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Transplanting Pacific Salmon

— good reviews glacier history & distribution

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TRANSPLANTING PACIFIC SALMON

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ABSTRACT

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Changes in Pacific salmon distribution before and after man's intervention demonstrate that salmon are as remarkable for their ability to invade new territory as they are for their ability to home to their place of birth. Since the late 1800s man has been transplanting Pacific salmon into barren waters for the purpose of establishing new self-sustaining runs. Review of the many transplant attempts shows that occasionally salmon introduced to regions outside their native range will survive and establish new and persistent stocks. For example, chinook salmon from eggs imported from California in 1901 have persisted on New Zealand's South Island for 80 years. Pink salmon fry from eggs tranferred over several years from Sakhalin to hatcheries on the Kola Peninsula have founded self-sustaining runs there and perhaps further along the coast of northern Europe. Coho, chinook, and pink salmon have become established in the Great Lakes and maintain themselves either without hatchery assistance (pinks) or with some (coho, chinooks).

Transplants within the Pacific salmons' normal range have been singularly unsuccessful in producing new anadromous stocks, except where natural colonization has been prevented by an obvious physical barrier. In only one of many transplants into watersheds where there was no physical obstruction to upstream migration has a new run developed: sockeye fry and fingerlings of Skagit River origin planted in 1937 in Issaquah Creek (Lake Sammamish) and Cedar River (Lake Washington) developed into self-perpetuating runs.

Where a physical barrier has been removed or circumvented to permit either initial colonization or reinvasion, substantial new stocks have sometimes become established. A major sockeye run now occupies the Frazer Lake (Alaska) watershed following construction of a fishway around an impassable falls and concurrent plantings of eggs, fry and adults from adjacent systems. Occupation by pinks of upriver portions of the Kakweiken River has coincided with years in which a fishway permitted passage around a normally impassable falls. Fraser River pink salmon now numbering millions have re-established themselves by re-invasion of areas above Hell's Gate, where the slide of 1913 completely barred them from upriver spawning grounds.

On the basis of the past record of natural and man-directed colonizaton of new territory, most success from transplanting can be expected where access to unused spawning and rearing areas can be provided by circumventing obvious barriers to upstream migration. Whether transplanting truly accelerates occupation of the new territory is not known since no objective tests have been made. In situations where obstacle removal or circumvention is too costly, it may be justifiable to seed inaccessible areas by transplanting on an annual basis. To be most effective all attempts to utilize new territory should be part of an overall stock management scheme

which provides adequate escapement with which to populate the new territory.

Key words: Pacific salmon, sockeye, pink, chum, coho, chinook, transplants, invasion, colonization, glacial history.

RESUME

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Les changements de la répartition du saumon du Pacifique avant et après l'intervention de l'homme révèlent que le saumon est aussi remarquable par sa capacité d'envahir de nouveaux territoires que par sa capacité de revenir au ruisseau natal. Depuis la fin des années 1800, l'homme a transplanté le saumon du Pacifique dans des eaux stériles dans le but d'établir de nouvelles remontes qui se perpétuent. Un examen des nombreuses tentatives de transplantation démontre qu'à l'occasion, les saumons introduits dans les régions à l'extérieur de leux dispersion natural survivent et établissent de nouveaux stocks permanents. Ainsi, le saumon quinnat provenant d'oeufs importés de Californie en 1901 s'est-il perpétué dans l'Île du Sud (Nouvelle-Zélande) depuis 80 années. Des alevins de saumon rose provenant d'oeufs transférés sur plusieurs années de Sakhalin à des piscifactures de la péninsule Kola ont établi des remontes suffisantes pour perpétuer l'espèce à cet endroit et peut-être plus loin le long de la côte de l'Europe septentrionale. Les saumons coho, quinnat et rose se sont établis dans les Grands lacs et s'y maintiennent avec un ensemencement nul (saumon rose) ou faible (saumons coho et quinnat).

À noter que les transplantations à l'intérieur de l'habitat normal du saumon du Pacifique n'ont pas permis de produire de nouveaux stocks anadromes, sauf là ou un obstacle physique évident avait empêché la colonisation normale. Une seule transplantation dans des bassins hydrographiques exempts l'obstacles physiques à la montaison s'est soldée par le développement d'une nouvelle remonte: les alevins et les tacons de saumons rouges provenant de la rivière Skagit et transplantés en 1937 dans le ruisseau Issaquah (lac Sammanish) et la rivière Cedar (lac Washington) ont formé des remontes suffisantes.

Lorsqu'un obstacle physique a été enlevé ou contourné afin de permettre une première ou une nouvelle colonisation, des stocks importants se sont quelquefois établis. Une importante remonte de saumon rouge a lieu maintenant dans le bassin hydrographique du lac Frazer (Alaska) suite à la construction d'une échelle à poissons contournant une chute infranchissable et à l'ensemencement simulanté d'oeufs, d'alevins et d'adultes prélevés dans les bassins limitrophes. L'ocupation des parties d'amont de la rivière Kakweiken

par le saumon rose a coïncidé avec les années où une échelle à poissons permettait le passage autour d'une chute normalement infranchissable. Les populations de saumon rose du fleuve Fraser, chiffrées maintenant à plusieurs millions, se sont rétablies en envahissant à nouveau des régions en amont de Hell's Gate, où, depuis 1913, un glissement de terrain empêchait la remonte.

D'après les antécédents de colonisation de nouveaux territoires, naturelle ou dirigée par l'homme, la transplantation sera menée avec le plus grand succès là où l'on peut donner l'accès aux aires de reproduction et de croissance non utilisées en contournant les obstacles évidents à la montaison. On ne sait pas si la transplantation accélère vraiment le peuplement de nouveaux territoires du fait qu'aucun test objectif n'a été effectué. Lorsque l'enlèvement ou le contournement des obstacles est trop onéreux, il peut être justifiable d'ensemencer chaque année les régions inaccessibles. Pour une meilleure efficacité, toutes les tentatives d'utilisation de nouveaux territoires devraient faire partie d'un plan global de gestion des stocks, qui stipulera les quantités de saumons de remonte suffisantes au peuplement du nouveau territoire.

Mots-clés: saumon de Pacifique, saumon rouge, saumon rose, saumon kéta, saumon coho, saumon quinnat, transplantations,invasion, colonisation, antécédents glaciaires.

INTRODUCTION

The long history of man-directed colonization of fresh waters by salmonids is marked by some spectacular successes and by many equally remarkable failures. In light of our modern and still imperfect understanding of why salmon populations behave as they do, some past attempts to introduce salmonids to barren waters now appear to have been infantile in concept. We shouldn't laugh; this preoccupation with salmonids and the over-optimistic and costly schemes devised to spread them around the world simply reflect man's fascination with the world's best-known and most desired fish. Hundreds of millions are still being spent to increase their numbers, to defend their habitats and to enlarge their distribution over the globe.

The early introductions have improved our understanding of the salmonids' capacities and limitations. He would have been a courageous biologist who, 30 years ago, would dare forecast the current abundance and range of pink salmon in the Great Lakes, from the release of a few thousand fry 25 years ago. Our understanding of the mysteries of homing must be influenced by the successful adaptation of chinook salmon to foraging in the oceans of the southern hemisphere, and returning faithfully to their natal rivers in New Zealand.

The practice of introducing salmon to barren waters presents the best kind of challenge to a fisheries biologist--resolution of the unknowns will demand the best brains we can find, success could return the Pacific salmon yield to its earlier levels and perhaps surpass them.

In the course of this review, I will examine the background to the present distribution of Pacific salmon, what can be learned from man's earlier attempts to increase their range, which situations can be regarded as immediate introduction opportunities, and some of what we must learn to be better at intentional colonization. The focus will be Pacific salmon in British Columbia waters, although I may draw upon relevant experience in other parts of the world for insight into the workings of our own salmon stocks.

RECENT DISTRIBUTION OF NORTH AMERICAN SALMON

To understand the natural distribution of Pacific salmon in modern times, it is necessary to understand past major shifts in climate and their effects on the watercourses which drain western North America. During the Pleistocene (roughly the last one million years) there were four principal cold periods in the area of our interest: the Nebraskan of about one million years ago, the Kansan of about 700,000 years ago, the Illinoian of about 300,000 years ago, and the Wisconsin which is believed to have begun about 50,000 years ago and to have persisted until approximately 10,000 years before the present (Clark and Stearn 1960). Between each period of glaciation the climate was equivalent to the present temperate zone.

Material deposited by each subsequent glaciation overlies that of the preceeding so that most glacial evidence we have today is attributed to the Wisconsin. Because of a lack of intense research, our knowledge of the nature of glaciation over B. C. is fragmentary.

During the Wisconsin almost all of Canada except B. C. and the Yukon was under a sheet of ice known as the Laurentide Ice Cap (Flint 1957, Clark and Stearn 1960, Holland 1976). This sheet covered an area extending north over Greenland and the Arctic islands and south to below the Great Lakes, with its centre in the Keewatin area of the Northwest Territories. The western margin reached to what is now Calgary and butted against the foothills of the Rocky Mountains, extending into B. C. only in the Peace River area.

