplementation projects return south Puget Sound summer chum populations to sustainability? No, but the returns of supplementation fish did decrease the extinction risk through a period of over 20 years of high harvest, which was likely a major contributing factor for the decline. When harvest rates were reduced in the early 1990s, the supplemented populations provided sufficient escapement to allow populations to succeed and produce at self-sustaining levels.

Supplementation of a salmonid population at risk of extinction should be seen as a Alife boat@ that can be used to sustain the population until rescue arrives. Rescue in this case was improved survival resulting from mitigating a major factor for decline. Had harvest rates not been lowered, post-supplementation runsizes may have shown another decline similar to that of the late 1970s and the summer chum could have reverted to Baseline stage abundances. This would not have meant that supplementation failed, only that rescue never came.

While it is impossible to know what would have happened to south Puget Sound summer chum without supplementation, Hood Canal summer chum provide an interesting comparison. Hood Canal runsizes declined at the same time, and for many of the same reasons as the south Puget Sound summer chum runs. Without supplementation the Hood Canal summer chum stocks showed no signs of recovery during the 1980s, and several stocks suffered extirpation. The remaining stocks are now listed as a threatened population under the Endangered Species Act. State and tribal co-managers are currently implementing a comprehensive conservation plan with the goal of recovering the Hood Canal populations (WDFW and PNPTT 2000).

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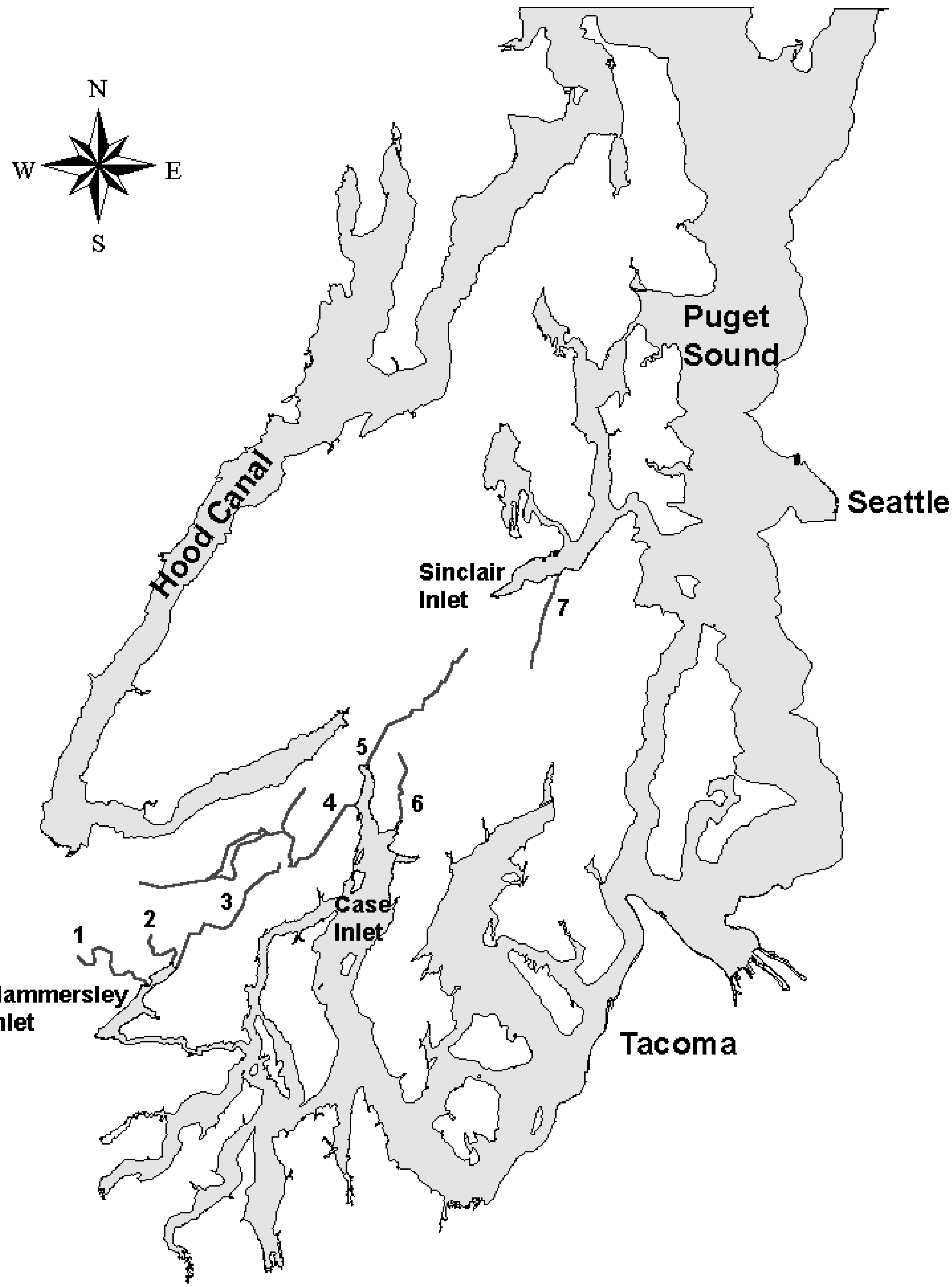

