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THE STUART-TAKLA FISHERIES/FORESTRY INTERACTION PROJECT: STUDY DESCRIPTION and DESIGN[1]

by

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ABSTRACT

Macdonald J.S., J.C. Scrivener and G. Smith. 1992. The Stuart-Takla Fisheries/Forestry Interaction Project: Project Description and Design. Can. Tech. Rep. Fish. Aquat. Sci. No. 1899: 39p.

The early Stuart run of sockeye salmon (*Oncorhynchus nerka*) in the Stuart-Takla watershed is at risk from impacts of logging. Much of the effort directed at removing wood from beetle infested areas in the Bowron district has been redirected to the Stuart-Takla area. There are serious implications for altering stream temperatures and potential for impacts from sedimentation of incubation habitats. These fish spawn in large numbers (escapements of 10,000 to 300,000) in the tributaries of Middle River at temperatures considered to be at the upper limit for sockeye salmon. The relationship among forest harvesting and silvicultural activities and the productive capacities of aquatic environments in the interior of British Columbia is poorly understood as little fish/forestry research has occurred there.

This report describes a project that is focusing on the effects of forest practices on interior fish stocks and the carrying capacity of the habitat they occupy. We are collecting biological and physical measurements from four watersheds and adjacent portions of the Middle River in the Takla Lake area. Our research, which began in 1990, investigates: streambed gravel composition and movement, and the physical environment of salmon eggs, distribution of large organic debris (LOD), predator-prey interactions, aquatic insect drift, and distribution, movement, growth, and habitat use by salmonids. Data loggers continuously monitor suspended sediments, incident radiation, stream discharges and stream and air temperatures. Adult and fry enumerations that have been made for a number of years on the creeks are continuing. These watersheds have received little human disturbance. The majority of the logging activities will commence in autumn 1994, permitting the collection of 3 years of prelogging data.

Research results will be incorporated into guidelines for interior logging. The forest harvest guidelines generated from these and earlier studies will have application to logging throughout the interior of British Columbia and thus will assist in integration of fishery and forestry resource management.

RÈSUMÈ

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La remonte hàtive de saumon rouge (Oncorhynchus nerka) dans la Stuart, qui fait partie du bassin hydrographique Stuart-Takla, est menacée par less effets de l'exploitation forestière. Une grande partie des efforts portant sur l'extraction du bois des zones infestées par des coléoptères dans le district de Bowron ont été réorientés sur la zone Stuart-Takla. La modification de la température des cours d'eau a de graves répercussions, et la sédimentation a des effets potentiels sur les habitats servant à l'incubation. Ces poissons frayent en grand nombre (échappée de 10 000 à 300 000) dans les affluents de la rivière Middle dont la température est considérée comme à la limite supérieure tolérable par le saumon rouge. On connait mal la relation entre l'exploitation des foréts et les activités sylvicoles et les capacités productives des milieux aquatiques de l'intérieur de la Colombie Britannique étant donné qu'on y effectue peu de recherche dans les domaines de la pêche et de la foresterie.

Le présent rapport décrit un projet portant sur les effets des pratiques forestières sur les stocks de poissons des zones intérieures et al capacité limite de leur habitat. Nous recueillons des données biologiques et physiques dans nos bassins hydrographiques et les portions adjacentes de la rivière Middle dans le région du lac Takla. Nos recherches, qui ont débuté en 1990, portent sur : la composition et le déplacement du gravier du lit du cours d'eau, et le milieu physique des frayères à saumon, la répartition des débris organique de grande taille, les interactions prédateur-proie, la dérive des insectes aquatiques, ainsi que sur la distribution, le déplacement et la croissance des salmonidés et l'utilisation de l'habitat par ces derniers. Des collecteurs de données surveillent en permanence les sédiments en suspension, le rayonnement incident, le débit du cours d'eau ainsi que la température de l'eau et de l'air. Les dénombrements d'adultes et d'alevins qui sont effectués depuis de nombreuses années dans les ruisseaux se poursuivent. Ces bassins hydrographiques ont été peu perturbés par des activités humaines. La majorité des acitivités forestières débuteront à l'automne 1994, permettant la collecte de données pendant trois ans avant le début des travaux.

Les résultats des recherches seront incorporés dans des lignes directrices pour l'exploitation forestière de l'intérieur de terres. Les lignes directrices sur l'exploitation forestière découlant de celles-ci et d'études antérieures s'appliqueront à l'exploitation forestière de toute la zone intérieure et elles permettront donc l'intégration de la gestion des ressources halieutiques et forestières.

INTRODUCTION

Coastal based research of Fishery/Forestry interactions in the Pacific Region of Canada has been conducted since 1970 when the Carnation Creek project was initiated (reviewed in Hartman and Scrivener 1990). Other projects were initiated in the 1980's including the FFIP (Fishery-Forestry Interaction Program) on the Queen Charlotte Islands (Poulin 1984) and a synoptic survey (e.g., Brown et al. 1987). They have involved federal and provincial agencies and universities in the Pacific region of Canada. Experience gained from these studies has been used to develop logging guidelines for coastal British Columbia (BCMFL et al. 1988). Guidelines were incorporated in handbooks (Chatwin et al. 1991) and videos used to train biologists and foresters and have reduced the uncertainties concerning the effects of forest harvest practices on fish production. Research therefore played a catalytic role in identifying cause and effect relationships and data gaps associated with logging related activities on fish habitats.

The relationship between forest harvesting activities and productive capacities of aquatic environments in the interior of British Columbia is poorly understood because little research has been done there. Interior based projects in the Slim Creek watershed (near Prince George, B.C.; Slaney et al. 1977) and at Tri-Creeks (near Edson, Alberta; Sterling 1985) have provided valuable information about sediment inputs after logging, but small fish populations and short time frames limited application of the research (reviewed by Macdonald et al. 1988). Application of results from coastal research to interior watersheds is hampered by regional differences in climate, hydrology and geology. In order to assist with the development of fish/forestry guidelines for the interior a new research project was initiated in 1990, on four tributaries of the Stuart/Takla watershed in the interior of B.C. Following the proven pattern of previous research, this project incorporates long-term (6+ years), integrated, multidisciplinary, case study approaches. Results will promote an understanding of fish production as it relates to the ecosystem processes that effect stream production and forest outputs. Participants from a number of agencies are involved including the B.C. Ministry of Forests (MOF), Fisheries and Oceans Canada (DFO), the Tl'Azt'En Tribal Nation and local universities. Results from these studies will assist in the development of fisheries/forestry guidelines for the interior of British Columbia.

Project objectives focus on the effects of forest practices and natural phenomena on interior fish stocks and the carrying capacity of the habitat they occupy. Sockeye salmon (*Oncorhynchus nerka*) are the species of particular interest because of their economic importance and prevalence in the area. The issues are listed below.

A. Forest Practices:

1. Rate of cut - harvesting rates within watersheds,
2. Cumulative impacts from long-term forest industry activities (e.g., combined influence of water temperature, sedimentation, fish growth, habitat changes etc.),
3. Harvesting methods and timing.
4. Post-harvest treatments.

B. Natural Phenomena:

1. Role of large organic debris (LOD) in interior streams,
2. Downstream effects,
3. Floods,
4. Beaver activity,
5. Seasonal temperature changes.

C. Biological Associations:

1. Sockeye - Kokanee relationships,
2. Salmonid and bird predation on sockeye salmon fry,
3. Insect production,
4. Sockeye salmon fry abundance and outmigration timing,
5. Sockeye salmon escapement estimates,
6. Lake productivity seasonal timing.
7. Early feeding habits of sockeye salmon fry

STUDY AREA

Location and Physical Features

The Takla Lake/Middle River drainage basin with approximately 33 tributaries represents the most northern extent of the Fraser River watershed (Fig. 1; Lat. 55°.00' N. Long. 125°.50' W.). Four adjacent tributaries which flow northeast into lower Takla Lake (Bivouac and Gluskie Creeks) or into the upper portion of Middle River (Forfar and O'Ne-eil[4] Creek), have been chosen for this project (Fig. 2). These tributaries have watersheds of 36-75 km^2 and they are all approximately 20 km long.

To date, little disturbance has occurred in the four adjacent watersheds. A single road has been built across the flat and narrow valley bottoms of each watershed. Bridges cross Bivouac, Gluskie, Forfar, and O'Ne-eil Creeks at points 500 m, 450 m, 1650 m, and 1700 m, respectively, from their mouths. The bridges confine and control the stream channel making them stable sites for rating stream flows.

The watershed basins are in the Hogem Range of the Omineca Mountains and as such have a relatively high relief. Three distinct channel types occur in each stream. In the upper-most channel areas (but below the steep mountainous canyons) valley walls are steep, unstable and show evidence of recent land failures that have resulted in direct input of sediment and debris into the stream channels (Harder and Assoc. 1989). The channels in these areas are strongly influenced by sediment derived from hillslope processes (mass wasting, soil creep). Channels are straight and bed and bank textures are coarse. At intermediate elevations, stream channels remain straight and steep but they are influenced to a greater degree by normal alluvial processes with some modification from downstream

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[4]also called Kynock Creek.

transfer of sediment and debris introduced upstream. At these elevations the stream crosses a bench composed of glacial till deposits which likely provide the source of the spawning gravel found at lower elevations. Interspersed among the glacial till are extensive deposits of lacustrine clays which, if allowed to enter the stream in large quantities, could lead to sedimentation problems in the salmon incubation habitats. Lacustrine deposits in Forfar and O'Ne-eil Creeks are more exposed than in Gluskie Creek. The lower 3-4 kms of the watersheds have lower gradients (0.5-2%) with large fluvial fans near their mouths. The streams meander through these fans which form the spawning gravel used by the sockeye salmon populations. Large organic debris (LOD) is abundant in all channel zones.

The valleys of these watersheds form the northern end of the Sub-boreal Spruce biogeoclimatic zone, while the higher elevations are within the Engelmann Spruce - Subalpine Fir zone (BCMFL 1988). Air temperatures are warm only during June, July, and August (Fig. 3), which are the only frost free months (ANON 1970-1990). Leaves of deciduous vegetation appear during May and fall during September so the growing season is short compared to other zones. Annual precipitation is ~50 cm (ANON 1982), with seasonal peaks occurring as rain during June/July and Late August/September (Fig. 3). Precipitation occurs almost exclusively as snow during November to March (ANON 1982). Sunny days occur during July and August when temperatures frequently exceed 20°C (Fig. 3), and during February and March when they are frequently below -20°C (ANON 1970-1990).

Temperatures of the streams are also extremely variable and seasonal. Water temperatures do not exceed 1°C until April and a diurnal cycle does not appear until May (Fig. 4) when the sun becomes high enough to penetrate through the forest canopy over the streams and after much of the snow has melted in these small watersheds. Diurnal variability rarely exceeds 3°C in the forested watersheds. Daily temperatures rise rapidly from 4 to 10°C during June, vary from 8 to 13°C during the summer, and drop rapidly to 1°C again during early October (Fig. 4). Temperatures remain ~0.5°C throughout the winter. Snow bridges the channel by bending the minor streamside vegetation over it, thus insulating the stream and stabilizing temperatures. Occasionally stream temperatures are recorded below 0°C, but this may be associated with short periods of ice formation on the thermistor probes.

Early results from analyses of streambed samples from Gluskie, Forfar and O'Ne-eil Creeks, indicate that gravel composition varies among sites. All streams contain high quality environments for incubating salmon eggs. Only 17 of 190 frozen cores that were obtained from the streams during the autumn of 1990 and 1991 contained particles larger than 100 mm in diameter. Ninety-two of them contained particles larger than 70 mm in diameter. Particles smaller than 0.074 mm (silt and clay) and 0.3 mm (fine sand and smaller) comprised less than 1% by weight of 189 and 71 of the frozen cores, respectively. Therefore, our preliminary results indicate that the streambeds are likely to be excavated by spawning sockeye salmon and there are few fines to fill the pore spaces in the gravels (Everest et al. 1987; Burgner 1991).

