An Integrated Approach to Rebuilding Stave River Chum Using Harvest Reduction, Hatchery Augmentation, Flow Control and Habitat Improvement

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AN INTEGRATED APPROACH TO REBUILDING STAVE RIVER CHUM USING HARVEST REDUCTION, HATCHERY AUGMENTATION, FLOW CONTROL AND HABITAT IMPROVEMENT

by

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Salmon populations in Stave River were severely impacted following hydroelectric developments between 1910 and 1930. The Stave River chum run was further reduced by very high exploitation rates during the 1950s. Rebuilding of the Stave chum population was achieved through a combination of efforts including harvest reduction, hatchery augmentation, a flow agreement between BC Hydro and Fisheries and Oceans Canada to improve spawning and incubation flows, and habitat improvement to maximize the benefits of improved flows.

These combined rebuilding efforts resulted in a 5-fold increase in the average Stave chum returns and a 7-fold increase in the average Stave chum escapements between the pre-enhancement period (1960-84) and the 1990-2002 period when all the rebuilding components were in place. Other salmonid populations in Stave River also benefited from hatchery augmentation, flow control and habitat improvement.

RÉSUMÉ

Bailey, D.D., A.Y. Fedorenko and R.J. Cook. 2005. An integrated approach to rebuilding Stave River chum using harvest reduction, hatchery augmentation, flow control and habitat improvement. Can. Tech. Rep. Fish. Aquat. Sci. 2593: vi + 33 p.

Les populations de saumon de la rivière Stave ont subi un déclin important à la suite des aménagements hydro-électriques effectués entre 1910 et 1930. La remontée du saumon kéta de la rivière Stave a été réduite davantage par les taux très élevés d'exploitation au cours des années 50. Le rétablissement de la population de saumon kéta de la rivière Stave a été réalisé grâce à la réduction des prises, l’augmentation de la production en élevage, la régulation du débit pour améliorer le frai et l’incubation par le biais d’un entente entre BC Hydro et Pêches et Océans et l’amélioration de l'habitat afin de maximiser les avantages du débit amélioré.

Ces efforts de rétablissement ont eu pour effet de quintupler le taux de retour moyen des saumons kéta de la rivière Stave et d’augmenter l’échappée à un taux de sept fois la moyenne entre la période avant la mise en valeur (1960-84) et la période 1990-2002 lorsque tous les éléments des initiatives de rétablissement étaient établis. D'autres populations de salmonidés de la rivière Stave ont également tiré bénéfice de l'augmentation de la production en élevage, la régulation du débit et l'amélioration de l'habitat.

INTRODUCTION

Rebuilding of salmon stocks can be accomplished in several ways, depending on the mechanisms that originally acted to depress the stocks. These mechanisms include habitat degradation and inadequate water flows which affect freshwater survival, unfavourable estuary and ocean conditions which affect marine survival, and overharvesting which leads to insufficient adults returning to spawning grounds.

Hatchery augmentation of native stock is one tool for stock rebuilding. This approach may lead to a more rapid stock increase (especially when marine conditions are favourable to survival) compared to harvest reduction and habitat improvement alone. However, if the benefits of hatchery augmentation are to be translated into future increased escapements, then additional measures, such as flow and habitat improvements, may be required to correct the damage from some of the mechanisms that acted originally to depress the population.

This report focuses on the efforts to rebuild the Stave River chum stock. Stave River is a major tributary to the lower Fraser River (Fig. 1) and historically has been an important contributor to the Fraser River chum production (DFO 1996). Between 1910 and 1930, extensive hydroelectric developments were carried out in the Stave River watershed, including a water diversion from the adjacent Alouette River system into Stave Lake, the Stave Falls Dam and powerhouse complex constructed at the Stave Lake outlet, and the Ruskin Dam and powerhouse complex constructed during 1929-1930 approximately 3.5 km upstream from the Stave River outlet (Fig. 1) (Lamont and Foy 1995).

Prior to these hydroelectric developments, the natural canyon in the lower Stave River (current site of Ruskin Dam) was apparently passable at high water levels, based on hydrology, while the Stave Falls, situated approximately 5 km further upstream (current site of Stave Falls Dam), apparently blocked all upstream access (Andrew and Killick 1957, Lamont and Foy 1995). Although spawning records for the period prior to the hydroelectric developments are limited, several reports from 1922 to 1936 indicate that chum, coho and pink salmon spawned in Stave River, in the lowermost 5 km reach downstream of the rapids; the 1935 report shows 500-1,000 chum, 100-300 coho, 500-1,000 pinks and 50-100 steelhead (Andrew and Killick 1957). There are also incidental reports of chinook and cutthroat trout in Stave River, and indications that Stave Lake supports populations of kokanee, trout and other fish species (Andrew and Killick 1957, Brown and Musgrave 1979).

As a result of the construction of Ruskin Dam, all upstream access was blocked, restricting fish access to the lowermost 3.5 km of Stave River; furthermore, operations at the Ruskin power plant led to extreme flow fluctuations in Stave River downstream of the dam (Lamont and Foy 1995). The construction of Ruskin Dam also resulted in the creation of the Hayward Lake Reservoir where daily water levels fluctuated by up to 1.8 m due to peaking operations (Hirst 1991).

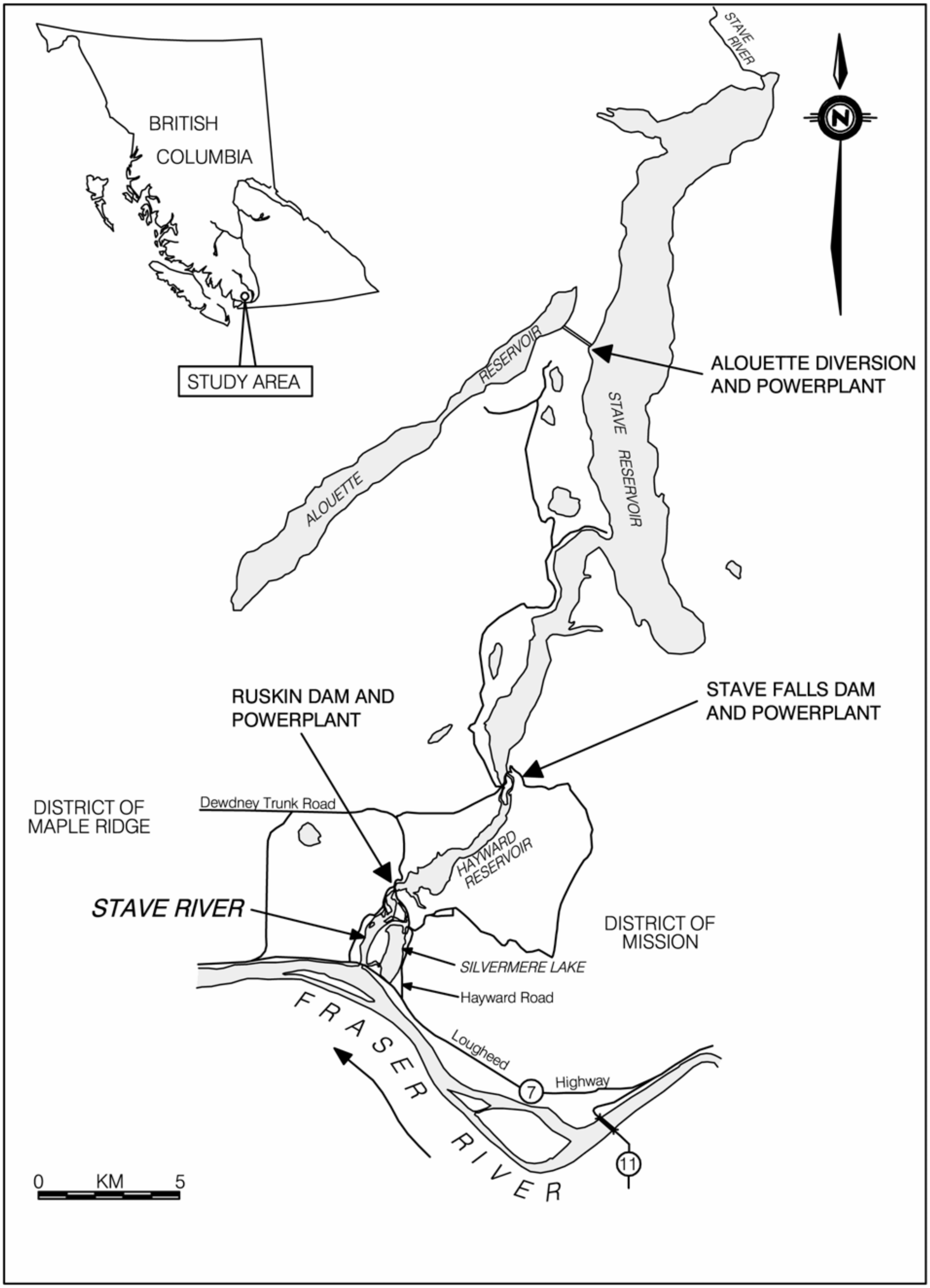

Figure 1. The Stave River system showing the Alouette-Stave Falls-Ruskin hydroelectric complex (adapted from Wilson 1996).

The extreme water level fluctuations in Stave River downstream of the Ruskin Dam severely disrupted salmon spawning and incubation by scouring and dewatering redds and stranding fry and adults (Wilson 1996). These effects, combined with the destruction of fish habitat during gravel removal operations in the 1950s (Lamont and Foy 1995) and other impacts associated with flood control, dredging and logging practices in the area (Wilson 1996), reduced the overall fish productivity in the Stave River.

Palmer (1972) was the first to suggest the enhancement of Stave chum – the dominant salmonid population in Stave River (Hancock and Marshall 1985, DFO 1996). He recognized that any large-scale spawning channel development would not be feasible due to extreme flow fluctuations in Stave River. However, there was a possibility of constructing small spawning channels below the Ruskin Dam and using incubation boxes or ponds to be gravity-fed by the dam overflow, but this was never undertaken.

An alternative approach to the enhancement of Stave chum was provided through the success of Japanese-style chum hatcheries introduced through the Salmonid Enhancement Program (SEP) in the 1970s. This technique involves the incubation of eggs in bulk-upwelling incubators, followed by the development of alevins in keeper channels and the rearing of fry in raceways. The use of relatively warm groundwater promoted accelerated development of eggs and fry, allowing the fry to reach approximately 1.0-1.5 g size, in time for release at natural migration timing. This size advantage was expected to double the survival of fed fry compared to unfed wild fry. The Inch Creek Salmonid Enhancement Facility was built in 1981-82 and used the Japanese technique for augmentation of Stave River chum, beginning with the 1982 brood.

In addition to the hatchery augmentation plans for Stave chum, the Department of Fisheries and Oceans Canada (DFO) developed a strategy in 1980 to increase the returns of Fraser River salmon stocks (including the Stave chum stock) by combining hatchery augmentation and harvest reduction (DFO, 1988).

For long-term stock rebuilding, increases in escapements through hatchery augmentation and harvest reduction alone would be of little benefit unless other limitations to fish production, such as unfavourable water flows and limited fish habitat, were also addressed. This meant that the operation of Ruskin Dam had to be modified to ensure adequate spawning and incubation flows downstream of the dam, and the Stave River fish habitat had to be increased.

In response to these concerns, a water flow agreement was reached in 1990 between BC Hydro and DFO to provide favourable water flows for spawning and incubation in Stave River downstream of the Ruskin Dam (Lamont and Foy 1995). This agreement also provided an opportunity to improve and increase the Stave River fish habitat through major restoration works. The present report describes the joint efforts of harvest reduction, hatchery augmentation, flow control and habitat improvement to rebuild the Stave River chum population.