Figure 1. Map showing location of south and central Puget Sound summer chum streams. Streams indicated by number: 1. Johns Cr. 2. Cranberry Cr. 3. Deer Cr. 4. Sherwood Cr. 5. Coulter Cr. 6. Rocky Cr. 7. Blackjack Cr.

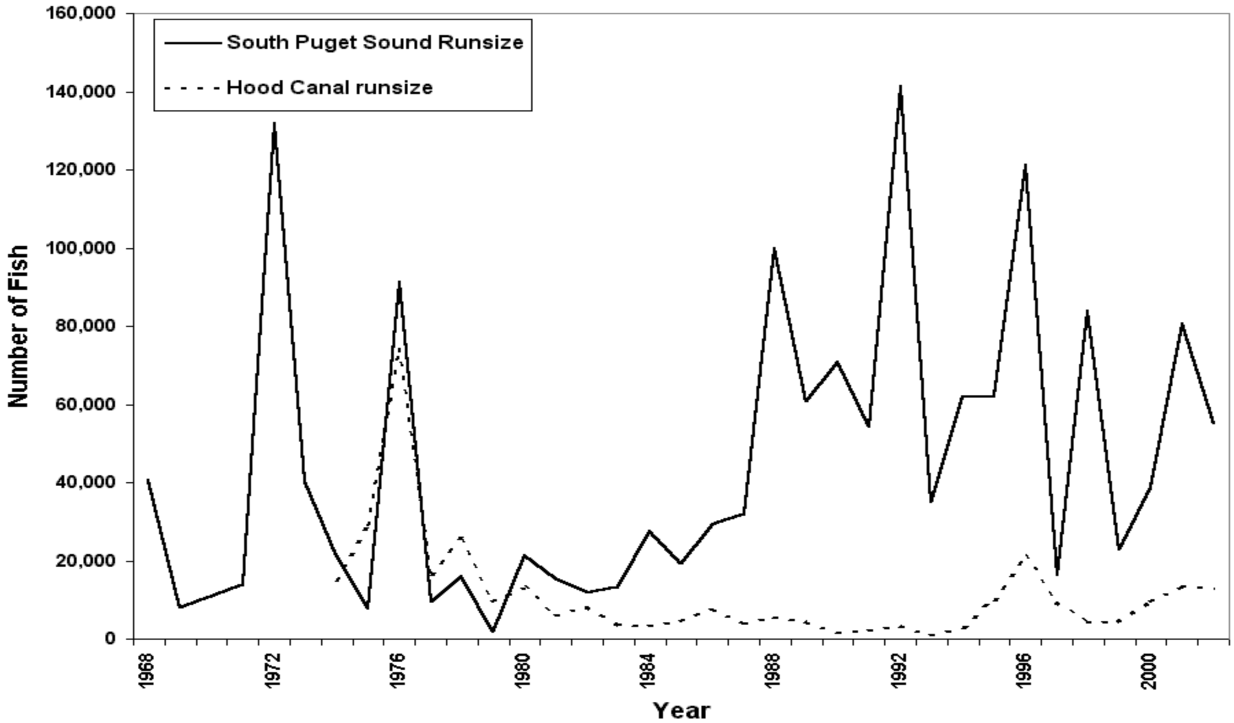

Figure 2. Total runsizes for south Puget Sound (1968-2002) and Hood Canal (1974-2002) summer chum.

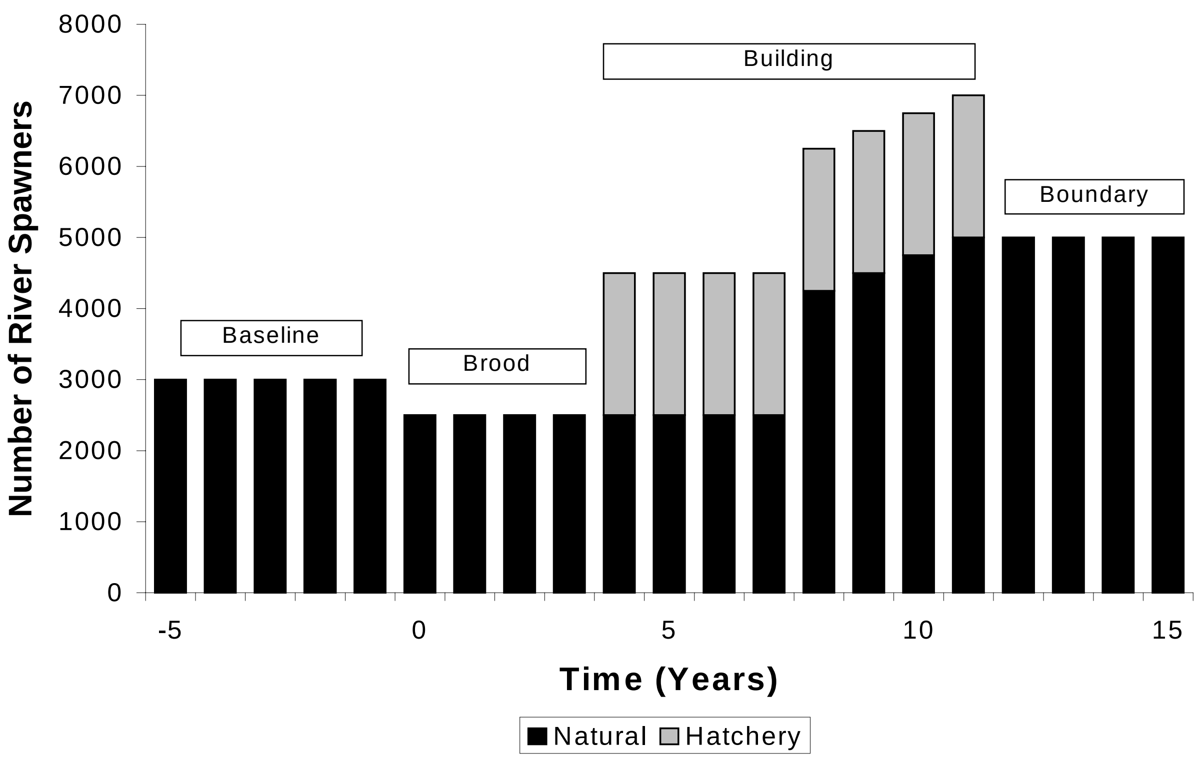

Figure 3. Hypothetical chronology of a successful supplementation program, as presented by Pearsons (2002).