The remainder of B.C. and part of the Yukon and Alaska were covered with a separate sheet--the Cordilleran--which flowed from several centres (Holland 1976). This sheet extended north along the coast into Alaska, westward over the Aleutian Islands and south to the Columbia River. Approximately 75% of Alaska and a small portion of western Yukon were left unglaciated and served as a refuge for many species, including salmon. The coastal rivers south of the Columbia River and to some extent the Columbia itself provided a southern refuge for salmon (McPhail and Lindsay 1970).

The Cordilleran ice sheet built up gradually. At first, small glaciers developed in valleys of the Coast Range and Rocky Mountains (Flint 1957). These grew and coalesced into long trunk glaciers occupying major valleys. Extensive glaciers developed along mountain flanks, especially in the Coast Range, eventually all but burying the coastal mountains. The climactic ice-sheet developed from the coalescing of glaciers between the Coast Range and the Rockies. This sheet was at least 2300 m thick over the valleys with a dome over the province centered approximately over 53° N. latitude. From this centre the ice flowed out to the ocean on the west and to the Laurentide Ice Cap on the east. Vancouver Island glaciers evolved to the mountain ice-sheet stage and became contiguous with the mainland sheet (Holland 1976). The Queen Charlotte Islands developed their own ice sheet which is believed also to have abutted the mainland sheet. The widespread proliferation of ice over the province forced most forms of life from the area.

As the ice moved outward from the centre, its tremendous weight caused valleys to be dug hundreds of metres deeper. Later, on receding, it deposited vast amounts of sand and gravel in the deepened valleys, in some case to depths of 350 m (Holland 1976). These valleys became the salmon-producing watercourses of today.

About 20,000 years ago, the climate began to warm and the ice to recede. Its recession reversed the pattern of the build-up (Flint 1957), finally leaving today's steep-sided river valleys and sharply peaked mountains. The coasts of the Queen Charlotte Islands, Vancouver Island and the mainland were bared about 12,000 years ago. Several small readvances kept the Fraser Valley glaciated until 11,000 years ago (Clark and Stearn 1960). Coastal areas as far as Juneau were ice-free by 10,000 years ago (Olson and Broeker 1957) and dispersal of freshwater fishes along the coast must have been possible shortly thereafter.

Very little is known about deglaciation of B. C.'s interior. It is likely that the glaciers did not recede to their present size until 3,000 years ago or even more recently (Clark and Stearn 1960).

Several derangements of drainage took place during recession. These were caused mostly by lobes of ice or by glacial moraines which blocked channels and forced new drainage patterns (Holland 1976). Ice blockages were usually temporary--an ice plug in the Fraser Valley near Dog Creek diverted water by way of Canoe Creek across the head of Bonaparte River into Deadman Creek and glacial Lake Kamloops and thence into the Okanagan Valley and the Columbia River drainage (Matthews 1944). When the plug melted, normal Fraser Valley drainage resumed. In other cases, moraine blockages of earlier watercourses caused permanent derangements--moraines left by receding ice forced the former Nass and Skeena drainages into new, north to south courses (Holland 1976).

Large lakes were formed by meltwater from receding glaciers (Matthews 1944). Many are not present today although their former shorelines can be seen. A glacial lake formed in the Prince George basin by an ice dam caused the Fraser to drain into the Peace River; at a different time Miette Lake was formed receiving waters from the Thompson Valley and draining them east over the Continental Divide. With complete melting of the ice sheet, these lakes disappeared and the present drainage configurations appeared.

If we assume that British Columbia, Puget Sound and southeast Alaska have been accessible to Pacific salmon for only the last 10,000 years, their reinvasion of these areas from the Wisconsin refugia has taken remarkably few generations. For one or other of the cycles of pinks this period represents only 5,000 broods, for those of sockeye, coho, chinooks and chums only some 2,000 to 3,500. Already within these re-invaded territories unique stocks or races have evolved from the first invaders, as for example the several stocks of kokanee now partially or wholly isolated from their anadromous progenitors. Thus, while Pacific salmon are noted for their remarkable ability to "home" from great distances at sea, they are equally adept at invading new territory by straying from established stocks, and at adapting quickly to new and different habitats.

MAN'S ATTEMPTS TO INTRODUCE SALMON

We have seen above that, left to their own devices, salmon are effective colonizers of accessible fresh waters of the temperate and sub-arctic regions of western North America. As the climate has changed and these regions have shifted over the continent's face, salmon have adjusted their distributions by penetrating waters as they became habitable and, presumably, deserting those which became unsuitable. What happens if man attempts to speed up this process, or to move them outside of their native North Pacific waters?

TRANSPLANTS OUTSIDE OF THE SALMONS' NORMAL RANGE

The first and best known successful transplant of Pacific salmon outside their normal range was that of chinooks to New Zealand (Waugh 1980). Between 1875 and 1879, several hundred thousand fertilized eggs were shipped from the McLeod River hatchery in California to New Zealand. So far as is known, no adult salmon were produced from the small numbers of fry which survived the voyage. Then in 1901, after establishment of a government policy of intensive salmon stocking, 50,000 California chinook eggs were imported and reared in the Hakataramea and Lake Ohau hatcheries, from which yearlings and 2-, 3-, and 4- year old fish were released into tributaries of the Waitaki River. Further importations were made in 1906 and 1907, but by this time the numbers of chinooks returning were sufficient to satisfy hatchery needs and by 1910, to allow for export of eggs to Tasmania. Since that time, chinooks have spread into several rivers entering the sea along a 500 km stretch of the South Island's east coast. It is not clear whether they have spread by natural straying, by transplanting, or by both; what is clear is that self-sustaining runs of chinook salmon imported from California are well established in a portion of the southern hemisphere.

Less publicized was the one successful transplant of sockeye eggs to New Zealand. After an earlier unsuccessful attempt in 1900, a shipment of 500,000 eggs in 1901 from the Granite Creek hatchery (Shuswap Lake, B. C.) was sent via San Fransisco (Aro 1979). These eggs were part of those assembled at the hatchery from Canoe, Scotch and Tappen Creeks. They arrived in New Zealand in poor condition--only some 115,000 fry hatched. These were liberated in various tributaries of the Waitaki River and Lake Ohau and in the Hakatumarea River. From these plantings, landlocked ('kokanee') populations developed in Lake Ohau and the Waitake and Hakatamarea Rivers. Interest in the transplanted sockeye was overshadowed by that in the large, sea-going chinooks which soon supported a combined sport and commercial fishery (Waugh 1980).

Major sea-run stocks of pink salmon are becoming established in the inhospitable waters of the Arctic. Since 1956, Russian fish culturists have transplanted some 200 million pink eggs, mostly from Sakhalin rivers, to hatcheries on the Kola Peninsula in northeastern USSR (Bakshtansky 1980). Over the years the returns have been variable, from practically none to over 200,000 in any one year. Large returns in the even-year line have been few, but recently returns of the odd-year line have been so great as to preclude the possiblity that they now arise only from transplanted eggs. Straying of the transplanted fish has been substantial--individuals have entered streams in Norway, Finland, Iceland and Britain to the west and south of the Kola Peninsula, others have entered streams as far east as the Yenesei River. Sufficient numbers of pinks in Finmark, North Norway, have been observed to suggest that self-sustaining runs may have established there from strays (Bjerkness 1977). The success of the odd-year line is attributed to the fact that this line matures and spawns earlier (August-September) than do the even-year imports (September-October). The difference in spawning time is believed to have been inherent to the stocks from which the transplanted eggs were collected. In the colder Kola Peninsula the developing odd-year eggs have passed the stage where they are susceptible to death or malformation by the time river temperatures drop to less than 4-5C (Dyagilev and Markevich

1979). During the first years of the 'acclimatization' experiment (1957-64) more than 50 million chum salmon eggs were also transplanted, cultured and their fry released into these northern waters, but returns have been few and interest in chum transplants to this area has flagged.

Transplants of chums from the USSR Far East to the Caspian Sea may succeed (Magomedov 1978). During 5 years (1962-1966) of transferring fertilized eggs of autumn chum salmon, 5.5 million fry were released into rivers flowing into the Caspian. Sexually mature chums first appeared in the lower reaches of the Samur River in 1964, and individuals were taken along the entire Dagestan coast from 1964 to 1970. Some have entered the Volga and the inland waters of Azerbaydzhan. Russian fish culturists believe that the spread of chums in the Caspian may be limited by the restricted area of suitable spawning ground and have recommended rehabilitation of potential spawning rivers affected by logging.

The most spectacular introductions of Pacific salmon to areas outside their native range are those to the North American Great Lakes. The transplants of coho and chinooks into the Great Lakes, and their adaptation to an entirely freshwater existence are now legendary. Of the 10.5 million coho planted in the lakes in 1966-69, about 2 million were caught, mostly by anglers (Parsons 1973). Survival such as this (19%) would be considered exceptional among coho released from West Coast hatcheries. The proportions of coho returning from plantings in the different lakes have been variable, but it is now clear that many fish escape to spawn (Peck 1970) and that natural reproduction contributes a significant but unknown proportion of the stock. The greatest single year's catch of 516,000 coho was made in 1970 in Lake Michigan.

The chinook stocks now present in the Great Lakes were derived from plantings of some 6 million juveniles introduced in the years 1967-80 (Parsons 1973). Recoveries from the original plantings have been numerous (190,000 were caught in Lake Michigan in 1970, mostly by anglers), and natural reproduction is fairly common (Carl 1980). The bulk of the population probably is still maintained by stocking of juveniles from hatcheries.