METHODOLOGY

REBUILDING COMPONENTS

The chronology of the rebuilding components for Stave River chum is shown in Figure 2.

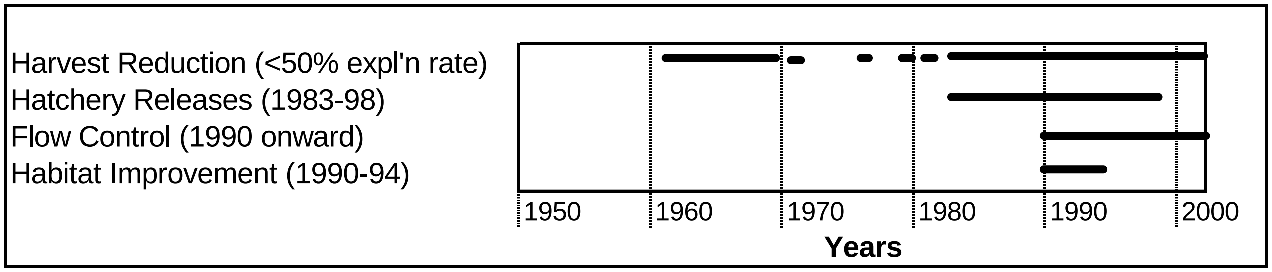

Figure 2. Chronology of rebuilding efforts for Stave River chum for the period 1950 to 2002.

Harvest Reduction

Historical exploitation rates are available only for the overall Fraser River chum population which is managed for total fish abundance rather than for individual stocks (Joyce and Cass 1992, DFO 1996). Accordingly, the exploitation rates for Stave chum are assumed to be similar to those for the Fraser River chum population since the Stave chum are a mid-timing stock within the Fraser River chum stock aggregate, based on earlier tagging studies (Palmer 1972).

The Fraser River chum population (including Stave stock) is harvested primarily in the Johnstone Strait, the Strait of Georgia, the Fraser River terminal fishery and Washington US waters (Palmer 1972, Joyce and Cass 1992). During the 1950s, the exploitation rates for Fraser River chum were very high, often exceeding 80%, and contributed to a major decline in that population during the 1950s and 1960s (Fig. 3, Append. 1). In response, fishery managers imposed progressively greater fishing restrictions during the 1960s on all major chum fisheries in southern BC waters, including a nearly complete closure of chum fisheries in 1965 and 1966 (Palmer 1972, Beacham 1984). The average exploitation rates fell to approximately 30% during the late 1960s and the Fraser chum population appeared to rebound. However, harvesting increased again in the 1970s to approximately 50%, and the Fraser chum population declined from an average of 929K in the early 1970s to an average of 627K in the early 1980s (Fig. 3). Fraser chum escapement remained fairly stable from the late 1960s to the early 1980s at 300-400K adults.

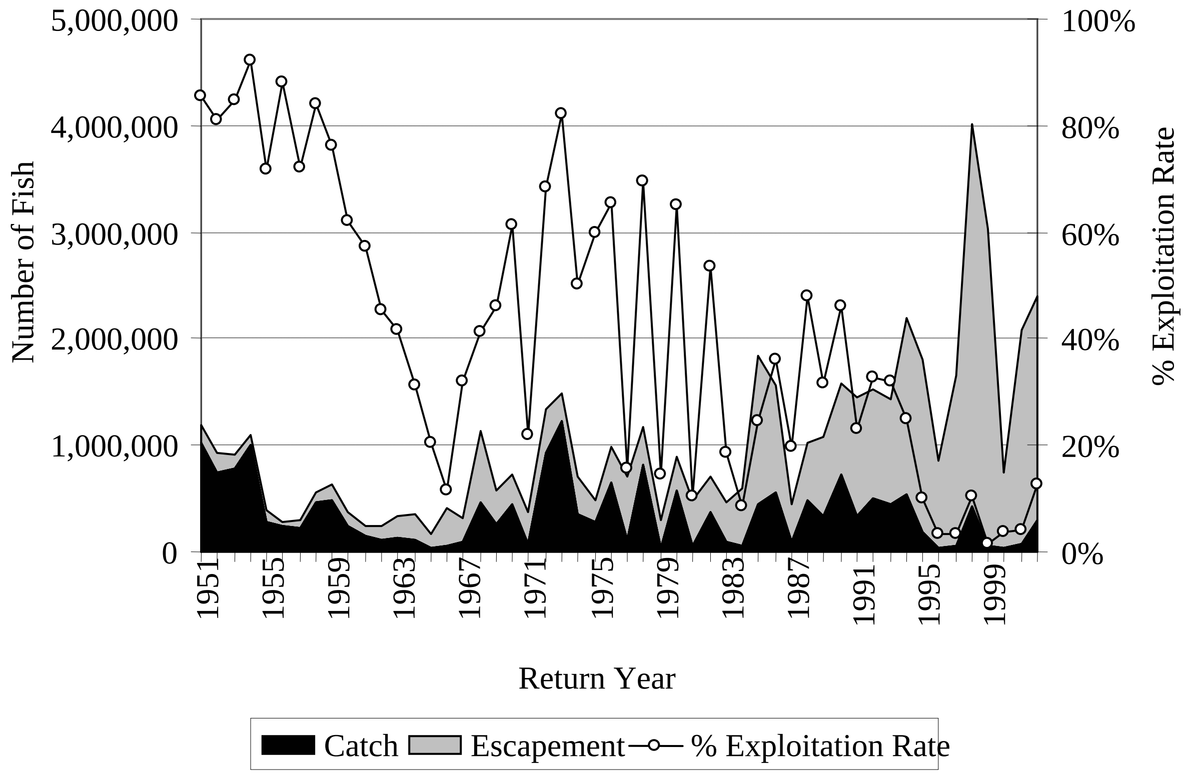

Figure 3. Estimated cumulative catch and escapement, and exploitation rates for Fraser River chum, 1951-2002 return years.

In 1983, prompted by declining trends in the abundance of the Fraser and other chum populations in southern B.C., a new "Clockwork" management plan was introduced to regulate chum catches in the Johnstone Strait interception fishery (Joyce and Cass 1992, DFO 1996) in order to help rebuild these stocks. In 1987, that plan was revised and an additional management plan was implemented to allow for a separate regulation of chum harvest in the Fraser River terminal area (Gould et al. 1991).

As a consequence of these management actions, the exploitation rates on Fraser River chum stocks declined to an average of 32% (9-65%) during the 1980s and were further reduced to an average of 19% (1-46%) during the 1990s (Fig. 3). This harvest reduction strategy complemented other rebuilding efforts on the Fraser chum stocks, including increased hatchery augmentation efforts starting in the early 1980s (DFO 1996), and led to stronger Fraser chum returns beginning in 1985 (Fig. 3). The Stave chum stock also showed an increasing trend, with strong returns starting in the late 1980s (Fig. 4, Append. 1) attributed in part to harvest reduction and hatchery augmentation.

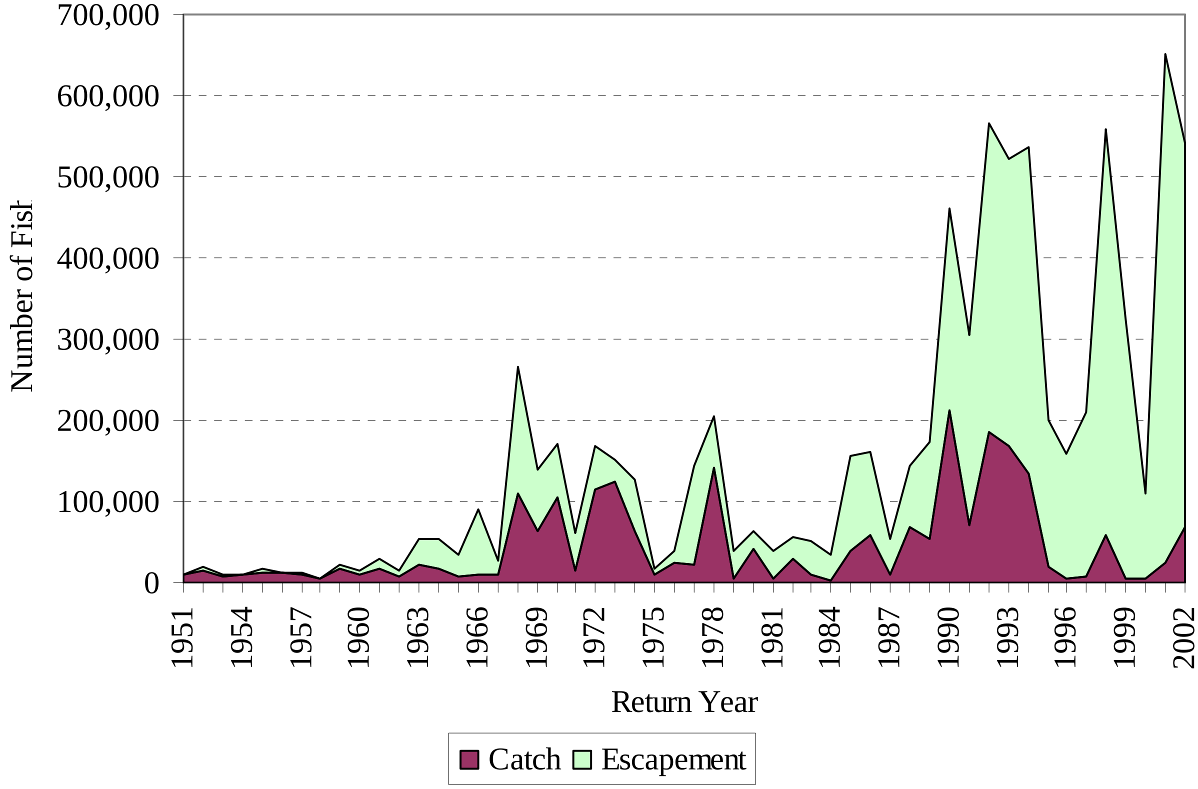

Figure 4. Estimated cumulative catch and escapement for Stave River chum, 1951-2002 return years.

Hatchery Augmentation

The Japanese hatchery technique for enhancing chum salmon (McNeil and Bailey 1975) was adopted with little modification by SEP. This involves bulk incubation to the eyed stage, placement in gravel-lined channels until swim-up, then rearing in concrete raceways to the 1-3 g size for release in the spring. Naturally-spawned chum salmon normally migrate to estuarine areas immediately upon emergence from the gravel, but a short-term of feeding in fresh water has been shown to give a substantial increase in marine survival (Salo 1991).

Hatchery augmentation of Stave River chum began with the 1982 brood year, using the native stock. The intent was for returning hatchery chum to spawn naturally in Stave River. The proposed annual production target of 4.0 million eggs was expected to produce a total annual return to catch and escapement of 57,600 chum adults (based on original DFO survival standards for chum of 72% egg-to-fed fry release and 2% fed fry-to-adult). Between 1982 and 1997, approximately 2,000-5,000 chum adults were collected annually in the Stave River for hatchery broodstock (Append. 2) and transported to the nearby Inch Creek Facility (Fedorenko and Bailey 1980) for egg-takes, incubation and rearing.

