Influence of Water Level Drawdown on the Fish Populations of Cross Lake, Manitoba

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Regulated discharges into Cross Lake, Manitoba, resulted in average summer water volumes in 1980 and 1981 that were 49% lower than preregulated volumes. Water level drawdown in the summer reduces the amount of available habitat. Consequently, the standing crops of lake whitefish (*Coregonus clupeaformis*), walleye (*Stizostedion vitreum vitreum*), northern pike (*Esox lucius*), and cisco (*Coregonus artedii*) are lower now than in preregulation and early postregulation years. Unusually early and rapid drawdown in March 1981 resulted in a severe winterkill, causing a substantial decrease in catches per unit of effort (CPUE) for most species from 1980 to 1981. The most affected species were whitefish and cisco, which showed a 50% reduction in CPUE from 1980 to 1981. The amount of fall to late spring drawdown and the year-class strengths of coregonid fishes were inversely related. A marked overwinter drawdown reduces whitefish and cisco hatching success apparently by dewatering their spawning areas and desiccating the eggs. Low water levels in spring prevented pike and walleye access to spawning areas.

Au cours des étés 1980 et 1981, les volumes moyens d'eau s'écoulant dans le lac Cross (Manitoba) étaient de 49% moins élevés par rapport à ceux d'avant le réglage du débit. La baisse du plan d'eau en été réduit le nombre d'habitats disponibles. Par conséquent, la biomasse du grand corégone (*Coreganus clupeaformis*), du doré jaune (*Stizostedion vitreum vitreum*), du grand brochet (*Esox lucius*) et du cisco de lac (*Coregonus artedii*) est actuellement moins élevée que pendant les années d'avant la régulation du débit ou au tout début de celle-ci. Une baisse exceptionnellement hâtive et rapide du plan d'eau en mars 1981 a entraîné une forte mortalité hivernale qui s'est traduite par une baisse importante des prises par unité d'effort pour la plupart des espèces par rapport à 1980. Le grand corégone et le cisco de lac, les espèces les plus touchées, ont accusé une baisse de 50% des prises par unité d'effort comparativement à 1980. Il existait une relation inverse entre, d'une part, la baisse du plan d'eau de l'automne à la fin du printemps et, d'autre part, l'abondance des corégonidés d'une classe d'âge. Une baisse prononcée de l'eau pendant la période hivernale diminue le succès de la reproduction du grand corégone et du cisco de lac car les frayères s'assèchent et les oeufs se déshydratent. De faibles niveaux d'eau printaniers ont empêché le grand brochet et le doré jaune d'atteindre les frayères.

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Hydroelectric development of the Nelson River included construction of the Jenpeg generating station to regulate the level of Lake Winnipeg and use it as a storage reservoir for generating stations farther downstream (Dickson 1975). Cross Lake (54°45′N, 97°30′W) (Fig. 1) is immediately downstream of Jenpeg and its water levels have been controlled by tailwater discharges from Jenpeg since 1974. The regulation regime has reversed the pattern of seasonal fluctuations in Cross Lake. Prior to regulation, the mean monthly water levels were highest in the summer, while now they are highest in the winter (Fig. 2).

The eastern portion of Cross Lake was commercially fished from 1959 to 1979, with an average annual harvest of 44 100 kg. Through this period, lake whitefish (*Coregonus clupeaformis*) and walleye (*Stizostedion vitreum vitreum*) were the premium species in the catch, comprising 81 and 17%, respectively. The western portion of the lake, reserved for unlicensed subsistence fishing, has an estimated annual harvest of 40 500 kg of lake whitefish and walleye (Gaboury and Patalas 1982).

Brief fisheries surveys conducted in 1965 (Driver and Doan 1972), 1973 (Ayles et al. 1974), and 1977 (B. H. Wright, Manitoba Department of Natural Resources, unpublished data) provided information on species composition and catch per unit of effort (CPUE). Koshinsky (1973) predicted that under the proposed hydroelectric operating regime at Jenpeg, productivity of lake whitefish, walleye, and northern pike (*Esox lucius*) would be reduced in Cross Lake because of lower summer levels and increased water level fluctuations.

Reports of catch declines by commercial and unlicensed fishermen in Cross Lake prompted this study to determine the impact of the current water level regime on lake morphometry and fish population dynamics.

