

PERSPECTIVES

Learning to Enhance Salmon Production: Lessons from the Salmonid Enhancement Program

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Hilborn R., and J. Winton. 1993. Learning to enhance salmon production: lessons from the Salmonid Enhancement Program. *Can. J. Fish. Aquat. Sci.* 50: 2043-2056.

We evaluate the Salmonid Enhancement Program (SEP) to determine its effectiveness at producing adult fish in the catch and its ability to learn from experience. The original goal of SEP was to produce up to 86 000 metric tons (t) of salmon per year, and it has relied primarily on three major technologies to achieve this goal: hatcheries, spawning channels, and lake enrichment. We estimate that SEP's annual production is about 12 400 t of salmon per year. Thus, the program has fallen short of its objective. We show that SEP has devoted considerable effort in evaluating individual facilities and sites: however, SEP has been unable or unwilling to evaluate overall program success and direction. Due to natural variation in survival rates, it is difficult to determine, even after 15 yr, which technologies are likely to be successful. Furthermore, there is a paucity of information on wild stocks and the extent to which these enhancement activities have an effect on their numbers. We conclude that no technology has been proven, that 15 yr is insufficient to determine which technologies to explore, and that programs like SEP must rely on outside evaluation of overall program success and outside direction for program guidance.

Nous évaluons le Programme de mise en valeur des salmonidés (PMVS) de façon à déterminer son efficacité pour la production de poissons adultes dans les captures et son aptitude à s'enrichir de l'expérience. Le but original du PMVS était de produire jusqu'à 86 000 tonnes métriques (t) de saumon par an, et le programme a misé avant tout, pour atteindre ce but, sur trois grandes approches technologiques : écloséries, chenaux de ponte et enrichissement des lacs. Nous estimons que la production annuelle du PMVS est d'environ 12 400 t de saumon par an. Le programme est donc loin d'avoir atteint son objectif. Nous montrons que le PMVS a accordé une attention considérable à l'évaluation des installations et des sites pris individuellement; toutefois, ses responsables n'ont pas pu ou n'ont pas voulu évaluer dans son ensemble la réussite et d'orientation du programme. À cause de la variation naturelle des taux de survie, il est difficile de déterminer, même après 15 ans, quelles technologies vont vraisemblablement réussir. En outre, nous n'avons pas assez d'information sur les stocks sauvages et sur la façon dont ces activités de mise en valeur ont un effet sur leurs effectifs. Nous concluons qu'aucune technologie n'a fait ses preuves, qu'une période de 15 ans est insuffisante pour déterminer quelles sont les technologies à explorer, et que des programmes comme le PMVS doivent avoir recours à une évaluation extérieure pour mesurer leur réussite globale et faire appel à l'extérieur pour déterminer leur orientation.

Received October 6, 1992
Accepted April 26, 1993
(JB648)

Reçu le octobre 1992
Accepté le 26 avril 1993

Nearly every political jurisdiction that has spawning stocks of Pacific salmon (*Oncorhynchus* sp.) has created some form of enhancement program employing various strategies including fishways, hatcheries, spawning channels, habitat improvement, fertilization of lakes, and predator control. One of the most ambitious undertakings is the Salmonid Enhancement Program (SEP) in British Columbia. Formally established in 1977, SEP has now been operating for 15 yr and has spent over \$450 million on construction, operation, and research. While the program was designed to accomplish several goals, including enhancement and preservation of natural salmonid stocks, economically stimulating underdeveloped areas, and actively involving the public in the program, the primary goal driving SEP has been to double the number of salmon available for catch in British Columbia. This same goal has also been adopted by the Northwest Power Planning Council for Columbia River runs and by the Washington State Legislature for the salmon runs in Washington.

We have considered the success of several components of SEP, including spawning channels for sockeye salmon (*Oncorhynchus nerka*) (Hilborn 1992) and supplementation hatcheries for chinook salmon (*Oncorhynchus tshawytscha*) (Winton 1991; Winton and Hilborn 1994), and examined the technologies used, how well they worked, and what SEP as an organization learned from the success and failure of different approaches. Our present purpose is to examine the history of SEP as a program and in particular to see how successful it has been at both learning about and producing adult salmon.

The Condition of the Salmonid Resource Prior to 1977

One of British Columbia's most prized and sought-after natural resources has been its great runs of salmonid stocks. Over the past century, those runs have provided much economic benefit to both the province and Canada. Scientists have estimated that at the turn of this century, Canada's west coast waters

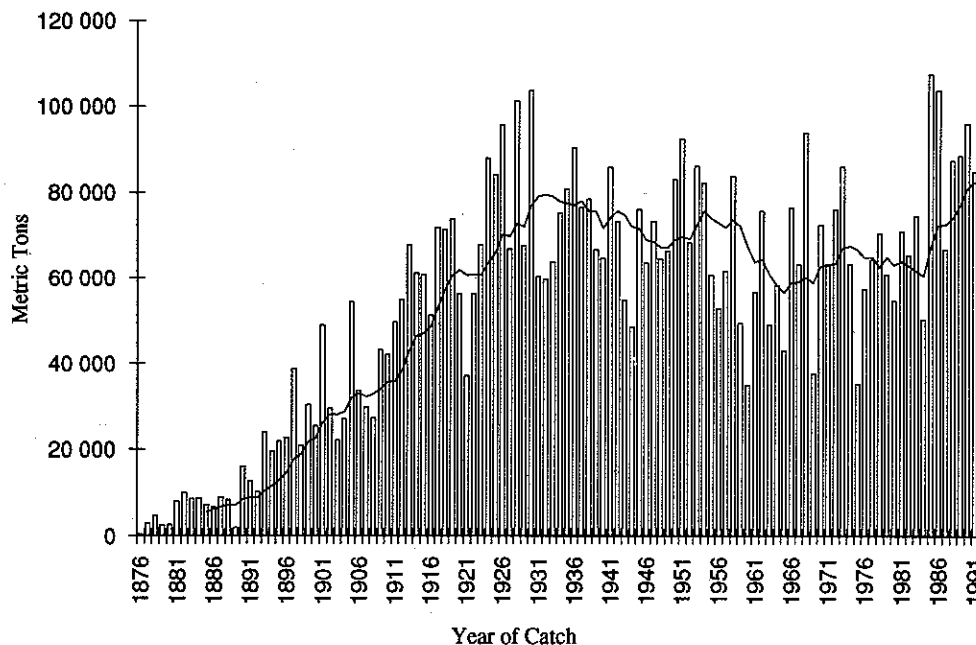


FIG. 1. History of commercial catch in British Columbia from 1876 through 1991. The line on the chart indicates the 10-yr running average. Sources: Shepard et al. (1985) for 1876–1982 and DFO (1992) for 1983–91.

TABLE 1. SEP production targets for each species. Source: DFE (1978).

Species	Target production (millions of fish)	Average weight/fish (kg)	Total target weight (1000 t)
Sockeye	6.4	2.6	16.6
Chum	7.3	4.0	29.2
Pink	6.5	1.7	11.1
Coho	4.6	2.3	10.6
Chinook	2.3	6.2	14.3
Total	27.1		81.7

were capable of producing a potential salmonid harvest of from 136 000 to 163 000 metric tons (t) per year (DFE 1978; Ricker 1962). While average annual catches never approached these figures, they had been building throughout the early 1900s, reaching a high point in 1930 at 104 000 t (Fig. 1). Then production turned downward, declining to roughly 60 000 t in the mid-1960s. While the decline was neither continuous nor precipitous (in fact, throughout the late 1960s and early 1970s, catches began to build again), the perception was that catch levels were falling drastically. Furthermore, projections indicated that unless concentrated efforts were made to rebuild the runs, they would decline by another 20–30% by the year 2007 (DFE 1978). These dire forecasts prompted the federal government's Department of Fisheries and Oceans (DFO) to sponsor a policy development seminar in Vancouver in 1974 (Pearse 1982). Participants included federal and provincial people, industry representatives, and the academic and scientific communities. DFO was able to convince the participants that proven technology existed to rebuild the runs (DFO 1979). With that understanding, the assembly concluded that a cost recoverable

program to increase salmon production was both economically and scientifically feasible and should be launched immediately. Doubling the catch to the turn-of-the-century potential quickly became the new holy grail. In 1975, program planning began, and 2 yr later, SEP was born.

