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Institutional Learning and Spawning Channels for Sockeye Salmon (*Oncorhynchus nerka*)[1]

Ray Hilborn

School of Fisheries WH-10, University of Washington, Seattle, WA 98195, USA

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In the 1960s and 1970s, six artificial spawning channels for sockeye salmon (*Oncorhynchus nerka*) were constructed in British Columbia. I use the evaluation of these facilities and the response to the evaluation to test the hypothesis that fisheries management agencies can learn from experience. One of the facilities was almost immediately determined to be successful, but it took approximately 20 yr for the agency to evaluate the success of the other five. The evaluation was ambiguous for three of these. Only when facilities were overwhelmingly successful or total failures did clear answers emerge. The Canadian Department of Fisheries and Oceans (DFO) has experimented, evaluated, and learned about design, construction, and operation of spawning channels. DFO appears to be less successful at using the evaluation of adult production resulting from spawning channels. Learning appears to work best when goals are well defined, experiments can be conducted and evaluated rapidly, and there is a close organizational connection between decision makers, evaluators, and operators.

Dans les années 60 et 70, on a construit en Colombie-Britannique six frayères artificielles pour le saumon rouge (*Oncorhynchus nerka*). J'ai pris comme point de départ l'évaluation de ces installations et les réactions suscitées par cette évaluation pour vérifier l'hypothèse selon laquelle les organismes de gestion des pêches peuvent tirer des leçons des expériences antérieures. Dans l'un des cas étudiés, on a conclu presque immédiatement que l'expérience serait couronnée de succès; cependant, il a fallu une vingtaine d'années à l'organisme de gestion pour évaluer le rendement des cinq autres installations. Trois de ces cas ont abouti à des conclusions ambiguës. Seules les installations qui fonctionnaient très bien ou qui ont subi un échec total ont donné lieu à des conclusions précises. Le ministère des Pêches et des Océans (MPO) du Canada a expérimenté, évalué et analysé la conception, la construction et l'exploitation de frayères artificielles. Il semble que MPO réussisse moins bien à interpréter l'évaluation de la production de spécimens adultes dans des frayères artificielles. Les recherches s'avèrent plus fructueuses lorsque les objectifs sont clairement définis, lorsque l'on peut effectuer les expériences et les évaluer rapidement, et lorsqu'il existe un lien organisationnel étroit entre les décideurs, les évaluateurs et les exploitants.

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One of the key tenets of fisheries management is that we learn by experience: we believe that a management action which results in a good outcome is more likely to be repeated than a management action which results in an undesirable outcome. The critical components of such learning — evaluation and response — may be difficult, but they are, in theory, possible.

The purpose of this paper is to examine institutional learning in one particular circumstance, the construction, operation, and management of artificial spawning channels for sockeye salmon (*Oncorhynchus nerka*) in British Columbia. Spawning channels were chosen as a case study of institutional learning because (1) they involve a very discrete well-defined decision: to build or not to build, (2) spawning channels have been intensively evaluated and the evaluation has often appeared in the primary literature, and (3) the design, construction, and evaluation have all taken place almost exclusively within a single government agency, the Canadian Department of Fisheries and Oceans (DFO).

I will examine the history of spawning channels to answer the following questions: (1) how were channels evaluated, (2) how clear was the evaluation (did clear yes/no answers emerge from the evaluation), (3) how long did it take to obtain reliable evaluation results, and (4) did the results of the evaluation affect subsequent decisions?

Spawning channel technology will be used to illustrate the problems and potential of institutional learning — the focus of this paper is not about spawning channels, but on how fisheries agencies learn from experience. Nevertheless, in the process of asking about institutional learning, I will address several key questions specific to spawning channels. In particular I will ask whether, given our present knowledge, spawning channels do appear to be an effective way to increase the harvest of sockeye salmon and whether DFO designed and implemented an effective evaluation program.

History of Sockeye Spawning Channels

Sockeye salmon spawn in rivers and streams adjacent to lakes, and in some systems in gravel areas of lakes themselves. The eggs are deposited in the fall, and alevins emerge from the gravel in the spring. They then migrate to the lakes, normally downstream by passive drift, but in some areas by upstream migration. The juveniles usually spend 1 or 2 yr in the lake and then smoltify and migrate downstream to the ocean, where they may spend 1–3 yr. Spawning channels for sockeye salmon were developed in the 1960s as a means of increasing the production

[1]Contribution No. 841, School of Fisheries WH-10, University of Washington, Seattle, WA 98195, USA.

FIG. 1. Map of British Columbia showing the location of the eight spawning channels mentioned in the text.

of fry to the rearing lakes. A spawning channel is an artificial river with regulated flow, gravel size, and spawner density. Channels are normally constructed as a serpentine set of loops, bulldozed on a graded area, with gravel added, and some form of flow control structure to provide water. In some cases the spawning channels were built to compensate for degraded spawning habitat or in areas subject to flooding and in others areas simply to utilize the apparent underutilized rearing capacity of lakes.

Six channels built in the 1960s and early 1970s (Table 1) provide almost all of the information used in this paper. These include three channels (Weaver Creek, Gates Creek, and Nadina River; Fig. 1) built by the past International Pacific Salmon Fisheries Commission (IPSFC) and now operated by DFO. The Weaver Creek channel was built because of deteriorating river conditions resulting from logging in the watershed (Cooper 1977). The Gates Creek channel was also built to compensate for apparent deterioration of the natural stream. The Nadina channel was built to add fry to the apparently underutilized Francois Lake. The three channels built by DFO on streams adjacent to Babine Lake on the Skeena River constitute the Babine Lake Development Project (BLDP). This project grew out of biological studies (Johnson 1956, 1958) which indicated that Babine Lake was underutilized by sockeye juveniles because of limited spawning beds near the lake. Information from these six channels and two channels built in the late 1980s is given in Table 1.