Perhaps the most intriguing introduction of salmon into the Great Lakes is that of pinks. As part of a program to establish pinks and chums in James Bay, 787,000 pink eggs were collected in 1955 at Lakelse Lake on the Skeena River and eyed at the Horsefly Lake hatchery on the Fraser River system. They were shipped to the Port Arthur, Ontario, hatchery to complete their incubation, and the bulk were planted in a stream tributary to Hudson Bay (Nunan 1967). Some 21,000 excess fry were discarded into the hatchery sewer, which emptied into the Current River near Port Arthur. In 1959 two pink salmon were caught by anglers at the mouths of Minnesota streams flowing into Lake Superior (Schumacher and Eddy 1960). Subsequently more pinks were observed in both Ontario and Minnesota streams, and in 1969 pinks were observed in a tributary to Lake Huron on the upper Michigan Peninsula. Successful spawning was observed in the Mindemoya River on the south shore of Manitoulin Island (Lake Huron) in 1973 (Collins 1975). Since that time odd-year pinks have been found also in streams tributary to Lake Michigan (1973), Lake Erie (1979) and Lake Ontario (1979) (Emery 1981, Kwain and Lawrie 1981).

The Lake Superior pinks have developed an off-year line. In their normal range the occurrence of a 3-year-old pink is so rare as to warrant special note (Anas 1959, Turner and Bilton 1968). Yet in Lake Superior sufficient pinks of the 1955 lineage apparently have matured as 3-year-olds to establish an off-year cycle of even-year lineage (Kwain and Chappel 1978). The even-year spawners were first observed on spawning grounds used by the odd-year line in the Steel River flowing into northern Lake Superior.

The purpose of this section has been to demonstrate the high degree of flexibility and adaptability of Pacific salmon, which allow them to invade foreign waters. Of course, not all attempts at introduction have been successful. Pink salmon never became established in Maine and Newfoundland although the numbers of returns from transplanted eggs were encouraging initially (Lear 1975); the chinooks transplanted to Tasmania from New Zealand failed. Whether these and other attempts failed from biological inadequacies - poor food supplies, inadequate homing cues, excessive predation, unfavorable temperatures, too few transplanted - or from inadequate technique or lack of persistence, isn't clear. What <u>is</u> impressive, is the colonizing ability demonstrated by the successes, made more so by the fact that the successful introductions in some cases violated our beliefs about the salmons' needs based on observation within their natural range.

TRANSPLANTS IN BRITISH COLUMBIA AND WESTERN UNITED STATES

The record of transfers of salmon from one river to another on the North American west coast is extensive. Tabulations of eggs and young transferred in British Columbia alone take up nearly 50 pages (Aro 1979). The number of transfers in United States waters, where hatchery practice has been more widespread, would be greater. Even so, existing records are probably incomplete and the numbers transferred are greater than actually recorded.

Transfers of eggs and young quickly followed the introduction of artificial propagation practices from Europe to North America in the mid-1800s. Eyed eggs incubated in hatcheries near the spawning grounds of abundant runs could be transported by the million over long distances to be planted directly into stream gravel, or further incubated in receiving hatcheries and released as fry or fingerlings. The following sections deal, by species, with the major introduction attempts for which the records are most complete.

<u>Pinks.</u>

The most ambitious attempt to establish runs in 'barren' streams was that intended to establish pink runs in Puget Sound in even-numbered ("off") years. In 9 of the 10 odd-numbered years between 1915 and 1933 inclusive, a total of 85 million fry was liberated in Puget Sound streams. These were derived from eggs collected from even-year runs in Afognak, Cordova and Yes Bay streams in Alaska (Neave 1965). The attempts were suspended after the returns were found to be disappointing, but introductions of fingerlings were begun in 1949 after the technology and facilities for rearing pink fry in saltwater impoundments prior to release became available (Ellis and Noble

1959). From 1949 to 1959, about 1.7 million fingerlings from eggs collected from even-year runs in Alaska and at Lakelse River, B.C. were released from salt-water ponds adjacent to streams in Puget Sound where conditions for success appeared optimal. These efforts also failed to provide substantial returns and no even-year pink stocks have so far been established in Puget Sound.

The most ambitious attempt to introduce pinks into a B.C. stream took place over a six-year period from 1959 to 1964. Some 32 million eggs were collected at various times from the Indian, Tsolum, Atnarko and Bear Rivers and planted in a spawning channel on Robertson Creek, an outlet of Great Central Lake (Neave 1965). The planted eggs survived well to hatching so that over the period some 30 million fry emerged and presumably migrated down the Stamp and Somass Rivers to enter Alberni Inlet. In only one year was the return of adults great enough to replace the number of eggs which had produced it, and the attempt was abandoned.

At about the same time (1963 and 1964), some 12.6 million introduced eggs were planted in the Big Qualicum River in an attempt to augment the few pinks which appeared there each year (Walker and Lister 1971). At times prior to 1950, the river apparently had supported runs of commercial quantity. The survival of planted eggs to the emigrant fry stage was disappointing, poor survival being ascribed mostly to inadvertent silting of the incubation channel and to disruption of planted eggs by later spawning chum salmon. The output of fry was nevertheless substantial because the plantings had been large. For example in 1963 some 5.8 million eggs from Cheakamus River pinks were planted; it was estimated that these produced 1.55 million fry. The run of pinks in 1965 was only about 100, no greater than those in years immediately prior to planting. In 1964, 6.85 million eggs from the Bear River were planted and produced an estimated 2.97 million emigrants. The return in 1966 was 11,940. Allowed to spawn naturally these produced 3,000 adults in 1968, which in turn produced 300 in 1970 (it was suggested that the total survival from the 1964 brood of planted eggs might have been 35,000-40,000 adults, with the difference having been caught in the fishery). In any case, with no further introductions the even-year returns to the Big Qualicum declined and pinks there have all but disappeared.

In an earlier experiment, fry derived from eggs collected on the Tlell River (east coast of Graham Island, Queen Charlotte Islands) were planted in McClinton Creek, another Queen Charlotte stream which flows into Masset Inlet and which lacked pinks in odd-numbered years (Pritchard 1938, Neave 1965). From eggs collected in 1931, 878 thousand fry were released in 1932, and in 1936, 506 thousand were released from eggs collected in 1935 (540 thousand eyed eggs were planted in the fall of 1933, but these were believed destroyed by winter freshets). There were few returns to the stream in succeeding years, although some marked adult pinks with missing fins corresponding to the marks applied to the fry released were caught in the Fraser River fishery in 1933. No odd-year run evolved from these transfers.

In the Fraser system an attempt to establish an off-year run (in this case the even year) was carried out at Jones (Wahleach) Creek, a lower river tributary (Wickett 1958, Neave 1965). In 1954, 2.6 million eyed eggs from the Lakelse River pink run were planted in a newly-constructed spawning channel from which 1.1 million fry migrated the following spring. In 1956, about 2800 adults returned to the stream and some 1800 were reported caught in the Indian-food and Fraser River gillnet fisheries. The 2 million eggs believed deposited by the returning 1956 run were supplemented by another 1 million eggs from the Lakelse River, and an estimated 321 thousand fry left the stream in 1957. About 100 adults returned in 1958. No further plantings were made, only a few adults were seen in 1960, and the run has subsequently disappeared.

In 1975, an experiment was carried out at Bear River (flowing into Johnstone Strait from Vancouver Island) where the pink run in even-numbered years may be as great as 100,000 spawners, whereas very few pinks appear in the river in odd-numbered years. The purpose of the experiment was to determine whether or not the infusion of home-stream genes would improve the return of adults to the Bear River from eggs introduced from another stream in the off year. Three types of fry were produced and marked distinctively: those from Glendale River (donor stream) eggs fertilized by cryogenically preserved sperm from on-year Bear River males, those from Glendale eggs fertilized by sperm from artificially-matured, one-year-old males from the on-year run, and those from Glendale eggs fertilized by Glendale males. The latter were to serve as a control against which to measure the effect of infusion of Bear River genes. In total, about 1.6 million fry were released in the spring of 1976. In 1977, only a few marked individuals were recovered from the commercial pink salmon catches of southern B.C. in an intensive sampling program at canneries. No marked pinks of any type returned to Bear River and the experiment was deemed a failure.

In Alaska, an attempt was made to establish a pink run by the introduction of adult fish just prior to spawning. In earlier years both odd- and even-year lines of pinks had been abundant in Sashin Creek, Baranoff Island (McNeil et al 1969, Ellis 1969). After 1944, the even-year run declined to less than 1000, and for a period in the 1950s and early 1960s, efforts were made to exterminate the adults and fry of the even-year line for the purpose of measuring the amount of straying into Sashin Creek. In 1964, about 1139 females and 750 males from a small stream in Bear Harbour (some 50 km distant) were introduced above the weir in Sashin Creek. In Addition another 327 adult pinks (166 females and 161 males) were permitted to enter the stream (it was presumed these were strays from some other stream). In the spring of 1965, some 310 thousand fry were believed to have emigrated to sea. The return of adult pinks to Sashin Creek in 1966 numbered 5,761, a figure which must be considered a minimal reflection of survival, since some would have been caught in the fisheries. This return represented an excellent return of adult spawners from fry released (1.9%) and was regarded as a successful introduction attempt. There is some doubt, however, as to the degree to which the transplanted adults contributed to the return as opposed to 'strays'; 10 years earlier an even-year spawning run of 21 adults (in 1954) appeared to produce a return (in 1956) of 933 fish to the stream, an increase of some 44 times.

