SOME IMPACTS OF MAN ON KOOTENAY LAKE AND ITS SALMONOIDS

Great Lakes Fishery Commission

TECHNICAL RERORT No. 25

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April, 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop co-ordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

SOME IMPACTS OF MAN ON KOOTENAY LAKE AND ITS SALMONOIDS

by

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TECHNICAL REPORT No. 25

GREAT LAKES FISHERY COMMISSION
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FOREWORD

This paper is one of seven lake case histories-Lake Superior, Lake Michigan, Lake Huron, Lake Erie, Lake Ontario, Lake Opeongo, and Lake Kootenay. Concise versions of these papers, *together with* other lake case histories developed for and by an international symposium on Salmonid Communities in Oligotrophic Lakes (SCOL) appeared in a special issue of the Journal of the Fisheries Research Board of Canada (Vol. 29, No. 6, June, 1972).

While this and each of the others in this series is complete in itself, it should be remembered that each formed a part of SCOL and is supplemented by the others. Because much detail of interest to fisheries workers in the Great Lakes area would not otherwise be available, this and the other case histories revised and refined in the light of events at the symposium are published here.

SCOL symposium was a major exercise in the synthesis of existing knowledge. The objective was to attempt to identify the separate and joint effects of three major stresses imposed by man: cultural eutrophication, exploitation; and species introduction on fish communities. Recently glaciated oligotrophic lakes were chosen as an “experimental set.” Within the set were lakes which have been free of stresses, lakes which have been subjected to one stress, and lakes which have been subjected to various combinations of stresses. The case histories provide a summary of information available for each lake and describe the sequence of events through time in the fish community. Some of these events were inferred to be responses to the stresses imposed. Lakes Opeongo and Kootenay were included in this set somewhat arbitrarily, with the case histories of the Laurentian Great Lakes, to illustrate similarities and differences in the problems associated with other recently glaciated oligotrophic lakes.

We began organizing SCOL in 1968 and were later supported by a steering committee: W. L. Hartman of the U.S.A., L. Johnson of Canada, N. A. Nilsson of Sweden, and W. Nümann of West Germany. After two years of preparation, a work party consisting of approximately 25 contributors and a similar number of interested ecologists convened for two weeks in July, 1971 at Geneva Park, Ontario, Canada.

Financial support was provided by the Great Lakes Fishery Commission, Ontario Ministry of Natural Resources, Fisheries Research Board of Canada, Canadian National Sportsman’s Show, and University of Toronto.

Editorial assistance was provided by P. H. Eschmeyer, K. H. Loftus, and H. A. Regier.

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T. G. Northcote

ABSTRACT

Exploitation of fish stocks for food by native Indians, at their population maximum in the late 1700's, was heavy and probably surpassed the present catch by the recreational fishery of some 35 tons per annum. Exploitation of salmonoids for fish culture from 1912 to the early 1950's never exceeded 7 tons annually but probably had serious effects on some localized populations of kokanee and rainbow trout. Introduction of non-native fishes seems to have had little effect on native stocks to date but introduction of the non-native invertebrate *Mysis relicta* probably has, in large part, been responsible for marked growth enhancement in some fish species, particularly kokanee. Evidence of cultural eutrophication has become obvious in the lake since the mid 1950's, probably from phosphates entering the lake from a fertilizer plant on a Kootenay River tributary. The most serious damage to salmonoids appears to have been caused by alterations to spawning tributaries resulting from mining, agriculture, logging, and dam construction.

INTRODUCTION

Impacts of man on salmonoid communities of oligotrophic lakes have been investigated for several decades, especially in regions subject to active industrial development. The extensive studies in Scandinavia (Nilsson, 1964, 1965; Nilsson and Svärdson, 1968; Grim% and Nilsson, 1965; Lindstrom, 1962, 1965, 1967; Lindstrom et al., 1970; Fürst, 1965) are outstanding, but documentation of such changes have been widespread (Kreigsmann, 1955; Nümann, 1964; Beeton, 1969; Larkin et al., 1959; Larkin and Northcote, 1969). Rarely, however, has it been possible to assemble a picture in any way complete, starting with the first influences of man and following through to the multiple and diverse abuses of his rapidly expanding, modern technology. The early effects are usually confused in a long and largely unrecorded span of at least a millennium. In many ways Kootenay Lake is an exception to this pattern.

Although parts of the general area may have been accessible to man for over 10,000 years, it seems unlikely that anything other than a very sparse population sporadically inhabited the region until about 1700 A.D. A little over a century later the first European explorers and traders had arrived and a recorded history of man's effects began. These are largely ones of exploitation (first for food; later for sport and fish culture) and cultural eutrophication (starting essentially in the recent two decades), but also include introductions (both of fish and invertebrates) as well as other alterations of salmonoid habitat.

This contribution attempts to assemble effects of man on Kootenay Lake and its salmonoids from their earliest to recent contact; a synopsis and discussion has been published separately (Northcote, 1972a). Understandably documentation of early contact, however recent, must be developed from sketchy accounts coupled with hopefully reasonable assumptions. Surprisingly even some of the recent effects have had to be pieced together from the accessible fraction of data collections made on the system between 1964 and 1969.

Kootenay Lake contains six native salmonoid species-kokanee or land-locked sockeye salmon (Oncorhynchus nerka), Dolly Varden (Salvelinus malma), rainbow trout *(Salmo gairdneri),* mountain whitefish *(Prosopium williamsoni),* Yellowstone cutthroat trout *(Salmo clarki lewisi),* and pygmy whitefish *(Prosopium coulteri).* The latter two will not be considered as they apparently are rare and little is known of their ecology in the lake.

KOOTENAY LAKE PRIOR TO MAN

Kootenay Lake (Fig. 1A,B) now occupies about half the length of a deep, steep-sided valley extending in a northerly direction over 225 km into British Columbia from 49° (Canada-U.S.A. border) to at least 51° latitude. It is bounded on the west by the Selkirk Mountains which rise to elevations exceeding 3000 m and on the east by the Purcell Mountains, reaching heights of nearly 3500 m. The lake itself lies at 532 m. Its two major influents, Kootenay River[1] entering from the south and Duncan River from the north also follow this valley (the Purcell Trench) although the former arises in the Rocky Mountains to the east and drains a section of the Rocky Mountain Trench. The lake discharges near its midpoint through *a* transverse valley containing the west arm of the lake and its outlet, the lower Kootenay River, which flows southwesterly to join the Columbia River. The portions of the main lake north and south of the west arm are commonly referred to as the north and south "arms".

Since the brief review of the origin of Kootenay Lake given by Schofield (1946), several workers have contributed to the glacial and post-glacial history of this and adjacent portions of the upper Columbia system, notably Alden (1953) Little (1960), Richmond et al. (1965), Walker (1967) and Fulton (1968). From these studies and comments of W. H. Mathews (Dept. Geol., Univ. Brit. Col.) a summary of the glacial lakes in the region has been developed (Fig. 1A). The first, Lake Missoula, occupied the Clark Fork branch of the Columbia. Later a portion of this branch was joined with part of the upper Kootenay River, the south arm of Kootenay Lake and sections of the Pend Oreille system to form glacial Lake Kootenai. Both glacial lakes drained to the southwest into the Columbia River.

1 called the Kootenai in the United States, but referred to herein as the Kootenay River throughout its length.

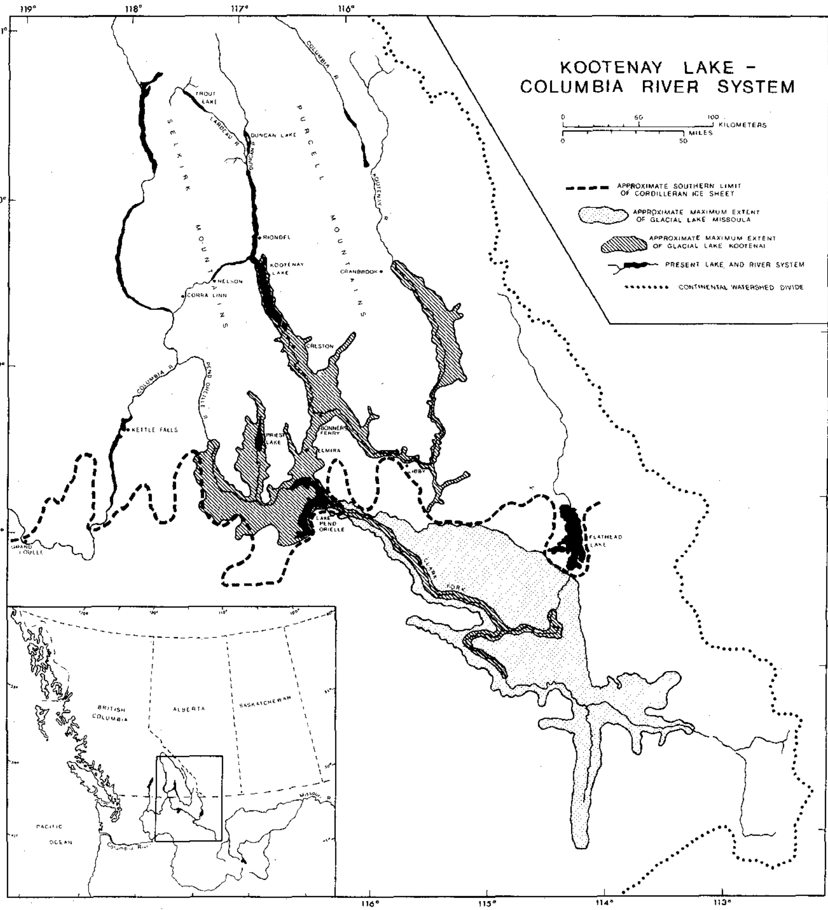


Fig. 1A. The postglacial and present Kootenay Lake-upper Columbia River drainage system. Extent of the glacial lakes indicated includes some islands and higher elevations not flooded; all areas shown may not have been covered at the same time, especially for glacial Lake Kootenai. Inset shows location of area included.

With further glacial recession an outlet opened to the north along the west side of stagnant ice in the Purcell Trench, along the south side of the transverse valley of the west arm and lower Kootenay River and into the Columbia River which by then had abandoned its former course through the Grand Coulee. Thereafter the lake level lowered gradually as the west arm was cleared of ice. Radiocarbon dating from a peat bog at the north end of Kootenay Lake (Fulton, 1968) indicates that the trench was clear of ice and supporting vegetation by 10,270 years B.P. (before present). The south arm then extended almost to Bonners Ferry (Alden, 1953), and at this stage heavy silt loads would have been carried into the lake by streams and rivers cutting away bed deposits as well as from glacial meltwater itself.

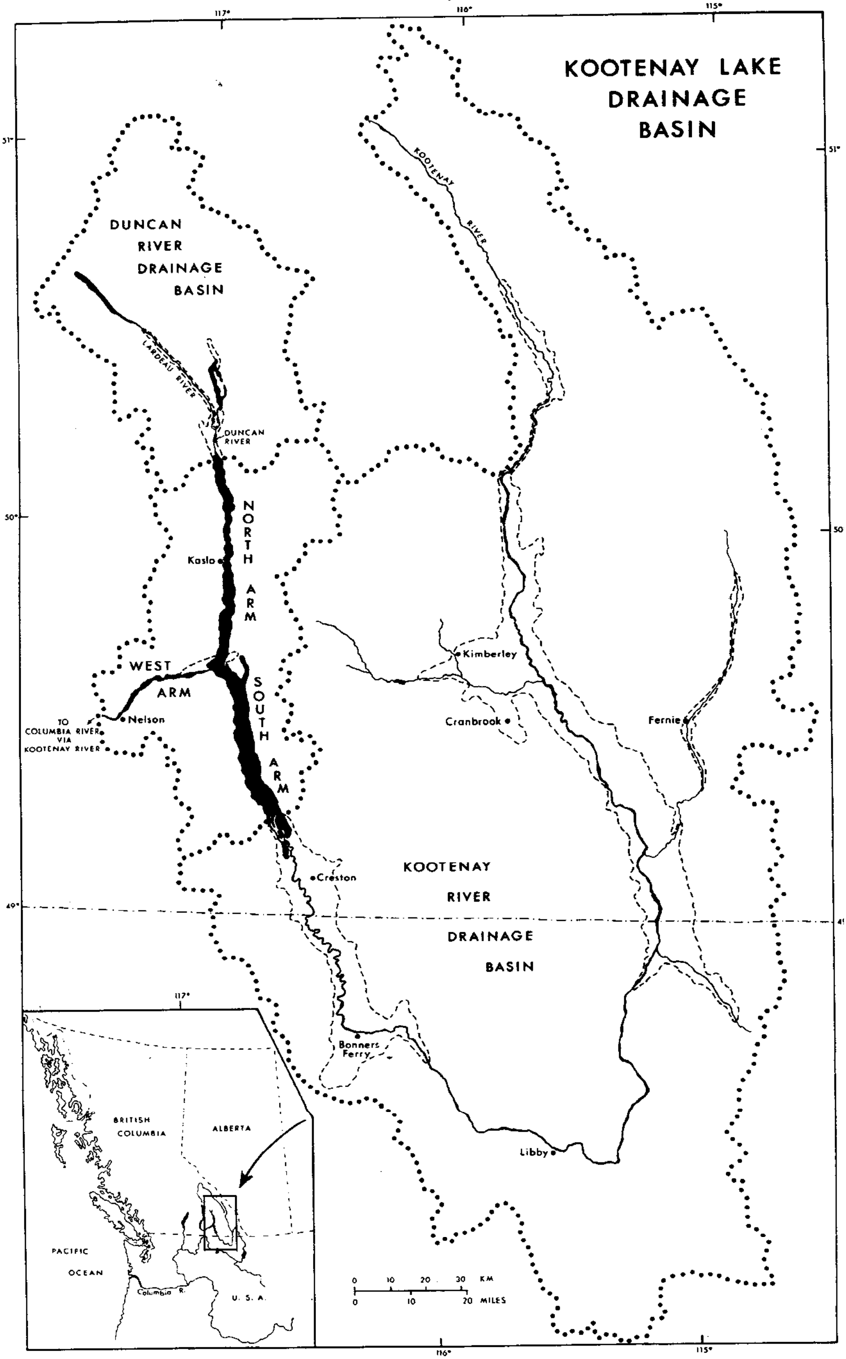


Fig. 1B. Kootenay Lake showing the three major arms and subdivisions of its drainage basin (heavy dotted lines). Extent of major agricultural soils shown by fine broken lines within each drainage subdivision.

The extensive connections between waters of the Kootenay system and the large glacial lakes occupying valleys of the Columbia system to the south (Fig. IA) permitted colonization of the region by species of fish whose entrance would now be blocked by the falls on the Kootenay River, about 20 km upstream from the junction of the Kootenay and Columbia rivers. In addition to mountain whitefish and Yellowstone cutthroat, at least one species of sucker, three species of cyprinids, and one species of sculpin probably entered the Kootenay system through such a southern route (Carl et al., 1967). Kokanee presumably gained access by this course.

