# DISCUSSION

## FISH AS INDICES OF EUTROPHICATION

Information on a number of attributes of the fish populations in 6 Okanagan basin lakes has been presented. An attempt will now be made to use these characteristics in assessing the present status of eutrophication in the lakes.

There are marked differences in species composition between the uppermost and lowermost lakes in the drainage basin. Wood Lake has the lowest number of both salmonoids (3) and non-salmonoids (7) whereas Osoyoos has the highest (7 and 15 respectively). Intervening lakes are intermediate. However these differences do not seem related to eutrophication but instead probably result from barriers (both natural and man-made) to upstream movement of fish and from introductions by man. The ictalurid, percid and centrarchids found in Osoyoos Lake could surely thrive in Wood Lake if they had the opportunity of gaining entry. Although there is no clear evidence of a shift in species composition having occurred in the basin lakes as a result of their differential eutrophication, such a change may soon come if present trends go unchecked. The extremely small number of rainbow trout and few kokanee taken by the 1971 extensive netting in Wood Lake as well as the recent reports of kokanee mortalities there during summer undoubtedly are indications of changed lake conditions.

To fairly assess differences in relative abundance, average length, weight-length relationships and growth rates of the fish between lakes, it seemed essential to consider only those species common to all lakes. Furthermore some system, however crude, had to be developed to summarize and summate the considerable body of data presented for each attribute. This has been done in Table 12, where it is possible to compare the relative position of each lake with respect to any other in the system by examining its score in a particular cell of each column of any one matrix. Also one may obtain the general position of each lake for one attribute by summing its score for the 5 lakes with which it is compared in a column. These total scores for each lake are then ranked in order of the most "eutrophic" with respect to the attribute considered.

No attempt will be made to work through each matrix, cell by cell, although the sign and magnitude of the scores often seem reasonable and instructive on that basis. For example, Skaha Lake has a positive eutrophication score for the relative abundance index when compared to Wood (+15), Kalamalka (+50), Okanagan (+51) and Osoyoos (+45), but is negative (-25) in this respect when compared to Vaseux. On the other hand although Skaha shows positive growth rate scores in relation to all other lakes, it is very high (eutrophic) in comparison with Kalamalka (+118) but not so for Vaseux (+46).

Considering the summed (•) relative abundance scores for each lake (Table 12), one sees that Vaseux is by far the most eutrophic in this respect, while Okanagan and Kalamalka are the least. This seems a clear reflection of the large number of non-salmonoids and the few salmonoids taken in Vaseux and of the reverse situation in Okanagan and Kalamalka. Skaha ranks the second most eutrophic in the relative abundance matrix, followed by Wood. Because of the lower number of salmonoids caught in 1971 compared to 1948 in Skaha and the occurrence of carp in net catches there in 1971 but not in 1948, this lake probably would have had a much lower summed relative abundance score in 1948. Although there apparently

Table 12. Matrices of weighted scores developed to compare six Okanagan basin lakes using four attributes of their fish populations in 1971 as indices of eutrophication.

RELATIVE ABUNDANCE[1]

| | WD | KL | OK | SK | VA | OS |
|---|---|---|---|---|---|---|
| WD | | - 33 | - 37 | + 15 | + 40 | - 28 |
| KL | +33 | | - 4 | + 50 | + 70 | + 4 |
| OK | +37 | + 4 | | + 51 | + 75 | + 9 |
| SK | -15 | - 50 | - 51 | | + 25 | - 45 |
| VA | -40 | - 70 | - 75 | - 25 | | - 75 |
| OS | +28 | - 4 | - 9 | + 45 | + 75 | |
| Σ SCORE | +43 | -153 | -176 | +136 | +285 | -135 |
| RANK | 3 | 5 | 6 | 2 | 1 | 4 |

