Eutrophication and Recreational fishes in two large lake basins in British Columbia

by

T. G. NORTHCOTE

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EUTROPHICATION AND RECREATIONAL FISHES IN TWO LARGE LAKE BASINS IN BRITISH COLUMBIA

by

T. G. Northcote[1]

ABSTRACT

The causes and sequence of cultural eutrophication and its impact on the recreational fishes of two large lake basins in British Columbia - the Kootenay and the Okanagan - are compared and evaluated. In Kootenay Lake high phosphate loading has come largely from operation of a fertilizer plant nearly 400 km upstream on the Kootenay River. Increased algal production, zooplankton abundance and growth of some salmonoids are probably attributable to this source, but not the sharply increased catch of sport fish.

The largest lake in the Okanagan drainage basin, Okanagan Lake, receives a major portion of its phosphate loading from two domestic sewage plants but, except for localized areas, does not exhibit serious effects of eutrophication. Intermediate-sized Skaha Lake receives high nutrient loading from a domestic-sewage treatment plant and has shown characteristic eutrophication effects including algal blooms and enhanced salmonoid growth. On the other hand Wood, one of the smaller lakes in the system, has shown more intense eutrophication effects for several decades and recent deterioration of recreational fishing.

In balance, effects of eutrophication in both major systems probably have not had such deleterious effects on recreational fishes as have losses of spawning stream habitat through various other man-induced disturbances.

[1]Institute of Animal Resource Ecology and Westwater Research Centre, The University of British Columbia.

INTRODUCTION

Impacts of man on western Canadian lakes are usually thought of as having started after the influx of European settlers, especially during the latter half of the 1800's. And yet in at least one such lake - Kootenay - the native Indian population a century beforehand may have taken for food nearly as large a biomass of salmonid fishes as does an intensive recreational fishery at present (Northcote, 1972 a,b). Nevertheless, native exploitation of fish stocks, even when moderately intensive, probably did not endanger them to the extent that European man more recently has done primarily through his degradation of the environment. Two of the largest lake systems in southwestern Canada - the Kootenay and the Okanagan - both have been subject to such treatment and effects on salmonoid stocks and each have been examined in some detail (Northcote 1972 a,b,c; Northcote *et al.* MS 1972). The causes and course of eutrophication have been quite different in these two systems, as have other impacts of man. Herein these will be compared and contrasted, particularly with reference to their effects on recreational fishes.

THE LAKE SYSTEMS

The Kootenay and Okanagan basin systems together form a major portion of the upper Columbia River system in Canada, (Fig. 1). Although the lakes are similar in area (Kootenay - 417 km^2, Okanagan - 344 km^2) and discharged into the United States only about 130 km apart, their watersheds and the lakes themselves show quite different characteristics (Table 1). Kootenay Lake drains a large area from the western slopes of the Rocky Mountains to the mid-Columbia Mountains, stretching from below 48° latitude in the south to over 51° in the north (Fig. 1). Its extensive drainage basin, over 100 times in area that of the lake, is comprised of three major sub-divisions of which the Kootenay River portion contributes about 80 percent. In contrast Okanagan Lake has a much more confined drainage basin, only about 16 times its own area. Two small subdivisions from Wood and Kalamalka lakes enter its northeastern corner (Fig. 1), while three other small drainages (Skaha, Vaseux and Osoyoos) are serially arranged at its southern end. Although Okanagan Lake is slightly smaller than Kootenay in area and mean depth (Table 1), its theoretical water retention time calculated from average annual discharge is 60 years whereas that for Kootenay is only a year and a half, reflecting high inflow from its two major rivers, the Kootenay from the south and Duncan from the north. Present population is nearly the same in each basin, but because of its more clustered distribution closely associated with the shoreline, that in the Okanagan probably has much greater impact on the lakes.