The basic assumption behind a spawning channel is that producing more fry will result in more fish available to be caught. This, in turn, requires four assumptions (McDonald and Hume 1984): (1) artificial channels can produce additional fry, (2) the viability of channel fry would be comparable with that of fry produced naturally, (3) the lakes have capacity to support a larger juvenile population, and (4) an increase in the juvenile output from the lake would result in a corresponding increase in the number of returning adults.

TABLE 1. Location, year built, size, flow, and velocity of sockeye spawning channels in British Columbia.

Channel name	Rearing lake	Year complete	Spawning area (m^2)	Flow (m^3/s)	Velocity (m/s)
Fulton I	Babine	1965	11 426	2.67	0.43
Fulton II	Babine	1971	73 154	3.60	0.52
Pinkut	Babine	1968	33 442	2.34	0.37
Weaver	Harrison	1965	17 429	0.67	0.27
Gates	Anderson	1968	10 995	1.26	0.31
Nadina	Francois	1973	18 131	1.78	0.35
Chilko	Chilko	1988	8 565	2.70	0.38
Horsefly	Stuart	1989	15 456	1.68	0.34

Methods of Evaluation

The biological effects of a spawning channel can be assessed by examining the numbers and quality of the fish produced from the channel and their impacts on numbers and quality of naturally produced sockeye from the associated lake and river system. In practice this means counting the number of adults entering the channel, counting the fry leaving the channel, counting smolts resident in or leaving the rearing lakes, and assessing the subsequent return of adult sockeye to catch and escapement.

Spawners to Fry

All spawning channels have means to limit and count the number of fish entering the channel. Because sockeye spawners are sexually dimorphic the number of females and males is recorded. Females are sampled for fecundity and carcasses are examined for egg retention, enabling estimates of total egg deposition.

Channel operators can, in theory, also control flow, gravel size, and gravel cleaning method and frequency. In practice, flow and gravel size are rarely modified once a channel is constructed, so choice of spawning density and of gravel cleaning frequency and method are the two major decisions facing a channel operator. Several channels have also had postconstruction engineering modifications to reduce sediment deposition.

Fry to Smolt

Once the fry leave the channel, evaluation of channel production becomes very difficult. In all systems, the channel fry mix with naturally produced fry. In the Babine system, smolt output from Babine lake has been measured; estimates of total natural fry production have been made, and detailed marking studies of survival of channel produced fry have been performed (Coburn and McDonald 1972; McDonald and Hume 1984). There have been no fry to smolt studies in any of the IPSFC channels; estimates of fry production from natural stream spawning have been made (Cooper 1977), but smolts have never been counted.

Smolt to Adult

Adult production of sockeye is the sum of the spawning escapement and the catch. Escapement is estimated for all major sockeye systems, usually by some form of visual counting. Allocation of catch to stock of origin is difficult, particularly from the many mixed-stock fisheries that take place on sockeye. Fish returning to the Babine system are captured in several fisheries in British Columbia and southeast Alaska. Various methods for determining the number of Babine fish caught in these fisheries have been developed (Starr et al. 1984; West and Mason 1987; Starr and Hilborn 1988). These methods, known as run reconstruction, use information about run timing and migration pattern to determine stock contribution.

Fraser River sockeye salmon are caught throughout southern British Columbia and northern Puget Sound. The IPSFC developed a scale pattern recognition system for identifying area of origin of Fraser River fish, but this system is not of sufficient accuracy on a small spatial scale to distinguish the fish from spawning channels from the sockeye produced from natural populations in the lake with the channel. Therefore, evaluation of adult returns to the IPSFC channels have been based solely on escapements.

Evaluation of Babine Channels

Evaluation of the Babine channels was much more thorough than the IPSFC channels. The Babine channels were conceived by researchers and have always had a major research component; the IPSFC channels were conceived as production facilities with little if any research components. The published evaluation history of the Babine projects is found primarily in six papers; McDonald (1969), Dill (1970), Ginetz (1977), West (1978), Mcdonald and Hume (1984), and West and Mason

TABLE 2. History of published evaluations of the Babine channels. An × indicates that the topic was treated in the paper; weak indicates that the topic was mentioned but not examined in any depth.

Topic	McDonald (1969)	Dill (1970)	Ginetz (1977)	West (1978)	McDonald and Hume (1984)	West and Mason (1987)
Spawner density			×	×		
Fry production	×	×	×	×		
Smolt production				Weak	×	×
Adult production						×
Cost benefits						Weak

(1987). Four of these six papers evaluate only one or two of the six possible topics, and fry and smolt production are the topics most commonly evaluated; stock interaction and benefit: cost ratios are weakly evaluated in any paper (Table 2).

Spawner Density

In most channels, egg to fry survival decreases as the density of spawners increases. Higher spawner densities tend to produce more fry, but have also been associated with outbreaks of infectious haematopoietic necrosis (IHN). Determination of the best spawner density has been an active topic of discussion and experimentation since the first year of channel operations (Ginetz 1977) and remains so today. For most channels there has been a general downward trend in survival over the years, which has also normally been associated with increasing spawner density. The density-dependent egg to fry survival results in a rather wide range of spawner densities that produce roughly the same number of fry. The first two major evaluations of the BLDP were by Ginetz (1977) and West (1978), both of whom were concerned almost exclusively with spawner density and fry production.

Fry Production

The first key question in evaluation of spawning channels was the ability to produce fry of good quality. The number of fry produced was available as soon as the channels went into production; the fry were counted out of the channel the spring after spawning. Biological experiments on relative viability and survival of channel fry were performed as soon as Fulton I began operating (1965) and were published in journals by 1969 (McDonald 1969; Dill 1970; Payne 1971; Ginetz 1972; Scarsbrook and McDonald 1970, 1972; Coburn and McDonald 1972, 1973). All of these studies indicated that the channel fry were as viable as natural fry. Fry production is closely tied with spawner density and outbreaks of disease mentioned above, and fry production was extensively reviewed in Ginetz (1977) and West (1978).

