INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

PROGRESS REPORT

No. 14

EFFECTS OF LOG DRIVING ON THE SALMON AND TROUT POPULATIONS IN THE STELLAKO RIVER

Prepared by the Technical Staffs of the
Canada Department of Fisheries and the International Pacific
Salmon Fisheries Commission in Collaboration with
the Fish and Wildlife Branch, British Columbia
Department of Recreation and Conservation

VANCOUVER, B. C.
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INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

Appointed under a Convention
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the Fraser River System

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ABSTRACT

Field and laboratory investigation of effects of log driving on the fish populations of Stellako River were carried out during 1965. Field studies showed that log jams caused damage to approximately eight per cent of sockeye spawning grounds by erosion of gravel and bark deposition. That the damage was real was verified through analysis of subsequent spawning distribution which showed that spawners tended to avoid the damaged areas. Laboratory results indicated that moderate gravel disturbance due to erosion and gouging by individual logs could also have killed incubating trout eggs in Stellako River, but that vertical impact on the gravel surface would have caused only occasional mortality.

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INTRODUCTION

In July, 1964, Fraser Lake Sawmills Ltd. of Fraser Lake, British Columbia advised the Canada Department of Fisheries of the Company's intention to resume log driving on the Stellako River (FIGURE 1) in the spring of 1965 and requested any comments, suggestions, or advice the Department might consider to be pertinent. The Department informed the Company of its concern and also the concern of the International Pacific Salmon Fisheries Commission, that resumption of log driving could result in serious damage to salmon spawning grounds in the Stellako River. Subsequent discussions were held between the Company and the fisheries agencies at which various aspects of the proposal were explored. It was concluded that the only method of transport available to the Company in 1965 would be by water, involving log driving on the Stellako River.

In order to protect resident populations of sockeye salmon (*Oncorhynchus nerka*), an order was issued restricting log driving to the period after completion of sockeye fry emergence and ending July 20, 1965, prior to migration of adult fish into Stellako River. Limitations on the storage of logs, use of explosives and extent of stream development work were also set. Subject to these restrictions, the log drive was undertaken from June 6 and extended to approximately July 20, 1965. Advantage was taken of this opportunity to study the effects of log driving on salmon and trout spawning grounds in the Stellako River. This report summarizes the results of these studies and presents recommendations with respect to log driving on the Stellako River.

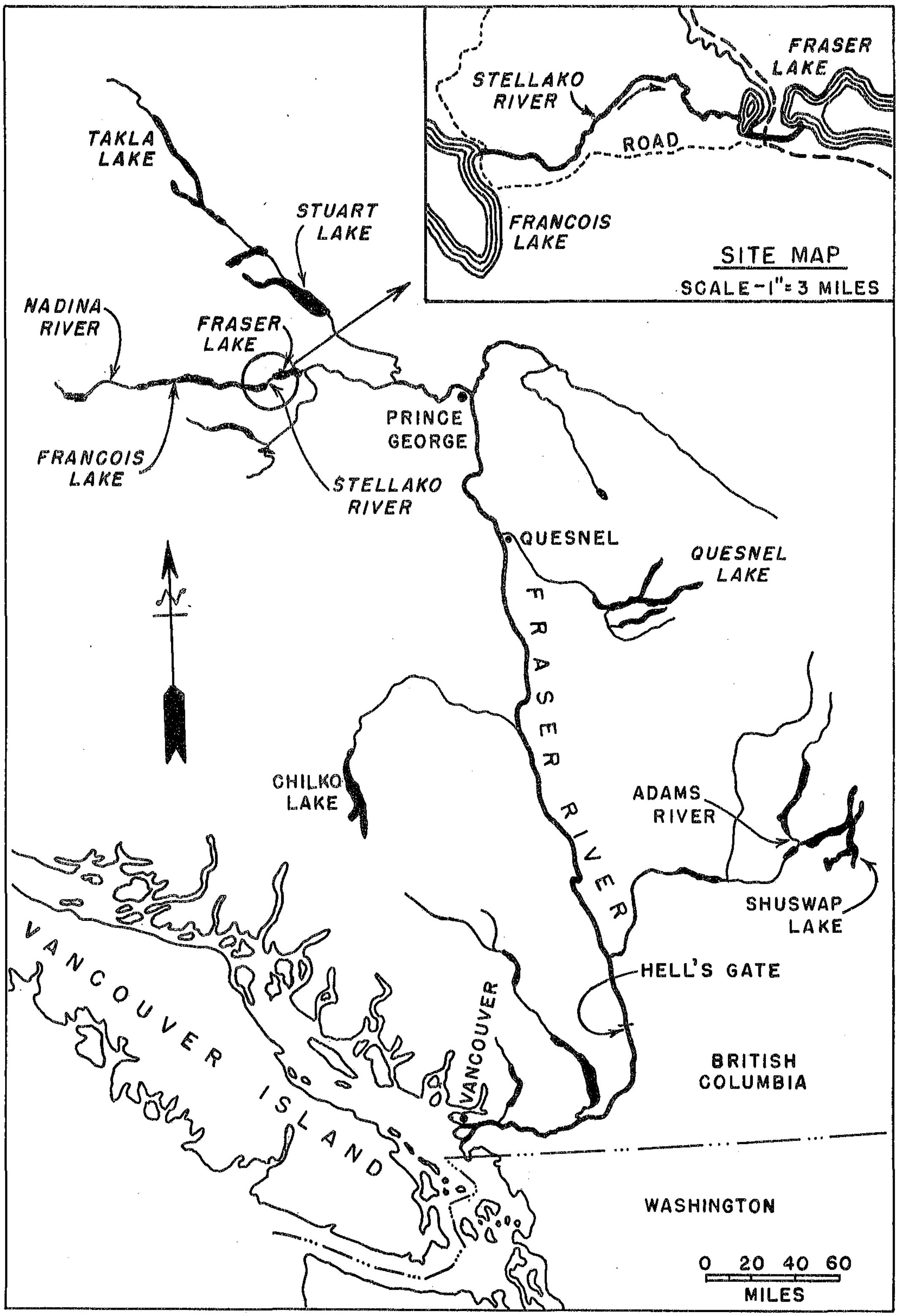

FIGURE 1 - Location of the Stellako River in northern British Columbia.

THE SALMON AND TROUT POPULATIONS OF THE STELLAKO RIVER

Sockeye salmon are the predominant commercial species now spawning in the Stellako River. Adult sockeye arrive in the Stellako River during late August and early September and the peak of spawning occurs near the end of September. Fry emerge from the gravel in the following May and early June and migrate downstream to Fraser Lake where they are reared for a year before proceeding to the ocean.

Early records indicate that prior to the 1913 obstruction at Hell's Gate, the largest or "dominant" runs returned in the quadrennial cycle years 1901-1913 (TABLE 1). It is not possible to determine the size of these early runs, but since Indian catches approached 60,000 sockeye in the dominant years, total escapements must have been several times larger. In the period 1917 to 1937, available records indicate that sockeye escapements to the Stellako River were small in comparison to recent years, and there was no clear indication of a dominant cycle. In 1935, 1936 and 1937, escapements were described by observers as light to medium, consisting of 100 to 500 spawners. In 1938, there were 3077 sockeye spawning in the Stellako River, and the fish were described as being in poor condition. However, this escapement was the apparent beginning of the existing dominant run. Two cycles later, in 1946, the escapement reached 245,200 - the largest ever recorded, and since 1942 all cycle years have increased in size (TABLE 1).

Surveys of the Stellako River indicate that the gross area of the stream bed is 603,300 sq yds, but of this only 277,000 sq yds is suitable for spawning and utilized by sockeye. It is estimated that the 1946 population of 245,200 spawners (approximately 150,000 females) was near optimum for this spawning ground area.

TABLE 1 - Cyclic escapements of sockeye spawners to the Stellako River, 1898-1965.

1962 Cycle		1963 Cycle		1964 Cycle		1965 Cycle	
1962	124,495	1963	138,805	1964	31,047	1965	39,418
1958	112,273	1959	79,355	1960	38,884	1961	47,241
1954	142,632	1955	51,971	1956	38,459	1957	38,922
1950	145,100	1951	96,200	1952	40,462	1953	45,057
1946	245,200	1947	55,000	1948	16,000	1949	104,800
1942	48,064	1943	9,142	1944	3,294	1945	20,826
1938	3,077	1939	1,446	1940	2,600	1941	5,230
1934	(50-100)	1935	(100)	1936	(300-500)	1937	(100-300)
1930	"800 estimated"	1931	"very poor run"	1932	"poor run"	1933	"largest in many years, double the 1929 run"
1926	"good run"	1927	"small numbers"	1928	"poor run"	1929	-
1922	"a few hundred"	1923	"poor run"	1924	-	1925	"very small Indian catch"
1918	"no fish above Quesnel"	1919	-	1920	"too small to be important"	1921	"present for first time in several years"
1914	"poorest in many years"	1915	"very small run"	1916	-	1917	"best since 1913"
1910	-	1911	"lightest in history"	1912	"not large"	1913	"only half of previous large runs"
1906	"practically none"	1907	"practically none"	1908	"good escapement"	1909	"very large escapement"
1902	-	1903	"poor run"	1904	-	1905	"plentiful"
1898	"lots of salmon"	1899	"good run"	1900	-	1901	"large run"

Commercial catches of Stellako River sockeye from 1952 to 1964 are shown in TABLE 2, together with the annual value of the pack. The value of the processed catch, calculated at $50 per case, averaged $1,188,500 annually during this 13 year period.

TABLE 2 - Commercial fishery catches of Stellako River sockeye and values of the canned salmon pack, 1952 - 1964.

Year	Catch	Pack in Cases	Value of Pack at $50/case
1952	146,081	12,170	$ 608,500
1953	138,935	11,580	579,000
1954	733,772	61,150	3,057,500
1955	298,424	24,870	1,243,500
1956	141,375	11,780	589,000
1957	110,301	9,190	459,500
1958	703,417	58,620	2,931,000
1959	524,454	43,700	2,185,000
1960	184,201	15,350	767,500
1961	95,090	7,920	396,000
1962	167,059	13,920	696,000
1963	354,747	29,560	1,478,000
1964	110,435	9,200	460,000
Average	285,253	23,770	$1,188,500

In addition, this run has contributed substantially to the annual catch of sockeye by native Indians along the Fraser River. Indian catches of Stellako River sockeye in the period from 1956 to 1959, when compared with the total catch of all sockeye runs, indicate that about 10 per cent of this food source for the Indians comes from the Stellako sockeye run (TABLE 3).

A relatively small population of chinook salmon (<u>Oncorhynchus tshawytscha</u>) utilize the Stellako River spawning and rearing areas. Annual escapements have usually ranged between less than 100 to less than 500 fish, with a peak spawning population of over 1000 fish recorded in 1958. Although few in number, these large fish make a contribution to the commercial and sport

TABLE 3 -- Indian catches of Stellako River sockeye and all Fraser River sockeye, 1956 - 1959.

Year	Catch of Stellako Sockeye	Catch of all Fraser River Sockeye
1956	6,590	62,188
1957	4,361	97,498
1958	9,562	82,365
1959	8,142	65,049
Average	7,164	76,775

fishery for chinook salmon in British Columbia. Mature adult chinooks enter Stellako River during late August and early September. Spawning commences in mid September and is completed by early October. Incubation and development of the young within the gravel extends from September to May. Fry emergence and downstream migration begins in early May and continues throughout June and early July.

Stellako River provides one of the few "quality" stream fisheries for rainbow trout (Salmo gairdnerii) in the northern interior of British Columbia. In addition to providing recreation for local anglers, it contributes substantially to the support of several resorts in the vicinity. Stellako River also serves as a major spawning area for trout from Fraser Lake. The important recreational value of this lake, some 12 miles in length and 13,500 acres in area, depends largely on the continued production of trout from the Stellako River spawning grounds.

Sport fishing in Stellako River commences in the spring before the spring freshet. The river can be fished from shore using waders or by drifting in rubber boats. The summer fishery provides excellent fly fishing for trout up to five pounds in size. A creel census in June, 1963, and again in May-June, 1964, showed catches averaging 1.47 and 1.0

fish per man hour, respectively. The total number of anglers using the stream is not known, but with rapidly increasing population in the area concurrent with industrial development and rapid expansion in tourist interest, it can be expected that fishing pressure on this easily accessible river and related Fraser Lake will increase in the immediate future.

Rainbow trout deposit their eggs in Stellako River during April and May and fry emerge from the gravel somewhat later than salmon. Many of these young trout become resident in the river in addition to maintaining the stock in Fraser Lake.

Stellako River also supports a substantial population of kokanee (Oncorhynchus nerka), the land-locked form of sockeye salmon. Records beginning in 1938 show a dominant population every third year, with lesser runs in the two intervening years (TABLE 4). Spawning occurs during late September and fry emerge in the spring at approximately the same time, or slightly earlier, than sockeye. Kokanee are not harvested commercially and are not sought to any extent by sports fishermen in this area. However, as fishing pressure increases, kokanee will become a much more important sports fish as they have in other areas.

TABLE 4 - Spawning populations of kokanee in the Stellako River, 1938 - 1965.

1965 Cycle		1964 Cycle		1963 Cycle	
1965	100,000[a]	1964	-	1963	4,600
1962	10,000	1961	5,060	1960	5,000
1959	11,500	1958	40,323	1957	present
1956	138,000	1955	460	1954	5,000
1953	450,000	1952	"small run"	1951	-
1950	large	1949	-	1948	-
1947	"largest since 1944"	1946	"quite a few"	1945	-
1944	apparently large	1943	-	1942	100
1941	"large numbers"	1940	-	1939	300
1938	"very abundant"				

[a] preliminary estimate.

It is difficult to assess the value of the sports fishery supported by Stellako River chinook salmon, trout and kokanee, particularly since the full potential of this fishery has not been realized. However, it is not unlikely that the recreational value of these fish may become a major support for the local economy.

It is evident that reproductive cycles of the fish utilizing Stellako River spawning areas are such that eggs and alevins of all species are present in the gravel during the spring months. With regard to the possible harmful effects of log driving, the time restriction stipulated for the 1965 log drive appears to have provided reasonable protection to the current sockeye population. However, full protection of trout and chinook salmon could not be achieved by restriction on timing, since adults, eggs, alevins or fry of these species are present in the river from late August until the following July, throughout most of the period when log driving would be possible.

EFFECTS OF LOG DRIVING ON SALMON POPULATIONS IN OTHER STREAMS

The main reason for concern over the proposal to drive logs in the Stellako River is the long record of unsatisfactory experience in many similar streams where logs have been driven. During early development of logging in the Pacific region of the United States, log driving in numerous streams which did not have sufficient flow required periodic releases of water from splash dams. These surges of water and logs eroded the stream beds, gouged the banks, and straightened out the river channel. Any fish present at this time were prevented from spawning. Any eggs deposited previously were subject to heavy losses caused by scouring and silting, or alternatively by the reduced flow when the splash dam was closed. In addition, rearing areas for stream dwelling species such as coho, chinook and trout were largely destroyed.

There were 139 splash dam installations in the Gray's Harbor-Willapa Bay area of South Western Washington alone. The effects of these operations on salmon runs are described by Wendler and Deschamps (1955) as follows:

> "The actual splashing of a dam affected fish in several ways. If fish were spawning, the sluiced logs and tremendously increased flows would drive them off their nests. On the day prior to the splashing of one of the large Stockwell dams on the Humptulips River, an observer had noted a large number of steelhead below the apron of the dam. After splashing, no fish were seen, nor were any seen the following day.
>
> "Besides harming the fish physically, the stream environment was often adversely affected by splashing. Moving logs gouged furrows in the gravel and in many instances the suddenly increased flows scoured or moved the gravel bars, leaving only barren bedrock or heavy boulders. In some cases new stream channels were constantly being created or the existing ones changed. If the sudden influx of logs into the stream below the dam caused a log jam, as was frequently the case, dynamite or black powder was used to clear the obstruction. The policy followed in those days was that if examination showed that two boxes of powder would suffice, four were used. On some areas below dams in the lower Humptulips region, an average of five boxes of powder a day were used to break up log jams. Great numbers of salmon and steelhead trout were reportedly killed by these blasts.
>
> "Dam operators have stated that fish runs reaching the dams were reduced within three to four years after the initial construction. Furthermore, they have recognized that splashing deleteriously affected the spawning below the structure. There were periods when splashing did not occur due to economic conditions, affording a normal flow pattern below the dams. Operators claim that spawning was more successful during these years as evidenced by increased runs in the next cycle."

It is important to observe that the stream bed was gouged by logs even though flows provided by splash dams presumably were adequate for log transport. As well as the periodic surges of water, the logs themselves appear to have contributed to stream bed damage and the reported decline in these salmon runs.

Similar logging practices were employed in Western Oregon on all coastal streams. The Coquille River had 10 logging dams and innumerable log jams were created by logging debris: "Splash dams in the Coos and Coquille systems, built for the purpose of sluicing logs down the rivers, blocked the salmon runs and eliminated the productivity of the streams above them. This practice has also resulted in the sluicing of the gravel and destruction of the spawning area below the splash dams" (Gharrett and Hodges, 1950). A further study of the effects of logging on coho salmon production of Coquille River showed that there was a significant relationship between production of lumber in Coos County (in which most of Coquille River lies) and the catch of coho salmon six years later, high lumber production tending to be followed by a decrease in the catch (McKernan, Johnson and Hodges, 1950). This relationship did not exist in an adjacent county where logging had not been as extensive.

In their survey of streams in Maine, Bond and DeRoche (1950) noted that it was common practice to bulldoze small streams to prepare them for log driving. This practice removed bank cover, filled pools, exposed unproductive rock ledges, and widened the stream. Damage caused by bark deposition was also reported: "Numerous instances of bark waste blanketing the stream bottom were noted in streams that had been driven. It was evident that the bottom areas covered with bark produced little or no food organisms. In some cases this bark waste was covering areas that would ordinarily be good spawning and nursery areas for trout and salmon." The authors further observed that: "Another logging practice which is considered harmful to trout and salmon is storage of wood in a lake or pond for long periods prior to being driven. This tends to loosen the bark which is subsequently deposited on the bottom of the lake or stream when the wood is driven."

The history of sockeye runs to Lower Adams River, tributary to the Fraser River in British Columbia, provides an outstanding example of the harmful effects of log driving on salmon. A typical splash dam was operated at the upper end of this river which sent surges of water and logs over spawning grounds utilized by large numbers of sockeye. One early observer (Baldridge, 1916) recorded the following impression of this operation: "When I arrived at the head of Adams River, or the mouth of Adams Lake, I found a large dam across the river. I found a fish ladder in it, and it was in good shape. This dam is used for splashing thousands of logs down the river in such a manner that without doubt it causes a great destruction of spawn in the Adams River."

