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KOOTENAI RIVER BIOLOGICAL BASELINE STATUS REPORT

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ABSTRACT

The Kootenai River ecosystem in Idaho, Montana and British Columbia (B.C.) Canada **has been severely degraded during the past 50 years. This aquatic ecosystem has changed from** one that was culturally eutrophic, to one that is oligotrophic due to **channelization,** diking, impoundment (construction and operation of Libby Dam), and pollution abatement measures in the watershed. As a result of these influences, flow regimes, temperature patterns, and water quality were altered, resulting in changes in primary production and **aquatic insect** and **fish** populations.

Average flows in the Kootenai **River** prior to construction and operation of Libby Dam **(1929-** 197 1) peaked at 60,000 cfs in the spring. Post Liiy Dam years (1973-l 989) demonstrated two similar average flow peaks of 20,000 **cfs occurring** in the spring and winter months. Temperatures downstream of Libby Dam are on the average 17 percent warmer than in **pre-dam** years, since the installation of the selective withdrawal system in 1977.

Construction of Libby Dam (creation of Lake Koocanusa) and closure **of Cominco's fertilizer** plant resulted in decreased phosphorus load to the Kootenai **River** to below historical levels. Dissolved orthophosphorus concentrations averaged 0.383 **mg/L** in 1970 as compare&to 0.039 **mg/L** in 1979. Total phosphorus concentrations followed a similar pattern. Both total phosphorus and soluble reactive phosphorus concentrations remained below 0.05 **mg/L from** 1976 to 1994, characterizing the river as oligotrophic. Post Libby Dam-primary **productivity** levels in the river represent an ultra-oligotrophic to mesotrophic system. Since the **construction and** operation of Libby Dam, invertebrate densities immediately **downstream** from the dam increased, but species diversity decreased. Insect diversity increased with increasing **distance from** the dam, but overall species diversity was lower than would be expected in a **free-flowing** river.

Fish species composition and abundance has also changed as a result **of the** changes in the river and its watershed. Rainbow trout numbers increased in the river **after installation** of **Libby** Dam, whereas westslope cutthroat trout, burbot, and white sturgeon numbers **decreased**. The white sturgeon population in the river decreased **from** an estimated 1,148 individuals in the early 1980% to 785 in 1993, with minimal natural recruitment to the population **since** 1974. The Kootenai **River** white sturgeon population was listed as **endangered** on **September 6, 1994** (59 **FR** 45989) under the authority of the Endangered Species Act of 1973.

INTRODUCTION

Study Area

The Kootenai River Basin is an international watershed. It is located primarily within the province of British Columbia (B.C.), with smaller portions of the basin located within the states of Montana and Idaho (Knudson 1994). The headwaters of the Kootenai River originate in Kootenay National Park, B.C., north of Mt. Assiniboine. From here the river flows south, within the Rocky Mountain Trench, turning west in Montana (MT) through a gap between the Purcell and Cabinet Mountains (Knudson 1994). The river continues west into Idaho (ID), and then north within the Purcell trench to Kootenay Lake, B.C. (Figure 1). The Kootenai River waters flow out the West Arm of the lake eventually joining the Columbia River at Castlegar, B.C. The Kootenai River is the second largest Columbia River tributary in terms of runoff volume and third largest in terms of watershed area (45,584 km^2) (Knudson 1994).

Historically, the outlet on the West Arm of Kootenay Lake was blocked by ice at the close of the last (Wisconsin) glacial period (Alden 1953). When this outlet was opened up with the recession of glaciation, levels of Kootenay Lake receded, exposing the flat lake bed in the southern portion of the valley. "Movement of the Kootenai River and tributary streams in the valley and springtime flooding formed numerous marshes and sloughs which, along with fertile soils, provided a variety of fisheries habitats" (Partridge 1983). Early attempts at diking the river began in 1892 with a desire to reclaim this land for agricultural purposes, although there was little success until the 1920's (Northcote 1973). In order to prevent flooding, drainage districts were formed in the 1920's. This in turn channelized the natural meandering tributary stream flow into straight ditches between the mountains and the river. By 1935, over 90 percent of the valley bottom in Idaho was in drainage districts (Partridge 1983). Topographic map comparison shows that an estimated 5,5 12 acres of wetland area was lost between 1928 and 1965.

The construction of Libby Dam, on the Kootenai River began in 1966, and Lake Koocanusa was officially impounded on March 21, 1972 (Woods 1982), approximately 27 kilometers (km) upstream from Libby, MT. The construction was authorized by the Columbia River International Treaty of 1964 and was an agreement between the United States and Canada to cooperatively develop the water resources of the Columbia River drainage basin (Knudson 1994). The dam was constructed in order to create a reservoir that would provide flood storage, hydroelectric power production, and recreation benefits (Woods 1982).

Downstream from Libby Dam the Kootenai River flows through a single channel into Idaho winding through a narrow steep-sided canyon; in this section, Kootenai Falls is thought to be an upstream migration barrier for white sturgeon. Further downstream, the river widens into a braided channel and gravel bar reach, then meanders northward through the Purcell Trench emptying into Kootenay Lake. This meandering section is characterized by very low gradient

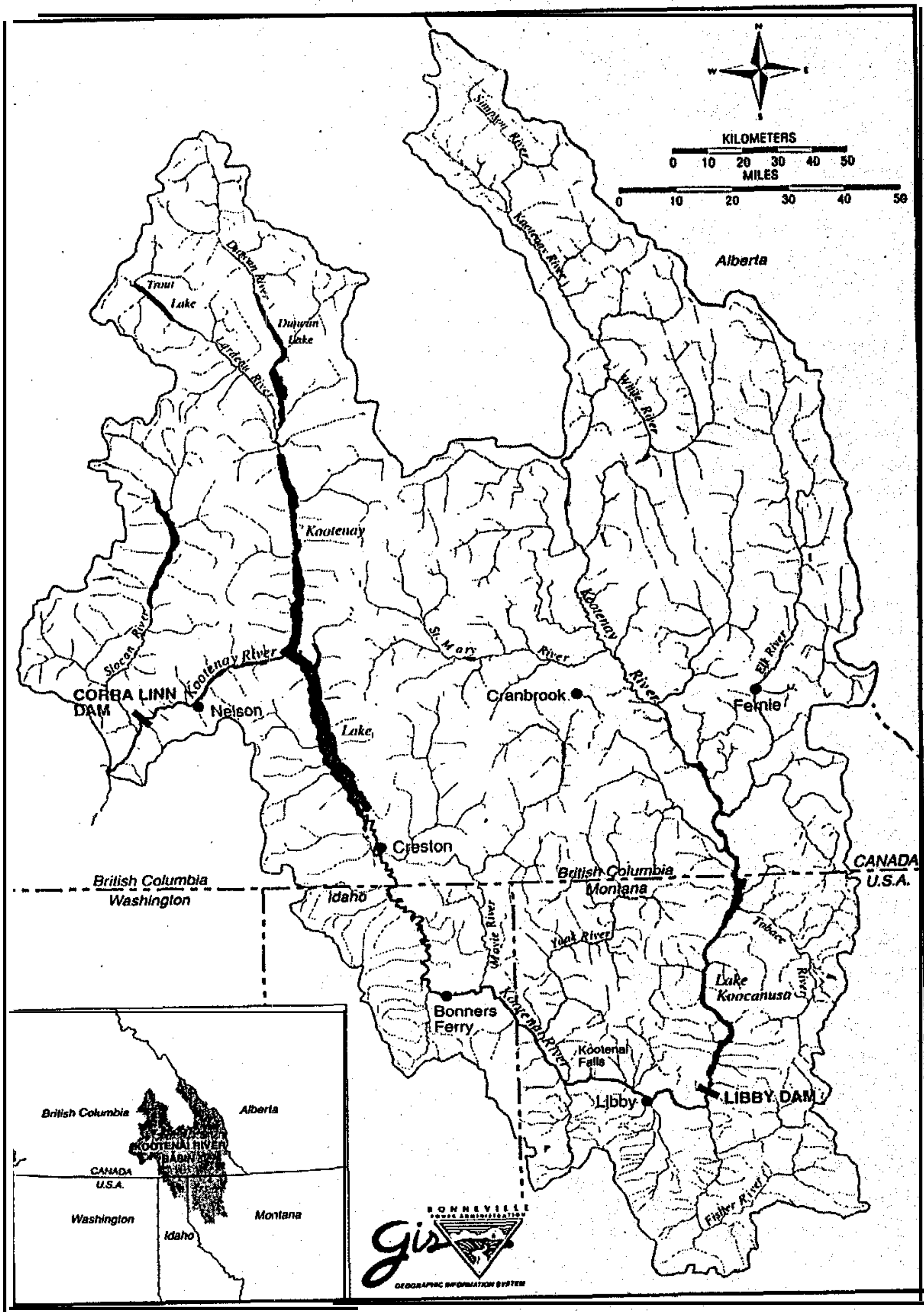

Figure 1. Map of the Kootenai River drainage basin.

and water velocity, with water depths of up to 12 meters (m) deep in runs and up to 30 m in pools (Snyder and Minshalll994).

Industrial aud Municipal Operations Within the Kootenai River Basin

Industrial

The two largest industrial operations and point source discharges to the Kootenai **River** are the Crestbrook Forest Industries' pulp mill in Skookumchuck, B.C. and the Cominco mining, milling, and fertilizer plant in Kimberley, B.C. (Figure 2) **(Daley** et al. 1981). Since **1968,** Crestbrook Forest Industries' **kraft-type** pulp mill in Skookumchuck has been the largest point source discharge directly into the Kootenai **River**. During the **1970's** angler use of the river below Skookumchuck decreased due to the adverse **effects** caused by the mill (discoloration of the river, toxicity, and fish tainting problems). Attempts to reduce pollution at the mill began in 198 1 when Crestbrook began disposing of its **effluent** during low flow periods. In 1992, a major upgradmg of the mill began in order to reduce polluted **effluent** discharging into the river (Knudson 1994).

The Cominco plant expanded from a lead smelter to the production of fertilizer in 1953 (Partridge **1983),** and began discharging wastes into the St. Mary **River,** a tributary of the Kootenai River. Fertilizer production was doubled in **1962** and **increased** again in **1965**. Water **pollution** control at the plant was improved in 1969, but it was not **operating** optimally until 1975 **(Daley** et al. 1981). Waste discharges **from** this plant increased phosphorus load throughout the Kootenai system, resulting in a four-fold increase **from** 195 1 to the 1960's **(Northcote** 1973). By 1965, new production created more waste than the plant's disposal **facilities** could properly dispose of, and high levels of zinc, fluoride, ammonia, and phosphate combined to create toxic conditions for aquatic organisms in the St. Mary River. In **1968,** a waste **disposal** system was installed at the plant, which reduced the levels of toxic compounds being discharged into the Kootenai River (Partridge 1983). Fertilizer productions decreased in the 1970's and 1980's until the plant closed in 1987 (Knudson 1994).

Cominco also operates the Sullivan Mine in Kimberley, one of the world's largest lead and zinc mining facilities (Woods and Falter 1982). This mine has been in production since 1900. As of 1973, total production of zinc, lead and silver was **increased** to a **combined** 10,000 tons per day **(Rocchini** et al. 1976 B). Wastewater from the mine was discharged into tributaries of the St. Mary River, and ultimately ended up in the Kootenai **River.** By 1979, wastewater treatment facilities were completed at Cominco, which removed heavy metals **from** the effluent before it entered the waterways (Knudson 1994).

Another industrial operation taking place in the basin is the mining and processing of vermiculite by the **W.R.** Grace Company. The mining takes place in Vermiculite Mountain, northeast of Libby, MT on Rainy Creek. The drainage **from** the tailings of the process caused water quality problems in **Rainy** Creek and the Kootenai **River until** 1971 when the facility constructed a closed-circuit m-circulation system **(Bonde** and Bush 1975).

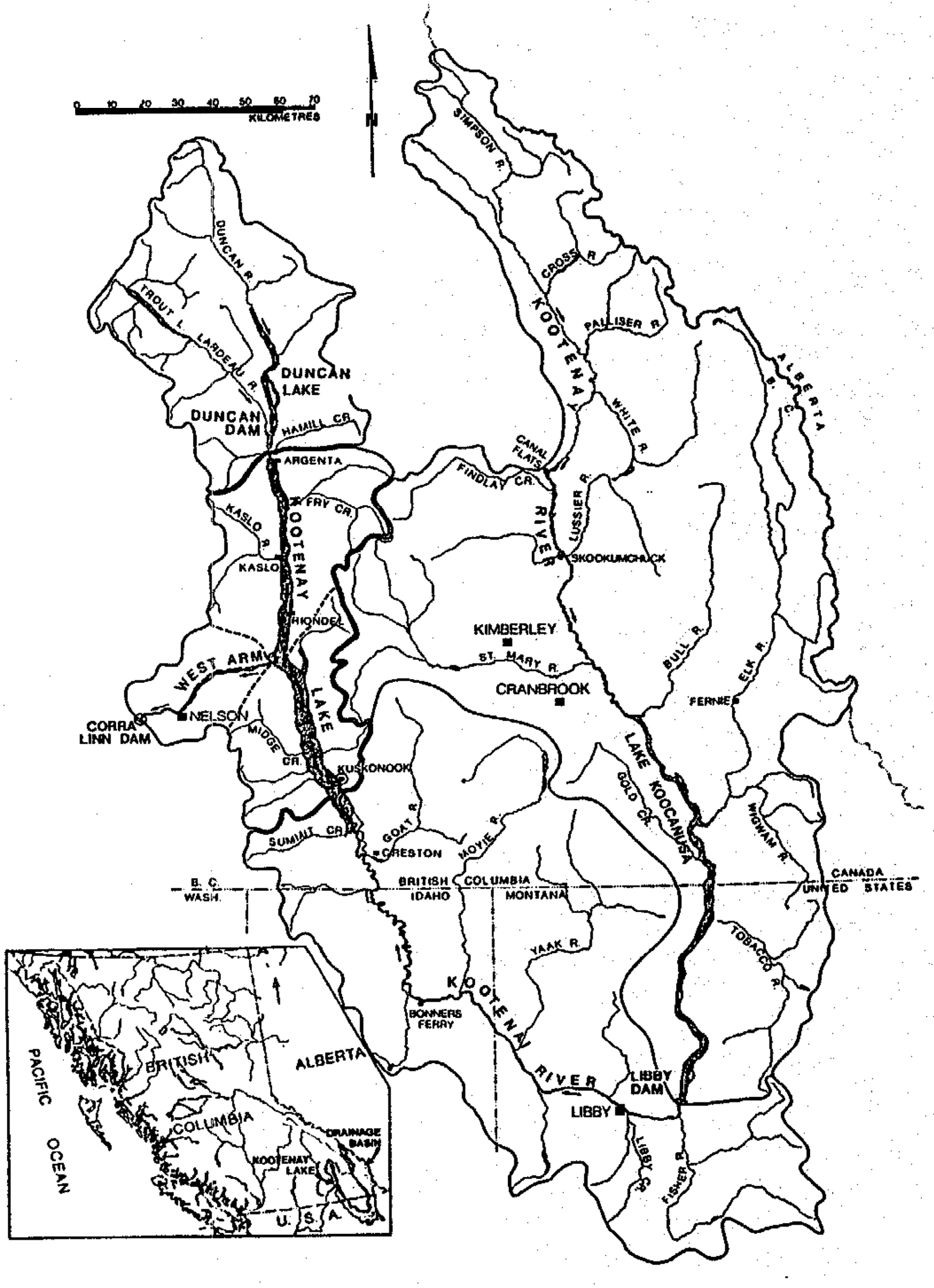

Figure 2. Map of the Kootenai River drainage basin, including major cities **and** rivers. *(Daley et al. 1981)*

Coal and hard rock mining are also prominent activities in the basin, particularly along the Elk and St. Mary Rivers (Figure 2), and in the northern Cabinet Mountains (Knudson 1994). Large-scale surface coal mining began in the Elk River Basin in the late 1960's. The most prominent water quality problem attributed to coal mining, is increased suspended sediment. In the mid-1970's, pollution abatement practices were implemented, reducing suspended sediment in receiving waters (Knudson 1994).

Agricultural development in the basin is limited. The largest block of agricultural land lies within the Purcell Trench, which extends from Bonners Ferry, ID to the river's entry into Kootenay Lake. Runoff from livestock feedlots, croplands, orchards, and heavily grazed pastures, along with grazing within riparian areas, all contribute to water quality degradation (Knudson 1994). Timber harvest and associated road building, along with the construction of highways and railroads within the Kootenai River Basin, have also had deleterious effects on the Kootenai River.

Municipal

Major municipalities in the Kootenai River Basin served by secondary waste treatment facilities include: Cranbrook, Kimberly, Fernie, Creston, Sparwood, and Elkford, B.C.; Libby, MT; Bonners Ferry, ID; and Troy and Eureka, MT (Figure 2) (Knudson 1994, Woods and Falter 1982, Bonde and Bush 1975). The rest of the populations in the basin use septic tanks or smaller community systems. All municipalities in the drainage basin discharge effluent directly into the Kootenai River, or into the water table by subsurface seepage, therefore degrading water quality. In 1976, Cranbrook ceased sewage discharge by employing a spray irrigation system. Water quality effects downstream from Libby, Bonners Ferry, and Troy are not as great as the effects from cities on smaller scale tributaries, due to the high volume of water, therefore greater dilution of the Kootenai River.

All industrial and municipal operations in the Kootenai River Basin have an effect on the water quality of the Kootenai River. In turn, the degradation of water quality in the river affects the entire aquatic ecosystem.

Purpose of Report

The quality of the Kootenai River aquatic ecosystem has been substantially degraded during the past 50 years. The Kootenai River, like other river-floodplain ecosystems, was historically characterized by seasonal floods that promoted the exchange of nutrients and organisms among a mosaic of habitats, and thus enhanced biological productivity (Junk et al. 1989, Bayley 1995, Sparks 1995). Before the construction of Libby Dam, the Kootenai River was characterized by a four to six kilometer wide flood-plain in the furthest downstream 128 km of the river. Diking of this stretch of river, from the 1920's to the 1950's, eliminated approximately 50,000 acres of natural floodplain in Idaho alone. Estimated flood-plain loss in British Columbia may be equal or greater.

Another factor contributing to this ecosystem collapse is the subsequent change in the natural hydrograph of the Koctenai River since Libby Dam began operating in 1972. The Kootenai River hydrograph has been very unstable and virtually reversed from pre-dam conditions, with discharges below historic levels taking place in the spring, and increased discharges occurring throughout the winter months. Low nutrient concentrations also appear responsible for declines in population densities of aquatic biota downstream from' Libby Dam. Lake Koocanusa is acting as a nutrient sink, Woods (1982) reported that 63 percent of total phosphorus (TP) and 25 percent of total nitrogen (TN) in the Kootenai River system never pass through Libby Dam to provide biological benefit downstream.

In the past, biological data have been collected, often intermittently from the Kootenai River, to address the status of specific species in certain trophic levels. However, no study to date has simultaneously and comprehensively collected and compiled data necessary to complete a suitable status review for aquatic organisms in all trophic levels. Completion of such a comprehensive inventory is essential to the restoration of the Kootenai River ecosystem.

The purpose of this report is to establish baseline status of aquatic biota in the Kootenai River system. This report is a product of literature review and synthesis of published and unpublished fisheries and aquatic biological data from the entire system (Idaho, Montana, and British Columbia). Upon completion, it will be determined which species of fish and lower trophic level organisms, if any, may need further investigation. Information contained within this document will eliminate unnecessary research duplication in the future.

This report begins with an overview of aquatic ecosystem conditions before and after the completion of Libby Dam. All trophic levels are discussed, with organisms of interest being periphyton, phytoplankton, zooplankton, aquatic macroinvertebrates, and fish. The current status of the Kootenai River ecosystem is also described, and areas that lack sufficient data are identified. Finally, specific recommendations are made concerning research and improvement measures needed for restoration of the Kootenai River aquatic ecosystem.

PRE AND POST LIBBY DAM CONDITIONS

River Flows and Temperature

The impaundment of the Kootenai River by Libby Dam, and the resulting discharge, patterns created by providing hydroelectric power during peak demand periods, has altered seasonal and daily flow patterns in the river. Since impoundment, water has been retained during historical periods of high discharge and released from Lake Koocanusa during historically low flow periods (Partridge 1983). Prior to impoundment, high flows increased in April, peaked in June, and then decreased in July and August. Following the completion of Libby Dam, spring flows are much reduced, and two peaks of equal magnitude are evident from April to July and October to February (Figure 3).