SEP Activities, 1977–92

In addition to the belief that appropriate resource technology existed, several other reasons combined to ensure SEP's creation. First, the new organization offered a golden opportunity to improve the general management of West Coast fisheries. A number of DFO managers saw the program as an "agent for change." Major committed funding meant more production facilities could be built, better management systems constructed, new research approaches tried, and more habitat areas opened for salmon enhancement (Dr. P. Larkin, University of British Columbia, Vancouver B.C., personal communication). For the first time, salmon were to receive their own protective umbrella organization devoted entirely to their preservation and enhancement. In addition, Ottawa saw SEP as a powerful political tool if awareness of the program were heightened by involving the public directly in its operation (F.E.A. Wood, Pacific Branch, DFO, Vancouver, B.C., personal communication). Thus, community involvement in local enhancement projects became a key element of the government's strategy.

Goals and Organization of the Program

SEP was designed to "preserve, rehabilitate, and enhance natural salmonid stocks" of Canada's West Coast (DFO 1979). Its long-term goal was to double fish production, implying an increase in existing catch levels of up to 86 000 t (DFE 1978). SEP felt that this target was attainable, believing as it did that "...the five species of Pacific salmon have a combined productive capacity of between 300 and 360 million pounds per

TABLE 2. SEP expenditures by expense category (see footnotes) for the years 1979-91. Source: SEP annual reports.

Year	Developmental ^a		Operational ^b		Program support ^c		Related non-SEP expenditures ^d		Total program expenditures
	\$000	%	\$000	%	\$000	%	\$000	%	\$000 (100%)
1978	3 737	45	2 609	31	905	11	1 063	13	8 314
1979	8 518	46	6 237	34	1 597	9	2 094	11	18 446
1980	14 715	54	8 558	31	1 584	6	2 368	9	27 225
1981	16 140	50	11 164	35	1 961	6	2 997	9	32 262
1982	15 280	49	13 614	43	850	3	1 758	6	31 502
1983	11 703	38	16 096	52	1 521	5	1 879	6	31 199
1984	5 159	20	18 565	70	972	4	1 682	6	26 378
1985	8 180	22	24 281	66	1 095	3	3 370	9	36 926
1986	9 955	25	24 627	63	1 191	3	3 468	9	39 241
1987	6 316	16	27 265	71	828	2	3 973	10	38 382
1988	6 909	18	27 650	70	681	2	4 175	11	39 415
1989	6 655	17	28 070	71	1 211	3	3 722	9	39 658
1990	5 732	14	29 853	74	954	2	3 752	9	40 291
1991	6 197	15	30 598	73	1 206	3	3 787	9	41 788

^aDevelopmental includes reconnaissance and feasibility studies and engineering and construction of major, minor, and pilot projects.

^bOperational includes facility operation and maintenance, community development, public involvement, and lake enrichment projects, and joint Canadian-U.S. operations.

^cProgram support includes manageability studies, SEP internal evaluation, applied research, management direction, Pacific Salmon Foundation support, and the federal share of the Provincial program

^dRelated non-SEP expenditures includes external program evaluation, basic contracted research, outside management studies, and other outside support services.

year" (DFE 1978), or roughly 136 000 to 163 000 t. Table 1 shows SEP's production targets by species (DFO 1978). As indicated, however, the agreement has more than one objective, and the resource goal was seen primarily as a means to achieve certain other economic and social objectives (Pearse 1982). These include augmenting national and provincial income, creating employment opportunities for Canadians, improving economic opportunities for native peoples, fostering development of economically disadvantaged communities and regions, and increasing recreational opportunities. A five-account planning system was constructed to document the benefits and cost of proposed developments for consideration by decision-makers, each account focusing on one of the priority objectives. A benefit/cost ratio of 1.5:1 was selected as a general yardstick against which to measure projects selected for development.

SEP headquarters are in Vancouver. The organization is managed by a Program Director who reports to the Director General of the Pacific Region of DFO in Vancouver responsible for fishery activities in British Columbia and the Yukon. Through the years there have been few organizational changes. The original joint agreement authorizing SEP provided for a Salmonid Enhancement Board composed of three federal officials, two provincial officials, and seven nongovernment members, all appointed by the Minister of Fisheries and Oceans in Ottawa (Pearse 1982). The seven nongovernment people were to be selected for their expertise in fishery resource management rather than be representative of any particular interest group. In effect, they were similar to an outside business Board of Directors existing to provide overall program review and direction. In 1984, a change of governments in Ottawa brought a new DFO minister who chose to dissolve the Board. While it was in operation, however, the Board provided an avenue of oversight. Recently there have been discussions about possible reinstatement of the Board.

Program Budget

As originally programmed, SEP was staged in two phases, the second phase to be dependent on the success of the first. Phase I, planned for 1977-82, received initial federal funding of \$150 million, an additional \$7 million from the province, and an interim target of increased production by 23 000 t per year. One hundred and seventy separate enhancement projects, combining habitat improvement and fish culture techniques, were identified for possible implementation. Of the original 170 projects, 103 were selected for development: 28 approved for early institution and the remaining 75 to be launched as time and money permitted (DFE 1978). Project development began immediately and the numbers built rapidly. By 1982, 15 major and 14 minor facilities, 14 community-development programs, 12 lake fertilization projects, and numerous small pilot and stream improvement projects were completed and operating (Pearse 1982). Program expenditures had reached \$117 million (Table 2). By 1984, juvenile fish production had risen to 376 million salmonids (AEIDC 1989) and program expenditures to \$175 million.

However, biological concerns were being raised. Ocean survival of coded-wire tagged (CWT) hatchery chinook and coho (*Oncorhynchus kisutch*) declined, and anxieties grew over the biological and genetic uncertainties inherent in enhancement programs, particularly the potential risks to wild stocks from large facilities with their sizeable production capabilities (Pearse 1982). At the same time, federal funding diminished and the program was slowed, entering a "transition phase" during which the program would be evaluated with those projects selected that would complement harvest strategies through the rebuilding of natural stocks. More emphasis would be placed on smaller projects, especially those requiring lower operating costs such as habitat restoration.

In 1986, DFO's Evaluation Branch concluded that much of SEP's information on existing wild stocks and possible impacts

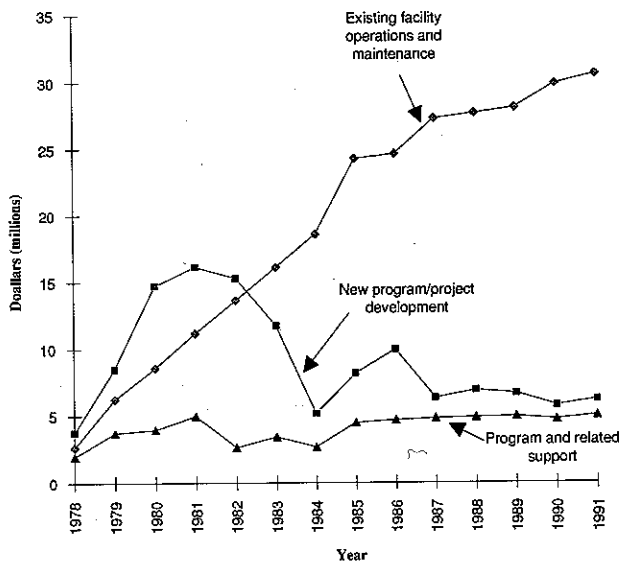


FIG. 2. SEP expenditures by major functional category for 1978–91. Source: DFO (1992).

of enhancement on them was uncertain at best and urged that research studies be launched immediately to find the answers. In 1987, the Branch's recommendations were incorporated in a Salmon Stock Management Plan which was accepted by the Minister of Fisheries and Oceans, and Phase II began. Despite a cutback in major facility construction, however, fry production continued to build. By 1987, output had jumped to 606 million salmonids released (AEIDC 1989), and total program expenditures had reached \$290 million.

As the program progressed, operational overheads grew rapidly. SEP had spent approximately 50% of its first five annual budgets on facility construction, and the costs to operate and maintain these facilities rose accordingly. Today those costs consume nearly three quarters of SEP's annual operating expenditures (Fig. 2; Table 2). Combined with inflation, this draw on the budget reduced the program's flexibility, limiting the type and scope of project SEP could consider. Monies for large, experimental projects became increasingly difficult to find, perhaps only at the expense of ongoing programs.

Below we review the program's production performance by type of project: hatcheries, spawning channels, lake fertilization, and smaller scale community involvement projects. Drawing on a recent study on chinook and coho which assessed efforts and results to date (Cross et al. 1991), the hatchery section of this report will concentrate on these two species. No similar assessment has been prepared by SEP on pink (*Oncorhynchus gorbuscha*), chum (*Oncorhynchus keta*), or sockeye, and information on those species is not as complete.