AVERAGE LENGTH[2]

| | WD | KL | OK | SK | VA | OS |
|---|---|---|---|---|---|---|
| WD | | + 9 | +31 | +24 | +15 | +24 |
| KL | - 9 | | +19 | +16 | + 6 | +16 |
| OK | - 31 | -19 | | - 4 | -12 | - 7 |
| SK | - 24 | -16 | + 6 | | - 9 | - 1 |
| VA | - 15 | - 6 | +12 | + 9 | | + 9 |
| OS | - 24 | -16 | + 7 | + 1 | - 9 | |
| Σ SCORE | -103 | -48 | +75 | +46 | - 9 | +41 |
| RANK | 6 | 5 | 1 | 2 | 4 | 3 |

WEIGHT - LENGTH[3]

| | WD | KL | OK | SK | VA | OS |
|---|---|---|---|---|---|---|
| WD | | +10 | +15 | +26 | +11 | +26 |
| KL | -10 | | +14 | +10 | + 2 | +17 |
| OK | -15 | -14 | | + 4 | - 6 | - 1 |
| SK | -26 | -10 | - 4 | | - 8 | + 2 |
| VA | -11 | - 2 | + 6 | + 8 | | - 1 |
| OS | -26 | -17 | + 1 | - 2 | + 1 | |
| Σ SCORE | -88 | -33 | +32 | +46 | 0 | +43 |
| RANK | 6 | 5 | 3 | 1 | 4 | 2 |

GROWTH RATE[4]

| | WD | KL | OK | SK | VA | OS |
|---|---|---|---|---|---|---|
| WD | | - 11 | +16 | + 65 | +12 | +47 |
| KL | + 11 | | +47 | +118 | +21 | +45 |
| OK | - 16 | - 47 | | + 93 | + 5 | +32 |
| SK | - 65 | -118 | -93 | | -46 | -65 |
| VA | - 12 | - 21 | - 5 | + 46 | | +33 |
| OS | - 47 | - 45 | -32 | + 65 | -33 | |
| Σ SCORE | -129 | -242 | -67 | +387 | -41 | +92 |
| RANK | 5 | 6 | 4 | 1 | 3 | 2 |

[1] Scores equal differences between lakes in total number of the 7 common species of fish caught in standard gill net sets (Fig. 5) weighted so that 1 score unit = 2.5 rainbow trout, 10 kokanee, 5 mountain whitefish, 5 largescale suckers, 50 peamouth chub, 10 squawfish, 2.5 carp; salmonoids given negative score, non-salmonoids positive score, so that score shown in each cell represents their algebraic sum.

[2] Scores equal differences between lakes in average length of the 7 common species of fish caught in standard gill net sets (Fig. 6) weighted so that 1 score unit = 1 cm; score shown in each cell represents algebraic sum of differences for the 7 species.

[3] Scores equal differences between lakes in weight-length regressions (log 10) of the 7 common species of fish; score obtained by adding any statistically significant ($P<0.05$) difference in slope (X100) to a 3 unit index for displacement (+ or -) of the regression line.

[4] Scores equal differences between lakes in "growth rate" (average size attained by each age group) of the 7 common species of fish weighted so that 1 score unit = 1 cm; score shown in each cell represents algebraic sum of differences for age groups of the 7 species.

has been a reduction in total abundance of fish in Wood Lake between 1935 and 1971, the relative abundance of species and hence its position in the present ranking may not have changed markedly.

Average length may not be a particularly good attribute to consider in using fish as indices of eutrophication. It, perhaps more than the others used, may be easily influence by unrelated conditions. Okanagan fish have the highest pooled score for average length (Table 12), followed by Skaha and then Osoyoos. Those in Wood and Kalamalka are lowest. That Wood Lake fish now are so consistently smaller than those from any of the other basin lakes seems most significant, especially since a few decades ago this lake supported a flourishing sport fishery for good sized kokanee.

Skaha Lake has the highest weight-length score followed closely by Osoyoos (Table 12). Scores for Kalamalka are low, and only positive for one comparison (with Wood). Weight-length relationship scores for Wood Lake are negative for all comparisons, giving it a highly negative total score. That the slope of the weight-length regression for carp in Wood has significantly decreased between 1935 and 1971 suggests that conditions for growth of this species may have worsened over this period. In contrast, slopes and/or displacement of the weight-length regression for at least 4 species of fish have increased sharply in Skaha Lake between 1948 and 1971, again suggesting rapid and recent eutrophication there.