The operation of this dam was of considerable concern to the fishery overseer. He reported that even when an effort was made to avoid the adverse effects of sudden releases of water, considerable damage was done to spawning areas (Shotton, 1926a). In the drive started on November 13, 1926, a special effort was made to keep the flow high enough to prevent logs from dragging on the gravel beds. By November 19, the pole drive (5500 logs) had reached the lower end of Adams River, and poles were raking the spawning areas so badly that the fisheries guardian is reported to have left the river in disgust. In a subsequent assessment of the drive, the overseer (Shotton, 1926b) reported as follows:

> "The last mile was the scene of many jams and this is where the most damage was done both by the men tramping over the shallows and the poles raking almost every foot of that part of the river. It is almost impossible for the Guardian or myself to estimate the amount of damage done as there is no practical way of making such an estimate. The time occupied in the last mile was seven days, that in itself gives you some idea of what damage was done."

Thompson (1945) concluded that manipulation of river flow by the dam had adversely affected the Adams River sockeye run and most probably had caused the decline in this run observed after 1913. Subsequent increases in the sockeye population and the shift in dominance from the 1925-1961 cycle to the 1926-1962 cycle were attributed to the return to normal flow conditions in 1922. Here again, it was not possible to distinguish between the damage caused by surges of water and that caused by logs in gouging the river bed and driving fish out of the river.

Following a survey of Lower Adams River and the splash dam in 1940, Bell and Jackson (1941) observed that: "The effects of driving logs down a salmon stream are illustrated well in the Adams River. Bars and shallows are deepened and pools are filled due to gouging of the bottom. Curves on the course are straightened by the impact of floating logs and the stream tends to become a swift straight raceway of uniform depth and velocity. When driving ceases, the river begins a return to the natural conditions, but the process is slow. Eleven years later the Adams River still shows markedly the alterations due to the movement of logs."

Most of the splash dams were of a temporary nature and were abandoned after timber in the immediate vicinity had been removed. All but 48 of the 135 referenced dams in Maine were no longer useable when inspected in 1950, but 118 still remained as obstructions to the upstream migration of fish. Of the 139 dams reported in Washington, 53 washed or rotted out and 44 were later removed at the expense of the fishery agencies. The Lower Adams River dam was removed by the Salmon Commission at its expense in 1945 after lying unused for more than fifteen years.

The modern method of transporting logs from the forests to mills or shipping points is by trucks using public or private roads. As a consequence, log driving is no longer a common practice. There are no log drives in the rivers of Washington or Oregon, nor in any California streams used for spawning. The Clearwater River in Idaho is still used for log driving but there is little spawning (steelhead trout) in the affected part of the river.

Two rivers in Maine frequented by Atlantic salmon are also used for log drives. In this case, special provisions have been made to reduce interference with the salmon runs. Log driving is no longer common in the Maritime provinces of Canada, and water transport of logs has been replaced by trucking. The St. John River system in New Brunswick is used for pulp log drives, and special provisions, not altogether successful, have been utilized in an effort to protect salmon runs from the adverse effects of splash dams, fluctuating water levels, and the use of machines to move logs in these rivers (Ruggles, 1964).

In its brief to the Sloan Commission on Forestry, the Department of Fisheries of Canada (Whitmore, 1955) summed up the effects of log driving and concluded that driving in shallow rivers had caused extensive damage in the past and still remained a threat to the salmon fishery. In addition to the destruction caused by gouging of gravel spawning bars and resultant channel erosion, it was evident that construction of so-called "river improvements" created further dangers to salmon spawning and incubation by disrupting the normal regime of the river. It has also been observed that "Stranded logs may divert water flow from gravel bars, resulting in drying out of deposited spawn, or diversion of normal water flows from potential spawning areas" (Larkin and Graduate Students, 1959).

A large proportion of the bark on logs is knocked off during a drive, either by contact with the stream bed or bank, or by contact with other logs. It is estimated that approximately one-third of the bark is removed from logs driven down the Stellako River. Vladykov (1959) reports that about 40 per cent of the bark is removed during pulpwood drives in Quebec, and that bark deposition in some rivers amounts to several tons each year. Because of this deposition, spawning areas may be reduced and rich food production areas may be completely smothered. McCrimmon (1954) concludes that bark deposits not only reduce spawning area, but also destroy the shelter for salmon fry, making them more vulnerable to predators.

In northern British Columbia, the present practice is to log during the winter when the ground is frozen and roads remain passable before spring break-up. Where water transport is to be used, logs are stored until such time as the waterways are open. Although bark on these winter cut trees is more securely attached than that on trees cut in summer, it becomes waterlogged and very easily removed if the logs are stored in water. When dislodged, this bark sinks to the bottom as observed on both the Nadina and Stellako Rivers.

Rarely is it possible to drive logs down a river without some form of "improvement" at difficult spots to prevent permanent stranding or jamming of logs. Even in a large river such as the Fraser near Quesnel, British Columbia, it has been necessary to construct booms to direct logs away from certain areas. In the Quesnel River, projecting rocks have been removed to prevent log jams and some side channels have been closed to prevent loss of logs in shallow water. In the Stellako River, a new channel was made near the lower end of the river, diverting flow from the original channel and destroying spawning grounds in 600 to 900 ft of river length. The new channel has never been productive. Resulting changes in hydraulic structure have reduced the amount of suitable spawning ground for approximately 1500 ft upstream from the new channel.

The Canada Department of Fisheries (1964) reported that channeling on the Kitsumgallum River did not stabilize the river bed because as the flow was directed from one place, it scoured others. During log driving on this river, now discontinued, the company continually made requests for further river improvements and in some instances, had to repair and renew previous work.

Despite construction of "improvements" to facilitate log driving, stranding of logs remained a major problem. Concerning Kitsumgallum River, the Fishery Officer reported; "stranded logs that piled up on spawning riffles changed the river flow and velocity on these bars with resulting scouring in some places and stranding in others."

Salvage of stranded logs is an inevitable feature of river log driving. This may involve the use of river boats and manpower, dynamite to break up jams, or bulldozers to push logs into the river. Such operations cause breakdown of the river banks and gouging of the stream bed, as well as disturbance and killing of fish and eggs.

In view of all available evidence concerning the effects of log driving on salmon, it was clear that log driving in Stellako River could only adversely affect the salmon and trout populations reared in this stream. As already mentioned, log driving was permitted in 1965, subject to a number of restrictions, only since no other means of transporting logs to the mill appeared to be feasible during the 1965 open water period.

HISTORY OF LOG DRIVING IN THE STELLAKO RIVER

Fraser Lake Sawmills started log driving in the Stellako River in 1914 and continued this practice until 1948. The Company also drove railroad ties during this period and some tie driving continued until 1957. Annual drives reportedly comprised a maximum of 3,000,000 to 4,000,000 fbm (foot board measure) of logs and the maximum annual drive of logs and ties combined is reported to have been in excess of 10,000,000 fbm (Dahlgren, 1965). Drives are said to have started late in the spring and continued until late August. The cessation of log driving in 1948, and tie driving in 1957, has been attributed by the Company to changing economic conditions.

During almost this entire period of log driving, sockeye runs to the Stellako River were at a low level of abundance. Sockeye populations declined in 1913 and did not recover appreciably until 1946, the recovery coinciding approximately with the cessation of major log drives. However, the extent to which log driving contributed to the reduction in sockeye runs is difficult to assess. The decline in sockeye after 1913 has been attributed primarily to an obstruction at Hell's Gate which impeded the migration of sockeye en route to their spawning grounds. This obstruction first developed in 1913 and remained in effect for many years. Although a few sockeye must have reached Stellako River each year, recovery of the run did not start until 1938, when the river at Hell's Gate dropped below the obstruction level (gauge height of 25 ft)in the latter part of August for the first time since 1913. Similar occurrences in 1941 and 1942 allowed increased escapements on these two cycles. In 1945, the partially completed fishways at Hell's Gate were in operation during passage of the runs, and since 1946 the completed fishways have removed all obstruction to migration at this point. In recent years, Stellako sockeye runs have maintained a relatively high level of abundance. Whether the cessation of log driving has contributed to this increase in sockeye runs, independent from the effect of removing the Hell's Gate obstruction, cannot be ascertained. Furthermore, as no observations were recorded at the time, it cannot be determined to what extent these log drives damaged or shifted the gravel areas utilized at the time by salmon and trout spawning populations.

Logging operations in the area changed after 1948, with small scattered mills located near the timber being harvested. The large mill at Fraser Lake was dismantled and the small mills, including one at the east end of Francois

Lake near Nithi River, were supplied with logs hauled by truck from adjacent timber stands. In the latter part of this phase of development of the industry, Fraser Lake Sawmills acquired the timber quotas of a number of these small operations, including several along the western portion of Francois Lake. With the advent of pulp harvesting areas and increased wood utilization practices, Fraser Lake Sawmills has built a new mill at Fraser Lake to centralize sawing and pulp chipping at one location. The timber from holdings along Francois Lake is being brought by water down Francois Lake to the outlet.

As previously stated, the driving of logs was permitted in 1965 subject to limitations established by the Department of Fisheries. This was considered an interim measure to give the Company opportunity to establish other means of utilizing timber from the Francois Lake area. Review of the history of logging has shown that log driving is usually a temporary expedient, often used in the early stages of logging an area, to take advantage of timber stands most accessible to waterways. It is believed that in this case also, log driving in Stellako River is a temporary measure sought by the Company to deliver logs from its small scattered holdings to the Fraser Lake mill, until such time as these holdings can be consolidated into areas closer to the mill. The economic necessity of this expedient is the subject of another study which is to be presented separately from the findings in this report.

OBSERVED EFFECTS OF THE 1965 STELLAKO RIVER LOG DRIVE ON SALMON AND TROUT

Erosion and Gravel Displacement on Spawning Grounds

Stream bed scouring has been observed in association with log driving in many rivers. In general, gravel scouring occurs wherever a log jam forms in a location where velocities are strong enough to remove any loose gravel in the vicinity. The severity of erosion depends on stream bed gravel composition and water velocity at the site. It has been noted that when logs begin to accumulate they are forced either to roll under the existing jam and drag along the bottom, moving any loose gravel with them, or else form a solid barrier to the river flow. In the latter situation, the re-directed current tends to force gravel away from the upstream face of the jam until a relatively solid substrate is reached. Thus as the jam continues to build, gravel is continually swept away from its face as far as the current will carry it. In locations where relatively shallow gravel beds exist this is a rapid process, but where gravel is deep, erosion tends to continue as long as logs are available to fill the vacancy created by the eroded material. This process continues until a firm substrate is reached which will resist the force of the current, or until excess head is released by flooding over the existing river bank. Scouring also occurs when log jams form from an island to shore or in any situation where most of the flow is forced through a restricted channel.

Stream bed scouring and bank erosion were considered to be important factors to examine in studying the effects of log driving over major sockeye and trout spawning grounds. Scouring would be damaging not only to eggs, alevins or fry currently in the gravel, but also to subsequent runs if gravel were shifted to locations where velocities or depths were no longer suitable for the spawning fish. Loss of gravel from scoured areas could also leave insufficient material for redd-building at the scoured site. In either case, the result would be a reduction in the amount of available spawning area. Bank erosion could contaminate downstream spawning beds by silting, or contribute to instability of the stream by removing or undermining existing banks. Any resultant widening or re-channeling of the river could then cause flow in adjacent spawning areas to become too shallow for spawning and incubation later in the season when stream flow reached a minimum.

In 1965, log driving on the Stellako River commenced on June 6. Logs released at the outlet of Francois Lake travelled the entire length of the river and were recovered near the lower end of the stream. The first drive consisted of 3,900,000 fbm of logs and extended from June 6 to June 30 (TABLE 5). A second, smaller drive began on July 3 and was completed by approximately July 20. In all, the 1965 drive totalled an estimated 5,500,000 fbm of logs.

TABLE 5 - Log release schedule at Stellako River, 1965, giving approximate volumes of logs based on visual estimates of bag booms.

DATE	VOLUME OF LOGS (fbm)	
	Daily Releases	Totals
June 6	800,000	3,900,000
7	1,500,000	
8	1,000,000	
16	450,000	
17	150,000	
July 3	400,000	1,600,000
5	800,000	
6	200,000	
7	200,000	
Total		5,500,000

Observations were made throughout the length of Stellako River during the period of log driving. All observations were recorded with reference to spawning ground "Areas" established in 1942, and survey markers erected by the International Pacific Salmon Fisheries Commission in 1950. Survey markers are numbered consecutively downstream from 1 to 215, those on the right and left banks being designated by the prefix "R" or "L", respectively; survey hubs on islands are identified by the prefix "Is." Location of spawning ground areas, numbered consecutively downstream from I to IX are shown in FIGURE 2, and their relation to the 1950 survey hubs given in TABLE 6. Areas VIII and IX are referred to as the "lower river".

TABLE 6 - Location of Stellako River spawning ground Areas I-IX in relation to survey hubs erected in 1950.

Spawning Ground Area	Survey Hubs
I	Hub R1 to R27
II	Hub R27 to R45
III	Hub R45 to R61
IV	Hub R61 to R85
V	Hub R85 to R92
VI	Hub R92 to R134
VII	Hub R134 to Is.180
VIII	Hub Is.180 to Is.190
IX	Hub Is.190 to Is.215

Following the release of logs on June 6, 7 and 8, a total of 26 major log accumulations developed in Stellako River. Of these, 11 were on or adjacent to important salmon spawning grounds and in most cases some erosion was detected. Log jams formed by later releases were similar to these initial accumulations, although some occurred in different locations due to changes in water level and flow pattern.

In order to examine the effects of log driving on stream bed structure, groups of markers had been placed in the river prior to June 6, in four areas where erosion was anticipated. These markers, consisting of heavy, painted objects (bricks, large stones, etc.), were photographed in position on the stream bed before and after log driving. One set of markers was completely removed by high velocities and shifting stream bed during formation of an adjacent log jam (Hub R180). A second set of markers was largely obliterated by fine materials deposited during jam breaking (Hub R204-R205). Markers

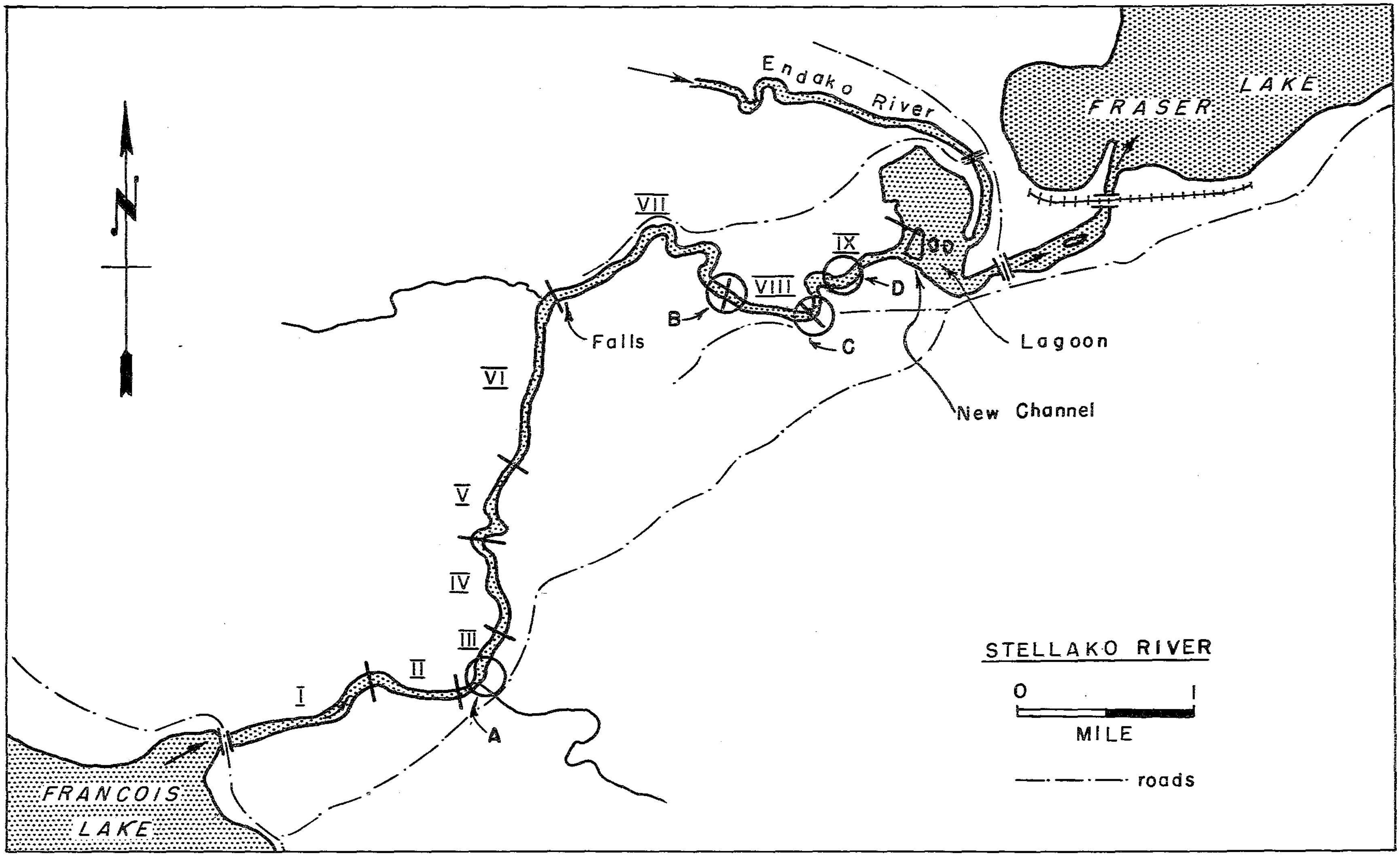

FIGURE 2 - The Stellako River showing spawning ground Areas I-IX and four Sites (A-D) where the effects of log driving on major spawning beds were examined in detail, 1965.

in the two remaining areas were only slightly disturbed as log jams did not form in adjacent waters (Hub L70A, and Hub R194 to R195). Photographic documentation of these patterns is contained in a preliminary report (Boyd and Ryan, 1965).

Additional markers were placed in different locations after log driving was well underway, and were located in areas where some scouring had already occurred (Hub R49-R50, Is.179-Is.180-L180). Although high velocities and turbulence precluded useful photography in these areas, it was observed that almost all markers were shifted. Only occasional markers remained in position, wedged between large rocks. Markers were also placed between Hubs L209-L210, an area where no log jam occurred. In this location, offshore markers were moved only by passing logs and those near shore remained undisturbed. Displacement of these painted markers showed conclusively that erosion was occurring, particularly in gravel areas adjacent to log jams.

Of the 26 log jams resulting from the initial drive, four were located in areas judged to be most critical with regard to salmon spawning grounds (Sites A to D, FIGURE 2). Detailed studies of scouring, bank erosion and bark deposition were carried out at these four locations (FIGURES 3 to 6).

At Site A in Area III, both bank and bottom erosion occurred (FIGURE 3). The bottom structure originally consisted of large boulders covered with a relatively thin layer of fine gravel. During build-up of a large log jam on June 6-8, much of the gravel beneath and adjacent to the jam was eroded. Most of the displaced material was deposited behind an island (Hub R50A to R51) while the remainder was swept down the main channel. Although the jam was subsequently broken, it was rebuilt by later releases of logs and further scouring occurred. Erosion and jam formation in this area are also shown in FIGURES 7, 8 and 11 and are further documented on movie film.