Chum salmon were captured from holding pools on the Stave River using a beach seine set from a jet boat. Initially, capture crews had to search throughout the river to find enough broodstock but after the hatchery-produced fish began returning in large numbers, all collections could be made from a large holding pool adjacent to the BC Hydro park. Captures were routinely carried out 2-3 days per week starting in late October and ending in late November of each year. Chum salmon were checked for ripeness and ripe fish were transported to the Inch Creek Salmonid Enhancement Facility by truck in oxygenated tanks. Each tank could hold ~75 adult chum salmon, for a total of ~300 fish per trip, with 2 trips per day required to collect the 3400 fish (1700 females, 1700 males) needed to meet the 5.0 million egg target during the peak operations years. At the Inch Creek Facility, the adults were released down wet vinyl chutes (to minimize abrasion) into large concrete holding ponds, with a capacity to hold about 1000 adult chums each.

Once per week, the fish in the holding ponds were crowded and sorted for ripeness. Eggs from 5 females and milt from 5 males were combined in a pail and water was added to complete fertilization and initiate water hardening. Ovidine disinfectant was added and the eggs were then loaded into the incubators.

The chum eggs were incubated to the eyed stage in Atkins boxes, which are configured so that water up-wells through the eggs that are lying on a raised screen. Each box can hold about 300,000 chum salmon eggs. After the eyed stage was reached, the eggs were transferred to screens lying on top of gravel in keeper channels, which are shallow concrete raceways each designed to hold ~1.0 million chum eggs. After the fish hatched, they passed through the screens to nestle in the gravel during the alevin stage. The screens would then be removed, which incidentally removed any dead eggs, which were counted and adjustments made to egg inventory. After the eggs absorbed their yolk sacs they volitionally migrated downstream into the rearing channels. The fish were fed a moist diet at approximately 2.0% of their body weight per day. The goal was to grow the fish to as large a size as possible by the preferred release timing at the end of April each year.

At the target release time and size, the fry were transported back to the Stave River by truck in oxygenated tanks. The fish were not fed for two days prior to transport to reduce the amount of feces ejected during transport. Fish transport and release was conducted during the evenings to minimize bird predation on the newly released fry. For the 1982 to 1997 brood years, survival of egg-to-fed fry release averaged 85% and an average of 4.1 million (range 2.1-5.3 million) fed fry were released annually into Stave River at approximately 1.5 g (Fig. 5, Append. 2).

Prior to release each year, approximately 100,000 chum fry (range 50,000-150,000) were marked using a combination of adipose-clips and coded-wire tags (Ad-CWTs) (Append. 2); exceptions were the 1983 and 1984 brood years when all fry were released without marks. Marking allowed for assessment of hatchery fry survival and of adult contribution to catch and escapement. Hatchery production was discontinued after the 1997 brood year as the Stave chum stock was considered to be rebuilt. Other Stave River salmonid species (coho, chinook, steelhead) are still enhanced through hatchery production and cutthroat were enhanced until 1997.

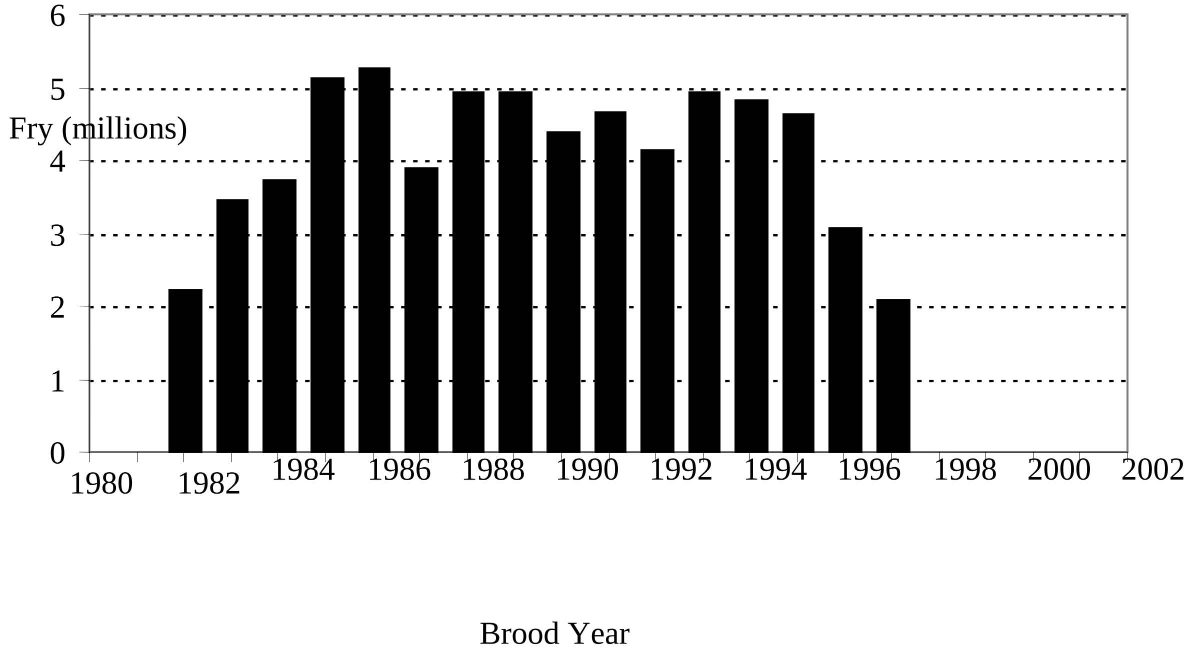

Figure 5. Chum hatchery fry releases to Stave River, 1982-1997 brood years.

Flow Control

The operation of the Ruskin hydroelectric power plant prior to 1989 was characterized by highly variable flows in the Stave River downstream of the Ruskin Dam. The peaking operations roughly followed the daily electrical demand, with large volumes of water generally released during the morning and evening periods when the power demand was high, and little flow released during the night periods when the power demand was low. The variable flows severely impacted fish production in Stave River by scouring salmon spawning beds, disrupting spawning behaviour, stranding fry and adults, and often leaving redds without flow (Lamont and Foy 1995, Wilson 1996).

In 1990, a provisional water flow agreement was reached between BC Hydro and DFO on acceptable flows during salmon spawning and incubation periods (DFO 1995, Lamont and Foy 1996). This agreement would provide a continuous flow of 84 m^3/s (3000 cfs) during the fall period (Oct-Nov) to ensure successful salmon spawning, and a continuous flow of 28 m^3/s (1000 cfs) during the winter / spring period (Dec-Apr) to ensure successful egg incubation (Hirst 1991, Wilson 1996).

Since 1990, BC Hydro, and the federal and provincial fisheries agencies have reviewed annually the flow agreement in order to improve the hydroelectric operational flexibility without compromising the benefits to fish (Lamont and Foy 1995, Wilson 1996). Monitoring plans were also developed and funds made available for maintenance of the restored Stave River fish habitat, particularly the man-made, semi-natural spawning channels and rearing ponds described under Habitat Restoration.

In 1999, following a series of extensive consultations which dealt with the collective water needs of all user groups and interests, a Water Use Plan was developed for the Stave Falls and Ruskin projects (Failing 1999). The participating groups included government and non-government agencies, First Nations and local citizens. A variety of interests were represented including industrial interests, recreation, First Nations archeological values, fisheries, wildlife, power production and flood control. The key objective of the Plan was to support viability of fish populations in the Stave River system by increasing spawning and rearing capacity, reducing stranding of eggs and alevins, reducing risks of exposure to elevated levels of Total Gas Pressure and increasing the Hayward Reservoir productivity (Failing 1999).

The Stave River Water Use Plan was revised in 2003 (BC Hydro 2003) and implemented in 2004. The operational strategy included most of the previously implemented flow constraints, and introduced several new ones.

The key elements of the authorized Stave River Water Use Plan (BC Hydro 2003) were:

a) **Year-round minimum water levels –** a minimum tail water (just below the dam) level of 1.8 m (mid-Oct to end-Nov) to ensure sufficient wetting during the spawning period, and a minimum water level of 1.7 m for the remainder of the year.

b) **Regulated Fall Flows** (mid-Oct to end-Nov) **–** maintenance of relatively constant water flows on a weekly basis during the salmon spawning period. This modified strategy would allow for limited peaking at the Ruskin plant at discharges above 100 m^3/s, provided that each peaking event was less than 12 hours in order to discourage spawning in undesirable areas.

c) **Regulated Spring Flows** (mid-Feb to mid-May) **–** maintenance of relatively constant water flows on a daily basis during the fry emergence period. This strategy would allow for limited peaking at the Ruskin plant at discharges above 100 m^3/s, provided that a minimum flow of 100 m^3/s was maintained for the day.

d) **Ramping –** a previously implemented strategy to ensure a gradual rate of change in the total discharge from Ruskin Dam during the regulated fall and spring flow periods, as specified in the operational plans (BC Hydro 2003).

e) **Incubation Flows –** previously implemented constraints on incubation flows were modified.

This latest Water Use Plan should result in significant improvements to the Stave River rearing habitat downstream of Ruskin Dam, largely due to the introduction of regulated spring flows on a daily basis. This will minimize stranding of eggs and emerging fry and boost the overall fry production. Some adult stranding may occur due to the introduction of limited peaking in the fall, but this impact is expected to be negligible due to time restrictions placed on the peaking events.

The Stave Water Use Plan included a monitoring program to evaluate the effectiveness of the new operating constraints. The data would also provide improved and scientifically defensible information for directing potential operating constraints in the future (BC Hydro 2003).

Habitat Restoration

During 1990 to 1994, an intensive habitat restoration program was conducted on Stave River downstream of the Ruskin Dam. The aim of this 4-year program was to increase the usable spawning, incubation and rearing habitat downstream of the dam, and maximize the benefits from the 1990 flow agreement. DFO and BC Hydro jointly funded and carried out the restoration projects. The projects are detailed in DFO (1995) and Lamont and Foy (1995), and summarized by Wilson (1996).

Some of the highlights of the habitat improvement program included:

- Construction of new spawning channels,
- Addition of spawning gravel and recontouring of existing side-channels to provide additional fish habitat with adequate flows for spawning and incubation,
- Re-grading of selected river bars to provide flows to previously cut-off side-channels,
- Modification of overflow channels to reduce stranding of juveniles,
- Excavation of adult holding pools and angling pools,
- Deepening of selected side-channels and addition of complex cover for rearing juveniles, especially coho, and
- Construction of a wooden foot bridge across the upper channel to improve public access to the habitat improvement projects in Stave River.

The Stave River spawning habitat for the pre-and post-improvement periods is shown in Figure 6. As a result of the 1990 flow agreement and the 1990-94 habitat restoration program, the previous moderate-to-poor spawning area of 84,000 sq. m (under old flow regime) was improved and 118,000 sq. m. of new spawning area were added, more than doubling the total Stave River spawning habitat to 202,000 sq. m. This resulted in an increase in the chum adult spawning capacity from approximately 92,000 adults to 220,000 adults. Table 1 summarizes the combined effects of flow control and habitat improvement.

Table 1. Estimated chum spawning area and adult spawning capacity for Stave River below Ruskin Dam for the pre-improvement (pre-1990) and post-improvement (after 1994) periods.

Fish Habitat	Spawning Area		Spawning Capacity +
Original (pre-1990)	84,409 sq. m	*	91,774 adults
Improved (after 1994)	117,612 sq. m	**	127,875 adults
TOTAL	202,021 sq. m		219,649 adults

* Pre-improvement estimate (pre-1990) of usable spawning area was based on spawning distribution surveys in late 1960s (Palmer 1972, Wilson 1996).

** Post-improvement estimate (after 1994) of usable spawning area was calculated from topographical information and actual spawner distribution, as observed during the 1994 ground and aerial spawning surveys (Lamont and Foy 1995).

+ Based on a spawning requirement of 0.92 sq. m per adult (Palmer 1972).