Fredle indices (*Fi*) were calculated for each streambed sample using the diameter of the particle at the first (25%), second (mean) and third (75%) quartile of the distribution of particle sizes in a sediment sample (*Fi* = mean dia $/\sqrt{dia_{75}/dia_{25}}$; Lotspeich and Everest 1981). Fredle indices are positively correlated to particle size and incorporate a measure of particle size variability. Mean indices ranged from 5 to 7, with the larger values coming from Gluskie Creek sites and higher gradient sites further from the creek mouths (Figs. 5 and 6). Egg-to-fry survivals of >30% are expected from incubation gravels with $Fi \geq 5$ (Lotspeich and Everest 1981; Scrivener and Brownlee 1989; Scrivener *in press*). Survival of sockeye eggs should be even greater at Takla Lake than those predicted with data from other stocks of salmon, because the rarity of large rocks (>100 mm) tends to lower the *Fi* values and the small size of incubating alevins (30-33 mm) permits them to move through small pore spaces (Dill 1969). Composition of the incubation gravel is known to influence the size of emerging fry (Scrivener and Brownlee 1989).

Resources

Like the channel types, vegetation cover is divided into three zones. The uppermost zone consists of Engelmann spruce (*Picea engelmannii*) and sub-alpine fir (*Abies lasiocarpa*). Forests at intermediate elevations are formed by dense white spruce/pine stands (*P. glauca; Pinus contorta*). Mixed forests at lower elevations consist of white spruce, several northern deciduous species (e.g., trembling aspen, *Populus tremuloides*; black cottonwood and balsam popular, *P. balsamifera spp.*) and forest shrubs (e.g., sitka alder, *Alnus viridis*; devils club, *Oplopanax horridus*; thimbleberry, *Rubus parviflorus*; mountain ash, *Sorbus sp.*). Most forests are mature but some immature stands exist where there have been forest fires or forests have been killed by insect attack during the last century (Canfor staff Fort St. James).

Only one of the four watersheds (Bivouac Creek) chosen for this study has experienced logging activities; a few small cutblocks near the lower reaches of the stream comprising less than 10% of the watershed. However, much of the logging effort that was originally planned for the Stuart/Takla area but was directed at removing wood from beetle infested areas in the Bowron district in the 1970's, has now been redirected to the Stuart/Takla area. Both summer and winter logging activities are being initiated in specific areas throughout the region to deal with an insect epidemic. Logging activities create serious implications for altering stream temperatures which could influence the success of salmonid egg fertilization and their rate of development. Altered sediment transport could influence incubation success.

The Stuart/Takla watershed supports both early and late-timed sockeye salmon stocks and a distinct race of kokanee (Foote et al. 1989). The early stock typically spawns between July 27 and August 23 in the tributaries. The late run arrives between September 10 and 28 to spawn in the Middle River as water temperatures decline (Hickey and Smith 1990). They often incubate their eggs in gravel deposited at the mouths of the tributaries. Kokanee spawn in the tributaries throughout August. Since the first records in 1951, annual escapements of early run sockeye salmon in the Stuart/Takla watershed have ranged from 20,000 to 300,000 fish (Fig. 7). Escapements in 1991 and 1992 are estimated at 141,000 and 48,000 respectively. Late run fish have exceeded these numbers on some years (Harder and Assoc. 1989).

Since 1938, escapements to Gluskie and Forfar Creeks have frequently exceeded 10,000 fish (Fig. 8). Runs to O'Ne-eil Creek are larger, frequently exceeding 15,000 fish (Harder and Assoc. 1989). Estimated escapements to the three creeks in 1991 were 17,364 to Gluskie, 21,883 to Forfar, and 28,503 to O'Ne-eil. Predicted escapements to all three streams in 1992 were similar (range = 10 to 60 K) but they were much lower than expected. During most years these three streams support in excess of 50% of the early sockeye salmon run to the Stuart/Takla watershed (48% in 1991). Bivouac Creek is the least productive of the four streams, having runs of less than 1000 fish on most years (~1% of the early sockeye salmon run, Harder and Assoc. 1989; Fig. 8).

The majority of sockeye salmon return as 4-year-old adults after spending one winter during instream incubation plus another in a lake (4_2). This age group forms 98% of total returns (catch and escapement) during peak years (e.g., 1985; Fig.7), but only 69% of total returns during low production years (e.g., 1984; Fig.7). Age 5_2 (2-28%), age 5_3 (0.1-3%), and age 3_2 are less commonly observed.

Estimates of sockeye salmon fry abundance and outmigration timing have been made since 1989 in Gluskie and Forfar Creeks (Hickey and Smith 1990). Outmigration occurs between late March and early June in coincidence with hydrologic events (Fig. 9). Peak outmigration occurs during mid-May, before the peak runoff of melting snow. Hickey and Smith (1990) note similarities in the timing pattern of outmigration between the two streams. Outmigration estimates from O'Ne-eil Creek were begun during 1992. Based on the preliminary 1991 estimates of egg deposition and previous years egg-to-fry survival (10-30%), total outmigration from each stream in 1992 could range from 3 to 20 million fry.

Smolt outmigration from the mouth of Stuart Lake was monitored in 1967. It occurred throughout the month of May (Fig. 10; Williams 1969). A smolt trap was deployed in 1992 to monitor timing.

Other species of fish live in the Middle River area including rainbow trout (*O. mykiss*), bull trout (*Salvelinus confluentus*), burbot (*Lota*), dace (*Notropis sp.*), mountain whitefish (*Prosopium williamsoni*), lake whitefish (*Coregonus clupeaformis*), redside shiner (*Richardsonius balteatus*), northern squawfish (*Ptychocheilus oregonensis*) and slimy sculpin (*Cottus cognatus*). Electrofishing surveys in Gluskie, Forfar and O'Ne-eil Creeks in the spring of 1990 found sparse populations of rainbow trout and a few juvenile burbot (Table 1).

Measurements of redd depths of sockeye salmon eggs have been obtained from the freeze-core samples since 1990. Redds are normally distributed around a mean depth of 17 cm in Gluskie, Forfar, and O'Ne-eil Creek (Fig. 11). They are also deeper in Forfar Creek (mean = 20 cm) than in Gluskie Creek (mean = 16 cm), but they are found at intermediate depths in O'Ne-eil Creek. Redd depths may be deeper in Forfar Creek, because large gravel particles are rare making redd excavation easier (lower *Fi*; Fig. 5).

STUDY DESIGN

During the first six years of this project the natural fluctuations of a number of biological and physical variables and the short term impacts of logging and road building will be monitored. Additional monitoring after six years will be necessary in order to realize results from the long-term post-logging phase of the project including the effects of silvicultural activities. The majority of the logging is scheduled to commence during the autumn of 1994, thus permitting the collection of three years of prelogging data. A small cut block in Gluskie Creek may be harvested during 1993 to deal with a beetle infestation epicentre. In 1994, road building and harvesting activities will begin in Gluskie and O'Neeil watersheds using a combination of conventional clearcutting techniques and minimum impact methods (single-tree or group selection cuts, small cutblocks, leave strips etc.) in selected cutblocks. Impact comparisons will consider the differences in soil morphology between the two systems. Forest activities will begin in the lower portion of each watershed and proceed upstream as the project progresses. Canadian Forest Products (Canfor) has altered their logging plans to accommodate our experimental design. A third watershed (Forfar Creek) will remain unlogged as a control for the life of the project. Thus the experimental design includes both a spatial and temporal control. The effects of streamside and watershed treatments can be restricted to the watershed in which they were performed. Bivouac Creek will act as a control for those experimental designs where a stream with few fish is required (e.g., salmon effects on bedload movement).

STUDY COMPONENTS

To understand the effects of road building and timber harvesting on aquatic environments and fish production it is necessary to have an understanding of the underlying processes involved in stream production and forest outputs. Studies that seek to define ecological processes allow broad application of their results to a wide variety of watersheds (Hartman and Scrivener 1990) and therefore are more useful in the development of interior fish/forestry guidelines. A large number of physical and biological variables are being collected in an effort to link the components within and between riparian and aquatic ecosystems (Fig. 12). Our activities in all streams will include, yearly sampling for streambed composition and egg distribution; yearly LOD surveys; monitoring of suspended sediments, stream and air temperatures, incident radiation, and stream discharges; predator-prey interaction surveys; insect drift sampling; and distribution, movement, growth and habitat use of resident salmonids in the streams and adjacent portions of Middle River.

The DFO habitat section is the lead agency and coordinates the Stuart/Takla Watershed Project, but many of the individual component studies are the responsibility of other groups. The channel morphology study, and parts of the sediment budget and hydrology studies are the responsibility of the B.C. Ministry of Forests. Parts of the historic channel and bedload movement are being studied by faculty of local universities. The stock assessment group of DFO monitors lake productivity.

Radiation and Temperatures

Continuous records of solar radiation, and air and water temperature are necessary to characterize the physical environment. Radiation and temperature effect plant growth and the activity and development of poikilothermic animals such as invertebrates and fish. Watershed disturbances can change radiation levels and stream temperatures (Hartman and Scrivener 1990). Results from the temperature studies are used for many of the biological components of this program (Fig. 12).

Data loggers are used for recording and storing information on the physical environment in digital format. Solar radiation and air temperature are obtained from a meteorological station at the Middle River camp (Fig. 2). Stream and intergravel temperatures are obtained from two or three loggers in each of Gluskie, Forfar, and O'Ne-eil Creeks. Two or three intergravel thermistors (~17 cm deep), and one for stream temperature, are monitored by each data logger. To maintain battery operation during the cold winters (-40°C), the loggers are packed within insulated containers and buried in the streambank. The earth and snow covering acts as insulation and maintains an operating temperature (≥1°C) throughout the winter. Data is extracted from the loggers four or five times annually. Visits to the sites are frequently made to obtain reference points with a digital watch and calibrated thermometer.

Thermal Units

Sockeye salmon have developed a number of mechanisms to optimize incubation survival in northern environments. For instance, their rate of embryonic development increases at lower temperatures thus promoting little fluctuation in emergence timing despite large year to year variation in temperature regimes (reviewed in Burgner 1991). Forestry disturbances may promote increases or decreases in inter-gravel water temperatures during the incubation period, depending on the mechanisms involved (Hartman and Scrivener 1990). The degree to which embryonic development compensates for these temperature changes will effect the ability of the fry to emerge at a time that will coincide with favourable feeding or survival conditions in their rearing habitat.

The degree to which yearly variation in stream and redd temperatures are correlated with outmigration timing will be examined before, during and after forestry activities. Periodic collections of developing embryos will be made as temperatures decline in the fall, to examine development rates (Velsen 1980) and the number of the eggs that have been successfully fertilized. Other factors that may effect development rates and outmigration timing are rate of water temperature decline in the fall and the water temperature during fertilization. Egg development baskets planted in each stream may assist in further defining temperature/egg development questions.

Escapement Estimates

Adult enumerations in Bivouac, Gluskie, and Forfar Creeks have been conducted on an annual basis since 1938 (Fig. 8). Enumerations began on O'Ne-eil Creek in 1991. This information has been used to determine the size and biological characteristics of the sockeye salmon population in the Stuart/Takla watershed. Yearly counts of the numbers of adult sockeye salmon in each stream have been made and estimates of sex ratio, age structure, mean fecundity, and overall stream egg deposition characteristics have been recorded. These activities will continue in the future.

The arrival timing at the fences of the early Stuart River sockeye stock is generally between July 15 to July 20. Peak spawning occurs between August 1 to August 10 and spawning and data collection is usually completed between August 20 to August 25. Annual variations in spawning timing rarely fluctuates more than ten days from the average.

A fence spanning each stream is constructed each year and a total count of adult sockeye salmon passing through an opening in it is made. The fences are of wood frame construction, each fence panel is 1.3 m high by 2.6 m long. Panels are covered by galvanised steel screen with a 2.4 cm mesh, and held in place by a combination of steel and wooden stakes. The base of the fence is sealed with a double layer of heavy gauge sheet plastic and secured with sandbags. Because of low flows during the spawning period fences require little maintenance under normal conditions but may require large amounts of maintenance for short durations during rainstorm freshets.

Every other day, spawner distribution is determined by counting live and dead fish along the length of each creek. Sex ratios and otoliths are obtained from the carcasses. Sex is also determined visually from 50 - 70% of the fish when they pass through the counting fence. Numbers of live fish during peak spawning and the cumulative numbers of carcasses, are summed and compared to actual fence counts to produce a expansion index which is applied to all other surveyed streams in the Stuart/Takla watershed.