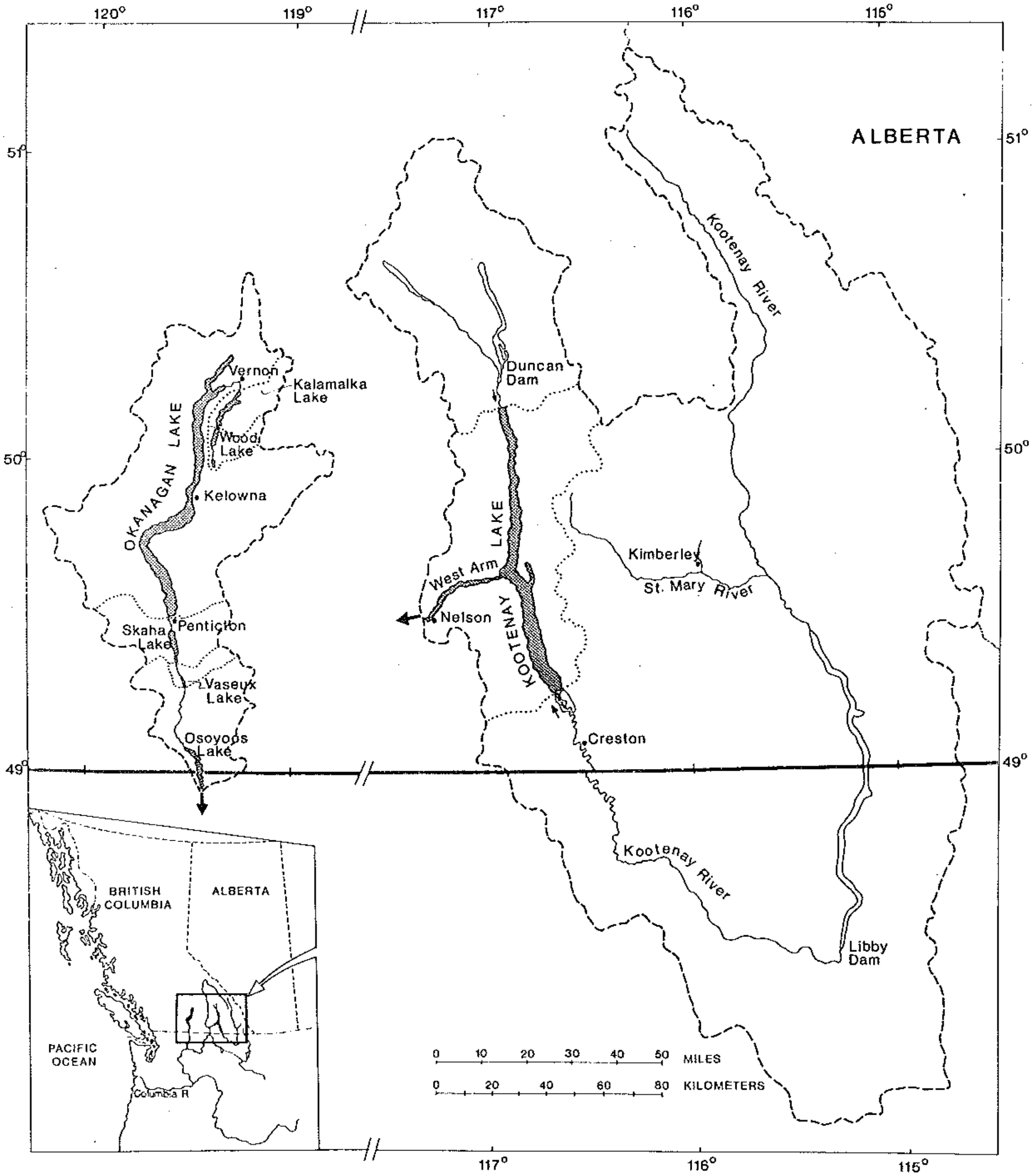

FIGURE 1. The Kootenay and Okanagan basin lakes systems showing their drainage areas (--) and major subdivisions (····). Inset shows location of the lake systems in western North America.

Table 1

Characteristics of Kootenay and some Okanagan basin lakes relevant to their cultural eutrophication.

PARAMETER	KOOTENAY	OKANAGAN	WOOD	KALAMALKA	SKAHA
Lake area, km^2	417	348	9	26	20
Drainage area (land) km^2	45,669	5600	184	500	6300
Land drainage/lake area ratio	109	16	20	19	315
Lake specific drainage area (land) km^2	45,597[a]	5099	182	316	701
Lake mean depth, m	102	76	22	9	26
Theoretical water retention time, years	1.5[b]	60	20	71	1
Present basin population	59,500	60,000	ca 12,000		20,000