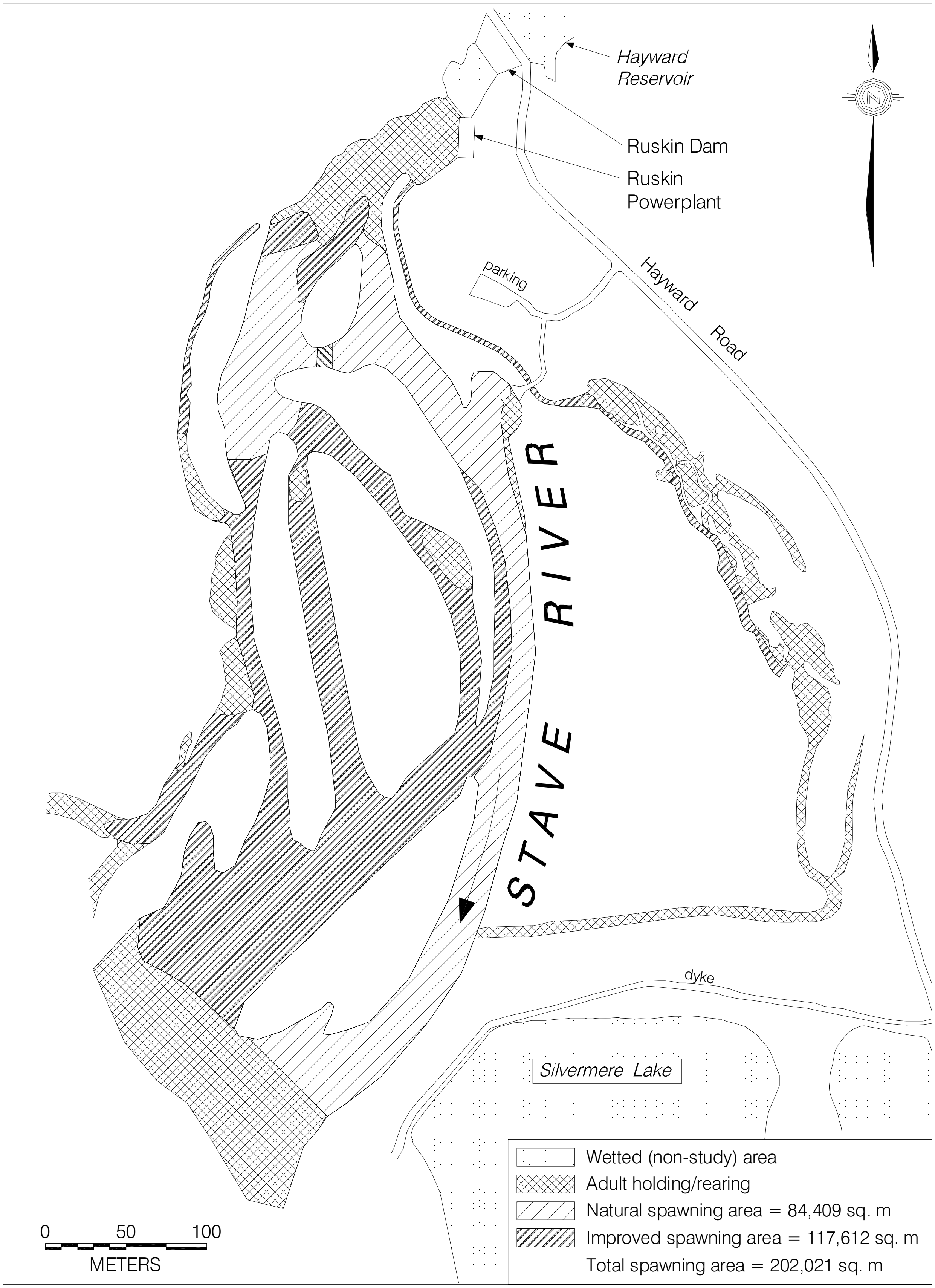

Figure 6. Stave River spawning habitat, 1994 (adapted from Wilson 1996).

ASSESSMENT OF ADULT RETURNS

The following terms were used in the assessment of Stave River chum returns:

- Hatchery chum – Returns originating directly from hatchery fry releases (i.e., 1st generation hatchery chum).
- Natural chum – Wild chum and all naturally spawning progeny of hatchery chum (i.e., 2nd and 3rd generation hatchery fish).
- River spawners – All chum adults (natural and hatchery) spawning directly in the river (excludes broodstock and other removals).
- Total chum escapement – All river spawners plus broodstock and other removals.
- Total return – Catch plus escapement.

Exploitation rates of chum salmon were calculated by dividing the total catch by the total return. Survival rates of hatchery chum were calculated by dividing the total estimated hatchery returns to catch and escapement by the numbers of fry released for each tag code.

Estimation of Total Stave Chum Catch

The total catch of Fraser River chum is estimated in the Canadian and US fisheries using adult tagging studies and Genetic Stock Identification (GSI) information (Gould et al. 1991, DFO 1996). The catch of individual Fraser chum stocks is not identified. Accordingly, the Stave chum catch was estimated indirectly by applying the Fraser chum exploitation rates to the total Stave chum escapements (Append. 1). The assumption was that the Stave chum, which are a mid-timing stock within the Fraser River chum stock aggregate (Palmer 1972), have similar exploitation rates as the Fraser chum population.

Estimation of Total Stave Chum Escapement

The pre-1961 Stave chum escapements were visual estimates made by fishery officers during foot surveys on the spawning grounds (Palmer 1972). Subsequent estimates were typically based on more rigorous assessment methodologies, including mark-recapture studies, helicopter counts extrapolated upwards using Area Under the Curve (AUC) methodology (Irvine et al. 1993), and visual estimates adjusted by expansion factors developed from previous studies (Append. 3). This report uses the visual estimates for the pre-1961 period, and the "best" available estimates for subsequent years (shaded values in Append. 3).

Assessment methodologies for estimating Stave River chum escapements are detailed in Appendix 3 and summarized below:

Prior to 1961: Visual estimates by fishery officers during walking surveys.

1961 - 1969: Tag and recovery programs involving all Fraser chum stocks (Palmer 1972) and visual estimates by fishery officers.

1970 - 1988: Visual estimates by fishery officers and in later years by the Inch Creek Hatchery staff; intermittent enumeration by airplane and helicopter overflights (Joyce and Cass 1992); tag and recovery programs by Fraser River Division (1977-79).

1989 - 1994: Tag and recovery programs by the Inch Creek Hatchery staff (1989-1991, 1994); helicopter overflight counts; indirect estimates by hatchery staff (1992-93).

1995 - Present: Weekly helicopter overflight counts by the Inch Creek Hatchery staff, combined with AUC methodology.

Due to the different assessment techniques used, the Stave chum escapement estimates vary in their reliability. The pre-1961 visual estimates are generally considered to be underestimates of the population (Palmer 1972). Subsequent estimates are generally considered to be more reliable as more rigorous methodologies were used, but the data quality remains variable with 95% confidence limits ranging from 17% to 63% (Append. 3).

Some straying of chum adults occurred into and out of the Stave River. In this report, the stray component is not quantified as the data are incomplete (only a small portion of total enhanced Fraser chum production was marked, and only a few streams were routinely checked for adult marks). Stave-origin hatchery chum that strayed into other streams are excluded from the estimate of Stave River hatchery escapement (but are included for calculating adult survival for Stave hatchery chum, Append. 2). The hatchery chum that originated from other enhanced stocks but strayed into Stave River are included as part of the total Stave River chum escapement (Append. 1).

Estimation of Hatchery Contribution

The general procedures used for estimating the hatchery contribution to catch and escapement are documented in the PSARC reports S88-11, S89-24 and S-90-11 (Bailey and Plotnikoff 1988, 1989, and Bailey et al. 1990, respectively). In general, the numbers of observed CWT marks for a given stock are expanded by the mark sampling rates in the catch and the escapement, and by the proportion of juveniles tagged, then adjusted upwards by 30% to correct for “mark mortality” based on previous mark mortality experiments (Bailey 1995). This mortality correction factor is a combination of actual fry mortality and fin regeneration where some fish can no longer be identified as having been clipped. For those groups released without marks, mark sampling data for tagged groups closest in size and time at release and in location of release to the unmarked groups, are used to calculate the expanded returns.

In this report, the catch of Stave hatchery chum in the Canadian fisheries is based on sampling and CWT recoveries in the Canadian commercial net fisheries, and is considered to be a reliable estimate. The relatively minor Canadian troll and sport catches are excluded as these estimates are considered to be unreliable due to limited CWT sampling.

The catch of Stave hatchery chum in the US fisheries, although considered to be important, can not be estimated directly as chum fisheries are not sampled for marks in southern US waters. Accordingly, the US catch component of Stave hatchery chum is estimated indirectly (Append. 4) by adjusting the Canadian net catch of Stave hatchery chum by the overall Fraser chum catch ratio of

[Canadian Net Catch / (Total Canadian + US catch)].

The assumption is that the Stave hatchery chum and the Fraser chum stock conglomerate have similar migration behaviour and fishery interception patterns.

The escapement of Stave hatchery chum was estimated by sampling during broodstock collection and river dead-pitch. The observed CWT marks were expanded by the mark sampling rates and by the proportion of juveniles tagged, then adjusted upwards by 30% to correct for "mark mortality". For years with no dead-pitch data (1985-1988, 1992, 1996), river mark rates were calculated indirectly by adjusting the broodstock mark rates by the mean ratio for broodstock : river mark rates for those years that had relatively complete sampling data (Append. 5). For those Stave chum groups released without marks, mark sampling data for tagged groups closest in size and time at release and in fishery patterns to the unmarked Stave chum groups, were used to calculate the expanded hatchery contribution to catch and escapement.

The reliability of the estimated Stave hatchery escapements depends on whether the total Stave River escapements (used for expanding the observed river marks) are reliable, and whether the mark samples for the broodstock and the river are representative of the total escapement. Appendix 5 shows that the mark rates are approximately 2 to 10 times higher for the hatchery broodstock samples than for the river dead-pitch samples, suggesting non-random sampling. This is likely related to the collection of Stave hatchery broodstock mainly from the mid-timing run segment, as part of the 1986 DFO fisheries management plan to concentrate hatchery augmentation of Fraser River chum on the mid-timing run component.

No attempt was made to estimate separately the naturally spawning progeny (2^{nd} generation) of hatchery chum, although this group likely contributed significantly to the overall Stave chum escapement. The concern was that in estimating the 2^{nd} generation hatchery chum, any errors made in estimating the 1^{st} generation hatchery returns would be compounded by additional assumptions required, for example, that the Stave wild chum and the 1^{st} and 2^{nd} generation hatchery chum have similar spawning success, egg fecundity, survival and fishery exploitation rates).

RESULTS

RESPONSE TO JOINT REBUILDING EFFORTS

Stave River Chum

The historical trends in the Stave River chum escapements and in the river spawning capacity are shown for the period 1951 to 2002 in Figure 7 (Append. 6). Exploitation rates for Fraser chum are shown in Figure 8. The low annual Stave chum escapements of approximately 2,000 adults during the 1950s were attributed in part to high exploitation rates, and to highly variable flows in Stave River downstream of the Ruskin Dam which led to poor conditions for spawning and incubation. Stave chum escapements increased during the late 1960s partly due to significant reduction in exploitation rates, but during the 1970s and 1980s the escapements remained generally well below the estimated river spawning capacity of approximately 92,000 adults (Fig. 7).