Study Area

The west basin of Cross Lake consists of narrow, deep river channels as well as shallow lake areas, while the east basin is uniformly shallow. Since the Nelson River flows only through the west basin, the retention time is much shorter here than in the east basin. As the influence of Nelson River flows decreases from west to east, conductivity and total dissolved solids also decrease, while nutrient and organic carbon concentrations increase (Table 1). Similarly, mean plankton biomass is much

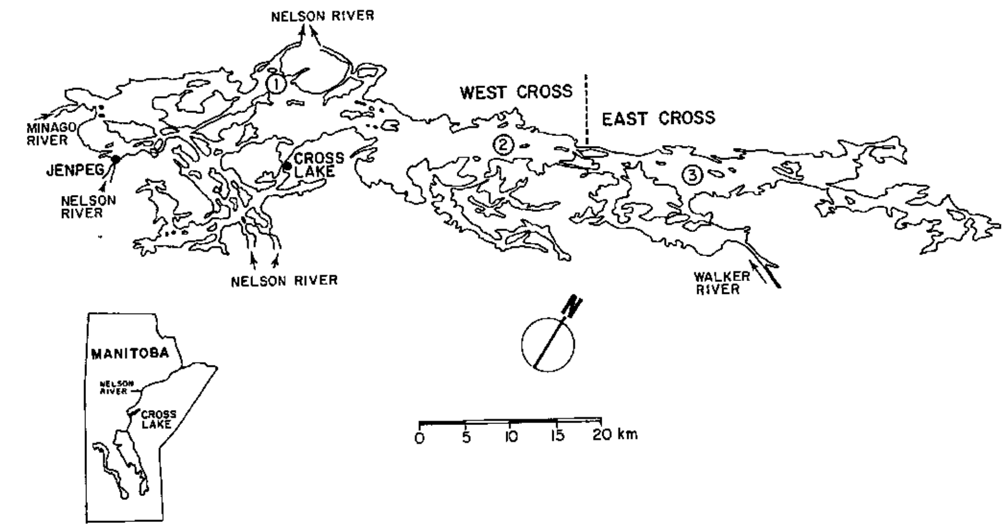

FIG. 1. Cross Lake showing locations of limnological stations (circled numbers).

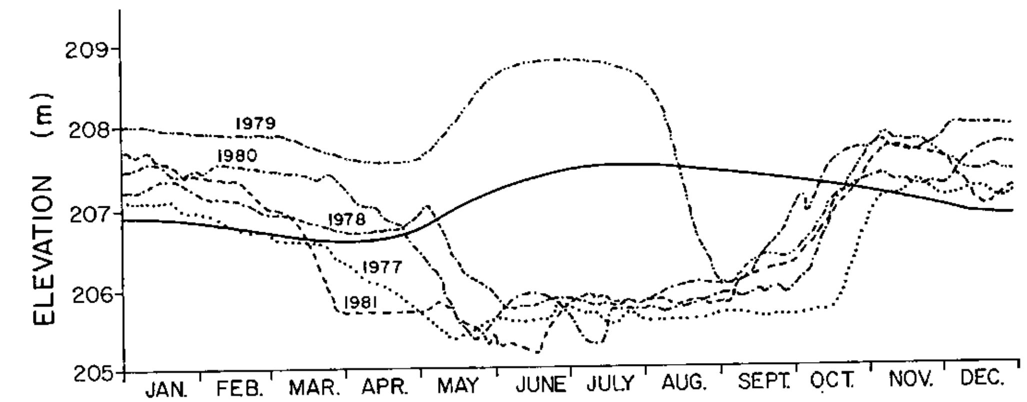

FIG. 2. Comparison of the average monthly water levels on Cross Lake under unregulated conditions (1918–73) (solid curve) and the daily levels recorded under regulation (1977–81) (data provided by the Manitoba Water Resources Branch). Standard error of unregulated hydrograph is ±0.10 m for each month.

TABLE 1. Physicochemical water quality and plankton biomass in Cross Lake, presented as means of monthly measurements from June through September (data from Cleugh 1974; Gaboury and Patalas 1981, 1982).

	1973	1980			1981		
Parameter	Stn. 1	Stn. 1	Stn. 2	Stn. 3	Stn. 1	Stn. 2	Stn. 3
Conductivity ($S \cdot cm^{-1}$)	277	289	220	139	314	196	118
Total dissolved solids ($mg \cdot L^{-1}$)	186	208	155	100	203	137	90
Total suspended solids ($mg \cdot L^{-1}$)	15	11	30	39	20	19	34
Total organic carbon ($mg \cdot L^{-1}$)	8.6	11.8	15.6	20.1	10.8	15.1	18.4
Total phosphorous ($mg \cdot L^{-1}$)	0.04	0.04	0.07	0.08	0.04	0.07	0.06
Total nitrogen ($mg \cdot L^{-1}$)	0.48	0.48	0.68	1.09	0.50	0.83	0.98
Plankton biomass ($mg \cdot m^{-3}$)	—	60	730	979	90	380	518

greater in the east than in the west basin. The water chemistry in the west basin in 1980 and 1981 was similar to that in 1973 (Cleugh 1974); however, there are no previous data on water chemistry in the east basin.