Smolt Production

The next stage in evaluation was smolt production; channels could put fry into the lake, but would this result in additional smolts leaving the lake? Ginetz (1977) did not address smolt production. West (1978) was chiefly concerned with the success of fry production and only considered smolt output in the last three pages of his 100-page report. Smolt production from brood years 1972–75 was disappointing (Fig. 2) and indicated that there might be a serious problem with the assumption that more fry into the lake meant more smolts out. West concluded in his abstract, "When large numbers of fry are produced, however, the smolt output has been found to be less than anticipated."

Thirteen years after the first channel began operations, the initial evaluation of smolt production was discouraging. Later evaluations (McDonald and Hume 1984; West and Mason 1987) examined smolt production with the benefit of additional years of data and both showed that increased fry into the lake did result quite clearly in more smolts leaving the lake.

Adult Production

Not until the mid-1980s did DFO biologists ask if more adults were being produced because of the BLDP. The adult production story was more complex than that for fry and smolts.

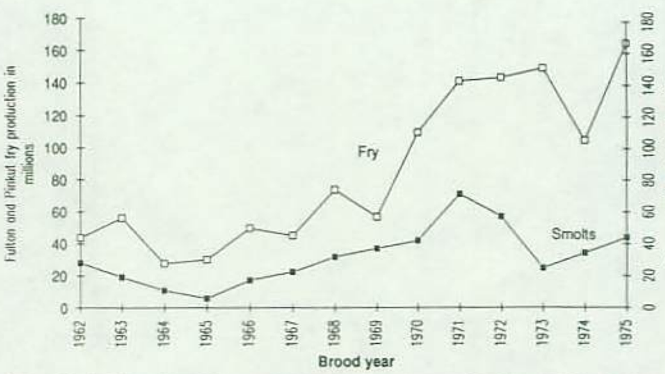

FIG. 2. Babine fry and smolt production from 1962 to 1975. Redrawn from fig. 39 of West (1978).

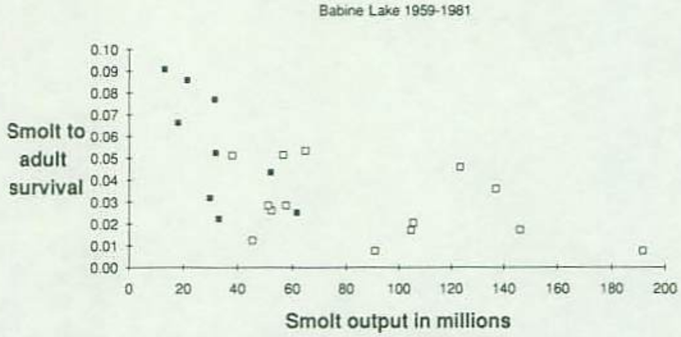

FIG. 3. Smolt to adult survival for Babine sockeye brood years 1959–81. Solid points indicate years before the BLDP; open points are years after BLDP. Data from Macdonald et al. (1987).

Peterman (1978) had published DFO data showing that smolt to adult survival decreased as total smolt numbers increased, thus greatly reducing the anticipated number of adults returning. The data were available in 1978 to examine total adult production, but no one associated with the BLDP was doing such evaluation. The smolt to adult survival versus smolt output data (Macdonald et al. 1987) are shown in Fig. 3.

Neither McDonald and Hume (1984) nor West and Mason (1987) chose to actually plot the adult production data. McDonald and Hume (1984) plotted log smolts versus log adults for even and odd years, and they showed that in odd years there seemed to be a more or less proportional increase in adults for an increase in smolts, while in even years there was no apparent increase. West and Mason (1987) estimated average annual production from the BLDP and all Skeena River stocks for the pre-BLDP period (calendar years 1958–71) and post-BLDP period (1973–85) (Table 3). They estimated that the annual Skeena River total return (Canadian and U.S. catch and escapement) fisheries in the post-BLDP period was 2 453 000 fish, with a net increase of 1 009 000. This was calculated by taking total returns for calendar years 1958–71 and comparing them with total returns for calendar years 1973–85. West and Mason (1987) did not present the year by year data.

Macdonald et al. (1987) presented brood year returns (not including Alaska catch) from brood years 1943–81. The average total return does now appear to be higher in the post-1968 period than before the BLDP (Fig. 4), but using the Macdonald et al. (1987) data the difference between pre-BLDP (1958–68) and post-BLDP (1970–81) is 832 000. Henderson and Diewert (1990) have reconstructed the Skeena River sockeye run from brood years 1965–82 using several methods, all of which include U.S. and Canadian catches, and their estimate of the increase from brood years 1965–68 to brood years 1970–81 is

TABLE 3. Annual pre- and post-BLDP adult sockeye production. Data from West and Mason (1987). All numbers in thousands.

Where adults ended up	Pre-BDLP (1958–71)		Post-BDLP (1973–85)		Skeena increase
	Babine	All Skeena	Babine	All Skeena	
Alaska fisheries	20	77	86	152	74
CDN fisheries	192	693	740	1318	625
Escapement	146	674	534	983	310
Total	358	1444	1360	2453	1009

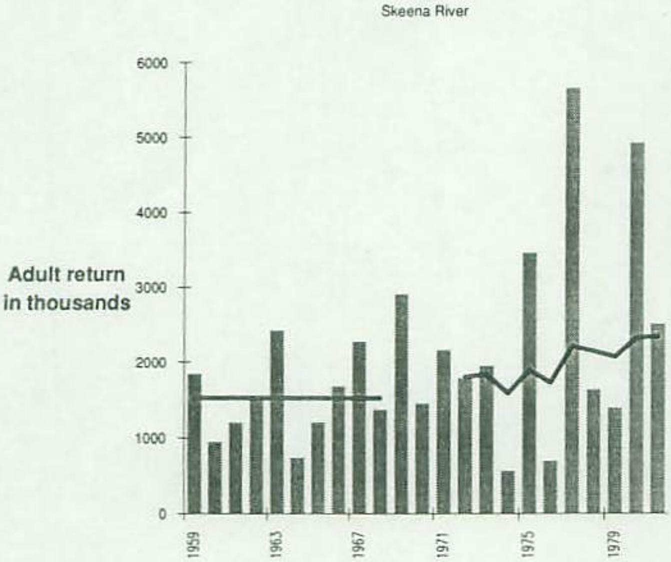

FIG. 4. Total return (Canadian catch plus escapement) of sockeye salmon to the Skeena River by brood year. The solid line before 1969 represents the pre-BLDP average total production; the solid line after 1970 is the running average after 1970. Data from Macdonald et al. (1987). The "postchannel" average return is therefore the solid line for brood year 1981.