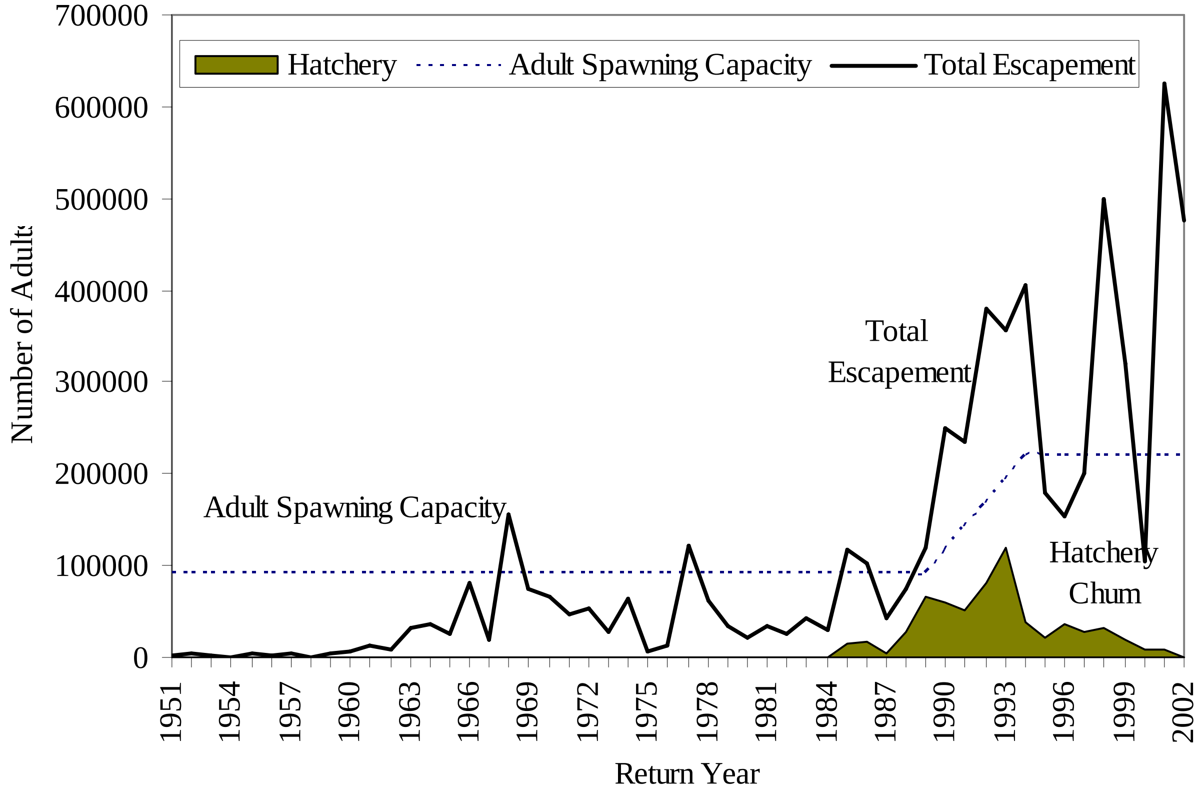

Figure 7. Estimated Stave River total chum escapements (hatchery contribution shaded) and adult spawning capacity

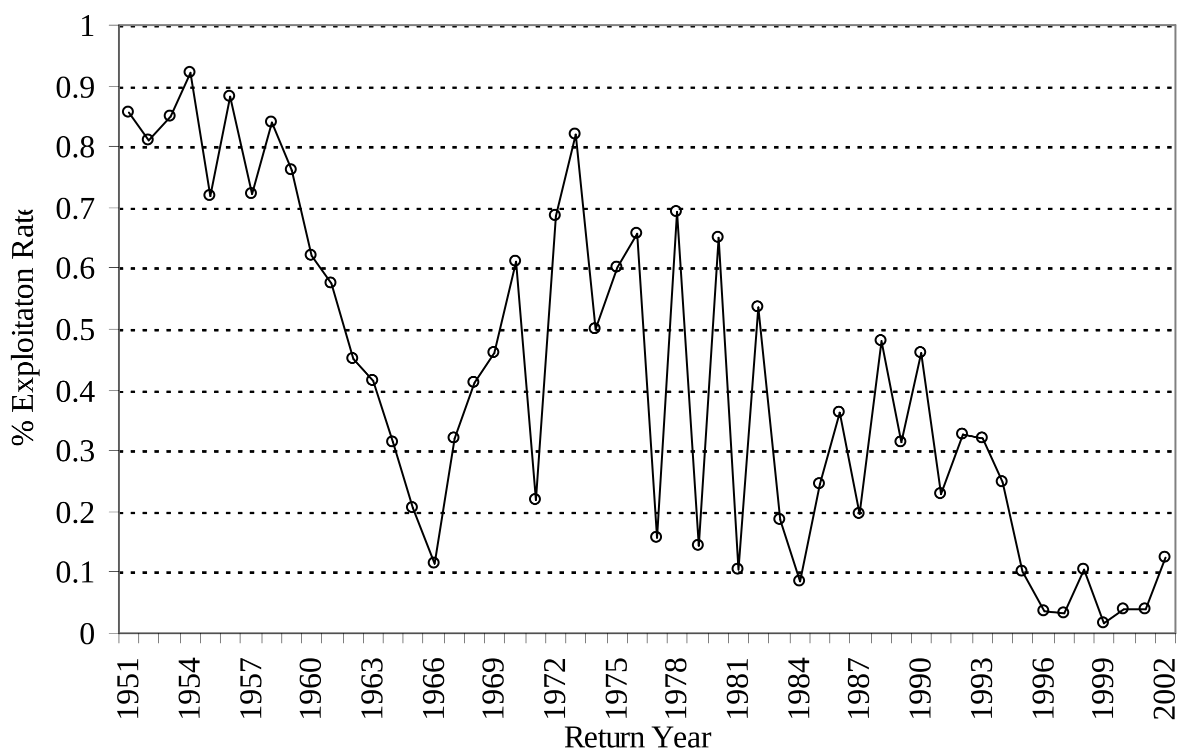

Figure 8. Fraser River chum exploitation rates, 1951-2002 return years.

In the early 1990s, the total Stave chum escapements increased considerably, coinciding with the first significant returns of Stave hatchery chum and the low exploitation rates (Fig. 7 & 8). By the mid-1990s when all the rebuilding components were in place (Fig. 2), the annual chum escapements to Stave River generally exceeded 200,000 adults, peaking at 625,000 chum in 2001 (Fig. 7).

Table 2 compares the mean annual production of Stave River chum for the period prior to the return of hatchery adults (1960-84) and for the period when all the rebuilding components were in place (1990-2002). In that relatively short time-span, the average total returns of Stave River chum increased nearly 5-fold from approximately 84,000 adults to 396,000 adults, the average escapements increased nearly 7-fold from approximately 44,000 adults to 322,000 adults, and the commercial catch nearly doubled, despite reduced exploitation rates.

Table 2 . Comparison of the mean annual production of Stave River chum for the period prior to return of hatchery adults (1960-84) and for the 1990-2002 period. *

Stave River Chum	(1960-1984)	(1990-2002)	Increase factor
Total return (catch & escap.)	83,562	395,837	4.7
Total escapement	44,050	321,913	7.3
Natural escapement	44,050	282,922	6.4
Hatchery escapement	0	42,241 **	-
Total commercial catch	39,512	73,924	1.9

* See Figs. 4 and 7 and Append. 1 and 6.
** Average for 1990-2001 (no hatchery escapement in 2002).

For the 1985 to 2001 period when the Stave River escapement included the hatchery chum, the hatchery escapement component varied widely from approximately 4,000 adults in 1987 to approximately 120,000 adults in 1993, and contributed an average of 18.5% (range 1.5% to 55.8%) to the total Stave chum escapement (Fig. 7, Append. 6). During that same period, the total Stave chum returns to catch and escapement (Fig. 4, Append. 1) and the total hatchery returns (Fig. 9, Append. 4) also varied widely, reflecting the variable marine survival for this stock (average hatchery survival 1.6%, range 0.1% to 5.0%, Append. 2).

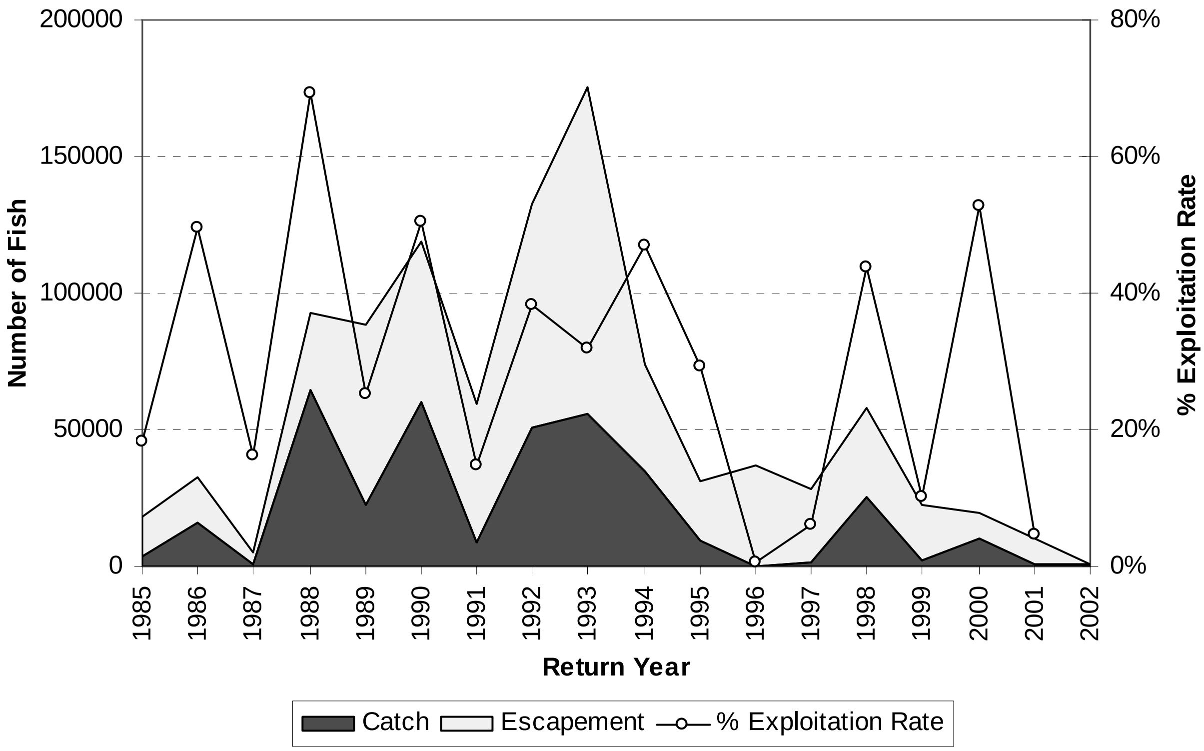

Figure 9. Estimated cumulative catch and escapement, and exploitation rates for Stave River hatchery chum, 1985-2002 return years.

Other Stave River Salmonid Species

Hatchery augmentation of other salmonid species in Stave River besides chum, was undertaken starting in the early 1980s. Appendix 7 shows the annual releases and marking strategy for each of the coho, chinook, steelhead and cutthroat trout. From 1990 onward, all these populations benefited from the flow control and habitat improvement in the Stave River. Some of the restoration work was directed specifically at improving coho and cutthroat trout rearing habitat. For example, construction of a side-channel using water-laden cedar stumps salvaged from Stave Lake to increase stream complexity, resulted in an additional 8,000 sq. m of prime coho rearing habitat (DFO 1995).

Although historical records are incomplete, there is evidence that coho escapements to Stave River increased substantially from only a few hundred adults prior to 1991 to over 3,000 adults on a number of occasions in recent years; chinook escapements also increased from negligible numbers to nearly 1,000 in recent years (DFO escapement records).