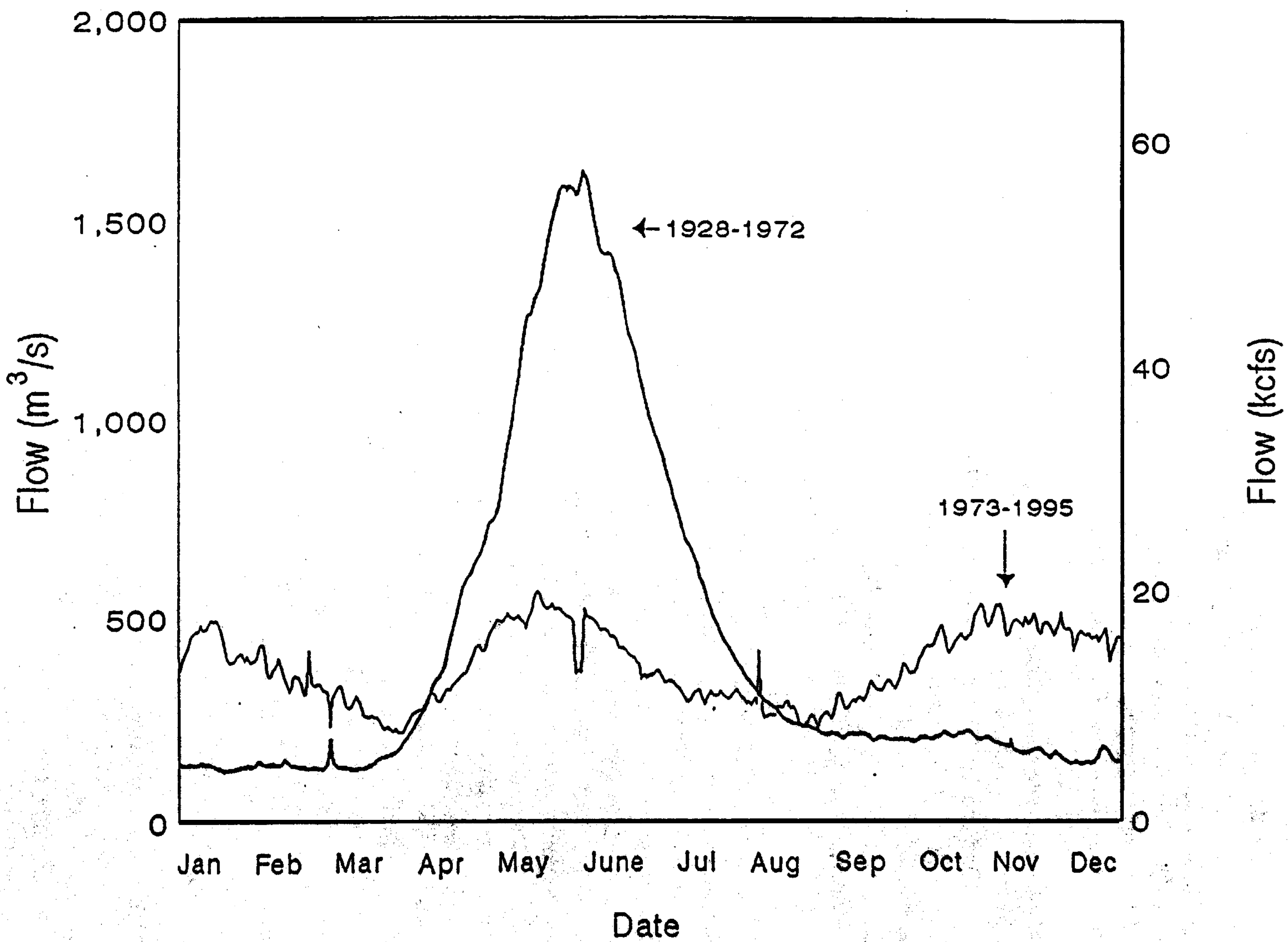

Figure 3. Mean monthly Kootenai River flows at Bonners Ferry, ID from 1928-1972 (pre-Libby Dam) and 1973-1995 (post-Libby Dam).

Prior to dam installation, flows in the river peaked at about 60,000 cubic feet per second (cfs) during April, May, and June. During July, the flows gradually declinedto less than 8,000 cfs (Figure 3). Historical mean annual flow was 12,170 cfs with a maximum recorded flow of 121,000 cfs in June of 1916 (May and Huston 1983). Post-dam flows were generally in the 8,828 to 15,890 cfs range (Apperson and Anders 1991) with a maximum of 49,000 cfs on June 5, 1996 (Pat McGrane, U.S. Army Corps of Engineers, personal communication).

In addition to the hydrograph alteration, natural thermal regimes also changed in the river since construction of the dam in the early 1970's and the selective withdrawal system in 1977. Between 1967 and 1972, average water temperatures in the Kootenai River were at or slightly above 0" C (32° F) from December through February, peaked in late July and early August, and declined rapidly in the fall, Prior to dam installation, water temperatures were above 10" C (50° F) for about four months, with peak temperatures reaching 20° C (68° F). Summer temperatures in the Kootenai River between 1972 and 1977 were also low because prior to the selective withdrawal system water was withdrawn from the hypolimnion (Snyder and Minshall 1994).

The selective withdrawal system was designed to produce downstream flows that comply with a temperature-rule curve established by the U.S. Army Corps of Engineers (USACE), in cooperation with the Montana Department of Fish, Wildlife, and Parks (MDFWP), Idaho Department of Fish and Game (IDFG), and the B.C. Fish and Wildlife Branch. The objective of the selective withdrawal system was to produce water temperature regimes in the river that closely resembled pre-dam conditions and to reduce the number of fish bemg drawn through the power generating turbines (Snyder and Minshall 1994). The plan increased the number of days above 0° C by approximately 30 percent (May and Huston 1979). This increase in river temperature is most evident from November through March, when average monthly river temperatures have increased by 3° C. This temperature increase, along with increased flows in the winter, caused the river to remain ice free, whereas it froze over before the construction of the dam. Since installation of the selective withdrawal system, annual water temperature patterns, have been on the average, 17 percent warmer than during pre-dam years (Bonde 1987).

Nutrients

Kootenay Lake

In 1953, when Cominco Ltd. began operating a large phosphate fertilizer plant on the St. Mary River near Kimberley, B.C., kokanee size in the West Arm of Kootenay Lake increased significantly (Ashley and Thompson 1993). Cominco tripled its fertilizer production by late 1964, with peak annual losses of phosphate exceeding 8,000 metric tons in the mid to late 1960's (Ashley and Thompson 1993). Although there was a dramatic increase in phosphorus levels, nitrogen load to Kootenay Lake was not markedly different during this period (Daley and Pick 1990). Diking of the Kootenai River, Libby Dam operation, and the reduction and eventual closure of Cominco's fertilizer plant on the St. Mary River in 1972, have collectively resulted in reduced Kootenay Lake phosphorus load to below historical levels. This reduction in nutrient load was followed by declines in phytoplankton and zooplankton biomass and kokanee numbers.

In **response** to decreased phosphorus load and the collapse of **kokanee** populations in Kootenay Lake, a computer simulation model was developed to predict responses of Kootenay Lake plankton and fish to restoration of **higher** nutrient load. **Although** the model predicted potential negative results of **fertilization,** it was also predicted that **kokanee stocks** would collapse if nothing was done. Therefore, it was decided to begin **fertilizing the North Arm of Kootenay** Lake in April of 1992 (Ashley and Thompson 1993).

In 1992 and 1993, the soluble reactive phosphorus (SRP) concentration was below low level detection limits **(<1 µg/L)** on most occasions in Kootenay Lake (Ashley an&Thompson 1993 and 1994). Inorganic phosphorus is readily used by plankton and bacteria, therefore the low SRP concentration characterized a nutrient limited lake **(Wetzel 1975)**. A decrease **in potential** primary production would also be **inferred** as a result of the low SRP concentrations seen in the lake (Jones and **Bachman** 1976). Total phosphorus **(TP)** concentrations in **the North Arm of** Kootenay Lake ranged **from** 5 to 10 **µg/L** in 1992 and 1993, which **indicated** an **oligotrophic to** mesotrophic classification **(Wetzel 1983).** In most lakes and reservoirs, trophic status is controlled by the ecosystem's nutrient content (Hamilton **et al.** 1990). An **oligotrophic ecosystem** is characterized by a low nutrient content, which results in low algal, **zooplankton, and fish** productivity, and usually high water clarity. In eutrophic lakes, nutrient content is high, algal growth is abundant, and severe algal blooms **frequently** occur. Mesotrophy is a trophic category intermediate between oligotrophy and eutrophy. Daley et. al **(1981) estimated** that phosphorus delivery rates to Kootenay Lake during the spring and **summer growing season have** been reduced by about 50 percent because of the presence of Libby Dam and its **reservoir** (Lake **Koocanusa).** Throughout 1992 and 1993, dissolved inorganic nitrogen and **Kjeldahl** nitrogen concentrations remained in the oligotrophic range; **<200 µg/L** (Wetzel 1983).

The ratio of total inorganic nitrogen to total dissolved phosphorus **(N:P)** can be used to determine the relative potential for phytoplanlcton growth **Generally,** nitrogen is potentially limiting **if the** ratio is less than 2, and phosphorus becomes a potentially limiting **factor** at a ratio greater **than** 20. Nitrogen and phosphorus are considered **co-limiting** at **ratios** between 2 and 20 (Morris and Lewis 1988). The N:P ratio of the nutrient load to Kootenay Lake has declined drastically (approximately 95%) since 1949. The ratio declined **from an estimated 14:1** in 1949, to about 0.8: 1 between 1966 and 1969, and then increased to **19:1** by 1977 **(Daley** et al. 1981). This fluctuation in nutrient ratio corresponds temporally with the operations of the **Cominco fertilizer** plant in Kimberley, B.C. during this time period. The idea **is to gradually** increase the nitrogen loading and N:P ratio throughout the fertilizer application **period.** This is supported by the observations of seasonal decline in dissolved inorganic nitrogen due to biological uptake (Ashley and Thompson 1993).

The Kootenai **River** supplied 75 and 55 percent of the **measured TP** input to Kootenay Lake in 1976 and 1977 (Daley et al. 1981). The limnology of the Kootenai Rive&s a **profound** effect on the down&ream aquatic ecosystem of Kootenay Lake, as seen by the relation **between nutrient** fluctuations in the lake and industrial operations in the Kootenai **River** drainage **basin.**

Kootenai River

During the past 30 years, the Kootenai River system has regressed from having an excess of nutrients to a system that has become nutrient depraved (Northcote 1973, Daley et al. 1981). In pre-impoundment years, water quality studies indicated the presence of high concentrations of TP, orthophosphorus, and total nitrogen (TN) in the Kootenai River, which were attributed to industrial point source discharges in the Canadian part of the drainage basin (Bonde and Bush 1975). Fisherman reported that in the 1950's there was a decline in the waterquality of the river, resulting in increased algal growth and sedimentation. These effects were attributed to the point sources of pollution in the basin, namely the fertilizer plant and mining operations (May and Huston 1983). Whitfield and Woods (1984) also reported that the majority of monthly 'post-impoundment concentrations of silicate, nitrate plus nitrite, and orthophosphorus were lower than pre-impoundment months (Figures 4, 5 and 6).

As a result of pollution control measures in the basin, and the impoundment of Lake Koocanusa, nutrient concentrations in the river downstream from Libby Dam have declined. Dissolved orthophosphate concentrations averaged 0.383 mg/L in 1970 as compared to 0.039 mg/L in 1979 (Figure 7) (May and Huston 1983). Total phosphorus concentrations showed a similar trend (Figure 8). There was a noticeable decrease in TP load from Lake Koocanusa in post-impoundment years, whereas TN load fluctuated with no apparent trend (Table 1). Hamilton' et al. (1990), reported TP and SRP concentrations below 0.05 mg/L between 1976 and 1989, and nitrogen concentrations below 0.50 mg/L between 1974 and 1988 in the river. Annual TN and TP load during 1971 at a point 6 km downstream of Libby Dam were 4,057 and 1,924 metric tons, respectively (Bonde and Bush 1975). Annual TN and TP load to the Kootenai River immediately downstream from Libby Dam during the period of 1972 to 1975 ranged from 1,736 to 3,5 12 metric tons of nitrogen and 320 to 913 metric tons of phosphorus. Total nitrogen, and TP concentrations have decreased by half since the construction and operation of Libby Dam in 1972.

United States Geological Survey (USGS) records indicated that from 1972 to 1990, orthophosphorus and TP concentrations increased downstream from Libby Dam to Porthill, ID. Although nitrate plus nitrite concentrations showed an overall irregular pattern between 1972 to 1990, the availability of nitrate and ammonia decreased in a downstream direction in 1993 (Snyder and Minshall 1994). In 1994, Snyder and Minshall reported TP concentrations ranging from less than 0.005 mg/L to 0.02 mg/L and orthophosphate concentrations from less than 0.005 mg/L to 0.013 mg/L in the Kootenai River from Libby Dam to Copeland, ID. According to Wetzel (1983), an oligotrophic lake contains approximately 0.05 mg/L of TP. The TP concentration detected in the Kootenai River is much less than this value, which would be considered extremely nutrient deficient or hyper-oligotrophic. Inorganic nitrogen (NO_3 + NO_2 and NH_4) values ranged from less than 0.01 mg/L to 0.14 mg/L, while total Kjeldahl nitrogen, (TKN) ranged from less than 0. 1 mg/L to 0.5 mg/L.

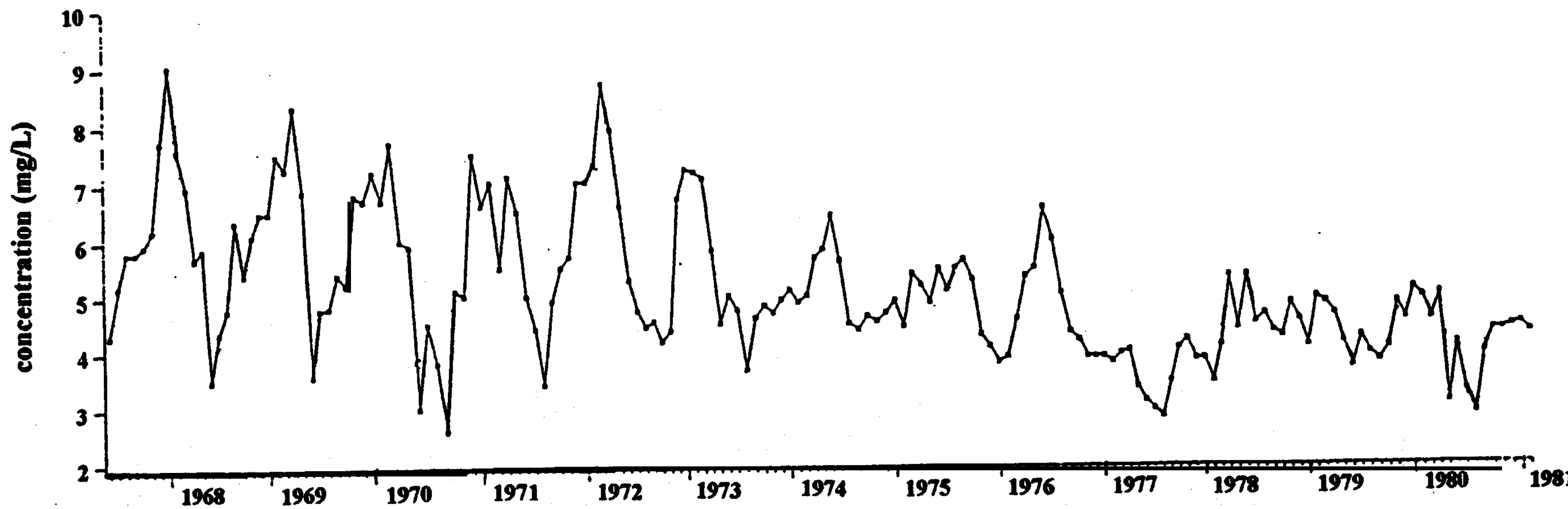

Figure 4. Monthly silicate concentrations from the Kootenai River downstream from Libby Dam. The pre-impoundment period is indicated by the heavy base line. (*Whitfield and Woods 1984)*

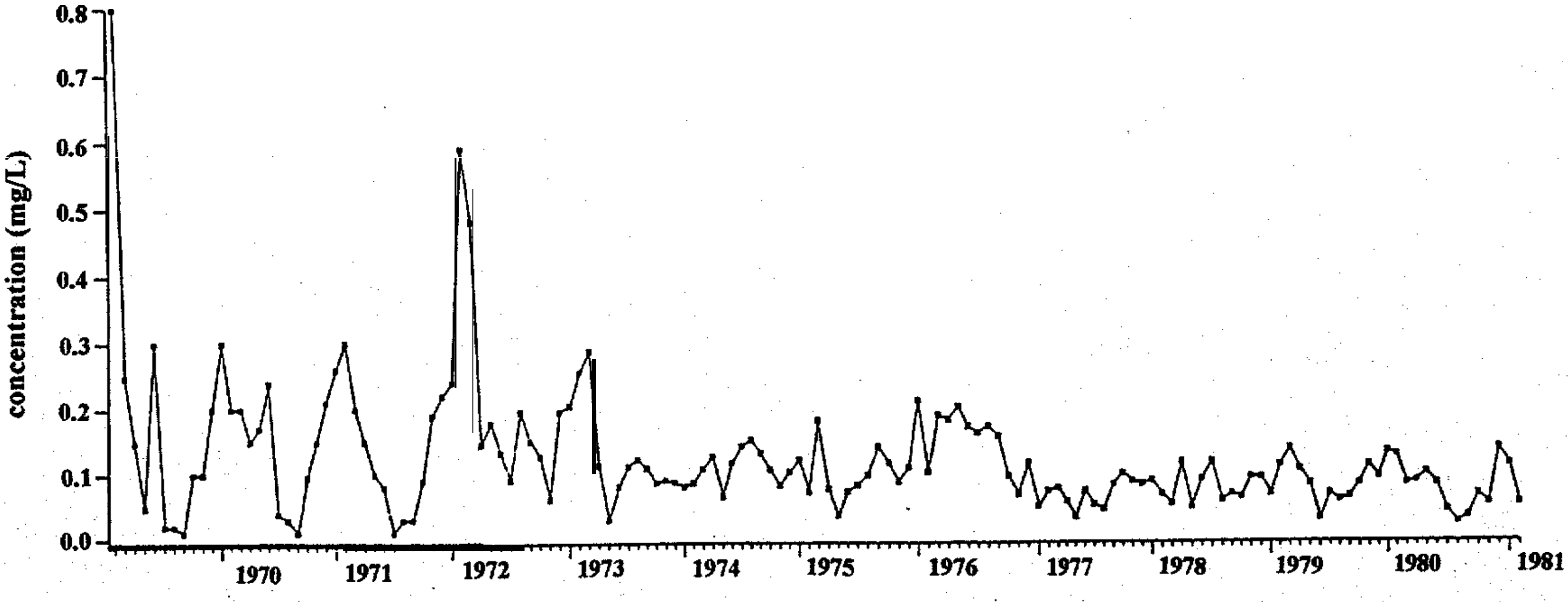

Figure 5. Monthly nitrate plus nitrite concentrations from the Kootenai River downstream from Libby Dam. The pre-impoundment period is indicated by the heavy base line. (*Whitfield and Woods 1984)*

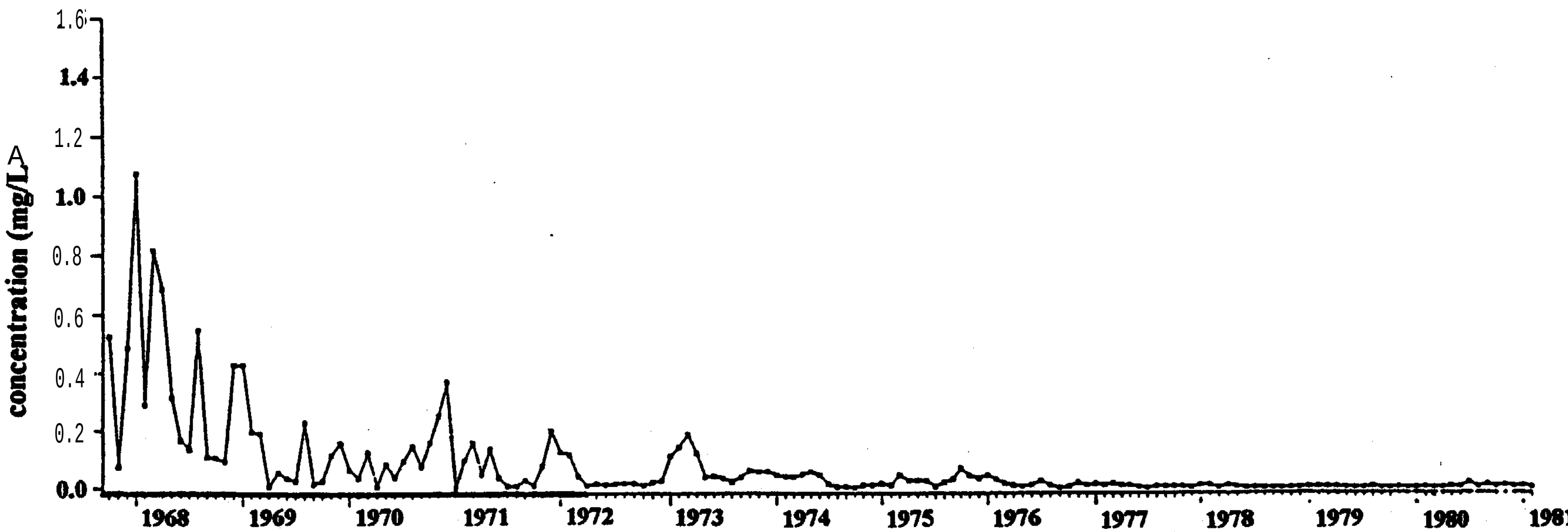

Figure 6. **Monthly** orthophosphorus concentrations **from** the Kootenai River downstream **from** Libby Dam. The pre-impoundment period is indicated by the heavy base line. (***Whitfield and*** *Woods 1984)*