EARLY MAN AND THE KOOTENAY INDIANS

Evidence of early man near Kootenay Lake has not been found, although an ice free route from the north into the plateau between the Rocky Mountains and the Cascade range may have been open to him not less than 15,000 years BP. (Cressman, 1942). It is probable that there were sparse populations there sporadically. Swanson and Sneed (1966) suggest that the high country of the Rocky Mountains in eastern Idaho was occupied by man 8000 years B.P. and Malouf (1956) notes that during prehistoric times the large intermountain lakes Pend Oreille, Coeur d'Alene, Arrow, Kootenay, and Flathead were centres of important culture horizons. However, Borden (1956) was unable to find any positive evidence of early man in the southern Rocky Mountain Trench of British Columbia.

The several bands of Indians historically associated with the Kootenay River and Lake drainage have been relatively recent immigrants, perhaps coming less than 300 years ago from the prairie regions east of the Rocky Mountains (Leechman, 1956; Jenness, 1967) although this origin is not well established (Borden, 1956). Those bands inhabiting the Rocky Mountain Trench region, the so-called Upper Kootenay group, relied upon the prairie buffalo for food. On the other hand fish was the staple diet of the Lower Kootenay Indians living downstream of the big bend on the Kootenay River (about at Libby), around the lake itself, its outlet and the Columbia River system from the Arrow Lakes to Kettle Falls (Turney-High, 1941). At least 10 different species of fish were used for food by the Kootenay Indians, although of these trout, whitefish, salmon, and sturgeon were probably the most important.

An approximation of the quantity of fish taken annually from Kootenay Lake and adjacent waters by the Kootenay Indians may be made by calculating probable food requirements of the population (Fig. 2). As Indians ancestral to the bands presently found in the Kootenays probably did not occupy that region until the early 1700's, the population and fish exploitation curves shown in Figure 2 have sharply ascending left limbs. According to Curtis (1911) the total Kootenay population (British Columbia and United States) was about 5000 at the beginning of the historical period and Turney-High (1941) places it in excess of 4000 individuals. The British Columbian Lower Kootenay band, living mainly near the south end of Kootenay Lake and in the adjoining valley of Kootenay River (inlet) fed heavily upon fish in the lake or migrating from it. No doubt those Indians

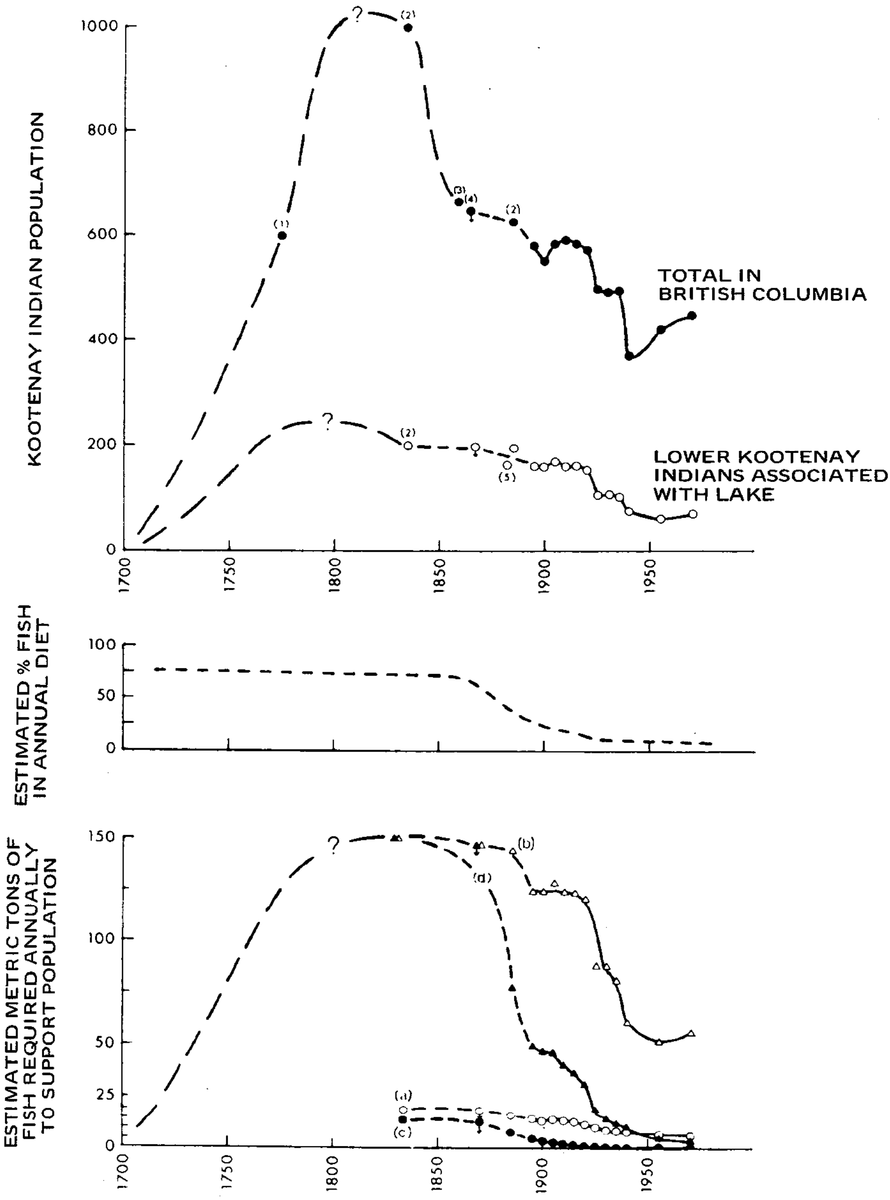


Fig. 2. Posthistoric changes in Kootenay Indian population (upper graph) and their estimated exploitation of Kootenay Lake fish for food (lower graph). Numbers in brackets on population curves refer to following authorities: (1) Borden (1954); (2) Brit. Col. Atlas of Resources (1956); (3) Palliser (1863); (4) Wilson (1866); (5) Baillie-Grohman (1918); for lower Kootenay Indians before 1895, the population is approximated from the total B.C. population by using a known ratio for the closest year available; all data after 1895 from census statistics in Annual Rept., Canada Dept. Indian Affiars. See text for derivation of fish requirement curves a-d.

living further up the river valley (in northern Idaho and northwestern Montana) also made some use of Kootenay Lake fish. Palliser's Expedition upon entering the lower Rocky Mountain Trench in mid August noted the "absence of all the Indians who were then fishing on the large Columbia Lakes" (Palliser, 1863). Even Upper Kootenay Indians from the Rocky Mountain Trench were invited to use the weirs of the Lower bands on occasion (Turney-High, 1941). The maximum recorded population of Kootenay Indians in British Columbia was about 1000 (Fig. 2). At least 200 probably were associated with the lake and its adjacent tributary system. This band may have been more numerous earlier, but probably not markedly so, and has since declined to a recent low of less than 70 individuals.

Exploitation of Kootenay Lake fish by Lower Kootenay Indians has been estimated in two ways-(l) by calculating annual amounts required for an adequate animal protein supply for the population, assuming all protein came from fish (curve a, Fig. 2) and (2) by calculating annual amounts required for a 2500 cal/day diet, assuming 75% of the total caloric intake came from fish (curve b, Fig. 2). The protein-based calculation utilized the 44g/day ration of animal protein considered essential in an "adequate" diet (Holt, 1967) and an average body composition (dry weight) of 75.8% protein determined for 10 salmonoid species (Love, 1957). The caloric-based calculation used an average value of 113.9 cal/100 g wet weight of whole raw fish obtained from rainbow trout, salmon, and whitefish data of Watt and Merrill (1963). Neither of these methods allowed for the known decrease in importance of fish in the diet of the population after the influx of Europeans. An attempt to do so was made by assuming a "decreased use curve" as shown in Figure 2 (middle graph), and then appropriately adjusting the data points of both methods to obtain the solid symbol curves (c, d) shown in the lower graph of Figure 2. The protein-based curve (c) must underestimate fish consumption before 1875 because the Indians, prior to predominant European influence, utilized fish for a major energy source in addition to an essential protein supply. However, that 75% of their total caloric demands came solely from fish (curve d) may overestimate exploitation of that food source by the Kootenay Indian population. A realistic level should lie between the two solid data point curves, perhaps closer to the uppermost, and a reasonable approximation of maximal fish exploitation by the Indian population would probably be in the order of 100 metric tons annually. If only 50% of this requirement was in the form of salmonoids from Kootenay Lake of which trout contributed 40%, kokanee and mountain whitefish each 25% and char 10%, then maximum exploitation would have required an annual take of about 20,000 trout averaging 1 kg; 125,000 kokanee averaging 0.1 kg; 50,000 mountain whitefish averaging 0.25 kg; 2500 Dolly Varden averaging 2 kg. These relative levels of exploitation seem reasonable considering what is known of the Kootenay Indian fishing methods and preferences (Northcote MS, 1971).

EUROPEAN INFLUX AND DEVELOPMENT

Although "whiteman's" discovery of gold on mainland British Columbia was made as early as 1833 on a tributary of Okanagan Lake by the botanist

David Douglas (Rickard, 1948), its “rediscovery” at the junction of the Pend Oreille and Columbia rivers shortly before 1856 (Graham, 1945) sparked- the first major influx of Europeans. Most placer miners used small scale rocker and sluice box set-ups and *a* few operated larger hydraulic systems; both undoubtably had detrimental effects on salmonoid spawning habitat in the creeks. Much of the early activity was centered in the East Kootenay region on streams entering Kootenay River but all major tributaries of the lake itself were subjected to at least cursory prospecting. Chinese miners often stayed on after the Europeans and by moving the boulders to the stream banks worked the gravels down to bedrock if possible, further disturbing the stream habitat. Although miners made some use of local fish for food, it was no doubt most often a relief item from the monotony of beans and salt port, or occasionally a supplement in periods of low supplies. By 1870 most miners had moved on to more promising fields and by 1882 there apparently were only 11 miners in the region (Flucke, 1955).

Mining activity flourished again when effective means of ore transport was possible with railway lines approaching the region from the south and the west. One of the oldest lode mines in British Columbia, the Blue Bell, was rediscovered and staked in 1882 on the edge of Kootenay Lake at Riondel (Fig. 1A) and by 1895 an on-site mill and smelter produced 52,000 tons of ore (Walker, 1929). Silver discoveries near Nelson in 1887 resulted in a flurry of prospecting there and in establishment and rapid growth of that community. By 1896 it also had a smelter in operation. Similarly mining communities such as Ainsworth and Kaslo sprang up around the lake, as did still others on the Lardeau River and around Trout Lake at the turn of the century. Early lode prospecting and mining probably was less damaging on stream habitat of salmonoids than placer operations. Their major effect was through attraction of a population which developed the beginnings of a sport fishery. Nevertheless small dams associated with mining operations on some streams did block upstream migration of spawning salmonoids.

The smelter associated with Blue Bell mine at Riondel operated periodically until 1908. Thereafter much of the ore continued to be milled on site but the smelting was carried out at Trail. In addition to shaft water, effluent from the mill and concentrator was discharged directly into the lake. Any deleterious effects on the lake biota were probably localized. Other small mills associated with mining operations sporadically discharged into Kootenay Lake, but their effects have probably been minimal.

The early miners utilized timber for construction of equipment associated with placer operations, as well as for construction of buildings, shelters, and for fuel. But it was the extensive development of underground mining, the construction of railways, the operation of lake steamers, and the rapid rise of towns all occurring in the 1880’s which brought about logging-off of most readily accessible forests. With the advent of truck and tractor logging and increasing mechanization of the industry, extensive areas of most major tributaries to the lake are now subject to logging. Many of the deleterious effects on stream environments associated with deforestation such as extreme discharge fluctuations and siltation have been particularly evident in the Kootenay region (Jeffrey, 1968; Chamberlin and Jeffrey, MS 1968). Although no pulp and paper mills are presently situated on Kootenay Lake itself, one started operation on the upper Kootenay River in 1968. No serious effects on stream biota have been noted yet (Williams et al., MS 1970) although water discoloration, odor, and foam problems have decreased qualitative aspects of sport fishing.

The annual flooding of the Kootenay River flats between Bonners Ferry and Kootenay Lake, so effectively exploited earlier for fishing purposes by the Indians, was a serious detriment to agricultural development of this fertile area. Reclamation attempts were started in the early 1880's by an imaginative Englishman, Baillie-Grohman, who built a canal to divert waters of the upper Kootenay River into the headwaters of the Columbia River and also attempted to lower the outlet of Kootenay Lake at Grohman Creek near Nelson (Baillie-Grohman, 1918; Constable, 1957). Neither projects were successful. In 1892 dyking of the river was started in the flats north of the border and continued sporadically with little success until the 1920's. Despite periodic damaging floods, over 68% of the area had been reclaimed by 1950 with dykes (Munro, 1950; Constable, 1957). Access of fish to and from spawning streams entering the Kootenay River between Bonners Ferry and the lake may have been seriously restricted by dyke works, but the magnitude of this effect is unknown. The possibility of increased nutrient load to the lake coming from fertilization of agricultural lands in the Kootenay flats will be considered later with effects of eutrophication in the basin. Very little agriculture has occurred elsewhere around Kootenay Lake, except for a few bench-land areas. Its impact on lake salmonoid populations has probably been minimal.

DAMS AND KOOTENAY LAKE SALMONOIDS

Outlet dams

The first hydroelectric dam on the Kootenay River system was completed in 1898 at Lower Bonnington falls, about 16 km downstream from Nelson. This falls had previously formed a barrier to upstream movement of fish on the Kootenay River. Corra Linn Dam, 12 km downstream from Nelson (Fig. 1A) was built in 1931 but operated on a free flow basis with no storage until 1939. The lake outlet channel was further enlarged and up to 1.8 m of head stored at Corra Linn Dam (Constable, 1957). An additional 60 cm of storage was developed in 1941 and has been utilized with minor adjustments up to the present. Prior to 1939 the west arm of Kootenay Lake was much more of a series of basins connected by short narrows and river-like stretches. Rainbow trout, as well as other salmonoids spawned in the narrows, and to some extent still do. Deleterious effects on spawning and egg survival may have resulted from partial or complete flooding out of west arm narrows by late summer to early spring water storage at Corra Linn.