Hatcheries

Chinook and coho

Once SEP got underway, the buildup of facilities was rapid. By 1988, chinook juveniles were produced in 81 facilities, both hatcheries and spawning channels, and coho juveniles in 218 facilities. Production strategies include both direct release of fry or smolts from these facilities and supplementation of watershed streams throughout a region with hatchery reared fish.

CWT marking and recovery data are the primary tools used to assess the survival and contribution rates of chinook and coho

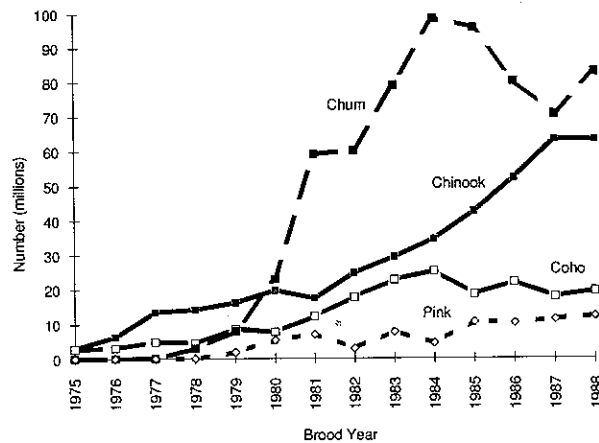


FIG. 3. Chum, chinook, coho, and pink releases for brood years 1975–88. Sources: Cross et al. (1991) for chinook and coho and D. Bailey, (SEP biologist, 55 W. Hastings St., Vancouver, B.C.) for chum and pink.

stocks. Virtually all production groups from large hatcheries are marked; those from small facilities usually are not. Groups of juveniles for which no portion of the release is marked are termed "unassociated releases." For such releases, survival and contribution rates are estimated based on those observed for comparably marked releases. This could produce errors in results, although to what extent or direction remains uncertain.

Fish captured for brood stock or attracted into a hatchery are counted and those numbers are considered quite accurate. However, for those hatchery-reared fish that are out-planted and return to spawn naturally, enumeration estimates are considered mere guesses unless a counting fence is used or a special mark-recovery study is performed. There are few of either. Furthermore, while the quality of catch data from the commercial fisheries is considered good, data are almost nonexistent for native food fisheries. These uncertainties in release, catch, and escapement data present a problem to SEP when it attempts to evaluate both the effects on wild stocks of human-produced salmonids and ultimately on the long-term success of the program.

Rapid buildup of chinook and coho juvenile releases followed facility construction. For chinook, this trend has continued (Fig. 3). In 1989, over 63 million chinook juveniles were released from SEP hatcheries, up from 14 million 10 yr earlier. Furthermore, high chinook release levels are expected over the next few years as more brood stock becomes available and incubation and rearing channels at several facilities are expanded. Since 1984, coho releases have remained fairly stable at around 19 million and are not expected to change markedly in the near future.

"Survival" is defined by SEP managers as adults surviving to catch and escapement from the total number of juveniles released. Despite increasing releases, survival of both hatchery chinook and coho smolts has been falling: in the case of chinook, from 2.3% for 1975 brood year fish to 0.3% for 1985 fish; in the case of coho, from 14.7 to 9.5% (Fig. 4). Many theories have been proposed to explain the decline in survival of hatchery fish (Walters and Riddell 1986). They include changes in environmental phenomena (such as EL Niño), loss of habitat, pollution, disease, predation, loading densities during the rearing stage, time and size at release, quality of hatchery stocks, as well as fishing pressure and changes in fishing regulations. Many of

these would have an effect on wild stocks as well, but to what extent is unknown.

Assuming that wild production remains constant, one measure of the program's success would be to determine if SEP's efforts have resulted in additional hatchery fish caught by Canadian west coast fishermen. In fact, they have for coho and to a lesser extent chinook. In 1979, approximately 6.1 million chinook and coho were taken by Canadian commercial and Georgia Strait sport fishermen. Of these, 6% or about 363 000 fish were estimated to be coho and chinook hatchery fish. By 1987-89, the total annual catch had dropped to around 4.7 million fish of which approximately 750 000 or 16% were SEP-produced coho and chinook. The coho catch has been rising, running between 600 000 and 750 000 fish from 1986 to 1989. On the other hand, production of chinook adults has been extremely poor, with total chinook catch declining and catch of hatchery-produced chinook showing no significant increase despite the 10-fold increase in chinook smolt releases from 1976 to 1990.

Against this background of decreasing survival, there is increasing concern over what effects, if any, hatchery production has on wild stocks. While there are no tagging data for wild chinook suitable for such analysis, some intermittent tagging studies have been done on several wild coho stocks on the Black, Quinsam, Trent, Little Qualicum, and Chilliwack watersheds. Those studies, summarized in a recent report (DFO 1990), chart the general decline in escapement of wild coho stocks in the Strait of Georgia, Fraser River, and Thompson River systems. The report states: "Escapements to central east coast Vancouver Island index streams have declined by 60% since the 1970's... For both the Fraser and Thompson rivers the average escapement to the index streams during the 1980's was more than 30% below the 1970's average" (p 13). Referring to Strait of Georgia wild stocks, the report goes on to say: "...spawning appears to be concentrated in fewer streams. This is a disturbing trend because it signals the potential reduction of genetic diversity necessary to maintain healthy fish populations and increases the vulnerability of wild stocks to catastrophic events such as flooding, pollution, and disease outbreaks.... Despite the weaknesses of the data, however, the decline in wild coho escapement estimates in virtually all areas...is definitely a cause for alarm" (p 15). Whether hatchery fish have had any effect on the decline is unknown. The report suggests that excessive fishing and lost habitat may be two key reasons, but points to the need for more complete information. Needless to say, sparse data make informed conclusions difficult to draw and increase the level of concern about the true condition of the wild stocks.

Chum and pink

Hatcheries also play a critical role in the enhancement of chum and, to a lesser extent, pink salmon. Efforts to increase chum and pink production had been made since the early 1950's beginning with attempts to improve egg-to-fry survival by hand-planting fertilized eggs in the gravel of controlled flow channels (Fraser et al. 1983). In 1955, the first spawning channel in British Columbia was constructed on Jones Creek, a tributary of the lower Fraser River. This was followed in 1963 by the Big Qualicum River Development Project which included extensive river temperature and flow control measures as well as a spawning channel. Once again, the objective was to increase salmon production by improving freshwater survival. In the years that followed, additional spawning channels were built on the Fraser River.

Hatchery-reared chum were released in increasing numbers

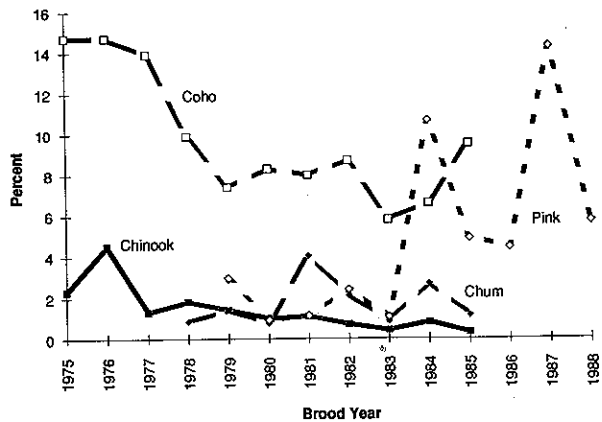


Fig. 4. Percentage of chum, chinook, coho, and pink surviving to adult for brood years 1975-88. Sources: Cross et al. (1991) for chinook and coho and D. Bailey, (SEP biologist, 555 W. Hastings St., Vancouver, B.C.) for chum and pink.

during the early SEP years (Fig. 3). By 1984, the construction of the major hatcheries was complete and most were running at or above design capacity. Since then, releases have run between 70 and 90 million juveniles. The total chum output for the 11-yr period from 1978 through 1988 was approximately 660 million juveniles. The survival trend has been fairly steady or perhaps slightly upward, and not downward, as detected with chinook and coho. A cautionary note, however, concerns survival rates for chum and pink salmon which are also subject to potential error as with chinook and coho. The use of CWTs is not nearly as extensive as with the other two species and some release groups are not marked at all. This is especially true of pink salmon. Thus, survival-to-catch figures are viewed with caution by SEP management and escapement figures are even less reliable.