Growth rate scores for Skaha Lake fish are highest for all between-lake comparison (Table 12); hence the pooled value is over four times that of the next highest, Osoyoos. Kalamalka shows the lowest score for this attribute, followed by Wood. It was noted previously that there has been a sharp increase in growth rate of all 4 Skaha Lake salmonoids between 1948 and 1971 whereas those in Okanagan have either remained the same or in one case, decreased since 1935.

Low average age of salmonoids taken from Vaseux, Wood and Skaha lakes in comparison with those from Kalamalka and Okanagan may be indicative of advanced eutrophication in the former group. Larkin and Northcote (1969) cite examples from Europe where the average age of coregonids in net catches gradually became lower as eutrophication of the lakes became more severe.

In summary, the four attributes used as eutrophication indices for Okanagan basin fish populations as well as other characteristics or changes presented above, all point towards Skaha Lake as being the most eutrophic followed by Osoyoos and Vaseux. Kalamalka would seem the least eutrophic. Although Wood Lake also ranks very low, several lines of evidence suggest that it has reached this position after passing through a more eutrophic stage, at least with respect to its fish populations. This should not be construed to indicate that Wood Lake today in other features of its limnology, may not be considered highly eutrophic.

For some, it may appear that this whole process has been a long and tedious exercise in proving the obvious; considering the history and success of man's attempts to control eutrophication however, even proving the obvious to many will be just that - a long and tedious process.

STREAM AND SHORE SPAWNING KOKANEE

The number of stream spawning kokanee are probably related to the availability, quality and size of spawning habitat rather than the eutrophic state of the neighbouring region of the lake. For example, 550 kokanee entered Whiteman Creek in 1971 when heavy rains provided a brief flow of water but were unable to use the creek at other times because, the entire flow was diverted. Large populations of spawning kokanee were noted in Coldstream (tributary to Kalamalka) and Mission (tributary to Okanagan) creeks because these streams provide large areas of spawning habitat. It is conceivable that both Kalamalka and Okanagan lakes could support larger numbers of kokanee if there was more spawning habitat in these lakes. There is a suggestion that the few remaining kokanee in Wood Lake spawn in Coldstream because of the lack of spawning habitat in streams tributary to that lake.

The availability of shore-spawning habitat, like that of stream spawning, appears to determine the number of spawners; the largest number (383,000) of shore spawners was observed in the northern section of Okanagan Lake where only 27,000 stream spawners were observed in 3 small streams. The largest number of stream spawners was observed in Mission Creek, a tributary to the central region of Okanagan but compared to the northern area, the shore-spawners were fewer in number; again probably a reflection of available habitat. Good shore-spawning habitat probably is lacking in the southern section of Okanagan Lake, Skaha, Vaseux and Osoyoos because no spawners were seen there; kokanee were observed spawning in tributary streams of these lakes.

## PESTICIDES AND HEAVY METALS

This study did not attempt to investigate the effect of pesticides or heavy metals on fish themselves but there is a vast literature dealing with the effect of the former on a variety of fishes and a growing body of information on the effects of heavy metals. Where these documented cases provide comparative information to that of Okanagan fishes, some mention will be made of them and enough data from elsewhere in North America will be given so that the Okanagan Basin case can be put in perspective.

There are two aspects to consider when interpreting the incidence and degree of contamination in fishes: (1) the effect of the compound(s) on the well-being and life cycle of the fish per se, (2) the concentration of the contaminants in fish as it affects the well-being of the consumer of fish - in this instance the angling public.