Duncan Dam

In 1965 construction was started on a dam across the Duncan River 0.8 km upstream from its confluence with the Lardeau River, which together as the Duncan River, enters the north end of Kootenay Lake (Fig. 1B). The 37 m high dam was closed in 1967 and when full formed a 3954 hectare reservoir. It could affect Kootenay Lake salmonoids in at least three ways: (1) by elimination or severe reduction of spawning areas utilized by populations migrating up the Duncan River from Kootenay Lake; (2) by alteration of conditions in the Duncan River during migratory periods of adult spawners leaving or of juveniles entering Kootenay Lake; (3) by alteration of limnological conditions in Kootenay Lake itself. Possible effects were considered prior to dam construction (Peterson and Withler, 1965), and actively investigated for several subsequent years.

Results of an enumeration program in 1964 (Bull, 1965) showed that over 4 million kokanee may spawn in the Duncan-Lardeau system, 2.8 million of which would be prevented from reaching their normal spawning area by the Duncan Dam. Estimates for 1965-1967 spawning populations of kokanee in this system exceeded 1 million fish in each year. Furthermore up to a hundred large rainbow trout and several hundred large Dolly Varden spawners probably migrated up the Duncan River annually before dam construction. Little is known of the former magnitude of mountain white fish spawning migrations in the Duncan River.

An artificial spawning channel was constructed at Meadow Creek, a tributary of the Duncan River, in 1967 for Kootenay Lake kokanee in an attempt to partially offset those lost as a result of Duncan Dam construction. This channel, over 3 km long and 9 m wide, provided nearly 30,000 m^2 additional spawning area and in its first autumn of use some 200,000 kokanee deposited approximately 25 million eggs there. In 1970 the kokanee spawning run to Meadow Creek (over 700,000 fish) was the highest ever estimated in that stream, with 220,000 spawning in the channel. Since 1967 fry production from the channel has ranged between 0.8 and 3.2 million with average survival at best comparable to that in Meadow Creek further upstream (15.2% in channel, 14.0% in creek for 1967-69). Survival in the channel was highest in its first year of operation and has declined thereafter (pers. comm. G. D. Taylor).

Although there is little possibility of successful spawning by the large Kootenay Lake rainbow trout migrating to the short section of Duncan River below the dam, a number of these mature adults were captured there in the spring of 1970 and 1971. Their offspring will be released in an attempt to offset losses of this species incurred by the dam. Virtually all the large rainbow trout from Kootenay Lake which spawn in the Lardeau River, do so in a restricted area at the head of this river where it leaves Trout Lake (Hartman, 1969; Hartman and Galbraith, 1970). While numbers counted on this spawning area have not been as high in some years following completion of Duncan Dam as in others immediately before (Fig. 10), there is no evidence of a decline in the spawning population there.

Of several hundred large Dolly Varden (4-12 kg) which now appear each summer in the Duncan Dam tail-race, few if any successfully spawn in that river (pers. Comm. H. Andrusak, Regional Fishery Biologist). Losses for the population of Dolly Varden formerly utilizing the Duncan River may be more significant than those for rainbow trout, but little information is available on Dolly Varden or on the mountain whitefish populations also affected.

Libby Dam

A dam now being constructed on Kootenay River near Libby, Montana, (Fig. 1B) will alter the flow regime, temperature, turbidity, and other water quality characteristics of this major tributary of the lake and thereby have impacts on its salmonoid populations. The possibility of direct effects via blocking of spawning migrations for large trout or Dolly Varden should not be disregarded, since the present falls on the Kootenay River near Libby may not be an absolute barrier to upstream movement of large salmonoids. A complex series of interrelated changes, many of which by no means seem beneficial, may be expected, but will not be considered further here. Some aspects are briefly reviewed by Schurr (MS 1969).

EUTROPHICATION OF KOOTENAY LAKE

Evidence for eutrophication

1. Physical-chemical changes

The total dissolved solid content of Kootenay Lake apparently increased in the mid 1960's above that in 1949-1950 (Fig. 3) but recently has returned towards its former level.

Of the major ions examined (Table 1), sulphate concentrations have increased since 1949, at least in the south and west arms. Calcium, magnesium and chloride also may have increased slightly, while bicarbonate content appears to have decreased.

Concentration of phosphorus has increased sharply in all three regions of Kootenay Lake since 1949 (Fig. 4). Highest values have consistently occurred in the south arm, with concentrations on some years showing over a hundred fold increase from earlier levels. On most years recorded since 1962 the

Table 1. Annual[1] average concentration (mg/l) of major ions in surface water from three regions of Kootenay Lake.

	MAIN LAKE						WEST ARM		
	NORTH ARM			SOUTH ARM					
IONS	1949/50	1964/66	1968/70	949/50[2]	1964/66	1968/70	1949/50	1964/66	1968/70
K^+	0.5	-	-	1.5	-	0.9	1.8	-	0.9
Na^+	1.4	-	-	1.9	-	2.9	21.8	21.9 -	24.4 1.7
Ca^{++}	20.8	17.4	-	27.0	22.4	32.8			
Mg^{++}	3.7	4.6	-	6.7	5.4	9.2	4.7	5.0	5.1
SO_4^{--}	11.5	12.1	-	12.0	16.6	26.8	12.6	13.4	18.5
Cl^-	0	1.1	-	1.3	1.2	2.4	0	0.9	0.7
HCO_3^-	71.9	61.2	53.5	103.0	64.5	88.3	78.5	64.4	63.1
CO_3^{--}	0.9	0	-		0	0.6	0.8	0	0.6
Number of Samples	12	8	12	36	9	26	36	8	28

1 represents data from all months available; 1964/66 data lacks late fall, winter samples.
2 Kootenay River at Porthill.

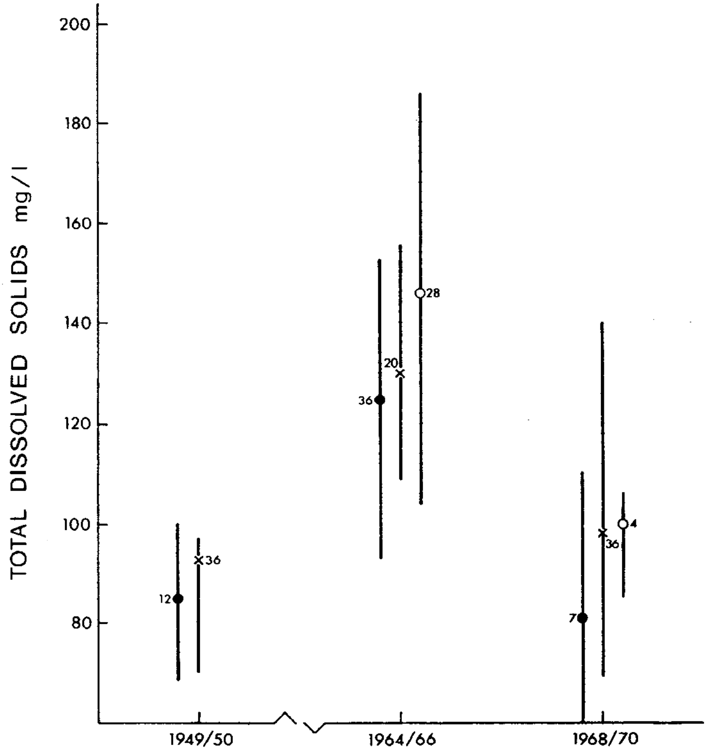


Fig. 3. Annual average and range of total dissolved solid content of midlake surface water from three regions of Kootenay Lake; - north arm, X west arm, o south *arm.* Numbers of samples given in brackets; some data obtained from specific conductivity determinations by correlation.

average concentrations in all regions have exceeded the suggested critical concentration (0.01 mg/l P) above which excessive algal blooms and aquatic plant growth may occur (Sawyer et al., 1945; Vollenweider, 1968; Lee, 1970). Furthermore all recent loading levels calculated for phosphorus in the main lake (Fig. 5) have consistently exceeded the dangerous level set by Vollenweider (1968). The Kootenay River would appear to make by far the greatest contribution to phosphorus loading, compared to that of the Duncan River, the only other major influent (see 1964, Fig. 5). The short theoretical renewal time of the west arm compared to the main lake (monthly maximum in June of 1.6 vs. 170.9 days; annual average of 5.5 vs. 566.0 days) may ameliorate somewhat effects of high phosphate loading there, at least with respect to planktonic algae.

There would seem to be no consistent, long-term change in nitrogen levels in Kootenay Lake (Fig. 4). Even maximum values have not exceeded 0.3 mg/l N, the suggested critical concentration (Sawyer et al., 1945; Lee, 1970). Furthermore for the main lake, nitrogen loading has usually been well below permissible levels (Fig. 5). As for phosphorus, the major nitrogen load comes from the Kootenay River, although a sizable portion is added by the

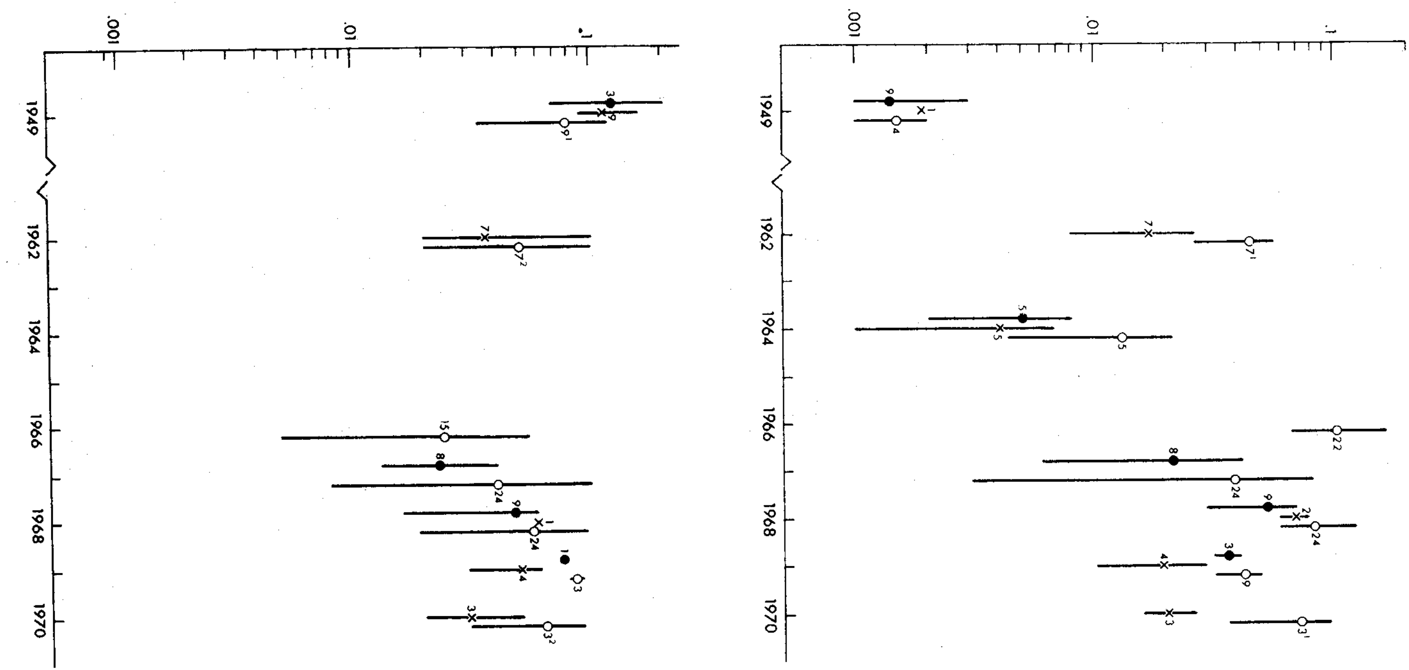


Fig. 4. Average and range of phosphorus (measured as reactive orthophosphate, expressed as P) and nitrogen (measured as total nitrate, expressed as N) in mg/l for summer (June-August) surface water from three regions of Kootenay Lake, ● north arm, X west arm, ○ south arm. Number of samples given near averages; note *logarithmic* scale. [1] Kootenay River near West Creston Ferry; [2] Kootenay River near Porthill.

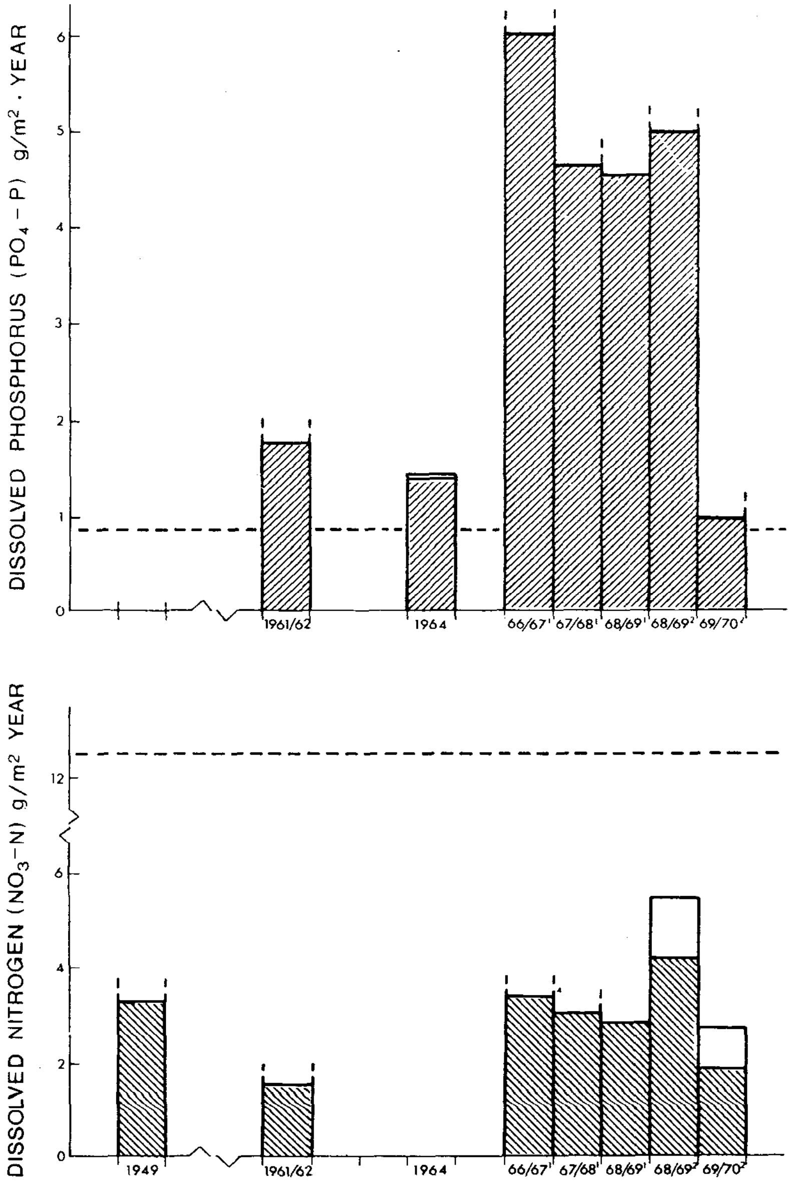


Fig. 5. Annual loading levels for phosphorus (measured as reactive orthophosphate, expressed as P) and nitrogen (measured as total nitrate, expressed as N) in Kootenay Lake (north and south arms only). Shaded portion of bars represent contribution from Kootenay River, clear portion (where shown) from Duncan River (excluding Lardeau River for N). Broken horizontal lines give dangerous loading levels for ***total*** nutrient (P or N) related to mean depth of the basin (from Vollenweider, 1968). [1] for April to March period; [2] for August to July period.

