# LIMNOLOGICAL CONDITIONS AND GROWTH OF TROUT IN THREE LAKES NEAR ROTORUA

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## INTRODUCTION

A small group of lakes near Rotorua has been the subject of research by the Marine Department for a number of years to determine the rate of growth of the resident rainbow trout (*Salmo gairdnerii*) (Smith 1959) and the effect of increasing these trout populations by artificial stocking with hatchery-reared fingerlings. As a result, fish size in some lakes has been noticeably reduced in recent years. It has been shown elsewhere that the quality of the water in a lake has an important effect upon the fish present (Hasler 1947). Some factors affecting water quality were therefore examined during the summer of 1962 in lakes Okataina, Ngapouri and Okaro. These data are correlated with others relating to those trout present which were over 20 cm. long (smaller fish are caught neither by anglers nor by the gill nets used in research).

The shores and catchment of Lake Okataina have not yet been subject to any extensive commercial development and are still covered by dense native bush. The lake is large (2450 acres, shoreline 17.5 miles), deep (270 ft. maximum) and well known for the excellence of its trout fishery.

Lake Ngapouri is in the high country near the thermal region at Waiotapu. Although smaller than Okataina (54 acres, shoreline 1.5 miles), it is relatively deep (88 ft. maximum). The clearing of the native bush from the area was begun in 1952 and the catchment is now wholly pasture land. During this period the fertility of the cleared land has been increased by regular aerial top-dressing. Although the lake has supported a large population of trout for many years, it is not popular with anglers because access is difficult.

Lake Okaro is similar to Ngapouri in size (80 acres, shoreline 1.5 miles) but shallower (52 ft. maximum). Its catchment consists mainly of well developed farmland and it is a popular resort for angling and water-skiing.

None of these lakes have large inflows or outflows, surface drainage and seepage being apparently the most important agents controlling the water level in the lakes.

## WATER TEMPERATURE

The temperature of the water at a fixed station in each lake was measured at frequent intervals from January until June, 1962. The data are plotted in Figure 1.

All the lakes were thermally stratified in January. Although this stratification was retained for the greater part of the period, seasonal cooling is evident from the end of January. The progress of the increase in depth of the epilimnion is remarkably similar in all the lakes. Ngapouri is exposed to cold south winds and this may account for its cool waters compared with the others. It can be seen that the surface areas of the lakes largely determine the depths of their thermoclines and that their relative volumes influence the dates of overturn in the autumn. The data show that large masses of cool water are apparently isolated for long periods in the lower depths of the lakes. Up to the end of April, mixing was only evident down to a depth of about 24 m. in Okataina and to 11 m. in both Ngapouri and Okaro. Although 1962 was notable for gales and high rainfall, in none of the lakes was the water completely mixed before mid-June.

## DISSOLVED OXYGEN

In Okataina, the oxygen content of the water exceeded 7 p.p.m. at nearly all depths throughout the summer. The lowest concentration recorded was 6.6 p.p.m. in the