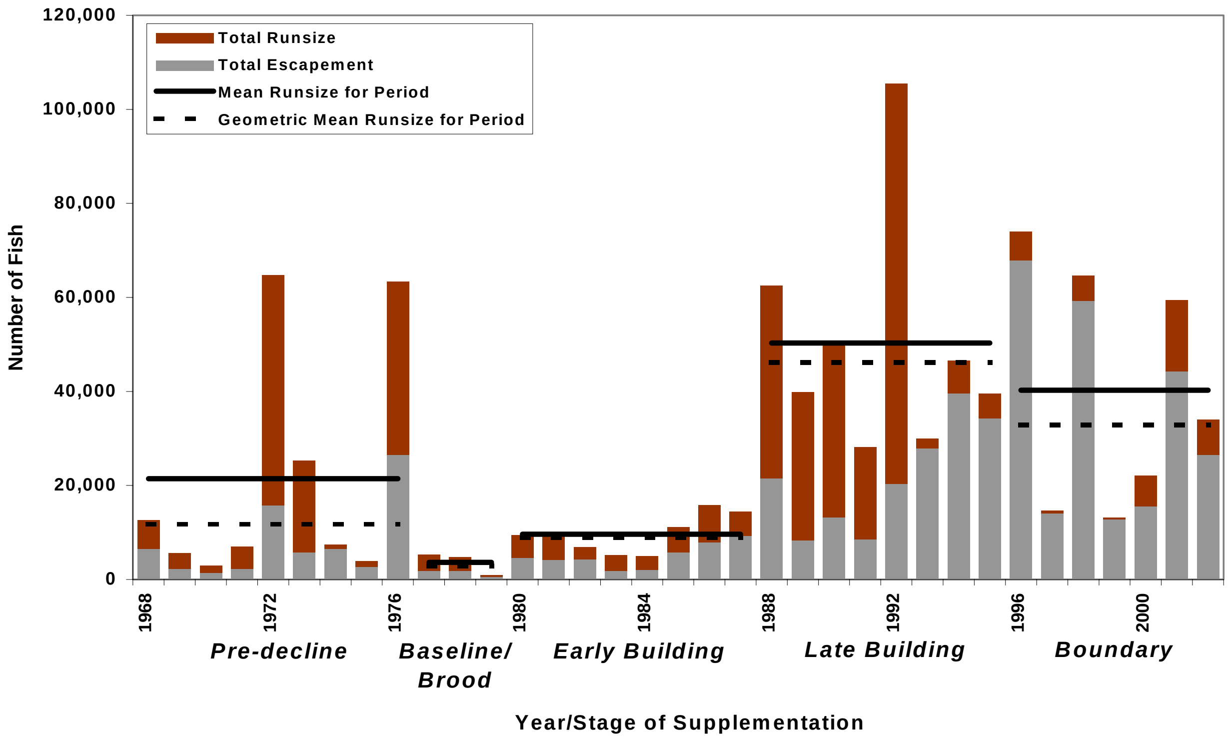

Figure 4. Hammersley Inlet summer chum escapement and runsize, 1968-2002. Horizontal lines indicate mean runsizes during stages of supplementation as described by Pearsons (2002).