In the case of chum, the latest years for which fry-to-adult survival figures are available are brood years 1978-85. From 1981 through 1985, the 11 major chum hatcheries released about 78 million chum fry annually. Fry-to-adult survival rates for that period averaged 2.06% which translates to about 1.6 million hatchery-reared chum returning annually to catch and escapement. Of these, an estimated 63% were commercially harvested (D. Bailey, SEP, Vancouver, B.C., personal communication), an average of slightly over 1 million adult chum per year. That harvest rate is high in relation to the 30% average rate on all chum fisheries in British Columbia due primarily to terminal fisheries on returning hatchery stocks. There is little information available on the sport or Indian catches of this species, but SEP believes it to be small compared with the commercial catch.

Enhancement of pink salmon has been dictated by economics. This fish is the least valuable of the salmonid species in terms of market price; consequently, the benefit/cost ratios for enhancement efforts are low. Thus, SEP spends comparably less time and money on pinks. Japanese-style hatchery production simply is too expensive to be used extensively on pink salmon, and only the Quinsam and Puntledge hatcheries produce them in an effort to recover from former levels of abundance. Because pinks tend to spawn near the mouths of large stream systems with slow flows, the rivers of these two Vancouver island hatcheries provide good spawning environments. Pink fry from these facilities are reared in sea pens.

For the 10-yr period from 1979 through 1988, the two hatcheries released 73 million pinks. Throughout that period,

fry-to-adult survival rates averaged around 5.6% of which 69% were caught commercially (D. Bailey, personal communications). Since the 1984 brood year releases, however, survival rates jumped to an average of over 7% as compared with under 2% for the 1979–83 period (Fig. 4). The reasons for this recent jump are uncertain. While explanations focus increasingly on ocean environment as a key determinant in adult survival, to what extent its effects influenced these survivals is unknown.

For brood years 1983–87, slightly over 8.8 million pinks were released annually of which about 7.1% survived. This means approximately 628 000 adults returning annually to catch and escapement which, at a 69% harvest rate, translates into an estimated 433 000 SEP-produced pinks contributed annually to the catch for recovery years 1985–89. Despite the recent jump in survival rates, however, because the low benefit/cost ratio for pinks is expected to continue, it is doubtful that SEP will increase its enhancement of that species through greater hatchery production. To a lesser extent, this is also true of chum salmon production. Rather, SEP will use its limited funds to concentrate on chinook and coho.

Spawning Channels

Spawning channels are human-made rivers that provide controlled flow, gravel, and spawning habitat. For sockeye, SEP recently built two spawning channels on the Fraser River, and since these are new, there is no record of their success. However, SEP operates three channels adjacent to Babine Lake which were built by DFO prior to funding of SEP. In addition, three channels on the Fraser River (Nadina, Weaver, and Gates) were constructed by the International Pacific Salmon Fisheries Commission in the late 1960's and early 1970's. The history of these sockeye channels, their adult production, and the history of their evaluation are reviewed in Hilborn (1992). Finally, SEP also operates two major spawning channels for chum salmon on Vancouver Island (Big and Little Qualicum), a spawning channel producing both pinks and chums (Jones), and a new pink channel (Glendale) which has yet to compile a record. In this paper, we will summarize the experience with these spawning channels and discuss how that experience can be used to understand the dynamics of SEP. We will concentrate our discussion on sockeye channels because they are the most successful in producing adult fish.

Fisheries agencies in the Northwest have experimented with spawning channels on a number of Pacific salmon species. Channels are intended either to replace lost or degraded spawning habitat, as in the case of the three Fraser River sockeye channels, or to provide additional fry input into underutilized rearing lakes — the Babine channels. Channel success may be evaluated by monitoring the downstream fry migration, the survival of fry in the rearing lake and/or smolt migration from the lake, and total adult production. The only marking technique used for sockeye spawning channel output was fin-clipping of some of the fry from the Babine channels. In the Babine system, fry survival, subsequent smolt migration, and total adult production estimates have been made by SEP. For the Fraser channels, SEP concentrated primarily on monitoring fry migrations, although some smolt or adult monitoring also occurred. Hilborn (1992) estimated total adult production of these channels by measuring changes in escapement to the channels and to nearby wild streams.

The results of these evaluations indicate that all sockeye channels have been successful at producing fry, although there

is a general trend towards declining egg-to-fry survival over time (Hilborn 1992). The Weaver Creek channel on the Fraser River was immediately and dramatically successful; producing an estimated increase of 200 000 fish per year after the first cycle of channel use. The other two Fraser River channels at Nadina and Gates creeks apparently added very little production to their local systems. The three Babine channels are estimated to have produced between 500 000 (Henderson and Diewert 1990) and 625 000 (West and Mason 1987) additional adult sockeye per year. It is interesting to note that at first there was no increase in adult production from these channels. It was only 12 yr after construction that increases began to appear.

From these experiences, one quickly realizes that a key lesson to be learned when evaluating sockeye spawning channels is the high degree of variability which ranges from immediate and dramatic success to virtually no increase or to delays or uncertainties in added production. The spawning channel results echo the hatchery lessons: some channels prove much more successful than others, and many evaluations seem ambiguous. As with hatcheries, there has been a general reluctance to evaluate adult production. SEP has done no estimates on the Fraser channels. The first evaluation of adult production from the three Babine channels was not published until 1987, 18 yr after the first channel went into operation. In addition, there appears to be no relationship between SEP's evaluations and its assumed survival rates for spawning channels. The survival rates assumed for the two new channels built on the Fraser River in the late 1980's were roughly five times higher than the observed rates of adult production for Fraser River channels and more than twice as high as the rates of adult production for the Babine channels. It has been suggested (Hilborn 1992) that these new channels were constructed to meet a political commitment to build sockeye enhancement facilities on the Fraser River and that realistic adult production objectives played no apparent role in the ultimate decision. While this suggestion can be debated, what becomes obvious is that, while some of SEP's efforts have proved very successful, in the case of sockeye channels the organization continues to be reluctant to make comprehensive evaluations of adult production a keystone of its program.

In addition to the sockeye channels, SEP operates several channels producing chum and pink salmon. Fry production from the Jones channel has been low, in the neighborhood of 0.5 million unfed chum and pink fry released in odd years with no apparent survival (unpublished data on chum and pink releases and survival rates provided by D. Bailey, SEP). The Glendale channel released 19 million unfed pinks, brood year 1988, which attained a 7.2% adult survival rate, but no subsequent history of releases or survivals has been compiled or is available. By far the major channel facilities for these two species are the Big and Little Qualicum channels. While they were constructed prior to SEP, both have been enlarged substantially over the years. Combined, they release over 60 million chum fry annually, virtually all of which (94%) are unfed. Unlike the sockeye channels, SEP keeps quite accurate records of both releases and adult survival rates of these fry, albeit unpublished. For brood years 1981–85, these channels contributed an estimated 312 000 chum annually to the catch (unpublished data on chum and pink survival rates provided by D. Bailey with a 63% exploitation rate applied to these brood year returns).

Lake Fertilization

In 1969, scientists with the Pacific Biological Station at

Nanaimo began an enrichment experiment at Great Central Lake on the western side of Vancouver Island to test the hypothesis that inorganic nutrients added to the lake during the planktonic growing season would result in larger standing stocks of zooplankton, leading to an increase in both growth and number of sockeye fry. They hoped that this would produce more returning adults (Manzer 1976). Great Central Lake is adjacent to Sproat Lake, approximately the same size, and produces comparable numbers of adult sockeye (Great Central runs were 1.6 times those of Sproat on average). Sproat Lake remained untreated throughout the test as a "control" lake. From 1970 through 1973, inorganic fertilizers were added to Great Central Lake weekly from April to October (Stephens and Stockner 1983). Both the nutrient levels and the sockeye seemed to respond positively. Primary phytoplankton production increased fivefold, zooplankton stocks ninefold, the survival rate from egg-to-fry 2.6 times, and the treated runs of returning adults jumped to more than 360 000 fish from pretreatment levels of under 50 000 (Hyatt and Steer 1987). Furthermore, for the period 1973–75, commercial landings of sockeye in Barkley Sound, which are largely supported by Great Central and Sproat Lake runs, were 7.6 times greater than for the years 1958–72, before the "treated runs" returned.

From a cost standpoint, the program also appeared to be a success. The fertilizers used were relatively inexpensive and, in addition, the program was not considered especially labor-intensive. Thus the conclusion was quickly reached that lake fertilization could be a highly cost-effective way to enhance sockeye salmon. These promising results lent weight to the government's ultimate decision to launch SEP, and SEP's initial funding included substantial monies for lake enrichment.

The Lake Enrichment Program (LEP) started with six projects. Over the next 7 yr, that number increased to 16, and program costs grew accordingly (Fig. 5). Smolt production varied widely, tripling in 1982, then dropping, leveling off, declining further in 1987–88, and jumping to over 40 million in 1989. Part of the reason for the jump was a new fertilization effort initiated in 1988 at Chilko Lake, a large interior lake connected to the upper Fraser system which once carried a sizeable sockeye population. The following year, over 22 million sockeye smolts, accounting for more than half the total program production, departed that lake. No public figures are available on increased smolt numbers due to fertilization.