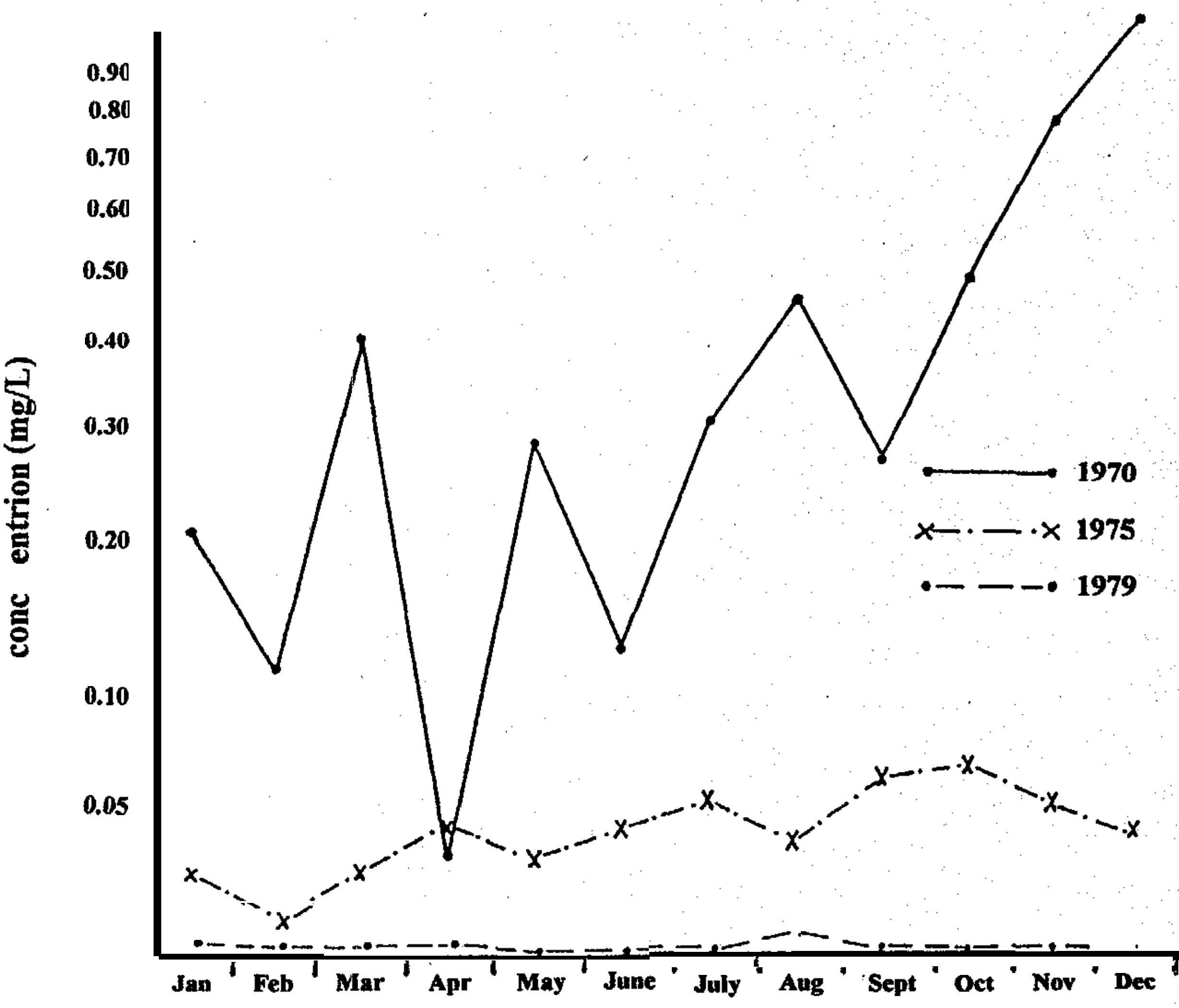

Figure 7. Total dissolved orthophosphate measured downstream from Libby Dam, prior to impoundment (1970), following impoundment (1975), and following operation of the selective withdrawal system (1979). (*May and Huston 1983*)

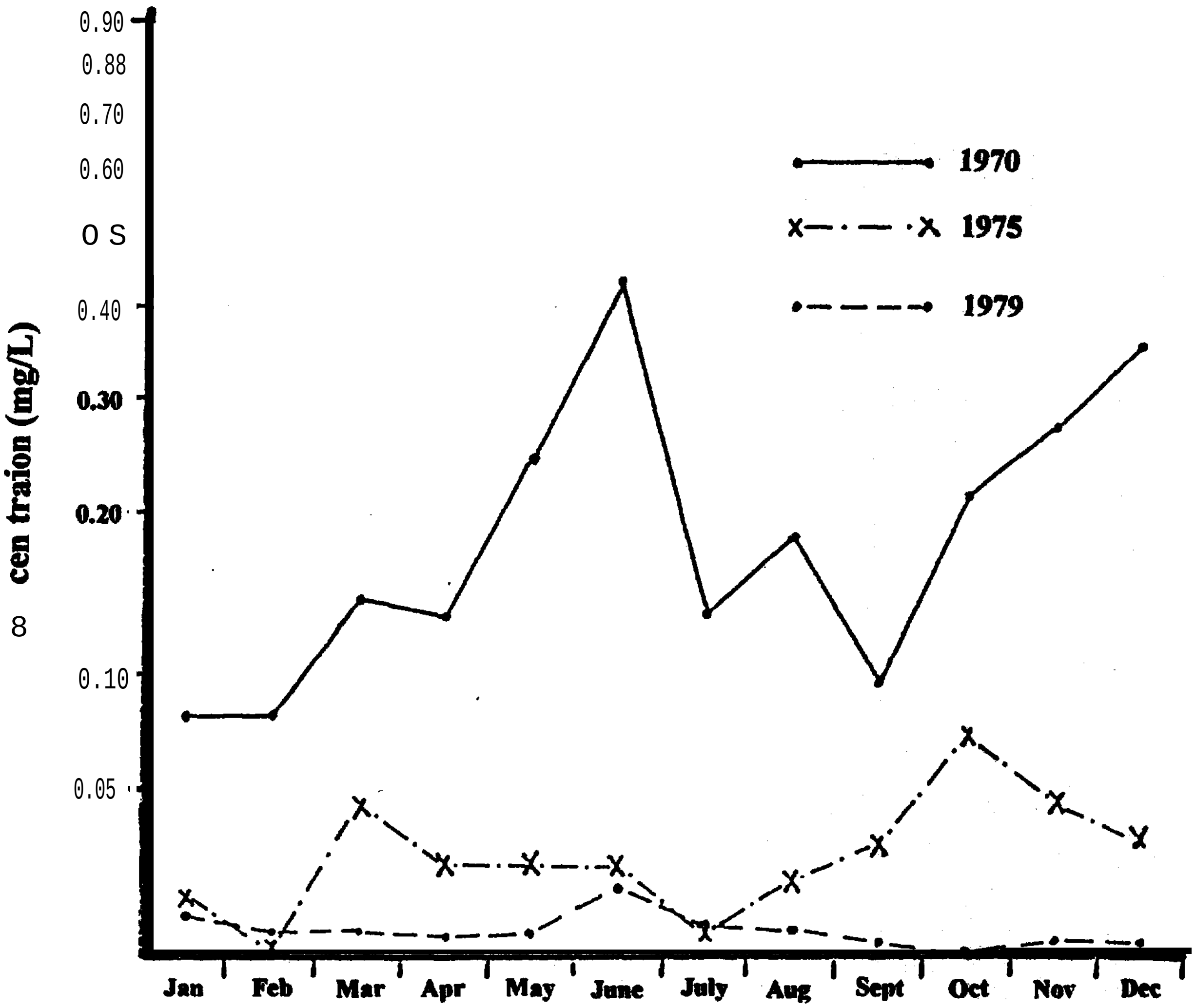

Figure 8. Total phosphorus measured downstream from Libby Dam, prior to impoundment (1970), following impoundment (1975), and following operation of the selective withdrawal system (1979). *(May and Huston 1983)*

Table 1. Annual total phosphorus (TP) and tot&nitrogen (TN) load discharged from Lake Koocanusa, 1970-80.

	Load (megagrams)		Load rate (megagrams per cubic kilometer of stream flow)	
	TP	TN	TP	TN
1970	1,905	2,825	255.1	378.3
1971	1,924	4,057	162.1	341.8
1972	997	4,004	78.5	315.1'
1973	554	1,702	98.5	302.5
1974	706	3,378	53.2	254.8
1975	326	1,876	35.9	206.3
1976	359	2,529	30.8	216.5
1977	125	2,359	15.9	299.4
1978	82	2,229	9.0	246.7
1979	45	2,201	6.1	295.3
1980	50	1,626	5.9	191.5

Woods 1982

Nutrient limitation occurs when concentrations are too low to meet biological demand. Snyder and Minshall (1994) determined that in the three river reaches they studied (Figure 9), phosphorus was the nutrient limiting algal growth, and nitrogen was potentially co-limiting in the meander 2 reach. Historical USGS nutrient monitoring, along with samples collected by Snyder and Minshall in May, July, August, and October 1994 also concur with the results they obtained in 1993 (Snyder and Minshall 1994).

Lake Koocanusa

The source of much of the phosphorus load to Lake Koocanusa was the fertilizer plant near Kimberley, B.C. (Bonde and Bush 1975). Daley et al. (1981) cited this plant as a major source of orthophosphate, and to a lesser degree, ammonia nitrogen that has entered Kootenay Lake, 230 km downstream from Libby Dam. A model developed by Vollenweider (1968 and 1976), which used areal nutrient load, mean depth, and hydraulic-residence time to estimate a water body's susceptibility to eutrophication was applied to Lake Koocanusa. It was determined that an annual areal load of 2.0 g/m^2 of TP and 8.0 g/m^2 of TN, which were substantially less than the predicted areal nutrient load, would be sufficient to cause concern for eutrophication of the reservoir (Woods 1982). The trophic state of Lake Koocanusa was categorized as eutrophic when based on the relationship of the nutrient load and-the-reservoir's ratio of mean depth to hydraulic-residence time. This prediction conflicted with the oligotrophic ranking the reservoir received based on its areal primary productivity. Pre-impoundment water quality studies showed that the areal load of TP and TN to the lake were 10 g/m^2 and 20 g/m^2 (Woods 1982).

Water pollution control at the fertilizer plant was not fully operational until 1975. The effects of the control measures are evident in the history of TP load to Lake Koocanusa (Table 2). Concentrations before 1975 were 0.026 mg/L higher than after 1976. Soluble reactive phosphorus concentrations showed a similar decreasing trend from 1973 to 1989 (Hamilton et al. 1990). On the other hand, the pollution control measures seemed to have had little effect on the TN load to the lake (Table 3).

In Lake Koocanusa, TP and TN load were both large enough to produce a eutrophic ranking (Bonde and Bush 1975). Iskandar and Shulcla (1981) concluded that Lake Koocanusa sediients function as a phosphorus sink because the sediments had limited abii to adsorb additional phosphorus and the sediments desorbed only small amounts of phosphorus. Results of previous studies demonstrated that Lake Koocanusa retained approximately 63 percent of its influent TP and 25 percent of its total influent TN and has a sediment trapping efficiency which exceeds 95 percent.

Between 1972 and 1988, controversial TN:TP ratios existed for Lake Koocanusa. The discrepancy was in TN values, with USGS measurements generally being greater than those obtained by B.C. Ministry of Environment. Accounting for these numerical differences still inferred phosphorus limitation in the lower reservoir, whereas evidence for phosphorus limitation was less conclusive at the upstream International Border site (Hamilton et al. 1990).

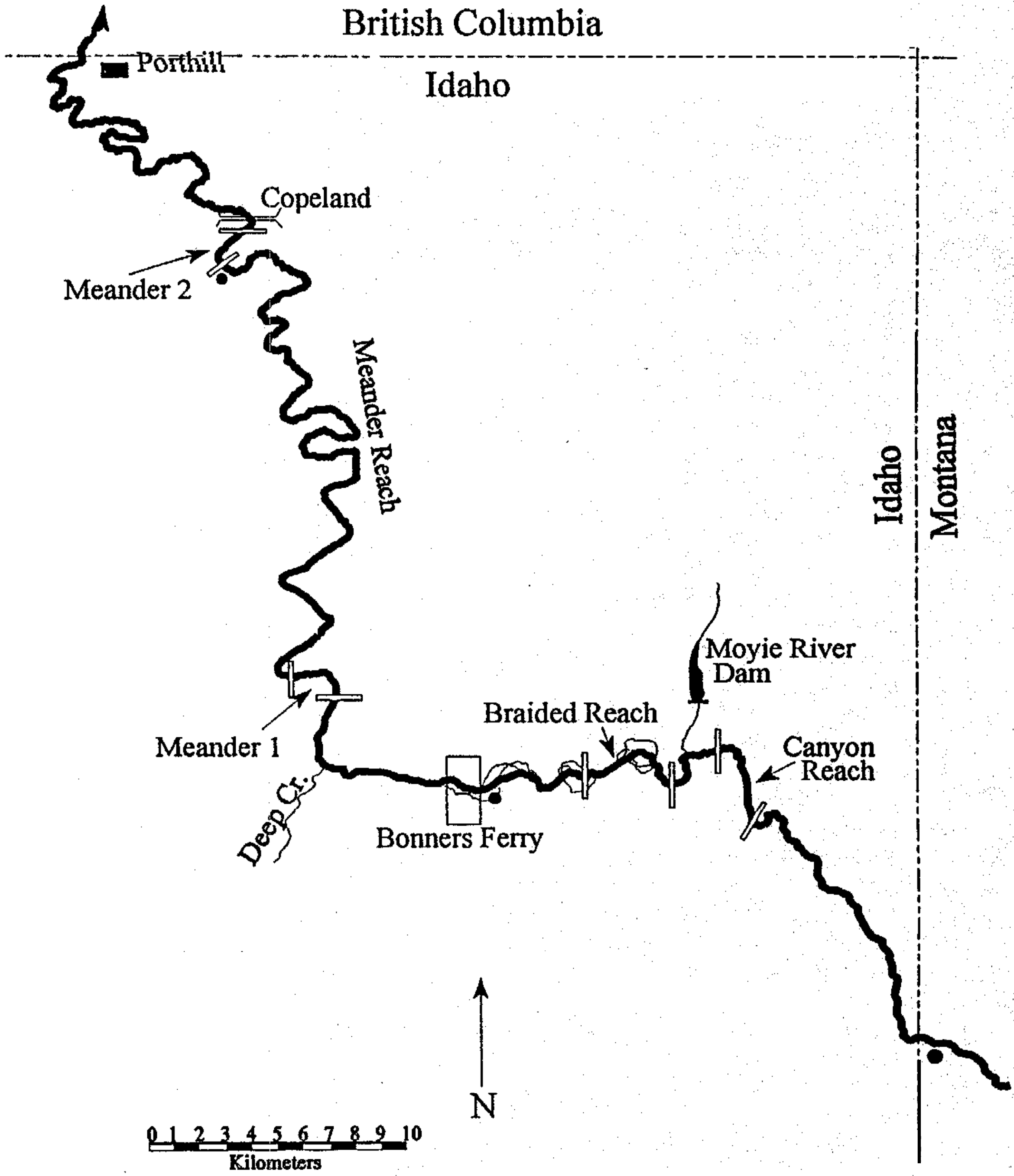

Figure 9. Location of different river reach types along the Kootenai River in Idaho. *(Snyder and Minshall 1994)*

Table 2. Aunual total phosphorus load that entered Lake **Koocanusa,** 1970-80.

	Load (megagrams)			
Year	Total	Gauged inflow	Atmospheric	Load rate, in **megagrams** per **cubic kilometer of stream flow**
1970	1,905	1,905		255.1
1971	1,924	1,924		162.1
1972	1,188	1,011	2.0	92.2
1973	1,626	1,449	2.1	194.1
1974	1,485	1,307	3.4	106.8
1975	1,304	1,126	3.4	129.2
1976	514	336	3.7	44.0
1977	362	184	3.4	58.3
1978	498	320	3.7	49.0
1979	416	238	3.8	59.8
1980	428	250	4.0	45.2

Woods 1982

Table 3. Annual total nitrogen load that entered Lake Koocanusa, 1970-80.

Year	Load (megagrams) Total	Gauged inflow	Atmospheric	Load rate, in megagrams per cubic kilometer of stream flow
1970	2,825	2,825	--	378.3
1971	4,057	4,057		341.8
1972	4,679	3,042	7.5	363.5
1973	3,228	1,590	7.8	385.3
1974	4,051	2,409	12.4	291.3
1975	2,798	1,156	12.3	277.2
1976	3,089	1,445	13.5	264.4
1977	2,451	809	12.6	395.0
1978	2,891	1,248	13.4	284.4
1979	2,707	1,063	14.0	389.5
1980	3,258	1,613	14.6	343.6

Woods 1982

Primary productivity

Kootenay Lake

Before and during the period of declining nutrient load to Kootenay Lake, Duncan and Libby dams were constructed. Their principal effect has been the reduction in supply of nutrients to Kootenay Lake, which in turn lowered primary production in the lake. Primary productivity refers to the growth of suspended algae (phytoplankton) and attached algae (periphyton), which are the principal food of small, lake-dwelling crustaceans (zooplankton). Zooplankton, in turn, are the major food source for fish such as the declining kokanee, which will be discussed in a later section. It has been shown that low primary productivity limits the production of higher trophic levels (Fretwell 1987, Randall et al. 1986), such as fish. "Phytoplankton form the base of the food chain in the lake; hence any physical or chemical changes affecting primary production, if severe enough, will affect the zooplankton and eventually the fishery of the lake." (Daley et al. 1981).

Between 1950 and 1970, phytoplankton and zooplankton levels in Kootenay Lake increased two to four-fold, and blue-green algae increased to nuisance proportions due to increased nutrient supply caused by historical industrial operations. With reduction of nutrients during the 1970's, following impoundment and pollution abatement in the basin, levels of phytoplankton and zooplankton declined, and blooms of blue-green algae diminished in magnitude (Daley et al. 1981).

Nitrogen and phosphorus play key roles in primary production, and largely control periphyton and phytoplankton growth in lotic and lentic systems. The calculated TP load associated with nuisance levels of phytoplankton in lakes similar to Kootenay Lake is 1.4 $g/m^2/yr$ (Vollenweider 1976). The TP load to Kootenay Lake in both 1976 and 1977 (1.2 and 0.74 $g/m^2/yr$) was less than this level (Daley et al. 1981).

Algal biomass can be used as an indicator of primary productivity. Phytoplankton biomass increased between 1950 and the mid 1960's in Kootenay Lake. Larkin (195 1) referred to Kootenay Lake as oligotrophic in the early 1950's. In contrast, by the early 1960's, the lake was experiencing sporadic blue-green algae blooms, increased macrophytic growth, and orthophosphate concentrations and load had risen substantially (Northcote 1973). These marked increases were due to industrial operations in the Kootenai River drainage basin. Between 1966 and 1977, after construction and operation of the dams and implementation of pollution abatement measures in the basin, average lake surface algae counts showed a four-fold decrease in diatoms and a two-fold decrease in blue-green algae (Daley et al. 1981). Average algal biomass in Kootenay Lake as a whole was higher in 1993 than in 1992 (Ashley and Thompson 1994), and has continued to increase since the beginning of the artificial fertilization program (Ashley and Thompson 1996).

Another method of determining the primary productivity of a system is to measure the chlorophyll *a* levels. "Chlorophyll *a* is the primary photosynthetic pigment of all oxygen-evolving photosynthetic organisms, and is present in all algae" (Wetzel 1983). Kootenay Lake exhibited decreasing chlorophyll *a* concentrations (primary productivity) from 1966 to 1978 (Table 4),

Table 4. Average annual chlorophyll *a* values in Kootenay Lake from 1966 to 1978 (mg/m^3 ± I.S.D.).

Year	south Arm	Mid-lake
1966-68	3.9 ± 0.3	2.9 ± 0.7
1972-74	2.6 ± 0.7	2.3 ± 0.0
1976-78	1.7 ± 0.3	2.0 ± 0.2

Daley et al. 1981

which were typical of a mesotrophic lake. Mesotrophic lakes contain chlorophyll *a* values ranging from 2 to 15 mg/m^3 (Wetzel 1983). In 1992 and 1993, during the growing season (April-October), chlorophyll *a* values in the lake ranged from approximately 1.3 µg/L (mg/m^3) to 6.5 µg/L and 1.0 µg/L to 6.5 µg/L, respectively, with peak values occurring in June (Ashley and Thompson 1993 and 1994). These values represent trophic status ranging from oligotrophic to-mesotrophic (Wetzel 1983).

Kootenai River

Primary productivity in lotic systems is represented mainly by periphyton rather than phytoplankton. In moving waters, phytoplankton retention time is usually short, contributing little to primary productivity. Therefore, estimates of primary productivity in rivers arc usually based on periphyton production.

Data obtained from the Environmental Protection Agency Storet system reveal low chlorophyll *a* concentrations in the Kootenai River after 1974. Average chlorophyll a levels recorded downstream from Libby Dam between 1974 and 1982 are characteristic of an ultraoligotrophic system. Wetzel (1983) states that the uhraoligotrophic range for chlorophyll a levels is 0.01 mg/m^3 to 0.50 mg/m^3, whereas the oligotrophic and mesotrophic ranges are 0.30 mg/m^3 to 3.00 mg/m^3 and 2.00 mg/m^3 to 15.00 mg/m^3, respectively.

Chlorophyll a data collected from 1977 through 1980 at Copeland, ID (Figure 9) are indicative of an oligotrophic to mesotrophic system. Although chlorophyll *a* concentrations reported by Snyder and Minshall(l996) increased from 1994 to 1995 in the Canyon, Braid and Meander reaches (Figure 9), they were considerably lower than values reported in earlier years. The 1994 values ranged from 2.1×10^{-5} mg/m^3 to 6.1×10^{-4} mg/m^3, whereas in 1995, the concentrations in these reaches ranged from 1.5×10^{-4} mg/m^3 to 5.1×10^{-3} mg/m^3. According to Wetzel (1983), these values fall well below the ultra-oligotrophic range. Montana Department of Fish, Wildlife, and Parks and the U.S. Army Corps of Engineers speculated that the low phosphorus concentrations found in the river could be the limiting factor for periphyton production (May and Huston 1983).