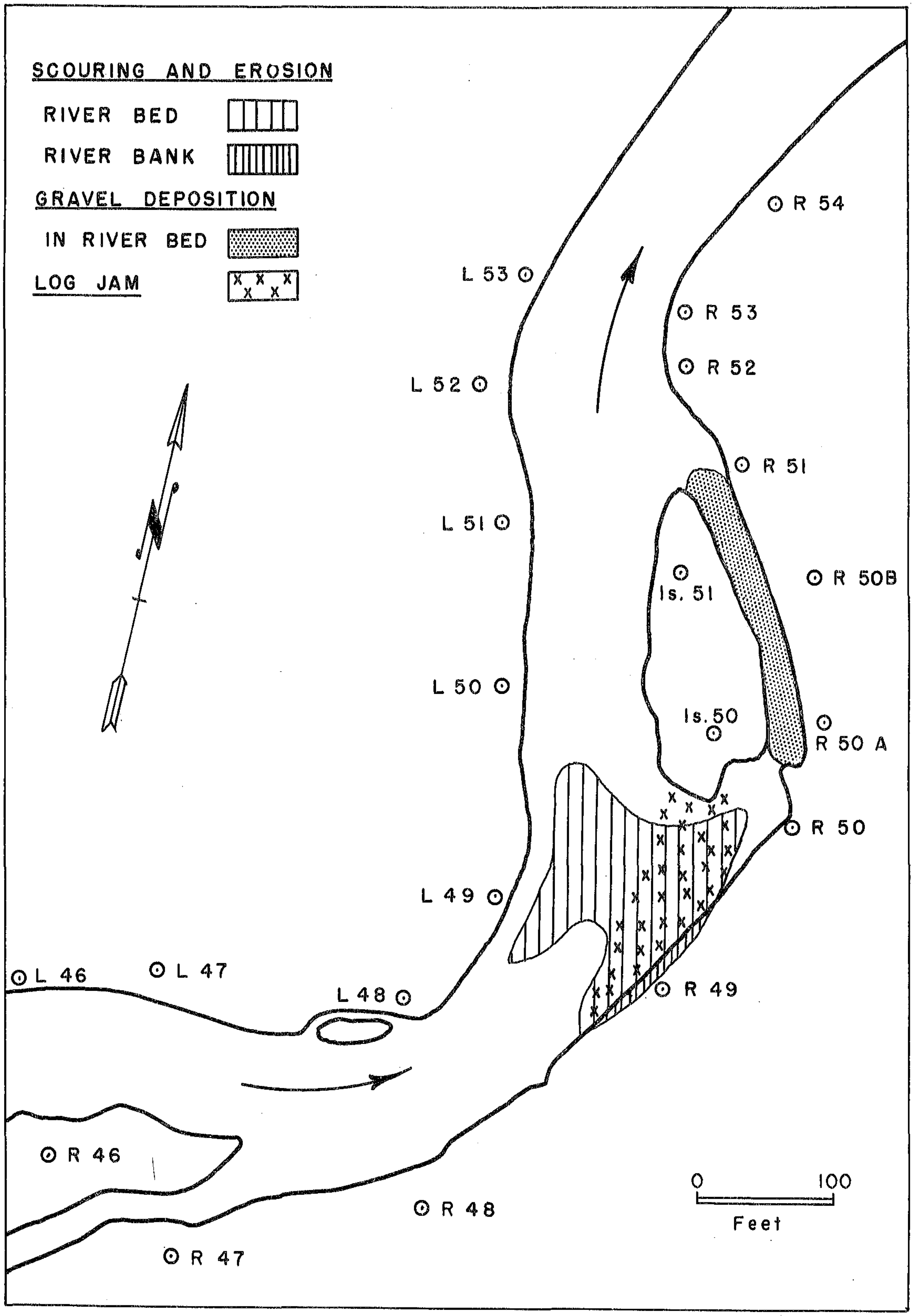

FIGURE 3 - Extent of log jam and resulting changes in the river bed at Site A in Area III, Stellako River, 1965.

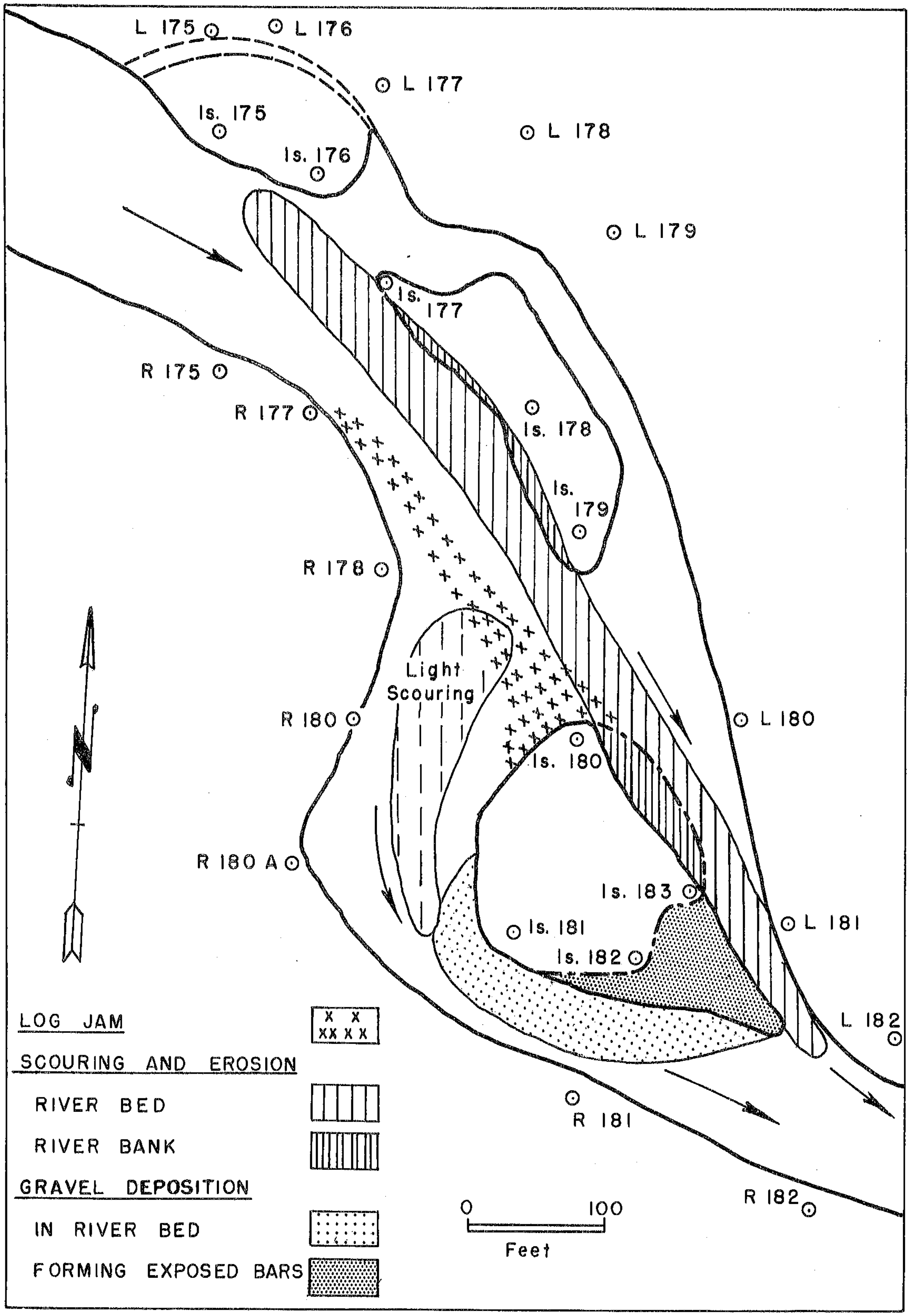

FIGURE 4 - Extent of log jam and resulting changes in the river bed at Site B in Area VIII, Stellako River, 1965.

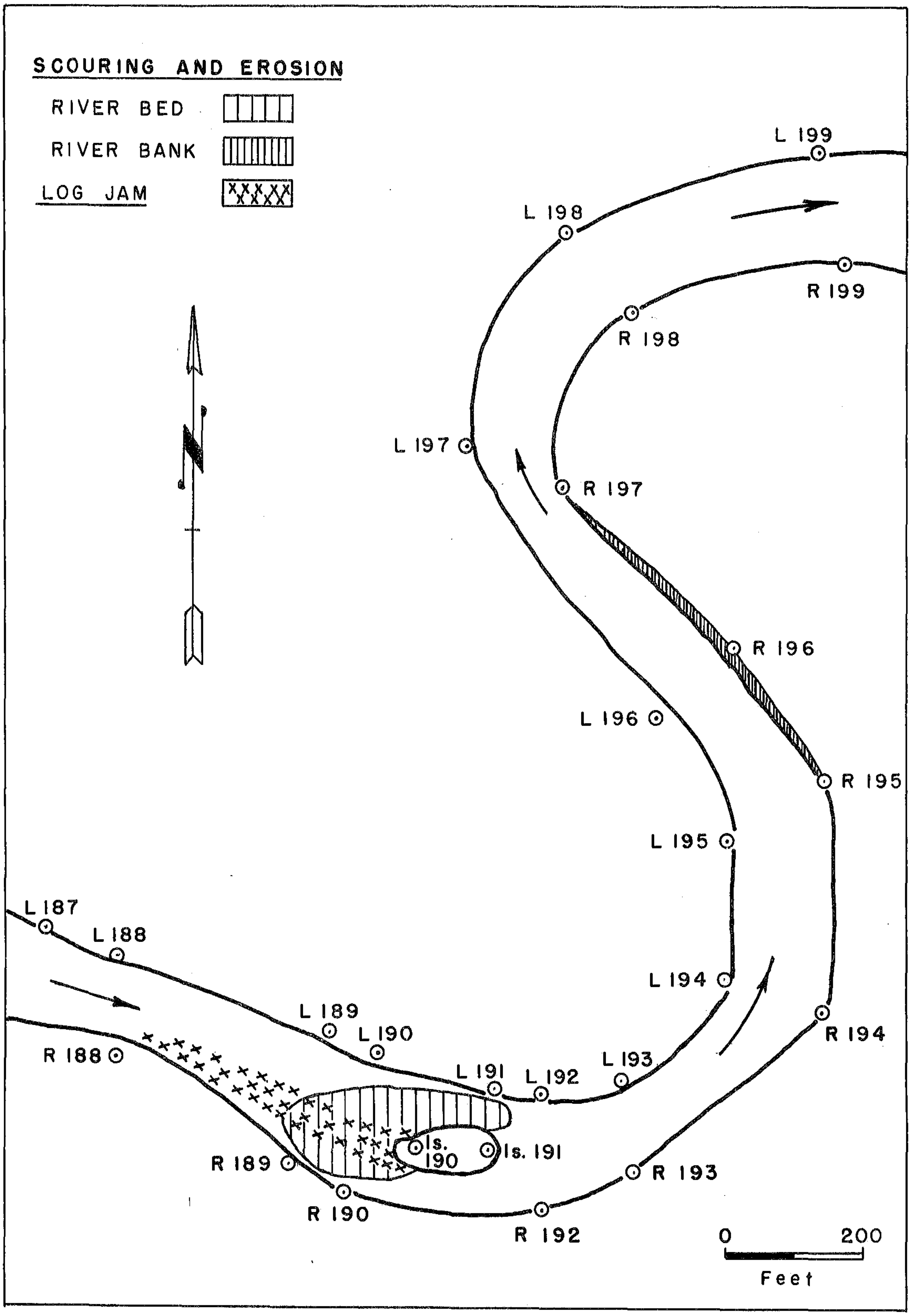

FIGURE 5 - Extent of log jam and resulting changes in the river bed at Site C in Area IX, Stellako River, 1965.

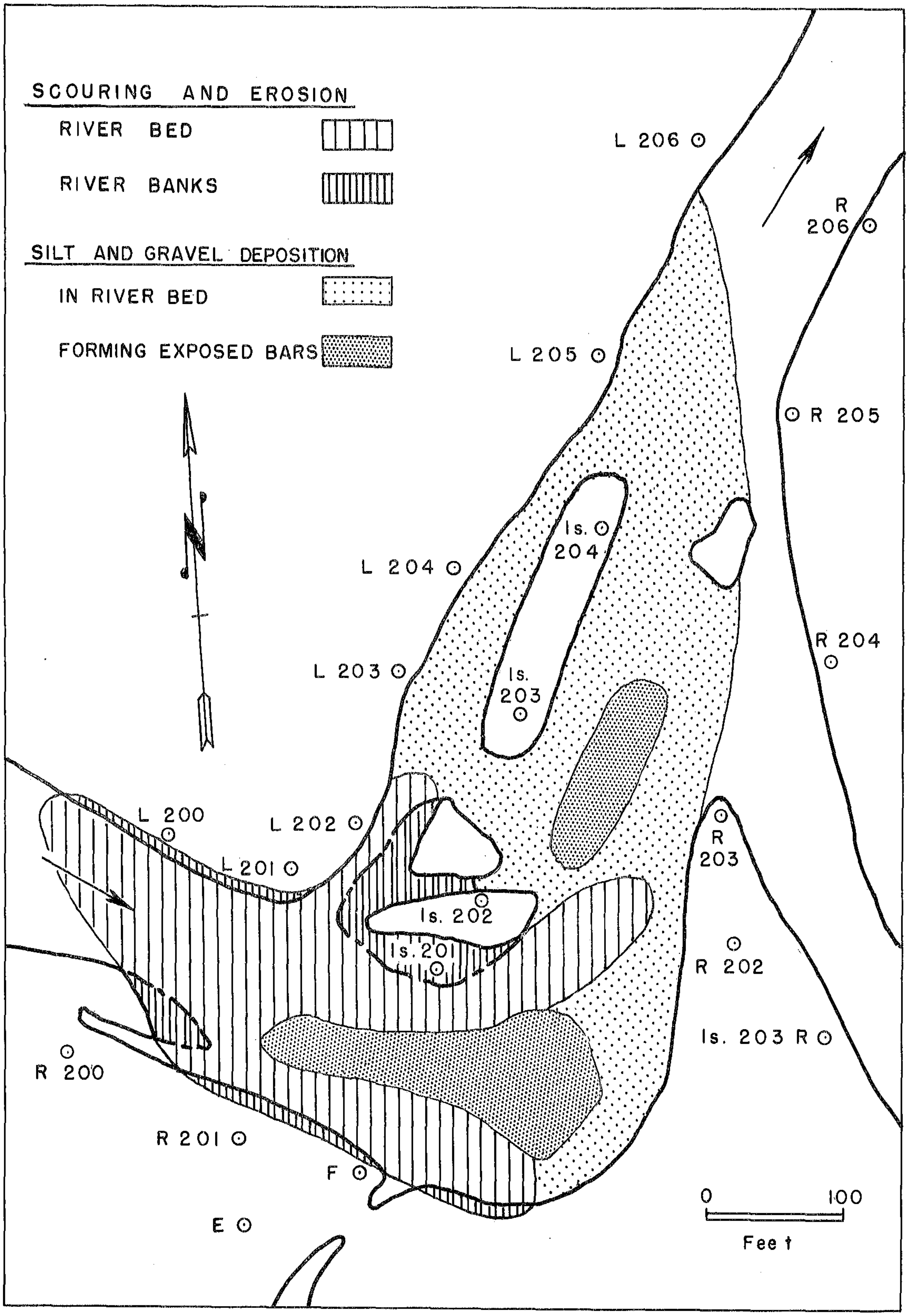

FIGURE 6 - Changes in river bed resulting from large log jam at Site D in Area IX, Stellako River, 1965. The log jam extended from above Hubs R200-L200 downstream to Hubs R203-Is.204 and covered the full width of the river (see also FIGURE 14).

The result of a large jam formed on an island in Area VIII was examined also (Site B; FIGURE 4). Here the bottom structure was originally formed by a deep layer of moderate sized gravel. One of the marker patterns described earlier was completely removed from the area marked "light scouring" and deposited some distance downstream below Hub Is.182. However, some suitable spawning gravel did remain in this location. Eventually this large jam restricted most of the flow to a narrow channel, causing very heavy scouring along nearly 800 ft of the river bed. Erosion was so extensive that little if any fine material remained in a location formerly well-suited for spawning (FIGURE 12).

A situation similar to that shown in FIGURE 4 also occurred at Site C (FIGURE 5), except that here the bottom was composed of much larger stones with a relatively small amount of fine material on the surface. Erosion at Site C occurred only during jam formation. Bank erosion from Hub R195 to R197 (FIGURE 5) did not result from the log jam above, but was caused by passing logs directed toward shore by the current.

The most severe scouring in the Stellako River in 1965 was observed at Site D in Area IX (FIGURE 6). Very severe scouring occurred during both formation and breaking of a large log jam in this area. Extremely heavy gouging took place along the upstream face of this jam and down the right bank of the river (FIGURES 9 and 10). Gravel, sand and silt were removed to a depth exceeding six feet in some cases and deposited downstream in areas which subsequently became very shallow or went dry (FIGURES 6, 13 and 14). The log jam, containing an estimated 2,000,000 fbm of timber covered the entire area from above Hub L200 down to Hub Is.204 (FIGURE 6), and filled the river from bank to bank (FIGURES 14 and 15). Some logs were forced deep into the gravel bed while others were elevated several feet above the water level (FIGURE 16).

FIGURE 7—Beginning of log jam in Area III. Note high velocities skirting jam and causing bottom erosion also bank erosion at right.

FIGURE 8—Continued build-up of log jam in Area III. Note restriction of channel on right causing stream bed erosion.

FIGURE 9—Log jam in Area IX. High velocities continually forced logs under jam and deeply eroded the river bottom.

FIGURE 10—Severe erosion occurred in this restricted channel (left side of picture) which was opened in order to remove log jam from Area IX.

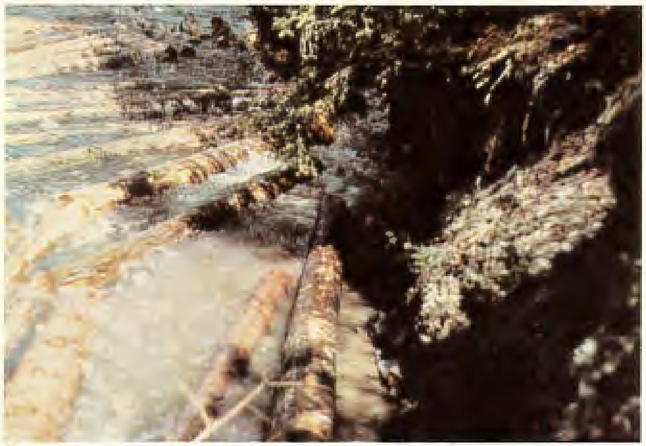

FIGURE 11—Bank and stream bed erosion on spawning beds in Area III resulting from logs gouging the bank and bottom at high velocities.

FIGURE 12—Log jam in Area VIII closed off inner channel (foreground) causing increased flow and severe erosion in left channel (background).

FIGURE 13—Silt deposited in a log jam in Area IX resulting from bottom and bank erosion in the vicinity.

FIGURE 14—Large log jam (partially removed) in Area IX. Note bed load deposits downstream (light color, left side of picture).

FIGURE 15—Central part of large log jam in Area IX. Logs here are piled more than twelve feet deep. Note extent of peeling.