[a]Neglecting Libby Reservoir area

[b]Main lake, excluding west arm

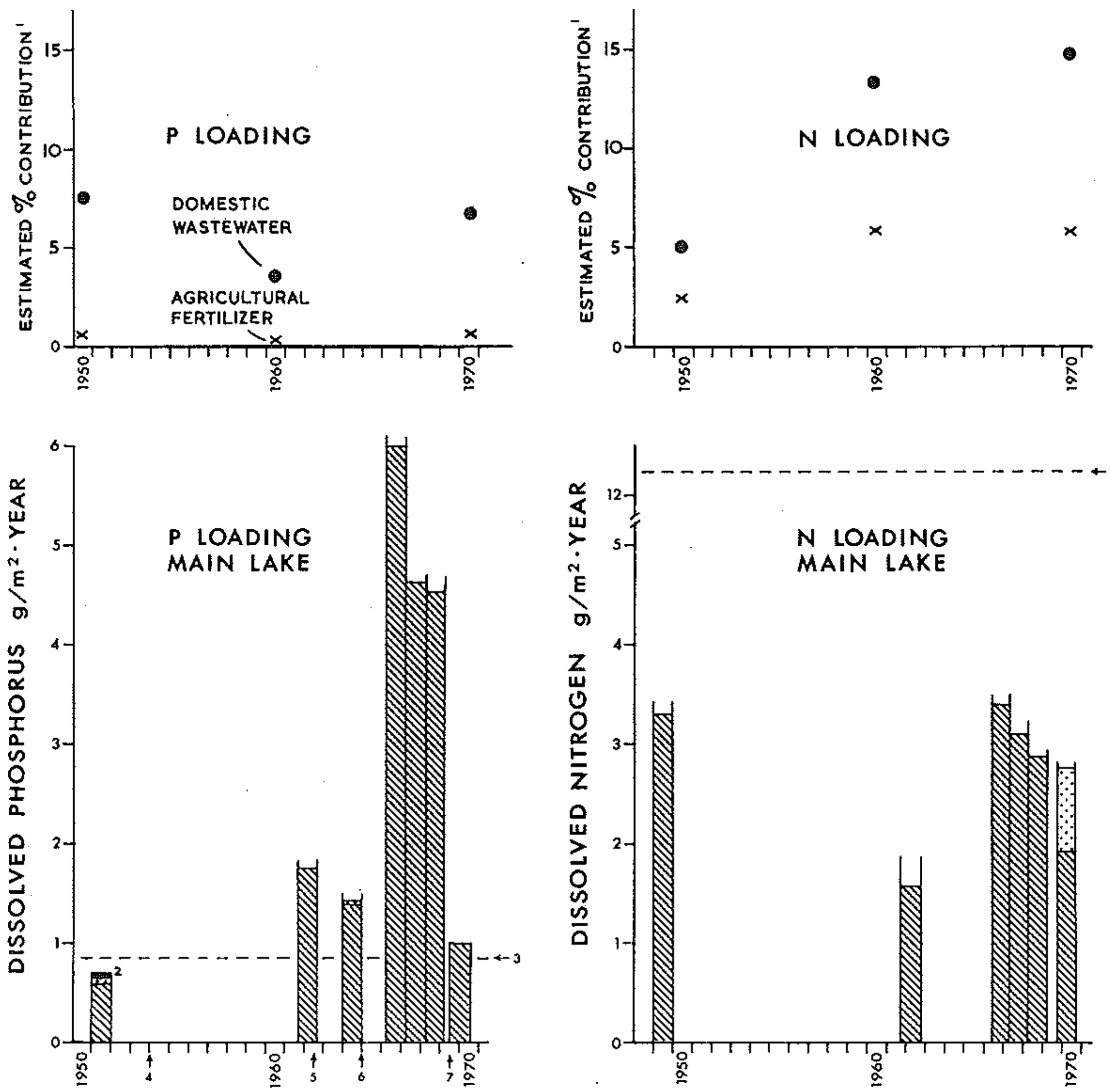

Figure 2. Lower: Annual loading levels for phosphorus (reactive orthophosphate expressed as P) and nitrogen (total nitrate expressed as N) related to unit surface area of Kootenay Lake main basin. Shaded portion of bars represents contribution from Kootenay River, stippled portion from Duncan River (excluding Lardeau River for N), solid portion from lateral lake margins.
Upper: estimated percent contribution to loading from domestic wastewater and from agricultural fertilizer application.