Sockeye

Within B.C., the objectives behind sockeye transplanting have changed over the years as our knowledge of their life history evolved, and as different needs were perceived. At first, after the establishment of the first hatchery at Bon Accord near New Westminster in 1884, sockeye eggs and fry were planted (or transplanted) because it was believed that simply adding large numbers of young to rivers and lakes would increase the numbers of returning adults for the fishery and spawning grounds. Their life history was so imperfectly understood that in some cases sockeye fry were planted in streams where they were unable to reach lakes in which to spend the requisite one or two years of lake residence--many were planted in non-lake streams tributary to the lower Fraser River. Later, after their early freshwater life was better understood, attempts were made to build up the sub-dominant sockeye runs to various Fraser watersheds where 'dominance' was evident (at the turn of the century most upriver watersheds supported large numbers of sockeye in the 1901-1905 cycle, with fewer fish appearing in the intervening 3 years). Then when some of the upriver Fraser stocks were wiped out by the Hell's Gate slide in 1913 and others were reduced to low abundance by continued heavy fishing, valiant efforts were made to re-establish the extinct or severely depleted stocks by transplanting.

In Table 1 I have attempted to calculate the numbers of eggs, fry and fingerlings moved from one major watershed to another within and to the Fraser system, and between other non-Fraser systems. The figures are based on those provided by Aro (1979) and must be considered as best guesses because many of the detailed hatchery records are no longer available. For the same reason they also must be considered minimal (K. V. Aro, personal communication).

In the Fraser River, many transplants were made between 1884 and 1934 to watersheds of the lower river below Hell's Gate (Table 1). Most of these were to watersheds which already contained substantial sockeye runs (Harrison, Pitt, Cultus, Birkenhead, Chilliwack) or to streams containing no accessible lakes (Coquitlam, Stave, Nikomekl, Serpentine, Salmon, Silverhope). The fate of the transplanted eggs and fry is unknown. Those placed in streams without lakes almost certainly perished; some of those placed in lakes and streams already containing sockeye may have survived to be absorbed into the existing stock. In any case, no runs were established in places formerly barren of sockeye.

Among early transfers of eggs between upper Fraser River watersheds were those in 1909 to the Nicola River and North Thompson River tributaries (Barriere River and Louis Creek) from Scotch and Tappen Creeks, Shuswap Lake. No record of observations concerning returns to these systems can be found, and the fate of the young can only be conjectured.

Between 1902 and 1931, many millions of eggs and fry were transferred from other systems to the Shuswap watershed, particulary in years of sub-dominant runs. Even prior to the 1913 slide, several million fry from Harrison, Pitt and Birkenhead sockeye were released into Tappen Creek (Aros's Table 10). No evidence of successful return of these fish could be found. In 1913, an effort was made to salvage eggs from sockeye blocked by the Hell's Gate slide. Millions of eggs were collected and distributed to the Harrison and Shuswap watersheds (the ultimate destination of the blocked sockeye parents isn't known, but many of them probably were bound for the Lower Adams River anyway). From these eggs, 8.7 million fry were released into Shuswap Lake. Their fate is unknown, but the effort was probably doomed to failure because any returnees would have experienced difficulty at the slide, which

Table 1. Summary of transfers of sockeye eggs, fry and fingerlings between British Columbia watersheds. Numbers are calculated from data presented by Aro (1979). Table numbers refer to those given by Aro.

Receiving area	Period	Eggs (1000's)	Fry (1000's)	Fingerlings (1000's)	Donor Watersheds	Aro's Table No.
Lower Fraser Valley below Nicomen Slough (a)	1884-1921	455	10,041	45	Harrison, Pitt (b), Birkenhead, (b), Shuswap, Cultus, Rivers Inlet	1
Pitt River System	1884-1934	5,094	51,627	85	Harrison, Birkenhead, Shuswap, Cultus	
Lower Fraser Valley between Nicomen Slough and Kawkawa Lake (c)	1884-1929	60	13,718		Harrison, Cultus, Pitt, Birkenhead	3
Harrison System	1905-1934	29,242	123,230	1,308	Shuswap, Birkenhead, Cultus, Fraser R. at China Bar, Pitt, Alaska	4
Birkenhead	1929		20		Cultus	5
Nicola River	1909	2,000			Shuswap	7
North Thompson River tributaries	1909	2,000			Shuswap	8
Barriere River (N. Thompson)	1956-1960	3,021			Raft River (N. Thompson)	9
Shuswap Lake	1902-1931	29,540	17,124		Harrison, Pitt, Birkenhead, Fraser R. at China Bar, Cultus	10
Upper Adams River (d)	1949-1975	9,764		217	Shuswap (d), Taseko Lake	11
Seton-Anderson System	1915-1930	4,380	17,881		Birkenhead, Cultus	5, 12

Table 1. (cont'd)

Receiving area	Period	Eggs (1000's)	Fry (1000's)	Fingerlings (1000's)	Donor Watersheds	Aro's Table No.
Seton-Anderson (Portage Creek and Anderson Lake, IPSFC)	1950	300		193	Shuswap (Adams R.)	13
Quesnel River System	1922-1928	22,005			Birkenhead, Lakelse (Skeena)	14
Quesnel River System (IPSFC)	1947-1972	1,410	1,366	405	Bowron, Stellako, Shuswap	15
Bowron Lake System	1924-1926	3,500			Lakelse	16
Lac La Hache (IPSFC)	1950			15	Shuswap (Adams R.)	17
Nadina River	1926-1928	15,023			Lakelse, Birkenhead	18
Nadina (Creek "X") (IPSFC)	1956	318			Stuart Lake System	19
Stuart Lake System	1907-1928	20,362	73,450 (e)		Babine System, Birkenhead, Lakelse	20
Total within and to Fraser System		148,474	308,457	2,322		
Sakinaw Lake and Squamish River	1892-1911		760		Harrison, Pitt, Birkenhead, Shuswap, Cultus	22
East Coast Vancouver Island Systems (f)	1885-1932	10,563	730		Harrison, Pitt, Birkenhead, Shuswap, Rivers Inlet, Henderson	23
Henderson and Kennedy Lakes	1905-1915		390		Pitt, Shuswap, Birkenhead, Alaska	24

Table 1. (cont'd)

Receiving area	Period	Eggs (1000's)	Fry (1000's)	Fingerlings (1000's)	Donor Watersheds	Aro's Table No.
Somass River System	1905-1932	39,496	160		Pitt, Shuswap, Birkenhead, Henderson	25
Maggie Lake	1929-1941	8,598			Henderson, Cultus	27
West Coast Vancouver Island Systems (g)	1904-1926	644			Harrison, Pitt, Kennedy	29
Northern B.C. Coastal Systems (h)	1915-1927	10,670			Rivers Inlet	30
Lakelse Lake	1924-1927	5,063	27,456	1,990	Birkenhead	31
Morice Lake (Nakina R.)	1960-1965	4,900	25,939		Babine	33
Total to non-Fraser Systems		79,934	55,435	1,990		
Total all systems		228,408	363,892	4,312		

(a) Fraser, Coquitlam, Stave, Nicomekl, Serpentine, Salmon Rivers and McKay Creek (Burrard Inlet).
(b) I have treated 'Harrison' (including Weaver Creek) and 'Birkenhead' as separate watersheds.
(c) Cultus, Sumas, Silver and Kawkawa Lakes; Chilliwack, Sumas and Vedder Rivers; Silverhope and Ruby Creeks.
(d) I have treated 'Shuswap' (including Adams River) and 'Upper Adams River' as separate watersheds.
(e) Shown by Aro as 'fry and fingerlings'.
(f) Cruikshank River (Comox Lake), Cowichan River and Lake, Nanaimo River and Lakes.
(g) Quatsino Sound (Colony Creek), Tranquil Creek, Megin River and Cecilia Lake.
(h) Scoular, No-end, Tuno, Little Tuno, Tinkey, Wolf, McLaughlin and Namu Lakes; Kainet Creek.

wasn't laddered until the early 1940s. In any case, when the Lower Adams River sockeye recovered their former characteristic 'dominant' line, it appeared in the 1902-06 cycle rather than in the orginal 1901-05 one.

As Ricker (1972, p. 111 and 113) points out, the Canada Department of Fisheries, following the removal of part of the slide in the winter of 1914-15, attempted to re-establish stocks in upper Fraser watersheds by transplanting eggs from unaffected areas below the slide, chiefly the Cultus and Birkenhead watersheds, and from the Skeena River. The results were disappointing, and the suitability of young derived from downriver or from non-Fraser systems for upriver planting was questioned. The Biological Board of Canada investigated the problem by rearing eggs and fry from both Cultus Lake and Lower Adams River stocks and marking and releasing them in different years as fingerlings into the Eagle River, tributary to Salmon Arm of Shuswap Lake. None of the marked sockeye of Cultus Lake origin was recovered on the Eagle River, while only a few of Adams River origin were seen. The return of these few was insufficient for the purpose of establishing a run (Ricker gives a detailed account of the experiment).