FIGURE 16—Log jam in Area IX. Note extent of peeling and height of logs above water level, caused by other logs forced underneath.

FIGURE 17—Very deep bark deposit (lower right), sand from erosion upstream (center), and original gravel bed (upper left) in Area IX.

FIGURE 18—Logs stranded on bar in Stellako River caused movement of surrounding gravel. A similar situation was examined in detail at Weaver Creek.

Originally composed of a deep layer of gravel, the resulting change in structure of the river bed has left little useful spawning ground in this entire area.

At the four sites described, the depth of erosion varied considerably and ranged from approximately six inches to more than six feet. The total area eroded in these four locations (Sites A to D) was approximately 23,800 sq yds, the majority of which was choice spawning ground. This represents 8.6 per cent of the entire useable spawning ground (277,000 sq yds) in Stellako River. It should be made clear that this represents only the four areas specifically described and does not include other locations in the river which were more numerous but less severely scoured.

It also must be recognized that the effects of erosion will remain in existence for several years, as Stellako River is void of any tributaries which contribute significant amounts of replacement gravel. Natural replacement must therefore come from movement in the existing stream bed and this process requires many years. Some areas scoured during log drives prior to 1947, and possibly augmented by tie drives until 1957, were only partially replaced by 1965.

Bank erosion occurred to varying degrees at Sites A to D (FIGURES 3 to 6) and to a lesser extent in several other locations throughout the river. While bank erosion caused by the 1965 log drive alone may not have serious consequences, continued driving of large volumes of logs would undoubtedly augment this damage. Erosion from Hub R195 to R197 (FIGURE 5), although not directly on the spawning beds, may be considered serious as it is undermining a single row of large trees which support the river margin. The area behind these trees is very low-lying land and would be subject to cutting and re-channelling if the existing river bank were destroyed. A long gravel bar in this area, extending from Hub L194 to L197 (FIGURE 5), is consistently utilized as a major spawning area and supported more than half the entire lower river sockeye spawning run in 1965. Loss of this spawning ground would be extremely serious and would be likely to occur if the river banks were permitted to deteriorate further in this area.

Loss of a significant amount of spawning ground was clearly shown as a result of the 1965 log drive. The continued driving of logs would result in further deterioration of the remaining spawning grounds in the Stellako River.

Deposition of Bark and Fiber on Spawning Grounds

Previous reports in the literature have indicated that much debris is carried along the river bottom during log driving and that some of this material is deposited on gravel spawning beds (Vladykov, 1959; Bond and DeRoche, 1950). To determine the amount of debris (bark, twigs, etc.) resulting from the 1965 log drive, sampling was carried out in the lower Stellako River, just where it enters the lagoon (FIGURE 2), approximately 300 to 400 ft downstream from survey Hub L213. Two methods were used to measure the movement and deposition of wood material. Sampling trays (1 ft x 1 ft x 1 in. deep), containing a wooden grating, were used to trap materials being carried along the stream bottom. Although these were not quantitative samplers, the trays yielded data on the relative movement of wood debris before, during and after log driving. The amount of debris deposited on or in the gravel was determined by collecting all material in an area one ft square and three in. deep, using a Surber sampler. Fifty-seven collections were made with the Surber sampler and 44 with the trays.

All debris collected was examined and that portion derived from wood (termed total fiber) was measured volumetrically. The total fiber was then examined in order to separate and measure the volume of bark material. Sampling trays were left submerged for varying periods from 5 to 30 days. In order to compare results, the volume of fiber or bark was divided by the number of days of exposure and the area of the tray to provide an index (ml/sq ft/day) of relative abundance. Fiber and bark from Surber samplers represented that volume present in an area 1 ft square and 3 in. deep and was expressed as ml/sq ft/3 in. depth.

Sampling trays were exposed for 42 days in the river before log driving commenced. During this time, melting snows were raising the river level and there would have been a tendency for material to be carried along the river bottom due to natural flushing. However, sampling showed that very little material was flushed out of the river during this period (TABLE 7), even though the discharge reached 3020 cfs on June 4. Sampling trays were emptied and replaced late on June 4 and log driving began on June 6. By the time these trays were removed on June 9, the samples indicated that much fiber, a great deal of it fresh bark, was added to the river by the log drive. The maximum discharge during this five day period was 3190 cfs, only 170 cfs greater than during the previous period. Trays were replaced on June 9 for a period of 21 days, and again much fiber was collected. The final sample obtained during log driving was taken for 28 days commencing June 30. This was followed by a 28 day sample to evaluate the amount of debris being carried after driving was completed.

Results obtained from sampling trays showed that the amount of bark and total fiber being carried along the river bottom increased tremendously when log driving began, especially along the left side of the channel, and then tapered off to a low level once driving was completed (TABLE 7). The increase in bark was due almost exclusively to that which was peeled from logs during

TABLE 7 - Measurement of wood fiber movement along the river bottom in Stellako River, 1965.

SAMPLING PERIOD	DURATION OF SAMPLE Days	MAXIMUM DISCHARGE cfs	TOTAL FIBER INDEX ml/sq ft/day Location in Channel Middle	TOTAL FIBER INDEX ml/sq ft/day Location in Channel Left	BARK INDEX ml/sq ft/day Location in Channel Middle	BARK INDEX ml/sq ft/day Location in Channel Left
		Prior to Log Driving				
April 23 to June 4	42	3020	0.08	0.01	0.02	0
		During Log Driving*				
June 4 to 9	5	3190	1.07	6.20	0.13	2.36
June 9 to 30	21	2510	-	3.86	-	2.28
June 30 to July 27	28	1960	-	1.14	-	0.76
		After Log Driving Completed				
July 27 to Aug. 24	28	1430	-	0.15	-	0.13

*Log driving began at noon, June 6.

driving. The quantity of twigs and old pieces of wood (total fiber minus volume of bark) being transported along the river bottom at this time also became larger (TABLE 7). Apparently log jams and erosion stirred up debris in the river bed and accounted for the increment in these older fibers.

An increase in the amount of fibrous material transported along the river bottom can lead to additional deposition on spawning grounds, and Surber samples were taken to measure this effect. Results of sampling in Stellako River before and after log driving (May and August) showed a considerable increase in the amount of bark deposited within the gravel (TABLE 8). Between survey Hubs Is.202 and R203 in the lower river, bark concentration rose

TABLE 8 - Surber sampler collections of wood debris in Stellako River spawning gravel, 1965.

AREA SAMPLED	NO. SAMPLES		TOTAL FIBER CONCENTRATION ml/sq ft/3 in. depth		BARK CONCENTRATION ml/sq ft/3 in. depth	
	May	Aug.	May 25	Aug. 23	May 25	Aug. 23
Between Survey Hubs Is.202 and R203, in Area IX.	6	6	2.00	30.50	0	25.30
Near Survey Hub F, in Area IX.	6	6	6.34	8.17	3.33	6.83
Near Survey Hub L210 in Area IX.	6	3	2.67	1.67	0.67	0.67
150 ft downstream from Glenannan Bridge, left bank, Area I.	6	6	5.83	2.33	0	1.83
Upstream side of Glenannan Bridge, right bank, Area I.	6	6	8.16	1.50	0	1.50
Weighted Mean			5.00	9.63	0.80	7.95

sharply from 0 to 25.3 ml/sq ft/3 in. depth. An increment of approximately 3.2 ml in the volume of older fibers also occurred at this location. Some increase in total fiber was measured at Hub F, while small decreases occurred at Hub L210 and at the two sampling locations in Area I. After log driving was completed, larger quantities of bark were found in all areas tested except at survey Hub L210. Since sampling did not cover the entire river, the total increase in wood debris could not be computed. However, average values determined from all locations indicated that fiber and bark concentrations remaining in August were greater than those present before the log drive (TABLE 8).

These two sampling programs indicated clearly that log driving added to the amount of fibrous material transported in Stellako River (TABLE 7), which in turn led to increased concentration of these materials within the spawning gravel (TABLE 8). It is likely that the amount of bark and fiber deposited is related to the volume of logs driven, and continued driving would probably lead to additional deposition within spawning gravel. Effects of these deposits on survival of salmon and trout are discussed in a following section of this report.

Additional information concerning wood deposition in Stellako River was gained from observations during and after log driving. During log driving, there was a continuous movement of bark and other woody material throughout the entire depth of the river. This material had been peeled from the logs as they moved downstream (FIGURES 15 and 16). After driving was completed, large accumulations of fibrous material remained, primarily along the shores and in quiet eddies throughout the river. In most cases this debris collected on the gravel surface, but in some areas became well interspersed within the gravel bed, or formed large deposits which were subsequently covered by eroded gravel.

The extent of bark deposition was examined in detail at Site D in Area IX (FIGURE 19). Areas indicated as "moderate" deposition show locations where small pieces of fibrous material became interspersed in the gravel, and those of "heavy" deposition indicate areas where large pieces of bark were deposited and sometimes overlaid by gravel and sand. It was at the lower perimeter of the exposed gravel bar between Hubs Is.202, Is.203 and R203 (FIGURE 19) that gas bubbles were observed rising from the bottom and the odor of hydrogen sulphide gas was detected in August, 1965. In June, this area had heavy bark deposits which were subsequently covered by eroded gravel and sand. Much organic material from eroded banks had also been deposited

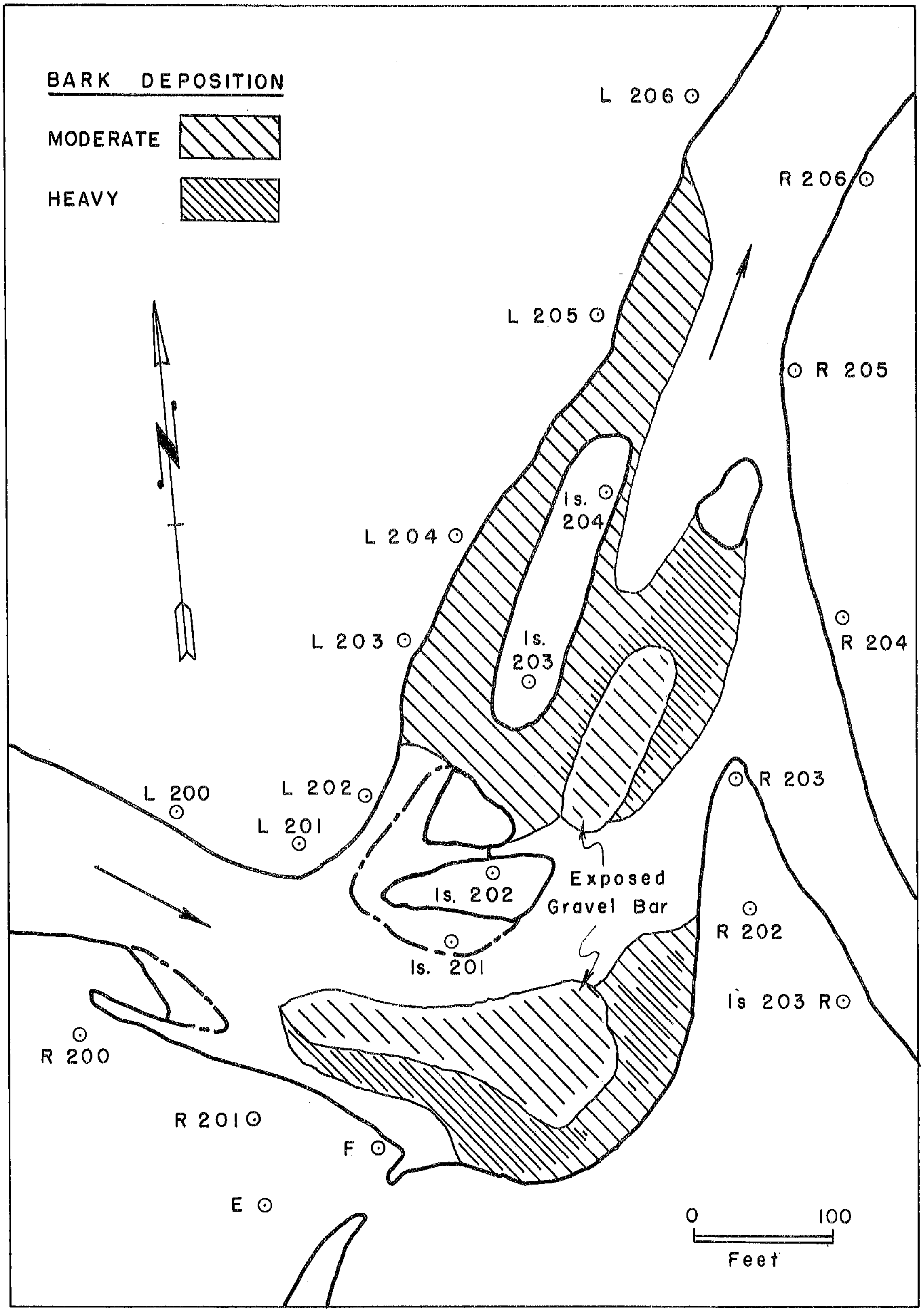

FIGURE 19 - Bark deposition resulting from a log jam at Site D in Area IX, Stellako River, 1965.

here. Limited examination showed wood debris to be interspersed within spawning gravel in several other areas (Hubs R50 to R51 - see FIGURE 3, Hubs L76 to L78, and Hubs R80 to R85) and further deposits probably existed in numerous locations throughout the river.

One example of the many deep wood deposits which remained on the gravel surface is shown in FIGURE 17 and locations of further accumulations are catalogued in TABLE 9. These represent deposits which were still evident by mid-October, 1965, and verify that the volume of material had diminished only moderately by that time. Any further decomposition will tend to proceed more slowly in the low water temperatures during winter months (November-April), as organic decomposers are less active at colder temperatures. It becomes evident that these accumulations will not be removed within one year at the present level of decomposition. If permitted, annual log drives of equivalent or greater volumes of timber will therefore tend to add organic materials on a cumulative basis, unless an increase in biological decomposers occurs which is sufficient to balance the increased volume of wood products. In any case, the natural ecology of the river bed is threatened by contamination with partially decomposed wood, and by an increase in the carbon dioxide concentration (and possible reduction in dissolved oxygen) resulting from greatly increased organic decomposition.

There is some evidence that adult salmon might respond unfavorably to large quantities of foreign substances deposited in or adjacent to their original spawning grounds. The extremely sensitive olfactory perception of Pacific salmon has been well documented (Brett and Groot, 1963), with experimental evidence of sensitivity to one organic compound at a dilution of approximately 1 part in 8×10^{10} parts water (Alderdice _et al._, 1954; Idler _et al._, 1956). Since olfaction is involved in the homing of salmon

TABLE 9 - Deposits of wood debris remaining in the Stellako River, October, 1965.

Spawning Ground Area	Location (Hub No.)	Extent of Wood Deposits
I	R & L3 - R & L27	Light accumulations along shore and in eddies.
II	R27 - R28	Light accumulations in eddies.
	L28	Light to moderate accumulations in eddy.
	R35 - R43	Light to moderate accumulations along shore.
III	R57 - R60	Light accumulations along shore.
	Below R60	Heavy accumulations along shore and in eddy.
IV	L70A - L71A	Light accumulations along shore.
	R72 - R74	Heavy accumulations along shore.
	R75 - R76	Heavy accumulations along shore.
	L76 - L77	Heavy accumulations along shore.
V	R85 - R87	Very heavy accumulation - reaching midstream.
	L87 - L88	Very heavy accumulation - off shore in eddy.
	L88 - L89	Moderate accumulation along shore line.
	L89	Heavy deposit - off shore in eddy.
	Below R89	Heavy deposit - along shore line.
VI	All	Very little bark - all high velocity.
VII	Below L157	Very small deposits in eddies.
VIII	R178 - R180A	Moderate collections along right bank.
IX	L201 - 204	Extremely heavy deposits.
	R210 - R212	Heavy deposits in slack water areas.
	Below L211	Moderate deposits along shore.
	Is.212 - L212	Moderate deposits along shore.

(Wisby and Hasler, 1954; Idler et al., 1961), the change in olfactory stimuli caused by greatly increased organic deposits might divert fish away from their original spawning areas into other parts of the stream. Although this problem has received little direct study, the possibility exists that deposition of bark and wood material could make large areas of spawning ground unattractive to the native salmon run.

Water Quality in the Stellako River

Samples of water were collected from the Stellako River before, during and after the log drive to assess the effect on water quality. It was expected that concentrations of solids would be the physical characteristics most likely to be increased by log driving, due to bottom and bank erosion and bark loss. Chemical contamination through leaching of tannin from the bark and wood was also considered to be a possibility. The concentration of tannin was of concern since tannin is known to be toxic to fish.

Water samples were obtained from three areas in Stellako River - the source of the river at Francois Lake outlet, the lower river in Area IX and farther downstream at the outlet of the lagoon (FIGURE 2). Samples taken before and during log driving were analysed for tannin, and for suspended, volatile (organic material) and total solids.

Because of certain chemical similarities, the analyses for tannin determined both lignin and tannin without differentiating between the two substances. Results showed that concentrations of tannin and lignin were very low and apparently remained unaffected by log driving (TABLE 10). Apparent differences between samples are believed to have been due primarily to the difficulty of obtaining accurate measurements at these low concentrations.

TABLE 10 - Water quality in Stellako River before and during log driving, 1965.

DATE	DISCHARGE	LOCATION	TANNIN & LIGNIN	SUSPENDED SOLIDS	VOLATILE SOLIDS		TOTAL SOLIDS
	cfs		ppm	ppm	ppm	per cent	ppm
			Before Log Driving				
April 23	418	Source	0.42	5.5	41.5	60.4	68.8
		Area IX	0.42	7.8	32.3	41.8	77.2
		Lagoon	0.50	2.9	40.2	53.9	74.6
June 5	3190	Source	0.25	ND	30.1	44.3	68.0
		Area IX	0.20	ND	21.6	31.1	69.6
		Lagoon	0.32	1.8	33.8	42.6	79.3
			During Log Driving*				
June 6	2540	Source	-	-	-	-	-
		Area IX	0.40	3.8	34.4	48.8	70.4
		Lagoon	0.30	3.2	34.9	50.0	69.8
June 7	2300	Source	-	-	-	-	-
		Area IX	0.48	5.0	-	-	-
		Lagoon	0.50	0.8	37.0	47.1	78.5
June 16	2080	Source	-	-	-	-	-
		Area IX	0.55	ND	56.8	68.3	83.3
		Lagoon	0.55	5.5	63.5	76.7	82.8
July 3	1520	Source	0.52	2.3	29.0	37.8	76.7
		Area IX	0.42	ND	74.1	69.8	106.1
		Lagoon	0.57	1.4	53.9	67.2	80.2
July 6	1320	Source	0.40	1.7	67.1	76.3	87.9
		Area IX	0.50	5.5	19.9	26.1	76.2
		Lagoon	0.57	2.0	43.8	63.0	69.6

*Log driving began at noon, June 6.

ND - none detected.