Materials and Methods

Morphometric Measurements

Cross Lake was sounded at a benchmark reference of 205.8 m, the average level recorded between May and September in 1980 and 1981. Aerial photographs were also taken to determine the shoreline at this lake level. The shoreline and depth contours at 205.8 m were transposed onto a map mozaic of Cross Lake composed of photographs taken at a high stage of 207.8 m. Calculations of lake area, volume, and mean depth at stages of 205.8 and 207.8 m were performed according to procedures described by Hutchinson (1957). Lake area at a stage of 207.1 m (historic mean open water stage) (Manitoba

TABLE 2. Morphometry of the west and east basins of Cross Lake at 207.1 m (historic stage for the open water season) and at 205.8 m (the average level between May and September in 1980 and 1981).

	Cross Lake stage			
	207.1 m		205.8 m	
Parameter	West	East	West	East
Area ($10^6 \cdot m^2$)	328	130	254	87
Volume ($10^6 \cdot m^3$)	847	198	470	58
Mean depth (m)	2.6	1.5	1.8	0.7
Maximum depth (m)	23.3	3.2	22.0	1.9

Water Resources Branch 1918–82) was determined from linear interpolation of the radii (r) (where area $\approx \pi r^2$) at stages 207.8 and 205.8 m. Using the interpolated area, volume at 207.1 m was calculated by determining the volume between 207.1 and 205.8 m and adding it to the volume at 205.8 m.

Fisheries

Fish were captured using a standard gang consisting of seven gill nets, each 22.9 m long by 1.8 m deep. Mesh sizes were in the following order: 3.8, 5.1, 7.6, 9.5, 10.8, 12.7, and 13.3 cm, stretched measure. Gangs were set at about 17:00 and were collected 16 h later. Fork length, weight, sex, and maturity were determined for lake whitefish, walleye, northern pike, and cisco (*Coregonus artedii*). Cisco were sampled only from the east basin of Cross Lake in both years. For age determination, opercula were taken from northern pike and otoliths from the other species. Procedures described by Snedecor and Cochran (1967) were followed for statistical analyses. Annual survival rates were computed according to Robson and Chapman (1961). The mean weighted age at onset of sexual maturity was calculated according to Abrasov (1967). Growth of fish was described using the von Bertalanffy model as outlined in Ricker (1975). For a more detailed description of sampling methods see Gaboury and Patalas (1981, 1982).

Results

Environment

Cross Lake water level decreased 1.7 m below the historic mean open water stage of 207.1 m at the minimum discharge from Jenpeg of ~20 $m^3 \cdot s^{-1}$. At 205.8 m, total lake area and volume had declined by 26 and 49%, respectively (Table 2). The west basin with its deep river channels and steep shorelines was less affected by drawdown than the east basin, where area and volume decreased by 33 and 71%, respectively, at 205.8 m. Most of the rock and cobble substrates in the lake were exposed under drawdown.

Bottom water temperatures in both basins were between 20 and 22°C for extended periods during July and August in 1980 and 1981. Maximum surface water temperatures of 26°C were recorded. Summer dissolved oxygen levels at the bottom ranged between 7.0 and 14.7 $mg \cdot L^{-1}$. Winter levels at the surface were between 7.1 and 12.9 $mg \cdot L^{-1}$ near the influence of river flows and between 0.9 and 2.4 $mg \cdot L^{-1}$ in areas where large tracts of submerged vegetation occurred in the summer.