Duncan River proper. Its contribution shown in Figure 5 does not include the Lardeau River which has about 1/3 of the annual discharge of the Duncan River, and probably similar nitrogen concentrations.

The pH level of all three regions of Kootenay Lake has increased strikingly between 1949 and 1970 (Fig. 6) especially in the north arm where over a pH unit increase in *average* values has occurred. Higher pH values may indicate increased phytoplankton abundance in the lake.

Zyblut (1970) compared the depth of light penetration in Kootenay Lake between 1949 and 1964; his and more recent data are summarized in Figure 7. For virtually all stations from June to September, Secchi disc readings were deeper in 1949 than in any of three recent years (1964-66).

2. Biological changes

The first indications of increased algal abundance (planktonic and epibenthic) as well as aquatic weed growth in Kootenay Lake were noted in the mid to late 1950's when anglers began reporting slime on their lines, the clarity of the water decreased, the high water mark of the lake became much more distinct, and formerly clear shoals and sand bars became covered with rooted aquatic plants (pers. comm. R. A. Rutherglen, R. A. H. Sparrow). Extensive algal blooms occurred on Kootenay Lake in the summers of 1958 and 1960, imparting an offensive odor and taste to the water and to fish

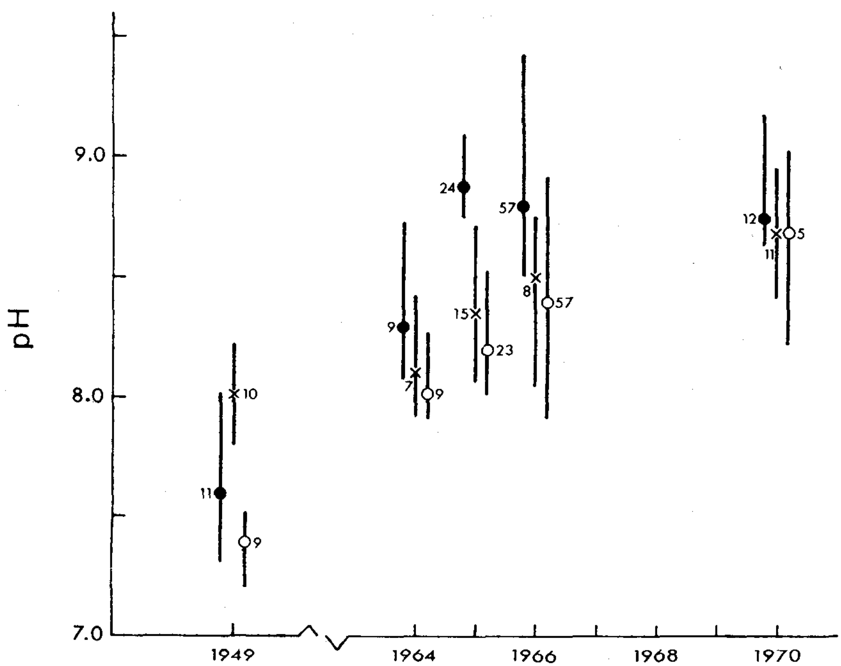


Fig. 6. Average and. range of pH for summer (May-August) surface water from three regions of Kootenay Lake; - north arm, X west arm, o south arm. Number of samples given near averages.

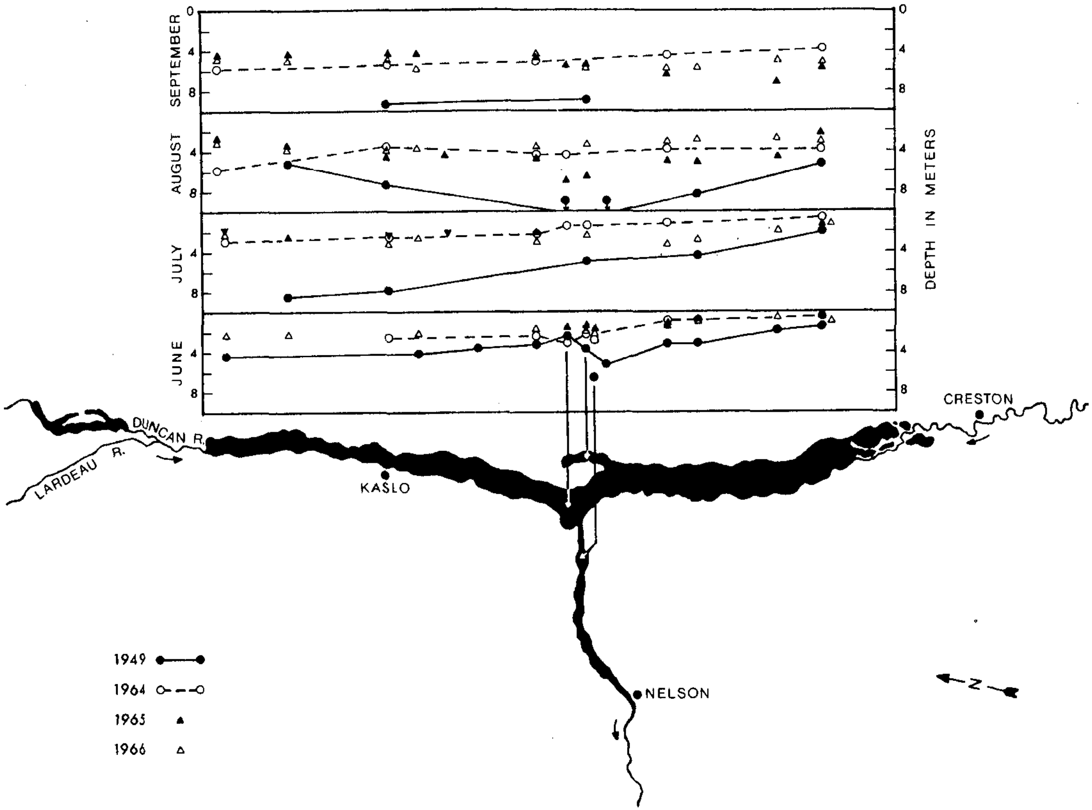


Fig. 7. Seasonal and annual changes in Secchi disc measurements in Kootenay Lake; except where indicated, the readings refer to mid-lake stations immediately beneath their location.

(correspondence from R. A. H. Sparrow, and K. Raht). Subsequently, major algal blooms have occurred in 1965 and 1967, with minor or localized blooms on other years. Phytoplankton production measured by standard ^{14}C techniques in, 1964 (a "non-bloom" year) gave values far above those to be expected in a normal oligotrophic lake (Table 2). Indeed average production values for the north and west arm were in the upper range of those characteristic of eutrophic lakes. That for the south arm, subject to severe photosynthetic inhibition due to high turbidity over much of the growing season, still fell in the lower eutrophic range.

Evidence for a two- to three-fold increase in standing crop of macrozooplankton between 1949 and 1964 in Kootenay Lake has been clearly documented (Zyblut, MS 1967; 1970). Zooplankton abundance was not exceptionally high in 1964 but instead the lowest of three successive years (1964-1966). All species present in 1949 were found in 1964, but *Daphnia galeata mendotae* was less numerous whereas *Diaphanosoma leuchtenbergianum* had increased sharply. In eutrophying Lake Erie, Bradshaw (1964) reported a threefold increase in standing crop of plankton over a 10 year period, with a decrease in *Daphnia pulex* and an increase in *Diaphanosoma leuchtenbergianum.*

SOURCES OF EUTROPHICATION

There are essentially three pathways by which the nutrient level of Kootenay Lake may be enriched: (1) atmospheric fallout, (2) ground-water seepage and (3) surface inflow.

Potential sources of atmospheric fallout include smelters, wood refuse incinerators at sawmills, as well as slash and garbage burning. Although there were smelters near the lake shore at both Nelson and Riondel which would have added sulphates through fallout to the lake, their operating period was short and terminated well before 1930. The Trail smelter has released quantities of sulphur to the air since 1896, ranging from about 12,000 tons/annum at the turn of the century to about 120,000 tons/annum at maximum discharge in 1928, and decreasing to about 1000 tons/month by 1954 (Snowball, 1954). Damage to trees and foliage was evident at least

Table 2. Approximate ranges of phytoplankton production (mg C/m^2 day, averaged over growing season) in general lake types (from Rodhe, 1969) and in three major areas of Kootenay Lake (May-September, 1964; averages and ranges based on 6 determinations in each area, D. B. Fillion data).

Lake Types	Oligotrophic lakes	Natural eutrophic lakes	Polluted eutrophic lakes
	30-100	300-1000	1500-3000
Kootenay Lake areas	North arm	South arm	West arm
	879	378	893
	(526-1781)	(29-1207)	(573-1704)

15 km away from the smelter. Judging from effects reported for Sudbury smelters by Gorham and Gordon (1960) it would seem unlikely that sulphur falbut from the Trail smelter might have appreciably affected even the outlet portion of Kootenay Lake, some 50 km up the valley.

At least ten sawmills on or near Kootenay Lake periodically operate waste burners which could add nutrients via gaseous (nitrogen oxides, various hydrocarbons, sulphur dioxide) or particulate (ash-K_2O, P_2Os) Ca, SiO_2 etc.) emissions. Considering quantities of these materials given off from burners described by Boubel (1965, 1968), and Corder et al., (1970) it would seem that such contributions to the nutrient income of Kootenay Lake would be small, as probably would be that from community garbage incineration or slash burning.

Some nutrient addition to the Kootenay Lake system no doubt occurs by groundwater seepage from individual septic tanks, from fertilizer application on agricultural land and from other sources, but there seems to be no way of even approximating the type and magnitude of nutrients so entering. Numbers of lakeshore cottages as well as quantity of fertilizer applied to agricultural lands in the adjacent drainage basin have both increased, the former considerably, in the last two decades. Phosphorus is usually strongly adsorbed by most ground materials whereas nitrogen is not (Lee, 1970) so that groundwaters are typically poor in phosphates but may be quite high in nitrate content. Therefore one might expect groundwater to increase the lake's nitrate but not phosphate income. That a change has been noted in the reverse direction suggests that there has not been a sizeable recent rise in nutrients from this source.

Surface inflow to the lake receives nutrient addition from the domestic sewage of several communities, from various agricultural sources, from industrial outfalls, and from other effects on the watershed such as logging. The potential contribution from domestic wastewater can be estimated from resident population equivalents for P and N (Table 3). Although the amounts of both nutrients coming from this source may have about doubled between 1950 and 1970, neither appear to make a sizeable contribution to the total nutrient load entering the lake. These calculations neglect transient tourist contributions, which would further magnify the increase since 1950, but probably not greatly.

Quantities of phosphorus and nitrogen applied to agricultural land in the Kootenay River valley (Table 4) may be estimated from data on areas under active cultivation and from average fertilizer composition and application rates. On the basis of these approximations there would seem to be only a slight increase in amount of basic nutrients applied and possibly lost to surface drainage between 1950 and 1970. Erosion losses are not included, but probably are minor. Prior to 1940 little chemical fertilizer was used on agricultural lands in the Kootenay Valley basin (pers. comm. W. R. Goerzen and B. Studer, District Agriculturists). That the phosphorus and nitrogen load of Kootenay River is not substantially increased by loss of these nutrients from agricultural land can be ascertained more directly by examining loads above and below the agricultural region (Table 5). For two recent years on which estimates could be made there was no marked or consistent change in nutrient load of the river after its passage through most of the agricultural

Table 3. Estimates of phosphorus and nitrogen (metric tons) which could be contributed to the Kootenay River by known domestic wastewater outfalls. Based on *connected* population equivalents[1] of 0.9 kg P/person/year and 3.2 kg N/person/year.

Locality or Tributary	Phosphorus 1950	1960	1970	Nitrogen 1950	1960	1970
Upper Kootenay R. (upstream from St. Mary R.)	-2	-2	-2	-2	-2	ca 0.5
Kimberley (plus nearby communities)	6.2	6.9	7.2	22.2	24.7	25.6
Cranbrook	3.2	5.0	9.4	11.6	17.7	33.6
Elk R.	3.2	3.8	4.5	11.3	13.4	16.0
Tobacco R.	0.8	0.9	1.1	2.9	3.2	3.8
Libby	1.8	2.2	2.9	6.4	8.0	10.4
Bonners Ferry	1.3	1.8	2.4	4.8	6.4	8.6
Creston	1.4	2.2	3.1	5.2	7.9	11.2
Load from domestic waste-water (Σ above)	17.9	22.8	30.6	64.4	81.3	109.7
Estimated total load entering lake	231“	685	455	1289	605	758
Maximum domestic contribution 3 (%)	7.7	3.3	6.7	5.0	13.4	14.5

1 after Lee (1970).
2 less than 0.5 metric tons.
3 assuming all P and N entering system from domestic wastewater reaches lake.
4 based on a calculated load from the drainage basin; see Northcote (1972b).

Table 4. Estimates of phosphorus and nitrogen (metric tons) applied to agricultural land in the Kootenay River valley (Bonners Ferry to Kootenay Lake).

Portion of Valley	Approximate Area Fertilized (hectares) 1950	1960	1970	Phosphorus 1950	1960	1970	Nitrogen 1950	1960	1970
In U.S.A.	14,000	14,000	14,200	110	138	142	70	76	91
In Canada	5,300	7,000	8,100	42	69	81	27	38	52
Total	19,300	21,000	22,300	152	207	223	97	114	143
Possible1 loss by drainage from total agricultural area (not including erosion loss)				0.64	0.87	0.94	30	35	44

1 assuming losses similar to those given for agricultural areas by Sawyer (1947).

area. Results of algal bioassay experiments and other data (D. B. Fillion, unpubl.; K. G. Taylor pers. Comm.) suggest that there may at times be some nutrient addition occurring in this portion of the river, presumably from fertilizer leaching,

Table 5. Estimated annual load (metric tons) and average concentration (mg/l in brackets) of phosphorus and nitrogen in the section of the Kootenay River associated with major agricultural fertilizer application.