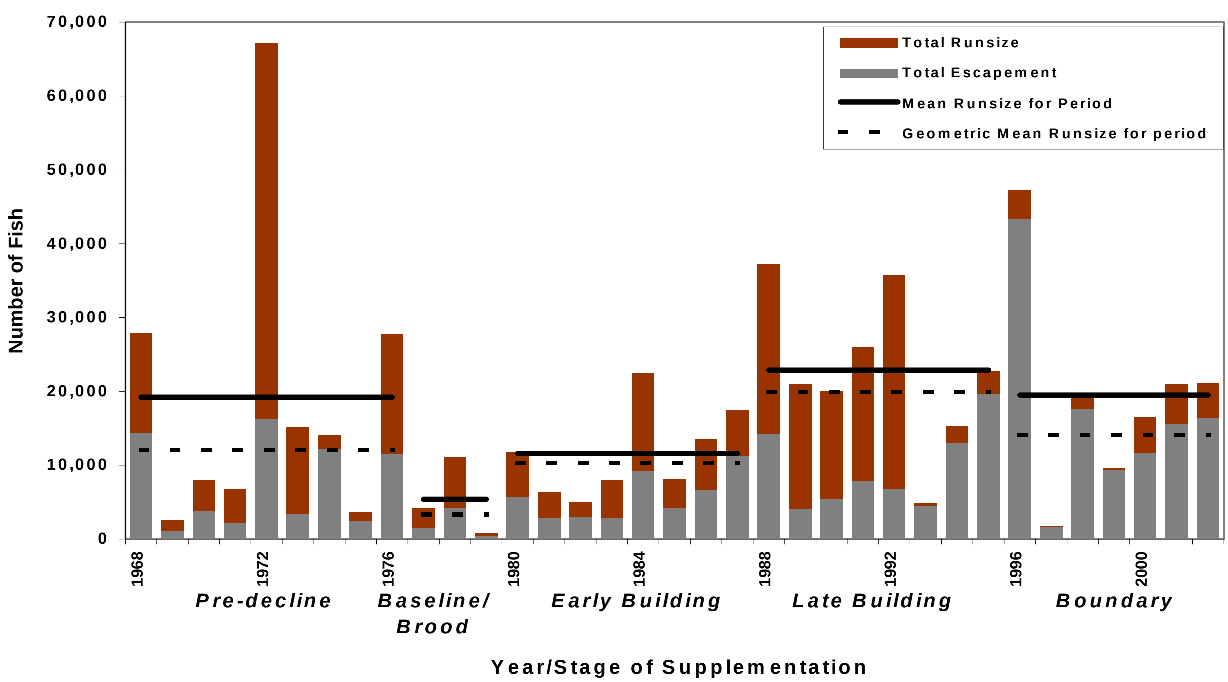

Figure 5. Case Inlet summer chum escapement and runsize, 1968-2002. Horizontal lines indicate mean runsizes during stages of supplementation as described by Pearsons (2002).