Lake Koocanusa

In large, deep water bodies, such as Lake Koocanusa, the bulk of annual primary productivity generally occurs in phytoplankton (Wetzel 1975, Likens 1975). Therefore, annual estimates of primary productivity in most large lakes, including Lake Koocanusa, are based on phytoplankton productivity.

Mean daily primary productivity in Lake Koocanusa between 1972 and 1975 decreased from 95.1 mg C/m^2 day to 66.8 mg C/m^2 day, respectively (Table 5), with a peak value of 105.5 mg C/m^2 day in 1973. According to these mean daily productivity values, Lake Koocanusa was classified as oligotrophic, using the trophic scale developed by Wetzel (1983). Primary productivity determinations from 1972 to 1980 (Woods 1982), along with mean daily primary

Table 5. Annual and mean daily areal primary productivity in Lake Koocanusa, 1972-75.

Year	Annual primary productivity (g C m^{-2} yr^{-1})	Mean daily primary productivity (mg C m^{-2} day^{-1})
1972*	27.1	95.1
1973	38.5	105.5
1974	25.5	69.3
1975	24.4	66.8
1972-1975	28.8 (mean)	84.2 (mean)

*March 2 1 to December 31

Woods and Falter 1982

productivity values from May, 1986 to January, 1986 (Chishohn et al. 1989) also suggest the lake is oligotrophic.

The annual mean chlorophyll *a* concentrations in Lake Koocanusa from 1972 to 1978 were 1.00 µg/L, whereas mean annual primary production was 123.1 mg/m²/day for these years, which also classified the lake as oligotrophic (Storm et al. 1982). Between 1973 and 1988, chlorophyll *a* values varied without any significant trend, ranging from 0.0 µg/L to approximately 6.0 µg/L, with annual means ranging from 1 .O to 2.0 µg/L (Hamilton 1990). According to these concentrations, the reservoir would be classified as oligotrophic (Wetzel 1983).

The concentration of phytoplankton biomass remained below 100 µg/L during the first four years after impoundment, which classified the lake as oligotrophic. After 1977, phytoplankton concentrations increased above 100 µg/L but generally remained below 300 µg/L until 1989, except during 1984 when algal biomass exceeded 600 µg/L (Hamilton 1990). Hamilton (1990) explained this increase as being associated with a jump in pH that year, rather than with increased phosphorus levels.

Analysis of seasonal distribution of phytoplankton biomass and chlorophyll *a* concentrations in Lake Koocanusa between 1972 and 1988 demonstrated that peak primary productivity in the lake took place in July and August, when surface waters were warmest and the euphotic zone extends to its greatest depth (Hamilton 1990). These findings are consistent with other studies (Woods 1979, Chishohn et al. 1989).

As stated in the nutrient section of this report (page 9), ratios of nitrogen to phosphorus can be used as an index of nitrogen versus phosphorus limitation for algal growth. Between 1972 and 1988 the TN:TP ratios in the reservoir inferred the possibility of phosphorus limitation Woods and Falter (1982) concluded that seasonal variations in primary production could not be explained by ambient concentrations of nitrogen and phosphorus, indicating that the phytoplankton was not nutrient limited.

Zooplankton

Kootenay Lake

Sampling of zooplankton in Kootenay Lake was sporadic between 1949 and 1972. In order to compare these data to those obtained after installation of Libby Dam in 1972, various conversion factors were used (Lasenby et. al. 1979). Number per square centimeter (no./cm²) for lakewide means in 1949 and 1964 and for a mid-lake station from 1967 to 1978 are shown in Figure 10. There was approximately a six-fold increase in peak zooplankton numbers between 1949 and 1968 due to a period of cultural eutrophication (Daley et al. 1981). After installment of pollution abatement measures and Libby Dam in 1972, zooplankton numbers decreased dramatically (Daley et al. 1981).

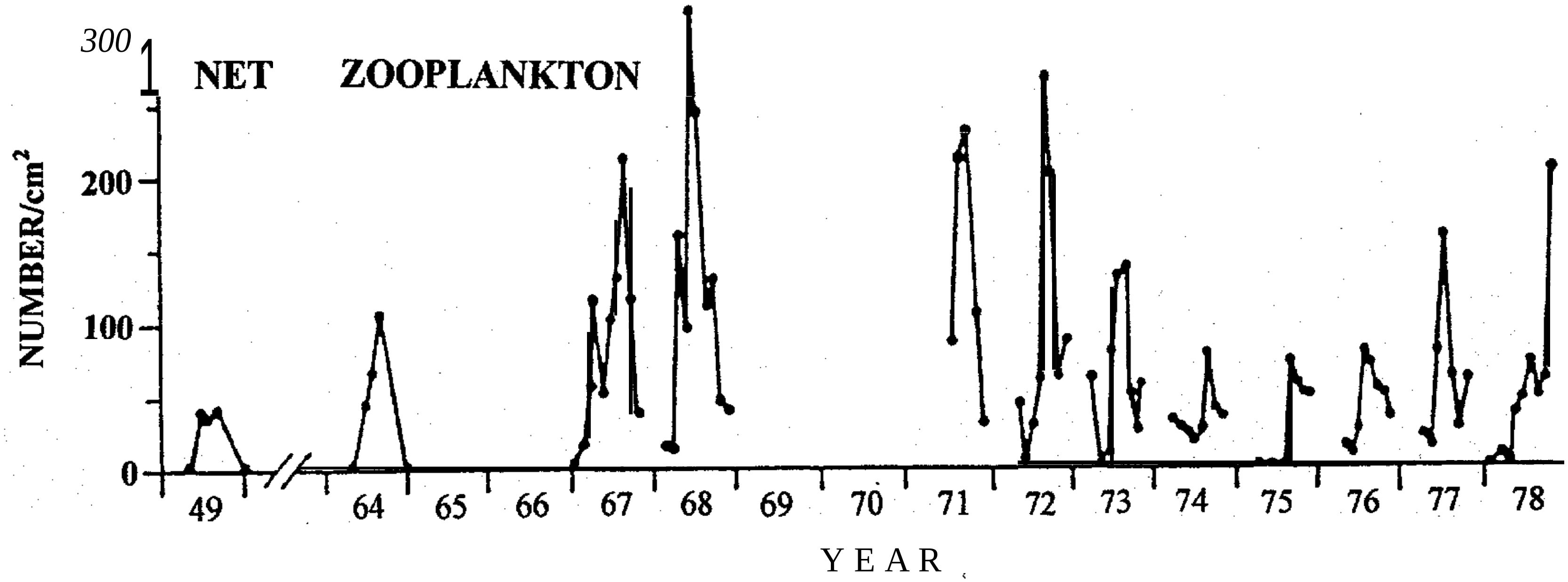

Figure 10. **Zooplankton** numbers in **Kootenay** Lake. **Lakewide means** are shown for 1949 and 1964, while **mid-lake** means are shown **from** 1967 to 1978. *(Daley et al. 1981)*

From 1950 to 1970, zooplankton numbers increased two to four-fold, showing similar trends as phytoplankton. In 1977, Kootenay Lake contained 11 macrozooplankton species: four copepods, six cladocerans, and one mysid (*Mysis dicta).* Copepods *were mom* abundant than cladocerans, which were usually only evident in the summer and fall. Figure 11 shows the seasonal distribution of total numbers of copepods and cladocerans in 1977. Zooplankton numbers in 1992 and 1993 were similar to those seen between 1972 and 1984 which ranged from approximately 7 to 27 individuals per liter (Ashley and Thompson 1994).

Introduction of *Mysis relicta*, a species of freshwater shrimp, to Kootenay Lake took place from 1949 to 1950. This introduction was done "with the intention of providing a supplementary food source for intermediate sized rainbow trout" (Sparrow et al. 1964). Mysids were first seen in the West Arm of the lake in 1961 (Sparrow et al. 1964). By 1966, their numbers increased to densities of 200 individuals/m^2 and continued to increase, reaching 1500/m^2 by 1978 (Figure 12). *Mysis relicta* followed a seasonal pattern similar to the copepods, increasing from very low winter levels to relatively high numbers in June, peaking in July and August, and then declining throughout the fall (Figure 13).

In 1992 and 1993, highest average mysid densities were observed in June and then slowly declined from July to August, through the fall. Maximum average density in 1992 was approximately 650/m^2, whereas in 1993, the highest average density was only 325/m^2. Average mysid densities in 1993 were approximately 50 percent lower than those recorded in 1992 (Ashley and Thompson 1994).

Kootenai River

Zooplankton densities in fluvial waters are normally lower than in lacustrine waters (Eddy 1932, Cushing 1964). The zooplankton density of the river is substantially lower than that of Kootenay Lake. The total mean density of Kootenay Lake zooplankton samples ranged from 1 to 69 individuals per liter (no./L), while that of the river was approximately 0.1 to 3.0/L (Paragamian 1995).

Five genera of zooplankton were captured in the Kootenai River from January to August, 1994, and six genera were collected from September, 1994, to August, 1995. In general, there was a lack of zooplankton in 1994 and 1995, even when they were at peak densities, ranging from less than 0.01 to 3.70/L for both years studied (Paragamian 1994 and 1995). Total densities of zooplankton in the Kootenai River were usually less than 0.1/L, which was among the lowest in comparison to other Pacific Northwest rivers. In both 1994 and 1995, *Cyclops* were the most abundant zooplankton genera in the Kootenai River, ranging from less than 0.01 to 2.00/L. All other genera were rare, and in some circumstances only one individual was collected (Paragamian 1995).

Total zooplankton densities in the river during 1994 were 100-fold lower than densities in Lake Koocanusa during the mid 1980's, and about 200-fold lower than the South Arm of Kootenay Lake in 1993 (Paragamian 1994). Total zooplankton densities in the river during 1994

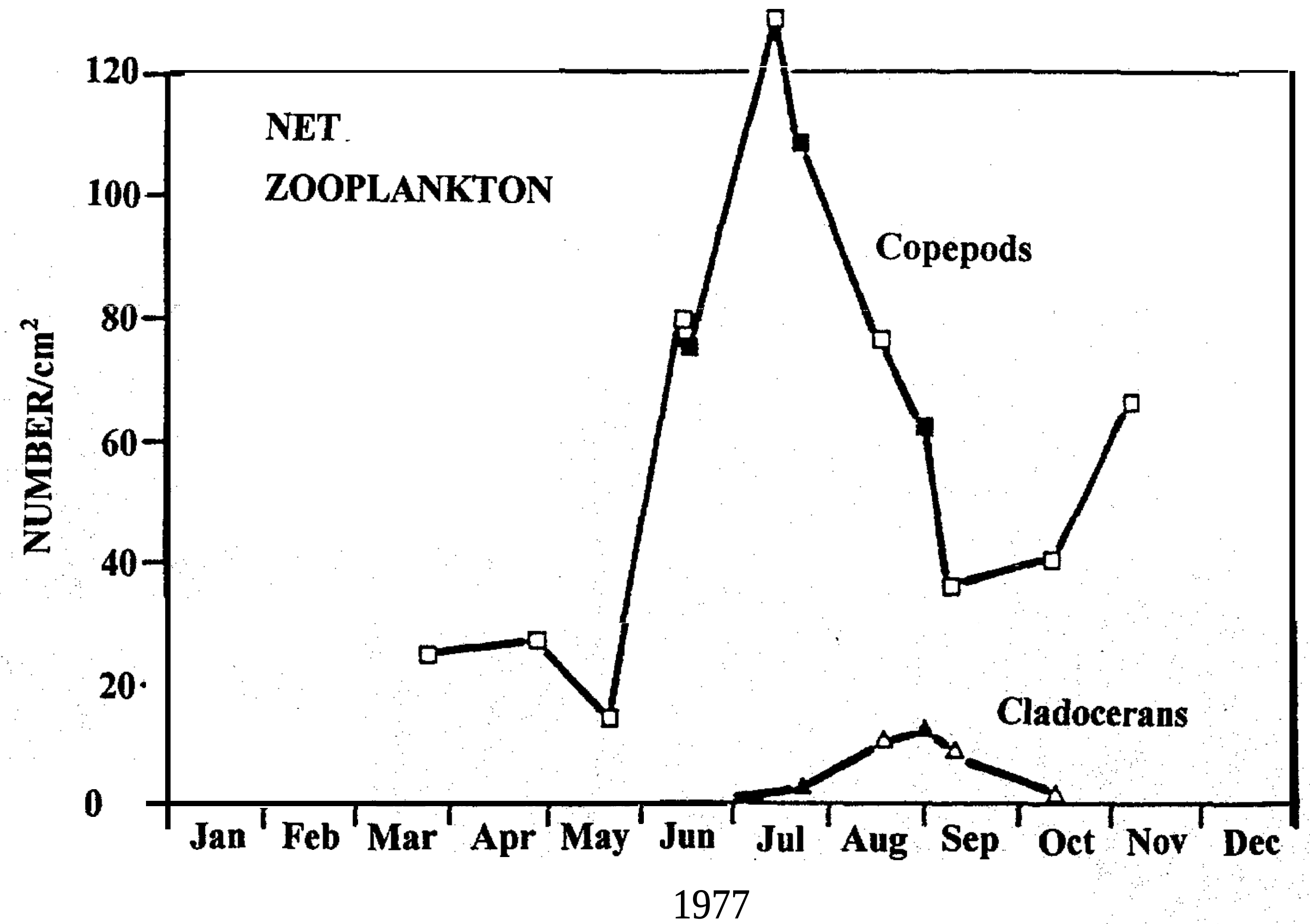

Figure 11. Seasonal distribution of total numbers of copepods and cladocerans in Kootenay Lake, 1977. (*Daley et al.* 1981)

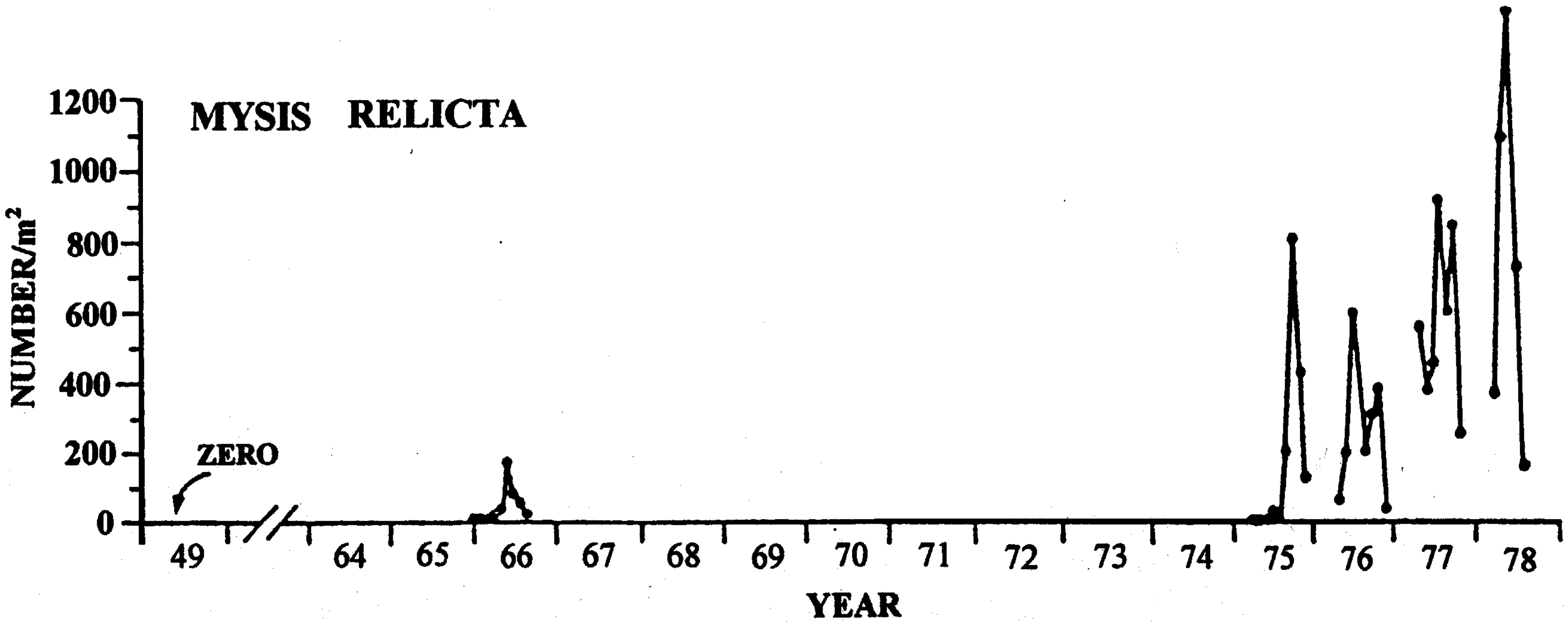

Figure 12. *Mysis reilicta* numbers in Kootenay Lake. Lakewide means are shown for 1949 and 1964, while mid-lake means are shown from 1967 to 1978. (*Daley et al. 1981)*

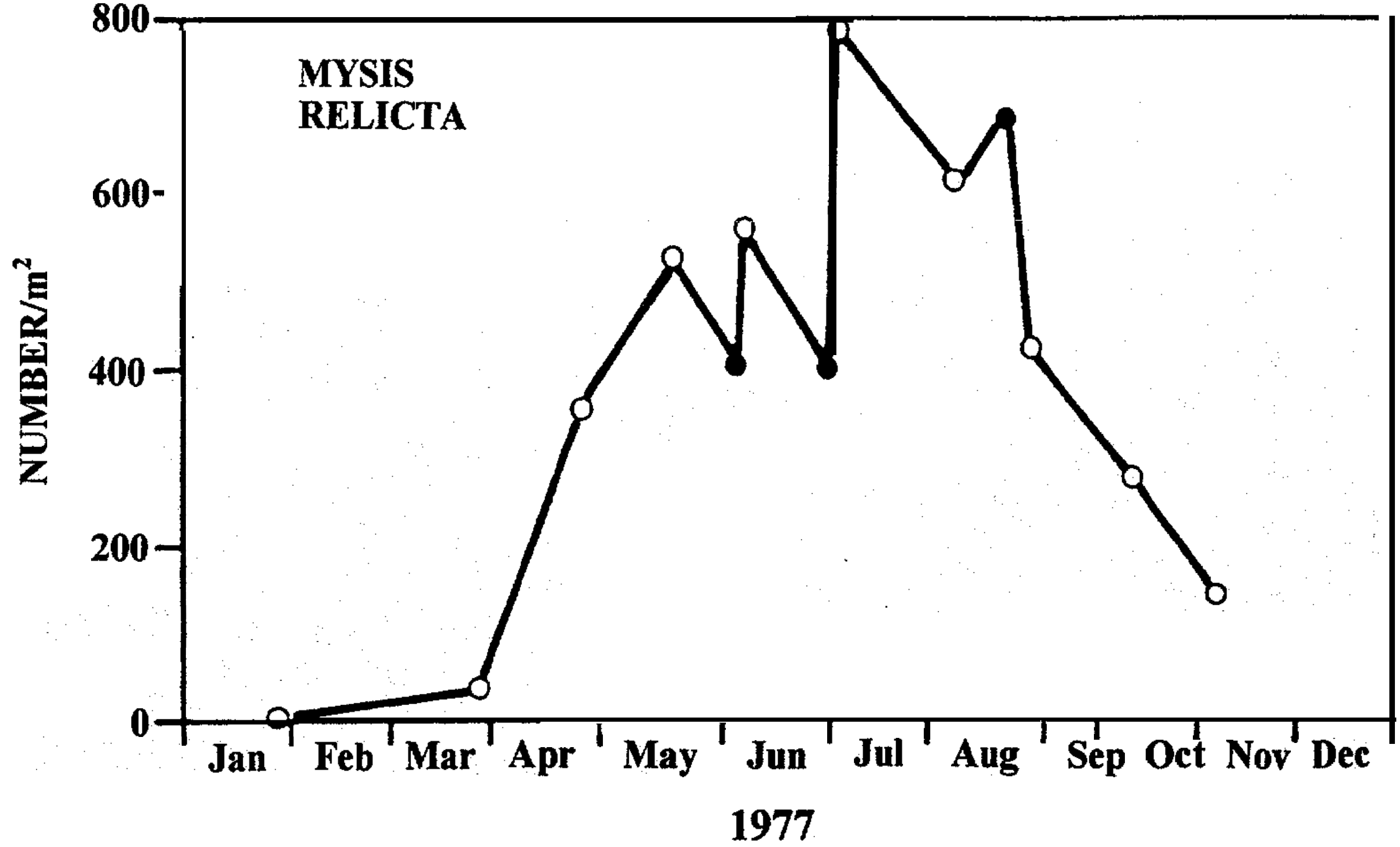

Figure 13. Seasonal distribution of total numbers of *Mysis relicta* in Kootenay Lake, 1977. *(Daley et al. 1981)*

were **100-fold** lower than densities in Lake Koocanusa **during** the mid **1980's,** and about **200-fold** lower than the South Arm of Kootenay Lake in 1993 (Paragamian 1994).

Lake Koocanusa

After impoundment in 1972 and prior to 1982, mean zooplankton **biomass was very** low at the International Border site; generally less than 1 **g/m²** (Hamilton et al. 1990). In 1982, biomass increased to over 11 **g/m²**, but then decreased substantially in the next four years. Although total zooplankton biomass increased between 1982 and 1985, the species composition remained virtually unchanged (Hamilton et al. 1990). **After** 1986, **zooplankton** biomass decreased even further to a mean concentration of less than **1 g/m²**.