Analyses for solids did not indicate any major changes which could be attributed to the log drive (TABLE 10). The concentration of suspended solids remained low throughout the period of sampling. Concentrations of total solids and volatile solids were affected only occasionally by log driving. Samples taken during the first log drive on June 6 showed no increase in total or volatile solids when compared with those from the previous day. However, water sampled on July 3 showed an increase in both total and volatile solids between the river source and Area IX, although this increase was less evident farther downstream at the lagoon. It should be noted that these water samples were obtained at mean stream depth and thus did not measure the debris which sank and was carried along near the river bed. Data on the movement of these solids have been presented elsewhere.

As previously mentioned, gas bubbles and the odor of hydrogen sulphide had been noted in late August, at a location in the river where extensive bark deposits had been covered with eroded gravel (Site D, Area IX). On October 17, three gas samples taken from the site indicated a high carbon dioxide content (0.58%, 0.43%, 0.16%) relative to air (0.03%), but there was no evidence of hydrogen sulphide or of any gases not usually found in pure atmospheric air. Results of water analyses did not indicate any significant change in water quality in this vicinity (TABLE 11). It is likely that air bubbles were trapped in the gravel, along with organic matter, during the severe turbulence and erosion caused by a log jam in this area. During August, at 70°F, rapid microbial degradation of organic matter apparently consumed the trapped oxygen, causing pockets of anaerobisis with hydrogen sulphide production. Oxygen apparently trapped without organic matter was not depleted and was detected in the subsequent samples. By October 17, water temperature dropped to 49°F, apparently reducing microbial activity so that anaerobisis no longer occurred and hydrogen

TABLE 11 - Water quality measured October 17, 1965 near the site of gas emission observed in August, 1965 (Site D, Area IX).

CHARACTERISTIC	LOCATION OF SAMPLES WITH RESPECT TO SITE OF GAS EMISSION			
	Upstream 250 ft	Upstream 50 ft	At Site	Downstream 50 ft
Dissolved Oxygen, ppm	10.7	-	10.7	-
Temperature, °F	49	49	49	49
Saturation Dissolved Oxygen, per cent	101	-	101	-
Alkalinity, ppm as $CaCO_3$	37	36	36	36
Hardness, ppm as $CaCO_3$	42.5	42.5	42.5	42.5
pH	7.0	7.0	7.0	7.0
Chloride	0	0	0	0
Tannin and Lignin, ppm	0.45	0.40	0.35	0.45
Conductivity, μmhos	73.2	72.6	73.7	72.6
Turbidity, ppm	0	0	0	0
Transmittance versus distilled water, per cent	95.5	95.5	95.5	95.5

sulphide was no longer produced. Anaerobic conditions, lethal to aquatic life, were evidently very localized and of brief duration in the Stellako River in 1965. However, the potentially dangerous consequences of increased organic decomposition are clearly indicated.

Eggs and Fry

In order to protect the resident sockeye population, the 1965 log drive in Stellako River was restricted to the period after sockeye fry had emerged from the gravel. A trap was installed in the river in May, 1965 to check previous measurements of emergence timing and indicate when the 1965 drive could begin. Trap catches of sockeye and other species, and subsequent observations throughout the river, provided limited information regarding the effects of log driving on eggs and fry. Further data were obtained experimentally and are presented in a later section of this report.

Since the trapping program was designed to measure timing of emergence, rather than estimate numbers, a single small trap (3 ft x 1.5 ft) was used to capture only a small percentage of the total sockeye fry migration. The trap was installed in the lower Stellako River (at Hub R194, Area IX) in a velocity of approximately 2.5 fps. It was operated throughout the nightly migration period (dusk until dawn) every second or third night from May 10 to June 3. Shorter periods of trapping were employed on June 11 and 23 while log driving was in progress.

Catches of sockeye fry indicated that emergence had already begun by May 10 and reached a peak from May 25 to 27 (FIGURE 20). Numbers dropped sharply thereafter, and by June 3 it was concluded that most sockeye fry had left the gravel. The Company was so informed and log driving began on June 6. Subsequent trapping showed that very few sockeye fry remained by June 11 and none were captured on June 23. These results confirmed previous measurements of the time of sockeye fry emergence in Stellako River and indicated that disturbance of the stream bed by log driving any earlier in the season would have been potentially dangerous to a large proportion of the resident fry population.

Chinook salmon fry were also captured throughout the trapping period. Although numbers were small, catches indicated a steady migration from May 10 to June 3 (TABLE 12). No chinooks were caught on June 11, but the fry captured on June 23 were well advanced and apparently had been feeding in the river for some time. Chinook fry were frequently observed in the river throughout the log driving period, providing additional evidence that part of this population resides in Stellako River for at least a month after emergence.

As expected, no trout fry were captured this early in the season. Trout eggs deposited in April and May would still be developing within the gravel at the time of trapping and presumably during much of the log drive. Effects of

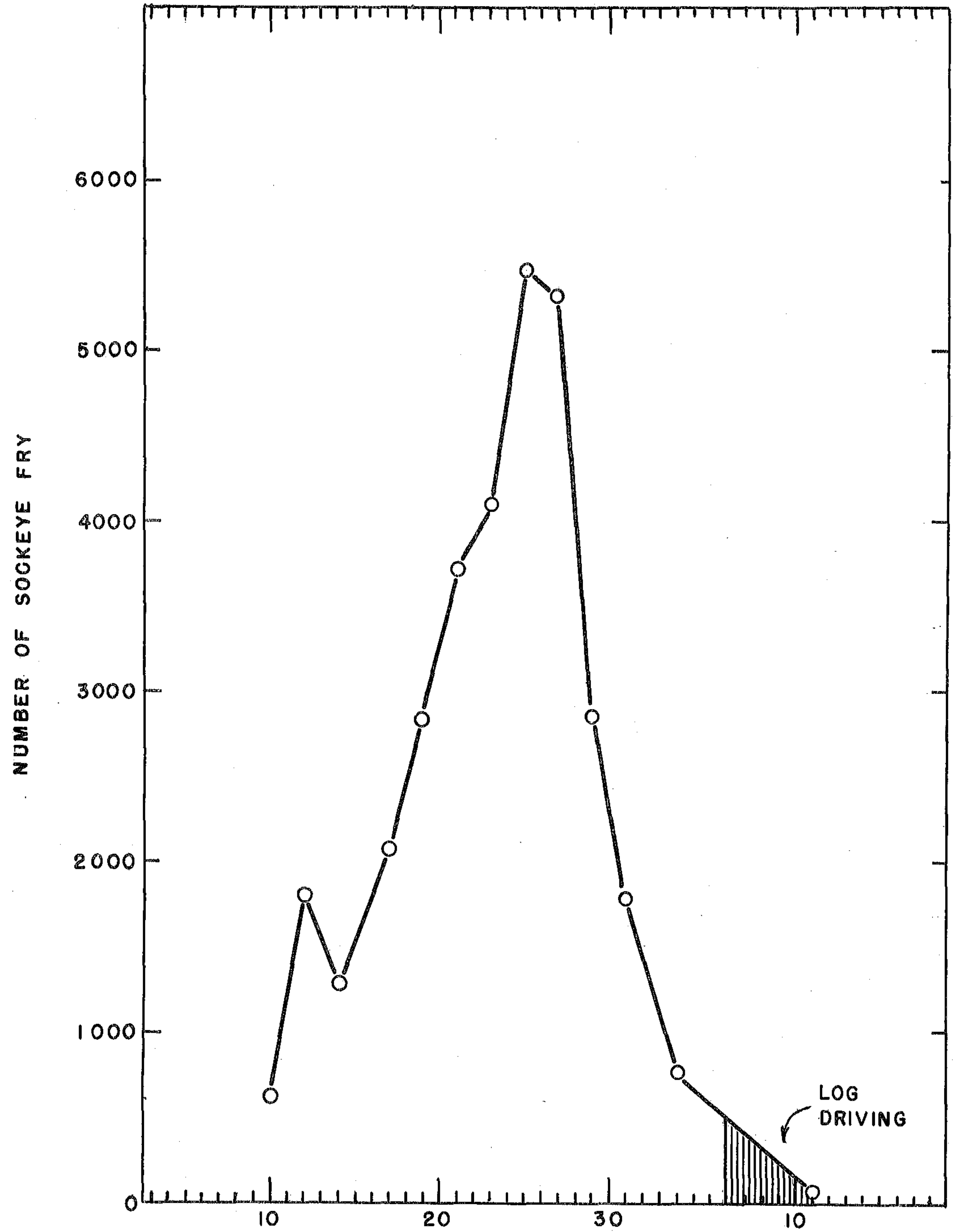

FIGURE 20 - Timing of sockeye fry emergence as shown by trap catches in lower Stellako River, 1965.

TABLE 12 - Trap catches of chinook salmon fry in lower Stellako River, May 10-June 23, 1965.

Date	Catch
May 10	8
12	25
14	33
17	77
19	76
21	98
23	126
25	92
27	78
29	60
31	18
June 3	8
11	0[a]
23	34[b]

[a] Catch during 2 hrs fishing.

[b] Catch during 2.5 hrs fishing.

the log drive on trout eggs remaining in the gravel could not be assessed from field observations, but those located in areas of severe scouring would have had little chance of survival. Certain aspects of this problem were studied experimentally and results are presented elsewhere in this report.

The effects of log driving on eggs and fry would not end when the drive itself was over. Deposits of bark and wood debris remaining on the river bed would tend to reduce the number of bottom organisms available as food for young fish (chinook fry, trout) residing in the river. This effect would be cumulative with each log drive as the deposits of debris increased in size and number. As already indicated, decomposition of this increased organic material could cause increased concentrations of carbon dioxide and even produce anaerobic conditions which would be lethal to stream life.

The fine particles of bark and wood introduced by the log drive might affect survival of fry, as well as smothering any eggs and alevins still within the gravel. Toxic materials leached from bark and wood could also have lethal or sub-lethal effects on the developing fish. These problems were also examined experimentally in 1965.

Although the majority of salmon fry had emerged from the gravel before log driving began, many remained to feed in the wide, lake-like areas of lower Stellako River. Large numbers of logs were stored at these locations and much of the area was shaded by log booms. It is possible that food production was reduced in these extensive, shaded areas and growth of juvenile salmon reduced accordingly.

Spawning of Salmon and Trout

Because of the adverse results of stream bed disturbance recorded on sockeye runs in other areas, it was anticipated that the extensive scouring and erosion observed in Stellako River during the 1965 log drive would influence the distribution of subsequent spawning runs. Detailed observations and counts in the fall of 1965 provided information as to the distribution of adult sockeye spawners throughout the river, and total numbers were determined by tagging and dead recovery. These data were then compared with similar records of sockeye spawning numbers and distribution collected in previous years. Effects of erosion on the distribution of other species of fish were examined in a more general manner, as detailed studies of spawning distribution of these fish were not available from previous years.

The total number of sockeye spawning in Stellako River have been enumerated each year since 1938. Since 1941, these data have been collected in a consistent manner by means of annual tagging and dead recovery programs of adult salmon on the spawning grounds. The accuracy of the method has been well established (Schaefer, 1951), particularly in relatively stable rivers such as the Stellako. To aid in this enumeration and determine distribution of fish, the river was divided into nine areas (FIGURE 2) and live counts of spawners were recorded by area. In 1950, the river was surveyed and a detailed study of the distribution and density of spawners was made throughout the duration of the run. Distribution of spawners by number on individual bars prior to, during and after spawning was plotted on large scale maps and from these data it was found that the most accurate distribution information was obtained at or near peak of spawning.

Live counts near the time of peak spawning were available for each year since 1950 (with the exception of 1952) and indicated the relative number of sockeye spawners utilizing the lower Stellako River (Areas VIII and IX) each year. These records showed that, prior to 1965, the percentage of each run spawning in the lower river ranged from 15 to 30 per cent and averaged 20.4 per cent for previous runs of similar size on the same cycle (1953, '57, '61) (TABLE 13). Over the entire 14 year period an average of 22.3 per cent of the run spawned in the lower river. In 1965, live counts indicated that only 11.9 per cent of the run spawned in Areas VIII and IX, a smaller percentage of the run than in any previous year and a reduction of 41.7 per cent from the previous cycle average (a reduction of 46.6 per cent from the 14 year mean).

The total number of sockeye spawning in the lower river (as determined from the relative distribution of fish counted) also appeared to be smaller in 1965 than in any previous year (TABLE 13). In fact, four previous spawning populations (1956, 1957, 1960 and 1964) had been somewhat smaller than the 1965 run, yet the number utilizing the lower river spawning grounds in these four years averaged 6693, some 30 per cent more than the 4691 fish spawning in this area in 1965. In comparison with previous years, the smaller number of spawners utilizing the lower river in 1965 indicated that there was a reduction in spawning area available in this portion of Stellako River.

TABLE 13 - Number and distribution of sockeye spawning in Stellako River, showing proportion utilizing lower river spawning areas, 1950-1965.

YEAR	PEAK SPAWNING PERIOD	DATE OF LIVE COUNT	LIVE COUNT		PER CENT COUNTED IN AREAS VIII & IX	TOTAL POPULATION FROM TAGGING	CALC. NO. IN AREAS VIII & IX
			All Areas	Areas VIII & IX			
1950	Sept.30-Oct.1	Sept.30-Oct.2	102,134	27,840	27.3	145,100	39,612
1951	Sept.28-Oct.1	Sept.27	88,536	19,619	22.2	96,200	21,356
1952	Sept.26-30	-*	-	-	-	40,462	-
1953	Sept.24-26	Sept.22	34,909	8,381	24.0	45,057	10,814
1954	Sept.25-27	Sept.27	50,349	14,217	28.2	142,632	40,222
1955	Sept.23-26	Sept.27	30,344	7,218	23.8	51,971	12,369
1956	Sept.24-27	Sept.24	22,701	3,733	16.4	38,459	6,307
1957	Sept.28-Oct.1	Sept.30	13,288	2,192	16.5	38,922	6,422
1958	Sept.29-Oct.1	Oct.1	40,977	11,383	27.8	112,273	31,212
1959	Sept.26-28	Oct.1	25,295	5,346	21.1	79,355	16,744
1960	Sept.24-28	Sept.29	20,198	4,264	21.1	38,884	8,205
1961	Sept.26-29	Sept.26	19,834	4,110	20.7	47,241	9,779
1962	Sept.29-Oct.4	Oct.1	69,345	20,689	29.8	124,495	37,100
1963	Sept.23-27	Sept.25	109,878	16,283	14.8	138,805	20,543
1964	Sept.26-30	Sept.27	19,104	3,585	18.8	31,047	5,837
1965	Sept.27-30	Sept.27	33,975	4,040	11.9	39,418	4,691
Average 1950-1964					22.3		
Average 1953, '57, '61					20.4		

*Live counts not made at peak spawning.

The reduction in available spawning ground in eroded areas of Stellako River was even more evident when detailed maps of the 1965 spawning distribution were compared with similar maps of previous spawning runs. As previously mentioned, detailed distribution studies were first carried out in 1950 and similar maps were also prepared for the runs of 1951, 1953, 1954 and 1955. Distribution of spawners in 1965 was compared with that of the 1953 run, since both populations were relatively similar in size (39,418 vs. 45,057 in 1953) and belonged to the same cycle.

Comparison of spawning distribution in the four areas of detailed erosion measurements (Sites A to D) indicated considerable reduction in the area utilized by spawning sockeye in 1965 (FIGURES 21 to 24). The reduction in

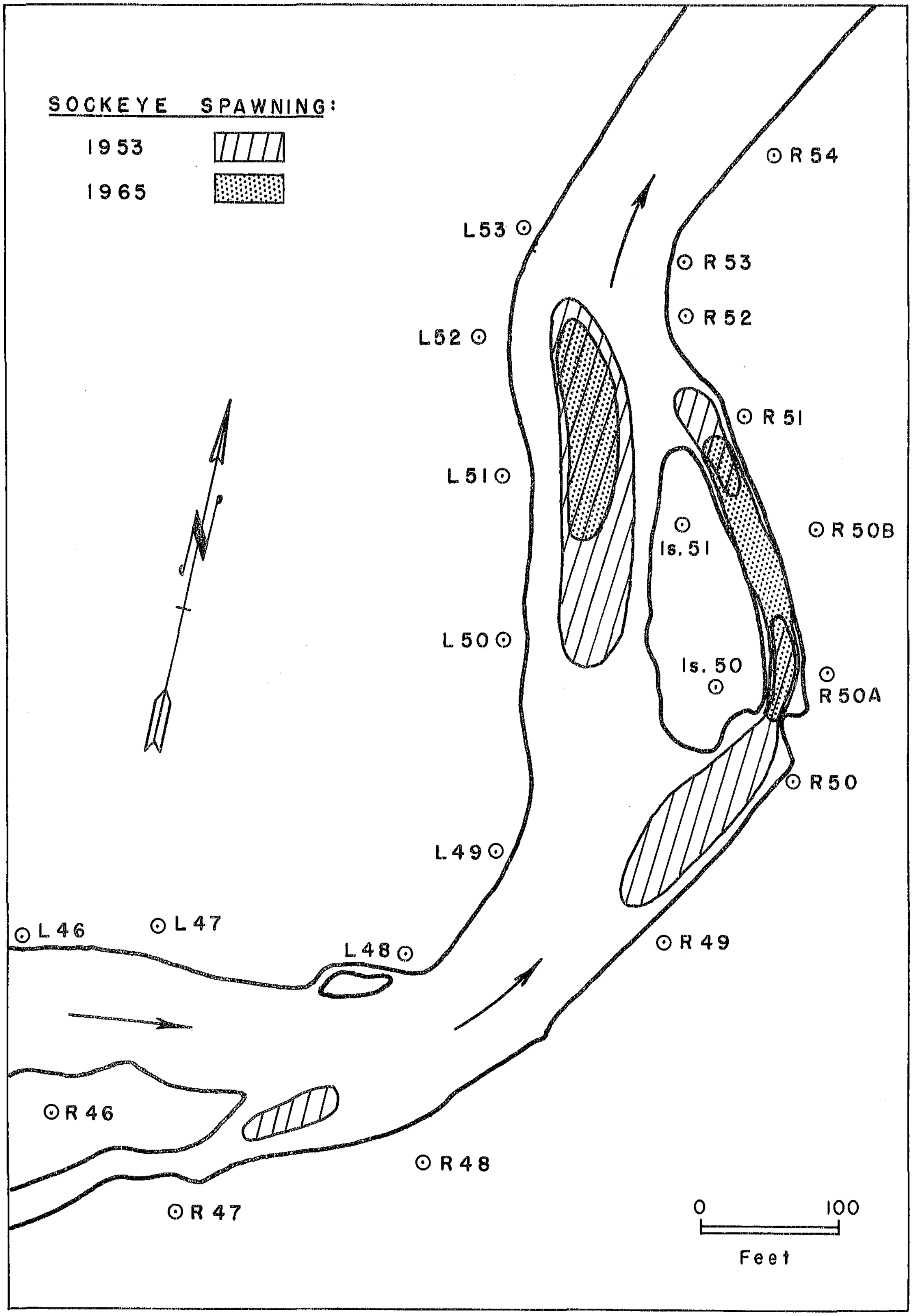

FIGURE 21 - Distribution of sockeye spawners at Site A in Area III, Stellako River, 1953 and 1965.