Despite this new effort, however, the number of LEP project lakes declined from a high of 16 in 1982 to five in 1992: Great Central, Henderson, Long, Hobiton, and Chilko. Various reasons led to the curtailment. One of those was the nature of the lakes: water temperatures and condition, size and depth, flushing rate, available spawning areas, food availability, climate, predation, other interacting species, and proximity to the ocean all play a part in production of sockeye salmon. Some lakes did not produce more than a marginal increase in sockeye following fertilization even though the enrichment strategy rests on the assumption that juvenile sockeye survival is density dependent on food availability. In addition, few lakes are sufficiently similar for one to be used as a control while experimenting with various fertilization techniques. Thus, prefertilization control data must be developed followed by years of experimentation to get a reasonably clear picture of the effects of fertilization on sockeye populations. This effort can be both time-consuming and costly if stretched over a large number of lakes. Therefore, scientists have tended to concentrate their efforts on tracking specific

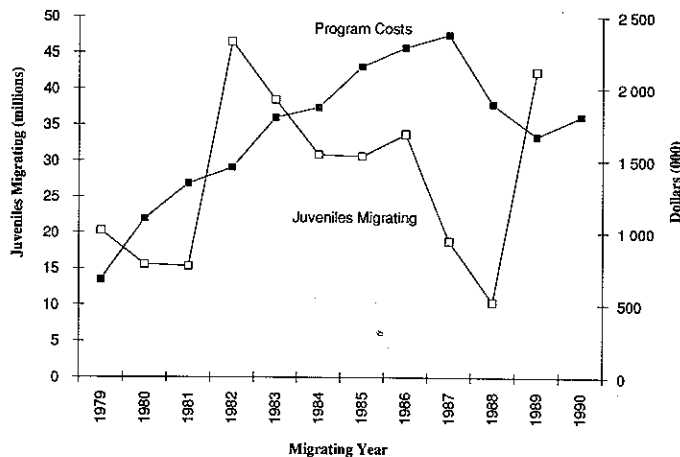


FIG. 5. Lake fertilization costs and juveniles migrating from all SEP fertilized lakes, 1979–90. Source: SEP (1990).

stocks from a few selected lakes.

Initially, the task of assessing juvenile biomasses was difficult because the outlets of many lakes were too large to install weirs, preventing accurate counts of departing smolts. To offset this problem, acoustic surveys now provide reasonably good data on juvenile numbers and gross production. The assessment of adult survivals, however, has proved to be onerous. There are no published data on the program's overall contribution to catch and escapement. Information on marine survival and the effects of lake enrichment on that survival is sparse. To estimate adult survival rates, SEP uses biostandards that it maintains for each technology including lake enrichment. These biostandards in theory reflect SEP experience with the technologies employed and are adjustable as that experience builds. Thus, if the biostandard for sockeye survival from an enriched lake is 4%, biologists assume that 4% of the sockeye fry migrating from that lake will survive to adulthood. Observed 1981–83 returns at five lakes that had been fertilized indicated a 7.3% survival rate to adult for 1978–79 brood year fish which was considerably higher than the predicted 4.5% biostandard used by SEP for its lake fertilization projects (K. Hyatt, LEP biologist, Pacific Biological Station, DFO, Nanaimo, B.C. personal communications). But to what extent that high survival rate was due to lake enrichment strategies as opposed to marine conditions or to baseline increases in productivity that might have occurred with no fertilization is unknown. What is increasingly recognized is that the marine environment can have substantial temporal and spatial effects on smolt-to-adult survival. Survivals in one area or time period do not necessarily correlate with survival patterns in others (Hyatt et al. 1990). Consequently, LEP scientists now compartmentalize freshwater and marine survival data, studying the sets separately. The potential effects of that environment on enhancement outcome have also heightened interest in the need for extensive marine research.

Thus, to date, SEP has been unable to measure LEP adult production. The results of present attempts at this evaluation are not public at this time: therefore, unlike the recent SEP chinook and coho hatchery report (Cross et al. 1991), any estimates of increased adult sockeye production due to lake enrichment remain subjective. If the 4.5% biostandard figure used by SEP is employed as an estimate of adult survival for the two key lakes (Great Central and Henderson) that have accounted for about 42% of total juvenile production from 1982 through 1988 (88

million out of a total 210 million), the average annual adult survival should have been about 566 000 fish. At an estimated 70% commercial exploitation rate, the annual sockeye catch from 1985 through 1991 should have averaged about 396 000 fish from those two lakes. In fact, for that period the average annual commercial catch in Barkley Sound largely coming from these two lakes, ranged from a low of 136 000 in 1986 to a high of 1.2 million in 1991, with an average of slightly over 460 000 sockeye per year. Thus, a 4.5% survival figure appears to be within reasonable bounds for this area. Further, that average compares with an average 37 000 sockeye commercially caught annually for the 7-yr period from 1962 through 1968 before these lakes were fertilized, a 10-fold increase, although to what extent lake fertilization contributed to that increase is unknown.

From 1979 through 1988, total juvenile migration from fertilized lakes annually averaged about 26 million juvenile sockeye. Assuming that the 4.5% biostandard is a reasonable survival figure and that all production is attributable to LEP, that yearly production should have contributed about 1.2 million adult returns annually. At a 70% commercial exploitation rate, an additional 820 000 adult sockeye, roughly 2100 t at an average weight of 2.6 kg per fish, should have been added to the catch, some portion of which would be due to fertilization. From 1982 through 1991, the annual commercial sockeye catch in British Columbia waters averaged about 24 000 t (SEP 1990; DFO 1992). If the entire 2100 t were ascribed to lake fertilization, it would have contributed 9% to the total catch.

Community Involvement

SEP has two community involvement programs: the Community Economic Development Program (CEDP) and the Public Involvement Program (PIP). Certain of SEP's objectives are social goals designed to increase employment and economic opportunities for Native peoples and communities in less-developed areas. To that end, an experimental program of six salmonid enhancement projects, entitled The Native Project Pilot Program, was initiated in 1979 as a jointly funded federal-provincial undertaking (Rank 1982). SEP administered the program and contracted the tasks of construction and operations to Native Bands. In addition, projects were launched in non-Indian communities with strong interests in salmonid enhancement and in areas of high unemployment. Thus the program took on a "community" approach, albeit strongly Native oriented. Three new projects were added in the first year and another five over the next 2 yr. In 1981, DFO assumed total funding responsibility for the effort, renaming it CEDP (DFO 1991).

In the first 2 yr, the program emphasized data gathering, including stream monitoring and cataloging biological and physical aspects of the resource. Then the projects moved into actual fish production. By 1982, there were 14 CEDP projects including 11 hatcheries, two sets of sea pens, and one set each of side channels and incubation pits. These were relatively small projects (none costing over \$500,000), not overly complex from a technological standpoint and designed to train Native personnel in salmonid management techniques. In addition, SEP wanted to test whether such projects could approach the efficiency of larger, more technologically complex projects. At the same time, SEP management regarded the program's salmonid production as secondary to the goals of increased employment and education and consequently evaluated the program on its social merits rather than on a strict 1.5:1 benefit/cost

ratio as with other SEP facilities.

Another objective was to engender a high level of public awareness of the salmon resource, both through direct engagement in SEP's enhancement efforts as well as through education (Pearse 1982). Thus, PIP was initiated with an incubation box on a small stream in the Queen Charlotte Islands. Enhancement projects under this program also were small in size and run by volunteers as groups or as individuals, the maximum SEP expenditure for annual operations rarely exceeding \$5000 per project (DFO 1991). Each project was assigned a management team — a SEP biologist, an engineer, and the project's volunteer manager — coordinating their activities with SEP Community Advisors stationed throughout the province who also have the responsibility of monitoring the CEDP projects in their areas.

In addition, SEP also funds a program, "Salmonids in the Classroom," which educates school children in the life cycle and related environmental needs of Pacific salmon and includes the raising of salmonid fry in small classroom incubators. This was the first federally sponsored education package to be accepted by British Columbia's Minister of Education and arguably the first of its type in North America. Today that program is headed by a Curriculum Coordinator located on the central mainland who develops educational materials and offers workshops and assistance to teachers using the program. That person is backed by Three Education Coordinators, two on Vancouver Island and one on the lower mainland. The group as a whole works with 500 elementary and secondary schools throughout the province overseeing the operations of 800 classroom incubators. Through these efforts, an estimated 100 000 students in British Columbia and the Yukon are exposed annually to the concepts of salmon conservation and the techniques of salmonid enhancement.