Location	Phosphorus		Nitrogen	
	1968/69[1]	**1969/70[2]**	**1968/69[1]**	**1969/70[2]**
Upstream from agricultural area (Leonia, Idaho)	1536 (0.142)	453 (0.046)	989 (0.065)	872 (0.052)
Within agricultural area (Porthill at U.S.A.-Canada border)	1305 (0.111)	544 (0.052)	1041 (0.070)	796 (0.091)
Near downstream end of agricultural area (Creston)	1406 (0.111)	455 (0.050)	915 (0.065)	758 (0.074)

1 March 1968 to February 1969
2 November 1969 to October 1970

Potential nutrient contributions to Kootenay Lake from the two major industrial operations on Kootenay River are summarized in Table 6. Although large quantities of carbon may be added to the system from pulp fiber, little reaches the lake. Additions of P and N from the pulp mill are not large and in any event it started operation long after effects of eutrophication were becoming evident in the lake.

High additions of phosphorus and other materials have been entering St. Mary River, tributary to the Kootenay River, since 1953 from operation of a fertilizer plant near Kimberley. Sizeable increases have occurred in the total dissolved solid content of the river system below Kimberley since the 1949/50 period, as well as a shift in its relative ionic concentration, sulphate increasing at the expense of bicarbonate (data not shown).

Phosphorus loads since the early 1960's (Fig. 8) are characteristically low in the Kootenay River upstream from the St. Mary River confluence and in the latter river above Kimberley (6-174 and 4-23 metric tons P/annum, respectively). They increase by about two orders of magnitude (1030-1468) in the St. Mary River below Kimberley and from one to two orders of magnitude (575-1723) in the Kootenay River downstream from the St. Mary River confluence. In March 1962 the phosphorus load of the St. Mary River below Kimberley decreased sharply as did that of the Kootenay River downstream from the St. Mary River confluence, although less strikingly. The phosphate fertilizer plant (Table 6) ceased operation from 7 March to 3 April, 1962 due to destruction of the line across Kootenay Lake supplying it with electrical power. When the plant commenced operation again, phosphate loads in both rivers rose to or above previous levels. Clearly, phosphate losses from the fertilizer plant are largely responsible for the dramatic increase in load of this nutrient in both the St. Mary and Kootenay rivers. There are no major changes in phosphate load of the Kootenay River between the entrance of the St. Mary River and near its mouth at Kootenay Lake (Fig. 8) where measured loads have approached 1000 tons/annum since the 1960's. The *estimated* annual P load for the Kootenay River mouth in 1951 , prior to installation of the fertilizer plant is 232 metric tons or about 0.6 g/m^2 of main lake surface (Northcote, 1972b).

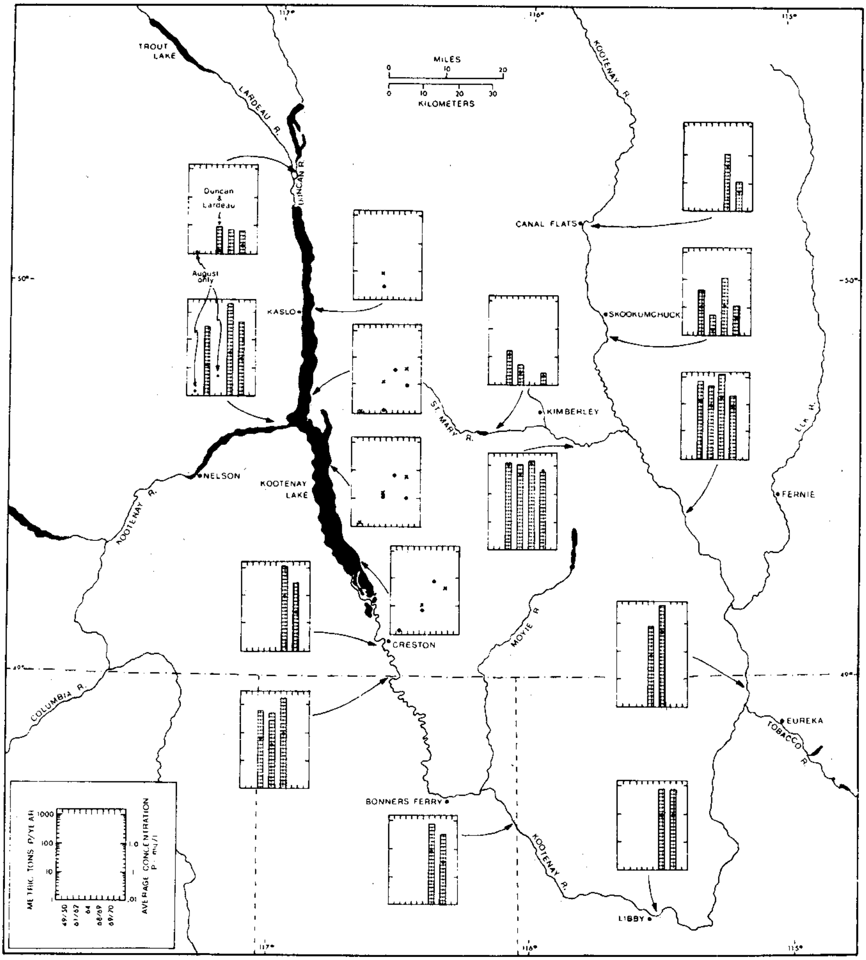


Fig. 8. Annual load (metric tons; left ordinate, hatched bars) and average concentration (mg/l; right ordinate, solid dots) of dissolved phosphorus (PO_4 - P) in waters of the Kootenay Lake system; note logarithmic scale. Average concentration in mid-summer also shown for lake near surface (solid dots) and deep water (> 100 m; crosses).

In direct contrast to phosphate loads, those for nitrogen (Fig. 9) show only a slight increase in the St. Mary River itself (cf. above and below Kimberley) or in the upper Kootenay River (cf. above and below its confluence with the St. Mary River). As noted previously, there are apparently no major changes in nitrogen load or concentration with passage of the river through the major agricultural area in the valley (Bonners Ferry to Kootenay Lake), nor throughout the system between 1949 and 1970 (Fig. 9).

Deforestation by logging of watersheds tributary to Kootenay Lake might increase their contribution of all major ions except NH_4^+, $SO_4^=$ and

Table 6. Summary of major industrial operations’ which may contribute significant nutrient loads to the Kootenay River system tributary to Kootenay Lake.

Location	Type of Operation	Nutrients	Quantity Lost to River System (metric tons/year)	Start of Operation	Major Changes in Operation
Kootenay River at Skookumchuck	Wood pulp mill	C via organic fiber P (dissolved ortho PO_4) N (as NO_3)	“large” up to 12 up to 20	1968	Considerable reduction in losses expected
St. Mary River near Kimberley	1. Lead-zinc mine and concentrator	1. S; SO_4: Fe	S[2] - 71,175 SO_4[2] - 44,530	1.1907	1. Reduction in loss by additional impoundings of concentrator tailings (1968).
	2. Iron-steel plant complex	2. Fe; Ca; P	Fe[2] - 21,535	2.1960	2. Second furnace installed in 1964 and closed in 1971.
	3. Phosphate fertilizer, sulphuric acid plants	3. $CaSO_4$; P	$CaSO_4$[2] - 294,044 P[2] - 8,176 N[2] - 328	3.1953	3. Production doubled in 1962, tripled in 1964 ; some reduction in production and considerable reduction in losses since 1969 (P down to 1455 metric tons/yr.).

1 see also Schurr (MS, 1969).

2 average losses from combined operations 1, 2 and 3; based on six month average daily losses (1966); the fertilizer plant accounts for virtually all of the N, $CaSO_4$, and most of the P loss.

HCO_3^-, if they responded similarly to the north-eastern hardwood forest described by Likens et al., (1970). In Pacific coastal oldgrowth Douglas fir stands nutrient cations in streams increased up to 3 fold following timber harvest and slash burning (Fredriksen, 1971).

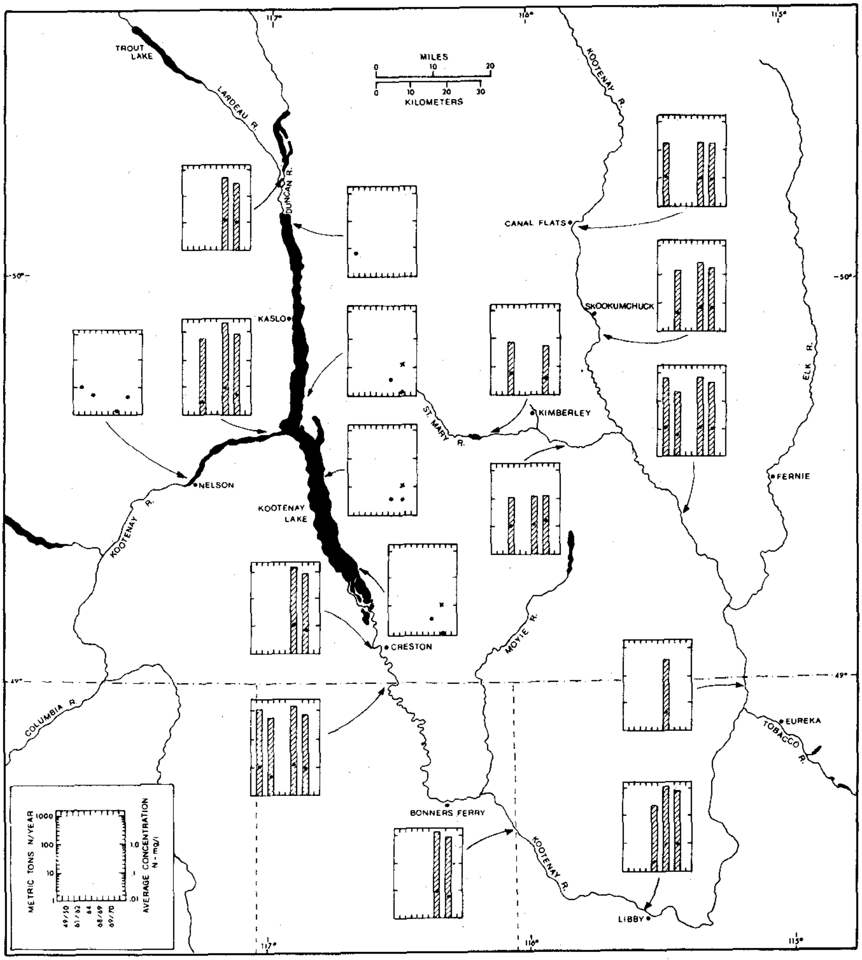


Fig. 9. Annual load (metric tons; left ordinate, hatched bars) and average concentration (mg/l; right ordinate, solid dots) of dissolved nitrogen (NO_3 - N) in waters of the Kootenay Lake system; note logarithmic scale. Average concentration in mid-summer also shown for lake near-surface (solid dots) and deep water (> 100 m; crosses).

INTRODUCTIONS TO KOOTENAY LAKE

Fish introductions

Kootenay Lake and its adjacent tributaries have been subjected to a long, varied, but only partially successful sequence of fish introductions (Table 7). Of the several salmonoid species introduced, none have become well established in the lake, although some such as the brook trout are taken occasionally. Largemouth bass and the pumpkinseed appear to have extended their distribution widely in the lake, but are restricted to shallow, protected habitats. Their impact on native species is unknown.

Invertebrate introductions

Mysis relicta and *Pontoporeia affinis* were introduced into Kootenay Lake in 1949 and 1950 in the expectation that they might form a supplementary food source for rainbow trout when the latter shift from feeding on small invertebrates to fish such as kokanee (Larkin, 1951; Cartwright, 1961). The mysid introduction proved successful (Sparrow et al., 1964) and by the early 1960's this invertebrate appeared in stomachs of rainbow trout as well as in Dolly Varden, kokanee and mountain whitefish. Zyblut (MS, 1967) has described the distribution and abundance of mysids in Kootenay Lake during the mid 1960's. They were most abundant throughout the year in the north arm, averaging from 1.0-1.3 individuals/m^3 there, but less than half as numerous in the south arm with densities less than 0.2/m^3 near the extreme south end of the lake. Both north and south arm populations under go diel vertical migrations.

Pontoporeia affinis has not been observed in the lake since its introduction nor has it been recognized in stomach contents of the many fish of different species examined.

RECENT EXPLOITATION OF KOOTENAY LAKE SALMONOIDS

Local food exploitation

Kokanee and to some extent Dolly Varden spawning runs in streams tributary to Kootenay Lake have been exploited for food by local families who preserved the fish for winter use. Small streams such as Meadow Creek were most heavily exploited but even there only a few thousand fish were probably taken on most years.

Commercial fishery exploitation

No sizeable commercial fishery has ever operated on Kootenay Lake. However, at least from the early 1900's until the mid 1930's a few individuals gained most of their livelihood by hand-trolling for large rainbow trout, Dolly Varden and burbot (pers. comm. Mr. G. Palmer). The fishery was largely restricted to the area near the mouth of the west arm at Balfour and the fish were sold in the round or filleted (burbot) to hotels and other local outlets, mainly in Nelson. At most, probably a few hundred fish were taken annually.

Table 7. Summary of non-native fishes or stocks introduced or recently gaining access to Kootenay Lake.

Species	Location	Date	Number & Type	Success
Coregonus clupeaformis (lake whitefish)	Kokanee Cr. (west arm)	1930	240,000 fry	No record of survival; none apparently caught during intensive gill netting and seining program in 1949.
Salvelinus fontinalis (brook trout)	Lardeau R.; creeks tributary to the west arm	Sporadically from 1915 on	Few thousand fry	No evidence of a well established population in Kootenay L.; present in some tributaries.
Salmo clarki clarki (coastal cutthroat trout)	West arm	1911; possibly on other years about then	125,000 fry	No record of survival but may have been confused with or hybridized with indigenous Yellowstone cutthroat trout.
Salmo gairdneri (rainbow trout) Stocks from southern interior plateau lakes (Pennask and others)	Lardeau R.; west, north and south arms of Kootenay L.	Sporadically in 1940's and 1950's	Several hundred thousand fry and fingerlings	Small spawners attributed to this stock reported at Gerrard (head of Lardeau R.) for several years after introduction.
Salmo salar (Atlantic salmon)	West arm	1911	10,000 fry	No record of survival
Ictalurus melas (black bullhead)	Kootenay Bay	1968	One or more adults	One live but moribund individual recovered from lake; probably discarded by anglers using live bait.
Perca fluviatilis (yellow perch)	Probably originated from Washington, U.S.A.	After 1890	Unknown	Abundant in Duck L., Leach L. and in sloughs and canals at south end of Kootenay L.; apparently confined to there.
Micropterus salmoides (largemouth bass)	Bonners Ferry on Kootenay R.	1916 in river; first taken at south end of lake in 1921	A few by escape from private ponds in Idaho	Abundant at south end of lake, but not uncommon in protected bays over entire length of main lake and west arm.
Lepomis gibbosus (pumpkinseed)	Unknown	Unknown	Unknown	Common in shallows at south end of main lake and in west arm.