Age structure is determined from scale and otolith samples taken from 30 males and 30 females from both Gluskie and Forfar Creeks and 60 males and 60 females from O'Ne-eil Creek. Scales and otoliths are removed from fish during the peak die-off period, which usually occurs in mid-August. These samples are also used for racial identification for comparison with fish captured in the commercial fishery.

A sample of 50 female sockeye is also sacrificed from each study stream approximately ten days after the arrival of the sockeye salmon, to determine the mean fecundity. During the dead recovery each female carcass is examined to estimate the degree of spawning (0, 50, or 100%). These data are used to estimate the total number of effective females in each stream. The number of effective females is multiplied by the mean fecundity to determine potential egg deposition.

Incubation and Outmigration Success

Daily and annual estimates of the number of sockeye fry outmigrating from Gluskie and Forfar Creeks have been obtained since 1989 (Fig. 9). Similar estimates have been made from O'Ne-eil Creek since 1991. Outmigration estimates were compared to egg deposition estimates from the previous year (see escapement estimate section) to determine egg to fry survival in each creek. Annual estimates of survival and fry outmigration timing will be compared among treatment and control streams and between prelogging and postlogging years.

Fry are captured by deploying a 2 m x 3 m floating inclined plane trap in the centre of each stream, near the mouths. In order to maintain adequate velocities, they are moved progressively upstream (~100 m) as the water level in Middle River rises. Traps are fished nightly from dusk until dawn, but periodically 24 hour sets are made, and hourly samples taken, to provide information about diel migration timing.

Trap efficiency is estimated using an adjusted Petersen mark-recapture technique (Poole 1974). Trap efficiency, which is normally 5 %, is estimated by marking 1000 to 2000 fry by immersion in Bismark 'Y' biological dye on a nightly basis. They are then released the next night at a location 1 - 2 km upstream. At the beginning and end of the sampling period, small numbers of fry limit the size and frequency of releases.

Twice weekly during the run, 20 to 30 fry are removed from the traps and stored in 10 % formalin. These are used to determine the size and condition factor of fish in each stream. Fry samples also assist in determining the degree of post-emergent growth and feeding that occurs in the natal stream during outmigration (refer to fish diet section).

Lake Productivity

It is believed that the outmigration of sockeye salmon fry is timed to take advantage of the seasonal abundance of suitable prey items in their lake rearing habitats (reviewed by Burgner 1991). Logging induced changes in incubation habitat temperatures may alter outmigration timing such that fry entrance to the lake environment doesn't coincide with favourable feeding or survival conditions. Takla Lake has been described as having low phytoplankton and zooplankton biomass when compared to neighbouring lakes, but little is known about the annual production or variability in available food (Stockner and Shortreed 1978, 1983).

Measurements of chlorophyll, zooplankton, temperature, water clarity and water chemistry are being obtained at two stations (1 mid-Takla lake, 1 Middle River), once weekly between April (after ice breakup) and June 30, and once monthly from July until late October. The seasonal timing of sockeye emergence will be compared to the seasonal peak in lake productivity. Hydroacoustic and trawl surveys in the autumn are being used to obtain a population estimate of the sockeye salmon before their dispersal as smolts the following spring.

Hydrology

The hydrological cycle strongly influences the aquatic communities and fluvial processes that occur in Gluskie, Forfar, and O'Ne-eil Creeks. Measurements of precipitation (rain and snow) and stream flow are necessary to characterize the cycle. Precipitation is measured with a tipping bucket and recorded with the data logger at the Middle River camp (Fig. 2). Snow accumulations are measured for depth and water content during the winter. Water level and stream flow are measured at the bridge sites on each creek. A continuous record of water level is obtained with pressure probes and data loggers situated immediately above the bridges and is supplemented with opportunistic records from staff gauges in each creek. Flow measurements are obtained frequently from stable stream cross-sections from under each of the bridges. These data are used to generate a continuous hydrograph for each stream (Ozga 1974).

The hydrographs are used in most other component studies (Fig. 12). Sediment budgets are influenced by stream flow changes that may occur during forest harvesting operations (Bosch and Hewlett 1982, Thorne et al. 1987). Movement of both coarse and fine sediments influence channel morphology (Hogan 1986), and substrate composition (Scrivener and Brownlee 1989) which can alter salmonid incubation success (Fig. 12) (Hartman and Scrivener 1990).

Channel Morphology

The channels of Gluskie, Forfar and O'Ne-eil Creeks have many similar biophysical characteristics which change significantly from higher to lower elevations (see Introduction). Channel studies have been designed to include a range of channel types and to investigate the importance of large organic debris (LOD). Accordingly, channel studies are conducted at two spatial scales; channel and reach studies.

Channel scale surveys include the entire lower 3 - 4 km of the water courses. Although these surveys deal with a comprehensive list of channel attributes (Table 2), fewer details are included than in the reach scale surveys. They focus on channel morphological features of direct relevance to fish habitat. Pools, riffles, off-channel features and LOD characteristics are of main importance. The role of LOD accumulations, or log jams, are central to this study because of their influence on stream morphology and fish habitat. Their age and stability provides information regarding long-term channel changes and allows an estimation of the frequency at which new sources of LOD enter the stream. The log jam attributes to be studied are presented in detail in Table 3.

Low level aerial photographs are another important technique used in channel scale surveys. Photographs obtained from 70 mm cameras held aloft by a helicopter, have extremely high resolution. They are analysed with the assistance of a computer linked analytical plotter to quantify channel morphology on a aerially extensive basis.

Reach scale surveys are conducted within three reaches in each stream. They provide a more detailed examination of channel morphology, channel bed and bank characteristics, the functional role of LOD, scour/fill depths and bed material movements (Table 4). A combination of engineering survey techniques, tracer stones (bedload movement section) and scour chains are used at the reach scale level of this study.

Sediment Budget

Hillslope materials are moved downslope to contribute to stream sediment production by landslides and soil creep processes. Streambank erosion and gulley processes also provide sediment input. Fine lacustrine deposits are extensive in the Takla Lake area, and much of the sediment moved by these streams is likely transported in suspension. Sediment transport through the watershed is sporadic and sediment is stored in specific zones for various time periods.

Following logging there is commonly an increase in landslide rates, and streambank and surface erosion (Chatwin et al. 1991). To resolve landuse related sedimentation issues, it is necessary to create a sediment budget before, during and after land disturbances. The budget must account for all sediment entering and leaving the stream. It must partition sediment yield by source and allow calculation of the persistence of sediments in stream channels. A sediment budget must also identify the proportion of sediment mobilized on hill slopes that enters the stream channel.

Stream samples, turbidity meters, and stream hydrographs are used to generate a continuous record of suspended load in the streams. A D.A. Instrument's (Model OBS-3) back-scanner meter and recording data logger have been installed to continuously monitor turbidity (NTU) on Gluskie, Forfar, and O'Ne-eil Creeks at 450 m, 1650 m and 1700 m from the stream mouths respectively (ie. above the bridges). Back-scanner meters are rated for stream discharge and calibrated for sediment concentration with paired water samples taken weekly with a DH48 water bottle holder at sites adjacent to the meters. Samples are periodically obtained more frequently during hydrological events and spring snow melt. Concentration of suspended sediment ($mg*L^{-1}$) is obtained from sample volume and the weight of filterable solids it contains. Thus turbidity from the meters can be calibrated for concentration of suspended sediment in each stream (Lloyd et al. 1987). Sediment hydrographs are then generated using stream flow and sediment concentration data (Stichling 1973).

Samples are also taken from the mouths of the creeks and from Bivouac Creek (500 m upstream from the mouth) and at sites identified as sediment sources. Although continuous sediment hydrographs can not be generated for these sites, sediment loads can be calculated for short periods for the purposes of locating sediment sources. These studies will likely expand when road construction and logging has begun.

The sediment budgets will be further defined with additional information as follows:

a) Stored sediment will be monitored through channel surveys of depositional areas (backchannels and overbank deposits) and by gravel sampling (streambed composition section).

b) Watersheds will be mapped to establish terrain units (1:20,000 scale) with descriptions of surficial materials, textures.

c) Sediment sources (e.g., type, texture, location) will be identified and classified into representative process groups. This inventory will be updated annually.

d) Measurement of sediment yields from representative sedimentation classes will be made. This includes chronic sources as well as sporadic sources (e.g., landslides). Sediment yield monitoring will be done on an individual storm basis and on snow melt freshets.

e) The stream channel network will be partitioned into sediment transfer links to identify sediment pathways and storage locations. Determination of persistent sediment sources, historical zones of channel change and sediment transfer zones will determine the final subdivision of the watershed. Zonations will follow procedures detailed by Hogan and Wilford (1989). This will include dating of sediment wedges and fan deposits within the deposit.

f) Repetitive stream channel morphology surveys will be conducted at established control points and complete channel monitoring will occur using low level stereophotography (1:500 scale). This will allow identification of areas of bedload storage and erosion, as well as provide information on fluxes of bedload material.

Streambed Composition

There are three objectives in this study component, each necessary to achieve our main objective to determine the effect of forest harvesting on streambed composition. First, to characterize the spawning gravel in Gluskie, Forfar, and O'Ne-eil Creeks. Second, to quantify gradients of streambed composition among or along these creeks. Third, describe the range of annual change of spawning gravel composition under natural conditions in each stream.

Samples of the gravel from the streambeds are obtained by a freeze-core method and they are processed annually. Ten samples from each of four study sections are obtained during September/October from each stream (total = 120). Whenever possible, sample sites are chosen at established cross-sections from the channel morphology study. Acetone cooled with dry ice is used to freeze a 20-30 cm diameter core around a steel probe that is driven 30 cm into the streambed (Ryan 1970; Scrivener and Brownlee 1982 and 1989). Each core is split into top and bottom layers. Particle size distributions are determined for each layer after drying and weighing, by passing the sample through seven nested sieves, weighing the contents on each sieve, and calculating cumulative percentage of a layer smaller than each sieve size. Mean diameter is also calculated for the largest rock. Significant relationships are obtained between percent of a layer passing, and size of the sieves. They can be used to predict the percent smaller than any particle size, the geometric mean of the particle diameters, and the fredle index for each layer of each sample (Shirazi et al. 1981; Lotspeich and Everest 1981).

Characterization of the habitat where eggs of sockeye and kokanee salmon are incubating provides important inputs to other component studies (Fig. 12). Gravel texture is known to be influenced by forest harvesting, by ponding (beaver activity), by sediment production, and by bedload movement (Scrivener and Brownlee 1989). Gravel texture influences the rate of streambed scouring, the aquatic insect community and production, and the incubation success of salmonids (Hartman and Scrivener 1990).

Invertebrate Production

Logging and road construction in mountainous terrain in the interior of B.C. may have an adverse impact on macroinvertebrate communities. Sedimentation that results from improper land use practices may reduce the density of drifting invertebrates (Tebo 1955, Slaney et al. 1977) which may reduce the feeding success of fish resident in the stream and its receiving waters (Burns 1972). Whether sockeye fry remain in their natal stream (Burgner 1962; Rogers 1968) or move to adjacent lakes or rivers or directly to sea (Wood et al. 1987) to rear, invertebrates (particularly chironomids) originating from stream habitats predominate in their diets during the period immediately after emergence (Simonova 1972; Goodlad et al. 1974).

Invertebrate drift samples are taken in Gluskie, O'Ne-eil, and Forfar Creeks using a technique described by Cushing (1964). Sampler aperture is 2.54 x 15.24 cm with a 200 uM Nitex collecting net. Concurrent estimates of stream velocity and water depth are taken at the sampler aperture to standardize the invertebrates caught to density in the water column. Samples are taken weekly during a 24 h period (n=2), at sites near the mouths of each creek with occasional additional sampling effort at sites 1500-2000 m upstream. Tsitsutl Creek is also sampled monthly at a site near its confluence with O'Ne-eil Creek. Sampling effort is maintained from the period after ice melt until mid-August. Effort is reduced to a bimonthly schedule in late summer and autumn.