The DDT group of insecticides has been shown to kill many of the species of salmonoids and cyprinids found in the Okanagan system. In one experiment, the DDT concentration required to kill 50% of the tested individuals in 96 hours was 0.007 for rainbow trout, 0.002 for large-mouth bass, 0.009 for yellow perch and 0.001 for carp (Pimentel, 1971). In addition to acute toxicity there are sub-lethal effects of the DDT group that inhibit reproduction and alter behavior patterns. When levels of DDT and its metabolites were above 0.4 ppm in eggs of hatchery trout, mortality of the resulting fry ranged from 30 to 70 percent. In another study fewer fry survived from lake trout eggs that had 3 ppm DDT and all fry died that hatched from eggs having concentrations of 5 ppm and above - concentrations in eggs ranged from 3 to 335 ppm. It is interesting to note that most mortality occurred in the fry stage at the time of final absorption of the yolk sack rather than in the egg stage (Pimentel, 1971).

Concentrations of chlorinated hydrocarbons are higher in fatty tissue because these compounds are fat-soluble. Concentrations of DDD, which was applied directly to Clear Lake, California, ranged from 5 - 130 ppm in fish of several species but in the fat of those fishes, ranged from 40 to 2,690 ppm or about 20 times the highest concentration (O'Brien, 1967). In 16 species from New York waters, concentrations in flesh ranged from 0.2 to 7 ppm DDT but in other tissues, egg and reproductive organs, up to 40 ppm - about 6 times the highest figure (Pimentel, 1971). If the concentrations of DDT in eggs and reproductive organs of some large rainbow trout from Kalamalka Lake were 6 times the concentration found in flesh there would be as much as 412 ppm or as little as 1.38 ppm. Concentrations in eggs and reproductive organs of larger rainbow trout in Okanagan lakes would probably exceed the 5 ppm level that produced 100 percent mortality in fry of lake trout. The same thing may well apply to some squawfish in Okanagan Lake and some lake whitefish from Skaha Lake. This phenomenon applied particularly to older and therefore usually larger fish because DDT compounds accumulate in tissue with time (Pimentel, 1971). Fish with high concentrations of chlorinated hydrocarbons in their fatty tissues may themselves remain relatively healthy until some stress such as reduced food intake causes the fat in the body to be mobilized. In all probability therefore the larger rainbow trout in Kalamalka and Okanagan lakes are unable to reproduce successfully.

Sub-lethal effects were observed to occur in juvenile Atlantic salmon in streams in areas that had been sprayed with DDT; these fish selected abnormally high water temperatures. Such a physiological change could lead to stress or death in fish that require specific ranges of temperature for survival and/or reproduction. Brook trout fed sub-lethal doses (0.02 ppm) of DDT in the laboratory lost their learned avoidance behavior; doses of 0.02 to 0.06 ppm altered their thermal acclimation mechanism (Pimentel, 1971). Physiological and behavioral changes like these may occur in juvenile salmonoids in Okanagan streams and lakes thus reducing survival.

The allowable limits of DDT for human consumption were exceeded in 14 percent (15 out of 107) of all analyses. It is significant to note that only 2 of the 15 analyses that exceeded the limits were for species (squawfish and lake whitefish) seldom utilized by anglers; nonetheless they are consumed by some anglers. The majority of species containing excessive amounts are those that are given top priority by anglers (Anonymous, 1972). As shown by rainbow trout in Kalamalka and Okanagan lakes, concentrations of total DDT are generally below prohibitive levels in smaller sized fish. These appear safe for human consumption. Similarly, non-piscivorous species such as kokanee, whitefish, suckers and carp are, for the most part, below the 5.0 ppm limit set for chlorinated hydrocarbons.

Average concentrations of total DDT from some species in the Great Lakes are higher than those for the same species in Okanagan basin lakes; lake trout in Michigan and Superior lakes were 6.96 and 7.44 ppm compared to 5.26 and 4.61 ppm in lake trout from Kalamalka. Perch from Vaseux Lake had lower average concentrations (0.24 ppm) than perch from Lake Erie (0.87 ppm) and Lake Ontario (2.10 ppm; Pimentel, 1971). In these lakes, as in Okanagan lakes, the insecticide was applied to the land to control insect pests but found its way into aquatic non-target organisms.