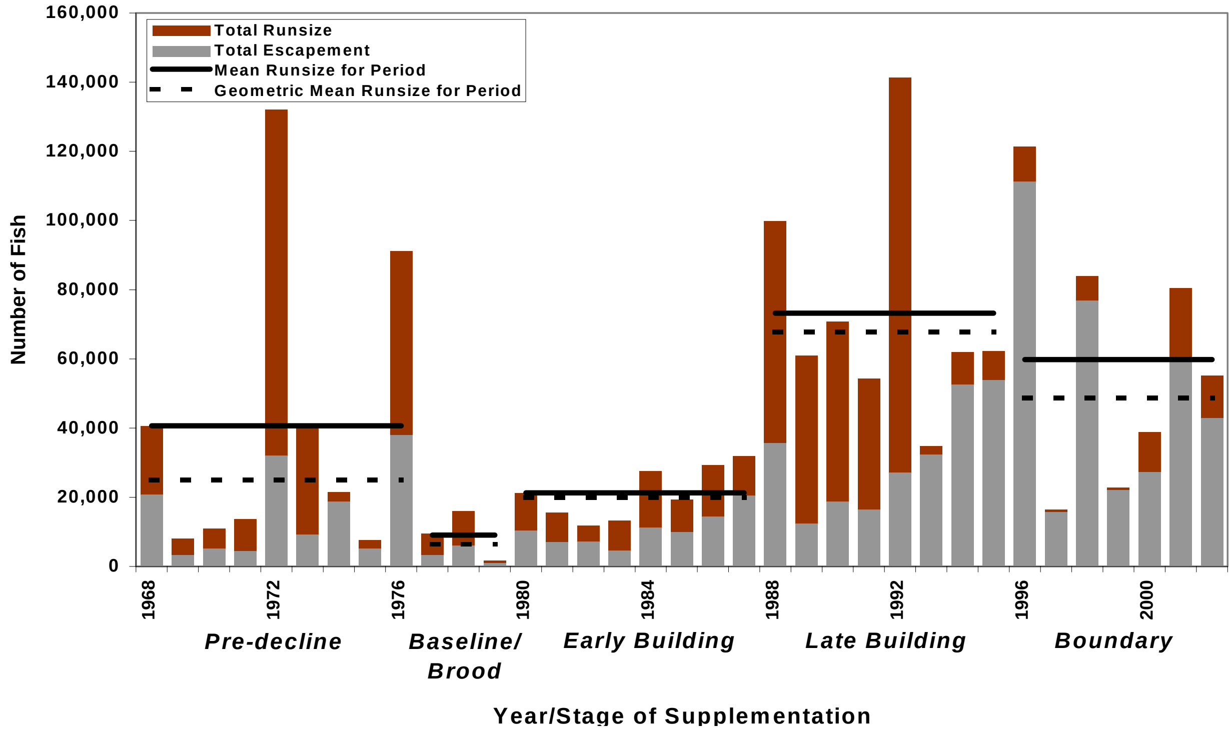

Figure 6. South Puget Sound summer chum escapement and runsize, 1968-2002. Horizontal lines indicate mean runsizes during stages of supplementation as described by Pearsons (2002).

Table 1. Escapement, runsize, and harvest rate data for south Puget Sound summer chum, 1968-2002.

	Escapement			Runsize			Harvest Rate (%)
Year	**Hammersley**	**Case**	**South Sound**	**Hammersley**	**Case**	**South Sound**	**South Sound**
1968	6,490	14,379	**20,869**	12,613	27,945	**40,558**	48.5
1969	2,303	1,030	**3,333**	5,607	2,508	**8,115**	58.9
1970	1,398	3,801	**5,199**	2,929	7,967	**10,896**	52.3
1971	2,290	2,218	**4,509**	7,005	6,785	**13,790**	67.3
1972	15,747	16,342	**32,089**	64,775	67,222	**131,997**	75.7
1973	5,799	3,469	**9,268**	25,274	15,120	**40,394**	77.1
1974	6,509	12,232	**18,740**	7,459	14,016	**21,475**	12.7
1975	2,633	2,467	**5,100**	3,916	3,670	**7,586**	32.8
1976	26,526	11,601	**38,127**	63,430	27,742	**91,172**	58.2
1977	1,873	1,496	**3,369**	5,293	4,227	**9,520**	64.6
1978	1,848	4,271	**6,119**	4,817	11,136	**15,953**	61.6
1979	529	463	**991**	911	797	**1,708**	41.9
1980	4,650	5,784	**10,434**	9,467	11,775	**21,242**	50.9
1981	4,193	2,877	**7,070**	9,203	6,318	**15,521**	54.4