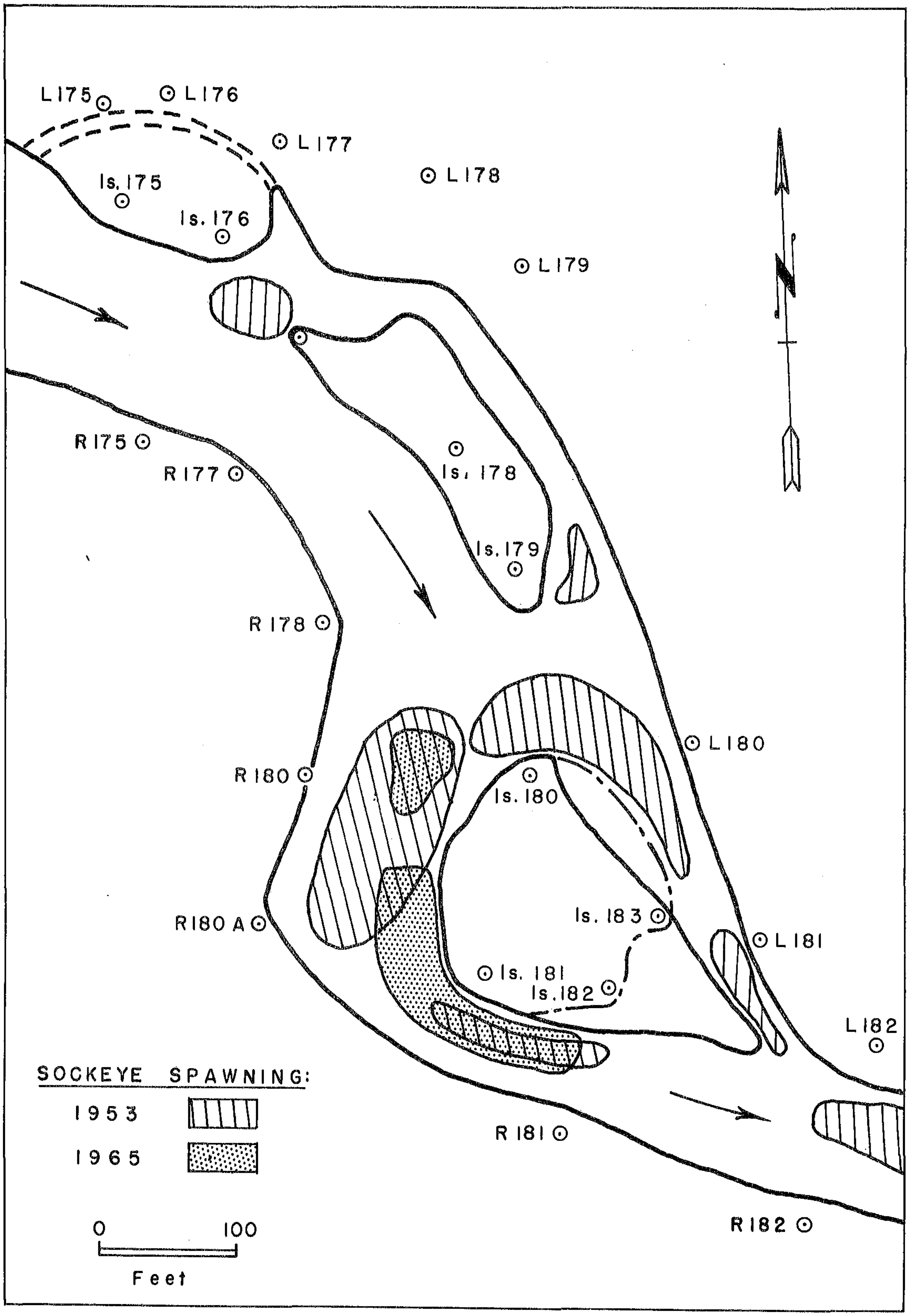

FIGURE 22 - Distribution of sockeye spawners at Site B in Area VIII, Stellako River, 1953 and 1965.

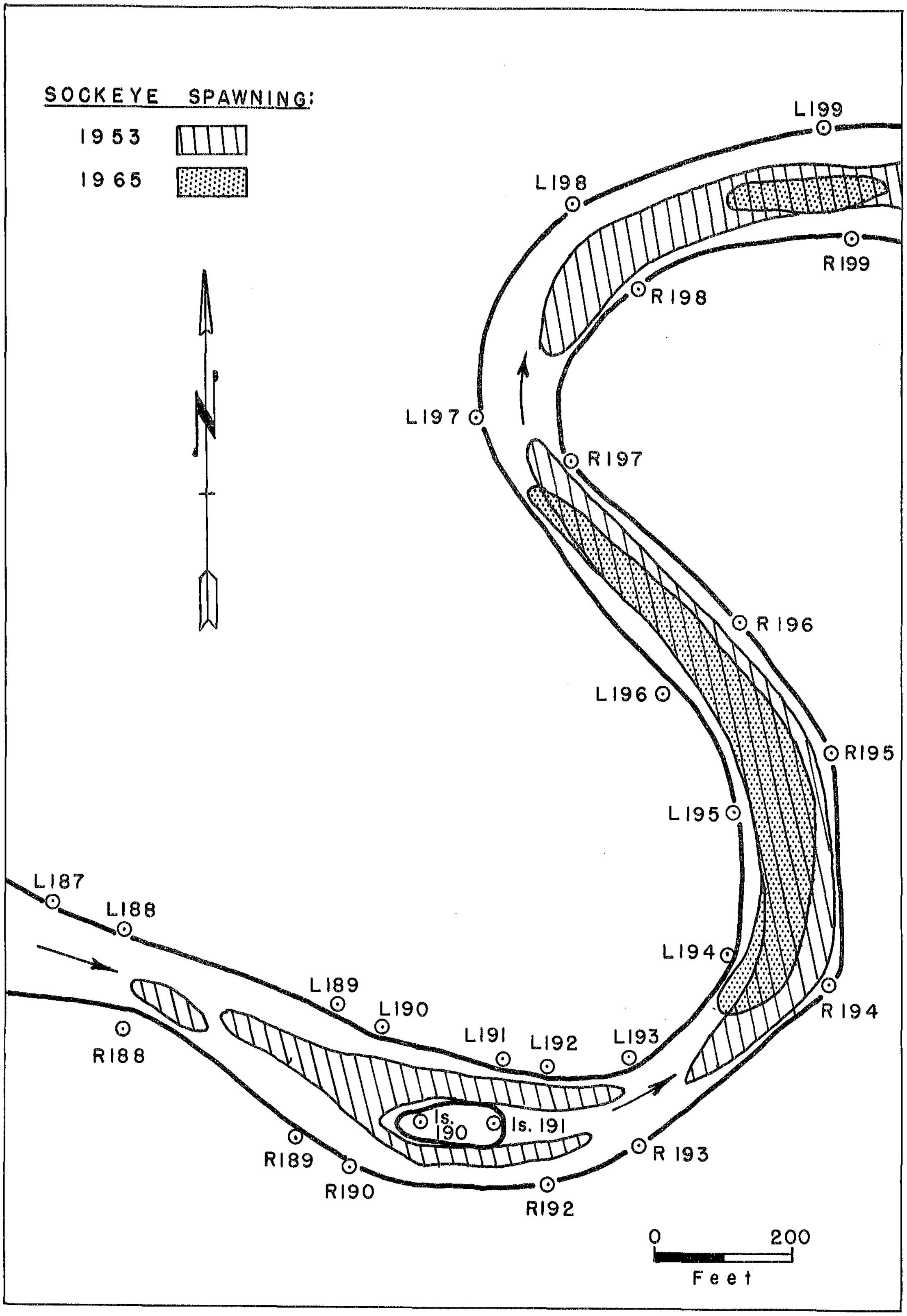

FIGURE 23 - Distribution of sockeye spawners at Site C in Area IX, Stellako River, 1953 and 1965.

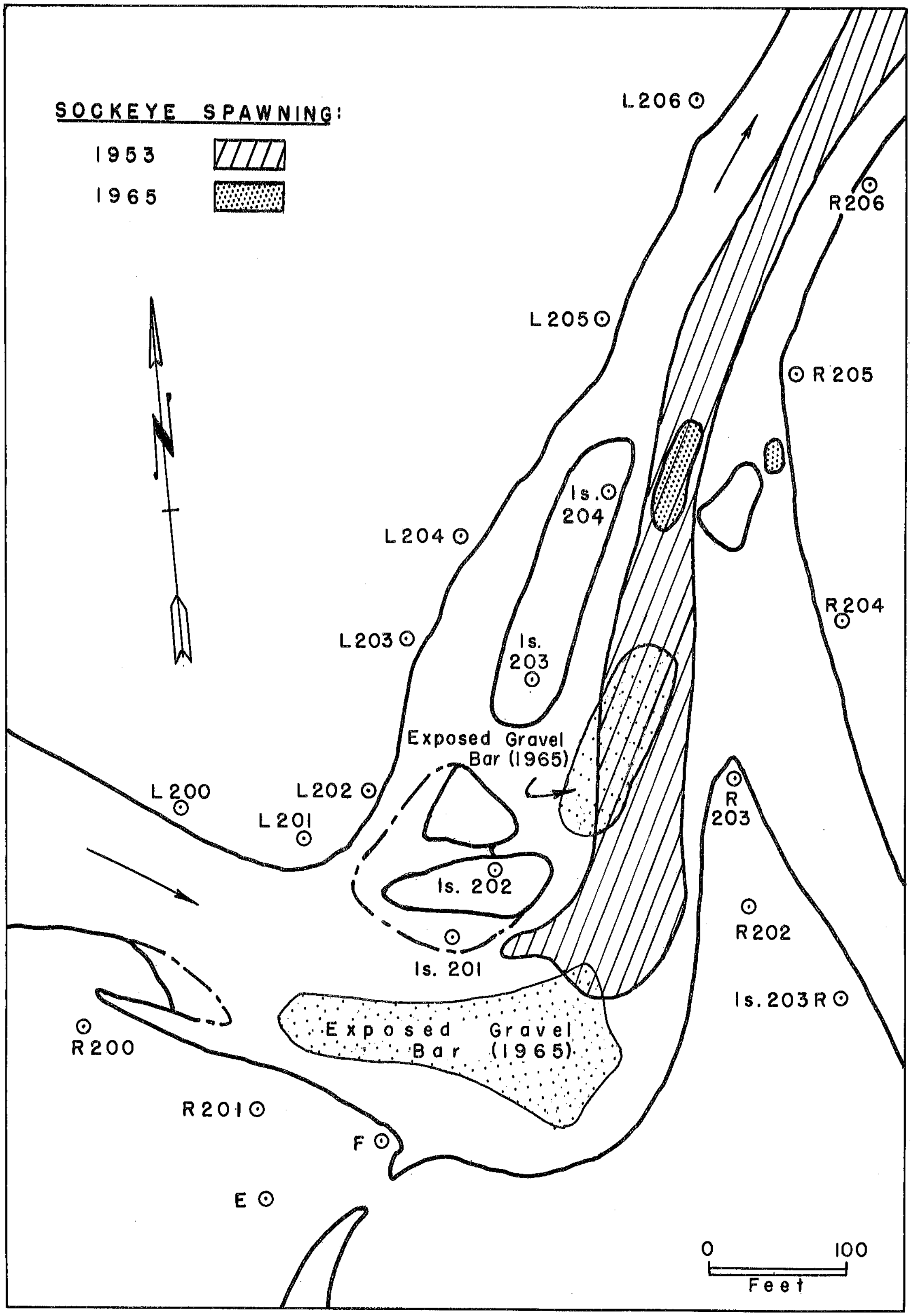

FIGURE 24 - Distribution of sockeye spawners at Site D in lower Area IX, Stellako River, 1953 and 1965.

spawning area was most evident at Site D (FIGURE 24) where the most severe erosion had occurred during log driving. In addition to these specific locations, a reduction in area utilized for spawning was observed throughout the remainder of the lower river in 1965.

Calculation of the spawning ground areas utilized in 1953 and 1965 confirmed that major changes had occurred in heavily eroded areas, as well as in the remainder of the lower river (TABLE 14). Only 17,000 sq yds of spawning ground were occupied in 1965, in comparison with the 41,200 sq yds utilized in 1953, a reduction of 24,200 sq yds. Even after correcting for the difference in total number of spawners in these two years, it is evident that the 1965 run utilized at least 19,050 sq yds less than would have been used by the 1953 run, assuming the relative density and distribution of fish remained the same each year.

TABLE 14 - Area utilized by sockeye spawners before and after log driving in Stellako River (1953 vs. 1965) showing areas measured at Sites A-D and throughout the remainder of Areas VIII and IX.

LOCATION	AREA UTILIZED BY SPAWNING SOCKEYE (SQ YDS)	
	1953	1965
Area III		
Hub R49-R53	3,300	1,600
Area VIII		
Hub R180-R188	5,500	600
Hub R188-R190	3,200	0
Area IX		
Hub R190-R193	1,700	0
Hub R193-R200	19,200	12,100
Hub R200-R205	4,200	200
Hub R205-R211	4,100	2,500
Total	41,200	17,000

This area has apparently become unuseable or at least undesirable to adult sockeye spawners. As much of this same area was observed to have been scoured or otherwise damaged during the 1965 log drive, it must be concluded that the drive was responsible for the majority of this loss. This is further supported by the observed reduction in percentage of the 1965 run utilizing the lower river as compared with all previous years.

Displacement of spawners to other areas may compensate for the present loss of spawning ground in years with small populations. As the 1965 cycle is, on the average, the smallest of the four cycle years, it is likely that fish displaced in 1965 were able to find suitable spawning areas elsewhere in the river. Counts in 1965 indicated a shift in distribution of fish to upriver spawning grounds. However, the loss of spawning area will reduce production by the more numerous dominant runs, by forcing fish to spawn in fringe areas unsuited for incubation of eggs or alevins or by overcrowding the remaining spawning ground. Certainly this loss of spawning ground has already reduced the productive potential by the dominant cycle run. Continued log driving could result in further loss of spawning ground and displacement of spawners into less productive areas in years of both large and small populations, and further reduce the potential sockeye production from this important spawning river. It is also possible that fish displaced from the lower river may not reproduce successfully, even in years when adequate spawning area is available upstream. Differences are evident in the timing and thermal history of fish utilizing different spawning areas of Stellako River which might well prevent the survival of offspring produced by displaced spawners. The basic question involves the unknown thermal tolerances of race and what constitutes a separate race within a rather extensive spawning area represented by Stellako River.

Effects of erosion on spawning distribution of other fish species in Stellako River can be determined less directly, as records of previous runs are less detailed. Spawning of rainbow trout was nearly over by the end of May, before the log drive began, so that any interference with the 1965 run would have affected incubating eggs, rather than the adult spawners. Most rainbow trout spawn in Areas II and IX. If the erosion in Area IX reduced trout spawning areas to the same extent as that described for sockeye, the adverse effect on future trout populations may be even more severe, as this is one of only two main spawning areas currently utilized by this species.

Most kokanee spawn in Areas I, II and V, and only occasionally have any number been observed spawning below Area VI. Observations in the fall of 1965 did not indicate any change in spawning distribution from previous years.

At the present time, chinook salmon runs are relatively small in comparison with those of other species utilizing the Stellako River spawning grounds. In 1965 only a few fish were observed, most of which spawned in Area III. Loss of spawning grounds could force displacement of these fish to other locations in the river, but the area remaining is presumably more than adequate for the present number of fish. However, as sockeye, chinooks and kokanee spawn at approximately the same time in Stellako River, reduction in the total available spawning ground may tend to increase competition between species for the remaining area. This would be particularly true when populations were large and fish were forced to utilize areas other than those preferred by the particular species, hence competing or overspawning in areas utilized primarily by one of the other populations.

It has been shown that a relatively large proportion of the 1965 sockeye run was displaced from the spawning grounds in lower Stellako River. There is considerable evidence to suggest that any such displacement of spawners is of a relatively permanent nature. In studies of sockeye spawning in Karluk River, Alaska, Barnaby (1944) suggests that "under natural conditions, an extremely high percentage of the fish returning to spawn proceed to the same area where they emerged from the spawning gravel as fry. There is a slight degree of straying, but the fact remains that if a spawning area has not been seeded, there will not be a run of fish returning to that area in one or more subsequent years."

Further evidence showing the permanent nature of spawning displacement comes from observations in Nadina River, tributary to Francois Lake (FIGURE 1). In this river, the entire early sockeye run has gradually been displaced from its original spawning grounds during the past ten year period, when log driving and associated re-channelling of the river have affected part of the spawning area. Log drives averaging approximately 1.7 million fbm annually have taken place since 1956. Since that time the number of sockeye utilizing the previously productive lower area of the river have gradually diminished until in 1965, the year of the largest cycle run, none were on their original grounds. In general, the displacement has been to spawning areas several miles upstream, although a small number of fish spawn below the original grounds. The total number of spawners has also diminished greatly, but adverse water temperatures during spawning in some years have contributed to this reduction.

This displacement of sockeye spawners in Nadina River has occurred in spite of the fact that some gravel bars, apparently undisturbed, remain within the original spawning grounds. The absence of spawners from their original spawning locations was first noted in and adjacent to newly disturbed areas, where straightening and "improvements" had been made to ease log driving, in the vicinity of Mile 58 (as measured on the road to Nadina Lake). Sockeye have gradually been displaced or eliminated from this entire area over the past decade until scarcely any fish remain below Mile 64, even though several miles of apparently good spawning area remain down-river in the vicinity of Mile 58. Increased deposition of sand and silt may be responsible for this lack of spawners in these remaining gravel areas. However, as suggested in a previous section, the increased deposits of organic material following log driving may have influenced fish to seek new spawning areas.

Displacement of fish to upstream locations appears to be the usual response, whenever part of the original spawning area has become unsuitable for spawning. This is evident in Nadina River and the same appears to be true of the fish displaced from lower areas of Stellako River in 1965. However, displacement upstream can serve only as a temporary measure, since eventually the upstream reaches of the stream become overcrowded while the downstream portion is vacated.

As the result of destruction of the lower portion of a stream, with or without upstream displacement, the following streams within the Fraser River system can be cited.

In Birkenehead River, a tributary of the Harrison Lake system, construction of a dyke eliminated part of the sockeye spawning grounds in the lower river. Although upstream displacement of spawners was evident, the runs declined sharply. Escapements averaging 70,000 fish in the four years immediately prior to dyke construction were reduced to less than half during a subsequent four year period. Evidently, fish displaced upstream had been unable to reproduce at a normal rate in the new environment.

Weaver Creek, a previously highly productive salmon stream in the Harrison River drainage, was seriously influenced as a result of logging the headwaters and surrounding watershed. The resulting flash floods scoured a large portion of the stream below the junction of a major tributary and deposited fine materials in the lower reaches of the stream. Though the rapid reduction in number of spawners was largely attributed to flushing of eggs and alevins from the gravel, it also became evident in a surprisingly short time that, even in the absence of floods, this portion of the stream was no longer utilized by any appreciable number of spawners. The relatively undisturbed upstream portion of the stream was already carrying a maximum number of spawners for optimum production and the overall result was a rapid decline of the salmon run. An artificial spawning channel has recently been constructed adjacent to the lower portion of Weaver Creek to offset this loss.