Fisheries

Cisco was the most abundant species in catches in 1980 and

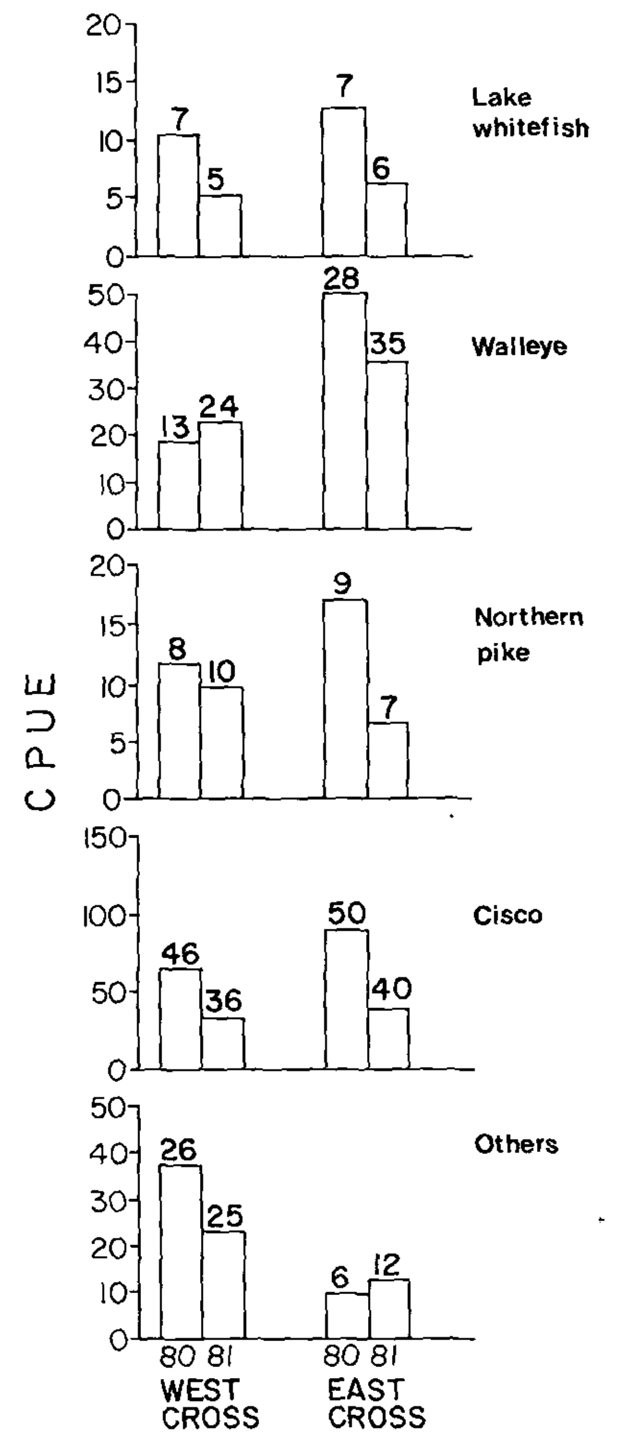

FIG. 3. Comparison of CPUE (number·standard gang$^{-1} \cdot$16 h^{-1}) and relative abundance (in % above bars) for fish captured in Cross Lake in 1980 and 1981 (see text for other species).

1981, averaging 43% of the total catch, followed by walleye (24%), northern pike (9%), and lake whitefish (6%) (Fig. 3). Other species caught, in order of abundance, included white sucker (*Catostomus commersoni*), yellow perch (*Perca flavescens*), mooneye (*Hiodon tergisus*), sauger (*Stizostedion canadense*), shorthead redhorse (*Moxostoma macrolepidotum*), longnose sucker (*Catostomus catostomus*), freshwater drum (*Aplodinotus grunniens*), goldeye (*Hiodon alosoides*), burbot (*Lota lota*), and common carp (*Cyprinus carpio*). From 1980 to 1981, walleye increased in relative abundance, cisco decreased,