[1]see Northcote (1972b) for details, [2]calculated loading by Vollenweider-Patalas method, [3]dangerous loading level for total nutrient (from Vollenweider, 1968), [4]phosphate fertilizer plant started operation, [5]production doubled, [6]production tripled, [7]production reduced and P loss considerably lowered.

CAUSES AND CONSEQUENCES OF EUTROPHICATION

Kootenay Lake

Phosphorus loading to Kootenay Lake even before European colonization probably was moderately high because of a large total P-export from its extensive drainage basin. Calculated loading in the early 1950's (Fig. 2) was below Vollenweider's dangerous level but by the early 1960's measured loading had considerably exceeded it, particularly so by the late 60's. Nitrogen loading does not seem to ever have been excessive or to have increased during the last two decades (Fig. 2). Of the various sources of phosphorus enrichment recently entering the lake drainage system, that arriving by surface inflow from an industrial smelter-fertilizer complex on a tributary of the Kootenay River nearly 400 km upstream clearly seems dominant (Northcote 1972 b,c).

The series of changes which have occurred over the last two decades in the physical, chemical and biological limnology of Kootenay Lake have been reported in detail elsewhere (Northcote 1972 b,c). Herein only a brief summary will be given. Average summer transparency (Secchi disc) has decreased by nearly a half, whereas average phosphate concentration has increased almost 50-fold and pH more than 1 unit. As might be expected, dense algal blooms (greens and blue-greens) have appeared on several summers since 1958 when first noted. Primary production levels (^{14}C determinations) during the growing season in the mid-60's would place the lake in the upper range (Rodhe 1969) for a natural eutrophic lake, quite out of keeping with its generally oligotrophic nature. Zooplankton abundance has increased two to three times between 1949 and 1964, the latter a year of *lower* than normal crop (Zyblut, 1970). At least three of the four major salmonoid sport fish species in the lake (rainbow trout, kokanee, Dolly Varden and mountain whitefish) have shown changes in part attributable to eutrophication effects.

Okanagan Basin Lakes

1. Okanagan Lake

Use of presently available data to calculate P-loading to Okanagan Lake (Annual Report, Okanagan Basin Agreement, 1972) gave widely disparate values, one well below Vollenweider's dangerous level and the other above (Fig. 3). The value for 1971 is probably unusually high as a result of watershed disturbances and other causes (J.G. Stockner, pers. comm.), especially since Patalas has estimated recent annual loading for the lake to be 0.39 g/m^2 based on probable levels of phosphorus export from the land area in the basin and from contributions by the human population (Patalas and Salki MS 1971). The best estimate averaged over the three recent years is 0.44 $g/m^2 \cdot$ year (Stockner MS 1972). On the other hand, nitrogen loadings for the two years (Fig. 3) are reasonably similar, and both are well below the dangerous level. Although partitioning of nutrient sources for Okanagan Lake has not yet been completed, preliminary studies indicate that domestic sewage plants at Vernon and Kelowna (Fig. 1) supply up to 60 percent of the P - PO_4 and 15 percent of the N