The pink salmon run to the lower Chilliwack-Vedder River has also been virtually eliminated in the same manner as that of Weaver Creek. In 1965, with only an average spawning population, the upper portion of the river was reported to be heavily overspawned, presumably as a result of displacement from undesirable spawning grounds in the lower portion of the river.

The once valuable Chehalis River pink salmon run has been reduced to a remnant for the same reason. Here there was no upstream displacement due to a lack of suitable spawning beds in the upper river. The result has been a direct loss of a major spawning population in little more than a decade. The loss can be attributed to a grossly changed environment in the lower portion of the river.

While these changes in the Weaver, Chilliwack-Vedder and Chehalis salmon runs were not caused by log driving, they point out the results of erosion and stream instability, indicating the eventual and usually rapid decline following displacement or loss of spawners from their selected spawning beds.

It can be concluded that when spawning areas are damaged or become undesirable to the native spawning run, the general result has been, first, a displacement of fish to spawning areas further upstream. This displacement may be relatively permanent, even when some good spawning ground appears to still be available in the affected area. Secondly, upriver spawning grounds eventually become overcrowded and total production by the stream is reduced. Ultimately, expensive measures for artificial production are required in order to rebuild the population and maintain this resource so valuable to the economy.

Sports Fishing

Throughout the period of the 1965 log drive, movement of large quantities of bark and wood fiber made Stellako River practically unfishable, as this material constantly fouled lines and hooks. Floating logs also presented a serious physical hazard to any fishermen wading in the stream, and almost completely precluded the use of rubber boats for drifting down the river. This boat service is provided by resort operators for their guests and is a major attraction of the Stellako River. As a result of the log drive in 1965, much of the recreational use of the river was lost for a substantial portion of the short five month season.

EXPERIMENTAL EVIDENCE OF THE EFFECTS OF LOG DRIVING

Because of the difficulties of field observation regarding certain aspects of log driving, tests were conducted under controlled conditions at the Sweltzer Creek Field Station near Chilliwack and at Weaver Creek, tributary to the Harrison River. The following sections of this report summarize the results of these tests.

Stream Bed Erosion Caused by a Stranded Log

In May, 1965, a study was made to determine the effect of a stranded log on a gravel stream bed. The test site was located in a typical part of the sockeye spawning ground in lower Weaver Creek in the Harrison River drainage.

After determining the approximate location at which a floating log would become stranded, the area around this position was marked off, and elevations of the stream bottom were measured every 2 ft along both coordinates. The stream was 44.5 ft wide, averaged 0.88 ft in depth, with a cross-section area of 39 sq ft and an average velocity of 3.47 fps. A weathered cedar log with a mean diameter of 17.5 in. and cut to a length of 10 ft was released and floated downstream to become lodged on the gravel in the test area. Observations were carried out for 48 hours following stranding, during which time the stream discharge remained relatively constant at 135 cfs.

The log became stranded at an angle of 60° to the stream flow, with the upstream end about 10 ft from shore. During the first night it rolled approximately 2 ft downstream but retained its original position in relation to the flow. The log created a head differential of approximately 0.3 ft between its upstream and downstream sides. Combined with the 3 to 4 fps approach velocity, this head produced velocities of 7 to 8 fps beneath and around the end of the log which eroded the gravel to a depth of approximately 0.25 ft (FIGURE 25). This gravel was deposited downstream in the quiet water behind the log. Following erosion, the head decreased to 0.1 ft and velocities under the log were reduced to 4 to 5 fps. The stream bed material at the test site ranged in size from coarse sand to stones having a maximum diameter of 6 in. and was sufficiently coarse to withstand velocities of approximately 5 fps. After 48 hours, erosion appeared to have ended and the log remained suspended on several larger stones (FIGURE 25).

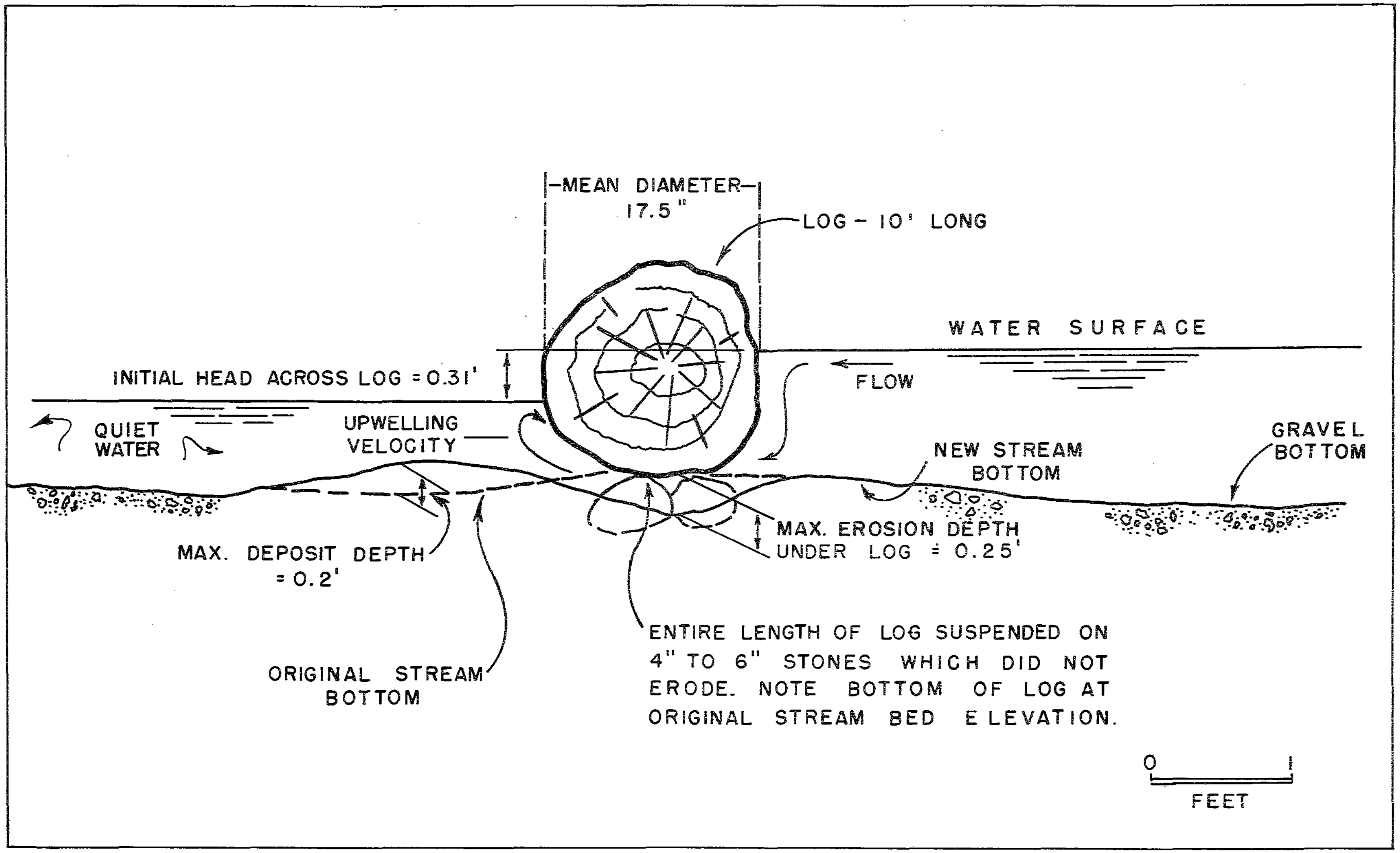

FIGURE 25 - Erosion and gravel displacement caused by a stranded log, Weaver Creek, 1965.

Except for the movement of gravel beneath and immediately downstream from the log, no change could be detected in the elevations of the gravel bed within the 600 sq ft test area. The single stranded log caused erosion and displacement of gravel within a restricted area but did not affect the spawning ground to any significant extent. Similar erosion was observed later in the Stellako River but here the cumulative effect of many logs and the much greater effect of log jams produced very significant changes in the gravel spawning areas.

Effects of Gravel Disturbance on Incubating Eggs

Log driving in the Stellako River began in June, 1965, after most sockeye and chinook fry had left the gravel. However, trout eggs were still developing within the spawning beds at this time. Earlier sections of this report have shown that considerable disturbance of the gravel stream bed occurred during the log drive, and without doubt, any eggs located in these areas of severe erosion would have been destroyed. In addition, frequent "moderate" gravel disturbance was evident, caused by individual logs in their progress downstream. As effects of this moderate gravel disturbance could not be measured under field conditions, tests were conducted at the Sweltzer Creek Field Station to assess this additional potential danger to developing eggs and alevins.

Experiments designed to evaluate the effect of moderate gravel disturbance on developing eggs were carried out in the fall of 1965, after observations had indicated the types of disturbance which occurred most frequently during the Stellako River log drive. These tests included studies of the gravel disturbance caused by a log digging a path into the gravel as it became grounded. Observations made in the Stellako River indicated that, even in a moderate velocity of 2.5 fps, a 16 ft log with diameter of 18 in. would dig a horizontal path at least 4 ft long in the gravel. Eggs exposed by this gouging would be destroyed, but the fate of those buried somewhat deeper required experimental evaluation. Secondly, adverse hydraulic conditions caused by single logs or small accumulations could cause erosion and disturbance of eggs in the gravel bed. Field observations indicated that small log jams and grounded logs created increased velocities in a number of areas, causing gravel to be washed away or churned up. Eggs uncovered by this action would be lost, but those remaining in the gravel might also be killed if gravel movement were severe or if velocities in the gravel pores increased to the point where eggs were jostled against the surrounding rocks. Finally, incubating eggs might be harmed by the sharp impact of a log perpendicular to the gravel surface. This impact could compact the gravel in the immediate area, jostle the eggs, or exert abnormal pressure - any one of which could rupture the yolk membrane and cause death.

Experiments designed to evaluate each of the three types of gravel disturbance were carried out using sockeye eggs, since trout eggs were not available this late in the season. Although sockeye eggs are slightly larger than those of trout, it was felt that they were similar enough to allow application of the results to either species. All experiments were conducted using compartments measuring 19 in. wide, 12.5 in. long and 7 in. deep. Compartments were filled with gravel and placed in large troughs with upwelling flow of 3.3 gpm and water temperature maintained at approximately 52°F. Five compartments were arranged in series in each of the troughs, the first and last compartments being used as controls. Water hardened eggs (approximately 100) were placed in small (5 in. diameter) depressions in the gravel of each compartment and were covered with gravel to a depth of either 3 in. or 4 in. Gravel was pushed slowly over the eggs (Experiments 6 and 7) or stones were replaced individually (Experiments 1 to 5) until eggs were buried to the required depth. In addition, a few eggs were incubated in a covered basket (without gravel) in each trough so that the progress of development could be observed.

The membrane surrounding the yolk of the salmonid egg is sensitive to physical pressure, force and shock, and may be ruptured causing death of the developing embryo. Since salmonid eggs are most sensitive during the period between fertilization and blastopore closure, all tests of gravel disturbance were carried out during this period. Sockeye egg development at the time of each experiment was measured in terms of the size of blastodisc or blastoderm as fraction of a sphere (TABLE 15). Blastopore closure of these eggs, ending the most sensitive stage, would have occurred after accumulation of approximately 250 temperature units.

TABLE 15 - Sockeye egg development at the time of each gravel disturbance experiment.

Experiment Number	Temperature Units	Blastodisc or Blastoderm as Fraction of Sphere
1, 2 and 4	146	0.4
3 and 5	186	0.7
6 and 7	60	0.1

Following application of gravel disturbance, incubation was allowed to continue until the eggs developed nearly to the eyed stage. At this time all eggs were removed from the gravel, cleared in a saturated sodium chloride solution and sorted into two groups - those which had developed nearly to the eyed stage and those whose development had stopped at or before the stage at which gravel disturbance had been applied. The number in the latter group were expressed as per cent mortality of the total sample. Although it was not possible to differentiate between infertile eggs, those killed by handling and those killed by the gravel disturbance, it was assumed that mortalities in test groups exceeding those in control lots resulted from the disturbance imposed.

To simulate lateral movement of a grounding log, a segment of an 18 in. diameter circle was forced through the gravel, by applying pressure to a platform scale mounted on a rod extending through the side of the trough. The scale recorded the force applied to the gravel. Three trials were performed in which the bottom of the simulated log extended into the gravel to depths of 4 in., 3.25 in. and 2 in., respectively. The eggs were buried 4 in. below the gravel surface in all of the foregoing trials. The force applied to the scale simulated actual conditions, based upon computations using Work and Energy principles. It was calculated that a 37 lb force would halt a balsam fir log (45 lb/cu ft density, 18 in. diameter, 16 ft long) travelling in the stream at a velocity of 2.5 fps within a distance of 4 ft. Judging from field observations, a 4 ft stopping distance was approximately the minimum for a log grounding in 2.5 fps velocity, hence the force used was about the maximum for this velocity. For greater stopping distances, forces are less, while for higher velocities the forces are greater.

Hydraulic erosion was simulated by directing a stream of water (49 gpm, 2 in. diameter, velocity of 5 fps) onto the gravel, causing erosion which was allowed to continue just to the point where the first egg was uncovered.

Vertical impact was applied by dropping a log into the gravel test compartments. The force exerted by the log was determined from the weight of the log, height of drop and depth of penetration of the log into the gravel.

Experiment 1, simulating gouging by a log, showed that mortality could be expected when a grounding log eroded a path to a depth coinciding with that of the eggs (TABLE 16). However, when the path eroded was 0.75 in. or more above the eggs, mortalities were not increased over those found in controls. Examination of dead eggs indicated that in no case were eggs broken or crushed by the disturbance. Gravel has little or no resistance to horizontal shearing forces and therefore mortality beneath the path of erosion was unlikely since gravel would not be disturbed.

TABLE 16 - Mortality of eggs (buried at a depth of 4 in.) subjected to gravel disturbance. Experiment No. 1 - Erosion caused by grounding log.

Test	Lateral Force lbs	Depth of Erosion in.	Mortality %
Control 1	-	-	18.7
Control 2	-	-	18.5
Test A	35	4.00	27.8
Test B	27	3.25	8.9
Test C	25	2.00	19.5

The effects of hydraulic erosion on mortality were studied in Experiments 2 and 3. In Experiment 2, hydraulic erosion to the depth of the eggs caused a marked increase in mortality over that in the controls (TABLE 17), but in Experiment 3, similar erosion apparently had no effect on egg survival. The more advanced development of eggs in Experiment 3 (TABLE 15) may have been responsible for the difference in results; on the other hand, variable protection afforded by the gravel may have been equally responsible.

The effect of impact on incubating eggs was evaluated in Experiments 4, 5, 6 and 7 (TABLE 18). In Experiment 4, an impact of 1100 psf did not affect survival, but in Experiment 5, slightly greater impact caused mortality

TABLE 17 - Mortality of eggs (buried at a depth of 3 in.) subjected to gravel disturbance. Experiments 2 and 3 - Hydraulic Erosion.

Experiment Number	Test	Depth of Erosion in.	Mortality %
2	Control 1	-	17.2
	Control 2	-	10.0
	Test	3.0	55.0
3	Control 1	-	6.4
	Control 2	-	4.8
	Test A	3.0	4.0
	Test B	3.0	7.0
	Test C	3.0	10.0

approximately twice that recorded in control groups. Comparison of the three trials in Experiment 5 indicated that mortality was not directly dependent upon magnitude of force, pressure or compaction. Interpretation of data from Experiments 6 and 7 was difficult because mortality in the control groups was high and variable. It is possible that pushing gravel over the eggs, instead of replacing stones individually (as was done in the other experiments), may have been responsible for these high mortalities. Nevertheless, the fact that mortalities in some test groups of Experiments 6 and 7 were less than in controls does allow some evaluation of mortality caused by varying degrees of impact. Results from trials 6B and 7C indicate that at a minimum, two-thirds of the eggs survived gravel surface pressures of 3060 and 4220 psf, respectively. The latter pressure was the highest used in the impact experiments, while the former was created by the second largest force, 816 pounds. Furthermore, the greatest compaction measured, 0.65 in. (trial 7B), was associated with only 25 per cent mortality.

TABLE 18 - Mortality of eggs (buried at a depth of 3 in.) subjected to gravel disturbance. Experiments No. 4, 5, 6 and 7 - Vertical Impact.

EXPERIMENT NUMBER	TEST	DIMENSIONS OF LOG		HEIGHT OF DROP in.	COMPACTION OF GRAVEL in.	FORCE lb	PRESSURE psf	MORTALITY %
		Diameter in.	Weight lb					
4	Control 1	-	-	-	-	-	-	17.2
	Control 2	-	-	-	-	-	-	10.0
	Test A	5.2	20	1.5	0.47	84	569	14.3
	Test B	5.2	20	3.0	0.42	163	1100	17.0
5	Control 1	-	-	-	-	-	-	9.4
	Control 2	-	-	-	-	-	-	5.0
	Test A	7.0	45	3.0	0.37	410	1572	21.0
	Test B	7.0	45	6.0	0.49	596	2190	17.9
	Test C	5.2	20	6.0	0.58	227	1540	20.0
6	Control 1	-	-	-	-	-	-	59.3
	Control 2	-	-	-	-	-	-	36.3
	Test A	7.0	45	3.0	0.34	442	1655	30.1
	Test B	7.0	45	6.0	0.35	816	3060	35.5
	Test C	7.0	45	9.0	0.50	855	3200	63.9
7	Control 1	-	-	-	-	-	-	50.5
	Control 2	-	-	-	-	-	-	34.4
	Test A	5.2	20	3.0	0.40	170	1155	57.5
	Test B	5.2	20	6.0	0.65	204	1387	25.0
	Test C	5.2	20	9.0	0.30	620	4220	37.5

It was noted that none of the eggs were crushed in any of the impact experiments. The eleven vertical impact trials indicated that although mortality of incubating eggs occurred in some cases, in others the gravel provided considerable protection. Variations in mortality were to be expected since during vertical impact the gravel was compacted and mortality may have occurred as reduced gravel pore space caused some eggs to be squeezed. Since gravel is heterogeneous, compaction will not always cause the same local decrease in pore space and therefore mortality will vary.

As noted previously, incubating eggs are most easily killed by disturbance during the period between fertilization and blastopore closure. During the next interval between blastopore closure and pigmentation of the eye, eggs are not as easily harmed as in the earlier stage, although they are still sensitive to disturbance. Blastopore closure of rainbow trout eggs occurs after approximately 175 temperature units have been accumulated, and eye pigmentation occurs after about 300 temperature units (Leitritz, 1960). It was computed, using Stellako River mean water temperatures, that trout eggs deposited on or after May 26, 1965 would have accumulated less than 175 temperature units by June 6, and therefore would have been at a highly sensitive stage of development when the log drive began. Data from past temperature records indicate that eggs deposited on or after May 23 would normally be at a highly sensitive stage of development on June 6, and eggs deposited between May 11 and 23 would be at the somewhat less sensitive stage between blastopore closure and eye pigmentation by this date. On the other hand, previous temperature records indicate that eggs deposited on or before May 25 (approximately the latest date of trout spawning) would have passed the sensitive stages by June 16, at the latest, depending upon temperature.