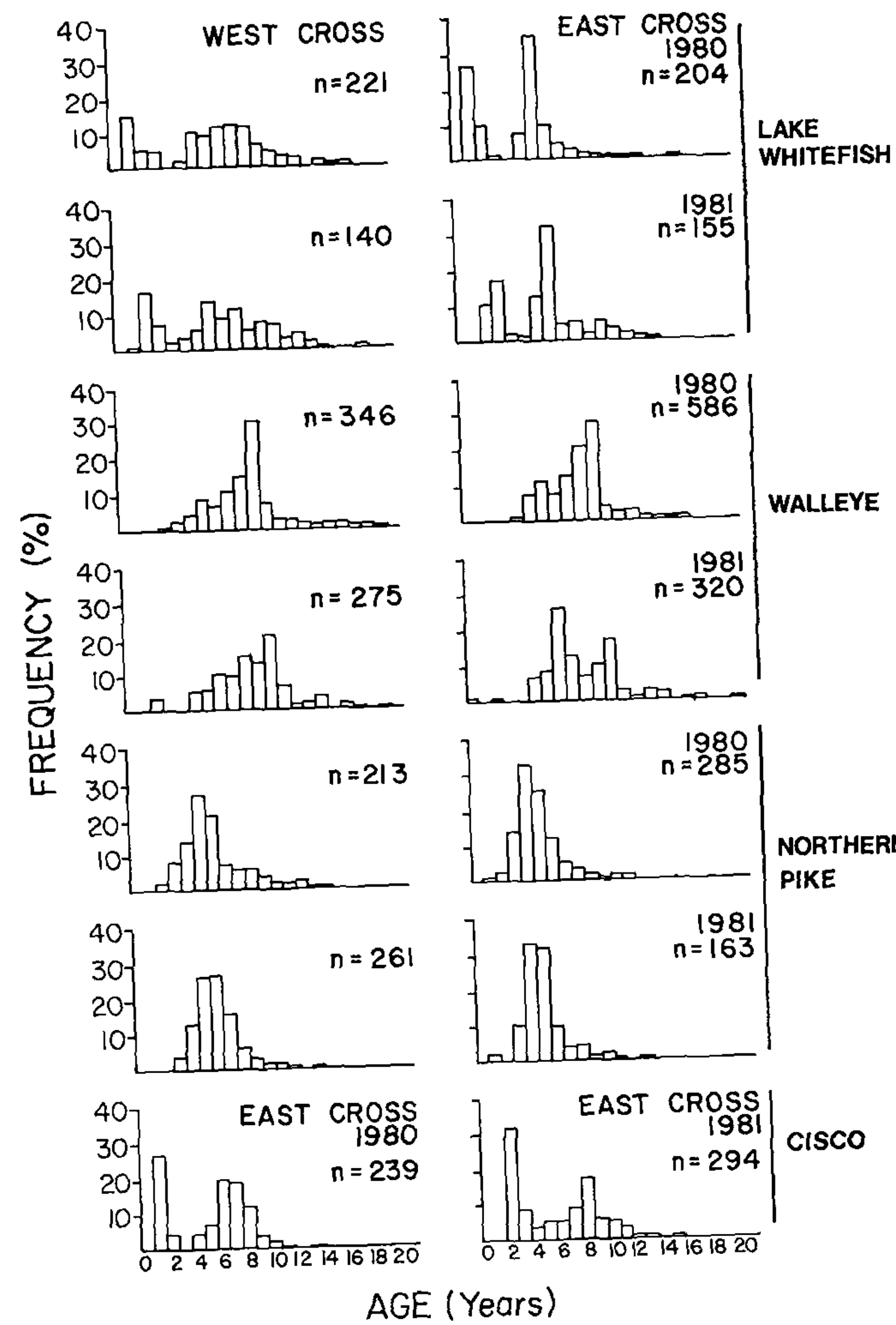

FIG. 4. Age–frequency distributions of lake whitefish, walleye, northern pike, and cisco caught in Cross Lake in 1980 and 1981.

and lake whitefish and northern pike remained unchanged. CPUE of lake whitefish, northern pike, and cisco decreased in both basins of Cross Lake from 1980 to 1981. CPUE of walleye increased in west Cross but decreased in east Cross. Lake whitefish and cisco showed the greatest declines, with CPUE 50% lower in 1981 than in 1980. Fish survival rates between 1980 and 1981 and between basins did not change significantly (Table 3).

Covariance analysis of Brody regressions indicated that the growth rates of lake whitefish, walleye, and northern pike were different ($P < 0.05$) between the east and west basins (Gaboury and Patalas 1981, 1982). For each species, the mean age at onset of sexual maturity (sexes combined) was similar between basins and between years (Table 3).

Fewer older lake whitefish and northern pike were caught in the east basin than in the west basin of Cross Lake (Fig. 4). Walleye had similar age distributions in both basins. Lake whitefish and cisco had bimodal age distributions with relatively

TABLE 3. Summary of growth parameters, mean age of maturity, and annual survival rates of Cross Lake fish (sexes combined) in 1980 and 1981. Growth was calculated according to the von Bertalanffy equation $L_t = L_\infty(1 - e^{-K(t - t_0)})$ where L_t is the fork length at age t, L_∞ is the asymptotic fork length, K is the Brody growth coefficient, and t_0 is the time when length would theoretically equal zero.