The sudden change in zooplankton biomass after 1982, **occurred** two years **after** an accidental release of 250,000 kokanee **fry** into the Lake **Koocanusa** (Hamilton et al. **1990),** and could have been related to this event. Zooplankton populations in the lake between 1983 and 1987 exhibited typical patterns found in most temperate lakes and reservoirs **(Wetzel 1975),** with maximum abundance in the spring and early summer, a decline throughout the summer, and a slight increase in the fall.

Zooplankton species composition generally remained the same **from** 1973 to 1988. The three dominant genera were ***Daphnia, Diaptomus,*** and ***Cyclops***. Less common genera included ***Bosmina, Epischura, Leptodora, Ceriodaphnia,*** and ***Diaphanosoma*** (Chishohn et al. 1989, Hamilton et al. 1990). The **copepods *Cyclops*** and ***Diaptomus were* the** most common genera in the lake **from** 1983 to 1987, together accounting for 67.5 to 77.7 percent **of the** total zooplankton population (Chishohn et al. 1989). The relative abundance of ***Cyclops*** and ***Diaptomus have*** increased more than any other zooplankton since 1982. Before 1982, they each accounted for less than 20 percent of the total zooplankton biomass, but after 1982 they each accounted for approximately 20 to 50 percent of the total biomass.

While ***Cyclops*** and ***Diaptomus*** populations increased **after** 1982, ***Daphnia has*** decreased by the same proportion **(20-50%),** probably due to predation by kokanee (Hamilton et al. 1990). In 1984 and 1985 there was a noticeable increase in the ***Bosmina*** population. At the time ***Bosmina were*** at their highest **abundance,** kokanee numbers were at their peak (accidental release in 1980). Kokanee apparently prefer ***Daphnia,*** and a reduction in this species may have favored an increase in the smaller, less utilized (by kokanee) ***Bosmina*** (Chisholm et al. 1989).

Macroinvertebrates

Kootenai River

In addition to periphyton, macroinvertebrates are one of the most **important** lower **trophic** level organisms in river ecology. The invertebrate community is the link **between nutrient** supply and food availability for fish. A pre-impoundment survey of the aquatic insects in the Kootenai River in Montana was conducted as part of the **USACE's** pre-impoundment water quality study from 1967 to 1972. Bonde and Bush (1975) reported that the aquatic invertebrate population of the river increased between 1968 and 1969, and remained high through 1972. Chemical changes noted in the river after implementation of the industrial effluent control in Canada had a beneficial effect upon the invertebrate populations. Results from the 1968 to 1971 sampling of the Kootenai River showed that the standing crop of aquatic insects increased by 273 percent upstream from the Libby Dam site and 392 percent downstream from the site.

Out of the eight major insect orders that were found in the Kootenai River from 1968 to 1971, the four that were most common included Plecoptera (stoneflies), Ephemeroptera (maytlies), Trichoptera (caddisflies), and Diptera (true flies). Taxa within these four orders made up 99 percent of the total invertebrates sampled. The remaining one percent consisted of Odonata (dragon flies), Coleoptera (beetles, mostly of the family Elmidae), Megaloptera (alder&s), and Hemiptera (aquatic bugs, all in the family Corixidae) (Bonde and Bush 1982).

Percent of total number (no./m^2) calculations revealed that from October 1979 to September 1980, Ephemeroptera and the dipteran family Chironomidae were the two dominant invertebrate taxa. Annual mean densities of Chironomidae were greatest of all the invertebrates sampled downstream from Libby Dam between October 1979 and September 1980, and Ephemeroptera densities were the second greatest (Perry and Huston 1983).

In March, May, and July, 1982, representatives of eleven families of aquatic insects (Table 6) were found at two sampling sites in the Kootenai River (Hemlock Bar and Bonners Ferry), and 21 families were found in four tributary streams (Boulder Creek, Moyie River, Ball Creek and Long Canyon Creek) (Figure 14) (Partridge 1983). Dredge samples taken in the river below Bonners Ferry showed a limited variety of aquatic invertebrates with Chironomidae larvae and Oligochaetes being the two dominant groups (Partridge 1983).

Sediment samples taken in the Kootenai River downstream from Bonners Ferry in 1982, revealed a limited variety of aquatic invertebrates with Chironomidae larvae and Oligochaetes being the two dominant groups. These invertebrates were common in samples containing organic detritus which had settled into slack water areas, but uncommon in areas exposed to the main current (Partridge 1983). Variation in stream discharge has been known to cause changes in invertebrate abundance, productivity, and species composition (Cushman 1985).

Between June and September, 1993, the flora and fauna of the Kootenai River downstream from Libby Dam remained fairly stable. Earlier studies showed diverse invertebrate populations at this location, but these had apparently been eliminated and chironomids were the only remaining invertebrate taxon.

Out of the four sites sampled between 1979 and 1980, Dunn Creek had the highest total density of macroinvertebrates (Table 7). Overall, post-impoundment densities were an order of magnitude higher than those found at the Dunn Creek site in pre-impoundment studies (Figure 15) (Perry and Huston 1983). These increased densities were due to higher numbers of a few species of maytlies and dipterans. The percent composition of stoneflies and caddisflies has decreased dramatically at this site since impoundment, while the densities of mayflies and

Table 6. Numbers of aquatic insects collected with six Surber samplers at selected sites on the Kootenai River and four tributary streams in March, May, and July 1982.

Taxa	Baulder Creek			BMoyiel River			Creek			Long Canyon Creek			Kootenaf River Hemlock Bar			Bonners Ferry		
	3/26	5/13	7/8	3/25	5/13	7/8	3/26	5/14	7/9	3/26	5/14	7/9	3/25	5/13	7/8	3/25	5/13	7/8 ...
Eohemeroptera				20														
Heptageniidae	20	4	1	13	2 1	27	67	7	9	22	33	la	121	2	1	3	11	4
Baetidae	17	-	2			-	45	49	12	35	54	15	-		-	-	1	3
Ephemerellidae	1	13	-	11	-	2	12	5	-	26	52	3	136	i	6	3	6	-
Leptophlebiidae		-	-	-	-	-	2	-	-				-	-	-		1	-
Siphlonucidae		-	-		-	-		4	-	3	27	-	-	-	-		-	-
Ephemeridae	3	-	-	-	-	-		-	-	-	-	-	-	-	-		-	-
Plecoptera																		
Perlidae		2	-	-	-	-	3	-	1	1:	1:	2	2	-	2	-	-	1
Perlodidae	18	-	-		-	1	5	-	-				1	-	-		-	-
Chloroperlidae	11	2	4	3	3	4	2	-	-	1	15	i	7	-	1	I	1	8
Peltoperlidae	5	1	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-
Trichoptera																		
Rhyacophilidae		-	1	-	-	-	2	2	2	2	4	1	3	-	-	-	-	-
Hydropsychidae	ii	1	3	-	-	1	9	-	-	10	13	2	18	-	-	-	-	-
Glossomatidae		-	-	-	-	-	31	1	-	18	g	-	-	-	-	-	-	-
Leptoceridae		-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-
Limnephilidae		-	-	-	-	1		-	1		-	-	-	-	1	-	-	-
Hydroptilidae	i	-	4	-	-	-		-	-	-	-	-	-	-	-		-	-
Dfptera																		
Chironomidae		-	-	30	1	2	37	5	1	18	4	-	64	37		-	-	-
Simuliidae		-	-	-			7	-	-	-	-	-	5	-	-	-	-	-
Tipulidae	i	-	-	4		I-	3	-	2	3	4	'1	-	-	-		-	-
Tabanidae .		-	-	-	-	-	-	-	-	-	3	-	-	-	-		-	-
Coleoptera .																		
Elmiaae	-	-	-	-	-	-	2	-	-	3	1	-	-	-	-	-	-	-
Oligochaeta		-	-	4	-	-	1	1	-		3	-	2	69	-	-	6	-
Total Number	a7	24	11	91	7	38	229	74	28	160	— — 238	43	359	75	18	6	26	16

Partridge I983

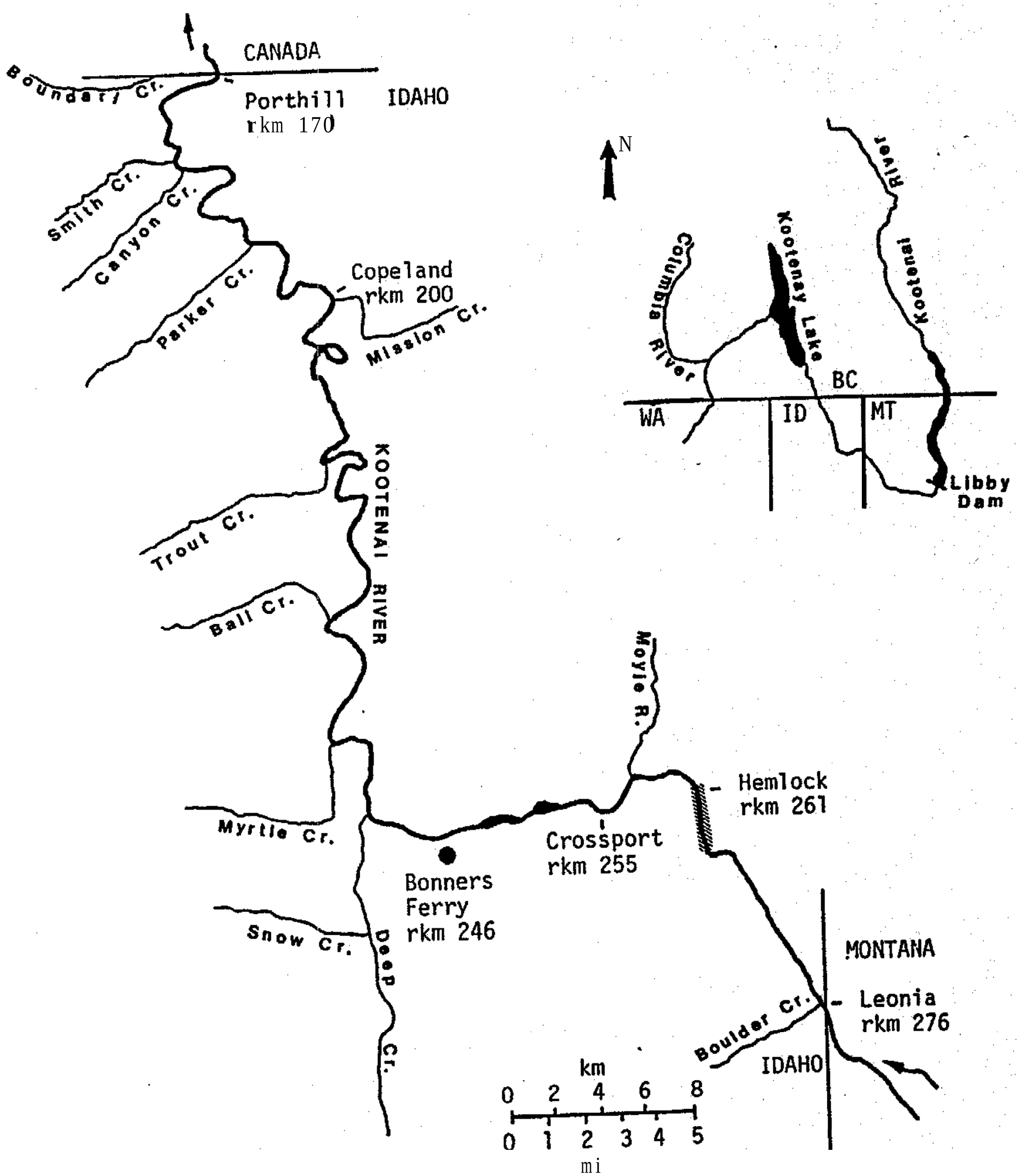

Figure 14. Location of the Kootenai River and major tributaries in the Idaho Panhandle with river distances in kilometers of major access points. *(Partridge 1983)*

Table 7. Insect densities as annual mean of monthly means per square meter for Kick, Circular and Knapp water samplers combined, October, 1979 through September, 1980.

	Dunn Creek n=10 $\bar{x}$(s.d.)	Elkhorn n=10 $\bar{x}$(s.d.)	Pipe Creek n-9 $\bar{x}$(s.d.)	Fisher River n=7 $\bar{x}$(s.d.)
Ephemeroptera	8,797(7,778)	5,627(3,079)	2,821(1,241)	4,443(1,784)
Plecoptera	6(6)	14(10)	15(11)	670(119)
Trichoptera	62(32)	953(799)	1,282(1,365)	1,657(944)
Coleoptera	7(6)	49(29)	34(28)	446(234)
Chironomidae	15,803(6.,905)	7,587(3,047)	11,061(6,263)	2,207 (395)
Other Diptera	1,560(1,417)	2,598(2,511)	1,970(2,309)	718(569)
Other Invertebrates	1,877(1,615)	1,658(698)	2,423(1,438)	535(251)
TOTAL	28,112(8,394)	18,486 (7,919)	19,606(9,259)	10,676(3,325)
Percent Composition				
Epherneroptera	31.3%*	30.4%	14.4%	41.6%
Plecoptera	0.1%	0.08%	0.08%	6.3%
Trichoptera	0.2%	5.2%	6.5%	15.5%
Coleoptera	0.02%	0.3%	0.2%	4.2%
Chironomidae	56.24	41.0%	56.4%	20.7%
Other Diptera	5.5%	14.1%	10.0%	6.7%
Other Invertebrates	6.7%	9.0%	12.4%	5.0%

* Percentages do not always total 100% due to rounding.

Perry and Huston 1983

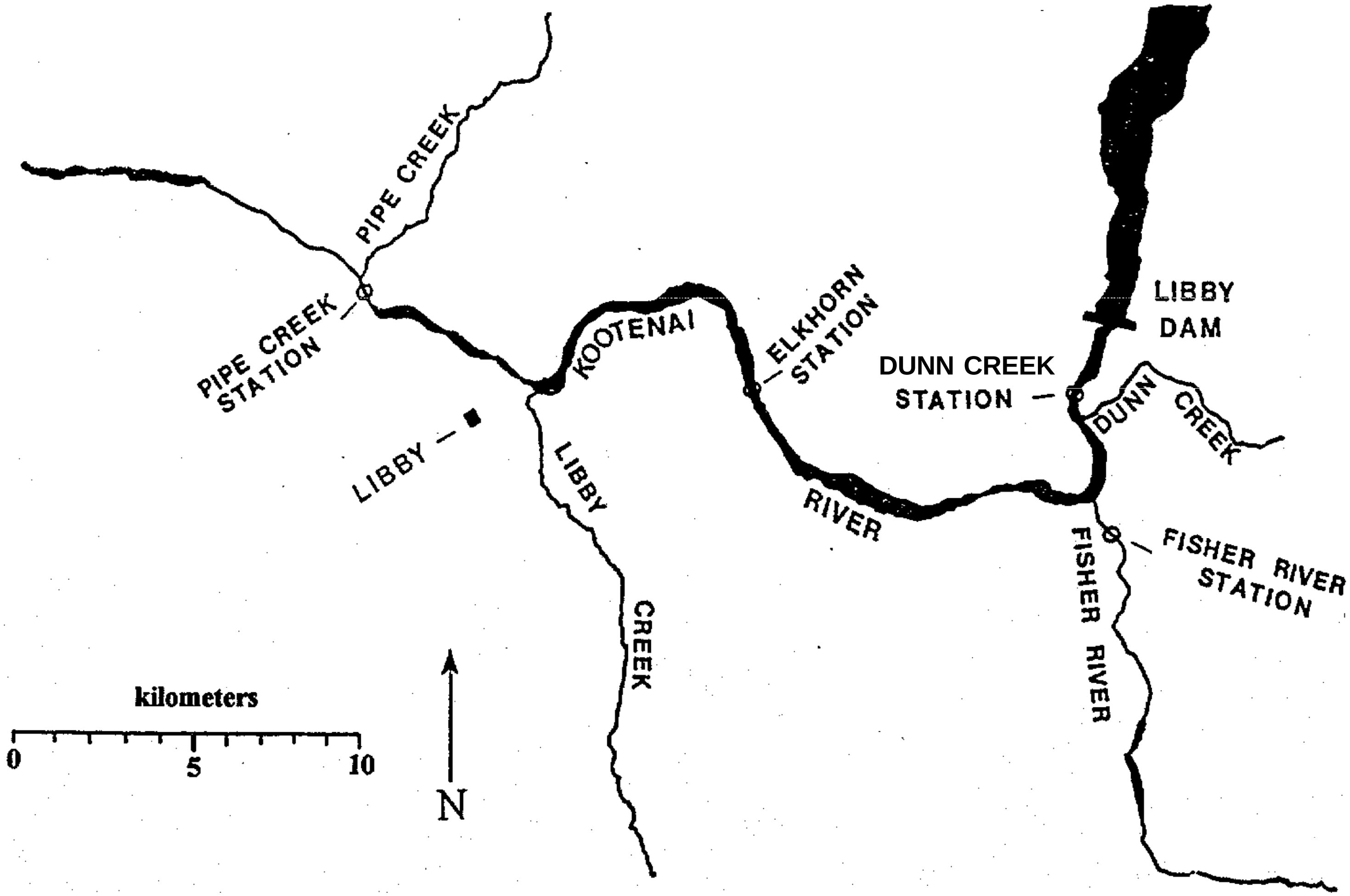

Figure 15. Location of macroinvertebrate sampling stations on the Kootenai and Fisher Rivers. *(Perry and Huston 1983)*

dipterans appear to have increased substantially. Perry and Huston (1983) reported a six-fold increase in the percent composition of mayflies and a 2.5-fold increase in dipterans. Annual mean densities of all invertebrates sampled between 1979 and 1980 ranged about 1.5 to 2.5 times greater in the Kootenai River than in the Fisher River (Perry and Huston 1983).

Invertebrate densities near Libby Dam increased, but species diversity decreased. Species diversity increased with increasing distance downstream from the dam, but was lower than would be expected in a free-flowing river. Biomass of aquatic insects was highest near the dam. Limited invertebrate sampling done near Kootenai Falls, 47 km (29 miles) downstream from Libby dam (Graham 1979), indicated major changes in invertebrate diversity and composition since impoundment. Bonde and Bush (1982) reported that "the aquatic insect popuiation for 14.5 km (9 miles) below the Libby Dam site was found to be smaller than the population above the dam site. The suppression of the insect population below the dam is attributed to the increase in suspended sediment caused by construction activities related to the Libby Dam Project."

Lake Koocanusa

A total of 635 benthic samples were collected between 1983 and 1987. Forty-four percent of the samples were taken in the Tenmile area, 42 percent in the Rexford area, and 14 percent were collected in the Canada area (Figure 16). Average invertebrate densities in the shallow, mid and deep zones of Libby Reservoir were 178.7, 569.9 and 1,099.8 individuals/m^2, respectively (Chisholm et al. 1989). The order Diptera constituted the predominant group in the benthic fauna of each drawdown zone in Libby Reservoir. Dipterans averaged approximately 70 percent of the total number of benthic invertebrates sampled between 1983 and 1987. Although dipterans comprised the greatest portion of the total benthic invertebrates collected, densities in the reservoir averaged 337/m^2, which is low compared to other North American reservoirs (Chisholm et al. 1989).

In the U.S. portion of the reservoir, surface invertebrate densities increased from 1972 through 1985, decreased in 1986, and then increased again in 1987. A difference in trends was noted in the Canadian portion of the reservoir, where densities in 1983 were relatively high and tended to decrease, except in 1986 (Chisholm et al. 1989). Average surface invertebrate densities from 1983 to 1987 ranged from 6.4 invertebrates per hectare in the Rexford area to 201.1 invertebrates per hectare in the Canada area. Maximum densities of surface invertebrates from 1983 to 1987 were seen in April. The individual invertebrate order with the greatest density between 1983 and 1987 was Hymenoptera. The next invertebrate orders sampled, by decreasing densities were Diptera, Homoptera, Coleoptera, Hemiptera, and Arachnida (Chisholm et al. 1989).