Fish Diets

Little information exists on the feeding behaviour of sockeye fry during the period immediately after their emergence (Higgs et al. in press). Stomach contents of sockeye fry (n=10/week) that have been captured by incline plane traps at the mouths of each creek are analysed to quantify food species, describe feeding behaviour and identify food sources. Contents are compared to available food as estimated from invertebrate drift samples. Stomachs of sockeye fry captured by electofishing during creek surveys in early June and July are also analysed. Fish diets will continue to be examined during and after forestry activities to monitor the effect of changes in food sources and water temperature that may occur. Diets of sockeye salmon juveniles that are captured during autumn trawl surveys in Takla Lake are also analysed.

Beaver Effects

Periodically in the autumn, beavers build dams near the mouths of the experimental creeks. Ponds are created that cover a 50 - 100 m section of stream with depths of 1 m. They frequently cover incubating sockeye and kokanee salmon eggs. Ponding reduces water exchange and dissolved oxygen in the streambed, and it can cause increased sedimentation. These impacts can cause mortalities among incubating salmon eggs and entombment of fry attempting to emerge in the spring (Scrivener and Brownlee 1989). Beaver populations appear to be increasing in northern British Columbia because changing public attitudes and fashions have nearly ended fur trapping. The magnitude of these beaver effects on salmon is unknown. Characterization of the effects of beavers on aquatic environments provides important baseline data for comparison to sedimentation events that may occur once forestry activities begin.

If opportunities to measure beaver effects arise, we plan to quantify intergravel dissolved oxygen, egg mortalities, gravel permeabilities, and sedimentation rates in control and impacted sections of the streambed. Intergravel dissolved oxygen and permeabilities can be measured within stand pipes that are driven into the streambed (Wickett 1958; Scrivener and Brownlee 1982). Sedimentation rates can be obtained from Whitlock-Vibert boxes that are filled with pebbles and set into the surface of the streambed (Reiser et al. 1989). Incubation mortalities can be determined with an egg pumping technique (McNeil 1964).

Beaver impacts on sockeye salmon populations can be quantified when the incubation success in all three creeks and the length of beaver impacted stream channel are known. Studies of gravel composition, bedload movement, scour depth, and incubation habitat will characterize Gluskie, Forfar, and O'Ne-eil Creeks (Fig. 12). Incubation success can be measured as the percent survival from number of spawned eggs (count of adult females x fecundity) to number of emigrating fry during the spring.

Bedload Movement

The streambed in the lower kilometre of Gluskie, Forfar and O'Ne-eil Creeks is composed of glaciolacustrine laminated silts and clays inset with gravel stringers which move in response to physical and biological agents. Redd excavation by spawning salmon is one mechanism by which bedload materials can be transported downstream (Scrivener and Brownlee 1982). Bedload budgets in streams that are heavily utilized by spawners may be controlled by salmon activity. Other influences include seasonal stream flow, channel morphology, and forest harvesting. Both the amount and volume of bedload moving through a stream system is indicative of stream stability and thus influences both physical and biological processes in streams (Fig. 12). Bedload movement can affect composition of the spawning gravel and thus habitat for incubating salmon eggs or aquatic benthos (fish food). This component study is designed to measure the effect of sockeye salmon, stream flow and forest practices on bedload budgets.

Bedload storage reservoirs constructed from 20 L plastic buckets are buried along transects that span Bivouac, Gluskie, Forfar, and O'Ne-eil Creeks (total = 20). The tops of the buckets are level with the streambed. Lids covering the top of each bucket have a 5 x 7 cm slot through which a sample of gravel is taken as it moves downstream. The buckets are lined with polyethylene ore bags which are removed when full. Volumes and weights of the contents are determined and a subsample is taken for particle size analysis (see gravel composition). The height of the contents of the buckets are measured weekly during the ice-free months

Distance of bedload transport is determined by tracing the movement of magnetic pebbles and rocks that have been placed in two reaches of each stream. A representative sample of the size distribution is collected from the armouring layer of each reach. The rocks are marked with orange paint, with two neodymium magnets and with an individual ID number (epoxied into a groove). They are returned to the same reach as a cluster in the thalwag of the stream. At regular intervals throughout the year (particularly after major hydrologic events), the rocks are relocated with a FMD-4, SECO magnetic locator. Their depth in the streambed and map location are measured using a rod, laser theodolite, and permanent survey hubs. Measurements of distance between the release and recovery location of each rock are accurate to ± 5 cm. The rocks are left in place and reburied. Recovery rates of 65-80% from depths of ≤ 30 cm were achieved after the 1992 spring flood. To date, 1400 rocks have been marked. With both distance and volume measurements of bedload movement throughout the year, the relative importance of physical, biological, and human-induced influences can be determined.

Research results will contribute to the understanding of the interaction between sockeye salmon and their effects on the physical environment. This research has important implications for determining desirable escapement levels. Data from this study will complement other components of the project including investigations into incubation habitat, gravel composition and historic channel changes.

Historic Channel Changes

There are numerous former channel segments and evidence of channel changes in Gluskie, Forfar and O'Ne-eil Creeks. Modern gravel bars are formed by annual floods, but larger deposits occur on the scale of decades and several of the former channel segments are more than a thousand years old (pers. com. A. Gottesfeld, University of Alberta, Edmonton). Mapping and measuring these features permits evaluation of the frequency and magnitude of the water and sediment discharge events that led to the channel change disturbances. Knowing the response to climate warming during the last 150 years will allow insight into the susceptibility of these tributaries to future climate induced changes or to changes due to forestry. This information also provides a baseline to which modern rates of sediment movement and frequency of channel shifts can be compared.

The annual scale of change is measurable by determining the size of individual gravel bar accumulations and by measuring annual bedload transport (bedload movement section). Channel changes on a decadal scale can be determined from sequential airphoto interpretation. Measurements of the size of gravel deposits resulting from channel changes of the past few decades, and establishing the dendrochronological dates of the deposits and abandoned channels (e.g., Gottesfeld and Gottesfeld 1990) will permit the frequency and magnitude of disturbances to be determined for the experimental creeks. Channel segments that date back several centuries (C^{14} dating) will be examined to determine their former width, depth, sinuosity and activity level. This may allow predictions of the effects of future climate induced changes on stream morphology and the associated sockeye salmon incubation habitat.

Field work to collect the paleohydrological data has begun, with preliminary results expected late in 1992. This study will be coordinated with the bedload movement component of the project. The resulting information will complement other aspects of this project including, stream morphology, sediment budget and basin geomorphology components.

Incubation Habitat

Incubation habitat characteristics and the area within each stream that is used for incubation, will be determined. Habitat area will be obtained from the distribution of adult spawners in each stream. Depth ranges of eggs in the spawning gravel are measured whenever eggs are encountered in the frozen cores which are taken during the gravel composition studies.

Incubation habitat will be described using the results from other component studies. Stream and intergravel temperatures characterize incubation habitat during the incubation period. Temperature strongly regulates rate of egg development and timing of chum and coho salmon fry emergence (Hartman and Scrivener 1990). Stream flows influence water exchange rates and scour depths in the habitat (Scrivener and Brownlee 1982). Substrate composition and permeability influences water exchange rates, permeability, dissolved oxygen and movement of alevins through the interstitial spaces in the streambed (Dill 1969). Incubation success is measured as total egg-to-fry survivals and as survivals and fry sizes from individual redds.

Predation Studies

Each spring as the sockeye fry leave their natal streams to enter the Middle River or Takla Lake, concentrations of large, potentially piscivorous fish gather at the mouths of the streams. The degree to which they feed on sockeye fry and the percent of the sockeye population consumed has not been determined. Predator population size is estimated by beach seining (catch per unit effort) the shoreline adjacent to the creek mouths. Stomach contents of predators captured are collected by a gastric lavage technique and analysed to determine the degree of piscivory. Literature values of gastric evacuation rate will be used to estimate daily fry mortality during the outmigration period. Incidental angler captures during the spring and summer will also be analysed.

Resident Fish Research

In the Stuart/Takla watershed, rainbow trout and bull trout contribute to an established sport fishery on the Middle River and the adjoining Takla and Trembleur Lakes. Sport fish in interior rivers and lakes are highly dependent on tributaries for spawning and rearing (1-3 year residence). Studies of rainbow trout in the Upper Nechako, the Blackwater and the Slocan Rivers have demonstrated that there is negligible spawning of adults and rearing of fry within mainstems. Rather, small tributaries are utilized for spawning and rearing (Slaney 1986, Griffith 1991).

Forest harvesting in small interior watersheds can effect water temperature, sedimentation, insect abundance and composition and channel morphology (Slaney et al. 1977). As a consequence, production of juvenile trout and char (e.g., lake trout) may be altered and their size distribution and survival to adult stage may be impaired. Shifts in the timing of available food or its abundance, including sockeye eggs and fry, and insects, may also effect resident fish populations.

Migrant trout (age 1+ to 3+) will be trapped, enumerated, tagged (cwts at the base of the dorsal fin), and released in Gluskie, Forfar and O'Ne-eil Creeks after spring freshet until the annual migrations of adult sockeye salmon enter the streams in August. Sub-sampling (calibrated with mark-recapture) will be conducted during the freshet and late summer, using cable supported, large-aperture nets located off the mouths of the three streams. Estimates of population densities of each age class, standing crops and mean size-at-age will be made within each stream during July using stratified sampling of habitat units by electrofishing (Hankin and Reeves 1988). Adults will be captured within the Middle River by large mesh seines and angling techniques, and then anchor tagged. Population size will be estimated by underwater counts (Slaney and Martin 1987), and movements will be tracked by subsequent recaptures and/or with telemetric tags. Age and sizes will be recorded for each species. Coded wire tags recovered from adults will allow estimation of size-biased survival. They will also be used to calibrate back-calculation estimates of size at river entry as juveniles (Ward et al. 1989). The abundance and movements of other resident fish (burbot, whitefish) both within the tributaries and at the deltas in Middle River will also be monitored. In subsequent years, diet studies will be conducted on resident fish to examine the inter-relationships and potential dependence on sockeye eggs or fry within the Middle River.

These parameters will be examined before, during and after forest harvesting treatments, and related to physical and biological changes documented in the overall study. Because of lack of replication of the experimental units (Hurlbert 1984), temporal replication coupled with a spatial control will be utilized in a before and after controlled impact design (BACI) to detect differences related to forest harvesting (Stewart-Oaten et al. 1986).

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Table 1. Numbers of fish/100 m as determined from electrofishing surveys in streams (single pass). Collections were made on June 20 and July 22, 1991. Samples from Middle River were taken in an offchannel slough 50 m south of the Middle River logging bridge. Samples from the tributaries were taken from the lower 500 m and from a 3-400 m stream reaches in lower (500 m from stream mouth) and upper (1 km from the stream mouth) stream locations. Certain date/stream reaches were not sampled (n/s).

SPECIES		GLUSKIE		FORFAR		O'NE-EIL		MIDDLE RIVER
		JUNE	JULY	JUNE	JULY	JUNE	JULY	
Sockeye	lower	23.8	0.3	28.7	-	n/s	-	-
	upper	n/s	n/s	50.0	6.0	50.0	-	
Rainbow	lower	0.7	2.4	0.2	0.9	n/s	0.4	-
Trout	upper	n/s	n/s	-	2.7	3.0	4.0	
Burbot	lower	0.2	-	0.2	0.3	n/s	-	-
	upper	n/s	n/s	-	-	-	0.4	
Bull	lower	-	-	0.2	-	n/s	-	-
Trout	upper	n/s	n/s	-	-	-	0.4	
Sculpin	lower	0.9	0.2	-	0.3	n/s	0.7	-
	upper	n/s	n/s	-	-	-	1.2	
Dace		-	-	-	-	-	-	150
Sucker		-	-	-	-	-	-	10

Table 2. Field methods used for channel surveys. W_b - bankfull width.