Species	Basin	Year	No. sampled	Growth K	Growth L_∞	Growth t_0	Mean age of maturity (yr)	Annual survival rate (S ± 2 SE)
Lake whitefish	West	1980	221	0.239	530	−0.232	5.50	0.567±0.127
		1981	140	0.256	523	−0.451	5.93	0.731±0.055
	East	1980	204	0.304	529	−0.312	5.30	0.526±0.164
		1981	155	0.305	531	−0.473	6.06	0.720±0.078
Walleye	West	1980	346	0.217	477	−0.265	7.65	0.723±0.105
		1981	275	0.227	464	−0.439	7.63	0.574±0.057
	East	1980	586	0.222	462	−0.838	7.38	0.651±0.166
		1981	320	0.186	466	−1.201	7.48	0.697±0.038
Northern pike	West	1980	213	0.147	945	+0.057	3.95	0.600±0.092
		1981	261	0.211	784	+0.184	4.05	0.490±0.082
	East	1980	285	0.144	897	−1.128	3.07	0.465±0.108
		1981	163	0.131	947	−0.763	3.49	0.476±0.078
Cisco	East	1980	239	0.392	404	−0.436	2.90	0.444±0.051
		1981	294	0.372	410	−0.793	3.36	0.525±0.100

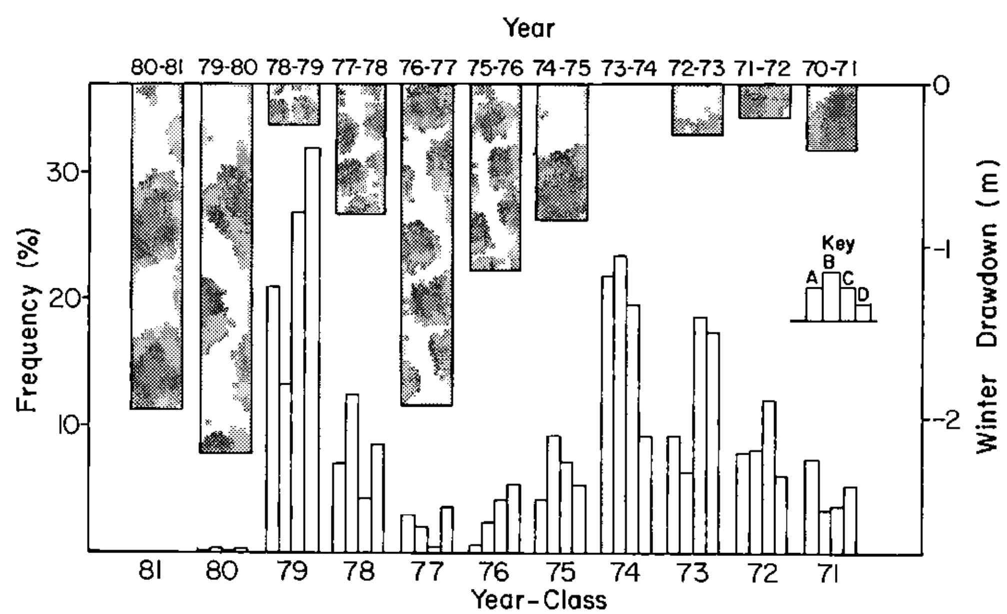

FIG. 5. Relationship between winter to spring drawdown in Cross Lake and lake whitefish and cisco year-class success, 1971–80. Winter and spring drawdown was calculated as the minimum level between October 28 and May 31 subtracted from the level on October 28. A, percent frequency of lake whitefish in 1980 gillnet catches; B, percent frequency of lake whitefish in 1981 gillnet catches; C, percent frequency of cisco in 1980 gillnet catches; D, percent frequency of cisco in 1981 gillnet catches.

strong 1974 and 1979 year-classes and weak 1975–78 year-classes.

An inverse relationship was found between the strengths of lake whitefish and cisco year-classes produced in 1971–80 and the difference between water levels at spawning time (October 28) and the lowest water level until the end of May (Fig. 5). Weak year-classes of lake whitefish and cisco were produced in years with a marked winter or spring drawdown, and strong year-classes appeared in years with little drawdown.

Observations on Fish Movements and Winterkill

In May 1981, walleye were observed congregating below known spawning tributaries made inaccessible by low water levels, and known spawning areas for northern pike were dewatered prior to spawning. In late October 1981, lake whitefish were found congregating at a known spawning area in the west basin of Cross Lake. It was apparent that the lake whitefish were spawning on submerged rocky reefs in river channels.

In March 1981, fish kills occurred in shallow bays and channels that were dewatered as a result of drawdown. The affected species were white sucker, walleye, and lake whitefish. Other species may have been killed but the ice cover prevented an accurate determination of the extent of the fish kill.