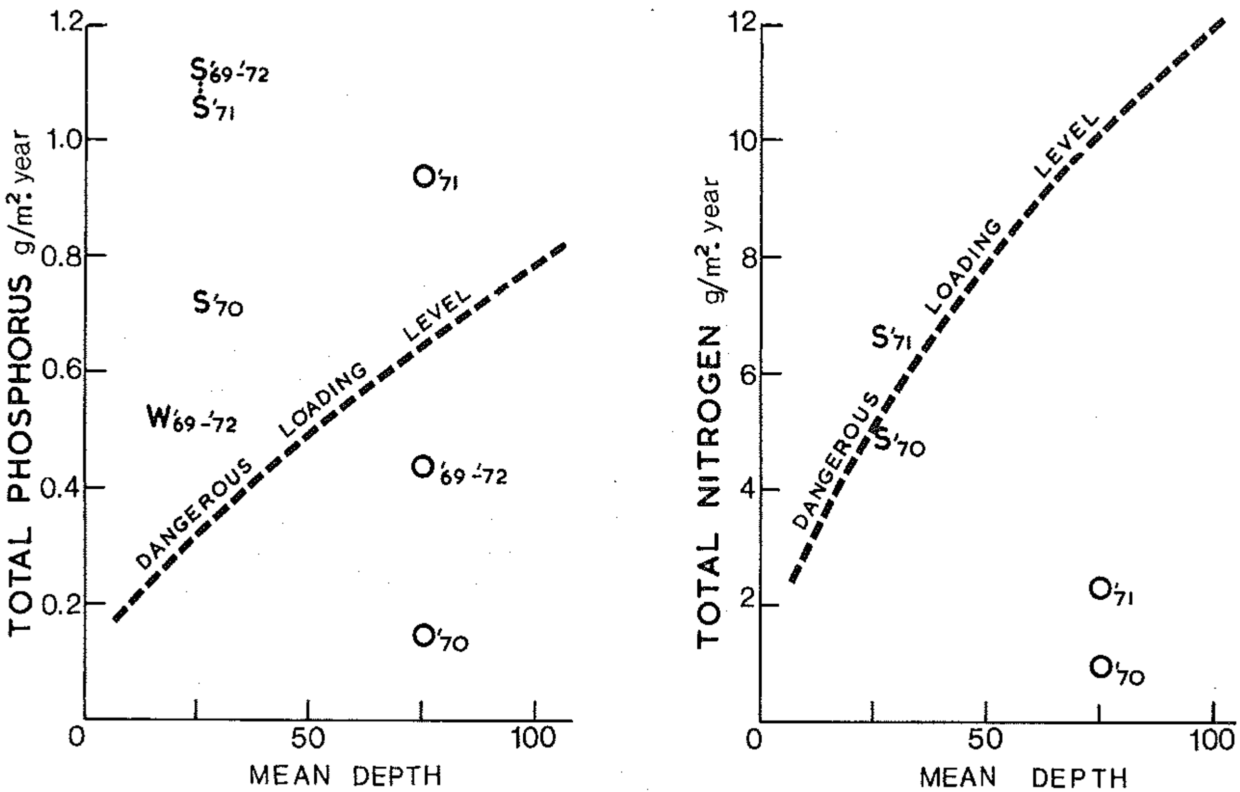

Figure 3. Total phosphorus and nitrogen loadings to some Okanagan basin lakes in relation to the Vollenweider (1968) dangerous limits. Loadings for single recording years taken from Canada-B.C. Okanagan basin preliminary study data Bulletin No. 2 (subject to revision); '69-'72 data represent best estimate of average loading over the 1969-1972 recording years from Stockner (MS 1972); O, S, W, represent Okanagan, Skaha and Wood lakes, respectively.

to the lake (Annual Report, Okanagan Basin Agreement, 1972). Some lateral tributaries also give relatively high contributions but industrial macronutrient inputs to the lake apparently are not extremely large.

Localized areas of Okanagan Lake do show effects of eutrophication (excessive attached algae and rooted aquatic weed growth) but the lake in general has retained its basically oligotrophic state. Patalas and Salki (MS 1971) found no substantial changes in species composition of zooplankton but net plankton volume in 1969 was about five times larger than in 1935. There have not been any marked changes in the bottom fauna or fish populations that give clear evidence of rapid cultural eutrophication occurring in the lake. However, man's activities have had deleterious effects on some fish stocks; these will be noted later.

2. Skaha Lake

Loading of both phosphorous and nitrogen to Skaha Lake are high (Fig. 3), as might be expected in a relatively small lake receiving input from the drainage system upstream as well as sewage effluent from Penticton (Fig. 1). The latter probably accounts for about 80 percent of the P - PO_4 and 40 percent of the N - NO_3 entering the lake (Annual Report, Okanagan Basin Agreement, 1972). Dense blue-green algal blooms now occur most autumns in the lake and rooted aquatics grow excessively in some areas. The benthic fauna of the lake has shifted towards eutrophy (Saether, 1970) and some members of the fish community have shown sharp growth enhancement as well as other indications of eutrophication (Northcote *et al.* MS 1972).

3. Wood Lake

Average phosphorus loading to Wood Lake has been well above the dangerous level during the three recent years (Fig. 3) and probably has been for many years. Heavy blue-green algal blooms have been recorded there since 1935 (Clemens *et al.*, 1939). Land drainage and groundwater are probably major nutrient sources (Okanagan Basin Agreement, Bulletin No. 3).