Procedure	Equipment, units	Method and Notes
Longitude profile		
Thalweg distance	Auto level, stadia Hip chain, m	Elevations by different distance along thalweg, read by rodman
Water surface width	Fibre tape, m	All channel widths (main, secondary and side/back channels) measured (+ 0.05 m) at the 5 Wb interval
Water depth	Stadia, m	Depth of water at the thalweg, read by the rodman
Bar surface	Auto level, stadia	Elevation of bar surface at each interval
Bank top	Auto level, stadia	Elevation of overbank surface was sighted whenever possible
Bankfull width	Fibre tape, m	Measured to nearest 0.1 m at the 5 Wb interval; distinguished by vegetation breaks primarily; bank profile and materials noted
Large organic debris		
LOD quantity	Ranking	Groups of LOD classes based on diameter, length and number of pieces for every W_b length of channel: Rank diameter, length, m No. of pieces 1 ≤0.1 1-5 ≤2 2 0.1-.03 5-10 2-3 3 0.3-0.7 10-15 4-7 4 0.7-1.2 15-20 7-10 5 >1.2 >20 >10
LOD orientation	Ranking	Primary orientation ranging from perpendicular to parallel to the flow
LOD function	Ranking	Basic description of LOD sediment trapping and scouring action (lateral or under scour, LOD step, etc.), also if wad attached
Surface sediment and Morphology		
Largest sediment	Hand tape, mm	Visual inspection of the bar surface and the largest stone transported by flood flows was estimated and measured (b-axis), large blocks dropped from local bedrock banks were not included in the largest sediment class; a qualitative rating was also assigned to the local areal sediment texture at each interval
Morphology	Descriptive	Each interval point was identified as a pool, riffle, cascade or rapid (according to Sullivan, 1986) whenever possible-- often just called a riffle at high flows

Additional notes include details regarding bank materials and profile, occurrence of bank erosion and apparent cause (logging, debris, etc.) and any other feature of interest.

Table 3. Debris Jam Classification. Symbols are W_b - bankfull width; D_b - bankfull depth.

Jam feature	Characteristics	Symbol
Age	Very young; primarily new trees (bark, branches, etc.) includes new debris from upstream and upslope, apparently formed during the last major storm event. No nursed trees.	1
	Recent: less than 10 years have some bark and few branches, nurse trees (usually alder) are less than 5 m high, nurse trees are aged in the field (cut and rings counted)	2
	Moderate; nurse trees between 10 and 30 years old, aged by visual inspection (see following classification of or by increment cores)	3
	Old; moss or debris, nurse trees 30-50 year old	4
	Very old; nurse trees >50 years old, debris has no bark or branches	5
Integrity	Very solid; compact, strong wood (no rot), v. large debris (largest LOD pcs have diam >1 Db and lengths >1 W_b v. stable and large anchors present (e.g., wad, bedrock, etc.)	
	Solid; compact, strong wood but smaller LOD than in Rank 1 (i.e., largest pieces have diam ~ 1/2 W_b and lengths ~ 3/4 D_6), and less well anchored	2
	Moderate; less compact (spaces between LOD pieces), smaller and more mobile LOD pieces	3
	Weak; predominantly small debris pieces generally rotten and jam has poor or precarious anchor (moved at high flows)	4
	Very weak; very small debris pieces, no anchor and jam is in transition (hard to determine if a jam exists)	5
	Very weak; very small debris pieces, no anchor and jam is in transition (hard to determine if a jam exists)	5
Span	(Lateral extent)	
	Complete. Jam completely crosses the channel and forms a dam, water flows over the top	1

Incomplete. 3/4 <span <1 W_b, water flows around one end or through mid section of jam	2
1/2 <span <3/4 W_b, water flows around one end, etc.	3
1/4 <span <1/2 W_b, water flows around one end, etc.	4
span <1/4 W_b, water flows around one end, etc.	5
Height (vertical extent or depth)	
Full; jam is as high or higher than the local bank height	1
Not full; 3/4 - full bank height	2
1/2 - 3/4 bank height	3
1/4 - 1/2 bank height	4
<1/4 bank height	5
Sediment Storage (upstream of jam)	
Full; the channel zone is completely full of sediment (i.e., sediment is filled to the top of the jam and extends completely across the channel, sediment extends upstream as a function of the channel gradient, or until the next debris jam	1
Not full; <1/4 of the sediment evacuated (compared to full --as a function of the channel width, and jam height)	2
1/4 - 1/2 of the sediment removed (e.g., partially full	3
1/2 - 3/4 of the sediment removed	4
>3/4 or all sediment removed	4
Location	
In-channel	
on one side of channel only	RB,LB
mid channel (open on sides)	M
Along channel	
at a bend	B
at a bedrock knob or outcrop	R
at a wad or tree stump anchor	W
Shape	
Perpendicular to channel	L
Diagonal to channel	
Parallel to channel	II
Arched, apex downstream	V
Arched, apex upstream	A
No. of channels (includes flood channels)	
One	1
Two	2
Three	3
Braided	4
Braided	5

Table 4. Equipment and methods used within study reaches in the Stuart/Takla Fish/Forestry Interaction Study

Task	Equipment	Methods
Field:		
A) Channel morphology		
Low level photographs	Helicopter boom photos	Vertical photograph pairs taken from an altitude of approximately 50 m. Photogrammetric models constructed and detailed morphological measurements obtained.
Cross-sections	Nikon AS-IS Stadia rod Rod level Survey chain	Attach survey chain to monumented survey hub. Extend the chain across the channel to the survey hub on the opposite bank. All survey hubs are tied together geographicalod level (location and elevation). Record: a) distance (+0.05 m) directly from the chain (rod level used to ensure vertical placement of the stadia against the chain). b) level foresight - Survey points include all breaks in slope (as a function of sediment size, banks, vegetation and water edges, thalweg, changes in sediment texture, water depth (read directly by the rodman) and LOD edges and tops.
Longitudinal profile	as per cross	Thalweg and water surface elevations taken from the cross-sectional data with intermediate survey sites to include all morphological breaks. All horizontal distances by survey chain.
Bed texture	Templates	Surface sediment textures by Wolman's method. Sampling criteria according to Bray (1972) and Wolcott and Church (1991).
Bank character	Stadia rod	Bank sediment type and texture, shape, stability and height measured at each cross-sectional transect (both banks).
B) Large organic debris		
LOD	Survey chain	Measure diameters and lengths of LOD. Document function of LOD (orientation, scour/trap, morphology etc.) and detail log jam characteristics (see table).
C) Bedload movement		
Net channel changes	Cross-sections	Channel aggradation/degradation calculated from cross-sectional and longitudinal surveys.
Tracer stones	Magnetically tagged stones	A group of magnetic stones will be deployed in each reach; these will be relocated during each summer survey. Location according to distance down-stream, burial depth, site morphology and stone identification number recorded.
Scour depths	Scour chains	Scour chains will be located at six (6) locations in each study reach. Both scour and fill depths measured during annual surveys.
Office:		
A) Channel morphology		
Low level photographs	Carto AP 190	Vertical photographs used to construct photogrammetric models. Developed film stored in computer data base. Plots on Autocad and PAMAP

Cross-sections	Micro-computer	All cross-sectional survey data (horizontal distances, foresights, water depths, etc.) to be entered into a commercial spreadsheet (Microsoft's Excel). All cross-sections will be plotted by computer graphics. Plannemetric maps of each reach will be constructed by used cross-sectional, longitudinal profiles and low level air photographs.
Longitudinal	Micro-computer	Horizontal distances, thalweg and water surface elevations taken from the cross-sectional data Profile cross-sections. These data will be entered into computer files and plotted.
Bed texture	Micro-computer	Surface sediment textures will be analyzed by standard sedimentological procedures. All textural data will be plotted by phi units.
Bank character	Micro-computer	Bank sediment type and texture, shape, stability and height measured at each cross-sectional transect (both banks) will be compiled on computer files and their location cross-referenced on the reach maps.
B) Large organic debris		
LOD	Micro-computer Reach maps	All debris will be analyzed to describe the functional role of LOD. Size and volume inventories will be maintained. LOD characteristics will be included on the reach maps.
C) Bedload movement		
Net channel changes	Micro-computer	Channel aggradation/degradation rates will be calculated from cross-sectional and longitudinal surveys. Net changes will be calculated by computer program.
Tracer stones	Micro-computer Reach maps	Sediment travel distances, burial depths and depositional site characterizations will be analyzed longitudinally
Scour chains	Micro-computer	Scour depths and fill amounts will be analyzed in relation to flow and morphological characteristics.

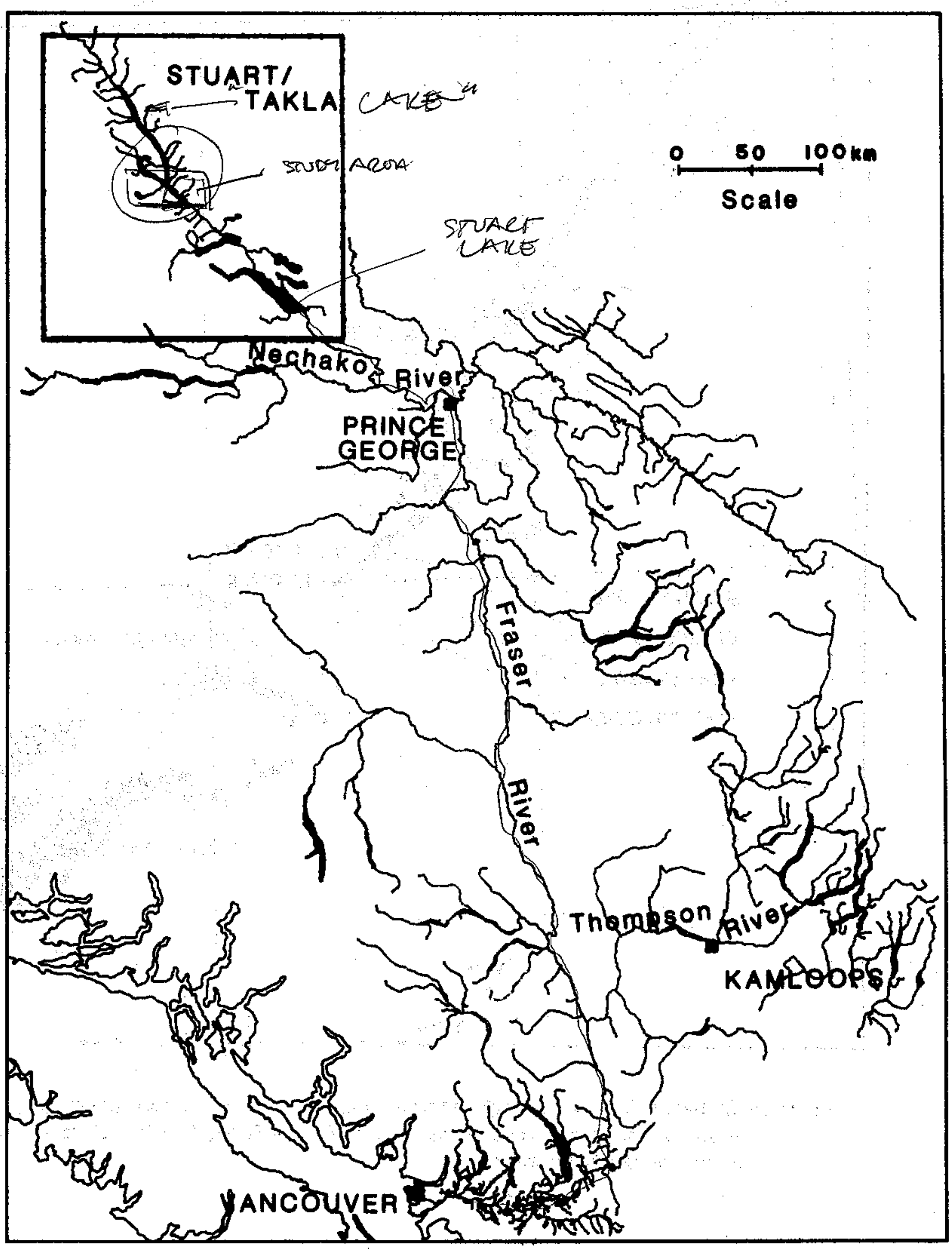

Figure 1. Fraser River watershed showing the location of salmon streams, the major cities, and the Stuart/Takla watershed.