In general, these experiments have shown that incubating eggs can be harmed by gravel disturbances during log driving. The two forms of erosion, hydraulic and gouging, are the most probable causes of egg mortality, while mortalities resulting from impact on the gravel surface are less apt to occur. Of course, impact on spawning gravel may occur during formation and breaking of log jams, but since so much erosion is caused by jams, eggs which might have been affected by impact would be swept away in any case.

The force (35 lb) used experimentally to study erosion by a grounding log was essentially equal to the calculated force (37 lb) expected during actual grounding of a log. Results of experiments can therefore be considered indicative of conditions caused by individual logs grounded in the Stellako River. The significant finding showed that eggs were harmed if the log's path intersected the eggs, but mortality of eggs buried deeper in the gravel was unlikely, since gravel movement appeared restricted to the zone in contact with the log. Logs observed grounding during the Stellako River drive may have intersected trout eggs, although there was no visual proof.

Field observations indicated that hydraulic erosion varied and frequently appeared more violent in the Stellako River than that tested in the laboratory. Since moderate hydraulic erosion caused mortality in these experiments, the erosion which occurred during log driving can be assumed to have caused mortality of trout eggs.

Toxic Effects of Products Leached from Bark on Young Salmon and Trout

Field observations indicate that approximately one-third of the bark on logs was scraped off during the 1965 log drive in Stellako River. As previously described, much of this bark was carried along the bed of Stellako

River. As previously described, much of this bark was carried along the bed of Stellako River or was deposited on the gravel. This material could affect the survival of eggs and young fish by release of toxic materials such as tannin and resin. In order to investigate this aspect of log driving, two experiments were performed at the Sweltzer Creek laboratory.

The first experiment examined the effect of logs and bark on fingerling sockeye. Fifty-three sockeye were reared in a 300 gallon control tank, and a similar number were reared in an identical experimental tank containing 0.575 cu ft of logs with 60 per cent of the bark removed and added to the tank. Flow rate in each tank was 300 gpd. Dissolved oxygen was maintained near saturation with compressed air, and a peripheral current of 1.2 fps was maintained using a cast iron pump with plastic plumbing. Fish were kept at a constant temperature of 47°F and fed Abernathy wet diet* at 4.05 per cent of body weight for three weeks. The three week test period resulted in an overall concentration of logs, by volume, in the total amount of water used, of 0.07 per cent. With respect to tank volume (300 gal) the concentration of logs was 1.4 per cent. The average concentration of logs during driving on Stellako River was estimated at about 0.013 per cent, based upon 5,500,000 fbm of logs, 41 days of driving and an average river discharge of 1934 cfs. Hence, the concentration of logs used in the experiment was approximately five times greater than that occurring during driving. The logs used in the experiment, lodgepole (black) pine (Pinus contorta), balsam (alpine), fir (Abies lasiocarpa) and spruce (Picea engelmannii), were winter-cut in the interior of British Columbia, similar to the logs driven in Stellako River.

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*Salmon Cultural Laboratory, Abernathy Creek, U.S. Fish and Wildlife Service, Longview, Washington.

A sample of 22 fish taken when the experiment began, and compared with the control group at the end of three weeks, showed that weight and length of controls increased at a rate of 78.4 mg/day and 0.214 mm/day, respectively. Experimental fish grew at a rate of 79 mg/day and 0.217 mm/day. No mortalities occurred and all fish appeared vigorous during the experiment. Tannin and lignin concentrations were approximately 0.1 ppm in the control tank and ranged from 0.1 to 0.2 ppm within the experimental tank. At these concentrations, accuracy of the tannin-lignin measurement was so low that differences may have been due to analytical technique. Results indicated that logs and bark at concentrations greater than those in the Stellako River did not cause mortality or reduce growth of sockeye fingerlings.

The second experiment examined the effect of products leached from finely divided bark (hereafter referred to as bark flour) on the development of rainbow trout eggs, alevins and fry. Rainbow trout eggs were obtained from Beaver Lake (Summerland, B.C.) by the British Columbia Fish and Game Branch and were transported to the Sweltzer Creek laboratory following fertilization, water hardening and separation into two 1200 egg lots. Eggs and alevins were incubated in identical baskets (4.4 in. by 13 in.) in troughs with an upwelling flow of 1.9 cm/hr, temperature of approximately 52°F and dissolved oxygen greater than 90 per cent saturation. Both groups of eggs were incubated in water from Cultus Lake. Bark flour from balsam fir, black pine and spruce logs was produced by a device (Servizi, 1965) which continuously ground bark from the log and washed it, along with fluid secreted from the log, into the trough containing the experimental group. Bark flour concentration ranged between 11 ppm and 126 ppm and was near the higher value during approximately one-third of the experiment. The fine bark particles, about 0.1 mm in diameter, presented a large surface area from which tannin and resin could be leached.

Analyses of water samples showed that tannin and lignin were not increased by the addition of bark flour. Insoluble resins were observed floating on the water surface, indicating that these substances were released from the bark.

Bark flour settled from suspension and covered the incubating eggs with a thin film of fine particles. It was found that this film of bark flour adhered to the eggs and had to be removed by wiping, it would not float away. Such a film may have disrupted the flow of water at the egg-water interface and reduced oxygen transfer to the egg. Dead eggs were examined at a magnification of 25 X power and sorted into those which did or did not show embryonic development. Those showing no evidence of development were considered to have been infertile or killed before the experimental conditions were imposed. Results indicated that considerably more eggs died in the experimental group (28.7 per cent) than in the controls (10.4 per cent) (TABLE 19). It is likely that the film of bark flour disrupted water flow and caused the experimental eggs to suffocate.

TABLE 19 - Mortality of rainbow trout eggs to time of hatching.

	NO EMBRYONIC DEVELOPMENT*		EMBRYONIC DEVELOPMENT*	
	Number	Per Cent[a]	Number	Per Cent[a]
Control	104	8.7	116	10.4
Experimental	192	16.0	345	28.7

*Observed at magnification of 25 X power.

[a] Based on 1200 eggs measured volumetrically.

The record of hatching (TABLE 20) showed that experimental eggs required an additional four days to reach 100 per cent hatch. This delay may have been caused by the film of bark flour reducing oxygen transfer to the egg.

Lack of oxygen as a cause of delayed hatching is a likely possibility judging from work by Garside (1959), who found that hatching of lake trout eggs was delayed by low dissolved oxygen, Silver, Warren and Doudoroff (1963) and Shumway, Warren and Doudoroff (1964) also found that hatching of salmon eggs was delayed by low dissolved oxygen concentration.

TABLE 20 - Temperature units required for hatching of rainbow trout eggs.

DATE	TEMPERATURE UNITS	CONTROL		EXPERIMENTAL	
		Number	Per Cent	Number	Per Cent
June 24	481	2		0	
25	500	17		39	
26	519	17		46	
27	538	123		57	
28	558		100		35^{e}
29	577				55^{e}
30	598				65^{e}
July 2	640				100

^{e}Estimated per cent.

Addition of bark flour to the water was continued after hatching and resulted in some deposition of bark particles on the alevins. Alevins with substantial yolk were not capable of shaking the bark flour loose and some apparently suffocated. As alevins became more vigorous they stirred up the bark flour and much of it was carried away by the current. Experimental alevins were examined at 1012 temperature units and no bark particles were found in their gills or mouths. However, mortality among the experimental group was higher than among controls (TABLE 21).

TABLE 21 - Mortality of rainbow trout alevins during the period from hatching to yolk absorption.

	Control	Experimental
Number	11	51
Per cent[a]	1.12	7.7

[a] Based upon 1200 eggs minus eggs dead before hatching.

Samples of 20 alevins were taken from each group for weight determination after accumulation of 870 and 1012 temperature units. Embryos were separated from their remaining yolk by careful dissection, dried for 24 hours at 98°C and weighed on an analytical balance. The first sample indicated that control alevins had larger embryos and smaller yolks than the experimental groups, indicating more rapid development by the controls (TABLE 22). The second sample showed that although the experimental embryos had grown at a slower rate, they were approaching the same weight as those in the control group. Statistical comparison of embryo weights, using the Student's "t" test, showed a significant difference in weight at 870 temperature units but no difference at 1012 temperature units. Although the first food was introduced at 994 temperature units, one day before the second weight samples were taken, it is unlikely that this influenced the weights since active feeding did not begin for two or three days.

TABLE 22 - Average dry weight of rainbow trout embryos and yolks.

TEMPERATURE UNITS	CONTROL		EXPERIMENTAL	
	Embryo mg	Yolk mg	Embryo mg	Yolk mg
870	12.02 ± 1.64	2.19	8.63 ± 1.61	5.62
1012	11.92 ± 1.53	0.011	11.47 ± 2.01	0.91

Since only two sets of samples were taken, it is not certain that the results obtained were maximum embryo weights. It is likely that controls reached a maximum weight sometime between the two sampling periods and in order to estimate this maximum weight, yolk conversion data were used. Calculations (Servizi, 1965) showed that maximum dry embryo weight was 12.40 ± 1.58 mg for the controls at 954 temperature units, while for experimental fish the maximum dry embryo weight was 11.47 ± 2.01 mg at 1012 temperature units. Statistical comparison of computed maximum weights indicated that there was no significant difference between the control and experimental groups. These results are similar to those obtained by Brannon (1965b) using sockeye alevins, where he found that growth of embryos under hypoxial conditions was delayed, but that maximum weights eventually attained were the same as those of alevins which grew under oxygen saturated conditions. It is concluded that even though the water was nearly saturated with oxygen, bark flour created hypoxial conditions and reduced the rate of development of trout eggs and alevins.

The final phase of investigation concerned the growth of fry produced, and to prevent overcrowding, numbers were reduced to 200 fish per group. Fry were fed Abernathy dry diet, in excess, starting at 994 temperature units on July 19. Since this was the first food introduced, the fish required two or three days before they started feeding well.

Two samples of fry were taken for weight determinations on August 12 and 21. Statistical comparison of weights indicated that there was no significant difference in size of fish on either occasion (TABLE 23). However, introduction of food to both groups of fish at the same time may have had some effect on subsequent growth, since feeding of the controls started approximately two days after maximum weight was attained, while feeding of experimental fish started one day before maximum weight was reached. There was a wide range in size of fry as evidenced by the large standard deviation from the mean (TABLE 23). No bark particles were found in gills or mouths of the fry and mortalities were insignificant.

TABLE 23 - Dry weights of rainbow trout fry following feeding.

Date	Control mg	Experimental mg
Aug. 12	21.65 ± 10.53	20.12 ± 6.29
Aug. 21	29.65 ± 18.19	27.99 ± 10.15

A second study of fry growth was made to check results of the first test, and on Aug. 21 control fish were separated into two equal groups, one group again being reared in water containing bark flour. Trout average wet weight at this time was 190 mg. The fish were fed equal amounts of Abernathy dry diet and on September 8, all were removed and weighed. The controls averaged 240 mg in weight, while those fish subjected to the bark flour had an average weight of 260 mg. The difference in weight was insignificant and, as earlier, mortalities were negligible.

Experimental results indicated that any toxicants leached from the wood and bark were not present in large enough concentrations to influence growth or survival of rainbow trout during early development, or sockeye salmon at the fingerling stage. Application of these results to conditions in the Stellako River is based upon the premise that the concentration of toxic products leached from the wood and bark is proportional to the surface area per unit volume exposed to dissolving action of water. Since the concentration of logs in the test on sockeye fingerlings was several times the average concentration in Stellako River during log driving, the surface area exposed to leaching was proportionately much greater experimentally than in the river. Similarly, due to the small diameter (0.1 mm) and high concentration of bark flour, the bark surface area in contact with water in the trout experiments was also much greater than that which occurred in Stellako River. Hence in both experiments, proportionately more surface area was exposed to leaching of toxicants than in actual river conditions and the more toxic conditions would have been expected to occur in the laboratory. However, measurements of tannin and lignin showed that concentrations were not increased above background levels, either in the river or the laboratory. The foregoing comparisons indicate that chemical conditions influencing growth or survival of trout and salmon would not have occurred during the 1965 log drive in Stellako River.

Although the primary objective of the bark flour experiment was to detect whether toxic conditions resulted from leaching of bark, the results included the physical effect of fine bark particles on trout eggs, alevins and fry. By apparently reducing water flow and thereby restricting oxygen transfer, bark flour caused slower development and mortality of trout eggs and young alevins. However, advanced alevins and fry were not affected.

In contrast to these latter results, Kramer and Smith (1965) found that pulp fibers at 60 ppm suspended solids clogged the mouths and gills of rainbow trout alevins with resultant impairment of vital functions. Pulp fibers were also responsible for mortality of walleye fry at 75 ppm suspended solids and 91 per cent dissolved oxygen saturation, and only 8 ppm suspended solids caused mortality when saturation of dissolved oxygen was reduced to 53 per cent (Smith and Kramer,1964). The difference between the results obtained with pulp fiber and those found with bark flour may have been due to the difference in size of the particles. Pulp fibers ranged from 1 to 3 mm in length, while the bark flour particles were nearly spherical and only 0.1 mm in diameter. The pulp fibers, being larger, clogged gills and mouths and caused harm while the smaller bark flour particles apparently passed through mouths and gills without clogging. It appears that size and configuration of particles in relation to the fish under study are important considerations influencing the extent of mortality caused by suspended solids.

In Stellako River, the concentration of fine particles was increased only occasionally by log driving (TABLE 10). It is unlikely that these particles were numerous enough, as indicated by relatively low concentrations of suspended solids, to cause clogging of the gills of fry or suffocation of eggs. However, eggs, alevins and other aquatic life may have been smothered by the many accumulations of larger pieces of bark and wood deposited on the river bed (FIGURE 17, TABLE 9). The silt stirred up by erosion may also have caused mortality of eggs by suffocation.

SUMMARY AND CONCLUSIONS

1. Historical records indicate that prior to the 1913 obstruction at Hell's Gate, the Stellako River supported a large sockeye spawning run, and produced a significant proportion of the total sockeye salmon run of the Fraser watershed. Until 1945, migration was affected and runs were small. Elimination of the Hell's Gate obstruction in 1945 allowed rehabilitation of the Stellako sockeye run, to the extent that production by this race in recent years has averaged over $1,000,000 annually in

the commercial catch and in addition, contributed approximately 10 per cent of the entire Indian catch of Fraser River sockeye.

2. The Stellako River also serves as a spawning area for chinook salmon, kokanee and rainbow trout - the latter species being of particular importance to the growing tourist and recreational economy of the surrounding area.

3. The proposal to resume log driving in Stellako River was viewed with serious concern by the agencies responsible for protection of this fisheries resource. History of log driving in many spawning streams showed that spawning ground destruction frequently resulted from the gouging, hydraulic erosion and so-called river "improvements" associated with log drives. Even when driving was carried out under conditions of supposedly adequate flow, considerable damage to spawning grounds was evident. Irrespective of the method of log driving, heavy deposits of bark accumulated on the stream bed, reducing spawning areas and threatening production of aquatic life.

4. Annual drives comprising a maximum of approximately 3 to 4 million fbm of logs were carried out in Stellako River from 1914 to 1948. As these drives coincided almost entirely with the period of obstruction to migration at Hell's Gate, relatively few sockeye would have been affected, as spawning runs were small. Driving of smaller, bark-free ties during this same period and extending until 1957 presumably would not have influenced the river bed to the same extent as logs.

5. Log driving was permitted during a restricted period in 1965 as an interim measure to allow Fraser Lake Sawmills, Ltd. the opportunity to establish other means of utilizing timber from the Francois Lake area.

6. Field investigations and related experimental tests were carried out during and following the 1965 log drive to evaluate the effects on species of fish utilizing Stellako River spawning and rearing areas.

7. It was found that several log jams were produced by the drive, causing severe gouging and erosion of the gravel stream bed. Some areas were eroded to a depth in excess of six feet. Within four specific sites, erosion resulted in loss of more than 23,800 sq yds of sockeye spawning area, some 8.6 per cent of the total utilizable spawning ground in Stellako River. Lack of ready replacement gravel indicates that effects of this erosion will remain in existence for many years.

8. River bank erosion caused by the log drive could eventually lead to re-channelling of the river in some locations, and further loss of spawning area.

9. The log drive led to increased movement of wood fiber within Stellako River, causing numerous areas on the stream bed to be covered with deposits of bark and wood debris. These deposits not only reduce the available spawning area, but will also limit production of bottom organisms which form food for trout and chinook salmon reared in the river. As these deposits appear to be cumulative, the area affected would be increased if further log drives occurred.

10. The log drive also resulted in accumulation of bark and other wood debris within the gravel bed of Stellako River. The apparent emission of hydrogen sulphide gas from these debris deposits during August indicates the possibility that anaerobic conditions may exist during periods of warm water temperatures.

11. Examination of water quality indicated that concentrations of toxic materials (tannin and lignin) apparently remained unaffected by the log drive. Subsequent experimental tests on sockeye supported the conclusion that toxicants would not have been present in adequate concentration to affect growth or survival of juvenile fish in Stellako River.

12. Although large concentrations of fine bark particles were found to cause mortality of trout eggs experimentally, water analysis during the log drive indicated that any solids of this type were increased only occasionally and would probably not have caused mortality.

13. As the 1965 log drive was restricted to the period after sockeye fry had emerged from the gravel, mortality of developing eggs and alevins would have been minimal. However, rainbow trout eggs were still present in the gravel, subject to mortality by the action of log gouging, hydraulic erosion and suffocation by silting and bark deposits.

14. As well as mortality of eggs in areas of severe erosion, experimental tests showed that gravel disturbance caused by individual grounding logs and moderate hydraulic erosion could cause mortality if erosion extended to the depth of the eggs.

15. As rainbow trout spawned in some areas of Stellako River where erosion of gravel occurred, trout populations will be reduced to some extent by loss of these eggs. Spawning areas for future runs may also have been reduced. Such losses would not only reduce the recreational value of Stellako River but also that of adjacent Fraser Lake.

16. That the observed erosion and damage to spawning grounds was real was illustrated by analysis of sockeye spawning distribution in 1965, in comparison with previous years. A reduction of more than 40 per cent was recorded in the percentage of the run spawning in the heavily eroded lower river, and approximately 24,000 sq yds of spawning area utilized by a previous run of similar size was not occupied in 1965.

17. Upstream displacement of sockeye spawners was evident in 1965 and may become permanent, even if some gravel remains in the original spawning area. Differences in thermal environment of the separate spawning areas may prevent the successful reproduction of these displaced spawners. In any event, overcrowding of the remaining spawning area will lead to a decline in salmon populations. Similar declines are evident in other streams of the Fraser system following a major disturbance of the spawning grounds which has resulted in displaced spawners.

18. The log drive made the Stellako River practically unuseable by sports fishermen throughout a substantial part of the major recreational season. Continuation of the log drive would undoubtedly reduce public interest in the Stellako River as a recreational area, with consequent effect on the income of fishing resorts in the vicinity.

19. It is concluded that it is essential to the fishery for sockeye and chinook salmon, and to the maintenance of the local sport fishery, that the spawning grounds of Stellako River be preserved and that no further damage to these spawning grounds be allowed. Therefore, it is recommended that the Stellako River should not be used for log driving.

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