540 000 or 750 000, depending upon which method they used. None of these estimates is directly comparable, since West and Mason (1987) used calendar year returns, Macdonald et al. (1987) did not include U.S. catches, and Henderson and Diewert (1990) only began in 1965. Nevertheless it is clear that the total return to the Skeena has increased since the BLDP by somewhere between 500 000 and 1 000 000 fish.

In asking whether the BLDP produced the additional fish, should we simply accept the 1 million estimate? It is not at all clear. This assumes that in the absence of the BLDP, the Skeena and Babine production would have stayed the same. Is this a reasonable assumption?

There are at least two reasons this may not be reasonable. First, the pre-BLDP period was one of recovery from the landslide of 1951, which reduced Skeena stocks to their lowest levels in history (Larkin and Mcdonald 1968). A major slide into the Skeena River had partially blocked upstream passage, and escapements in the first few years thereafter were reduced. In response, DFO reduced harvest pressure, and the trend in abundance post-1951 was one of increase. This trend might have continued even if the Babine channels had not been built. For this reason, the estimates of post BLDP production from the Henderson and Diewert (1990) data (which use only post-1965 data) are lower than the estimates from West and Mason (1987). Second, a greater challenge to the before and after BLDP comparison is that the largest sockeye producing systems in the U.S. and Canada also showed significant increases in abundance in the 1970s and 1980s.

Bristol Bay Alaska and the Fraser River are the number 1 and number 2 sockeye producers in North America and both showed proportional increases similar to or greater than the Skeena in the pre- and post-BLDP periods (Fig. 5). One could argue that the Babine has gained no production in comparison with the other large sockeye-producing systems over the same period. I believe we cannot determine how effective the BLDP has been at producing additional sockeye. In the absence of controls, we do not know what would have happened if the channels were not built (and we never will).

Economic Benefits

There remain the questions of net economic benefits (benefit:cost ratio), interaction with other stocks, and effects of increased production on price. West and Mason (1987) addressed all of these questions briefly. They presented some simple benefit:cost numbers to indicate that given an estimate of 600 000 extra fish in the catch (1 000 000 increase in return), the benefit:cost ratio was 3:1, although little documentation for this was provided. In particular, almost all of the extra production came from two brood years, 1977 and 1980. West and Mason (1987) suggested that the benefit:cost ratio was calculated based on an extra \$5.5 million in landings every year in the post-BLDP period. Since the actual increase in production did not occur until about 15 yr after the construction was begun, a more rigorous benefit:cost evaluation (one including discounting for instance) might produce a much lower ratio. Mcdonald and Hume (1984) presented no analysis of cost effectiveness. Essentially there has been no documented evaluation of the cost effectiveness of the BLDP.

Impacts on Other Stocks

West and Mason (1987) also examined the impacts of the BLDP on non-Babine stocks. They showed that non-Babine stocks declined 40% in the post-BLDP period. This was felt to be due to the reduced ocean survival of all Skeena fish due to large smolt migrations and, for some non-Babine stocks, higher harvest rates associated with fisheries on the larger Babine runs. However, since the Babine stocks constituted over 90% of the Skeena sockeye stock before the BLDP, the decline in non-Babine stocks is not a major factor in total Skeena production. It is, nevertheless, a serious concern for local fishermen, particularly subsistence fishermen on the affected non-Babine stocks. Decline of non-Babine stocks is also of great concern for long-term conservation — few biologists would be comfortable with the loss of the non-Babine stocks.

No one has addressed possible decreases in price due to increased production from the Babine, but given the small pro-