In 14 years during the period 1949 to 1975, the International Pacific Salmon Fisheries Commission (IPSFC) attempted to establish a sockeye run in the Upper Adams River, which flows into Adams Lake and subsequently into the Adams River and Shuswap Lake. Many of the eggs and fry released were derived from the Seymour River (tributary to Shuswap Lake), but others were transplanted from the re-established Lower Adams River run and from Taseko Lake (a tributary of the Chilcotin watershed). In spite of concerted effort over many years, the most recent Commission reports indicate there are only a few returning spawners, whether in the dominant cycle, when commonly over a million occupy the Lower Adams River downstream, or in the sub-dominant cycles (IPSFC 1976-80).

The fate of some 20 thousand Cultus (Sweltzer River) (Table 1) fry from the 1929 brood released in the Birkenhead River is unknown.

At the time of the 1959-1960 transplants from the Raft River to the Barriere River (Table 1), the Barriere River was being reinvaded by small numbers of sockeye, perhaps strays from the Raft (Ricker 1972, p. 119). Hence the transplants probably didn't contribute to the re-establishment of the run. Recent reports of the IPSFC (1976-1980) indicate that the number of spawners in the Barriere in any of the cycles is less than 100.

There is no evidence that the large numbers of eyed eggs and fry transferred to the Seton-Anderson watershed between 1915 and 1930 by the Canada Department of Fisheries from the Birkenhead and Sweltzer Rivers contributed to subsequent Seton-Anderson runs (Table 1). Most of the eggs and fry were planted in Gates Creek and Lake. Later the IPSFC planted 300 thousand eyed eggs from the 1950 Adams River brood in Portage Creek (joining Anderson and Seton Lakes) and 193 thousand fingerlings in Anderson Lake. The adult sockeye present in Portage Creek in 1954 would represent a 1.2% survival of the eggs planted there (Ricker 1972), but it is not clear whether they came wholly, partly, or at all, from the transplant because there was already a small native run to Portage Creek. The escapement to the creek in recent years averages about 14 thousand.

Following decimation by the Hell's Gate slide of sockeye runs to the Quesnel system, the Canada Department of Fisheries transferred millions of eggs to the Horsefly and Mitchell Rivers in that watershed. The eggs came from the Birkenhead River and from streams tributary to Lakelse Lake on the Skeena drainage. No runs were established as a result of these transfers. Between 1947 and 1972, the IPSFC carried out a series of experimental transplants of sockeye eggs, fry and fingerlings. The planted fish in many cases were marked, so that returns could be identified. Ricker (1972) gives a detailed account of the results up to 1959, which could only be classed as disappointing. The IPSFC Annual Report for 1956 (IPSFC 1957) includes the following statement, referring in part to the Quesnel transplants: "In spite of these rigid requirements, the twelve transplants of healthy fingerling stock carried out between 1949 and 1956 failed in their purpose of returning a transplanted stock of spawners to a barren spawning area located in another watershed." In 1972, a planting in the lower Horesfly River of 1 million eggs of Stellako origin, fertilized by sperm from Horsefly jack males produced". . no evidence of returning adults in 1976" (IPSFC 1977). The re-establishment of large runs to the Quesnel system has taken place gradually by natural reivasion and expansion of remnant stocks, in spite of intense and sometimes imaginative attempts to speed the process by transplants from other watersheds.

The effect of the transfers in the period 1924-26 to the Bowron River and Kibbee Creek from the Lakelse watershed on the Skeena River (Table 1)is unknown. Presumably the planted eggs suffered the same fate as other transplants to the upper Fraser, and the current healthy stock (about 35 thousand in the 1975-79 line) developed from expansion of a remnant left after the slide.

No sockeye returned to Lac La Hache from a planting of 15 thousand fingerlings from the 1950 Lower Adams River run (IPSFC 1955).

The transfers of some 15 million eyed eggs from the Lakelse and Birkenhead watersheds to the Nadina River during the period 1926 to 1928 evidently were unsuccessful, and a further transplant from Forfar Creek (Stuart watershed) by the IPSFC to Creek "X" at Nadina Lake failed (Ricker 1972).

Over a long period (1907-1928) before and after the Hell's Gate slide, the Canada Department of Fisheries transferred over 90 million eggs and fry into tributaries of the Stuart Lake watershed, chiefly from Pinkut and Sutherland Rivers of Babine Lake, but also from the Birkenhead and Lakelse watersheds. Since the fry and fingerlings were unmarked, the magnitude of return of these fish is difficult to measure, but Ricker's (1972, p. 119, 121) assessment suggests that few or none returned, for reasons which could only be guessed at. A planting in 1961 in Hatdudatehl Creek (Tezzeron Lake) of over 500 thousand eyed eggs from Gluske Creek (also within the Stuart watershed) failed (Aro 1979, Ricker 1972).

Outside the Fraser River system, before the shutdown of hatcheries in the early 1930s, many transfers of sockeye eggs and young were made to and between coastal B.C. sockeye-producing systems.

It is doubtful if any of the fry transferred to the Squamish River between 1892 and 1911 survived (Table 1), since the Squamish contains no lakes for the fry to enter. The fate of those transferred to Sakinaw Lake from various Fraser River watersheds during the same period is unknown. Sockeye are present in the Sakinaw-Ruby Lakes system today and probably were then, so that we must surmise that at best the fry transplanted there simply mingled with an existing stock, if they survived at all.

The effects of transfers of eggs and fry to three East Coast of Vancouver Island watersheds (Cowichan, Comox, Nanaimo) are hard to assess (Table 1). Itis likely that the eggs and fry planted in the lower Nanaimo and Cowichan rivers did not survive, but those planted in the Cruikshank River (tributary to Comox Lake), in Cowichan Lake itself (fry) and in the Nanaimo Lakes or River between the lakes (eggs and fry) may have survived as kokanee, since these watersheds contain kokanee today. However, so do other East Coast watersheds with or without impassable falls and for which there is no record of planting either sockeye or kokanee, e.g. McCreight, Horne and Brannen Lakes. In none of the systems where plants were made did a sea-run stock develop; whether or not the present kokanee stocks in these systems arose from the sockeye plantings is an open question.

On the West Coast of Vancouver Island, Henderson and Kennedy Lakes already contained substantial sockeye stocks in the period 1905 to 1915, and it is most likely that surviving offspring, if any, from transplants of Pitt, Shuswap, Birkenhead or Alaskan stocks were absorbed into existing runs (Table 1). The likely consequences of plantings into the Somass River system are hard to assess, although those made in Great Central Lake are of considerable current interest (in recent years the sockeye runs to the Somass system have been very large, coinciding with attempts to increase production by applying fertilizer to Great Central Lake). Aro's (1979) records show that sockeye eggs were first planted in Great Central Lake in 1921, and hatchery records state that ". . . large schools of sockeye fry were observed. . ." in 1922 (Rodd 1923). However, work to ease the passage for salmon at Stamp Falls below Great Central Lake had begun as early as 1912 (Rodd 1913) and it must be concluded from the presence of sockeye below the falls each year at that time, and the fact that later records show that sockeye passed upstream in some years without using the fishway, that some sockeye must have been able to reach Great Central Lake before either the construction of fishways or the plantings of eggs. It therefore seems unlikely that the transplants developed a new stock in Great Central Lake. The early annual reports of the Department of Marine and Fisheries show that there was a substantial run of sockeye to Sproat Lake prior to the planting of eggs and fry there.

No anadromous sockeye run developed from the 1929-1941 plantings of sockeye eggs in the Maggie Lake watershed (Table 1) in spite of the fact that small numbers of returning sockeye were observed at the fishway constructed below Maggie Lake to accommodate the hoped-for run (Atkinson 1942). Plantings were discontinued in 1942 because of the poor returns.

Whether the transfers of eggs to other West Coast of Vancouver Island watersheds (please refer to Table 1) produced new stocks is doubtful. Megin River supports runs of a few hundred to a few thousand sockeye today, but likely always contained a stock. Tranquil Creek does not support a run now, and perhaps never did. Prior to 1973 Cecilia Lake supported a few to several hundred sockeye, but none has been reported recently. Aro (1979) reports that kokanee are present in Colony Lake (Quatsino Sound) and wonders whether they might have originated from a planting, but no anadromous sockeye are present in the spawning stream.

Regarding the transfers of eggs from Rivers Inlet to Northern B.C. coastal systems (Table 1), little can be deduced. I have been unable to identify 'Wolf Lake' with certainty, although it is probably one of those on the Coldwell Peninsula, emptying into Spiller Channel. Early Departmental records show that it already contained a sockeye run. 'No-end Lake' is probably one of those in the Mink Trap Bay drainage which has contained sockeye since records began. Scoular Lake (Captain Cove, Pitt Island) supports a small run of sockeye and probably did so before the plantings, as did Kainet Creek, the Tuno Lakes, and McLaughlin, Tinkey (Tankeeah) and Namu Lakes. It is unlikely that the plantings in these watersheds contributed significantly to the stocks already present, and almost certainly did not result in new stocks in formerly barren waters.

Since the Lakelse watershed already contained substantial sockeye runs, it is highly unlikely that the 1924-1927 plantings of Birkenhead eggs, fry and fingerlings produced new runs (Table 1).