The hypolimnial water becomes severely depleted of oxygen during summer and the benthos there appears to have been drastically reduced. In addition to heavy blooms of blue-green algae from late spring to autumn, there are very dense growths of epibenthic algae and rooted aquatics. Abundance and probably growth of several salmonoid fishes appears to be reduced during recent decades (Northcote *et al.*, MS 1972).

SPECIFIC EFFECTS ON RECREATIONAL FISHES

Kootenay Lake

The modal length in the angler catch of both rainbow trout and kokanee from Kootenay Lake has increased since the late 40's and some stocks of kokanee have greatly increased their size at maturity. Both have shown increases in their length-weight relationship, i.e., they are now heavier at the same size than formerly. Although data are limited, it appears that similar changes have also occurred in some mountain whitefish populations in the lake. Growth rates have increased in rainbow trout and some kokanee stocks, evidently without any major shifts in their age class distribution or abundance. These various changes on fish cannot be ascribed solely to eutrophication effects. *Mysis relicta* was introduced to the lake in 1949 and since the early 60's has been a significant food item for some kokanee stocks and, at times, rainbow trout. An attempt has been made elsewhere (Northcote, 1972 c) to distinguish the role of mysid introduction and nutrient enrichment in effecting these changes.

Although Kootenay Lake anglers have periodically complained about taste of fish and about algal slime problems on their lines, there has been little direct evidence of eutrophication affecting the sport fishery. Despite angler effort having increased by nearly 10 fold over the last two decades, catch per unit effort has, if anything, increased during this interval and total salmonid catch has gone from some 5000 fish annually to well over 50,000 (Northcote, 1972 b). A massive mortality did occur in some adult mountain whitefish stocks in the autumn of 1969 (Andrusak MS 1970; Bell and Hoskins, 1971) and while the cause is still unknown, it did not seem directly related to any obvious changes in limnology of the lake induced by eutrophication.

Okanagan Basin Lakes

A consistent pattern of change emerges from an examination of some characteristics of Okanagan basin lake fishes over the recent few decades (Table 2). Salmonoids in Okanagan Lake have shown little change over this period in relative abundance, size or growth rate relationships, whereas those in Skaha Lake may have decreased somewhat in relative abundance but increased strikingly in both size and growth rate. In Wood Lake, subject to the most advanced eutrophication in the system, total catch of all species seems to have decreased between 1935 and 1971 although comparable netting data are meagre. Abundance, size and growth rate of kokanee probably have decreased over the last two decades in this lake. Although carp were fairly common in the basin lakes even in the mid-thirties, they were never taken then in offshore netting. Now, particularly in Wood, they commonly are caught offshore, suggesting that this species is extending the habitat it occupies there.

Eutrophication of some Okanagan basin lakes, being more advanced than that in Kootenay Lake, has had detrimental effects on recreational fisheries in at least one lake in the system - Wood. Here an important sport fishery for moderate-sized kokanee flourished up to the early 1950's

Table 2

Summary of changes in some fishes of Okanagan basin lakes between pre-1950 and 1971 standard net sampling periods; see Northcote *et al.* (MS 1972) for details.

LAKE	RELATIVE ABUNDANCE	SIZE	GROWTH RATE
OKANAGAN	Little difference in salmonoids between 1935 and 1971; carp now taken in offshore nets.	No obvious changes since 1935 for any species.	No change in mountain and lake whitefish since 1935; rainbow trout also similar up to age 3, slower thereafter.
SKAHA	Decrease suggested in salmonoid contribution to catch since 1948; carp now taken in offshore nets.	Marked increase in average length, maximum length and length-weight regressions for kokanee and lake whitefish between 1948 and 1971.	Marked increase evident in rainbow trout, kokanee, mountain whitefish and lake whitefish between 1948 and 1971.
WOOD	Sharp decrease in total catch of all species suggested since 1935; carp now common in offshore nets.	Average and maximum length of kokanee probably have decreased sharply since the 1940's.	Probable decrease for kokanee since the 1940's.

but now there is only a poor one for small kokanee. The size of kokanee taken from Skaha Lake has increased since the late-forties (Northcote *et al.*, MS 1972) but catch per unit effort there is now about six times lower than that for kokanee in the northern half of Okanagan Lake and a third that in southern Okanagan Lake (Koshinsky MS 1972).