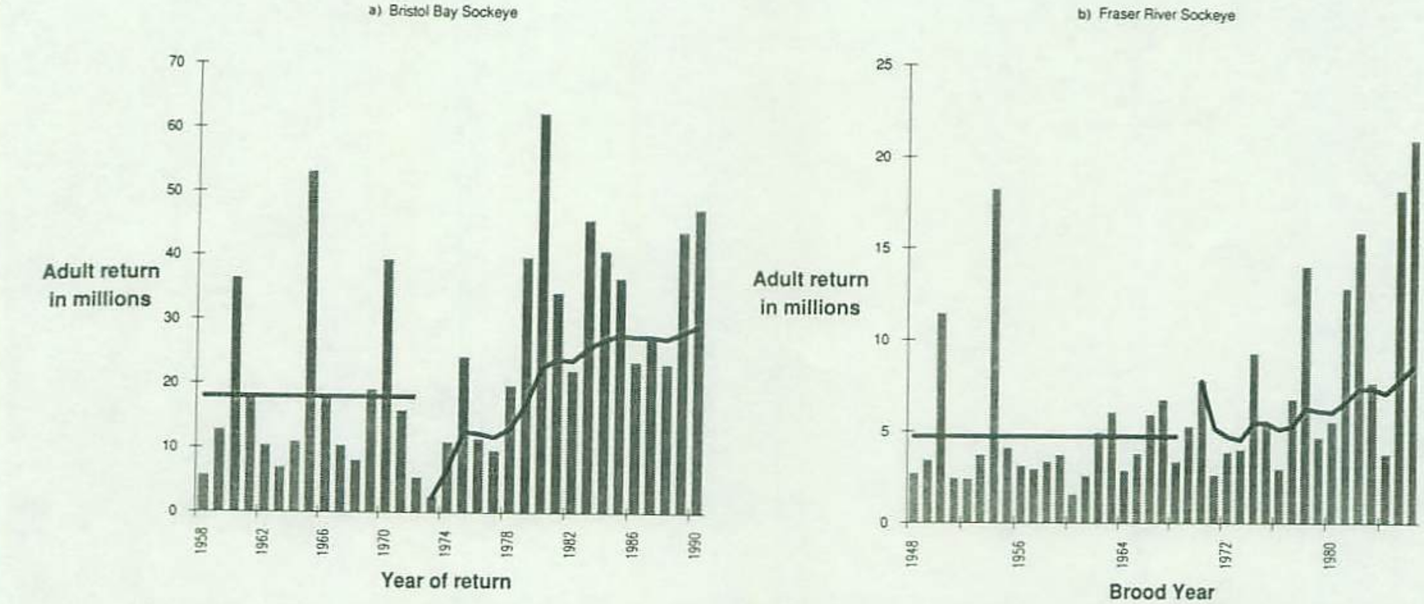

FIG. 5. Total returns (catch plus escapement) of sockeye salmon to (a) Bristol Bay Alaska and (b) the Fraser River. The solid lines are pre-1969 brood year average return and post-1970 brood year running average return to correspond with a similar format in Fig. 4. The Bristol Bay data are by year of return; the Fraser River data are by brood year.

portion of North American sockeye produced by the Skeena, any price depression would likely not be great, and in fact the price of salmon in the late 1970s increased. However, since almost all of the benefits of the BLDP have come from three large return years, there may have been local swamping of processing capacity in those years causing a local reduction in price.

IPSFC Channels

Evaluation of the IPSFC channels has been much less intense than the BLDP channels. Spawning input and fry output are monitored, as is escapement to natural streams. There have been no studies of fry viability or smolt production. The only published evaluation was by Cooper (1977), who reviewed the performance of all of the IPSFC spawning and incubation facilities for sockeye and pink salmon (*O. gorbuscha*). An extensive review of the IPSFC pink and sockeye facilities was contracted by the Salmonid Enhancement Program (SEP) in 1985 and was provided to me by SEP staff.

Cooper (1977) showed that all three channels had produced the expected numbers of fry, but the adult production picture is much different. The Weaver Creek channel has done very well, the escapement now being 47 087 fish larger than it was before the building of the channel (Fig. 6). In contrast the Gates and Nadina channels show much smaller increases in the escapement (8554 at Gates and 16 385 at Nadina); in comparison with Weaver Creek, they are disappointing. It is possible, of course, that the total runs have increased much more than shown by escapement because selective fishing on these stocks might have kept the escapement low, but there is no documentation of such stock-specific increases in fishing pressure.

My evaluation of the IPSFC channels is shown in Table 4. For Weaver Creek, the prechannel (1962–68) escapement was 13 904 and the postchannel escapement 60 991. The net increase in escapement is therefore 47 087. The exploitation rate for Fraser stocks averages about 80%; therefore, there are five additional fish in the adult return for every additional fish in the escapement.

However, there has been an increase in all Fraser stocks, and from 1969 to 1985 the Fraser returns were 1.37 times the average returns from the period 1962–69. The following equation was used to calculate the increase in adult production:

$$\text{Increased adults} = \left(\frac{\text{escapement after}}{\text{increase in Fraser}} - \text{escapement before}\right)\frac{1}{(1 - \text{harvest rate})}.$$

The escapement after channel construction divided by the increase in all Fraser River stocks during this period is an estimate of the escapement corrected for the overall trend in escapements on the Fraser. Subtracting the escapement before channel construction provides an estimate of the net increase in escapement due to channel construction. This is divided by 1 minus the harvest rate to estimate total adult production caused by channel construction. Table 4 shows these calculations for the three IPSFC channels. The numbers for Weaver Creek in Table 4 show why it is considered such a success, over 200 000 fish a year produced per year (at a value of over $10 per fish) for a few hundred thousand dollars investment. Table 4 also shows pre- and postchannel average wild escapement. For Weaver Creek the postchannel wild escapement was 22 124 higher than the prechannel escapement.

Table 4 shows that Gates and Nadina are much more disappointing. While both channels have shown an increase, even after adjustment, the increases are very small, and for both systems there has been a major drop in the wild spawners. There has always been a problem getting fish into Nadina to spawn, and only once in its history has it been fully loaded. The estimated increases in adult production of 12 134 at Gates and 17 703 at Nadina are much less than anticipated and reflect the almost total failure of these channels to increase adult production.

Cooper (1977) included a benefit:cost analysis of the channels. Unfortunately it is impossible to understand how the adult production was calculated, but he gave benefit:cost ratios for