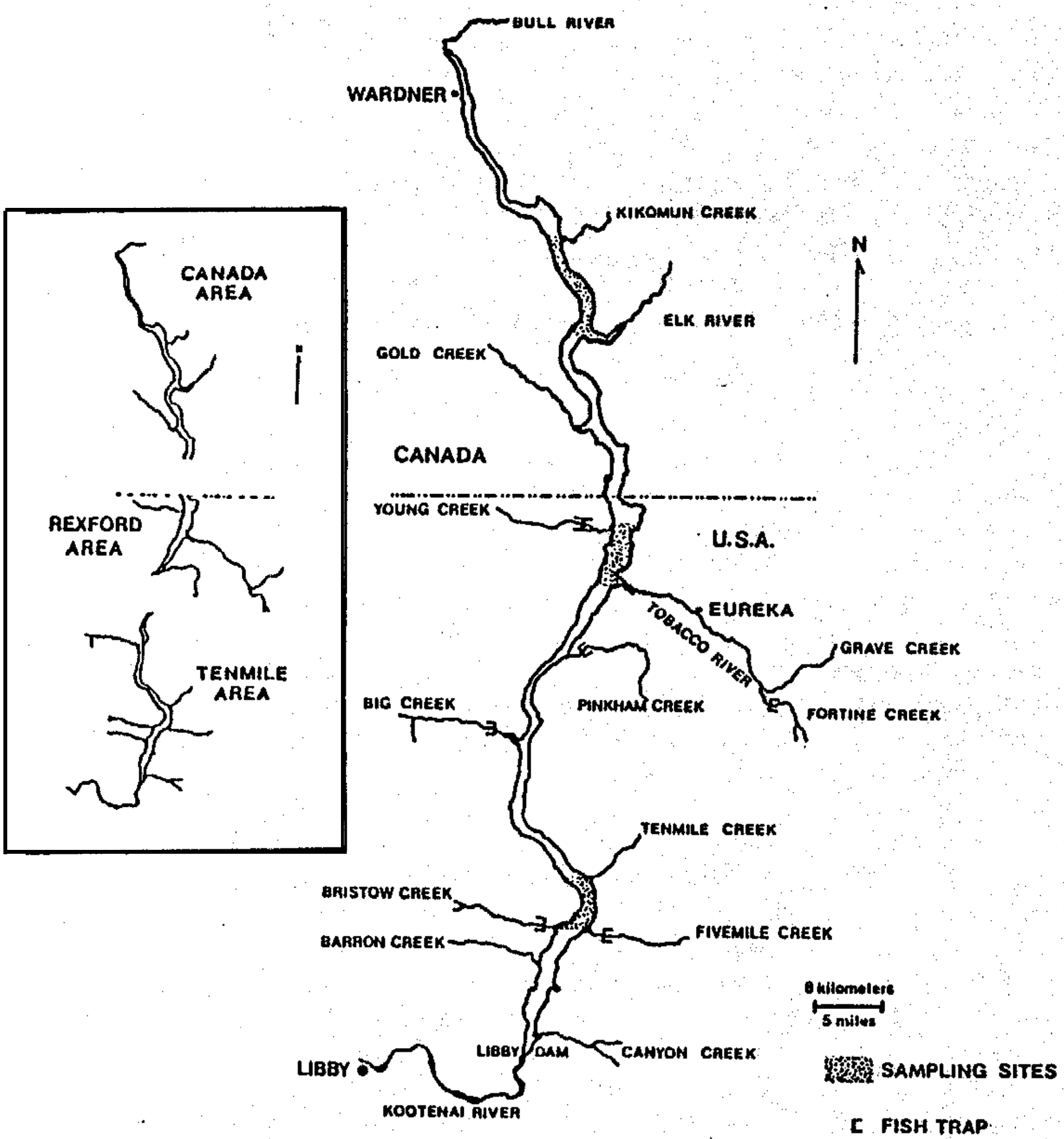

Figure 16. Three invertebrate sampling areas along Libby reservoir, 1983 to 1987. *(Chisholm et al. 1989)*

Fish

Kootenay Luke

Fishing is the primary recreational activity on Kootenay Lake. Important species to the recreational fishery include: rainbow trout **(*Oncorhynchus mykiss*)**, kokanee **salmon (*Oncorhynchus nerka*)**, bull trout **(*Salvelinus confluentus*)**, mountain whitefish **(*Prosopium williamsoni*)** and burbot **(*Lota lota*)** **(Northcote** 1973, Andrusak and Crowley 1977). Before 1960, the main fishery of the West Arm of the lake focused on small rainbow trout, but by the mid **1960's,** whitefish, burbot and kokanee fisheries developed. Shortly **after,** the burbot and whitefish fishery declined, but the kokanee fishery persisted. By the early **1970's,** kokanee catches in the West Arm increased to over 50,000 fish per year (Figure 17).

A steady increase in the size of West Arm kokanee was noted from the 1940's and 1950's to the 1960's and 1970's due to the greater availability of food, mainly **mysids (Daley** et al. 1981). Stomach analysis indicated that the large increases in the size of West Arm kokanee were the result of the introduction of mysids to the lake **(Northcote** 1973). Since 1970 there has been an increase of the trophy rainbow fishery into the South Arm, and a rapid expansion of the kokanee fishery in the North Arm. Whitefish and burbot were caught primarily in the West Arm. The West Arm of the lake is rapidly flushed with insects and plankton which are transported **from** the main lake, over the shallow West Arm sill. This has proven to be a good food source for fish inhabiting this portion of the lake, mainly kokanee.

The construction of Duncan Dam in **1967** and Libby Dam in 1972 resulted in a reduction in nutrient loading that was followed by a decline in phytoplankton and zooplankton biomass and kokanee numbers (Ashley and Thompson 1993). Kokanee populations continued to decline throughout the 1980's and by 1990, the South Arm stocks of kokanee had become **virtually** extinct. North Arm kokanee stocks also continued to decline throughout the 1980's. With these declining populations and the concerns for the collapse of the trophy Gerrard rainbow trout in Kootenay Lake, an Adaptive Environmental Assessment (AEA) workshop was organized. The goal of the workshop was to develop a simulation model so that various management options for Kootenay Lake could be explored (Ashley and Thompson 1993). As a result of the workshop, it was decided to start fertilizing the lake in April 1992.

The kokanee responded positively to the nutrient additions that were initiated in 1992. Figure 18 shows a comparison of the densities of age **1+** and 0+ kokanee between 1992 and 1993. Similarly, lengths of 0+, **1+,** and **2+** kokanee increased over the 1993 study period (Ashley and Thompson 1994). There was also a gradual increase in size and total escapement of Gerrard rainbow trout **from** 1957 to 1993, with a substantial increase in 1980 (Figure 19) (Ashley and Thompson 1994).

Kootenai River

As of 1983, May and Huston (1983) reported that sixteen species of fish were documented in the Kootenai River downstream from Libby Dam: westslope cutthroat trout

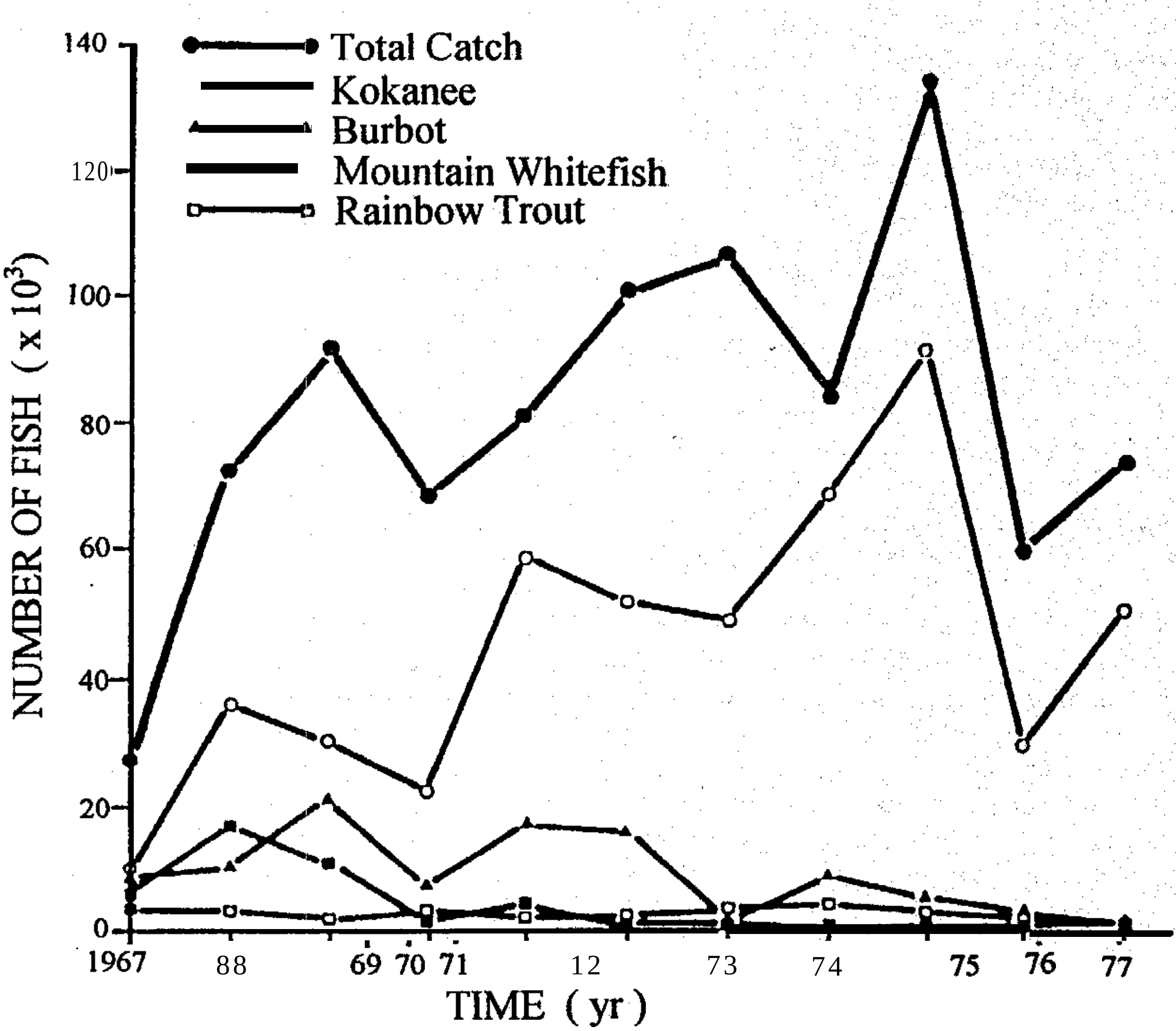

Figure 17. Historical trends in the fishery catch, by species, in the West Arm of Kootenay Lake. *(Daley et al. 1981)*

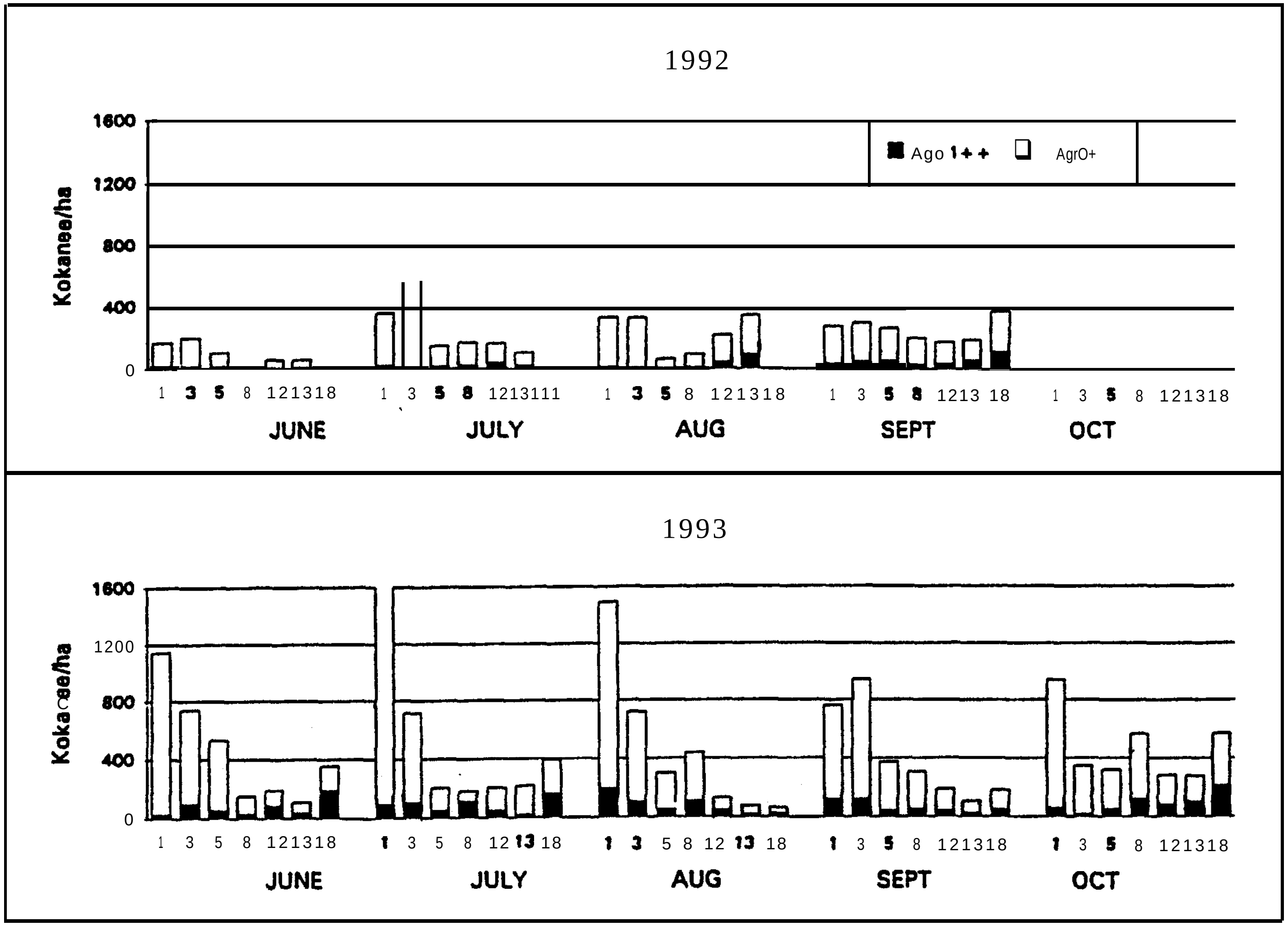

Figure 18. **Kokanee** densities in Kootenay **Lake** by age class in 1992 and 1993. Numbers on the x-axis represent fall trawl sites. *(Ashley and* ***Thompson*** *1994)*

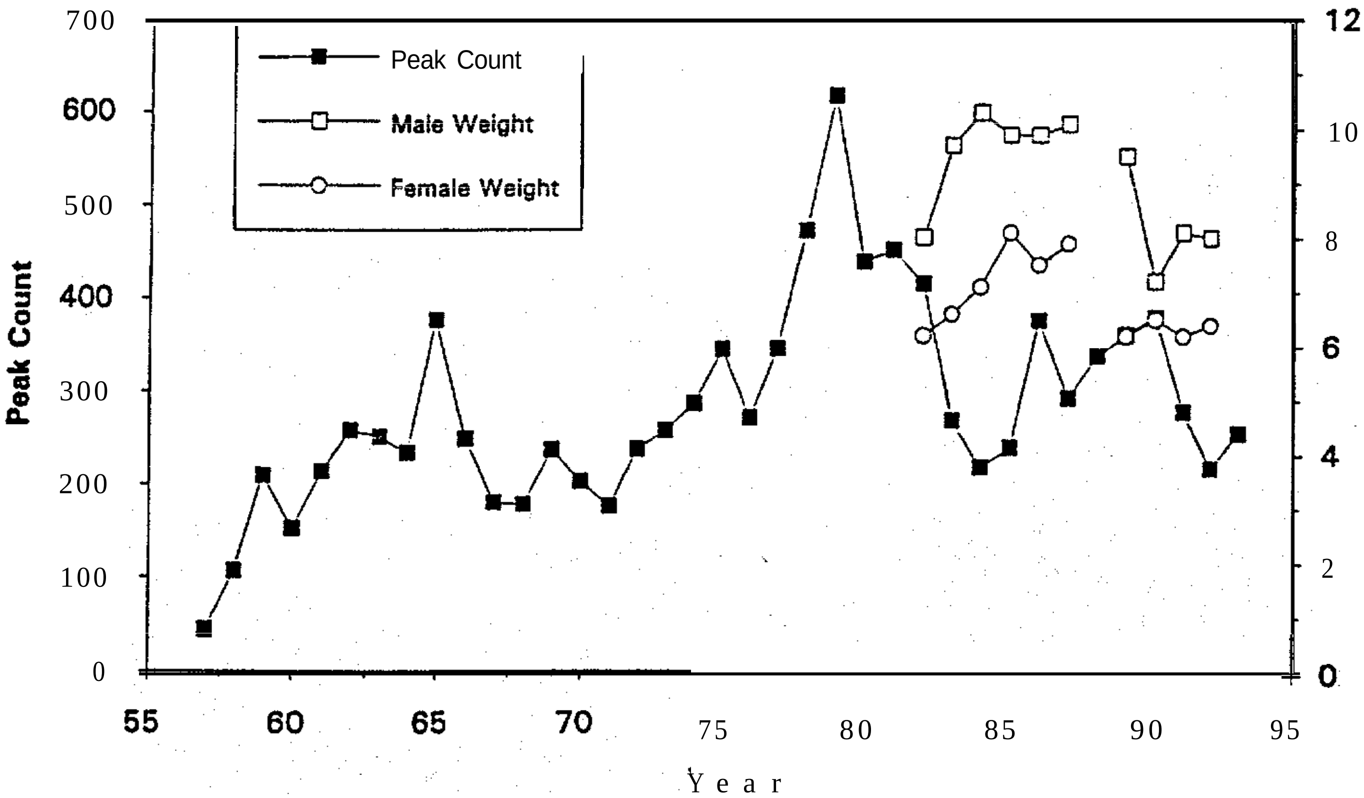

Figure 19. **Gerrard** rainbow trout **escapement** and **size at a northern river** spawning ground on Kootenay Lake, 1957 to 1993. *(Ashley* ***and*** *Thompson 1994)*

(*Salmo clarki*), rainbow trout, bull trout (*Salvelinus confluentus*), brook trout (*Salvelinus fontinalis),* mountain whitefish, white sturgeon *(Acipenser transmontanus*), burbot, kokanee sahnon, torrent sculpin (*Cottus rhotheus*), slimy *sculpii* (*Cottus cognatus*), largescale sucker *(Catostomus macrocheilus),* longnose sucker *(Catostomus catostomus),* northern squawfish (*Ptychocheilus oregonensis),* peamouth chub (*Mylocheilus caurinus*), redside shiner (*Richardsonius balteatus),* and longnose dace *(Rhinichthys cataractae*). Additional fish occurring in the Kootenai River drainage include brown bullhead (*Ictalurus nebulosus*), *yellow* perch (*Perca flavescens*), pumpkinseed *(Lepomis gibbosus),* largemouth bass (*Micropterus salmoides),* black crappie *(Pomoxis nigromaculatus*), lake chub (*Couesius plumbeus*) (Partridge 1983), and chiselmouth (*Acrocheilus alutaceus*) (Paragamian 1995). Relative abundance of fish species collected in the Kootenai River, downstream from Libby Dam to the Idaho border from 1971 to 1981 is presented in Table 8.

Species found downstream from Kootenai Falls are identical to those found upstream from the falls with the exception of white sturgeon (May and Huston 1983). Kootenai Falls is thought to be a natural barrier to the upstream migration of white sturgeon. May and Huston (1983) reported westslope cutthroat trout as being abundant upstream of Kootenai Palls before impoundment and then being uncommon after impoundment. Cutthroat trout are uncommon downstream from Kootenai Falls. Before impoundment, burbot were reported as being abundant upstream from the falls until 1960 when their numbers began to decline. Burbot have never been common below Kootenai Falls.

Fish data on the Kootenai River prior to 1969 is sparse. The only recorded data were obtained from creel surveys conducted by game wardens. Prior to the 1940's, cutthroat trout and burbot were the most abundant fish caught in the Kootenai River, while rainbow trout and mountain whitefish were less abundant. Conditions changed in the 1950's, with burbot and cutthroat declining in numbers and rainbow trout and whitefish flourishing (Bonde and Bush 1975). During the time of this species shift, there was a noticeable decline in water quality (increase in algae growth, silt, and sediment) due to industrial operations taking place on the major tributaries to the Kootenai River. These water quality problems limited aquatic invertebrate populations which was most likely the cause of the shift in fish species composition (May and Huston 1983).

Prior to impoundment, westslope cutthroat trout were abundant in the Kootenai River, along with noticeable numbers of bull trout. Between 1971 and 198 1, in the Jennings section of the river (Figure 20), cutthroat and bull trout declined in relative abundance. Cutthroat trout comprised 50 percent of the total catch in the Jennings section in 1971 and only 18 percent in 198 1 (May and Huston 1983). In the Flower-Pipe section of the river (Figure 20), cutthroat and bull trout comprised a total of 6.5 percent of the total catch in 1973 and less than 0.1 percent in 198 1. Reduced escapement from Lake Koocanusa following impoundment was the primary cause for the decline in cutthroat abundance seen downstream form Libby Dam after 1975 (May and Huston 1983). Fewer than 20 cutthroat trout were reported being caught in the Kootenai River, downstream from Bonners Ferry, ID, using hoop nets and electrofishing methods between 198 1 and 1995 (Partridge 1983, Paragamian 1994 and 1995).

Table 8. Relative abundance of fish species collected in the Kootenai River downstream from Libby Dam to Idaho.

		Upstream of Kootenai Falls		Downstream of Kootenai Falls	
Common name	Scientific name	Pre-Impoundment	Post-Impoundment	Pre-Impoundment	Post-Impoudment
Westslope cutthroat trout	*Salmo clarki leivisi*	A[1]	U	U	U
Rainbow trout	*Salmo gairdneri**	A	A	A	A
Bull trout	*Salvelinus confluentus*	U	U	U	U
Brook trout	*Salvelinus fontinalis*	U	U	U	U
Mountain whitefish	*Prosopium williamsoni*	A	A	A	A
White sturgeon	*Acipenser transmontanus*	*N*	*N*	U	R
Burbot	*Lota lota*	U[2]	C	U	U
Kokanee salmon	*Oncorhynchus nerka*	*N*	U[3]	U[4]	U
Torrent sculpin	*Cottus rhotheus*	A	C	U	U
Slimy sculpin	*Cuttus cognatus*	R	R	R	R
Largescale sucker	*Catostomus macrocheilus*	A	A	A	A
Longnose sucker	*Catostomus catostomus*	U	U	U	u
Northern squawfish	*Ptychocheilus oregonensis*	R	R	C	c
Peamouth chub	*Mylocheilus caurinus*	R	R	A	A
Redside shiner	*Richardsonius baltaetus*	C[5]	*C*	*C*	*C*
Longnose dace	*Rhinichthys cataractae*	A	C	C	C

* *AU* species of rainbow trout *have* since been collectively referred to *as Oncorhynchus mykiss* (Behnke, 1992).
1 A = abundant, C = common, U = uncommon, R = rare, N = not reported.
2 Abundant until 1960. then declined in abundance.
3 Drift from lake Koocanusa.
4 Spawning runs into Yaak River and Callahan Creek, origin is probably Kootenai Lake, B.C.
5 Found in backwaters and sloughs.