Of particular concern to maintenance of desirable salmonid sport fisheries in the Okanagan basin lakes is the severe loss of stream reproductive habitat, estimated to be in the order of 70-80 percent overall, and 100 percent for several streams (Okanagan Basin Agreement, Bulletin No. 6). Much of this loss has resulted from agricultural use of the stream water, but logging and channelization have also been involved.

While not usually considered under cultural eutrophication effects, the occurrence of pesticides and heavy metals in fish often goes hand in hand with this process. Perhaps paradoxically in the Okanagan basin lakes, those showing the least effects of eutrophication have the more serious accumulations of DDT and mercury in their fish (Northcote *et al.*, MS 1972). Thus, high levels of DDT (> 5 ppm) mainly were found in large rainbow trout, kokanee, lake trout and mountain whitefish from Kalamalka Lake and in large rainbow trout from Okanagan Lake. Similarly, high mercury levels were chiefly confined to a few large rainbow trout and squawfish examined from Okanagan Lake. In part this circumstance may be explained by the fact that large, old trout (expected to have higher accumulations than younger fish) were rarely taken in the more eutrophic lakes.

DISCUSSION AND SUMMARY

Cultural eutrophication of both the Kootenay and Okanagan systems seems largely a result of recent excessive loading of phosphorus, although from different major sources.

In Kootenay Lake phosphorus most probably arises from an industrial complex on a tributary far removed from the lake. Nevertheless, loading to the lake on some years has been over six times above Vollenweider's dangerous level. Perhaps it is not surprising that this large water body responded in the manner described previously. Hopefully, with the recent trend towards appreciably reduced phosphorus loss from the headwater fertilizer plant and with Libby reservoir now intervening in the system as a nutrient trap, there might be a considerable decline in the eutrophication rate of the lake. However, the reservoir will also act as a sediment trap, thereby counteracting the severe restriction of phytoplankton production which previously occurred over much of the southern half of the lake as a result of inflowing, highly turbid Kootenay River water (Fillion and Northcote, unpublished data). Prediction of the net effect of these various interrelated changes would seem most difficult.

In the Okanagan, loading to the main lake and the smaller one immediately downstream (Skaha) comes in large part from the domestic wastewater treatment plants of communities adjacent to the lakes. Loading to Okanagan Lake probably has not often been excessive and the lake has shown little evidence of eutrophication except in a few localized areas. On the other hand, recent loading to Skaha Lake has been over three times Vollenweider's dangerous level and the lake has shown changes characteristic of early phases of eutrophication (sporadic algal blooms, growth enhancement of fish). In Wood Lake where excessive nutrient loading has probably come from agricultural land drainage and groundwater sources over a longer time scale, eutrophication appears considerably more advanced. Here growth and abundance of kokanee apparently has declined, the latter possibly as a result of heavy epibenthic algal growths on shore spawning areas. The recreational fishery based on kokanee also has deteriorated.

While cultural eutrophication probably has had both advantageous and deleterious impacts on salmonid sport fishes in the two major systems considered, more serious problems may have arisen from other forms of man's activity. Rainbow trout and to a lesser extent kokanee, both major sport fish species, are dependent upon streams for reproduction. Loss of stream spawning areas as a result of dam construction, irrigation diversions, forestry practices, channelization and other causes has been severe in some regions of both drainage basins. In the Kootenays a restricted but critical river spawning area for large rainbow trout has been threatened as have many other smaller streams. In the Okanagan, reproductive habitat has been totally lost in several streams and about 75 percent reduced overall. Thus in these large oligotrophic lake systems of western Canada where stream spawning salmonids are the major recreational species, degradation of stream reproductive habitat would appear to be a more immediate threat to salmonid survival than cultural eutrophication, which often occurs at a later stage in the sequence of man's impacts and usually more slowly.

ACKNOWLEDGEMENTS

Dr. K. Patalas and Dr. J. G. Stockner kindly provided information on aspects of the Okanagan system and gave valuable criticism. T. G. Halsey and E. H. Vernon reviewed the manuscript and made helpful suggestions. The Fisheries Research Section of the British Columbia Fish and Wildlife Branch and the Canada - B.C. Okanagan Basin Study supported much of the data collection and analyses utilized in this paper.

REFERENCES

Andrusak, H. MS 1970. Interim report on the massive mortality of mountain whitefish (*Prosopium williamsoni*) in Kootenay Lake, 1969. Brit. Col. Fish and Wildlife Branch, 14 p.