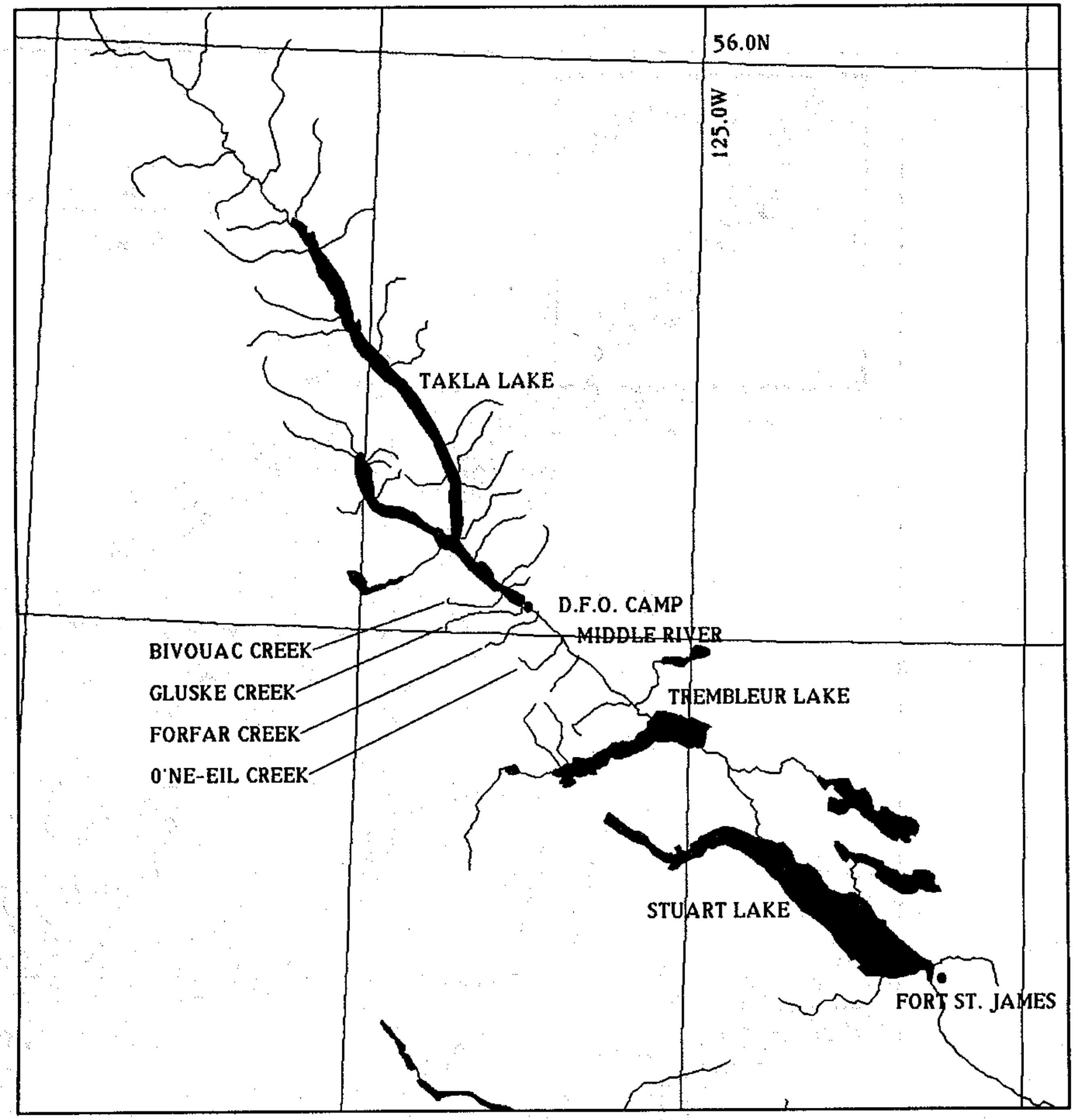

Figure 2. Stuart/Takla watershed showing the location of salmon streams and large lakes. Also shown are the locations of the Middle River, the D.F.O. camp and the four experimental streams.

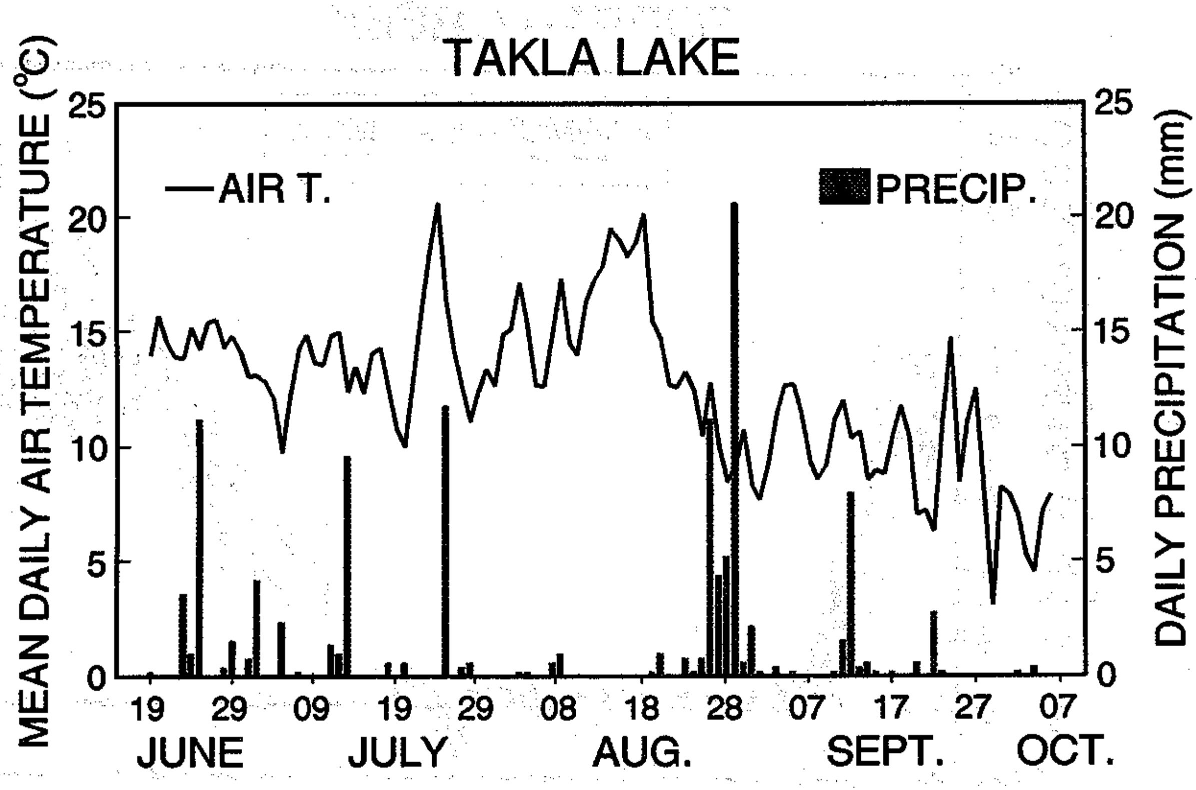

Figure 3. Mean daily air temperatures and total daily precipitation during the spring, summer, and autumn of 1991 at the southern end of Takla Lake.

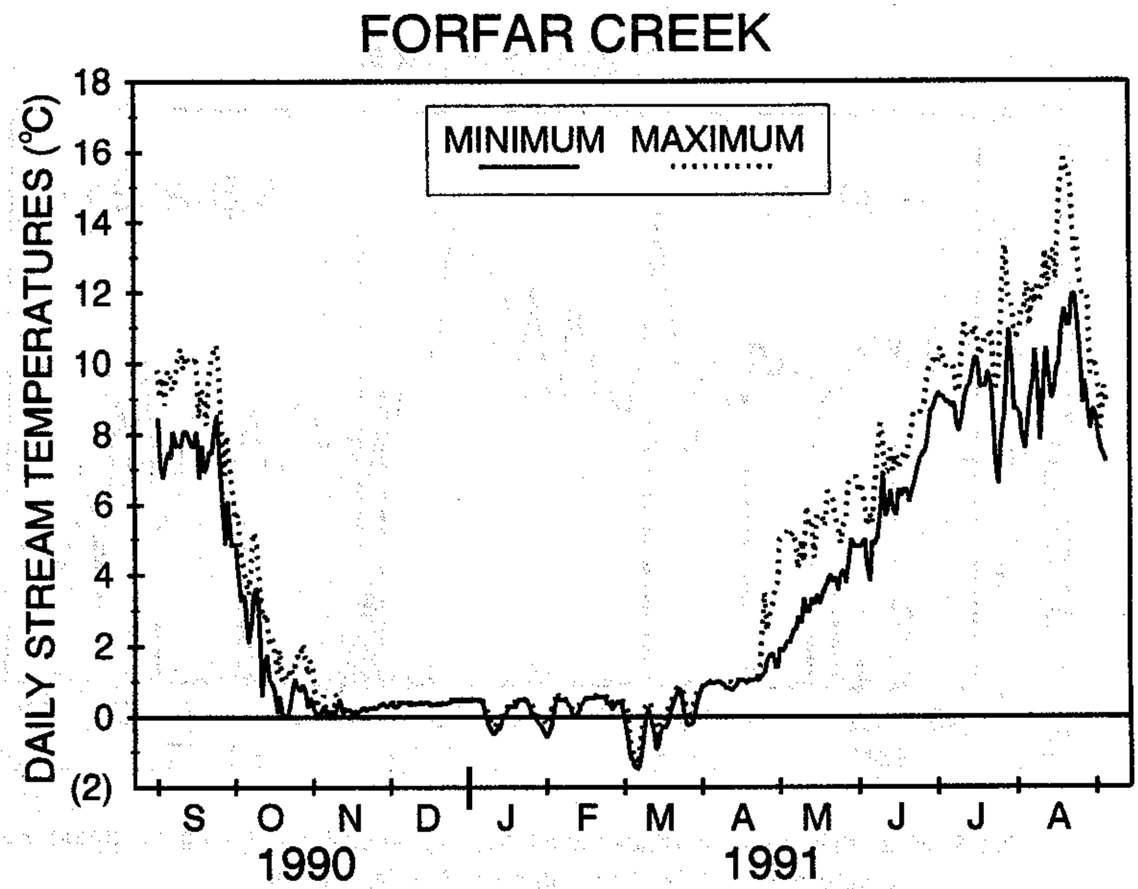

Figure 4. Daily minimum and maximum water temperatures in Forfar Creek for a twelve month period (1990-91). Each value is an average from two temperature probes in the stream.

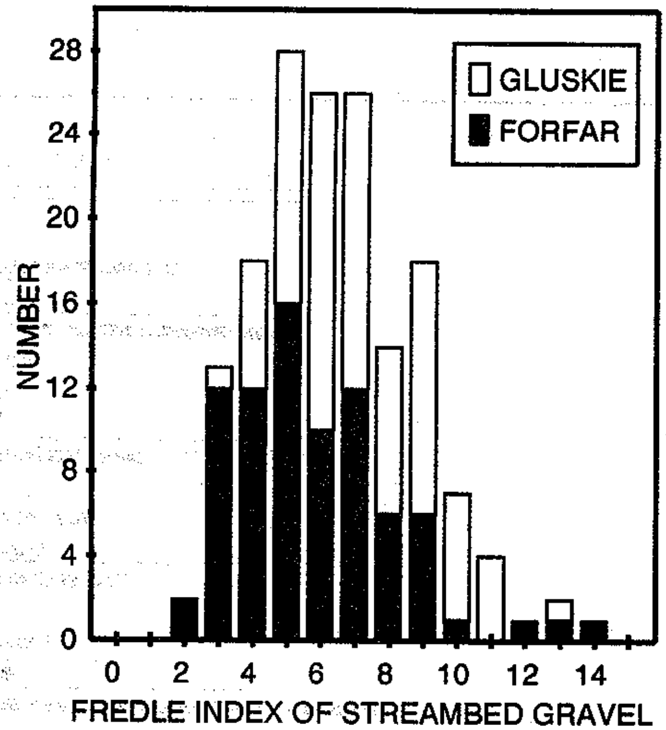

Figure 5. Size distributions showing the quality of spawning gravels in Forfar and Gluskie creeks during 1990.