Some heavy metals occur naturally and as pollutants in Okanagan lakes. They may constitute serious forms of pollution because they occur as stable compounds and are therefore persistent. Generally, fish concentrate heavy metals in their tissues where levels may be many times that found in the water or substrate. The amount of accumulation differs for different organs; concentrations in kidney and liver tissue are usually much higher than in muscle.

Heavy metal compounds of copper, lead, mercury and zinc in water, singly or combined, are lethal to fishes (Peterson et al., 1970). Like DDT compounds, sub-lethal concentrations can adversely affect the behavior and physiology of fish.

To date very little investigation has been made of the heavy metal content of fresh water fishes in British Columbia. Peterson, et al., (1970) lists concentrations of copper, lead, mercury and zinc in fish livers and mercury content of livers and muscle. The highest concentration of mercury in rainbow trout muscle elsewhere in the province (1.90 ppm) is about twice as high as the highest concentration (0.89 ppm) found to date in Okanagan rainbow trout. Concentrations of mercury in Okanagan fishes were found to be high (and exceeded limits) in large, old rainbow trout in Okanagan Lake, probably because they live for a long time and commonly prey on other fish which have accumulated lesser concentrations.

Concentrations of mercury above limits have accumulated in some squawfish from Okanagan, Skaha and Osoyoos lakes; like large rainbow trout, this species preys heavily on other fishes. The amount of mercury in one squawfish from Okanagan Lake was as high (1.79 ppm) as the highest concentration (in another predacious species, the lake trout) for the remainder of the province (Peterson, et al., 1970). Mercury concentrations in Lake Erie yellow perch (0.29 to 0.61 ppm) were higher than those found in yellow perch from Vaseux and Osoyoos lakes (0.09 to 0.50 ppm). Lake Erie coho salmon, which are probably much younger but have similar feeding habits to large Okanagan rainbow trout, had mercury concentrations ranging from 0.51 to 0.69 ppm compared to a range of 0.02 to 0.89 ppm for large rainbow trout in Okanagan and Kalamalka lakes. Surprisingly, burbot, also a fish predator, had comparatively low concentrations of heavy metals and pesticides.

Excluding zinc, only 6.5% (7 out of 107) of all analyses showed concentrations of heavy metals in excess of limits for human consumption, based on these data, sports fish are, for the most part, free of serious heavy metal contamination. Because of the difficulties encountered with the analyses of cadmium and zinc, it is not possible to meaningfully interpret the results. It is not surprising to find concentrations of copper in Okanagan fishes as the area has widespread copper mineralization.

Conclusive demonstration of changes in heavy metal content of Okanagan fishes over the years is difficult to make because of lack of an adequate number of museum samples with which comparisons can be made. Similarly, comparisons of analysis from headwater lakes with main basin lakes are based on too few samples to show any definite trends.

A variety of management strategies have been used by fisheries agencies when faced with the problem of contaminated sports fish. In Sweden, about 1 percent of the waters have been "black listed" because of mercury contamination in fishes. Swedish waters are black listed if a sample of 5 pike show residues of 1 ppm or more of mercury in most of the 5. If concentrations are between 0.2 and 1 ppm, Swedes are advised to eat fish from those waters no more often than once a week (Nelson, 1971). The level of 1 ppm chosen by the Swedes is considered too high but if they used the 0.5 ppm level as in Canada and the United States, 5 times as many waters would be black listed and the monitoring costs would be prohibitive (Nelson, 1971). Swedish health authorities sometimes allow species other than pike to be eaten from black listed waters.

In Ontario, sports fishermen have been advised not to eat any fish from some waters and only certain species from others. In British Columbia, a complete ban on fishing was placed on upper Howe Sound because of mercury contamination; later this was lifted but ground fishes and shellfish remained banned. In Okanagan Lake, anglers have been advised to eat rainbow trout only if they are less than 3 pounds (1362 grams).

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