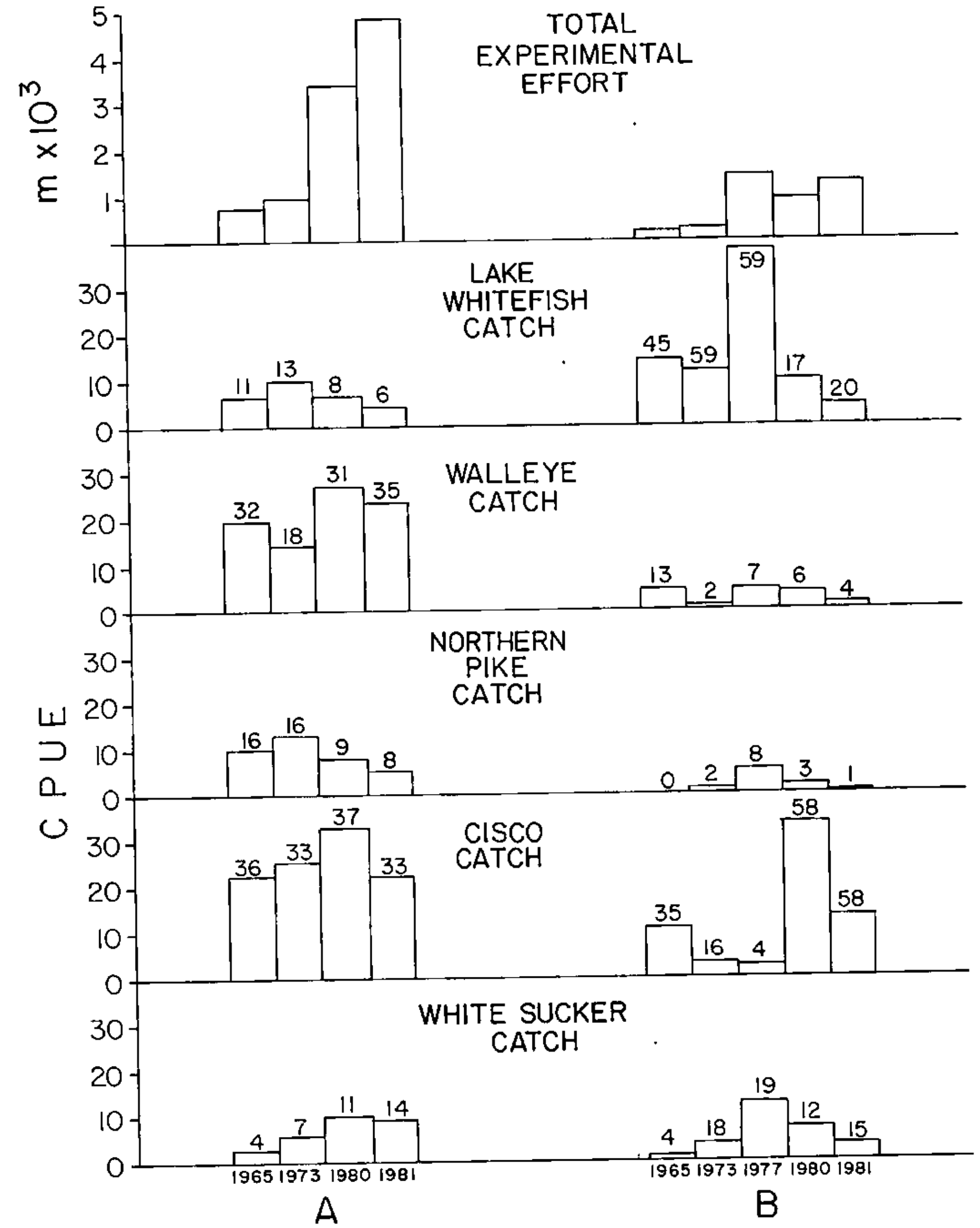

FIG. 6. Comparison of total effort, CPUE (number·100 m^{-1}·d^{-1}), and relative abundance (in % above bars) for fish captured in Cross Lake (both basins combined). (A) CPUE in 7.6-, 9.5-, 10.8-, and 13.3-cm meshes, common to the 1965 (Driver and Doan 1972), 1973 (Ayles et al. 1974), 1980, and 1981 surveys; (B) CPUE in 13.3-cm mesh, the only mesh used in the 1977 survey (B. H. Wright, unpublished data).