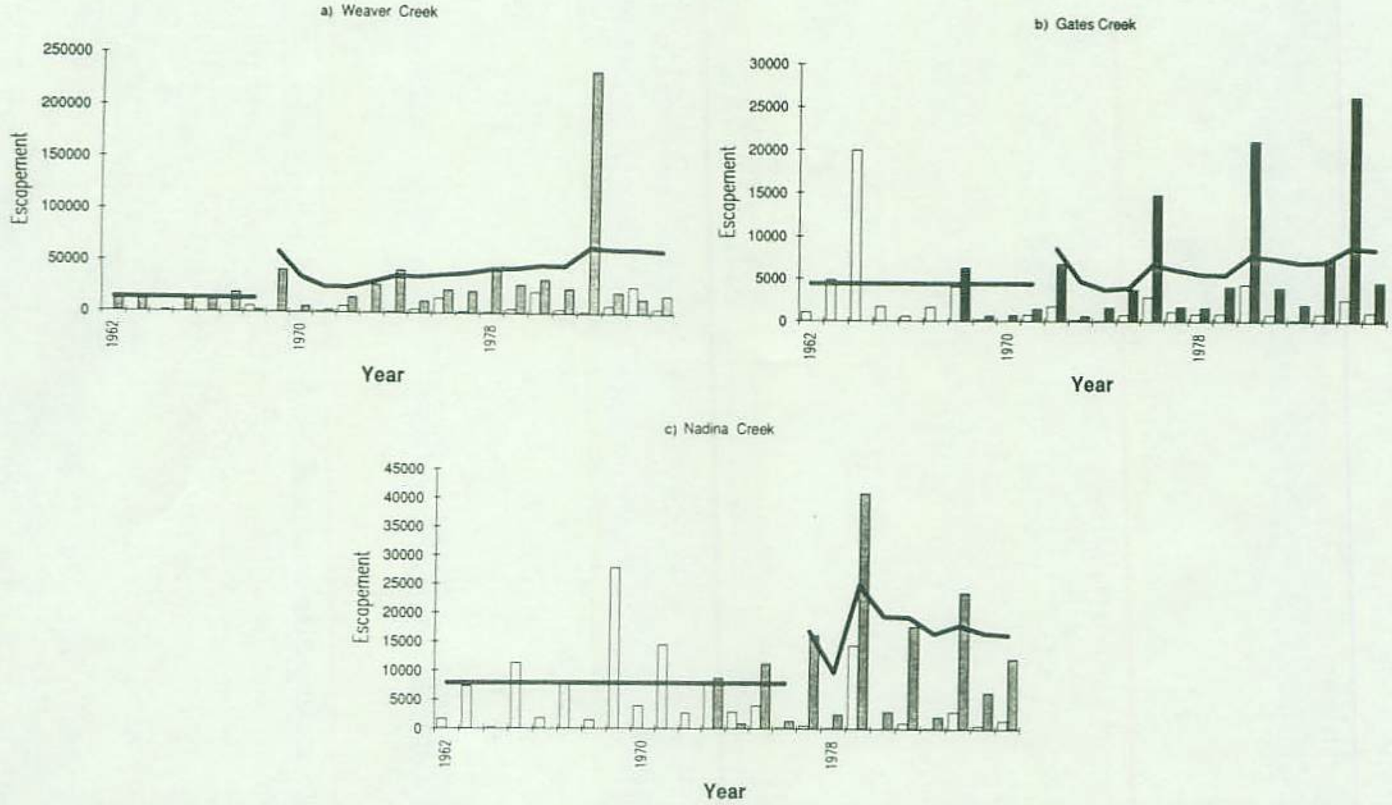

FIG. 6. Escapement to the (a) Weaver Creek, (b) Gates, and (c) Nadina channels on the Fraser River. Solid vertical bars are natural spawners; open vertical bars are fish spawning in the channels. Note that the "postchannel" average escapement is the height of the solid line on the far right-hand edge of the graph.

TABLE 4. History of channel production from Fraser River spawning channels, calendar years 1962–85.

	Weaver	Gates	Nadina
First year of channel loading	1965	1968	1973
First year of channel return	1969	1972	1977
Prechannel average escapement	13 904	4 408	7 880
Postchannel average escapement	60 991	8 554	16 385
Ratio of pre- to postchannel	4.39	1.94	2.08
Unadjusted increase in escapement	47 087	4 146	8 505
Increase in all Fraser stocks in same period	1.37	1.39	1.63
Adjusted increase in escapement	41 943	2 427	3 541
Adjusted increase in total adult production	209 713	12 134	17 703
Postchannel average wild escapement	36 028	1 349	2 422
Net change in wild stock	22 124	−3 059	−5 458

Weaver Creek of 9:1 and for Gates Creek of 2:1. No benefit:cost ratio was given for Nadina. These calculations are totally undocumented. The consultant's report did not address adult production.

Do the Results of Evaluation Affect Subsequent Decisions?

The published evaluations discussed above are only part of the evaluation process; they are the tip of a very large iceberg of studies, data reports, manuscripts, and personal opinion. I have concentrated on the published records because they are publicly available and easily obtained. When we ask if the results of evaluation affect subsequent decisions, we must deal not only with the published evaluations, but with personal opinion. In addition to examination of published reports, I have held formal and informal interviews and discussions with most senior SEP staff and many DFO biologists inside and outside of SEP.

Consensus about Historical Performance

Fortunately, there appears to be remarkable agreement among salmon biologists and engineers about the effectiveness of channel technology for sockeye. In January 1990, the University of Washington sponsored a workshop on spawning channel technology for sockeye, aimed at utilizing the lessons of British Columbia channels for application to a proposed channel in Washington (Hilborn 1990). Six DFO biologists were present who had extensive experience with channels, including former IPSFC staff, DFO research scientists, and DFO evaluation biologists. The discussion revealed general agreement that (1) Weaver Creek was an unqualified success, (2) the BLDP had produced additional adult sockeye, but the exact number was uncertain, and (3) Gates and Nadina were almost total failures at increasing the return of adults. Some facilities worked, and some did not.

The less than anticipated increase in Skeena River production from the Babine channels is primarily due to the lower smolt to adult survival that has occurred as smolt production increased. There has been some loss of non-Babine stocks, but most of the problem seems to have been with the smolt–adult survival. Despite the large increases in smolt production, only three brood years (out of 12 considered) have produced significantly improved adult returns. There was some suggestion (Peterman 1978) that this could be an interaction with pink salmon, but West and Mason (1987) pointed out that the apparent difference between even and odd broods shown in McDonald and Hume (1984) had not been supported by data that became available between 1984 and 1987. In short, no one has any idea how to improve production from the Skeena system — smolts have been produced as planned, but adults are not returning at the expected rate.

DFO biologists associated with the BLDP suggested that if there had been more evaluation at Gates and Nadina, particularly if fry survival and smolt numbers had been measured, we might know why there had been no increases there. For instance, if there is a problem with the in-lake growth or survival, whole-lake fertilization and predator control are possible remedial actions. However, in the absence of any postfry studies, no one knows why these two channels have been so unsuccessful.

Using Prior Experience

Let us now see if the information gained from evaluation was actually used. Spawning channels are a comparatively simple technology, and I will concentrate on three decisions: (1) how to clean the gravel, (2) how many fish to put in, and (3) if, when, and where to build additional channels.