Recreational Angling

Stave River supports year-round sport fisheries (Palermo and Thompson 2000). Recreational angling opportunities in Stave River increased on all salmonid species augmented through hatchery releases. Recreational anglers also benefited from the addition of angling pools during the 1990-94 habitat restoration activities, and the development below Ruskin Dam of a BC Hydro recreation site, together with associated facilities such as a parking lot and boat ramps.

In the last decade, three angler surveys were conducted on the Stave River:

- April 1993 to March 1994 survey of the entire Stave River system (ARA Consulting Group 1994 in Wilson (1996),
- September to December 1998 survey of the lower Stave River downstream of Ruskin Dam (Palermo and Thompson 2000) and
- September to December 2001 survey of the lower Stave River downstream of Ruskin Dam (Grant 2003).

In the 1993-94 survey, the estimated angler effort for the Stave River downstream of Ruskin Dam was 14,540 angler-days, or approximately three-quarters of the total angling effort for the entire Stave River system. In that survey, the estimated catch (harvest and release) for the entire Stave River system was 14,829 fish, mostly chum followed by coho. In the 1998 and 2001 surveys, which were limited to the Stave River downstream of Ruskin Dam, the estimated angler effort was 31,876 and 21,934 angler-hours, respectively, and the estimated total catch for that river section was 5,523 and 16,025 fish, respectively, mostly chum followed by coho.

Although the above surveys could not be compared directly due to the different methodologies used, it is apparent that the lower Stave River downstream of Ruskin Dam supports an important recreational fishery, with chum being the dominant species caught. Currently, the sport fishery for chum and coho is expanding and the sport fishery for chinook is developing.

Other Benefits

Other benefits to wildlife and recreation have also accrued. The large chum escapements to Stave River provide a plentiful food source for bald eagles wintering in the area. Further, nutrients from fish carcasses generate an abundant food supply for rearing juvenile salmonids and for the ecosystem as a whole (Cederholm et al. 1999). As well, the BC Hydro recreation site provides access to the left-bank spawning channel, and this area has become a popular area for viewing salmon spawning.

DISCUSSION

The integrated efforts of long-term harvest reduction, extensive hatchery augmentation, the 1990 flow agreement and the 1990-94 habitat improvements (Fig. 2), resulted in a 5-fold increase in the total Stave chum returns and a 7-fold increase in the total Stave chum escapements (Table 2). These rebuilding efforts were likely aided by favourable marine survival (average 1.6%, Append. 2). The returns of other salmonid species into Stave River also increased in part due to hatchery augmentation, flow control and habitat improvement.

The 1990 flow agreement and the 1990-94 habitat improvements together resulted in more than doubling of the Stave River spawning area downstream of the Ruskin Dam, and were implemented just in time to benefit the strengthening Stave chum escapements (Fig. 7). Without the significant increase in chum spawning area, the large Stave chum escapements could not have been supported.

It is noteworthy that the strong increases in the total Stave chum escapement observed in the early 1990s (Fig. 7) occurred before any benefits to adult production (ages 3, 4, 5) could be expected from the 1990 flow agreement and the 1990-94 habitat improvements. This indicates that significant rebuilding of this stock was already underway before 1990, with the increase in escapement attributed mainly to harvest reduction and hatchery augmentation efforts already in place.

The regulated flows were first introduced at the Ruskin Dam, as a preliminary measure, in the fall of 1989. The increased flows coincided with a period of a high rainfall, resulting in large water releases below the Ruskin Dam during 1989/90. This likely helped protect salmon eggs from desiccation and may have resulted in increased chum escapements beginning in 1992 when the age 3 adults from 1989 brood year were expected to return. The particularly high hatchery marine survival for adults from the 1989 brood year (3.5% compared to the average of 1.6%, Append. 2) was also a contributing factor.

In the course of data analysis, an effort was made to compare the enhanced Stave River chum escapements to an unenhanced control stream. The nearby Harrison mainstem, also situated in the lower Fraser River system, was selected as the best candidate due to its large chum escapements and extensive historical records (DFO 1996), similar escapement assessment methodologies over the years to the Stave River chum and similar harvest restriction measures over the same time period (but no extensive benefits from hatchery augmentation or habitat restoration). Other candidate streams either had a relatively small chum escapement or were extensively enhanced.

Ultimately, the Harrison mainstem could not be used as an unenhanced control as its chum escapement estimates after 1990 were not considered reliable, and the Harrison mainstem component could not be separated from the overall Harrison system escapement which includes the enhanced Chehalis River stock (Thomas et al. 2002, Thomas and Associates Ltd. 2003).

CONCLUSIONS

The successful enhancement of Stave River chum salmon serves as a prime example of how the combined efforts of harvest reduction, hatchery augmentation, flow control and habitat improvement can be used to rebuild a stock. Without the sustained efforts of harvest reduction and hatchery augmentation, the number of spawners would not have increased readily, and without the significant increase in the Stave River chum spawning area, due to flow control and habitat improvement, the greatly strengthened Stave chum escapements could not have been supported.

The above efforts, along with favourable marine survival, resulted in a dramatic increase in the Stave chum escapements since the early 1990s. Currently, this population appears to be at full production potential, based on the estimates of Stave River spawning capacity. With the successful rebuilding of the natural Stave chum population to the current river spawning capacity, hatchery augmentation of this species was discontinued after the 1997 brood year. However, the monitoring of Stave chum escapements will continue in order to assess whether this stock can maintain itself at the current levels. The Stave spawning grounds will also be monitored to ensure that habitat improvements are maintained.

The benefits of the flow agreement and habitat restoration in maintaining the Stave River chum population will be demonstrated particularly after 2002 – the final year of Stave hatchery chum returns. Already the river escapement estimates for the 2003 and 2004 return years (200,000 and 440,000 chum, respectively, Append. 3) indicate that the Stave chum returns continue to be strong. Given the numerous factors that affect salmonid survival at different life stages and the ever-changing stream characteristics of the Stave River, DFO and BC Hydro will need to remain vigilant to ensure that conditions remain optimal for salmon spawning, incubation and rearing. The continued cooperation between BC Hydro, DFO and the community to continue improving the Stave River flows and spawning / incubation / rearing areas should ensure high quality, abundant fish habitat in Stave River for years to come.

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Appendix 1. Calculation of total Stave chum catch using Fraser River chum exploitation rates, 1951-2002 return years.

	FRASER RIVER CHUM *				STAVE RIVER CHUM (natural + hatchery)		
Year	Catch	Escap.	Total	Expl'n Rate	Catch **	Escap. +	Total
1951	1,016,025	171,725	1,187,750	85.5%	8,875	1,500	10,375
1952	750,751	176,250	927,001	81.0%	14,909	3,500	18,409
1953	775,051	137,625	912,676	84.9%	8,447	1,500	9,947
1954	1,003,959	86,375	1,090,334	92.1%	8,717	750	9,467
1955	283,080	110,500	393,580	71.9%	12,809	5,000	17,809
1956	247,386	32,950	280,336	88.2%	11,262	1,500	12,762
1957	218,930	84,655	303,585	72.1%	9,052	3,500	12,552
1958	463,668	89,400	553,068	83.8%	3,890	750	4,640
1959	483,431	152,300	635,731	76.0%	15,871	5,000	20,871
1960	235,949	144,782	380,731	62.0%	9,778	6,000	15,778
1961	139,976	103,920	243,896	57.4%	17,329	12,865	30,194
1962	107,559	130,357	237,916	45.2%	7,094	8,598	15,692
1963	136,873	192,245	329,118	41.6%	22,185	31,160	53,345
1964	112,605	246,741	359,346	31.3%	16,886	37,000	53,886
1965	33,622	129,459	163,081	20.6%	6,804	26,200	33,004
1966	46,768	360,810	407,578	11.5%	10,383	80,101	90,484
1967	100,294	213,873	314,167	31.9%	8,924	19,029	27,953
1968	471,824	670,328	1,142,152	41.3%	110,305	156,712	267,017
1969	264,706	309,220	573,926	46.1%	64,213	75,011	139,224
1970	448,646	284,250	732,896	61.2%	104,329	66,100	170,429
1971	82,099	290,125	372,224	22.1%	13,441	47,500	60,941
1972	920,222	423,290	1,343,512	68.5%	115,221	53,000	168,221
1973	1,229,142	267,080	1,496,222	82.1%	124,258	27,000	151,258
1974	352,137	350,315	702,452	50.1%	64,031	63,700	127,731
1975	287,292	191,420	478,712	60.0%	9,605	6,400	16,005
1976	649,545	340,517	990,062	65.6%	25,179	13,200	38,379
1977	111,820	599,341	711,161	15.7%	22,556	120,900	143,456
1978	815,469	358,990	1,174,459	69.4%	142,654	62,800	205,454
1979	43,259	255,634	298,893	14.5%	5,635	33,300	38,935
1980	581,511	314,011	895,522	64.9%	40,445	21,840	62,285
1981	50,605	436,996	487,601	10.4%	3,995	34,500	38,495
1982	377,675	326,439	704,114	53.6%	30,150	26,060	56,210
1983	84,513	371,770	456,283	18.5%	9,548	42,000	51,548
1984	51,054	541,478	592,532	8.6%	2,854	30,271	33,125
1985	449,373	1,383,808	1,833,181	24.5%	38,325	118,018	156,343
1986	566,821	997,327	1,564,148	36.2%	58,470	102,879	161,349
1987	89,580	363,671	453,251	19.8%	10,776	43,748	54,524
1988	485,972	528,467	1,014,439	47.9%	68,508	74,499	143,007
1989	340,089	739,305	1,079,394	31.5%	54,605	118,703	173,308
1990	726,148	854,024	1,580,172	46.0%	211,844	249,150	460,994
1991	332,022	1,112,902	1,444,924	23.0%	70,068	234,860	304,928
1992	499,524	1,032,886	1,532,410	32.6%	184,160	380,796	564,956
1993	454,922	968,790	1,423,712	32.0%	167,166	355,993	523,159
1994	545,366	1,655,939	2,201,305	24.8%	133,210	404,475	537,685
1995	182,276	1,619,494	1,801,770	10.1%	20,257	179,978	200,235
1996	29,797	828,412	858,209	3.5%	5,502	152,957	158,459
1997	55,039	1,604,821	1,659,860	3.3%	6,916	201,663	208,579
1998	424,023	3,582,612	4,006,635	10.6%	59,178	500,000	559,178
1999	48,831	2,980,161	3,028,992	1.6%	5,243	320,000	325,243
2000	28,647	710,592	739,239	3.9%	4,233	105,000	109,233
2001	81,854	1,999,505	2,081,359	3.9%	25,586	625,000	650,586
2002	299,210	2,100,796	2,400,006	12.5%	67,653	475,000	542,653

(cont'd)

Appendix 1 (cont'd). Calculation of total Stave chum catch using Fraser River chum exploitation rates, 1951-2002 return years.