Discussion

Differences in physicochemical water quality, plankton biomass, and fish catches indicated that the east basin was more productive than the west basin. The two basins also supported discrete fish populations, as shown by the differences in growth rates and age distributions. Annual harvests of lake whitefish and walleye averaged 3.4 and 1.2 kg·ha^{-1} in the east and west basins, respectively. These yields suggest a higher level of exploitation in east Cross Lake contributing to fewer older fish and significantly faster growth rates in comparison with west Cross Lake.

Unusually early and rapid drawdown in March 1981 (Fig. 2) and low oxygen levels caused a winterkill, which contributed to the dramatic decrease in CPUE of Cross Lake fish from 1980 to 1981. Nonsignificant changes in fish survival rates from 1980 to 1981 suggested that all age-classes were affected by the winterkill. Decreases in CPUE were greater in the east than in the west basin. This was due to the winterkill being more severe in the east basin because of the lack of deepwater habitat for overwintering fish (maximum depth 1.9 m). Also, the west basin had generally higher winter dissolved oxygen concentrations due to the influence of the Nelson River. Evidence of stress was also found in the subsistence fishing census records, which indicated a three- to five-fold increase in CPUE of all species during late March 1981 (Gaboury and Patalas 1982). Increased fish movement probably resulted from the loss of available habitat and anoxic stress.

The 1st yr of extreme summer drawdown was 1977. This reduction in lake volume increased fish densities, resulting in higher CPUE for lake whitefish, northern pike, and white sucker than in preregulation years (Fig. 6). Cisco did not show a higher CPUE, perhaps because netting locations were biased to capture lake whitefish in deepwater channels. This would account for the extremely high CPUE of lake whitefish. Walleye abundances were not truly represented because of their low vulnerability to 13.3-cm nets.

Postregulation catches of adult lake whitefish have declined substantially, both in relative and absolute abundance. Under similar low water levels, CPUE of lake whitefish in 13.3-cm mesh declined from 38 fish$\cdot$100 m$^{-1}\cdot$night^{-1} in 1977 (B. H. Wright, unpublished data) to 9 in 1980 and 4 in 1981. Also, CPUE of lake whitefish decreased by similar proportions in the east and west basins from 1977 to 1981 (Gaboury and Patalas 1982).

Standing stocks of all fish species have declined since regulation, probably because of the reduction of summer habitat under the current water level regime. Comparisons of CPUE in mesh sizes common to both the preregulation (Driver and Doan 1972; Ayles et al. 1974) and postregulation (1980 and 1981) surveys suggest that fish densities have not changed significantly (Fig. 6). However, with up to a 49% decrease in summer water volume under drawdown the standing stocks of fish would be considerably lower in 1980 and 1981 than in preregulation years. Unfortunately, insufficient fishing efforts in 1965 and 1973 prevent confident comparisons with 1980 and 1981 data.

Increased winter and spring drawdown under the regulation of Cross Lake had a pronounced effect on the year-class strengths of coregonid fishes. Lake whitefish and cisco usually spawn in late fall on boulders and coarse stones in shallow depths (Machniak 1975). These substrates are common on the shores of Cross Lake but are exposed at low water levels. Rapid decreases in water levels in spring have occurred in 4 of the last 5 yr since regulation (Fig. 2), and fall to spring drawdowns of up to 2.2 m have occurred, as compared with the average natural variation of 0.8 m (Gaboury and Patalas 1982). It is believed that drawdown has detrimentally affected lake whitefish and cisco hatching success and recruitment by a dewatering of spawning areas and desiccation of eggs.

The low frequencies of the 1975–78 year-classes (Fig. 5) cannot be explained by gill net selectivity. A standard gang of gill nets tends to underestimate the relative frequencies of smaller fish, but as fish size increases, efficiency of capturing a greater proportion of the fish in successively larger size groups increases (Hamley 1975). Accordingly, the 1975–78 year-classes should be better represented than the 1979 year-class.

Although the effect of drawdown on coregonid year-class strengths, to our knowledge, has not been previously documented for lakes below generating stations, this inverse relationship has been found for lake whitefish inhabiting reservoirs (Ioganzen and Podlesnyi 1958; Smirnov 1964 (cited in Machniak 1975)) and for spring spawners when drawdown occurs just prior to spawning (Jester 1971; Benson 1973). June (1970) found that large numbers of atretic eggs in the ovaries of northern pike were associated with drawdown prior to spawning. Spawning of Cross Lake walleye and northern pike was also detrimentally affected by drawdown. Poor representation in the experimental net catches of walleye and northern pike younger than the 1976 year-class precluded a comparis[on] between drawdown and year-class strengths.

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