Fish cultural exploitation

Spawning runs of rainbow trout and kokanee from Kootenay Lake have been exploited over several decades as an egg supply for fish cultural purposes. An egg collecting station and hatchery was operated at the head of the Lardeau River by the federal Department of Fisheries from 1912 to 1932; nearly 2 million eggs were taken on one year (1929). It was closed shortly thereafter but later reopened and operated by provincial authorities from 1939 until 1949 and again in 1952. Total numbers of large female trout utilized, most or all of which came from Kootenay Lake, may be estimated from egg collection records (Fig. 10). During the 30 year operation, usually about 100 to 300 females were used annually; on some years over 400 were caught. Many but not all fish in each spawning run were taken by seining below a fence preventing their upstream movement into Trout Lake. The total spawning population probably ranged between 500 and 1500 fish (Fig. 10). The incision method of egg collection was practised in the early years so all females were sacrificed. Usually, however, stripped fish were returned alive to the river.

Some of the hatchery-reared offspring were returned to the Lardeau River as eyed eggs, fry or fingerlings but for 15 years on which records are available (1915-17, 193949, 1952) only 15% of all eggs collected were so treated; on 6 of the years none apparently was returned. The spawning run of these large fish declined sharply in the late 1940's, perhaps not surprisingly, and further collections virtually ceased shortly thereafter. Counts of spawners rose again in the late 1950's and leveled off between about 100 and 200 females in the last decade. In 1966 intensive studies on this population provided a good estimate of the total number of spawners for that year (Hartman and Galbraith, 1970) and although there may be inaccuracies in applying the ratio between maximum count and the total spawner population estimate to other years, a rough approximation of the latter is possible (Fig. 10). If the total spawning population during the recent decade has not been substantially lower than that estimated from mid 1910's to the mid 1940's (as suggested by the estimates in Fig. 10) then the egg collections during this period must have exploited a high proportion of the total female spawners available on most years.

Large collections of kokanee eggs have been made in the Duncan-Lardeau river system since 1914, as well as in Kokanee and other creeks tributary to the west arm of Kootenay Lake (Fig. 10). Although over 12 million eggs were taken from some 50,000 female kokanee in 1941, the year of the largest collection (made mostly at Meadow Creek), these may only have represented about 1/3 of the total females available in the spawning run, if numbers were comparable to recent total counts there (Fig. 10). On the other hand removal of over 4500 females from the Kokanee Creek spawning population as occurred in 1936 (Fig. 10) may have represented a much more significant exploitation in this creek. Of slightly over 100 million kokanee eggs taken from Kootenay Lake populations over the 36 years recorded, about 7% were restocked in this system.

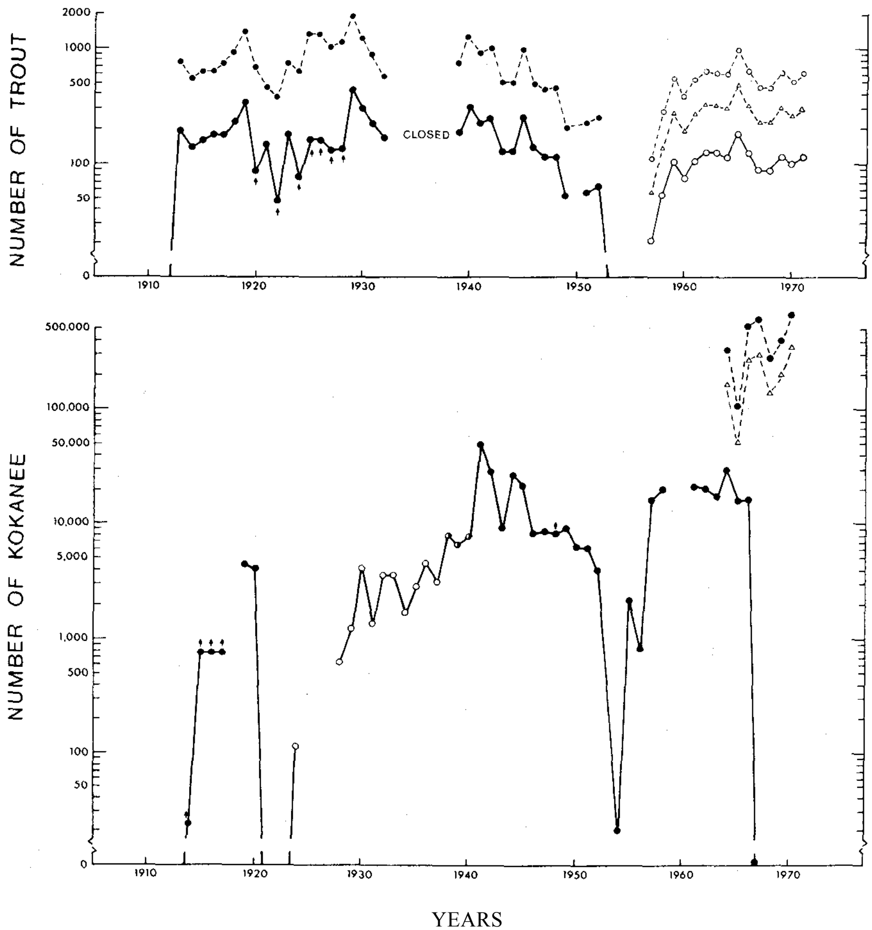


Fig. 10. Annual changes in estimated numbers of adult rainbow trout (upper) and kokanee (lower) spawners in streams subject to fish cultural egg collections; note logarithmic ordinates. Upper: ●—● shows number of female trout stripped of eggs estimated from egg collection records at the Gerrard hatchery (head of Lardeau River; assuming 4000 eggs/female); ı - ı shows estimated total number of spawners assuming 50% of all spawners were caught on most years and 25% on years with log jams or other unfavourable conditions (↑); o—o shows maximum number of female spawners (assuming **50/50** sex ratio) counted on spawning area; o - o shows total spawner estimate based on 1966 count and spawning duration (see Hartman and Galbraith, 1970); A - A shows estimated total number of female spawners in run (assuming **50/50** sex ratio). Lower: - shows estimated number of female kokanee stripped of eggs in Lardeau River-Meadow Creek (largely the latter) traps (assuming 235 eggs/female; ↑ minimal estimates based on records of young later released); - shows estimated number of female kokanee stripped of eggs from west arm streams (6 mile, 9 mile, Sitkum, Redfish and Kokanee-largely the latter); ◑ shows estimates of female spawners on years when egg collections probably made from both Kokanee and Meadow Creek; ı - ı shows estimated total (largely based on trap counts) of kokanee spawners in the Meadow Creek system; A - A shows female fraction of these assuming 50/50 sex ratio.

Sport fishery exploitation

The Kootenay Lake sport fishery, especially that during the recent decade has been described by Gee (1959), Sinclair (MS, 1968) and its estimated total value ($5.8 million) subjected to rigorous economic analysis (Pearse and Laub, 1969). All that will be attempted herein is to summarize recent information on the quantity of the various salmonoids taken, and to review development of these sport fisheries for comparison with other forms of exploitation of the stocks by Europeans and earlier by native Indians.

The large rainbow trout of Kootenay Lake have provided a well-known "trophy" sport fishery at least since the early 1900's. By the late 1920's important but local fisheries had developed for these trout near the mouth of the west arm (Balfour area) and in the north arm near Kaslo; probably a few hundred at most were taken annually. During the 1940's recorded catches of large (> 2 kg) trout ranged between 242 and 595 fish (Fig. 11) with the largest usually exceeding 8 kg. Catches estimated by extensive creel census techniques were considerably above this level throughout most of the recent decade, ranging annually from about 1000 to over 1700 large trout. Until the last few years there has been no consistent change in the total number of rainbow trout angled from Kootenay Lake (Fig. 11); catches fluctuated considerably (from about 2500 to 6000) with some suggestion of a 4-5 year cycle.

Although a few anglers fished specifically for Dolly Varden prior to the late 1940's, most were caught incidentally by anglers trolling for rainbow trout. Only a few hundred were taken annually. Thereafter catches increased to about 1000 in the late 1950's to '60's and recently they have approached 3000 fish (Fig. 11). The Dolly Varden is now a well-accepted sport fish.

Like the Dolly Varden sport fishery, that for kokanee was largely incidental until the late 1950's when interest was generated by a few keen anglers chiefly in the west arm. Annual catches rose quickly from a few hundred to several thousand in the early 1960's (Fig. 11); most were small fish (< 30 cm; < 0.4 kg). However their size gradually increased (kokanee over 40 cm and from l-2 kg were not uncommon) and since the mid 1960's a very active, large and specific fishery for this species has flourished with catches up to 50,000 fish dominating the total taken from the whole lake (Fig. 11).

An important sport fishery for moutain whitefish also has developed recently (chiefly during winter in the west arm), in part due to larger fish being available. Over 15,000 were taken in 1968 (Fig. 11) but the 1970 catch (and also effort) declined in response to a mass whitefish mortality in the autumn of 1969 (Andrusak MS 1970).

The total salmonoid catch in the Kootenay Lake sport fishery increased gradually from about 5000 fish in the late 1940's and early '50's to nearly 10,000 in the mid 1960's. Thereafter it climbed sharply to over 60,000 fish by 1969, largely as a result of increased exploitation of kokanee in and near the west arm of the lake.

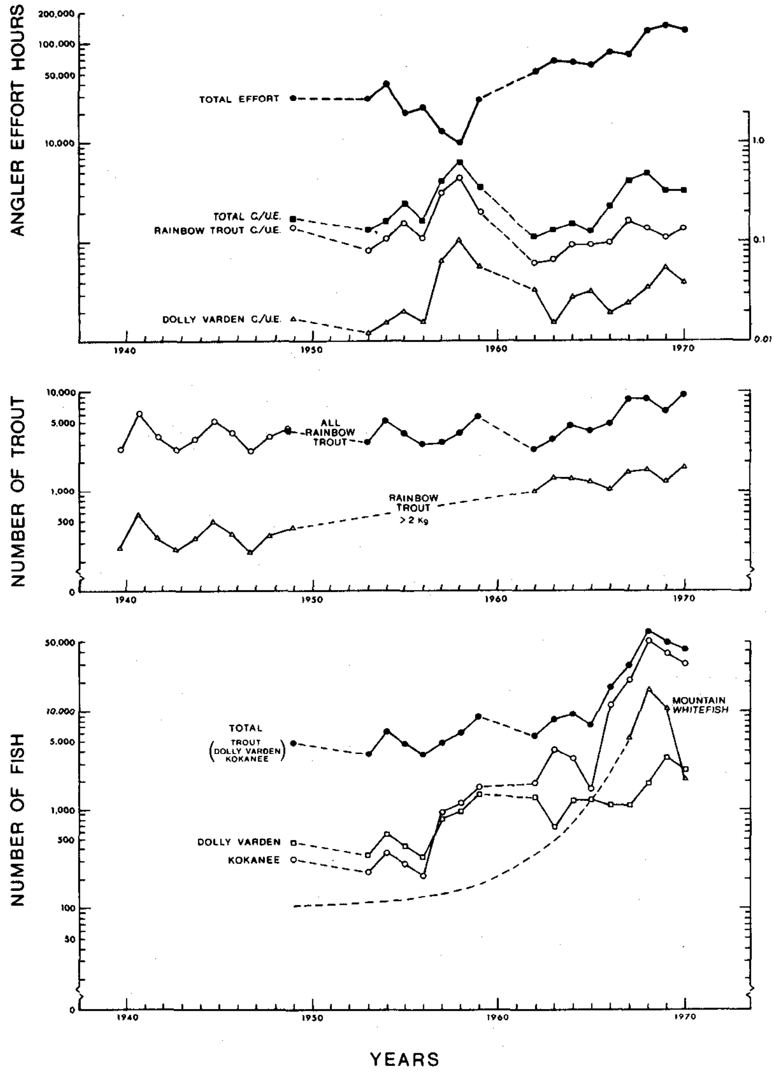


Fig. 11. Changes in salmonoid catch and angler effort in the Kootenay Lake sport fishery estimated for 1949-1970 from B.C. Fish and Wildlife Br. creel census and other records; note *logarithmic* ordinates, Lower; broken line for mountain whitefish shows probable trend. Middle: data (A - A) for trout > 2 kg from 1940-1949 show only recorded catches *in Nelson* Gyro Club *trout* derby (May-mid-November), and for other years from creel census; catches for all trout from 1940-1949 (o - o) estimated from Gyro Club records, assuming ratio between trout > and < 2 kg in 1949 creel census held for previous years when Club recorded catch only of > 2 kg trout; note that 1949 estimate so obtained from Club records and from creel census are close. Upper: total effort pertains only to trout, Dolly Varden and kokanee; that for mountain whitefish or other sport fishes not included; C/UE for rainbow trout calculated from effort applied to that species only, where possible; effort for Dolly Varden assumed to be same as for rainbow (undoubtably an overestimate).

Rainbow trout

1. Size

Comparisons of lengths of rainbow trout caught in the sport fishery during the 1940's and 1960's (Fig. 12) show an increase in relative abundance of intermediate size fish (30-60 cm), but no marked change in frequency of the larger size classes in the catch, This trend holds for all three areas of Kootenay Lake and would not seem to result from any obvious change in method or nature of the fishery. That "trophy" trout are still common is evident by comparison of weights of the largest fish recorded annually in the 1940's (average for 9 years is 8.5 kg; range 7.7-9.8) and in the 1960's (average for 9 years over 9.1 kg; range 8.6- > 9.3).