May and Huston 1983

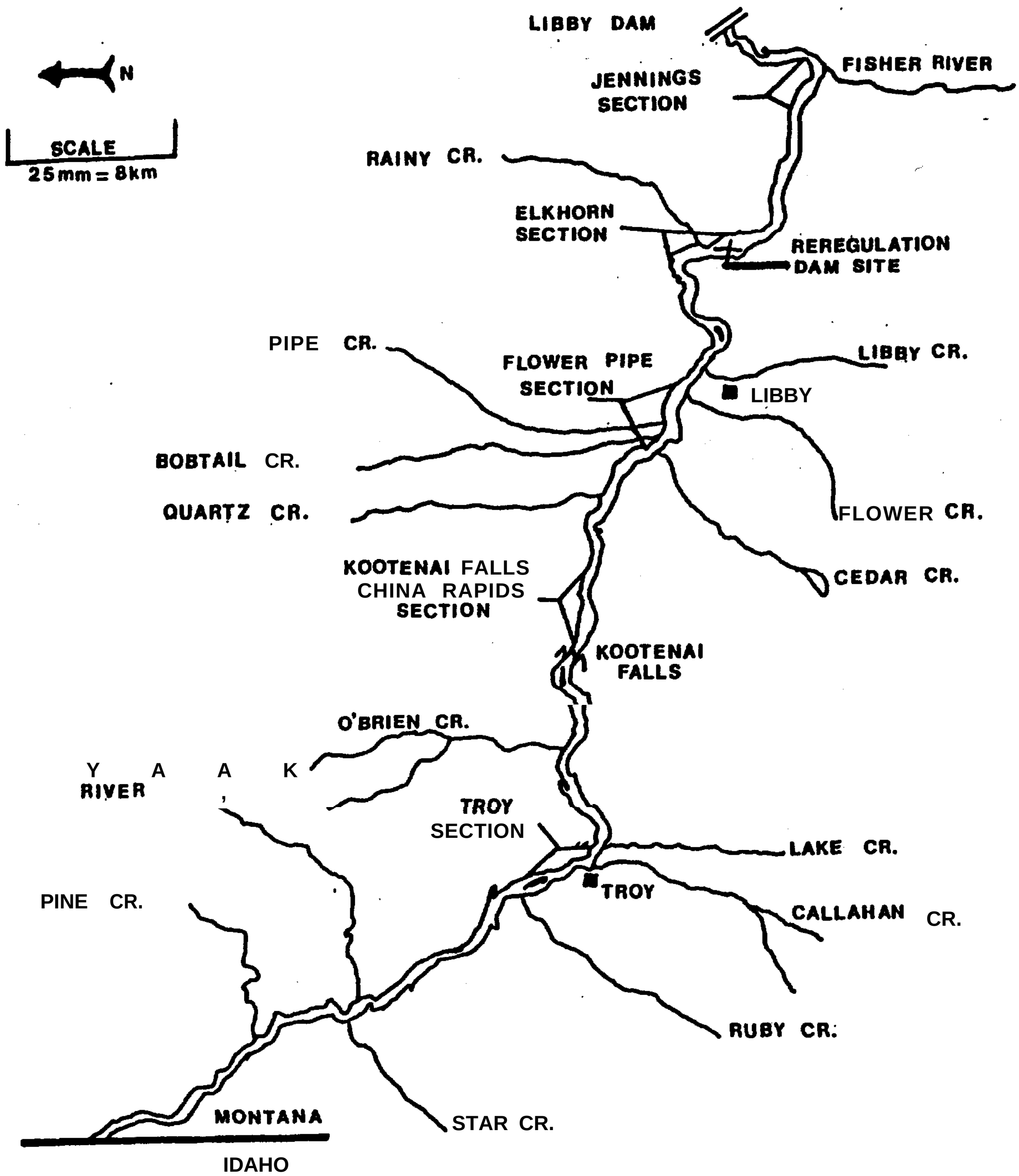

Figure 20. Map of the Kootenai River and its tributaries below Libby Dam, to the Idaho border. *(May and Huston 1983)*

Rainbow trout populations increased downstream from Libby Dam after impoundment (May and Huston 1983). Catch rates of rainbow trout in the Jennings section increased from 27 percent in 1971 to 79 percent in 1981 (May and Huston 1983). Rainbow trout catch rates in the Elkhom section of the river (Figure 20) increased from 0.1 fish per hour in 1971 to 1.1 fish per hour in 1974. There was an additional marked increase to 11.3 fish per hour in 1980, which is. a population estimate of 123 rainbowtrout per 300 meters of river (May and Huston 1983). From 1973 to 198 1, rainbow trout numbers increased nine-fold in the Flower-Pipe section of the river. The 1969 rainbow trout year class sampled in the Flower-Pipe section had the slowest growth rates, while the 1974 year class showed the fastest growth. The size of rainbow trout decreased with the increase in numbers. In 1977, 50 percent of the catch in the Flower-Pipe section was 305 mm or longer, while only 13 percent of the 198 1 catch was over 305 mm in length.

Average rainbow trout growth, downstream from Libby, MT, declined greatly after 1974 and continued to decline until 1979 (Table 9) (Mav and Huston 1983). According to May and Huston (1983), some of the reasons for the fast growth rates achieved by rainbow trout following impoundment of the Kootenai River in 1972 include low fish densities, substantial numbers of aquatic insects, and optimal water temperatures for growth: With the reduction of gas supersaturation in 1975, there was an increase in rainbow trout and mountain whitefish numbers, and therefore a decrease in growth rates (May and Huston 1983).

May and Huston (1983) showed that there was adequate stream habitat available (219 km of stream accessible for spawning and rearing) between Libby Dam and Kootenai Falls to maintain river populations of rainbow trout (Figure 20). It was determined that only 34 km of tributaries was accessible for rainbow trout use below Kootenai Falls to the Idaho border. Rainbow trout numbers are most likely limited by the quality and quantity of tributary habitat in this section of the river (May and Huston 1983). Data collected on rainbow trout spawning runs from the Kootenai River into Pipe Creek, Libby Creek and Bobtail Creek (Figure 20) between 1976 and 198 1 showed that a greater number of rainbow trout preferred Bobtail Creek for their spawning grounds (Table 10). Trap catches of spawning rainbow trout in Pipe and Libby Creeks seem to indicate increased numbers of fish entering these creeks from 1976 to 1977 and 1981 (May and Huston 1983). The total number of young-of-the-year rainbow emigrating from Bobtail Creek is estimated to be 7,000 fish per year (May and Huston 1983).

Eighteen species of fish were found by electrofishing or observation in 22 different tributaries in the Idaho portion of the Kootenai giver between 1980 and 1982 (Table 11) (Partridge 1983). Rainbow or rainbow x cutthroat trout hybrids were found in all streams. Cutthroat or hybrids were found in 5 streams, brook trout in 13, bull trout in 2, mountain whitefish in 9, kokanee in 9, and burbot in 2 streams. There were no non-game species sampled in Twenty-Mile, Caboose, Debt, and Cascade creeks (Table 11).

Trout populations in the tributaries were mainly comprised of young-of-the-year and yearling fish. Seventy-seven percent of the rainbow trout sampled were less than 80 mm in

Table 9. Length of migration class Xl rainbow trout by year class just downstream from Libby, MT in the Kootenai River. Number of fish aged is given in parenthesis.

Year class	Back-calculated length (mm) for age group I	II	III	IV
1969	107(19)	224(19)	295(19)	363(15)
1970	102(31)	208(3 1)	295(3 1)	401(4)
1971	102(26)	254(26)	358(15)	386(2 1)
1972	112(77)	279(77)	330(15)	
1973	97(85)	269(85)	437(4)	493(4)
1974	9(18)	330(18)	452(18)	
1975	97(65)	305(65)	383(26	409(4)
1976	44(49)	277(49)	371(39)	409(15)
1977	104(93)	264(93)	358(55)	396(3)
1978	104(116)	264(116)	335(68)	
1979	76(128)	244(128)		
Pre-impoundment averages				
1969-1971	104(76)	216(50)	295(19)	--
Post-impoundment averages				
1972-1976	104(294)	287(27 1)	373(83)	412(44)
1977-1979	97(337)	262(386)	353(188)	406(22)

May and Huston 1983

Table 10. Summary of data from rainbow trout spawning runs from Kootenai River into Pipe Creek, Libby Creek, and Bobtail Creek, 1976-1981. Box traps were fished in Pipe, Libby and Bobtail Creeks,

Time trap in operation	Days trap in operation vs. length of run	Number of spawners	Average length in mm		Sex ratio Male-Female
			Male	Female	
Bobtail Creek					
Mar 25-May 25, 1977	33	131	350	437	0.7 : 1.0
Mar 21-May 8, 1978	70-74	155	297	414	3.1 : 1.0
Mar 22-Jun 4, 1979		382	287	356	1.0 : 1.0
Mar 26-Jun 1, 1980	54-68	205	262	345	2.3 : 1.0
Pipe Creek 1/	18				
Mar 18-Apr 5, 1976	46	54	361	465	3.5 : 1.0
Mar 3-May 20, 1977		78	358	442	0.8 : 1.0
Mar 17-Apr 20, 1981	22	85	287	335	1.4 : 1.0
Libby Creek 1/		49			
Mar 24-Apr 5; 1976	13	49	409	472	1.5 : 1.0
Mar 14-Apr 27, 1977	23		411	485	0.7 : 1.0
Apr 16-Apr 24, 1981	8	67	368	394	2.5 : 1.0

1/ Traps only fished during part of the spawning run.

May and Huston 1983

Table 11. Numbers of fish electrofished and observed (x) in Kootenai River tributaries, 1980-1982.

Creek location	Rb[a]	Ct	RbxCt	EB	DV	MWf	Kok	Bur	LC	LND	RsS	NSf	Pm	LsSu	LnSu	BrB	Ps	YP	SlSc	TSc
Boundary #1	4						2			21					X	1			8	
Boundary #2	10					x				16										
Smith #1	2					1	1			18	2								17	
Smith #2	1					1	x	1											4	
Long Canyon	2			1		1	x			19									8	
Parker	2			18			x			7									16	
Trout			14				x												66	
Ball	18	4					x			1									3	
Burton	56			3															1	
Myrtle	3			x		2	x			2									9	
Cascade	35																			
Deep #1	26				x	1		x		97							3			10
Deep #2	43					4				120		1					1			4
Deep #3	57			1		2				17	1	11					2	84		10
Deep #4	41			5						63	30				x	x	x	67		9
Deep #5				15					12											
Snow	36			2		1				28									12	2
Caribou	17									3									14	1
Ruby #1	21.			1						14							1			
Ruby #2	74			2																
Ruby #3	50																			
Falls #1	36	1	1	6		x				74										9
Falls #2	34	1		4																36
Falls #3				14																15
Twenty Mile	65		1	34																
Trail #1	39			1						3										
Trail #2	62																			
Trail #3	56		1	15																
Dodge	83			35													6			
Caboose	1																			
Debt	5			2																
Curley	16			2	1	1				12										
Boulder #1	21						x			27										2
Boulder #2	15																			
Moyie River	x					x						x		x						x

[a] Rb-Rainbow trout; Ct-Cutthroat trout; RbxCt-Rainbow cutthroat trout; EB-Eastern brook trout; DV-Bull trout; MWf-Mountain whitefish; Kok-Kokanee; Bur-Burbot; LC-Lake chub; LND-Longnose dace; RsS-Redside shiner; NSf-Northern squawfish; Pm-Peamouth; LsSu-Largescale sucker; LnSu-Longnose sucker; BrB-Brown bullhead; Ps-Pumkinseed; YP-Yellow perch; SlSc-Slimy sculpin; TSc-Torrent sculpin.

Partridge 1983

length. Partridge (1983) reported trout run sizes in the Deep Creek drainage (Figure 14) was considerably less than runs into tributaries above Kootenai Falls where May et al. (1981) reported sampling 54 to 85 rainbow spawners in Pipe Creek from 1976-1981. Long-time residents also state that the trout runs in the Deep Creek drainage were substantially larger several years ago. The decreased quality of trout spawning areas due to man's impacts and the limited access in most of the tributaries in Idaho due to natural barriers at the edge of Kootenai Valley have resulted in only 8.9 km of good spawning habitat in Idaho accessible to trout from the Kootenai River (Partridge 1983). The total number of rainbow and cutthroat trout caught in most tributary streams in 1993 and 1994 exceeded or was similar to what was found in Partridge (1983). The one exception to this statement is that in Burton Creek, 56 rainbow and cutthroat trout were caught in 1983 as opposed to 10 in 1993 and 1994 (Paragamian 1994).

Mountain whitefish catch rates in the Jennings section of the river (Figure 20) from, 1972 to 1975 decreased due to the high levels of gas saturation caused by the beginning 'operations of Libby Dam (May and Huston 1983). Between 1977 and 1981, the catch of whitefish increased to near 1971 levels. Mountain whitefish catch rates in the Elkhom section of the river (Figure 20) followed a similar trend, with a decrease from 40 to 14 fish per hour noted between 1971 and 1974. Catch rates increased to 56 fish per hour in 1980. The 1980 population estimate in the Elkhorn section was 1,059 whitefish per 300 meters of river (May and Huston 1983). Mountain whitefish comprised 15.8 percent of the catch in the Troy section of the river (Figure 20) in 1971 compared to 60.7 percent in 198 1. Over 6,000 whitefish were sampled by electrofishing at the Hemlock Bar (Figure 14) reach of the Kootenai River from 1980 to 1982, whereas only 1,500 whitefish were sampled between 1993 and 1995 using a similar method (Partridge 1983, Paragamian 1994 and 1995). Records from 1966 to 1980 show that the @-impoundment growth rates of mountain whitefish were considerably less than in post-impoundment years (May and Huston 1983).

Mountain whitefish spawn in tributary streams as well as in the mainstem of the Kootenai River, and spawning and rearing habitat is considered to be excellent throughout the entire river downstream of Libby Dam (May and Huston 1983). The number of spawning whitefish captured in the Fisher River from 1969 to 1975, 1,978 and 1979 increased from 2,000 fish in 1969 to 20,000 and 30,000 in 1978 and 1979. A total of 3,403 spawners were trapped in Libby Creek (Figure 20) in 1976 as compared to 6,675 in 1978. This is an estimated run size of 5,000 in 1976 and 10,000 fish in 1978 (May and Huston 1983).

Historically, mature kokanee salmon moved into the Kootenai River from Kootenay Lake in early June, and began entering the tributaries in early August to begin spawning. Small spawning runs of kokanee ascended the Yaak River, Callahan Creek and Lake Creek (Figure 20) in September and October, 1971 (May and Huston 1975). These runs have not been sampled, and their current status is unknown. The origin of these fish was thought to be Kootenay' Lake. In 1981, an estimated 3,650 kokanee were observed spawning in Parker, Long Canyon, Smith and Boundary creeks (Table 12), an increase from the estimated 2,500 fish observed in these creeks in 1980 (Partridge 1983). In spite of this slight increase from 1980 to 1981, kokanee runs in Idaho from Kootenay Lake have decreased over the years due to the loss of spawning areas from stream channelization and the increase in fine sediments in most of the westside streams. Out of the eight

Table 12. Number of kokanee observed in selected portions of four tributaries to the Kootenai River, 1981.

Date	Parker (790 m)	Long Canyon (700 m)	Smith (380 m)	Boundary (610 m)
15 July	0	0	0	0
10 Aug.	90	125	40	22
18 Aug.	120	210	77	140
24 Aug.	300	580	175	520
30 Aug.	260	980	200	640
6 Sept.	105	760	300	470
14 Sept.	0	87	113	80
	Estimated peak number for entire stream			
	350	1,600	600	1,100

Partridge 1983

valley streams (Figure 14), only Parker, Long Canyon, Smith, and Boundary had significant runs of kokanee remaining in them as of 198 1. Anders (1993), reported that only 82 live kokanee and three kokanee carcasses were observed exclusively in Long Canyon and Parker creeks between August 26 and October 5, 1993.

The burbot population in the Kootenai River is mainly composed of mature fish that move into the river from Kootenay Lake during the fall and winter to spawn in the river or its tributaries (Partridge 1983). Prior to 1960, burbot in the Kootenai River were abundant, but populations declined drastically in the early 1960's, and continued to decline until 1972. This decrease was probably related to chemical and sediment pollution of the river during this time (May and Huston 1983). Despite the tremendous decrease in burbot numbers in the 1960's, a limited number of burbot were captured in the Flower-Pipe section of the river during electrofishing-fishing surveys in March, 1979. Par&ridge (1983) reported a significant decrease in burbot populations in the Kootenai River between 1957 to 1958 (214 burbot) and 1979 to 1982 (38 burbot), with only six percent as many fish being caught using the hoop net method of capture.

Between 1979 and 1982, only one adult burbot was sampled in the lower portion of Deep Creek (Partridge 1983). Although burbot were observed spawning in river tributaries under the ice prior to the decline in the population, it is most likely that significant spawning also occurred in the river in quiet backwaters and along side channels similar to spawning grounds found On rivers in the Lake Baikal region of U.S.S.R. (Sorokin 1971). Sorokin found that burbot spawn&i in these areas of low velocity, with the eggs settling into crevices in the cobble and debris, where they remained until hatching or the increased flows of spring runoff dislodged them. 'The increase in river levels and velocities, along with daily fluctuations in river levels in the Kootenai River during the early spawning period of January-February since the construction of Libby Dam, has probably eliminated most of the traditional burbot spawning areas in the Kootedai River and may he an important factor in keeping the burbot population depressed. Higher water temperatures during the winter months may also be detrimental to burbot spawning" (Partridge 1983).

The burbot stock in Idaho remains at a very low density with little or no reported reproduction (Paragamian 1994 and 1995). The mean size ofburbot captured from 1979 to 1982 were considerably larger on average than those caught between 1957 to 1958 'at each age class (Figure 21). The introduction of Mysis shrimp into Kootenay Lake may be the main reason for the increased burbot growth rates seen after the 1950's. Bailey (1972) reported that these shrimp were found to be an important food item for burbot in Lake Superior, where they averaged 21.5 percent of the volume of food items in the stomachs during the year. The number of burbot caught in hoop nets decreased by approximately 20 fish from the early 1980's to the early 1990's (Partridge 1983, Paragamian 1994 and 1995).

The earliest catch data for Kootenai River white sturgeon consisted only of creel reports collected by game wardens (Graham 1981, Partridge 1983, Apperson and Anders 1991), rather than population estimates. Population estimates for white sturgeon in the river were first calculated in the late 1970's when moderate-scale population studies were initiated.

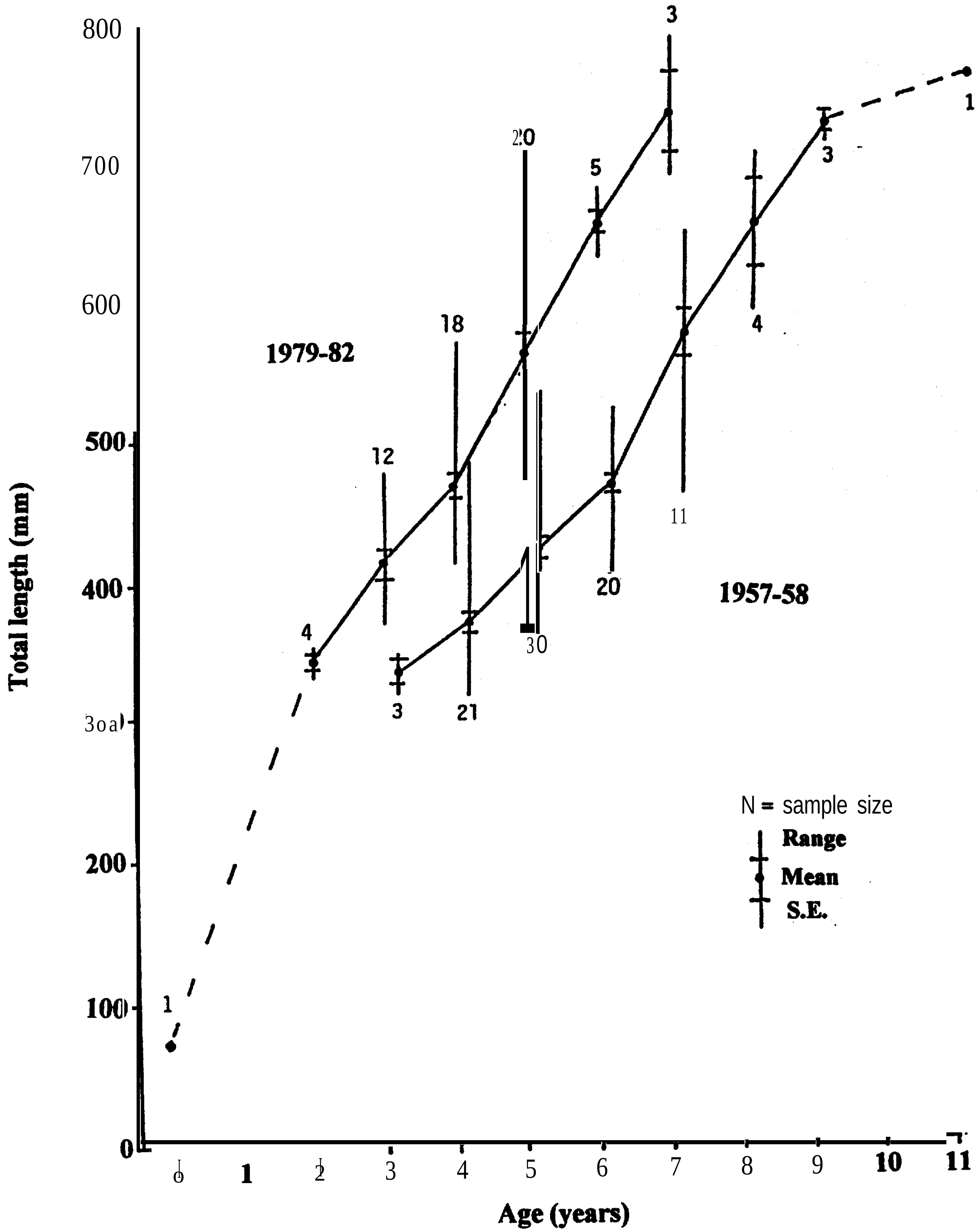

Figure 21. Age-size relationship of burbot in the Kootenai River, Idaho, during 1957-58 and *1979-82. (Partridge 1983)*

A total of 394 sturgeon were tagged in Idaho between 1977 and 1982 (Partridge 1983). An additional 143 sturgeon were tagged by British Columbia Fish and Wildlife branch personnel near the mouth of the river at Kootenay Lake between 1977 and 1980 (Partridge 1983). Montana also conducted sturgeon studies in 1975 to 1976, 1978 and 1980. During this time, the Montana Department of Fish, Wildlife, and Parks tagged five sturgeon below Kootenai Falls (Partridge 1983). During the period from 1968 to 1972, information from angler logs was obtained by Montana. Graham (1981) reviewed the data and estimated the sub-adult to adult segment of the Kootenai River white sturgeon population as being 4,000 to 6,000 fish. This estimation included several thousands of fish in B.C., 800 to 900 in Idaho, and only one to five adults in Montana (Lane 1991, Andrusak 1980, Graham 1981).