Over the years, SEP's community involvement efforts have broadened steadily. The original group of four Community Advisors has grown to 15. The cost of the program rose as its project base expanded, and by 1990, CEDP project expenditures had reached \$5.3 million annually and PIP projects \$1.7 million (SEP). According to the latest Community Involvement Directory, there now are 25 CEDP, 130 PIP, and 500 classroom projects producing chinook, coho, chum, and pink salmon. Fry releases from CEDP and PIP facilities have been sizeable, in excess of 30 million (DFO 1991).

Most CEDP projects are hatcheries although others include fishways, sea pens, and stream stewardship. PIP projects encompass spawning channels, habitat restoration, and the operation of incubators. Because few releases from these facilities are tagged, there is virtually no information to measure success in terms of enhanced catch and escapement. However, the success of this program should not be measured solely on production or placed on a strict benefit/cost ratio as applied to other SEP projects. The program has increased public awareness while providing employment in depressed areas. Cooperation with community groups has grown, and closer working relationships with Native Bands have resulted in new collaborative agreements on habitat improvement and upgrading facilities.

This is not to say the program has escaped controversy. The recent intense Native drive for self-determination raised the possibility of "co-management" of DFO-funded CEDP facilities with native bands. A determination has yet to be made on this issue. On balance, however, the community involvement program appears to be successful in reaching its social objectives; increasing public awareness of the government's salmonid conservation and enhancement efforts while simultaneously

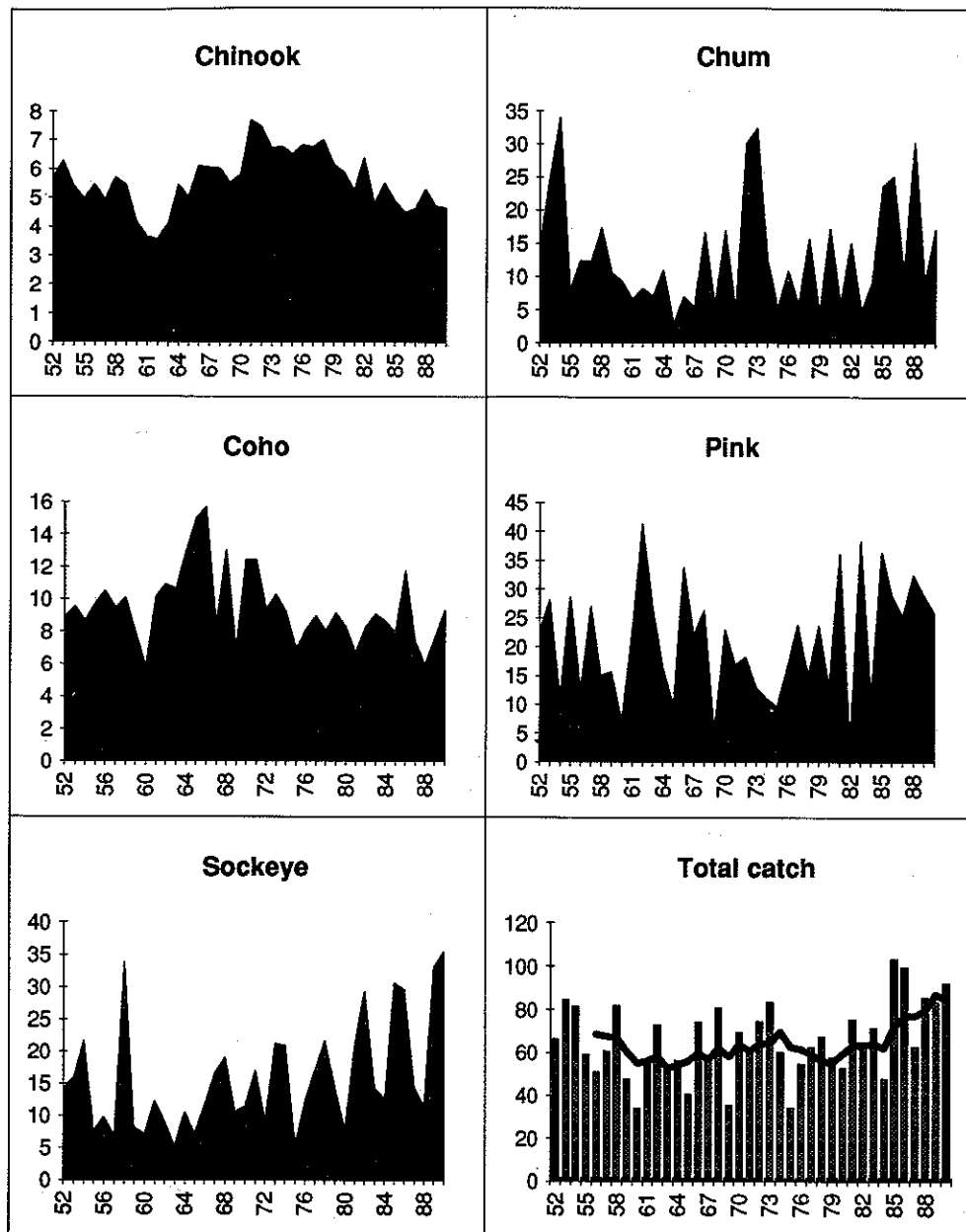


FIG. 6. Time trends in commercial catch by species and total, 1952-90. The line in the lower right graph is the 5-yr running average. Source: DFO (1992).

providing added employment and training to native peoples and to depressed communities.

Discussion

SEP has been the largest single enhancement program for salmonids in North America. It has spent \$450 million and developed a substantial physical infrastructure and a staff of several hundred. We seek to answer two key questions: is SEP succeeding in its objectives, and what lessons have been learned that are applicable elsewhere?

Has SEP Succeeded?

While SEP has been successful in reaching certain of its

objectives, it has been less so in attaining others. On the positive side, SEP has been effective in stimulating awareness of the salmonid resource throughout British Columbia. Thousands of volunteers work on community involvement projects, and SEP is regarded by many commercial and recreational fishermen as a key to the maintenance of British Columbia's salmon runs. However, the major goal of SEP was to increase salmon returns, specifically to allow a doubling of landings by adding up to 86 000 t to the catch in an unstated but presumably reasonable time frame, perhaps 10-20 yr. Its interim supplementary catch target, to be met originally by 1982 and later extended to 1984, was set as 23 000 t. The 1975-79 low point in the 5-yr average total catch (Fig. 6) roughly coincides with the advent of SEP. From that period to a decade later, 1985-89, catch rose by 31 600 t (Table 3). The salmon populations appear to be

TABLE 3. Annual average commercial salmon catch by species in thousands of metric tons for three 5-yr periods, indicating the increase or decrease from 1970-74 and 1975-79 to 1985-89. Source: DFO catch statistics data base.

	Chinook	Chum	Coho	Pink	Sockeye	Total
Annual average						
1970-74	6.86	19.49	10.76	16.44	16.05	69.6
1975-79	6.62	8.55	8.25	17.76	14.24	55.42
1985-89	4.76	19.88	8.14	30.38	23.89	87.05
Change from:						
1970-74 to 1985-89	-2.1	0.39	-2.62	13.94	7.84	17.45
1975-79 to 1985-89	-1.86	11.33	-0.11	12.62	9.65	31.63

rebuilding in conjunction with SEP, and anyone taking a cursory look at the program would be tempted to ascribe that increase to SEP's efforts.

A closer look, however, is needed to determine to what extent that increase is due to SEP, improved fisheries management, natural forces, or a combination of all three. In fact, the two species on which SEP concentrated most of its production expenditures, chinook and coho, have shown declines (Fig. 6). Increases in both tonnage and value added have come from the other species. Table 3 shows the salmon production by species for three periods. In the first period, 1970-74, some large-scale hatcheries, spawning channels, and lake enrichment projects were already in operation. The second period, 1975-79, is just prior to SEP's added enhancement efforts. The years 1985-89 are the most recent five yr for which we have complete catch data including those contributed by SEP. If one uses 1970-74 as the baseline period to compare against 1985-89, the incremental catch is 17 000 t, 82% of which is due to an increase in pinks on which SEP has expended the least amount of its efforts. If one uses 1975-79 as the base period, a more optimistic assessment is reached. The change in yield to 1985-89 is 31 600 t, again attributable to increases in species other than chinook or coho. This comparison between periods shows how critical the selection of the base-year period becomes when identifying potential catch increases that might be attributable to SEP.