Improving channel operation

There are many design and operational decisions to make when building and operating a channel such as choosing gravel size, flow, gradient, width, bottom material, etc. Once a channel is built and operational, almost all of these are fixed. Gravel cleaning is probably the most difficult operational problem for channel operators; the accumulation of silt, debris, and pathogens in the gravel is widely acknowledged to cause declines in egg to fry survival as channels age. Both DFO and the IPSFC (while it operated the Fraser channels) spent considerable time and money working on gravel cleaning. It is not yet clear if a completely satisfactory gravel cleaning technology has been developed. Most methods tend to redistribute the gravel with smaller particles dropping towards the bottom, and all methods cause significant sediment discharge that may pose water quality standards problems. It is uncertain if current cleaning methods can reverse the declining egg to fry survival rates seen in many channels. However, channel cleaning does show a very healthy level of experimentation, evaluation, and discussion.

Determining how many spawners to allow in a channel involves a trade-off between more eggs deposited and generally lower egg to fry survival as spawning numbers increase. Channel operators have experimented with different spawner densities and found that egg to fry survival decreased at higher densities. This issue is one of the main questions that Ginetz (1977) and West (1978) addressed. Generally, channel operators have chosen to load the channels at a lower density than would produce the maximum fry output because of concern about disease. IHN has been a problem in some years in several spawning channels (Traxler and Rankin 1989), and this has caused concern with channel operators.

The two operational decisions discussed above, channel cleaning and spawner densities, involve an evaluation–decision structure that works well for three reasons. First, the objective is quite clear — to produce good quality fry in large numbers. Second, the decisions can be quickly evaluated, since the number of fry is measured about 6 mo after the cleaning or spawner density decision is made. There is rapid feedback between decision and result. Third, all the decision and evaluation steps are taken within the channel facility, so that the same people who run the facility are involved in the assessment of fry production.

Predicting production for proposed projects

Do the results of evaluation affect the decisions to build additional spawning channels? The only two sockeye spawning channels that have been built since the completion of the BLDP are the Chilko River channel completed in 1988 and the Horsefly River channel completed in 1989. These are both relatively small channels, 8000 and 15 000 m^2, relative to the much larger Fulton II (73 000 m^2) and Pinkut (33 000 m^2). The 17-yr gap between completion of the last BLDP facility and the Chilko River channel provided time to conduct and act on the evaluations. Did DFO learn from the experience of the BLDP and IPSFC channels?

Within the realm of design, construction, and operation the answer appears to be yes. Discussions with DFO staff indicate that the design and construction process went very well — what had been learned in design and operations of the existing facilities was well incorporated into the Chilko and Horsefly channels.

The decisions to actually build the Chilko and Horsefly channels indicate much less learning. SEP maintains a list of "Bio-engineering Standards" which are assumptions regarding anticipated survival through different life stages. The biological standards published for sockeye spawning channels are 24.2 adults/m^2 of gravel in the Fraser and 10.8 adults/m^2 in non-Fraser areas. We might expect these standards to reflect the evaluation experience from the published papers discussed earlier.

Remarkably the standards appear to differ considerably from observed data (Table 5). For BLDP, West and Mason (1987) estimated additional production of 1 009 000 adults. This total divided by the area of the three BLDP channels provides a production estimate of 8.55 adults/m^2 whereas the SEP biostandard is 10.8 adults/m^2. Earlier I discussed several reasons why 1 009 000 may be optimistic, but even given this number the current SEP biostandard is too high.

On the Fraser, the biostandards are even more difficult to understand. I have used the adjusted adult production numbers from Table 4. Based on the three Fraser River experiences the average production rate would be 5.15 adults/m^2. The SEP biostandard is 4.7 times that number and twice the Weaver Creek results.

SEP staff told me that the sockeye channel biostandards were derived by taking observed fry per square metre and multiplying by literature values for average fry to smolt and smolt to adult survivals for Fraser and non-Fraser stocks. This means that the observed fry production from Gates and Nadina was multiplied by average Fraser River survivals to produce expected adult production. This method of calculation overestimates production for Gates, Nadina, and all three Babine

TABLE 5. Observed production from existing channels and SEP biostandards.

Project	Total area (m^2)	Adult production	Adults (no./m^2)		Ratio SEP/observed
			Observed	SEP biostandard	
Fulton I	11 426				
Pinkut	33 442				
Fulton II	73 154				
BLDP total	118 022	1 009 000	8.55	10.8	1.26
Weaver	17 429	209 713	12.03	24.2	2.01
Gates	10 995	12 134	1.10	24.2	21.93
Nadina	18 131	17 703	0.98	24.2	24.79
All Fraser	46 555	239 550	5.15	24.2	4.70

channels. This method says that Gates and Nadina were great successes. The SEP biostandards were used in estimated anticipated benefit:cost ratios for the Chilko and Horsefly channels, therefore overestimating the anticipated benefits by a factor of 4. Thus the results of the adult evaluation have not been used in the planning criteria for subsequent channels.

Providing for performance evaluation of new projects

A second area where there appears to be a failure to learn from experience is in planning for evaluation. All previous channels appear to produce fry successfully; when problems occur they are either in smolt to adult survival (the BLDP case) or at some unknown life history stage after the fry (Gates and Nadina). If we examine the Chilko and Horsefly channels we find little evidence that this lesson has been absorbed.

First and foremost, both of these channels have been built in very successful existing sockeye runs (the 1989 adult production from the Horsefly was over 10 000 000). Even assuming that the Horsefly channel is as successful as planned, it would produce 200 000 to 300 000 adults, a level of production that would likely be indistinguishable from the natural production. Similar problems are found at Chilko, where the run is not quite as large, but does return in the millions, and is building. Therefore, if density-dependent smolt–adult survival is a problem in these systems (as it was in the Babine), these channels will probably never make any contribution, and furthermore, they can never be evaluated.