The age-class structure of the sturgeon population in the Kootenai River is considered to be unbalanced. In order for the population to become balanced, it must contain a greater number of smaller, younger fish, rather than larger, older fish (Giorgi 1993). Data from Apperson (1992), and from samples taken from 1977 to 1982 (Partridge 1983) indicated a population comprised mostly of larger (older) individuals. Partridge's data indicated recruitment occurring during the years 1972 to 1977, with a dominant 1974 year-class. However, that was the only year-class since approximately 1961 that was identified as providing substantial recruitment to the population (Partridge 1983).

Based on tag recoveries, an estimated 1,148 sturgeon inhabited the river stretch between Bonners Ferry, ID, and Porthill at the Canadian border during 1979 to 1981 (Partridge 1983). Apperson and Anders (1991) estimated a total of 880 sub-adult to adult white sturgeon inhabiting the Kootenai River between Bonners Ferry and Kootenay Lake in 1990. In 1993, the Bonneville Power Administration (BPA) estimated that the Kootenai River population had declined to approximately 785 individuals based on (1) the 1990 population estimate, (2) recent estimates of annual mortality (3.7 %), and (3) assuming no natural recruitment since 1990. Given the 1990 population estimate, and an annual mortality rate estimate of 3.7 percent coupled with continuing minimal recruitment in the future, the population may further decline to an estimated 648 individuals by 1998 (BPA 1993). These estimates demonstrate that the sturgeon population in the Kootenai River has been steadily declining since the early 1980's. This trend will most likely continue until there is progress with Kootenai River ecosystem enhancement measures. Subsequently, the Kootenai River white sturgeon population was listed as endangered on September 6, 1994 (59 FR 45989) under the authority of the Endangered Species Act of 1973.

Lake Koocanusa

In 1972, the Montana Department of Fish, Wildlife, and Parks initiated an annual westslope cutthroat trout stocking program, which was terminated in 1976. By 1990, westslope cutthroat trout were still common in the reservoir (Hamilton et al. 1990). The majority of the kokanee stock in the reservoir originated from an accidental release of 250,000 fry from the Kootenay Trout Hatchery in 1980 (Hamilton et al. 1990).

Before Libby Dam was completed, the fishery in the upper Kootenai River consisted primarily of cutthroat trout, rainbow trout, mountain whitefish, and burbot. Immediately a&r impoundment, both trout species and mountain whitefish were common in gill net catches in Lake Koocanusa and then they began to decline in abundance (Hamilton et al. 1990). Chishohn et al. (1989) and Hamilton et al. (1990) reported that ten species of game fish, of which westslope cutthroat trout, bull trout, mountain whitefish, and burbot were common, and seven non-game species were present in the reservoir, of which yellow perch and longnose sucker were common. Of all the fish species present in the reservoir, kokanee and yellow perch were unintentionally introduced (Hamilton et al. 1990).

Since impoundment of the Kootenai River in 1972, the fish community of Lake Koocanusa has undergone a number of changes. The initial increase in nutrients due to the inundation of substrates was followed by a surge in fish biomass. There was an increase in biomass of several native species such as westslope cutthroat and rainbow trout, mountain whitefish, peamouth, northern squawfish, and two sucker species. The kokanee, which were introduced to the reservoir in 1979, responded well to the impoundment, while the cutthroat and rainbow trout were declining. Possible factors contributing to this trend include competition for available food, loss of spawning and rearing habitat due to deep drawdown levels, and flushing of nutrients out of the reservoir. Another trend that is evident since the impoundment is the increase in peamouth biomass, which is due to the creation of large areas of favorable habitat (S. Dalbey, Montana Fish, Wildlife, and Parks, personal communication).

The changes that have taken place in the fish populations of the reservoir since impoundment include the presence of two new species; kokanee and yellow perch. Kokanee were released into the reservoir from the Kootenay Trout Hatchery in British Columbia, and yellow perch may have come from Murphy Lake (Huston et al. 1984). Peamouth and squawfish have increased in abundance since impoundment in 1972, whereas mountain whitefish, rainbow trout, westslope cutthroat trout, and redside shiners, which were once common in the reservoir, have declined in numbers since installation of Libby Dam (Chisholm et al. 1989).

Peamouth were considered by Huston et al. (1984) to be rare in the Kootenai River before impoundment. Chisholm et al. (1989) stated that since 1979 peamouth have become the most abundant fish captured in the reservoir's fall gillnetting series. Other fish species that were rare before impoundment and have become more prominent since installment of Libby Dam include northern squawfish and longnose suckers. Although burbot were uncommon in the Kootenai River before impoundment, there was a gradual increase in their abundance from 1978 through 1987 (Chishohn et al. 1989). Kokanee were the second most abundant fish species captured in the reservoir from 1978 through 1987. Mountain whitefish numbers have declined since impoundment, along with rainbow and westslope cutthroat trout, which have both declined gradually since 1978 (Chishohn et al. 1989).

RECOMMENDATIONS

1. Obtain a complete and thorough macroinvertebrate data-base in order to provide a comprehensive ecosystem assessment for the Kootenai River.

The synthesis of published and unpublished fisheries and aquatic biological data from the Kootenai River system reveals a lack of macroinvertebrate data for the Idaho portion of the Kootenai River, and for the major tributaries in both Idaho and Montana. Invertebrates are an important link between nutrient supply and food availability for fish in river ecology, and a more extensive invertebrate data-base will produce valuable information on the transfer of energy throughout each trophic level.

2. Identify opportunities to restore natural floodplain functions along the Kootenai River.

The restoration of floodplain functions along the Kootenai River is a plan action, listed in the white sturgeon draft recovery plan (1996), prepared by the U.S. Fish and Wildlife Service. This plan action is aimed at restoring natural recruitment of white sturgeon to the population. Diking of river banks and channelization of streams have eliminated a significant amount of sloughs and backwater areas along the Kootenai River valley that were historically used for feeding and rearing of young sturgeon and other fish species. It is evident from the data presented in this report, that primary productivity in the Kootenai River system is low, and this ultimately has adverse affects on the fish. The immediate goal is to enhance the aquatic ecosystem in such a way that will provide for a healthy fishery of white sturgeon, burbot, kokanee, rainbow trout and mountain whitefish; species that were fished in the past. Opening up backwater areas would' enhance the aquatic ecosystem by promoting nutrient exchange, therefore increasing primary productivity and ultimately enhancing the fisheries of the Kootenai River system.

3. Construct a working model of the Kootenai River system that will be used in developing best management options for the Kootenai River aquatic ecosystem.

With all of the complex components of the Kootenai River aquatic ecosystem, the best approach for determining feasible enhancement measures will be to develop a working computer simulation model of the system. This model will be used to make quantitative predictions about the response of the system to various management options. The model will be developed using the Adaptive Environmental Assessment (AEA) workshop process, "where a senior scientist with programming experience works with an interdisciplinary group of participants to translate the ideas, data, and policy concerns of that group into a working model" (Ashley and Shepherd, 1996).

The ABA workshop process was developed at the University of British Columbia in the 1970's and has been used approximately 150 times since then. 'While the ultimate aim of the ABA process is to produce useful simulation models for management, the initial aim in the workshop development is to clarify research priorities by directing attention to: (1) processes that are key to the model predictions but are difficult to quantity, (2) discrepancies between historical data and model predictions, and (3) alternative hypotheses that would give rise to the same predictions" (Ashley and Shepherd, 1996). The modeling process will also provide the opportunity to filter out hypotheses which could lead to futile management efforts.

In order for the AEA process to work efficiently, it is imperative that international, federal, provincial, state, and tribal agencies cooperate in the exchange of data, ideas, and concerns. Provided that everyone can work together effectively, the AEA process will present an excellent opportunity for developing best management practices that will enhance the Kootenai River aquatic ecosystem.

LITERATURECITED

Alden, W.C. 1953. Physiography and glacial geology of Western Montana and adjacent areas. Geological Survey Professional Paper 23 1. U.S. Government Printing **Office.**

Anders, P.J. 1993. Kootenai River fisheries studies. Report C: Kootenai River tributary kokanee spawning ground survey. Prepared for U.S. Department of Energy, Bonneville Power Administration. Project No. 88-64. Portland, OR

Andrusak, H. 1980. Kootenay River white sturgeon. British **Columbia Ministry** of **Environment-** Fish and Wildlife Branch. Nelson, British Columbia.

Andrusak, H. and M.A. Crowley. 1977. Kootenay Lake sport fishery. British Columbia Fish and Wildlife Branch, Victoria, B.C. Unpub. rep.

Apperson, K.A. 1992. Kootenai River white sturgeon investigations and experimental culture. Annual Progress Report FY 1991. Prepared for U.S. Department of Energy, Bonneville Power Administration. Project No. **88-65**. Portland, OR.

Apperson, K.A. and P.J. Anders. 1991. Kootenai River white sturgeon investigations and experimental culture. Annual Progress Report FY 1990. Prepared for U.S. Department of Energy, **Bonneville** Power Administration. Project No. **88-65**. Portland, OR

Ashley, K. and Shepherd, B. 1996. Okanagan Lake workshop report and action plan. Fiies Project Report No. RD 45, Ministry of Environment, Lands and Parks, Province of British Columbia.

Ashley, K. and L. Thompson. 19%. Kootenay Lake fertilization experiment, Year 3 **(1994/95)** report. Fisheries Project Report No. RD 49, Ministry of Environment, Lands and Parks, Province of British Columbia.

Ashley, K. and L. Thompson. 1994. Kootenay Lake fertilization experiment, Year 2 **(1993/94)** report. Fisheries Project Report No. RD 41, Ministry of Environment, Lands and Parks, Province of British Columbia.

Ashley, **K.** and L. Thompson. 1993. Kootenay Lake fertilization experiment, Year **1 (1992/93)** report. Fisheries Project Report No. RD 32, Ministry of Environment, Lands and Parks, Province of British Columbia.

Bailey, **M.M.** 1972. Age, growth, reproduction, and food of the burbot, **Lota lota (Linnaeus),** in southwestern Lake Superior. Transactions of the American Fisheries Society **101 (4):667-** 674.

Bayley, P.B. 1995. Understanding large river floodplain ecosystems. ***Bioscience.*** Vol. 45, ***No. 3.***

Bonde, J.H. 1987. The Libby Dam/Lake Koocanusa project. Prepared for U.S. Army Corps-of Engineers, Seattle District. Shapiro and Assoc., Seattle, Washington.

Bonde, T.J.H. and RM. Bush. 1982. Limnological investigations: Lake **Koocanusa,** Montana, part 1, preimpoundment study, 1967-l 972. U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.

Bonde, T.J.H. and R.M. Bush. 1975. Kootenai River water quality investigations: Libby Dam preimpoundment study, 1967-l 972. U.S. Army Corps of Engineers, Seattle, Washington.

Bonneville Power Administration. 1993. Comments on the proposal to list the Kootenai River population of white surgeon as endangered under the Endangered Species Act. November 18, 1993.

Chisholm, I., M.E. Hensler, B. Hansen, and D.S. Skaar. 1989. Quantification of Libby Reservoir levels needed to maintain or enhance reservoir fisheries. Methods and data summary, **1983-** 1977. Prepared by Montana Department of Fish, Wildlife and Parks, Kalispell, Montana, for U.S. Department of Energy.

Cushing, C. 1964. Plankton and water chemistry in the Montreal River lake-stream system, Saskatchewan. Ecology **45:306-3** 13.

Cushman, R.M. 1985. Review of ecological effects of rapidly varying flows downstream **from** hydroelectric facilities. Transactions of the American Fisheries Society **5:330-339**.

Daley, RJ., EC. Carmack, C.B.J. Gray, C.H. Pharo, S. Jasper, **and R.C.** Weigand. 1981. The effects of upstream impoundments on Kootenay Lake, B.C. **Scientific** Series No. 117, National Water Research Institute.

Daley, R.J. and F.R. Pick. 1990. Phytoplankton biomass and composition of Kootenay Lake, British Columbia, following reductions in phosphorus loading. ***Verh. Intrnat. Verein. Limnol.*** **24:314-318**.

Eddy, S. 1932. The plankton of the Sangamon River in the summer of 1929. Illinois Natural History Survey Bulletin **19:469-486**.

Fretwell, S.D. 1987. Food chain dynamics: the central theory of ecology? Oikos **50:291-301.**

Giorgi, A. 1993. The status of Kootenai River white sturgeon. Report prepared for the **Pacific** Northwest Utilities conference Committee, September 1993.

Graham, P. 198 1. Status of white sturgeon in the Kootenai River. Montana Department of Fish, Wildlife, and Parks. Kalispell, Montana.

Graham, P. J. 1979. Kootenai Falls aquatic environment study, impact assessment. Montana Department of Fish, **Wildlife,** and Parks. Helena, MT.

Hamilton, **H.R.,** L.R **Linton,** P. Chow-Fraser, B. Taylor, and D. **Fernet.** 1990. Koocanusa Reservoir state of the aquatic environment 1972-1988. **HydroQual** Canada Limited, Province of British Columbia.

Huston, J.E., P.D. Hamlin, and B. May. 1984. Lake Koocanusa fisheries investigations **final** report. Prepared for U.S Army Corps of Engineers, Seattle District, Seattle, Washington.

Iskandar, I.K. and S.S. Shukla. 1981. Limnological investigations: Lake Koocanusa, Montana. Part 5: Phosphorus chemistry of sediments. Special Report 81-15. U.S. Army Engineer District, Seattle.

Jones, **J.R.** and **Bachman,** R. 1976. Prediction of phosphorus and chlorophyll levels in lakes. ***Journal of Water Pollution Control Fe&ration.*** **48:2176-2** 182.

Junk, W.J., P.B. Bayley, and RE. Sparks. 1989. The flood pulse'concept in river-floodplain systems. Canadian Special Publication. ***Fish Aquatic Sciences.*** ***106:*** 1 IO-1 27.

Knudson, K. 1994. Water quality status report, Kootenay (Kootenai) River Basin, British Columbia, Montana and Idaho. The Kootenai River Network.

Lane, E.D. 1991. Status **of white** sturgeon, ***Acipenser transmontanus, in Canada. Canadian Field-Naturalist*** **105 *(2):* 16 1.**

Lasenby, D.C., R.J. Daley, and S. Jasper. 1979, Kootenay Lake, B.C. XX. Net zooplankton and Mysis **relicta**. National Water Research Institute, West Vancouver, B.C. Unpub. Data Report.

Larkin, PA. 195 1. Summary of investigation conducted by the Fisheries Research Group, attached to the British Columbia Game Department, in 1949. Annual Report of the British Columbia Game Commission for 1949.

Likens, G.E. 1975. Primary production of inland aquatic ecosystems. In: Primary productivity of the biosphere (I-I. Lieth and RH. Whittaker Eds.). New York: Springer-Verlag.

May, B. and J.E. Huston. 1983. Fisheries investigations, July **1972-September** 1982. In: Kootenai River Fisheries Investigations. Final completion report, 1983. Montana Department of Fish, **Wildlife** and Parks.

May, B. and J.E. Huston. 1979. Kootenai River Fisheries Investigations. Completion Report. Mont. Dept. Fish, **Wildl.,** and Parks. Contract No. DACW 67-76-C-0055. Helena, MT.

May, B. and J.E. Huston. 1975. Status of fish populations in the Kootenai River below Libby Dam following regulation of the river. Final Job Report, Cont. No. DACW 67-73-C-003. Mont. Dept. Fish and Game. Helena, MT.

May, B., S. Perry, J. Huston, and J.D. Santos. 1981. Kootenai River fisheries investigations. Montana Department of Fish, Wildlife and Parks, Fisheries Division, Annual Progress Report.

Morris, D.P. and W.M. Lewis. 1988. Phytoplankton nutrient limitation in Colorado mountain lakes. ***Freshwater Biology.*** **20**:**3** 1 S-27.

Northcote, T.G. 1973. Some impacts of man on Kootenay Lake and its sahnonoids. Great Lakes Fisheries Commission Tech. Rep. 25.

Paragamian, V.L. 1995. Kootenai River fisheries investigation: Stock status of burbot and rainbow trout and fisheries inventory. Idaho Department of Fish and Game, Annual Progress Report FY 1995, Project No. 88-65, Boise, ID.

Paragamian, V.L. 1994. Kootenai River fisheries investigation: Stock status of burbot and rainbow trout and fisheries inventory. Idaho Department of Fish and Game, **Annual** Progress Report FY 1994, Project No. 88-65, Boise, ID.

Partridge, F. 1983. Kootenai River fisheries investigations. Idaho Department of **Fish** and Game. Job Completion Report, Project F-73-R-5, Boise, ID.

Perry, S. and J. Huston. 1983. Aquatic insect study, October **1979-June** 1982. In: Kootenai River Fisheries Investigations. Final completion report, 1983. Montana Department of Fish, Wildlife and Parks.

Randall, L.F., **Roelops,** and T.J. Fry. 1986. The importance of algae to stream invertebrates. ***Journal of the North American Benthologicai Society*** **5**:**290-296**.

Rocchini, R.J., J.C. **Arber,** J.J. Feddes, L. Gregory, R. **Nording,** J. Olan, D. Parsons, and L. Pommen. 1976 B. Kootenay air and water quality study, region 4, lower Kootenay River basin. BC Dept. of Environment. Water Resources Services. Victoria, BC.

Snyder, E.B. and G.W. Minshall. 1996. Ecosystem metabolism and nutrient dynamics in the Kootenai River in relation to impoundment and flow enhancement for fisheries management. Final Report. Stream Ecology Center, Idaho State University, Pocatello.

Snyder, E.B. and G.W. Minshall. 1994. Ecosystem metabolism and nutrient dynamics in the Kootenai River in relation to impoundment and flow enhancement for fisheries management. Annual Report. Stream Ecology Center, Idaho State University, Pocatello.

Sorokin, V.N. 197 1. The spawning and spawning grounds of the **burbot (Lota lota [L.]).** Limnological Institute, Siberian Division, U.S.S.R. Academy of Sciences.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. ***Bioscience.*** Vol. 45, No. 3: 168-182.

Sparrow, RAH., P.A **Larkin,** and RA **Ruherglen.** 1964. Successful introduction **of *Mysis relicta* (Loven)** into Kootenay Lake, British Columbia. J. Fish. Res. Board Can. **21(5);1325-1327**.

Storm, P.C. et al. 1982. Limnological investigations: Lake **Koocanusa,** Montana, part 3, basic data, post impoundment, 1972-1978. U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.

U.S. Fish and Wildlife Service. 1996. White sturgeon: Kootenai River population ***Acipenser transmontanus,*** draft recovery plan. U.S. Fish and Wildlife Service, Region 1. Portland, Oregon.

Vollenweider, RA. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. ***Mem. Ist. Ital. Idrobiol.* 33:53-83**.

Vollenweider, RA. 1968. **Scientific** fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as **factors** in eutrophication. Paris, Rep. **Organization** for Economic Cooperation and Development, **DAS/CSI/68.27**.

Wetzel, R.G. 1983. Limnology. Second edition. Saunders College Publishing, Toronto.

Wetzel, RG. 1975. Limnology. Saunders College Publishing, Toronto.

Whitfield, P.H. and P.F. Woods. 1984. Intervention analysis of water quality records. ***Water Resources Bulletin,*** Paper No. 84016. American Water Resources Association.

Woods, P.F. 1982. Annual nutrient loadings, primary productivity, and **trophic** state of Lake Koocanusa, Montana and British Columbia, 1972-80. Geological Survey Professional Paper 1283, United States Government Printing Office.

Woods, P.F. 1979. Primary productivity in Lake Koocanusa, Montana. Ph.D. Thesis. University of Idaho, Moscow, Idaho.

Woods, P.F. and C.M. Falter. 1982. Limnological investigations: Lake Koocanusa, Montana, part 4, factors controlling primary productivity. U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.