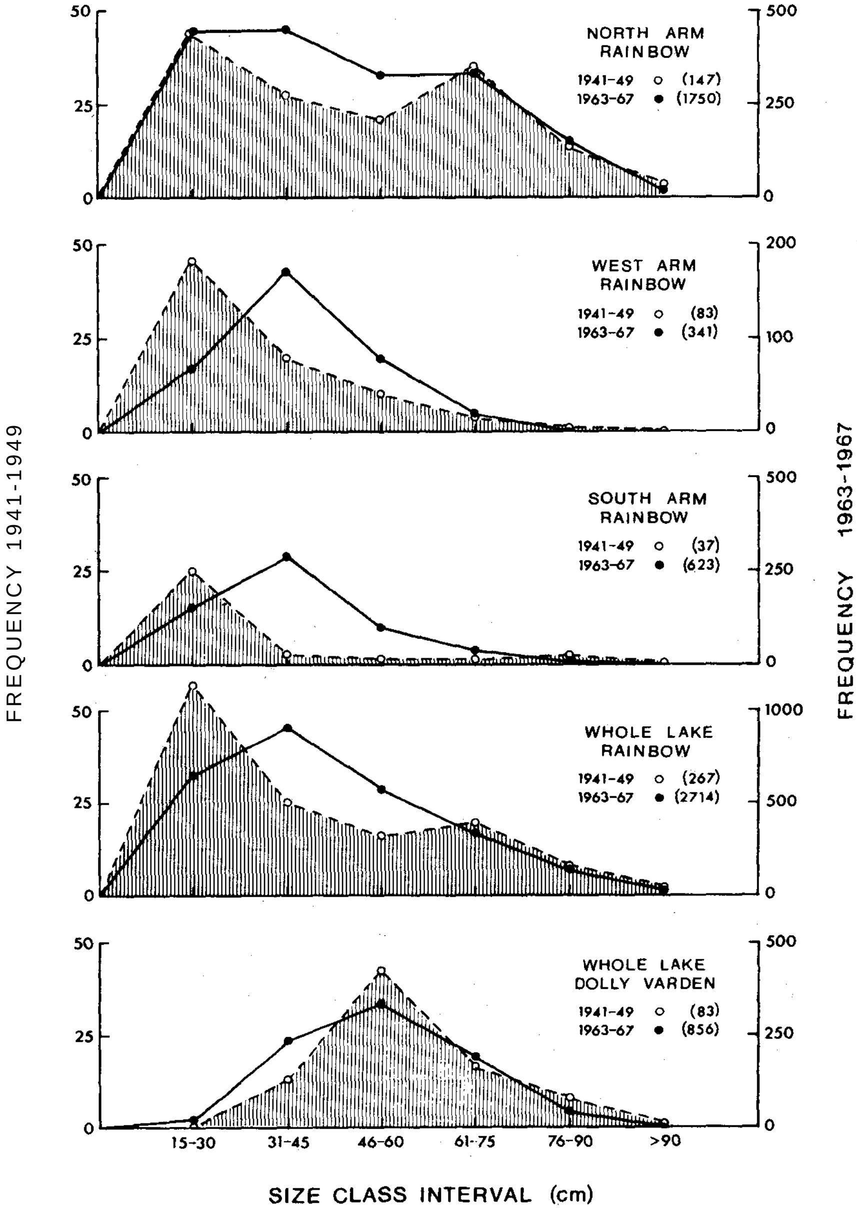
The length-weight relationship of small (< 30 cm) rainbow trout does not appear to have changed appreciably between the 1940's and mid 1960's (Fig. 13), although sample size is small for the early period. However trout larger than 40 cm caught in the mid 1960's are distinctly heavier than those taken in the 1940's. An analysis of covariance (logarithmic data) for fish >40 cm showed a significant displacement ($p < 0.001$) between the two regressions (length on weight for 1940's and 1960's). At some stage in their first 2-3 years rainbow trout in the 1963-'65 period must have been putting on more weight than in the 1940's, and after reaching about 40 cm, maintained that difference throughout the rest of their life in the lake. Recent data (1969-70) suggest a return in the length-weight relationship of trout > 40 cm towards that characteristic of the 1940's.

2. Food habits

There has been little change in the summer diet of small (< 30 cm) rainbow trout since the late 1920's (Fig. 14). Insects captured at the lake surface (largely terrestrial forms) contribute heavily both by occurrence and by volume. Such is the case also for intermediate sized trout (3045 cm) although aquatic insects, fish and in recent years mysids are of some significance. Fish (usually kokanee) have consistently formed a major item in the summer food of large trout, but apparently less so recently when surface insects became predominant. Unfortunately the small sample in this size class for 1928/29 precludes positive evidence of a shift in food habits. Mysids, while being utilized heavily by a few trout, do not contribute much to their average summer diet. However autumn and winter stomach samples suggest that this introduced invertebrate may then be of greater importance as a food supply for large trout.

3. Age characteristics

The large rainbow trout inhabiting the main body of Kootenay Lake may live up to 9 or more years; over 90% first spawn at 5 or 6 years of age and a few (ca 11%) spawn again (Cartwright, 1961). Trout from the west arm apparently spawn at an earlier age (3 to 4 years) than those in the main lake. While detailed studies have not been completed, there does not appear to have been any major shift in age characteristics of Kootenay Lake trout populations during recent decades.



Length-frequency distribution (fork length) of angler caught rainbow trout and Dolly Varden from Kootenay Lake for early (1941-1949) and recent (1963-1967) periods in the fishery; numbers in brackets show sample sizes.

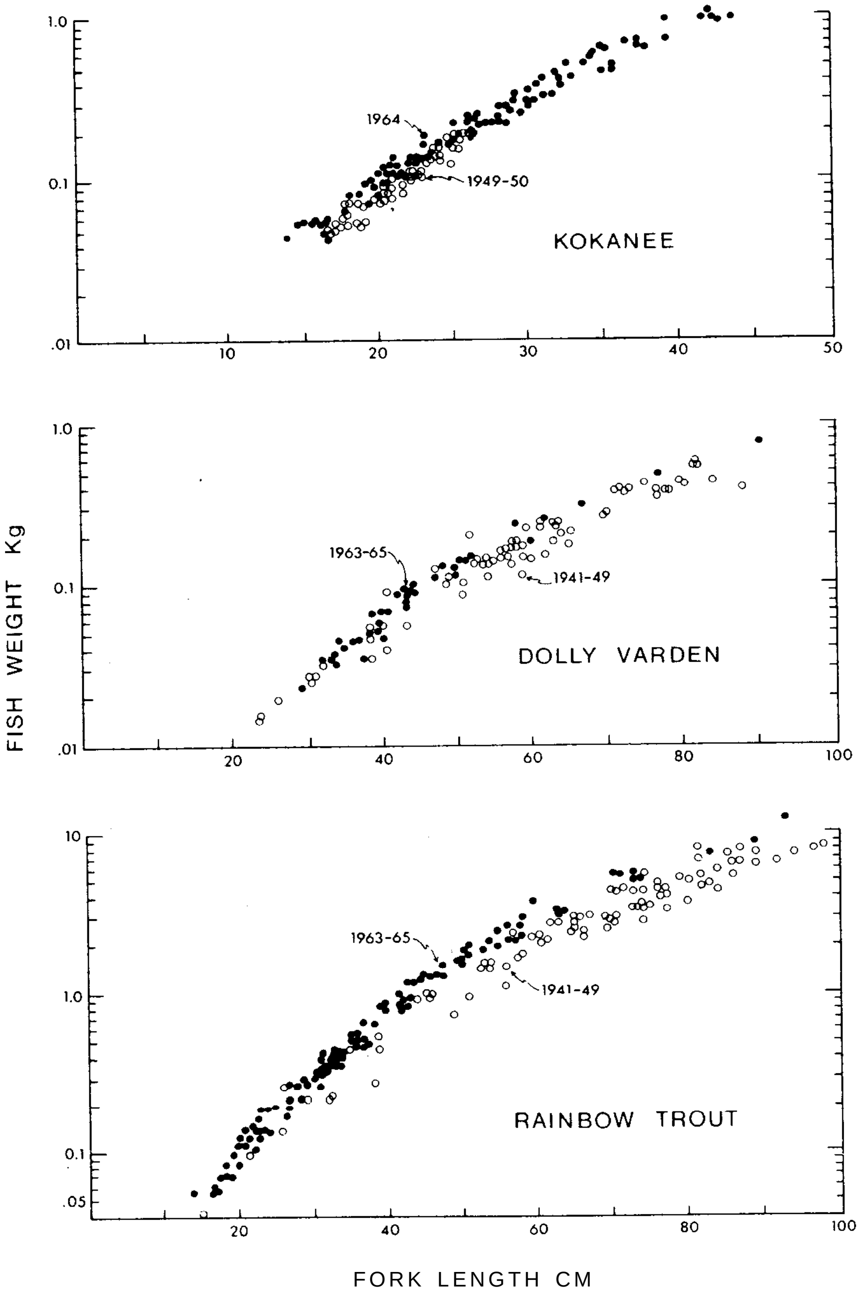


Fig. 13. Comparison of length-weight relationships for Kootenay Lake salmonoids between the 1940's (open dots) and 1960's (solid dots); data for all arms of the lake combined for each species; note logarithmic ordinates.

4. Growth rate

Cartwright (1961) has reviewed evidence for growth changes in the main lake population of Kootenay Lake trout, noting that "between 1943 and 1950 there was a general decrease in growth rate of trout of all ages from all year classes", and that "an almost steady increase in growth rate can be seen between 1953 and 1954 up to the present time" [1959]. Recent analyses, as yet incomplete, suggest that this trend probably continued until the mid 1960's at least. The change observed in length-weight relationship of trout (Fig. 13) would argue in favour of a higher growth rate at some stage compared to that in the 1940's.

In the west arm of Kootenay Lake, two groups of trout have been distinguished on the basis of their growth rate characteristics (Cartwright, 1961). One group shows a rate well above any observed for main lake trout since 1949, while the other up to two years of age is considerably below that level. Causes for more rapid growth in west arm trout may be both environmental (shallower, warmer water and greater food abundance) and genetic (Cartwright, 1961; Northcote et al., 1970).

5. Abundance

Changes in abundance of Kootenay Lake trout may be assessed from two lines of evidence: (1) numbers of spawners recorded on the major spawning area for large trout, (2) angler catch per unit effort (C/UE). The former (pertaining to only one stock and presented previously), suggested a sharp decline in abundance during the late 1940's with a subsequent rise in the late 1950's and 1960's to estimated annual totals between 500 and 1000 fish, representing a spawning population perhaps half as large as that in the late 1920's (Fig. 10). Unfortunately, C/UE data are not available prior to 1949 so that it cannot be determined if the decline in numbers of large trout spawners at Gerrard was also reflected in angler success. Cartwright (1961) discusses the various errors inherent in the trout catch statistics but concludes that the upward trend in catch success between 1953 and 1959 (Fig. 11) largely represents "an actual increase in numbers of fish available to anglers". However trout C/UE declined again to the lowest recorded level in 1962 (Fig. 11) and thereafter has climbed gradually upwards again to a level similar to that in 1949.

Dolly Varden

1. Size

No major changes are evident in the length-frequency distribution of angler caught Dolly Varden since the 1940's (Fig. 12) although relatively more small and fewer large fish seem to be taken in the recent period. There are no significant differences in either slope or displacement of the length-weight regressions for Dolly Varden taken in the 1940's compared to those of the recent decade (Fig. 13).

2. Food habits

The few Dolly Varden stomachs examined in 1949 contained almost exclusively fish. A similar pattern is evident in more recent and extensive samples (Fig. 14) although mysids have become a substantial food item for small individuals (< 30 cm).

3. Age, growth, and abundance

Dolly Varden from Kootenay Lake have been recorded up to 15 kg in weight. This char is probably less abundant than rainbow trout in the lake as indicated by estimates of numbers in spawning streams and suggested by its lower C/UE (Fig. 11). Although its numbers are said to be reduced from former years, especially in the west arm, conclusive evidence is not available.

Kokanee

1. Size

In the late 1940's and early 1950's all adult kokanee in Kootenay Lake were small (< 30 cm), even those from west arm populations (Fig. 13, 15). Larger kokanee were reported by anglers in the west arm in the early 1960's and their size gradually increased until fish over 45 cm in length and 2 kg in weight were not uncommon. Increased size of west arm kokanee in the early to mid 1960's is evident in fish from the angler catch, from gill-net records and from spawning stream samples (Fig. 15). North and south arm populations have also increased slightly in size, although not nearly as dramatically as those in the west arm. Perhaps the large fish in these arms represent strays from the west arm but this cannot be verified at present. Recently a few large kokanee also have been noted in the south arm, some up to 2 kg being caught and others up to 1 kg being recorded in spawning streams (pers. comm. H. Andrusak).

2. Food habits

Prior to introduction of mysids in 1949, Kootenay Lake kokanee undoubtably fed heavily on zooplankton and larval or pupal stages of aquatic insects as they do in other British Columbia lakes (Northcote and Lorz, 1966). In the mid 1960's, adult kokanee in the south and north arms continued to utilize zooplankton as a major food source (Fig. 16) but did take some mysids. For the larger (> 30 cm) north arm kokanee, zooplankton became less important, being replaced by aquatic insect larvae and mysids. The latter were the dominant summer food of west arm kokanee and zooplankton, in contrast to north and south arm populations, was an insignificant item (Fig. 16). In autumn, mysids became more important in the diet of south arm kokanee, and during winter and spring retained their predominance in food of west arm kokanee (data not shown).

3. Age characteristics

In 1951 kokanee spawning in north arm tributaries to Kootenay Lake were mostly four years of age whereas those in south and west arm streams were chiefly three years old (Vernon, 1957). Although some changes were evident in the age composition of mature kokanee in the mid 1960's, especially in the west arm where some large fish now are at least four years old, the general pattern appears to be basically similar to that in the early 1950's (pers. Comm. R. A. H. Sparrow).

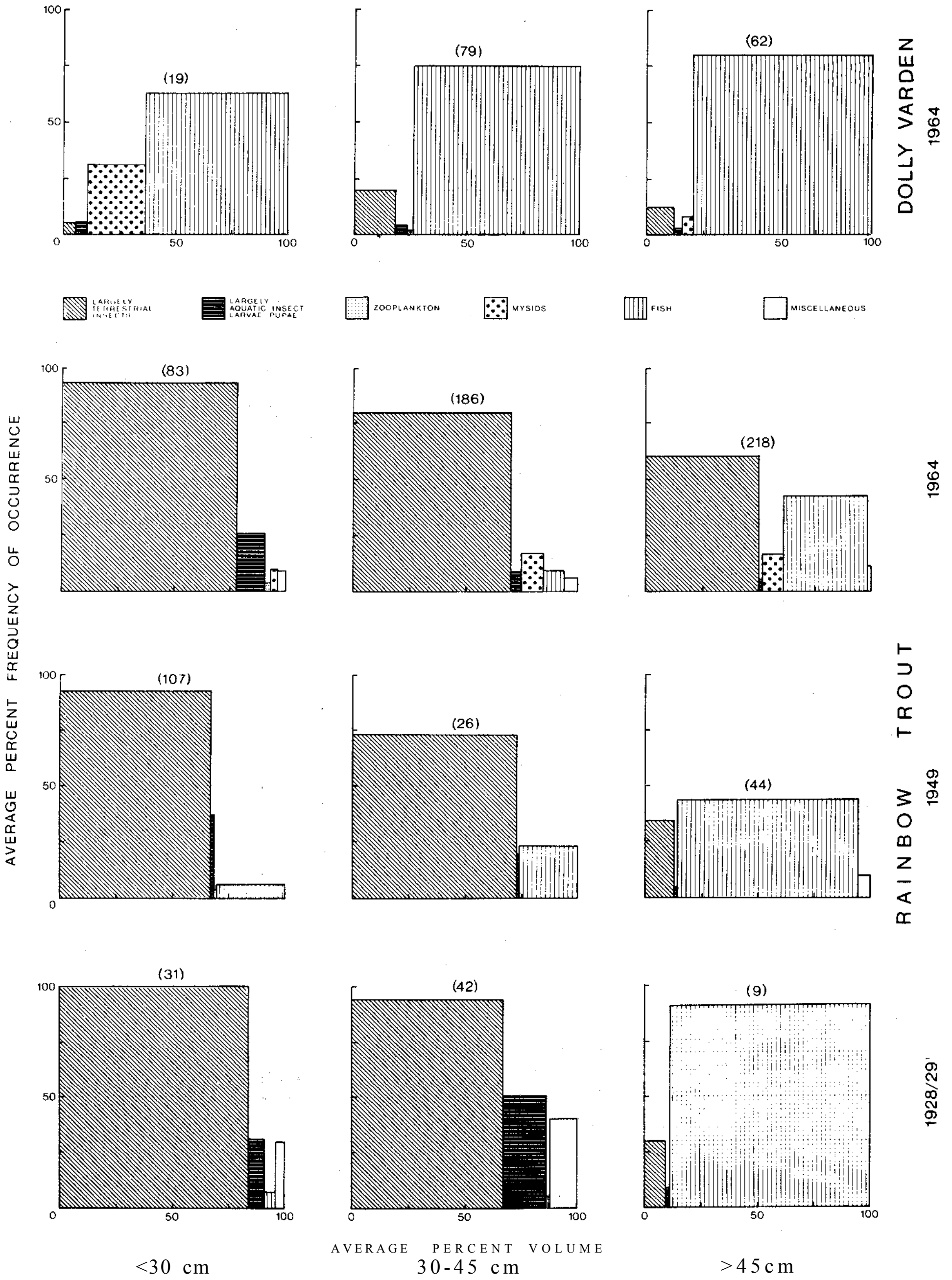


Fig. 14. Summer food of three size ranges of Kootenay Lake rainbow trout and Dolly Varden showing contribution of major items by occurrence and volume. Numbers in brackets show sample size, most of which were taken from the north arm.