Bell, G.R. and G.E. Hoskins. 1971. Investigations of wild fish mortalities in B.C. Tech. Rep. No. 245, Fish. Res. Bd. Canada, 19 p.

Clemens, W.A., D.S. Rawson and J.L. McHugh. 1939. A biological survey of Okanagan Lake, British Columbia. Fish. Res. Bd. Canada, Bull. 56:70 p.

Koshinsky, G.D. MS 1972. Creel census of Okanagan mainstem lakes and Okanagan River, 1971-72. Report to Canada-British Columbia Okanagan Basin Agreement, 49 p.

Northcote, T.G. 1972 a. Kootenay Lake: man's effects on the salmonid community. J. Fish. Res. Bd. Canada. 29:861-865.

Northcote, T.G. 1972 b. Some impacts of man on Kootenay Lake and its salmonids. Great Lakes Fish. Comm. Tech. Rep. (in press).

Northcote, T.G. 1972 c. Some effects of mysid introduction and nutrient enrichment on a large oligotrophic lake and its salmonids. Verh. Internat. Verein. Limnol. 18. (in press).

Northcote, T.G., T.G. Halsey and S.J. MacDonald. MS 1972. Fish as indicators of water quality in the Okanagan basin lakes, British Columbia. Preliminary Report No. 22 to Canada-British Columbia Okanagan Basin Agreement, 78 p.

Patalas, K. and A. Salki. MS 1971. Crustacean plankton and the eutrophication of lakes in the Okanagan Valley, British Columbia. Fish. Res. Bd. Canada, 46 p.

Rodhe, W. 1969. Crystallization of eutrophication concepts in northern Europe, p. 50-64 in: Eutrophication: causes, consequences, correctives. Nat. Acad. Sci., Wash. D.C.

Saether, O.A. 1970. A survey of the bottom fauna in lakes of the Okanagan Valley, British Columbia. Fish. Res. Bd. Canada, Tech. Rep. No. 196, 29 p.

Stockner, J.G. MS 1972. Water quality evaluation in the Okanagan mainstem system to 1980. Canada-British Columbia Okanagan Basin Agreement, 13 p., 6 tables.

Vollenweider, R.A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Tech. Rep. Organiz. Econ. Coop. Devel., Paris, 193 p.

Zyblut, E.R. 1970. Long-term changes in the limnology and macrozooplankton of a large British Columbia lake. J. Fish Res. Bd. Canada, 27:1239-1250.

OPEN DISCUSSION WITH COMMENTS AND QUESTIONS FROM THE FLOOR

E. Kupchanko, Chairman

* * *

Chairman: We only have time for one question.

R.L. Konizeski: One question! In the States we are not even allowed by federal law to think about such things as inter-basin transfer, let alone international water transfer. And I wouldn't want to start an international complication ... but, if you were allowed to think about the unthinkable, what would you think of the future of Lake Koocanusa, behind Libby Dam on the Kootenai, which sits right in the middle of everything you have been talking about, relative to the fisheries and eutrophication. What is going to happen to your fishery in Kootenay Lake, etc.? Amen! (Note: This body of water was named Lake Koocanusa by the U.S. Congress. Ed.)

T.G. Northcote: Well, in the first place, I wouldn't call it "Lake" Kookanoosa (or whatever you did), for it is a reservoir - Libby Reservoir (Laughter). I hate calling these bodies of water "lakes" when they are reservoirs - we have one here - Diefenbaker - and we have Williston in B.C., and I think we should be calling them reservoirs, for that is what they are! They are not natural systems.

However, I would point out that the reason that algal production is very low in the south arm of Kootenay Lake is that the high phosphate loading that you saw there is coming in with a high turbidity, and there is light inhibition over most of the growing season. It is not until late or mid-August that you are getting some really healthy carbon-14 production out of that south end of the lake. I think that the Libby Reservoir is going to act as a sediment trap much more effectively than it is going to act, perhaps, as a nutrient trap. Certainly there are going to be nutrients tied up there, biologically, and perhaps otherwise, but I suspect that it will be more effective as a sediment than a nutrient trap; so I would guess that we may see some enhanced algal production occurring in the south end of the lake, unless this trend for decreasing phosphate losses from the Kimberley fertilizer plant is continued - hopefully it will be. It is an intricate problem with a lot of things involved.

* * *