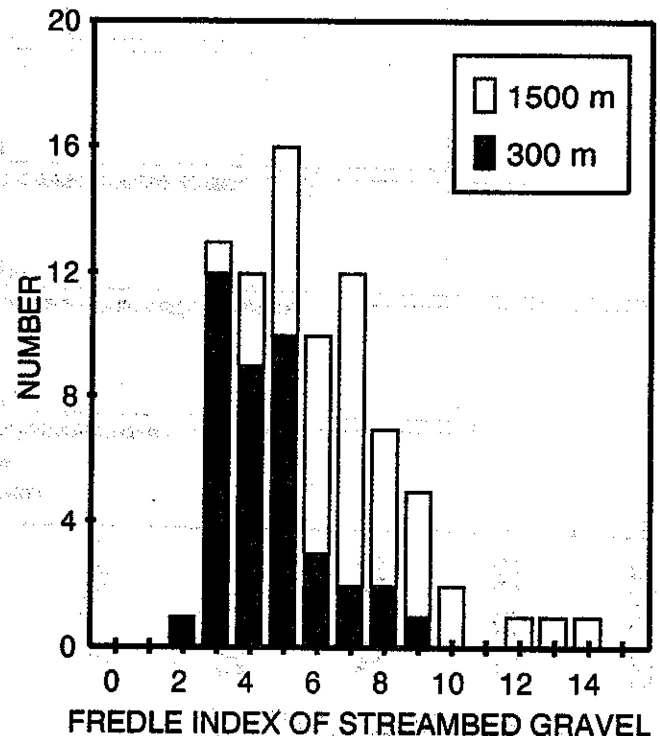

Figure 6. A comparison of spawning gravel quality in Forfar Creek at the bridge (1500m) and near the mouth (300m).

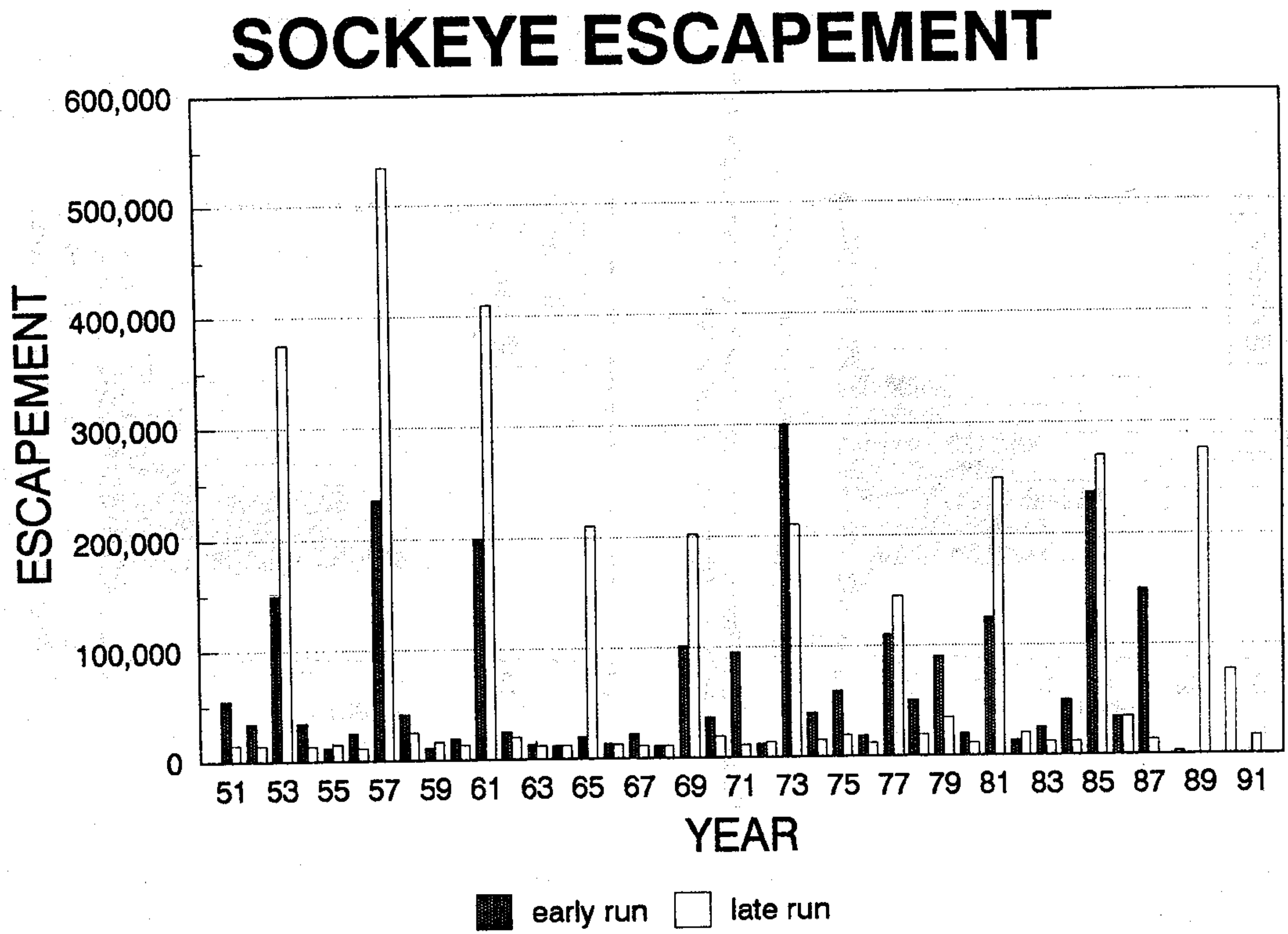

Figure 7. Escapements of early and late run sockeye salmon to the Stuart/Takla watershed since 1951 (from Harder and Assoc. 1989 and unpublished D.F.O. records).

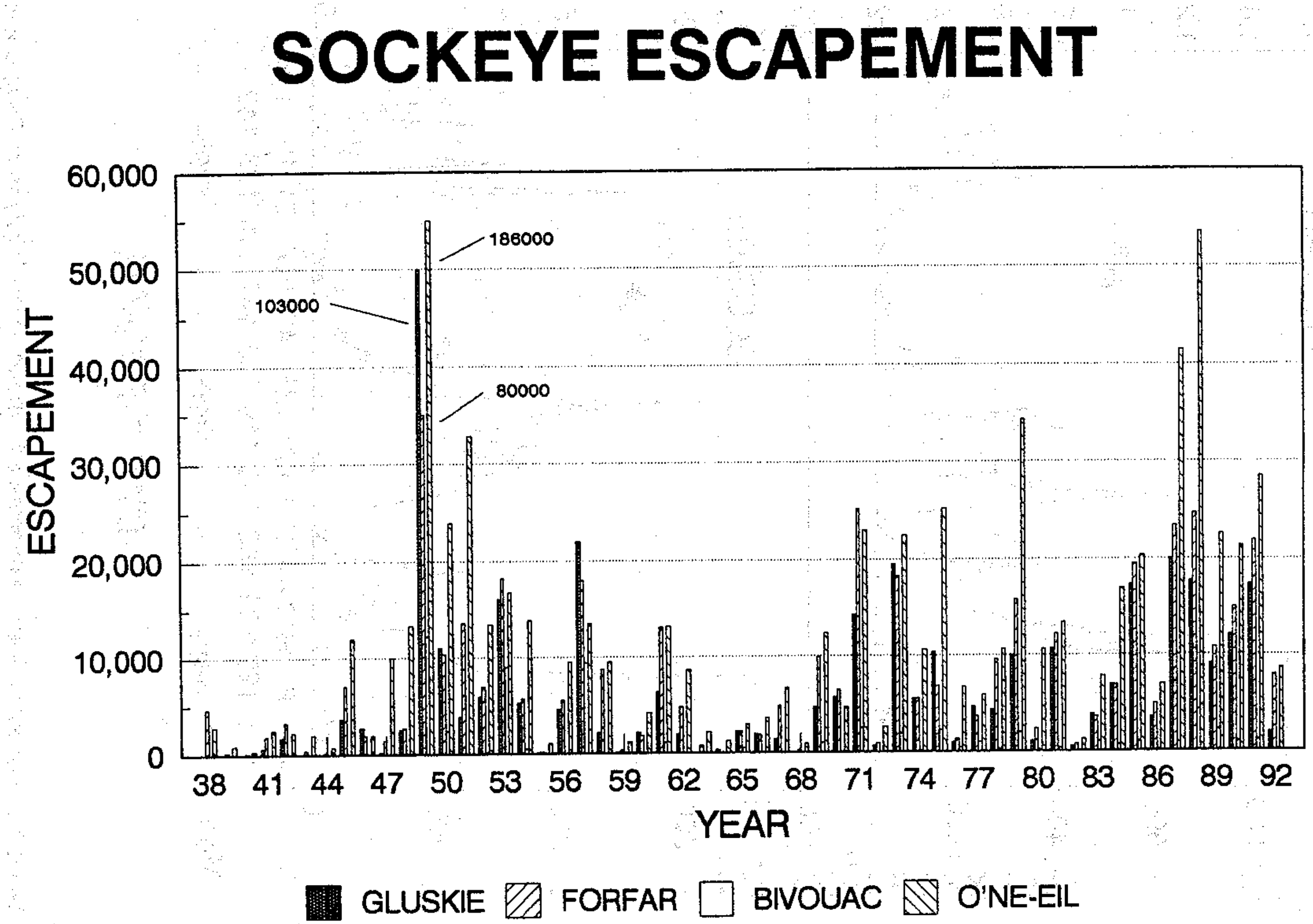

Figure 8. Escapements of sockeye salmon to Gluskie, Forfar, Bivouac and O'Ne-eil Creeks since 1938 (from Hickey and Smith 1990 and unpublished D.F.O. records).

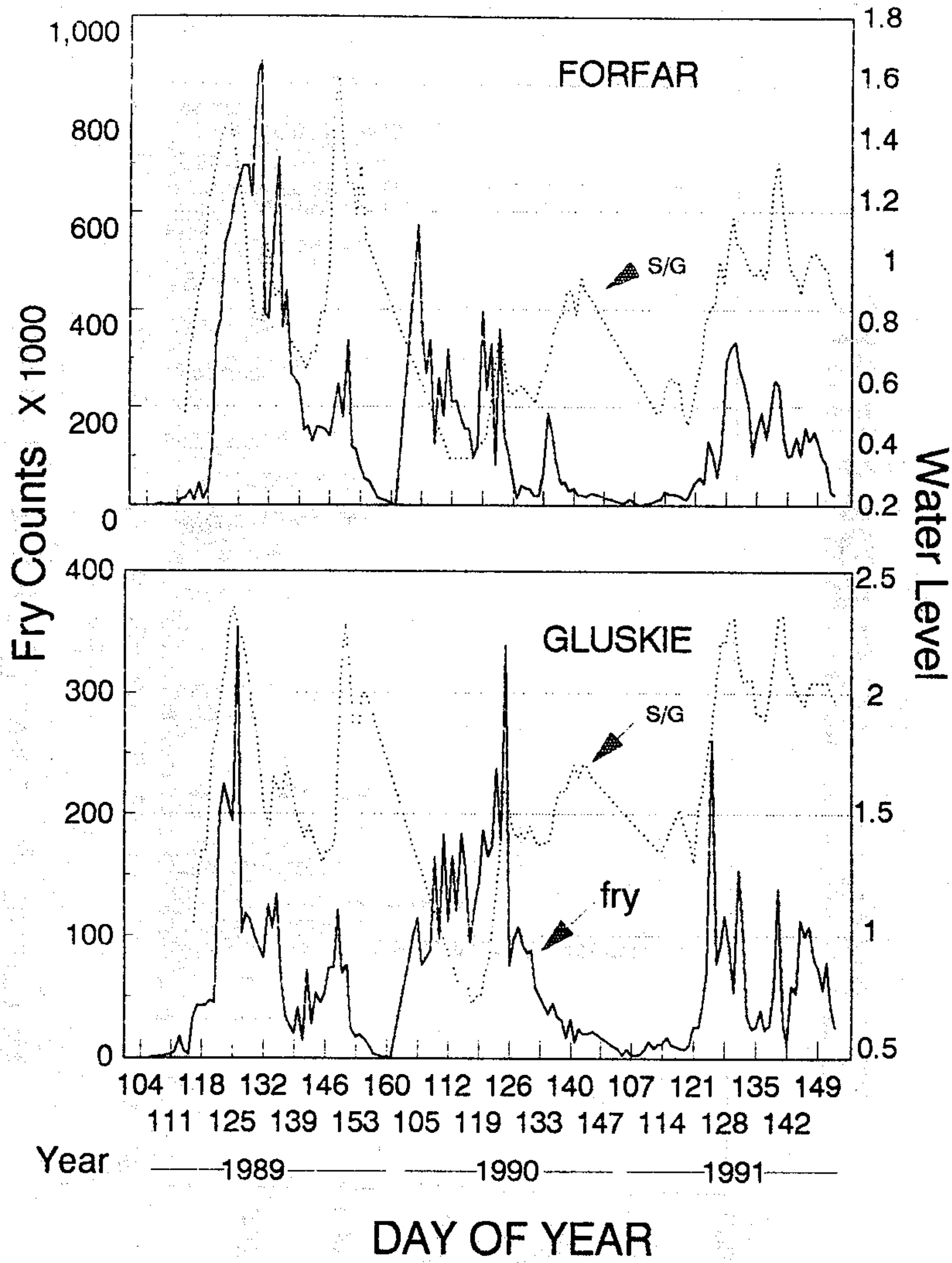

Figure 9. Fry outmigration estimates and stream water levels from Gluskie and Forfar Creeks made during the springs of 1989, 90 and 91 (S/G = staff gauge reading).