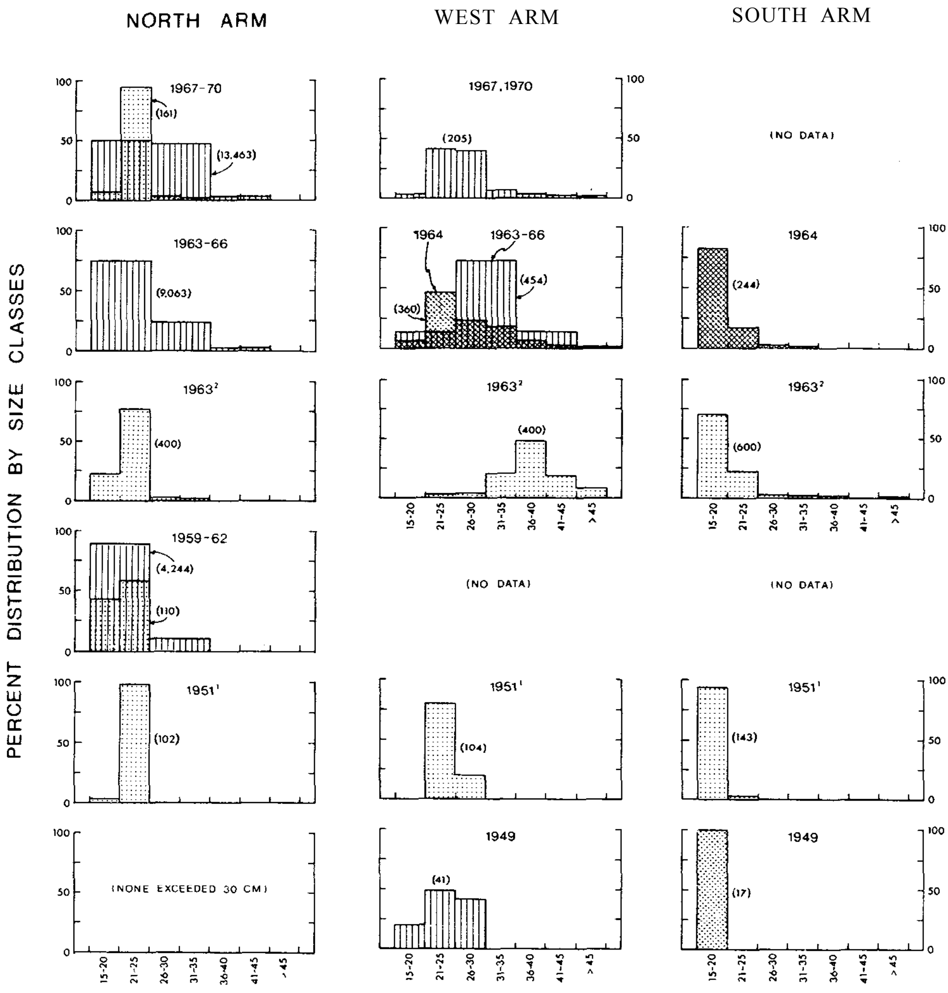


Fig. 15. Size distribution of kokanee in three regions of Kootenay Lake from angler samples (vertical hatching), lake gill net samples (cross hatching) and spawning stream samples (stippled); number in brackets show sample sizes; ¹ data from Vernon (1957); ² data from H. Sparrow (unpub.) samples in same streams as Vernon (1957).

4. Growth rate

As documented by Vernon (1957) west arm kokanee in 1951 were larger at maturity than were north arm kokanee and these in turn were larger than their south arm counterparts. Marked and characteristic differences in size of kokanee populations from the three arms of Kootenay Lake were shown to result from the following features:

(1) west arm kokanee had a much higher growth rate only in their first year; their larger size at age 1 was maintained thereafter.
(2) north and south arm kokanee had similar growth rates in their second year; both were somewhat greater than that of comparable west arm fish.
(3) older maturation, not differences in growth rate, accounted for north arm spawners being larger than those in the south arm.

R. A. H. Sparrow (MS in prep.) has examined 1963 growth characteristics of Kootenay Lake kokanee from the same streams as did Vernon (1957) and has provided the following information based on scale analysis:

(1) growth rate of west arm kokanee is now not only higher than that of other arms in their first year but also in their second and third years.
(2) growth rates of north and south arm kokanee are still similar in their second year, but both are lower than west arm fish.
(3) older maturation and not differences in growth rate still account for the characteristic differences in length at maturity of north and south arm kokanee.

5. Abundance

Estimates of kokanee population size from spawner enumeration in the Duncan-Lardeau river system since 1964 have been noted previously and recent fluctuations in number of spawners were given for one tributary (Fig. 10). Sudden changes in time, location, and intensity of the Kootenay Lake kokanee fishery (Sinclair, MS 1968) prevent use of C/UE statistics to give reliable estimates of the populations. Cessation of kokanee exploitation for egg collections and elimination of a major fraction of their spawning habitat on the Duncan system were approximately concurrent so effects of these factors on the north arm population cannot readily be distinguished.

Mountain whitefish

1. Size

According to Sinclair (MS, 1968) adult mountain whitefish in Kootenay Lake were small 15-30cm) in the late 1940's but have become much larger in recent years. Thirty-four specimens from angler and gillnet samples throughout the lake in 1949 averaged 26.7 cm fork length and ranged between 11 and 40 cm. The majority of whitefish now taken in the sport fishery are over 30 cm in length and some exceed 40 cm.

2. Food habits

Aquatic insect larvae and terrestrial insects were the important items in stomachs of small (< 30 cm) whitefish sampled in the summer of 1949. Larger whitefish (3040 cm) fed exclusively on benthic insect larvae then. Although stomachs of only a few specimens were examined in the summer of 1964, the small fish fed largely on benthic insect larvae. Larger individuals utilized these larvae but more so mysids which also were common in whitefish taken in the winter and spring of 1965.

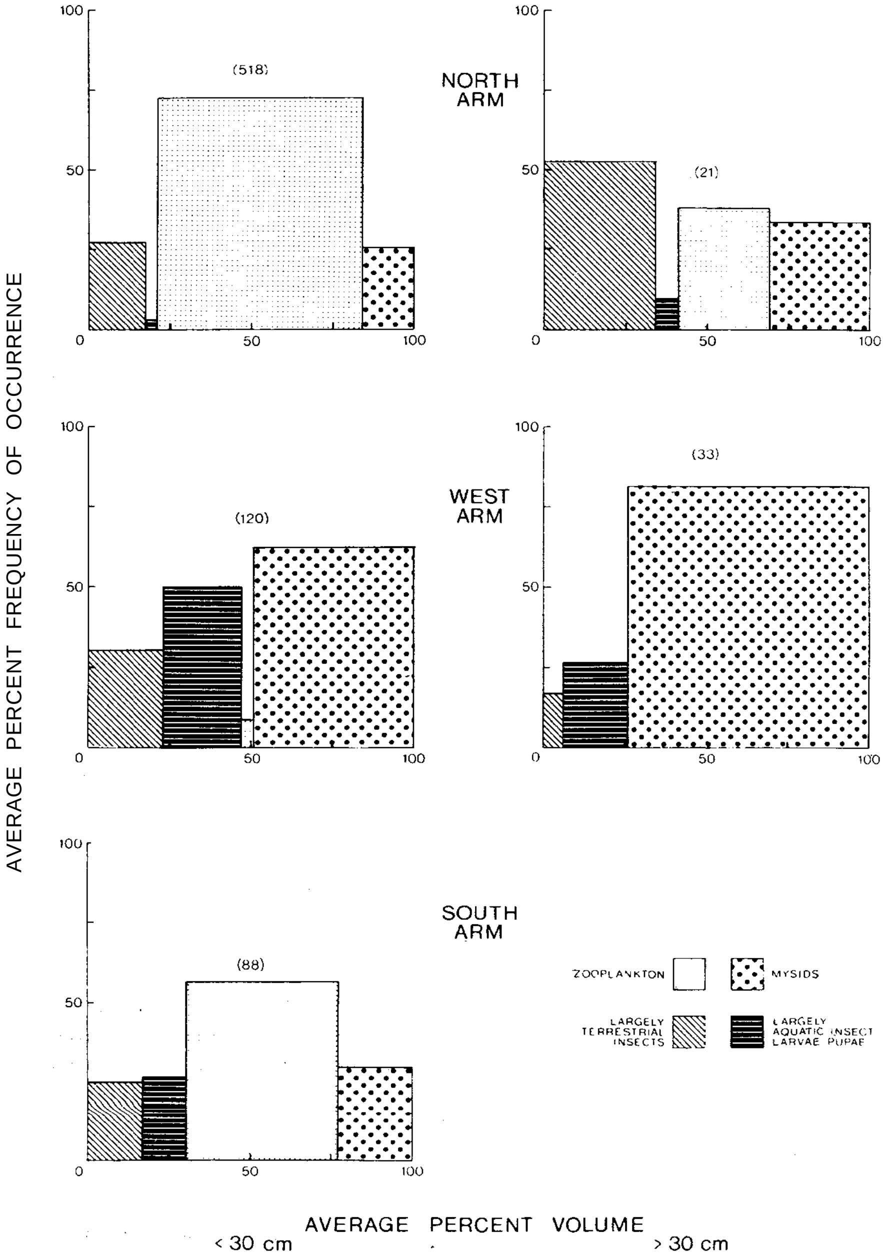


Fig. 16. Summer (1964) food of two size ranges of Kootenay Lake kokanee from the three major areas of the lake. Numbers in brackets show sample size. Of 257 south arm fish examined, 3 exceeded 30 cm and these had fed only on aquatic insect larvae.

3. Age characteristics

Most adult whitefish in 1949 samples were three or four years of age. Those examined recently appear to be chiefly from the same age groups (Andrusak, MS 1970).

4. Abundance

Virtually no information is available on the magnitude of mountain whitefish populations in Kootenay Lake. That the massive mortality of this species in the west arm during the autumn of 1969, estimated to involve one million fish (Andrusak, MS 1970; Bell and Hoskins, 1971) did not seriously depress the sport fishery there the following winter and spring, suggests that there must be several million fish in the total adult population.

SUMMARY AND CONCLUSION

Although a synopsis of man's effects on Kootenay Lake and its salmonoids has been published elsewhere (Northcote 1972a), it is useful to review them here.

Salmonoid stocks of the lake and immediate tributary waters may have been most heavily exploited by man in the late 1700's when the maximum Lower Kootenay Indian population relied to a major degree upon such fish for food. It is estimated that up to 100 metric tons of fish might have been required annually then and that at least 50% of this poundage would have been salmonoids. Such exploitation declined sharply thereafter to at most a few tons by the late 1800's when stocks began to be exploited by the recent immigrant population, first in a minor way for food, then for sport fishing, and later for fish-cultural purposes. The latter, though not removing more than seven tons annually, probably had serious impact on some local spawning populations of rainbow trout and kokanee. Fish cultural operations have been greatly curtailed recently. The sport fishery on the other hand has expanded rapidly since the 1950's, now reaching an annual catch of more than 35 tons.

Introduction of non-native fishes has not been extensive and does not appear to have had unfavourable effects upon the native stocks. Introduction of *Mysis relicta* has probably been responsible in large part for the marked increase in size and growth rate of kokanee and perhaps mountain whitefish in some regions of the lake (west arm) but has not had such dramatic effects on rainbow trout stocks.

Cultural eutrophication of the lake has been pronounced since the late 1950's with the major source of nutrients being phosphates lost from a fertilizer plant operating on a tributary of the Kootenay River nearly 400 km upstream from the lake. Effects of eutrophication on salmonoids are difficult to assess but increased zooplankton abundance associated with it may have increased the growth rates of some species, especially kokanee.

Perhaps the most severe effects of man on the salmonoid stocks of Kootenay Lake have resulted from his deleterious alterations of salmonoid habitat, particularly spawning streams. These effects started in the mid 1800's with placer gold mining and were followed by those resulting from dyking and irrigation operations associated with agriculture as well as the many changes of stream ecology due to intensive logging practices. More recently logging, combined with dam construction on the outlet of Kootenay Lake and its two major inlets, the Kootenay and Duncan rivers, has presented serious problems to management of salmonoid stocks in the system.

In the span of less than 300 years during which man has had much contact with the salmonoids of Kootenay Lake, virtually every stock has been subject to his influence. When acting without sophisticated knowledge but with an appreciation arising from dependence upon fish for life, he was able to co-exist in some measure of harmony for at least two centuries. When exploiting for short term economic gain and with disregard of fish and their habitat, he has effected damaging and perhaps irreversible change in a few decades. When attempting to improve conditions for fish or fishing he has produced results which often were unanticipated and sometimes were undesirable. The need is clear as well as urgent for man to develop a more sensitive, informed, and responsible approach to the utilization of the whole basin in order to preserve an environment there suitable for both salmonoids and himself.

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