The 1960-65 plantings of eggs and fry in the Nanika River (flowing into Morice Lake, Skeena River drainage) from Pinkut Creek (Babine Lake watershed) were suspended in 1966 after observation suggested that the transfers had not contributed significantly to the run. A hatchery had been built in 1960 to incubate eggs and fry with which to rehabilitate the run which had declined to less than 1,000 spawners in the late 1950's (Dep. Fish. Can. 1966). The run to the Nanika River improved somewhat in the mid-1960s but has since declined to less than 1,000 spawners per year since 1975.

Success in establishing new sockeye stocks by transplanting appears to have been achieved in two areas outside of B.C. In Puget Sound, Royal and Seymour (1940) describe the transfer of fry and fingerlings into the Lake Washington-Lake Sammamish watershed in Puget Sound. In 1937 fry and fingerlings of Baker River (Skagit drainage) origin were planted in Issaquah and Bear creeks (both tributary to Lake Sammamish) and in Cedar River (tributary to Lake Washington). The returns in the fall of 1940 to Bear Creek were only 2 adults, but over 9,000 returned to the Issaquah and 300-400 to Cedar River. Since that time these stocks have thrived, as has a beach-spawning stock in Lake Washington itself. Royal and Seymour believed that the Lake Washington-Lake Sammamish watershed was barren of anadromous sockeye prior to the transplants--"These facts have been presented as a clear cut example of the ability of artificially propagated sockeye to establish themselves . . . in a watershed heretofore uninhabited by the species"--although they recognized the presence of kokanee within the system. Recent studies of polymorphic enzymes among the 3 stocks (Issaquah, Cedar and L. Washington beach spawners) suggest that today's Issaquah and Cedar River stocks are indeed of Baker River origin (J. Woody, personal communication) and thus represent truly new, self-sustaining stocks established by transplants. The Lake Washington beach spawners appear to have had a different origin, and it now seems likely that they were already present but undetected at the time of the plantings.

A clear-cut example of successful establishment of a new run comes from Frazer Lake, Alaska (Blackett 1979). Frazer Lake lies between Karluk and Red lakes, two well-known sockeye producers on Kodiak Island. For 20 years beginning in 1951 green eggs, eyed eggs, fry and adults from adjacent lakes were planted or released into Frazer Lake. Returns were observed first in 1956 at the foot of an impassable falls in the outlet stream. Some returning adults were back-packed above the falls until a Denil fishway was built to bypass them in 1962. The returning runs have increased gradually over the years until, at the present time, the sockeye escapement to Frazer Lake numbers about 150,000 annually.

Chinooks

Aro (1979) lists the recorded transfers of chinook fry within the lower Fraser Valley from 1884 to 1920 (his Table 51). The origin of these fry was predominantly the abundant Harrison River stock which was reasonably accessible from the Fraser River and Harrison Lake hatcheries. Nearly 6 million fry were liberated into other watersheds (Coquitlam, Fraser, Pitt, Stave, Alouette, Sumas, Cultus). Most of these watersheds supported chinook stocks of their own at the time, so the effects of the plantings cannot now be determined. In any case, no new self-sustaining stocks resulted.

The fry emanating from the transfer of nearly 3 million eggs from the Harrison Lake hatchery in 1907 and 1908 (Aro's Table 52) were released into the Shuswap watershed in which substantial stocks of chinooks already existed. No new runs emerged.

Because the receiving streams already contained stocks of chinooks, the transfers of chinook fry from the Harrison watershed to the Cowichan and Nanaimo rivers (Aro's Table 53), those from the Cowichan River to Goldstream, Campbell and Quinsam rivers (Aro's Table 54), and those from Sproat River to Anderson River and Clemens Creek (Aro's Table 55) probably had little or no effect on the existing stocks and certainly did not produce runs where none existed previously.

The planting of chinook fry derived from Babine River eggs into Morrison Creek (part of the Babine Lake watershed) did not establish a run of chinooks to that stream (see Aro's Table 56).

In Washington, Oregon and California, where salmon hatcheries proliferated after the first one was built on the McCloud River in 1882 (Stone 1883), much effort has gone into producing chinook salmon. The records of transfers between watersheds is incomplete, and provides little useful information regarding the establishment of new stocks because many of the transfers were made between systems which already contained chinook salmon. The situation is further confused, particularly on the Columbia River, by the presence of "spring" and "fall" chinooks and the efforts to establish spring chinooks in systems already containing a fall run. Many experiments were carried out to determine the effectiveness of transplanting fingerlings from one watershed to another, where the return of transplanted stock was compared to that of native stocks. Ricker (1972, pp. 102-111) reviews many of the experiments in detail; the results show that in most cases the introduced fish returned less well than did the native, and there is no evidence of establishment of a self-sustaining (i.e. unsupported by hatchery production) new stock where none existed previously.

Coho

During the early period of active hatchery operations in B.C. ending in the 1930s, coho eggs and fry were cultured in conjunction with sockeye and in some cases were transferred between watersheds. Probably it was not the intention to establish new runs, but simply to augment existing stocks, since there are no records of transfers of coho into systems barren of them.

Transfers of coho fry among lower Fraser Valley streams were extensive during the period 1901-1920, using the Fraser River and New Westminster hatcheries as incubation centers (Aro 1979, Tables 47 and 48). Since the streams into which coho were planted already contained coho stocks, it is unlikely that any distinct new stocks evolved.

The 1907 transfer of coho eggs from lower Fraser River tributaries to the Granite Creek hatchery (Shuswap system), from which fry were planted in Tappen (or Granite) Creek, probably belongs in the same category. The Shuswap system already contained substantial coho stocks and Tappen Creek probably supported a few spawners then, as it does now.

The 1910-1934 transfers of coho on Vancouver Island among the Cowichan Lake, Anderson Lake and Kennedy Lake hatcheries (Aro 1979, Table 50) from which eggs and fry were distributed to various small streams and lakes could not be said to have established new stocks.

Ricker (1972, p. 126-130) reviews the results of experiments involving transplants of coho in Washington and California. The transfers within Puget Sound were made to streams or hatcheries where native stocks were already present. Usually some of the introduced fish returned to the receiving stream but did so less well than the native stock. In no case could it be claimed that an entirely new stock arose, although the transplanted fish may well have intermingled with native stocks.

The transfers of coho to the Sacramento River, in which there was no native stock, was revealing. The eggs were taken on the Lewis River, Washington, and the fish reared at the Darrah Springs hatchery on Upper Battle Creek. They were planted in Mill Creek as yearlings and returned as adults to the Sacramento system in substantial numbers predominantly near the release site. However, after 3 years stocking was discontinued and the abundance of coho declined rapidly. No permanent runs were established in spite of the abundant initial returns.

Chums

Aro (1979) in his Tables 45 and 46 lists the recorded transplants of chum eggs within B.C. The fry from the 1902 and 1908 transfers of eggs from Weaver Creek (79,700 and 224,000 eggs, respectively) to the Granite Creek hatchery at Shuswap Lake were released into Granite and Tappen Creeks, neither of which contained a natural run. As far as is known, no adult chums returned to Shuswap Lake from these releases.

Since the Harrison Lake watershed has always supported chum populations, it is impossible to determine whether or not the fry released there from the 1916 and 1920 runs to Sweltzer River and Trout and Weaver creeks produced any returns. It they did it is likely that they were absorbed into the existing runs.

The chum eggs transferred to Nile Creek (East Coast of Vancouver Island) from the 1946 to 1953 brood years of several other Vancouver Island streams were used in experiments to assess the effects of controlled surface and sub-gravel flows on egg survival. Since Nile Creek had always supported a small chum run (and still does), it could not be claimed that the eggs used in the experiments had created an entirely new run.

RECENT INVASIONS AND REINVASIONS

As was noted in the section dealing with their reoccupation of British Columbia's watersheds after recession of the Cordilleran ice sheet, the salmons' propensity for reinvading freshwater territory from which they have been excluded is very strong. There are several notable examples where man's intervention has promoted invasion or reinvasion.

In the case of the successful introduction of sockeye into Frazer Lake, Alaska (referred to earlier), bypassing an obstacle to upstream migration was accompanied by transplanting eggs, fry and adults into the barren lake.

In other cases man's intervention has been more passive--access to spawning and rearing area has been provided simply by removal of an obstacle, and establishment or increase in the stock has depended on greater numbers returning from existing small stocks or from strays generated below the obstacle. A most recent example is that from the Kakweiken River (L. Jamieson, personal communication). Following installation in the 1940's of a fishway providing access to an additional 12 km of apparently excellent spawning gravel, pink salmon invaded the upper waters of the river in large numbers (hitherto salmon access had been sporadic, with small numbers of spawners occasionally ascending the falls under favourable water conditions). Later the fishway became ineffective and from 1957 to 1962 spawners were observed above the fishway in only one year (1958). Another, temporary, fishway installed in 1964 passed no fish upstream that year presumably because the total run to the river was very sparse, but from 1965 to 1976 spawners again occupied the upper reaches. Then in 1977 and 1978 the fishway was inoperative and no pinks used the upriver area. A new fishway built in 1979 has permitted large numbers of spawners to use the upriver area from 1979 to the present (1981). The important points about the Kakweiken work, noted by Jamieson, are that some pinks always invaded the upper reaches when the fishway was operable, a greater proportion used the upper reaches in years when the Kakweiken run was large, and that the upriver fish spawned successfully, thus providing a significantly increased production from that system.