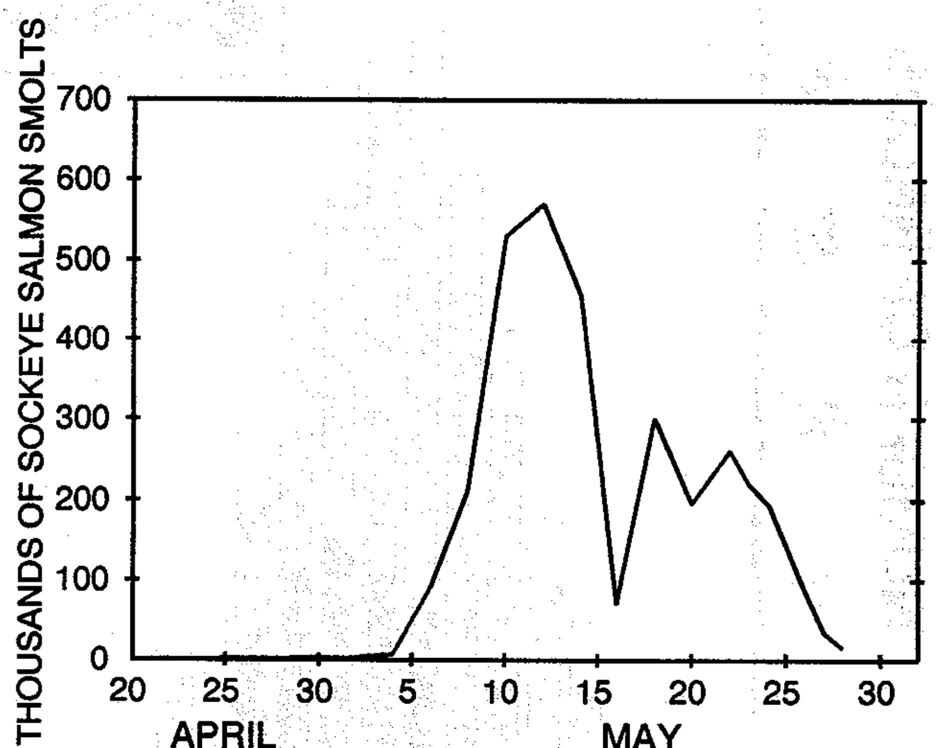

Figure 10. Two day totals of Sockeye Salmon smolts leaving Stuart Lake during the spring of 1967 (from Williams 1969). This is the combined stocks for Stuart, Trembleur, and Takla lakes.

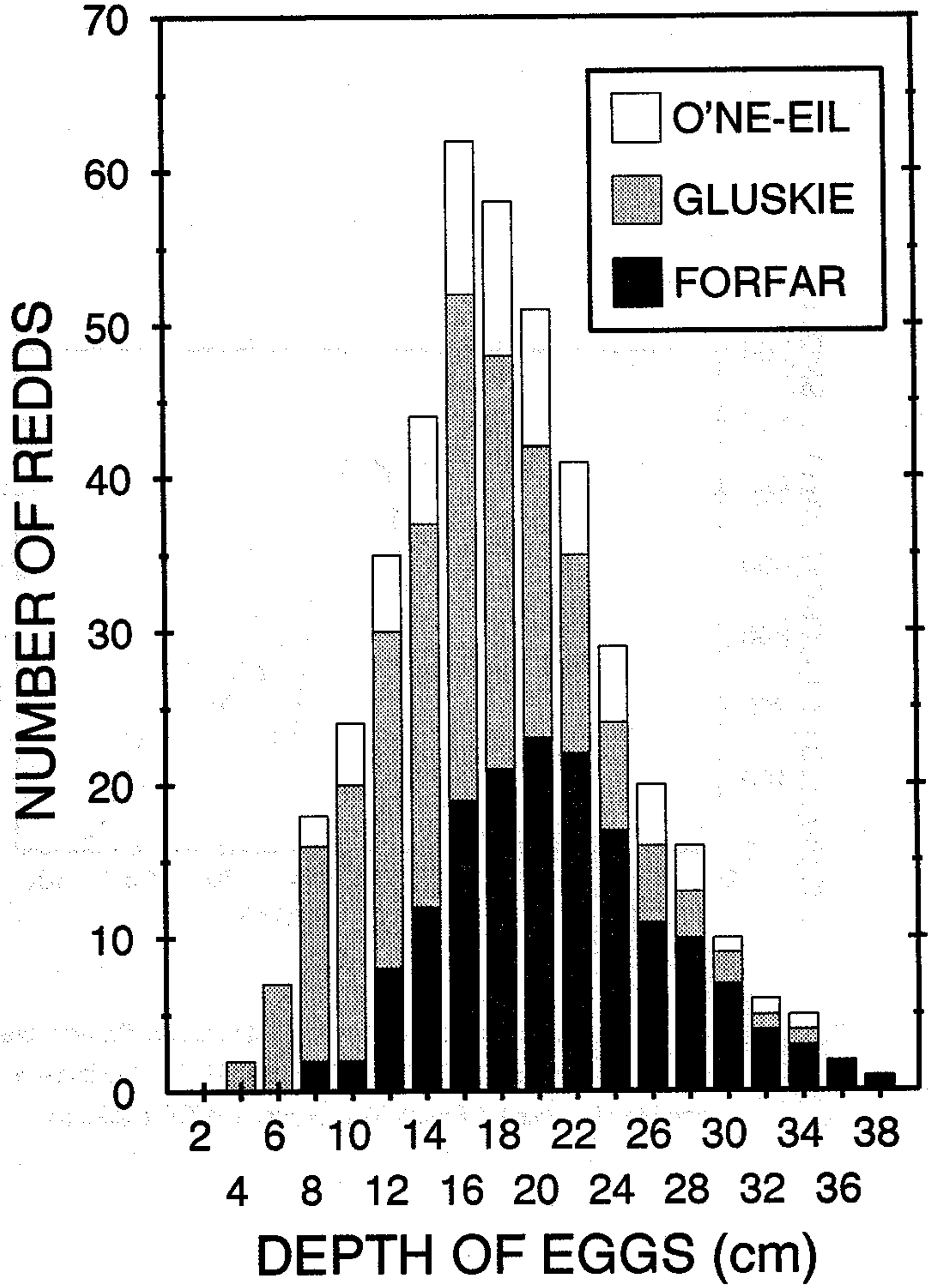

Figure 11. Distributions of egg depth for 105 Sockeye Salmon redds from O'Ne-eil, Gluskie, and Forfar creeks. Individual redds were distributed over 4-10 cm in 1990-92 freeze-core samples of the streambeds.

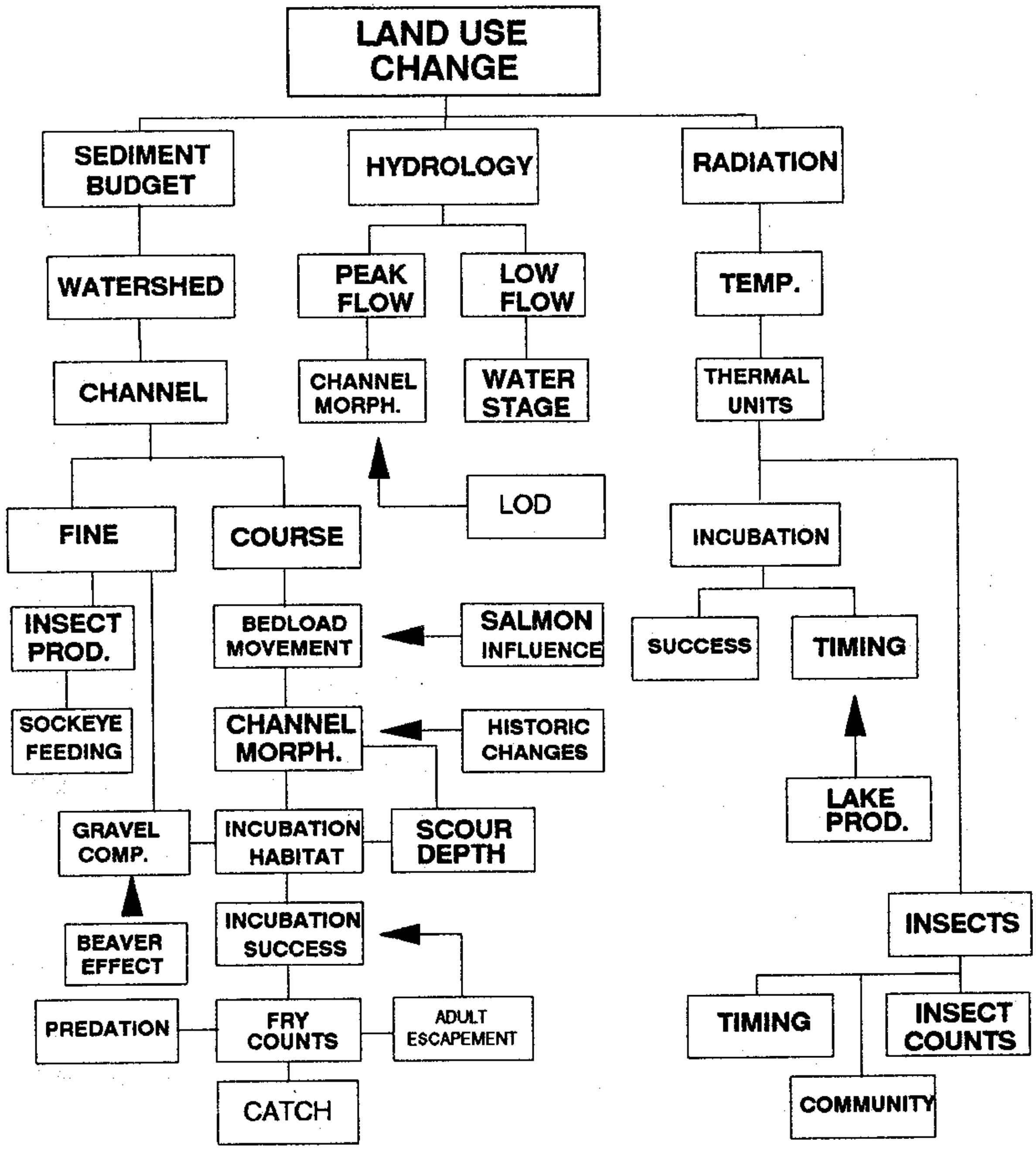

Figure 12. Flow chart describing the inter-relationships between physical and biological processes expected to be occurring in interior B.C. watersheds. Impacts from timber removal activities may effect fish production through a number of pathways.