1982	4,232	3,091	**7,323**	6,816	4,978	**11,794**	37.9
1983	1,836	2,802	**4,638**	5,237	7,993	**13,230**	64.9
1984	2,051	9,228	**11,280**	4,990	22,501	**27,491**	59.0
1985	5,790	4,211	**10,001**	11,230	8,167	**19,397**	48.4
1986	7,853	6,702	**14,554**	15,812	13,546	**29,358**	50.4
1987	9,322	11,265	**20,587**	14,460	17,475	**31,935**	35.5
1988	21,458	14,258	**35,715**	62,488	37,262	**99,750**	64.2
1989	8,270	4,145	**12,415**	39,868	21,014	**60,882**	79.6
1990	13,193	5,523	**18,716**	50,669	20,037	**70,706**	73.5
1991	8,569	7,924	**16,493**	28,189	26,068	**54,257**	69.6
1992	20,282	6,828	**27,110**	105,446	35,806	**141,252**	80.8
1993	27,874	4,506	**32,380**	29,967	4,848	**34,815**	7.0
1994	39,581	13,044	**52,625**	46,542	15,338	**61,880**	15.0
1995	34,218	19,707	**53,925**	39,492	22,744	**62,236**	12.0
1996	67,869	43,389	**111,258**	73,975	47,292	**121,267**	8.3
1997	14,075	1,646	**15,721**	14,642	1,712	**16,354**	3.9
1998	59,278	17,640	**76,918**	64,621	19,230	**83,851**	8.3
1999	12,734	9,339	**22,073**	13,149	9,644	**22,793**	0.4
2000	15,559	11,658	**27,216**	22,162	16,606	**38,768**	29.1
2001	44,312	15,653	**59,965**	59,461	21,003	**80,464**	25.5
2002	26,484	16,434	**42,918**	33,984	21,088	**55,072**	22.1