The reinvasion by pink salmon of the Fraser River and its tributaries above Hell's Gate following their complete decimation by the slide in 1913 probably represents numerically the greatest modern reinvasion of former territory. It is impossible to estimate the numbers of pinks spawning above Hell's Gate prior to the slide, but they must have been in the many millions. The report of the Commissioner of Fisheries for 1907 (Babcock 1908) states, for example "The run of humpback salmon to the spawning beds does not appear to have passed up the Thompson River beyond Kamloops, or the Fraser proper north of Seton Lake, and they do not appear to have entered the Harrison Lake section in any considerable number. In all the rest of the watershed the streams were crowded with countless thousands. The Nicola River was a wriggling mass of fish from a point about half a mile from Nicola Lake to the river's mouth, and they literally filled all the other tributaries of the Thompson and the Fraser below the points named".

In the year of the slide (1913) the Commissioner's report included the following statement under the heading "Conditions Below the Canyon". . . "Every tributary stream from Hell's Gate to Ruby Creek (including Spuzzum, Yale, Gordon, Mears, American, Coquihalla and Silver creeks) was filled with living and dead sockeye and living humpbacks . . . From Hell's Gate to Spuzzum, a distance of eight miles, the surface of every eddy and quiet stretch of river was covered with milling sockeye and humpbacks" (Bowser 1914).

Above the slide the story was different . . . "Notwithstanding the fact that this was a humpback-salmon year, and that in former years of their runs millions of humpbacks have spawned there, not a single one of that species reached Seton Lake . . . Since no humpbacks reached any stream north of the Fraser River Canyon this year, I am convinced that none of the species was able to get through the canyon". Subsequent annual reports make particular note of the absence of pink salmon above Hell's Gate until the report for 1923 . . ."For the first time since the fatal blockade of 1913 a few pink salmon were noted at Hell's Gate, several were found in Lake Creek at the outlet of Seton Lake, and others in tributaries of the Thompson - the first year since 1913 that any pink salmon have been reported in any section above Hell's Gate" (Sloan 1924).

The reports, *in toto*, make it quite clear that in all likelihood not a single pink salmon passed the Hell's Gate obstruction in 1913 and that it was 5 generations before they again were observed above the Gate. These few were the precursors for the reinvasion of the upstream waters, presumably strays from unaffected stocks below the Gate, able to proceed upstream after the attempts in 1914 and later to ease the passage there.

Table 2 records the escapements of pinks to streams upriver of Hell's Gate from 1947 to 1979, providing a dramatic illustration of their ability to occupy barren territory otherwise known to be favourable for reproduction. It should be borne in mind that the escapements shown represent only those portions of the runs which escaped the fishery. Undoubtedly had it been possible to refrain from fishing these runs when they first reappeared upriver, they would have rebounded even sooner.

Table 2. Pink escapements to Fraser River spawning areas upstream from Hell's Gate.[a] N/O - not observed.

	Anderson Cr.	Nahatlach R.	Stein R.	Seton R.	Portage Cr.	Bridge R.	Yalakom R.	Thompson River: Nicola R.	Bonaparte R.	Deadman R.	Thompson R.	N. Thomp. R.	S. Thomp. R.	Little R.	Adams R.	Total	Quesnel R.	Grand total
1947		25		1,500														1,525
1949		75		750				200			200					400		1,225
1951		500		15,000				3,500								3,500		19,000
1953				50,000	7,500			2,000	1,500	400	750					4,650		62,150
1955		75		50,000	400			3,500	25		75,000					78,525		129,000
1957		200	75	75,000	750			1,500	200	200	300,000					301,900		377.925
1959	200	200	75	7,500	200			200	N/O		75,000					75,200		83.375
1961	200	75	75	35,000	750	750		200	N/O		75,000					75,200		112,050
1963	200	750	400	123,000	7,500	3,500		400	1,706	101	282,240					284,447		419,797
1965	200	750	200	120,000	7,500	7,500		1,500	1,750	39	230,417		400		53	234,159		370,309
1967	100	25	150	225,000	7,500	7,500		1,000	3,500	N/O	448,000		200			452,700		692,975
1969	175	25	N/O	190,000	1,000	13,000		1,000	500		240,000		25	25	25	241,575		445,775
1971	300	25	300	275,000	100	1,000		1,600	250	25	250,000		25	25	25	251,950	3,500	532,175
1973	100	25	100	248,000	100	2,000		600	500		280,000		25	25	25	281,175		531,500
1975	N/O	50	100	46,000	1,000	5,000	2,000	4,000	500	500	350,000		25		25	355,050	600	409,800
1977	200		500	390,000		40,000		300	30	50	970,000	150	1,000	2,100	1,000	974,632	1,500	1,406,832
1979	116	750	1,000	200,000	53,200[b]	66,000	N/O		1,500	50	1,750,000	20	260	738	3,951	1,756,519	500	2,078,085

[a] 1947 to 1977 from Department of Fisheries and Oceans Stream Catalogues, 1979 from spawning ground reports.

[b] Including 1,200 pinks observed in the Gates River.

SUMMARY AND CONCLUSIONS

The foregoing review of transplant attempts and natural invasions can be summarized as follows:

1. Several naturally self-sustaining runs of Pacific salmon have been established by transplanting to areas outside the Pacific salmon's native range. The chinooks and sockeye in New Zealand, the pinks in northern USSR and the Great Lakes, and the coho and chinooks in the Great Lakes are good examples. Of course, many of the attempts to establish salmon runs outside of their natural range were unsuccessful, but occasionally transplantees to entirely foreign waters have found niches in which they could survive and increase.

2. In contrast, the record for success in establishing natural self-sustaining runs in barren waters within the salmons' native range is dismal, except where access to the barren territory has been denied by an obvious physical barrier. With the exception of the transplant of sockeye fry and fingerlings from Baker River into Issaquah and Bear creeks of Lake Sammamish and Cedar River of Lake Washington, no record of undisputed successful transplantation exists in situations where no obvious physical barrier was apparent.

3. In some cases where access to barren territory within the salmons' native range has been provided by removal or circumvention of an obstacle, there have been spectacular invasions or reinvasions. The establishment of pink salmon in the upper Kakweiken River after installation of a fishway is a good example of invasion resulting from "passive" transplantation (the pinks themselves occupied the new territory after ascending the fishway). At Frazer Lake (Alaska) sockeye became established above a formerly impassable falls by "active" transplanting - green eggs, eyed eggs, fry and adults were transferred from adjacent watersheds into Frazer Lake tributaries. The spectacular reinvasion by pinks of the Fraser and Thompson rivers after fishways were installed at Hell's Gate represents passive transplanting; improvement of passage immediately following the slide and the later construction of fishways were undertaken primarily to assist sockeye migrating to upper Fraser watersheds.

4. Within B.C., most efforts to establish or re-establish runs have been applied to sockeye and pinks. Before the Hell's Gate slide many transplants were made to establish or build up sockeye runs in sub-dominant cycles; after the slide there were massive transplants to re-establish sockeye runs which had been decimated. Most pink transplants in B.C. (and Puget Sound) were made to establish "off-year" runs. None of these attempts was successful.

In view of past experience and our present limited knowledge of how salmon invade and establish themselves in new territories, the following techniques currently offer the greatest promise:

1. Wherever extensive spawning and rearing area exists above an impassable obstruction in a watershed already occupied by salmon, removal or circumvention of the obstacle should be considered. The likely benefits must be weighed realistically against the cost of removing the obstacle but it must be borne in mind that this method of extending stocks minimizes the as yet poorly understood risks of disease transfer and introduction of undesirable genetic characters into existing stocks. Often the potential for increased production can be tested, at least tentatively, by transfers of adults, eggs or fry of stocks from below the obstacle and assessing survival and growth before a major investment is made. The question of whether it is better to attempt to accelerate occupation of newly accessible areas by transplanting from downstream stocks, or simply to let strays occupy the area, is moot. Perhaps strays represent the best colonizers from an existing stock. To my knowledge no objective tests bearing on this question have been made.

2. Even in those cases where there is no spawning or rearing area to support stocks below an obstacle (as in the case of a stream flowing over an impassable falls directly into the sea), the possibility of providing access by bypassing the obstacle should be considered. The successful transplants into Frazer Lake suggest that very productive self-sustaining runs may be established in this way. As mentioned above, it is usually possible to test the productivity of the watershed above the obstacle by transplants, and to determine whether the transplantees return to the new site, before an investment in obstacle removal is made.

3. In cases where removing or bypassing an obstacle is clearly too expensive relative to potential benefits, there exist opportunities to extend spawning and rearing area by transplanting on an annual basis. Particularly in areas where stocks exist below the obstacle, it may be possible to transfer surplus spawners, eggs or fry around the obstruction without using expensive incubation or rearing facilities. These techniques have, and are, being tried at present, e.g. surplus sockeye spawners are transferred above the falls on Pinkut Creek (Babine Lake), and surplus coho (fed fingerlings) are being transplanted from the Quinsam hatchery into the headwaters of the Quinsam River. It is important that these techniques be tested rigourously to determine their effectiveness in producing more adult fish and thus their cost effectiveness as an enhancement technique.