	FRASER RIVER CHUM *				STAVE RIVER CHUM (natural + hatchery)		
Year	Catch	Escap.	Total	Expl'n Rate	Catch **	Escap. +	Total
Averages (10-year for 1951-2002)							
1951-59	582,476	115,753	698,229	81.7%	10,426	2,556	12,981
1960-69	165,018	250,174	415,191	38.9%	27,390	45,268	72,658
1970-79	493,963	336,096	830,059	50.9%	62,691	49,390	112,081
1980-89	307,719	600,327	908,047	31.6%	31,768	61,252	93,019
1990-99	329,795	1,624,004	1,953,799	18.7%	86,354	297,987	384,342
2000-02	136,570	1,603,631	1,740,201	6.8%	32,491	401,667	434,157
Averages (5-year for 1985-1999)							
1985-89	386,367	802,516	1,188,882	32.0%	46,137	91,569	137,706
1990-94	511,596	1,124,908	1,636,504	31.7%	153,290	325,055	478,344
1995-99	147,993	2,123,100	2,271,093	5.8%	19,419	270,920	290,339
Averages (1960-2002)							
1960-84	309,407	314,136	623,542	**42.2%**	**39,512**	**44,050**	**83,562**
1985-2002	313,305	1,392,417	1,705,722	**20.4%**	**66,206**	**257,929**	**324,134**
1990-2002	285,204	1,619,303	1,904,507	**16.0%**	**73,924**	**321,913**	**395,837**

* Fraser River chum data from DFO database.

** Stave chum catch calculated indirectly by applying the Fraser chum exploitation rates to the total Stave chum escapements

+ Total Stave chum escapements (river spawners and all removals); see Appendix 6.

Appendix 2. Chum fry releases to Stave River and survival to release and return, 1982-1997 brood years. *

CHUM FRY RELEASES TO STAVE RIVER AND SURVIVAL TO RELEASE AND RETURN

Brood Year	Brood-stock Taken	Release Date	Release Size	Ad-CWTs	Total Released Stave R.**	Egg-to-Fed Fry Survival	Fed Fry-to-Adult Survival +
1982	1,060	Mar-Apr '83	1.3 g	100,193	2,210,264	61.9%	5.0%
1983	~ 2,000	Mar '84	1.2 g	0	3,445,880	79.3%	0.1%
1984	2,771	Mar '85	1.1 g	0	3,730,556	75.8%	1.4% ++
1985	2,804	Apr '86	1.0 g	102,865	5,129,095	96.5%	2.2% ++
1986	4,868	Apr '87	1.3 g	148,032	5,256,108	88.1%	3.0% ++
1987	3,365	Apr-May '88	1.4 g	76,863	3,877,296	94.4%	0.8%
1988	4,396	Apr-May '89	1.6 g	97,654	4,924,964	92.1%	2.4% ++
1989	3,962	Apr-May '90	1.6 g	153,869	4,937,938	88.8%	3.5%
1990	4,454	Apr-May '91	1.3 g	128,184	4,374,942	82.2%	1.9%
1991	4,583	Apr-May '92	1.7 g	125,051	4,661,291	89.4%	0.7%
1992	4,322	Apr '93	1.4 g	68,239	4,128,096	82.2%	0.2%
1993	5,993	Apr-May '94	1.7 g	99,992	4,940,250	82.8%	1.1%
1994	4,475	Apr-May '95	1.6 g	95,734	4,822,775	88.0%	0.8%
1995	4,978	Apr-May '96	1.9 g	97,665	4,624,227	82.8%	0.8%
1996	2,856	Apr '97	1.6 g	95,104	3,077,089	92.8%	0.9%
1997	1,663	Apr '98	1.9 g	49,614	2,078,952	87.3%	0.6%
Mean of Years			**1.5 g**		**4,138,733**	**85.3%**	**1.6%**

* Broodstock data from DFO escapement records.
Juvenile data from DFO Annual Brood Summary reports for Inch Creek Hatchery.

** Total releases include marks, incomplete marks and unmarked fry.

+ Adult survival rate = (Total returns to catch and escapement / Total released); from DFO database.
Expanded mean brood survival weighted by numbers released.

++ For 1984-86 and 1988 brood adult survival rates, total fry releases included a small unmarked component transplanted to other streams.

Appendix 3. Estimated chum river spawners (natural and hatchery) in Stave River (excludes broodstock and other removals) and the estimation methodology used, 1950 to 2004 (shaded values are "best" available estimates).*

STAVE CHUM RIVER SPAWNERS AND METHODOLOGY USED

Return Year	VISUAL ESTIMATES		OTHER ESTIMATES and METHODS USED		
1950	400	a			
1951	1,500	a,b			
1952	3,500	a,b			
1953	1,500	a,b			
1954	750	a,b			
1955	5,000	a,b			
1956	1,500	a,b			
1957	3,500	a,b			
1958	750	a,b			
1959	5,000	a,b			
1960	6,000	a	6,000	b	
1961	10,000	a	12,865	b	95% C.L.± 46.7% Tag recovery estimate (Palmer 1972) **
1962	6,000	a	8,598	b	95% C.L.± 52.4% " " "
1963	7,500	a	31,160	b	95% C.L.± 63.3% " " "
1964	20,000	a	37,000	b	95% C.L.± 59.0% " " "
1965	18,000	a	26,200	b	95% C.L.± 32.7% " " "
1966	75,000	a	80,101	b	95% C.L.± 35.4% " " "
1967	35,000	a	19,029	b	95% C.L.± 21.1% " " "
1968	75,000	a	156,712	b	95% C.L.± 21.7% " " "
1969	75,000	a	75,011	b	95% C.L.± 19.2% " " "
1970	75,000	a	66,100	b	Used expansion factors based on past visual vs tagging data ***
1971	35,000	a	47,500	b	" " " " " "
1972	35,000	a	53,000	b	" " " " " "
1973	15,000	a	27,000	b	" " " " " "
1974	35,000	a	63,700	b	" " " " " "
1975	3,500	a	6,400	b	" " " " " "
1976	7,500	a	13,200	b	" " " " " "
1977	12,000	a	120,900	b	Tag recovery (Clark MS 1978)
1978	15,000	a	62,800	b	Tag recovery (McIvor MS 1979)
1979	15,000	a	33,300	b	Tag recovery (Anon. MS 1980)
1980	12,000	a	21,840	b	Used expansion factors based on past visual vs tagging data ***
1981	34,500	a,b			
1982	25,000	a,b			
1983	40,000	a,b			
1984	27,500	a,b			
1985	113,000	b			
1986	95,000	Helicopter overflight counts			
1987	40,000	Hatchery staff			
1988	25,750	c Heli.	70,000	c	Helicopter overflight counts expanded.
1989	80,000	d Heli.	114,325		95% C.L.± 16.7% SEP Tag & Recovery
1990	120,000	Heli.	244,696		95% C.L.± 27.1% SEP Tag & Recovery
1991	222,000	Heli.	230,277		95% C.L.± 20.1% SEP Tag & Recovery
1992			376,384	f	Indirect estimate (no escap. estimate and no mark sampling).
1993			350,000	f	No data source found (prob. hatchery-based estimate).
1994	400,000	e Heli.	400,000	g	Mid-point of SEP Tag & Recovery and other estimates.
1995			175,000	h	- 5 Weekly helicopter counts; overall estimate expanded by 37%.
1996			150,000	h	- 7 " " " " " " " " " " " " " " 30%.
1997			200,000	h	- 7 " " " " " " " " " " " " " " 36%

(cont'd)

Appendix 3 (cont'd). Estimated chum river spawners (natural and hatchery) in Stave River (excludes broodstock and other removals) and the estimation methodology used, 1950 to 2004 (shaded values are "best" available estimates).*

STAVE CHUM RIVER SPAWNERS AND METHODOLOGY USED

Return Year	VISUAL ESTIMATES	OTHER ESTIMATES and METHODS USED		
1998		500,000	h - 7 Weekly helicopter counts; overall estimate expanded by	31%.
1999		320,000	h - 7 " " " " " " " " " "	32%.
2000		105,000	h - 6 " " " " " " " " " "	29%.
2001		625,000	h - 9 " " " " " " " " " "	32%.
2002		475,000	h - 7 " " " " " " " " " "	34%.
2003		200,000	i - Limited helicopter counts and other data, all expanded by	74%
2004		440,000	h - 5 Weekly helicopter counts; overall estimate expanded by	33%.
Averages				
1950-59		2,340		
1960-69		45,268		
1970-79		49,390		
1980-89		58,117		
1990-99		294,636		
2000-04		369,000		

Footnotes:

* The 1961-69 data from Palmer 1972; 1970-84 data from PBS Escap. database - SEDS); 1985-97 data from DFO escapement database; see also DFO (1996) and data sources below.

** 95% C.L. for Palmer (1972) chum estimates for 1961-69 calculated by D. Bailey (see Ricker 1975, Append. II).

*** For 1970-76 and 1980, expansion factors based on the relationship between previous visual and tagging estimates (Anderson 1977).

a Hancock and Marshall (1985).

b Farwell et al. (1987).

c The 1988 helicopter estimate (25,750 chum) based on 3 overflights (M Joyce, pers. comm.); the adjusted estimate (70,000 chum) based on expanding the observed mean helicopter estimate using data from previous years each with approximately 7 overflights (R. Cook, pers. comm.).

d The 1989 helicopter estimate (80,000 chum) based on 4 overflights, (M. Joyce, pers. comm.).

e The 1994 helicopter estimate based on 5 overflights, adjusted upwards by 30% (S. Barnetson, pers. comm.).

f See DFO escapement records.

g Final estimate (400,000 chum) was the mid-point of several escapement estimates (Petersen, Schaeffer, AUC, helicopter, recovery), wth a range of approx. 300,000-500,000 chum (D. Bailey).

h For 1995-2002 and 2004, used helicopter counts by hatchery staff plus estimates for weeks not surveyed, all expanded by 29-37% to adjust for viewing conditions and for the discrepancy between overflight frequency of approxiamtely every 7 days and in-river spawner residency of approximately 6 days.

i Based on limited flight data plus incidental chum netting during coho and chinook broodstock capture (S. Barnstson, pers. comm.).

Appendix 4. Estimated catch, escapements, total returns and exploitaton rates for Stave River hatchery chum, 1985-2002 return years.

STAVE HATCHERY CHUM

Return Year	Canadian Catch *	Total Catch **	Escape- ment ***	Total Return	Exploit'n Rate +
1985	2,396	3,310	14,747	18,057	18.3%
1986	14,321	16,248	16,541	32,789	49.6%
1987	614	814	4,170	4,984	16.3%
1988	51,371	64,164	28,325	92,489	69.4%
1989	18,571	22,182	66,238	88,420	25.1%
1990	48,157	60,118	58,808	118,926	50.6%
1991	5,792	8,694	50,484	59,178	14.7%
1992	41,632	50,783	81,779	132,562	38.3%
1993	43,757	55,911	119,634	175,545	31.9%
1994	31,105	34,592	39,286	73,878	46.8%
1995	7,563	9,169	22,068	31,237	29.4%
1996	213	213	36,883	37,096	0.6%
1997	1,692	1,698	26,734	28,432	6.0%
1998	23,868	25,427	32,546	57,973	43.9%
1999	2,241	2,244	19,983	22,227	10.1%
2000	10,264	10,352	9,289	19,641	52.7%
2001	454	467	9,392	9,859 ++	4.7%
2002	530	715	0	715 ++	-
Averages (5-year)					
1985-89		21,343	26,004	47,348	35.7%
1990-94		42,020	69,998	112,018	36.4%
1995-99		7,750	27,643	35,393	18.0%
1985-2001		**21,552**	**37,465**	**59,017**	**29.9%**

* Canadian net catch of Stave hatchery chum from DFO database (excludes Troll and Sport catch as unreliable).

** Total catch (Canadian and US) of Stave hatchery chum calculated by assuming that Fraser River chum and Stave chum have similar ratios for (Canadian catch to Total catch).

*** Expanded Stave hatchery escapement component from Appendix 5.

+ Exploitation rate = (Total catch / Total return).

++ Total returns of Stave hatchery chum were low in 2001 and 2002 as hatchery releases were discontinued after the 1997 brood year.