Not only will the adult production be impossible to evaluate, but because both the two new channels use intake water from streams with existing sockeye spawners, there will be naturally produced fry entering the channels, which will make it difficult to assess even egg to fry survival. I was told by several SEP biologists that evaluation of these facilities was not considered, and other biologists expressed great concern about the decision and design process for these two channels.

Discussion

Let us now return to the "big" question: do fisheries management agencies learn by experience? The examination of spawning channels shows that at one level the answer is yes. For operational decisions, the system works; decisions are monitored, the monitoring data evaluated, and the evaluation used in modifying subsequent decisions. Nevertheless, learning is slow. Considerable effort is still being expended on gravel cleaning methods, and there is lively debate about the appropriate spawner densities in channels.

At the second level — the decisions about when, where, and if more channels should be built — the picture is not nearly so clear. The results of the evaluations of the BLDP and IPSFC channels indicate that the success of a project is quite unpredictable. Attempts to increase fry numbers beyond historical levels (as in the Babine) may well encounter some form of density-dependent limit at later life history stages.

An examination of the decisions of DFO to build subsequent channels leads to the conclusion that the results of previous evaluations were not used to any great extent. The evaluation design of the Chilko and Horsefly channels shows little if any learning from past experience. I was told by several biologists that the decisions to build these two channels were driven by political and engineering concerns — the biologists were disregarded.

Perhaps the most useful lesson from examining the history of spawning channels for sockeye is the long time required for evaluation. It was nearly 20 yr before sufficient data were accumulated to enable an examination of the success of the BLDP channels to produce adult sockeye. Even after 25 yr, no clear answer has emerged. Given the natural variability and change common to most fisheries systems, evaluation is likely to take a very long time. Decision makers desiring a quick answer need to understand that it may take 20–40 yr before answers are available, and even then they may be ambiguous.

One of the most striking features of the evaluation history of the Babine projects is how long it took to ask if adult production was actually increased! Although consideration of the projects began in the early 1960s, and the channels came on-line in the late 1960s, it was not until 1987 (West and Mason 1987) that anyone actually directly addressed the question of increased adult production. For many years it appears that adult production was simply not of interest. The following quotation from Ginetz (1977, p. 125) reflects this apparent lack of interest of adult production: "The Babine Development Project was initiated on the basis of the following premises: (1) that the main basin of Babine Lake was underutilized and could support additional sockeye fry, (2) that these additional sockeye fry could be produced in artificial spawning channels and in natural streams with regulated flow, and (3) that the channel fry so produced are comparable to naturally produced fry in their ability to survive to the adult stage."

There is no mention in this quote that increased fry and smolt production might not lead to increased adult production. In his subsequent discussion, Ginetz (1977) argued that the evidence supports the three assumptions and that therefore the Babine Development was a success. Admittedly by 1977 there were few adult return years, but Ginetz never mentioned it. However, Peterman (1978) was able to look at adult production from the Babine system and concluded that smolt to adult survival declined as smolt numbers increased. These data were available to SEP biologists at the time but they did not choose to use them.

The same studious avoidance of adult production can be found in West (1978), Cooper (1977), and the unpublished consultant's report of 1985. While it did take 10 yr to accumulate sufficient brood year returns for evaluation, I believe the avoidance of consideration of adult production reflects "goal displacement" (Dowell and Wange 1986): the substitution of intermediate goals (fry production) for overall goals (adult production). The channel operators first and foremost want their channel to put fry out the gates of the channel. That is what they can measure, and so long as the channel can put out fry, their job is successful. A channel manager cannot assure that the fry find enough to eat in the lake, or avoid predators in the lake. Therefore there is a tendency to want to call a channel that produces fry a success. This rationalization is a natural phenomenon found throughout human behavior — the overall goal (adult production) is displaced by a simpler, more measurable goal (fry production).

The decisions to build the Chilko and Horsefly spawning channels might appear to indicate almost no learning from past experience about the success of spawning channels on the Fraser River. There is, however, another way to view this apparent lack of learning. The Pacific Salmon Treaty between the U.S. and Canada (ratified in 1985) set a ceiling on the U.S. catch of Fraser River sockeye. Previously under the IPSFC, the U.S. had been guaranteed half of the Fraser sockeye catch taken in convention waters. Canada had argued that it would not go ahead with enhancement activities on the Fraser so long as half of the benefits would accrue to the U.S.

Canada had promised its fishermen that if they made some short-term sacrifices, the U.S./Canada treaty would provide long-term benefits because of Fraser River enhancement. Having signed the treaty, DFO needed to show some enhancement on the Fraser. The Chilko and Horsefly channels are the major part of this enhancement. When DFO took over from the IPSFC, it was clear that spawners and fry production had been limited in many parts of the Fraser. There are few technologies available to enhance sockeye, and the Weaver Creek channel was successful. SEP staff argued that spawning channels were the best available artificial technology to enhance Fraser sockeye. I believe this is consistent with the evaluations.

Thus not only is the evaluation of spawning channels often ambiguous, the evaluation of the evaluation is equally ambiguous. On the one hand the biostandards used in planning do not reflect the results of evaluation. On the other hand, SEP now recognizes that part of its mandate is to enhance the Fraser, and the results of the evaluations do indicate that the spawning channels for sockeye are probably the best technology available. The only alternative sockeye technology used in British Columbia is lake enrichment, which has been used to increase juvenile growth in coastal lakes and is untried in the Fraser basin.

Has SEP learned from experience? The answer is yes, and perhaps no. Learning is most effective when goals are clearly defined, experiments can be conducted rapidly, and evaluation staff and decision makers are closely integrated. Decisions involving design and operation of spawning channels meet these conditions quite well, while the planning for further SEP activities does not.

The work on spawning channels described in this paper is part of a large project looking at other SEP technologies, and we are now examining learning in hatchery production for (*O. tshawytscha*) and coho salmon (*O. kisutch*) and in lake enrichment for sockeye salmon. This is work currently in progress.

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