Table 2. South Puget Sound summer chum stream, stock, and regional runsize averages for each stage of supplementation.

		Johns Creek		Sherwood Creek		Coulter Creek	
Period	**Timespan**	**Arithmetic**	**Geometric**	**Arithmetic**	**Geometric**	**Arithmetic**	**Geometric**
Pre-decline	1968-1976	20,400	10,900	13,100	7,900	5,600	3,200
Baseline/Brood	1977-1979	3,400	2,600	4,100	2,400	1,200	800
Early Building	1980-1987	8,900	8,300	4,500	4,000	7,000	4,400
Late Building	1988-1995	40,600	36,800	6,700	6,000	16,200	12,700
Boundary	1996-2002	22,000	16,700	8,600	6,900	10,900	6,500

		Hammersley Inlet		Case Inlet		South Puget Sound	
Period	**Timespan**	**Arithmetic**	**Geometric**	**Arithmetic**	**Geometric**	**Arithmetic**	**Geometric**
Pre-decline	1968-1976	21,400	11,800	19,200	12,100	40,600	25,100
Baseline/Brood	1977-1979	3,700	2,900	5,400	3,300	9,100	6,400
Early Building	1980-1987	9,700	8,900	11,600	10,300	21,300	20,000
Late Building	1988-1995	50,300	46,200	22,900	19,900	73,200	67,700
Boundary	1996-2002	40,300	32,800	19,500	14,100	59,800	48,700

Table 3. Total numbers and average size at release for summer chum released from south Puget Sound supplementation projects.

Brood	Johns Creek		Cranberry Creek		Sherwood Creek		Coulter Creek	
year	**Number**	**grams/fish**	**Number**	**grams/fish**	**Number**	**grams/fish**	**Number**	**grams/fish**
1976	3,719,121	0.93	1,800,000	0.38	500,000	0.38		
1977	205,825	0.28			175,000	0.43		
1978	680,678	0.83			438,000	0.36		
1979	287,340	1.06			32,500	1.75	32,500	1.82
1980	665,000	0.98			977,845	0.36	1,510,147	1.23
1981	1,003,606	1.21					518,630	1.21
1982	2,212,900	1.25	951,658	0.36	869,186	0.39	1,136,900	1.01
1983	1,230,800	1.38					2,227,600	1.21
1984	1,140,000	1.16			460,815	0.40	2,097,000	1.23
1985	2,500,800	1.57			451,255	0.39	1,367,000	1.21
1986	1,835,000	1.40			757,000	0.40	1,382,800	1.30
1987	2,100,000	1.18					1,159,300	1.30
1988	1,975,000	1.01					1,230,600	1.02
1989	1,956,300	2.45					1,150,000	1.19
1990	1,958,900	1.04					1,153,500	1.35
1991	1,382,700	0.30					1,152,000	0.45