4. Until the mechanisms that underlie the phenomena of pink on-offness and sockeye dominance are better understood, attempts to establish off-year pink runs and to build up sub-dominant sockeye runs by transplanting should be suspended. The sorry record for these attempts in the past shows that we don't understand the population controls involved in these special cases. Instead, field studies should be undertaken to test the various theories put forward to explain them. It is likely that understanding of the ways in which these mechanisms operate will present opportunities for increased production, while blind repetition of past practice may simply be jeopardizing existing stocks.

Of course, extending the spawning or rearing area available to salmon as recommended above serves no useful purpose unless the stocks from which the transplantees are derived are fully utilizing the areas already available to them. For example, providing access to the upstream portion of the Kakweiken River to part of a pink stock which in itself is inadequate to seed the downstream portion fully would be unprofitable. Enhancement plans of this nature must be integrated into an overall harvesting scheme which permits the required (usually additional) spawners to escape.

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A Genetic Method of Stock Identification in Mixed Populations of Pacific Salmon, *Oncorhynchus* spp.

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ABSTRACT—Basic procedures are presented and illustrated for a genetic stock identification (GSI) method that is based on the detection of genetic variability with gel electrophoresis. The method uses naturally occurring genetic differences between stocks to provide estimates of the composition of mixed-stock fisheries.

Three examples are given to illustrate the application of the GSI method to management of chinook salmon, Oncorhynchus tshawytscha, *fisheries: 1) Estimates for four potentially contributing populations of fall-run fish intercepted at Bonneville Dam (Columbia River) in 1980 and 1981, 2) an analysis of the 1982 winter gillnet fishery in the lower Columbia River, and 3) an analysis of the ocean troll fishery along the Washington coast during May 1982. The analytical, economic, and temporal advantages of the GSI method indicate that this procedure is a major new tool for the management of mixed stocks of anadromous salmonids.*

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Introduction

A fundamental principle of fishery management is that knowledge of stock composition is required for effective management of mixed stock fisheries (Larkin, 1981). Absence of this knowledge inevitably results in either overharvest or overescapement. However, such a stock-composition strategy has been practiced rarely in the management of anadromous salmonids because of the difficulty in adequately identifying component stock groups.

Coded wire tagging (CWT) has given managers a valuable tool for identifying specific salmonid groups of hatchery origin, but the method is difficult to use on wild populations and requires considerable effort and cost (Ihssen et al., 1981). Scale analyses have been effectively applied to salmon fisheries (Messinger and Bilton, 1974), but their utility appears to be limited. Also, scale pattern standards can fluctuate between years with changes in environmental conditions, requiring yearly examination and revision of the standards.

An ideal set of stock discriminators should be: 1) Expressed independently of environmental changes, 2) composed of discrete units of information so that population differences can be readily quantified, 3) stable from year to year, and 4) measureable with reasonable efforts and costs. Protein differences detected by gel electrophoresis generally fulfill these requirements. These genetic differences readily accumulate among anadromous salmonid stocks because of the temporal and geographic reproductive isolation associated with the strong homing tendencies of adult salmonids.

The use of genetic data in the management of mixed stock fisheries of anadromous salmonids has been anticipated for over 30 years; for early reviews see Ridgway (1957) and Ridgway and Klontz (1960). Early development of the concept came from anthropologists who used the distribution of blood groups to trace patterns of human migration and to identify relationships among major population groups (Mourant, 1954). These studies, coupled with the successful application of blood grouping methods to genetically characterize populations in other mammalian and avian species (Stormont et al., 1951; Briles et al., 1950), suggested that serological procedures might also be extended to characterize breeding units of fish species. However, this idea was abandoned because technical problems limited its application (Hodgins, 1972). Protein gel electrophoresis ultimately provided the quality and quantity of genetic data that had originally been expected from blood groups (Utter et al., 1974); among existing stock identifying procedures, electrophoresis most closely approaches the criteria listed above for distinguishing differences among populations (Utter, 1981).

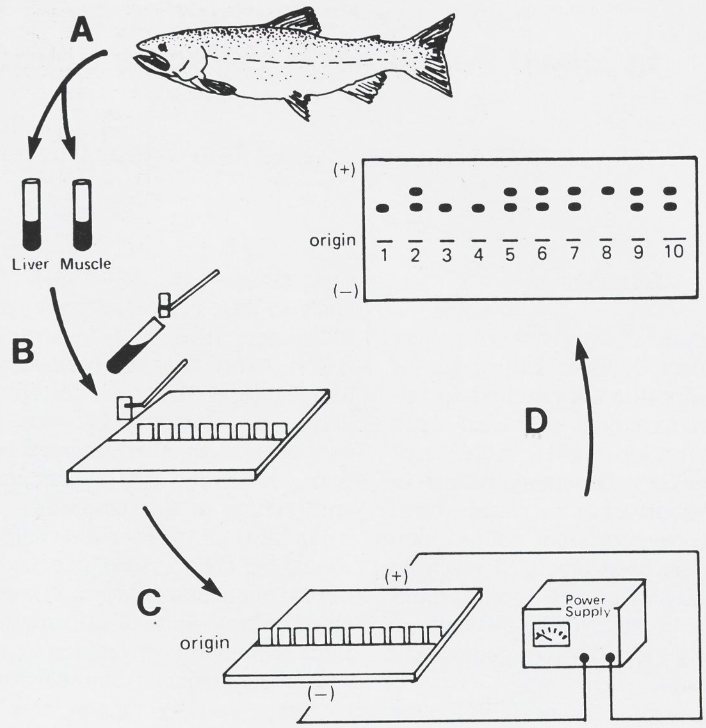
In addition to a reliable means for obtaining adequate volumes of genetic data, statistical and data processing methods were also needed to obtain estimates of stock contributions of mixed populations. A genetic stock identification (GSI) method has recently been developed and tested that meets these needs (Grant et al., 1980; Milner and Teel[1], and Milner et al.[2])

[1]Milner, G. B., and D. J. Teel. 1979. Columbia River stock identification study. Unpubl. manuscr., 68 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112. (Prepared for U.S. Fish and Wildlife Service under Contract 14-16-0001-6438.)

[2]Milner, G. B., D. J. Teel, F. M. Utter, and C. L. Burley. 1981. Columbia River stock identification study: Validation of genetic method. Unpubl. manuscr., 51 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112. (Prepared for Bonneville Power Administration under Contract DE-A179-80BP18488.)

Box A.—Basic Electrophoretic and Laboratory Procedures.

A. Tissue samples (e.g., muscle, heart, liver, and eye) are taken from each fish and placed in a culture tube with a small amount of water. Cellular proteins in the tissue are released into solution by freeze/thaw and mechanical agitation procedures.
B. A protein extract from each fish is individually absorbed onto a filter paper wick and placed onto the edge of a starch gel at the origin. Samples from 10 fish are shown loaded in the diagram, although typically, samples from 50 fish are loaded on one gel (i.e., with 50 wicks).
C. A direct current is applied across the gel. Protein molecules absorbed on each wick enter and move through the gel because of the molecule's net electrical charge and at a rate proportional to this charge. This charge, in turn, depends on the genetically controlled amino acid substructure of the protein molecules.
D. After about 4 hours, the gel is removed from the power source and the positions of specific proteins (usually enzymes) in the gel are identified by specific histochemical staining procedures (i.e., using general staining reagents or specific procedures involving the enzyme in the staining process). The relative migration distances of the proteins from the origin, indicated by the staining zones, are recorded as the raw data. The simplified genetic model used for interpreting electrophoretic protein variation is that one gene codes for one protein (polypeptide) chain. Therefore, electrophoretic differences between individuals in protein patterns that are based on amino acid differences are a direct reflection of genetic differences between the individuals. The simple extension of genetic differences between individuals to the evaulation of genetic differences between populations is outlined in Box B.



Steps for obtaining electrophoretic data.

It is evident from our early work that two conditions must be met for a GSI application. First, each stock that could contribute to a particular fishery must be electrophoretically characterized. Second, sufficient difeferences among these profiles must be identified to permit measurement of contributions from each contributing stock.

An extensive data base now exists for chinook salmon, *Oncorhynchus tshawytscha,* populations ranging from California through northern British Columbia (Milner et al.[3]). This data base is centered on populations of the Columbia River whose stocks continue to be major contributors to oceanic fisheries from Alaska southward. Proper management of chinook salmon harvests in this area constitutes a major challenge to regulatory agencies (Van Hyning, 1973).

This paper outlines the basic procedures for applying the GSI and describes the use of the chinook salmon data base in the analysis of stock contributions to three chinook salmon fisheries of varying complexity. Its purposes are to illustrate the various steps of this procedure and to demonstrate its unique capabilities through actual management applications. The format is intended to provide a complete overview within the main body of the paper. The underlying principles of genetics, statistics, and data processing involved in applying the GSI are given in Boxes A and B.

Methods

Use of the GSI method to estimate the composition of a mixed fishery can be divided into four steps.

Step I—Develop Electrophoretic and Laboratory Procedures

Initial laboratory work focuses on developing electrophoretic procedures

[3]Milner, G. B., D. J. Teel, and F. M. Utter. 1983. Genetic stock identification study. Unpubl. manuscr., 65 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112. (Prepared for Bonneville Power Administration under Contract DE-A179-82BP28044M001.)