For the years 1985-89, SEP contributed approximately 12 400 t per year to the catch (Table 4). When using the 1975-79 base period, that represents 40% of the 31 600 t increase in annual yield. More to the point, it also represents only one half of SEP's extended 1984 interim goal of 23 000 t and after 12 yr of effort, constitutes barely 14% of the program's ultimate target of 86 000 t. Based on the average 1985-89 price per species, the annual added value of that production was approximately \$44 million dollars, barely covering the annual operating costs of the program. This estimate does not include catch figures from Native subsistence fisheries and probably understates the sports fisheries for which the data are incomplete.

Of course, SEP produced other substantial benefits not included in this figure (added employment, public education, and resource research and information). Certain costs, however, such as the possible adverse effects on wild stocks or the costs in Ottawa of program management are not included. These and other costs and benefits would have to be measured to get a reasonably accurate overall benefit/cost ratio for the program. The fact remains, however, that after 12 yr of effort through 1989, the landed value of the catch added by SEP does not appear to be covering the program's operating costs.

To place SEP's production efforts in perspective, it is worthwhile looking at the changes in natural sockeye production from the Fraser River. With the exception of three spawning channels which produce an estimated 240 000 adults annually (Weaver, Gates, and Nadina), recent increases in Fraser sockeye numbers are the result of management decisions to increase escapements on the Fraser River — not the result of technological enhancement efforts. From the 10-yr period 1970-79 to that of 1981-90, average annual returns of adult sockeye to the Fraser increased from 5 million to 11 million fish. At an 80% harvest rate, that increase translates into an additional 4.8 million Fraser River sockeye contributed to catch yearly. At an average weight of 2.6 kg per fish and an average 1985-89 price of \$5.56 per kg, the landed value of those 4.8 million Fraser River sockeye was roughly \$69 million. In comparison, our estimates show that SEP's contribution from all species for the 5-yr period from 1985-89 averaged 4.1 million fish per year (Table 4) with a total annual landed value of \$44 million — or only 64% of the added value of Fraser River sockeye alone.

Lessons Learned from SEP

Table 4 poses the question: has SEP been worth the effort? At the outset, the enhancement program seemed eminently promising. Hatchery survival rates were high: early chinook survival rates were some 3% and coho survivals over 10%. The fertilization success at Great Central Lake promised millions of additional sockeye salmon from other oligotrophic lakes. The technology was considered to be at hand. In fact, the original 1979 agreement between Canada and British Columbia authorizing a cooperative SEP venture stated: "And whereas Canada and British Columbia agree that salmonid enhancement technology has been developed and refined in recent years to the state where it can now be applied with confidence....," a declaration full of promise (Federal-Provincial Agreement, DFO 1979). The desire to take action, the belief the time was right, and the conviction that DFO knew what to do combined to create an infectious optimism that gave impetus to SEP.

It is hard now to retain the optimism of the 1970's. None of the technologies that looked so exciting in the 1970's have turned out to work as well as had been hoped. Larkin (1974) signalled a warning about enhancement, using the analogy of a gamble: "The implication for enhancement programs is that results may be discouraging for a series of years, but then an explosive success may more than make up for the years of poor return. The process is akin to a gambling game in which there is an equal chance of doubling your stake or having it cut in half" (p. 1442). SEP received a major infusion of capital funds from Ottawa, bet

TABLE 4. Estimated 5-yr annual average contribution to catch and total value of salmonids produced by SEP for the years 1985–89 (except as noted in the footnotes).

Program	Average annual releases (000)	Average survival rate (%)	Number of adults produced (000)	Adults contributed to catch (000)	Average weight (kg)	Total weight produced (000)	Price per kg (\$)	Value produced (\$000)
Chinook hatcheries ^a				99	6.2	614	5.83	3 578
Coho hatcheries ^a				634	2.3	1 458	3.98	5 804
Pink hatcheries ^b	8 849	7.1	628	433	1.7	736	1.19	876
Chum ^b								
Hatcheries	78 585	2.06	1 619	1 020	4	4 080	1.95	7 956
Spawning channels	60 319	0.82	495	312	4	1 246	1.95	2 431
Sockeye								
Spawning channels ^c				817	2.6	2 124	5.56	11 811
Lake fertilization ^d	26 000	4.5	1 170	819	2.6	2 129	5.56	11 839
Program total				4 134		12 388		44 295

^aChinook and coho contribution to catch from Cross et al. (1991). Includes Canadian commercial and Strait of Georgia sport catch.

^bPink and chum contributions derived from release and survival data provided by D. Bailey (SEP). For pink, a 69% exploitation rate applied to survival, and an annual average of brood years 1983–87 used for releases and also for survivals to correspond with recovery years 1985–89. For chum, a 63% exploitation rate applied to survival, and an annual average of brood years 1981–85 used for releases and also for survivals to correspond with recovery years 1985–89. This applies to both hatcheries and spawning channels.

^cSockeye channel contribution to catch obtained by adding data in West and Mason (1987) indicating an average annual increase from 1958–71 to 1973–85 to Canadian fisheries of Skeena River sockeye from Babine Lake project of 625 000 adults to 240 000 Fraser River sockeye adults (Hilborn 1992) multiplied by an 80% exploitation rate (192 000) from Weaver, Gates and Nadina channels, totalling 817 000 SEP-produced sockeye contribution to catch.

^dSockeye contribution from fertilized lakes obtained from SEP annual reports. Used SEP's 4.5% survival biostandard on average of annual releases from 1979 to 1988 and applied a 70% exploitation rate.

it largely on chinook and coho hatcheries, has yet to hit that "explosive success", and may be unable to obtain similar large capital funds in the next few decades.

During the planning stage, there was considerable discussion of using an adaptive approach: experimenting with different technologies, determining what worked best, and then expanding the production using those technologies. A recognized problem with adaptive management was the long time-frame required to evaluate the effectiveness of technologies. Fisheries managers acknowledged that at least 10–20 yr would be needed before scientists could gain a clear understanding of how well different technologies worked. However, funding from Ottawa may have been compromised if such uncertainties had been admitted. Thus, except perhaps in lake fertilization, the adaptive approach was never completely adopted. Capital budgets were spent before realistic evaluations of the various technologies could be done. Part of this rush to build major facilities was due to the optimism mentioned earlier. Part also was due to the governmental system itself which encourages a rapid expenditure of appropriated monies. SEP was given a one-time opportunity to fund a major salmonid program. If SEP delayed major construction by 10 or more years in order to evaluate various technologies, the political winds might change and the capital funds for construction might not be there when needed. In addition, some have argued that there was a strong engineering mentality within SEP management convinced that it knew which enhancement strategies worked — thus the real job was to pour concrete. In fact in his early essay predating SEP, Larkin (1974) described the type of salmonid enhancement program envisioned for Canada as "...an essentially engineering enterprise that emphasizes construction" (p. 1446).

In retrospect, SEP management permitted the program to evolve too quickly and too inflexibly, committing itself to the

construction of large hatcheries before understanding their full implications. Initially, there was discussion of building portable, disposable hatcheries to try to minimize the fixed expenses, but this strategy was not pursued. The only technology that does not rely on large-scale fixed projects is lake fertilization, and this is the only technology that has been handled adaptively. Many different lakes have been tried and many have been abandoned. In contrast, hatcheries, which involve millions of dollars in fixed expenses, are difficult to shut off. Only recently has the possibility of curtailing certain hatcheries that appear to be unproductive been discussed (Dr. Carl Walters, Department of Fisheries, University of British Columbia, Vancouver, B.C., personal communications).

SEP has taught us a number of lessons about the problems in evaluating enhancement methodologies. One of SEP's strong features has been its attempt to evaluate certain individual projects. Without question, the CWT program at SEP coho and chinook hatcheries provides the best series of survival estimates in the world for those species. The evaluations of the Babine spawning channels are of equally high quality, as are those of certain experimental chinook hatcheries on the upper Fraser. Thus, it is disconcerting to find that after 15 yr, we still are not sure which technologies will work and under what conditions. We do not have a clear understanding of how natural forces such as weather or oceanic conditions affect those technologies, nor do we know if natural production has been lost due to the infusion of hatchery stocks. Lake fertilization has not turned out to be the magic solution originally envisioned. We need to know much more about when and where enrichment strategies work. Spawning channels have a similarly ambiguous record. We cannot say that any of these technologies are successful, nor can we say they are not, but it is clear that we need more time than previously thought to evaluate them. In the 1970's, we believed

TABLE 5. Comparison of biostandards used by SEP with observed adult returns for selected areas. Data are percentages. Sources: Hilborn (1992) for sockeye and Cross et al. (1991) for coho and chinook.