Appendix 5. Mark rates for Stave River dead-pitch samples (A) and broodstock (Brdsk) samples (B), mark rate ratios for broodstock : river dead-pitch samples (C), and expanded escapements for Stave hatchery chum (D), 1985-2002 return years. *

	(A)						(B)				(C)	(D)			
	Stave River Spawners						Stave Broodstock				Brdsk : River	Stave Hatchery Chum Expanded Escapements			
Return Year	Estimate *	Dead-Pitch?	Sampled #	Sampled % of Tot.	# Marks	Mark Rate	Counts *	# Sampl'd	# Marks	Mark Rate	Mark Rate Ratio ***	River	Brdsk	Unmkd	Total
1985	113,000	NO				0.00484 **	5,018	same	80	0.01594		12,788	1,959		14,747
1986	95,000	NO				0.00593 **	7,879	same	154	0.01955		12,404	3,697	440 ++	16,541
1987	40,000	NO				0.00186 **	3,748	same	23	0.00614		501	170	3,499 ++	4,170
1988	70,000	NO				0.00573 **	4,499	same	85	0.01889		23,096	5,229	18,134 ++	28,325
1989	114,325	yes	16,593	0.15	190	0.01145	4,378	same	108	0.02467	**2.15**	60,342	4,378 +	1,518 ++	66,238
1990	244,696	yes	16,617	0.07	109	0.00656	4,454	3,814	86	0.02255	**3.44**	54,861	3,947		58,808
1991	230,277	yes	22,315	0.10	157	0.00704	4,583	same	72	0.01571	**2.23**	47,132	3,352		50,484
1992	376,384	NO				0.00419 **	4,412	same	61	0.01383		78,738	3,041		81,779
1993	350,000	yes	34,277	0.10	341	0.00995	5,993	same	202	0.03371	**3.39**	113,641	5,993 +		119,634
1994	400,000	yes	43,092	0.11	98	0.00227	4,475	same	99	0.02212	**9.73**	35,504	3,782		39,286
1995	175,000	yes	3,230	0.02	14	0.00433	4,978	same	60	0.01205	**2.78**	19,492	2,576		22,068
1996	150,000	NO				0.00451 **	2,957	same	44	0.01488		34,631	2,252		36,883
1997	200,000	yes	9,732	0.05	21	0.00216	1,663	same	22	0.01323	**6.13**	25,731	1,003		26,734
1998	500,000	yes	35,205	0.07	46	0.00131	0					32,546	0		32,546
1999	320,000	yes	26,274	0.08	34	0.00129	0					19,983	0		19,983
2000	105,000	yes	21,790	0.21	66	0.00303	0					9,289	0		9,289
2001	625,000	yes	26,291	0.04	11	0.00042	0					9,392	0		9,392
2002	475,000	yes	22,090	0.05	5	0.00023	0					0	0		0

* Estimated river spawners (A) and counts of broodstock including other removals (B), from Appendix 6.
Mark sampling data for river spawners (A) and for broodstock (B), and expanded hatchery chum escapements (D) from DFO escapement records.

Hatchery chum from other enhanced stocks straying into Stave River, and estimated escapements of Stave-origin chum transplanted into other streams, were excluded from the expanded Stave River hatchery escapements (D).

** For years with no dead-pitch data (1985-88, 1992, 1996), river mark rates were calculated indirectly by adjusting the broodstock mark rates by the mean ratio for broodstock : river mark rates for those years with relatively complete mark sampling data (see DFO escapement records).

*** Ratio for broodstock : river mark rates (C) was calculated only for those years when mark sampling was conducted for both the broodstock and the river.

+ For 1989 and 1993, the expanded estimates of hatchery-origin broodstock (D) exceeded broodstock counts, so were artificially deflated to equal the actual counts.

++ For 1986-88, the expanded escapement estimates (river and broodstock) of unmarked Stave hatchery chum (D), were based on other tagged groups (see Text).

Appendix 6. Estimated adult spawning capacity and chum escapements to Stave River, 1951-2002.

STAVE RIVER		TOTAL ESCAPEMENT			HATCHERY		NATURAL
Year	Sp. Capacity *	River Spawners *	Removals **	Total	Estimate	% of Total	(Total - Hatchery)
1951	91,774	1,500	0	1,500	0	0.0%	1,500
1952	91,774	3,500	0	3,500	0	0.0%	3,500
1953	91,774	1,500	0	1,500	0	0.0%	1,500
1954	91,774	750	0	750	0	0.0%	750
1955	91,774	5,000	0	5,000	0	0.0%	5,000
1956	91,774	1,500	0	1,500	0	0.0%	1,500
1957	91,774	3,500	0	3,500	0	0.0%	3,500
1958	91,774	750	0	750	0	0.0%	750
1959	91,774	5,000	0	5,000	0	0.0%	5,000
1960	91,774	6,000	0	6,000	0	0.0%	6,000
1961	91,774	12,865	0	12,865	0	0.0%	12,865
1962	91,774	8,598	0	8,598	0	0.0%	8,598
1963	91,774	31,160	0	31,160	0	0.0%	31,160
1964	91,774	37,000	0	37,000	0	0.0%	37,000
1965	91,774	26,200	0	26,200	0	0.0%	26,200
1966	91,774	80,101	0	80,101	0	0.0%	80,101
1967	91,774	19,029	0	19,029	0	0.0%	19,029
1968	91,774	156,712	0	156,712	0	0.0%	156,712
1969	91,774	75,011	0	75,011	0	0.0%	75,011
1970	91,774	66,100	0	66,100	0	0.0%	66,100
1971	91,774	47,500	0	47,500	0	0.0%	47,500
1972	91,774	53,000	0	53,000	0	0.0%	53,000
1973	91,774	27,000	0	27,000	0	0.0%	27,000
1974	91,774	63,700	0	63,700	0	0.0%	63,700
1975	91,774	6,400	0	6,400	0	0.0%	6,400
1976	91,774	13,200	0	13,200	0	0.0%	13,200
1977	91,774	120,900	0	120,900	0	0.0%	120,900
1978	91,774	62,800	0	62,800	0	0.0%	62,800
1979	91,774	33,300	0	33,300	0	0.0%	33,300
1980	91,774	21,840	0	21,840	0	0.0%	21,840
1981	91,774	34,500	0	34,500	0	0.0%	34,500
1982	91,774	25,000	1,060	26,060	0	0.0%	26,060
1983	91,774	40,000	2,000	42,000	0	0.0%	42,000
1984	91,774	27,500	2,771	30,271	0	0.0%	30,271
1985	91,774	113,000	5,018	118,018	14,747	12.5%	103,271
1986	91,774	95,000	7,879	102,879	16,541	16.1%	86,338
1987	91,774	40,000	3,748	43,748	4,170	9.5%	39,578
1988	91,774	70,000	4,499	74,499	28,325	38.0%	46,174
1989	91,774	114,325	4,378	118,703	66,238	55.8%	52,465
1990	117,000	244,696	4,454	249,150	58,808	23.6%	190,342
1991	143,000	230,277	4,583	234,860	50,484	21.5%	184,376
1992	168,000	376,384	4,412	380,796	81,779	21.5%	299,017
1993	194,000	350,000	5,993	355,993	119,634	33.6%	236,359
1994	219,649	400,000	4,475	404,475	39,286	9.7%	365,189
1995	219,649	175,000	4,978	179,978	22,068	12.3%	157,910
1996	219,649	150,000	2,957	152,957	36,883	24.1%	116,074
1997	219,649	200,000	1,663	201,663	26,734	13.3%	174,929
1998	219,649	500,000	0	500,000	32,546	6.5%	467,454
1999	219,649	320,000	0	320,000	19,983	6.2%	300,017
2000	219,649	105,000	0	105,000	9,289	8.8%	95,711
2001	219,649	625,000	0	625,000	9,392	1.5%	615,608
2002	219,649	475,000	0	475,000	0	0.0%	475,000
Average 1960-84				**44,050**	**0**	**0**	**44,050**
Average 1985-2002				**257,929**	**37,465 +**	**18.5%**	**222,545**
Average 1990-2002				**321,913**	**42,241 +**	**15.2%**	**282,922**

* Adult spawning capacity (see Text); river spawners (see Append. 3); hatchery chum (see Append. 5).

** Removals (DFO records) include broodstock (Append. 2).

+ Average excludes 2002 return year.

Appendix 7. Releases of coho, chinook, steelhead and cutthroat smolts to Stave River, 1982-2002 brood years. *

RELEASES OF OTHER SPECIES TO STAVE RIVER

	Coho Smolts			Chinook Smolts				Steelhead Smolts				Cutthroat Smolts			
Brood Year	Rel. Size	Ad-CWTs	Total Rel'd *	Brood-stock **	Rel. Size	Ad-CWTs	Total Rel'd *	Brood-stock **	Rel. Size	All Marked	Total Rel'd *	Brood-stock **	Rel. Size	All *** Marked	Total Rel'd *
1982			0				0				0	F.R.	41 g	RM	13,150
1983			0				0				0	F.R.	67 g	LM	6,750
1984			0				0				0	F.R.	53 g	RM	10,000
1985	13.1 g	0	2,233				0				0	F.R.	68 g	LM	9,939
1986	22.3 g	0	4,496				0				0	F.R.	80 g	RM	10,556
1987	22.7 g	0	2,366				0				0	F.R.	103 g	LM	9,932
1988	19.6 g	8,385	38,253				0				0	F.R.	86 g	LM	10,000
1989	22.3 g	10,393	41,120				0				0	F.R.	101 g	Ad	10,000
1990	18.5 g	21,944	49,837				0				0	F.R.	89 g	Ad	16,043
1991	21.7 g	20,475	50,729				0				0				0
1992	17.5 g	19,840	40,420				0				0				0
1993	22.5 g	20,366	191,254				0				0				0
1994	18.6 g	21,082	169,456	Chillwk.	3.8 g	49,638	199,223				0				0
1995	22.6 g	20,252	164,433				0				0	F.R.	89 g	Ad	10,000
1996	20.5 g	448,085 +	448,085	Chillwk.	3-4 g	46,690	174,392				0	F.R.	108 g	Ad	10,928
1997	21.3 g	59,034 ++	180,025	Stave	4.8 g	50,205	206,141	Chillwk.	87 g	Ad-only	10,482				0
1998	20.6 g	118,927 +	118,927	Stave	6.7 g	50,349	227,046	Chillwk.	97 g	Ad-only	10,753				0
1999	20.5 g	496,757 +	496,757	Stave	4.9 g	50,337	155,894	Chillwk.	88 g	Ad-only	21,327				0
2000	20.5 g	48,394 +	48,394	Harrison	5.2 g	50,132	122,880	Chillwk.	91 g	Ad-only	19,048				0
2001	20.1 g	308,312 +	308,312	Stave	7.1 g	50,407	266,931	Chillwk.	86 g	Ad-only	19,934				0
2002	20.0 g	179,996 +++	179,996	Stave	8.1 g	0	170,216	Chillwk.	-	Ad-only	20,198				0

* Release data from DFO Annual Brood Summary reports for Inch Creek Hatchery (Chilliwack River Hatchery for 1994 and 1996 brood chinook). Total releases include marks, incomplete marks and unmarked fish.

** Broodstock source: coho (Stave R.), chinook (Chilliwack, Stave, Harrison), steelhead (Chilliwack R.), cutthroat trout (lower Fraser streams).

*** RM - Right maxillary clip, LM - Left maxillary clip, Ad - Adipose-only clip.

+ All coho were marked with Ad-only clips and/or Ad-CWTs for selective mark harvest.

++ These coho were marked with Ad-only clips and/or Ad-CWTs; the remainder were released unmarked.

+++ All coho were marked with Ad-only clips.