Area	Sockeye		Coho		Chinook	
	Observed	Biostandard	Observed	Biostandard	Observed	Biostandard
Babine River	8.55	10.8				
Fraser River	5.15	24.2				
Inside ^a			8.9	7.0	0.90	1.7
North ^b					0.44	2.0
West Coast ^c					0.56	1.4
Upper Fraser ^d					0.08	0.75

^aInside area includes Johnstone Strait, Strait of Georgia side of Vancouver Is., Strait of Georgia mainland, Juan de Fuca, and Lower Fraser River.

^bNorth area includes Nass, Skeena, Queen Charlotte Islands, North Coast, Central Coast, River's Inlet.

^cWest Coast area includes NorthWest Vancouver Is., and South Coast Vancouver Is.

^dUpper Fraser area includes Thompson River and Upper Fraser River.

that 10–15 yr might be required. From the data collected to date, perhaps 50 yr should be considered a more appropriate time horizon. Under more enlightened, scientifically informed management, free of bureaucratic decision-making, the time horizon might be reduced somewhat, but not as short as originally considered.

What has SEP learned in its 15 yr of existence and has that learning led management to make major course corrections? We have examined what SEP learned about technologies for sockeye spawning channels and supplementation hatcheries for chinook (Hilborn 1992; Winton and Hilborn 1994). In both cases, we found that SEP had respectable programs of experimentation and learning at individual sites and good programs of information transmission so that lessons learned at one hatchery or spawning channel were available to managers at other sites. Furthermore, this information was made available in a timely fashion to senior SEP decision-makers. Yet it appears that, in many cases, those decision-makers did not translate individual project findings into program course corrections.

Perhaps nothing is more indicative of SEP's failure to use its own evaluative results than its application of internal biostandards. Biostandards play a critical role in the decisions to build new facilities. The projected production from a facility depends on the biostandard assigned, and the decision to pursue a particular technology is based on its expected production. In the late 1980's, SEP constructed several new sockeye spawning channels on the Fraser River. Hilborn (1992) showed that the biostandards used were five times higher than SEP's previous experience with spawning channels on that river. For coho hatcheries and Babine spawning channels the biostandards are very close to observed experience. Indeed in the one area where figures are available, coho biostandards appear to be lower than experienced (Table 5). However, for sockeye spawning channels on the Fraser and for chinook at virtually all sites, the biostandards bear little relation to reality. SEP rarely reports adult fish produced. Its annual statements (discontinued in 1989) indicate juveniles released by facility and estimates of adult production based on biostandards for those facilities. Retrospective analysis shows that these estimates, particularly for chinook, have been consistently overstated.

SEP's reticence to indicate proven adult production was discussed by Hilborn (1992), who pointed out that the first report of actual adult returns from the Babine Lake spawning channels, which were completed in the early 1970's, did not appear until

1985. The only comprehensive report by SEP on adult chinook and coho production was released in 1991 (Cross et al. 1991), roughly 20 yr after the first hatcheries were built and 12 yr after funding for SEP began. No similar reports of actual adult returns have ever been published on chum, pink, or sockeye. The organization seems capable of evaluating specific projects but unable, unwilling, or not allowed to examine the key question critically — are more fish being produced?

Probably the least understood result of SEP has been the potential impact on natural-spawning fish. It was widely recognized at SEP's inception that there was great potential for damage to wild stocks via mixed-stock fisheries (Larkin 1974), and one of the key points discussed in SEP early planning efforts was the ability to manage the enhanced stocks separately. Not extensively recognized, however, was the possibility of biological interactions between enhanced and wild stocks and the potentially adverse effects of these interactions, a concern that is now wide spread. Stocks of wild chinook and coho in the Strait of Georgia and sockeye on the Skeena River have declined continuously since SEP began, while the big wild stock success story of the 1980's, Fraser River sockeye, took place in the one large watershed that had relatively little SEP activity related to that species. Admittedly, wild stocks of chinook and coho have declined over much of the West Coast during the same period. Yet today, no one is capable of determining the extent to which these declines have been caused by marine conditions, the fisheries, or by biological interactions with SEP production. The one point that is gaining recognition rapidly, however, is the need to launch research programs to find answers to these questions.

Thus in retrospect, SEP would appear to need a periodic and systematic external scientific review, perhaps performed by a panel of scientists knowledgeable in the field of salmon population dynamics. Previous "reviews" of the program, such as that made by the Commission on Pacific Fisheries Policy (Pearse 1982), used SEP biostandards as measures of adult production. Thus, their findings cannot be considered a true representation of program performance. Further, we see an important need for strong external guidance on major policy direction. It is difficult to trace why some SEP facilities were built and not others. What is clear is that early in its history, SEP lost a critical element of external guidance when its Board was disbanded. Several observers, both inside and outside SEP, have told us that, while the Board ought to have exercised greater oversight during its existence, at least it was in a position to serve as an arbitration

panel for arguing the scientific or production merits of specific technologies or sites (Dr. Peter Larkin and Dr. Carl Walters, personal communications). The lack of consistent, continuous external review and guidance would appear to be one of the key weaknesses of the SEP program.

Summary

SEP is an excellent test case of two critical resource management questions: can we enhance natural production, and can we learn from experience? The most important lesson to be learned from the first question is how little we know about enhancement — each technology that appeared proven 15 yr ago seems much less reliable today. For each major technology, hatcheries, spawning channels, and lake enrichment, the lesson appears to be that it works in some places and at some times, but not in others. Unfortunately, we still do not know with any assurance how to determine beforehand which places will work and which will not. Since SEP is the best documented program of salmonid enhancement on the Pacific Coast, this lesson should serve as a strong warning to other jurisdictions that have adopted the goal of doubling the salmon catch by artificial enhancement. There is no proven technology, and the time required to learn when and where a specific technology will work is very long, perhaps closer to 50 than to the 15 yr originally considered adequate by many fisheries scientists.

Our analysis of SEP's ability to learn from its own experience is also discouraging. The organization's apparent reluctance to determine if it is actually producing adult salmon and how its activities are affecting wild stocks forces us to conclude that, while SEP is capable of learning about the merits of a specific operating procedure, it has difficulty translating that learning into actions calling for major course corrections. To overcome this failing, we offer several suggestions for consideration based on SEP's long, often arduous, experience in attempting to enhance Canada's West Coast salmonid stocks.

First, allocate a substantial portion of an overall program budget (15% or more) to evaluation, and ensure that this percentage is maintained during the life of the program. Second, use flexible technology whenever and wherever possible, avoiding large permanent facilities until enough time has elapsed to permit an adequate evaluation of that technology. Third, prepare politicians and funding agencies for a long wait to determine what works: the research must be geared to the life cycles of salmon and not to political exigencies or timetables. Finally, rely on outside professional oversight for true evaluation of program success and for guidance in program direction. An independent board of outside experts representing a wide array of organizations and backgrounds might be considered one logical way to fill this need.

In conclusion, we see SEP entering a new phase. At the start of the program, many proponents argued that SEP would serve as an agent of change in fisheries management. It does appear that SEP successfully served that function in the early years when it was the principal source of uncommitted funds for new studies, projects, and any new initiative within DFO Pacific. Today, many of those same proponents believe that SEP has forfeited that role by becoming increasingly mired in its own operating expenses, its budgets dedicated to the maintenance of existing operations and funds available for planning and research disappearing. As SEP's flexibility diminishes, perhaps not surprisingly a new agent of change is appearing — the emerging

group of Native Bands commanding fresh resources and political support. Increasingly, discussions in DFO involving program initiatives turn to the potential for associating those efforts with the Bands. It is possible they will become the innovators in salmon management, ultimately assuming SEP's original role. We expect SEP itself, or possibly a reorganized version thereof, to continue, but with its role as innovator considerably reduced.

Acknowledgments

We thank those members of Canada's Department of Fisheries and Oceans, and especially those in the Salmonid Enhancement Program, who supplied us with much of the information used in this article. Specifically, we thank Mr. Al Wood of DFO; Drs. William Ricker, Brian Riddell, and Kim Hyatt of DFO's Pacific Biological Station in Nanaimo; Dr. John Stockner at DFO's West Vancouver Laboratory; and Mr. Ted Perry, Ms. Carol Cross, Mr. Don Bailey, and Mr. Bryan Allen at SEP's Vancouver headquarters for their time and effort. We also thank Drs. Peter Larkin and Carl Walters of the University of British Columbia for providing us with insights into the history and evolution of the Salmonid Enhancement Program.

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