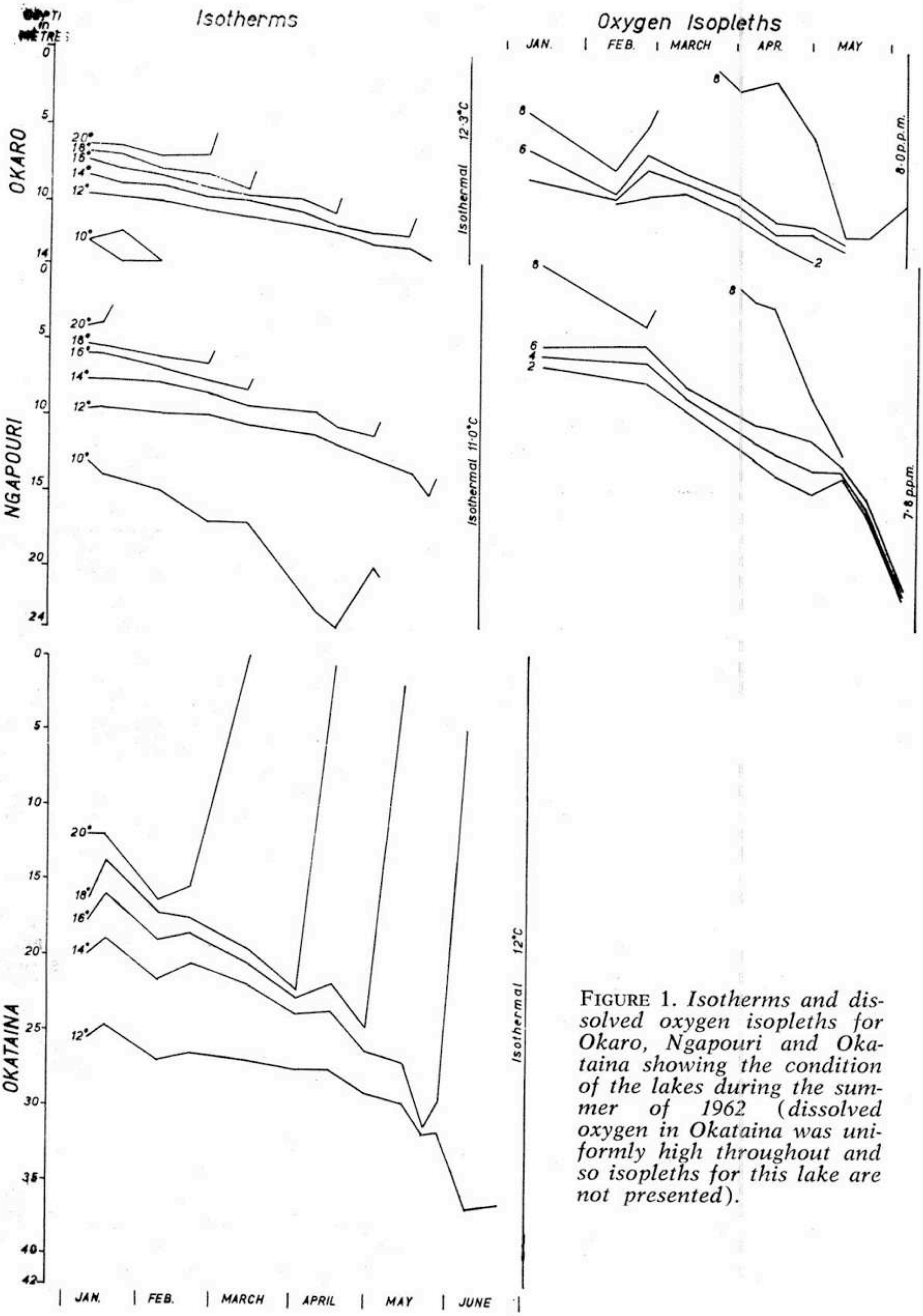


FIGURE 1. *Isotherms and dissolved oxygen isopleths for Okaro, Ngapouri and Okataina showing the condition of the lakes during the summer of 1962 (dissolved oxygen in Okataina was uniformly high throughout and so isopleths for this lake are not presented).*

bottom water for a brief period at the end of May. For the most part, the oxygen content at all depths was 8 to 10 p.p.m.

In Ngapouri, the only water with an oxygen content above 1 p.p.m. was the surface layer of 7 m. in January and 8 m. at the end of February (Fig. 1). Oxygenated water followed the thermocline which increased steadily in depth throughout the summer and by the middle of May there were about 13 m. of fairly well oxygenated water in the epilimnion. It is significant that, even in June, when thermal stratification was completely broken down, the oxygen content of the whole water column was less than 8 p.p.m.

Conditions were not as severe in Okaro although the hypolimnion became significantly deoxygenated for 9 m. up from the bottom during the first three months of the year (Fig. 1). During this period, the bottom four metres of water contained less than 1.0 p.p.m. of oxygen.

Low levels of dissolved oxygen in the hypolimnion not only create a direct potential danger to trout but also seriously limit the overall production of bottom food organisms. Such conditions are associated with algal blooms, especially in summer. At these times, it is intensely dark even a few feet below the surface. This factor is likely to favour the demersal prey of the trout.

## PRIMARY PRODUCTION

None of the lakes contained large growths of water weed, probably because, as a result of their volcanic origin, they are all relatively deep. Rooted aquatic plants did occur in shallow bays, especially in Okataina, but phytoplankton formed the main source of primary production in all the lakes. Some idea of the relative density of growth was obtained in January. The depth at which a Secchi disc disappeared from view was 13.0 m. in Okataina, 4.0 m. in Ngapouri and 3.6 m. in Okaro.

The diurnal fluctuations in total dissolved oxygen content of the water column in Okataina and Ngapouri on 15-17 January

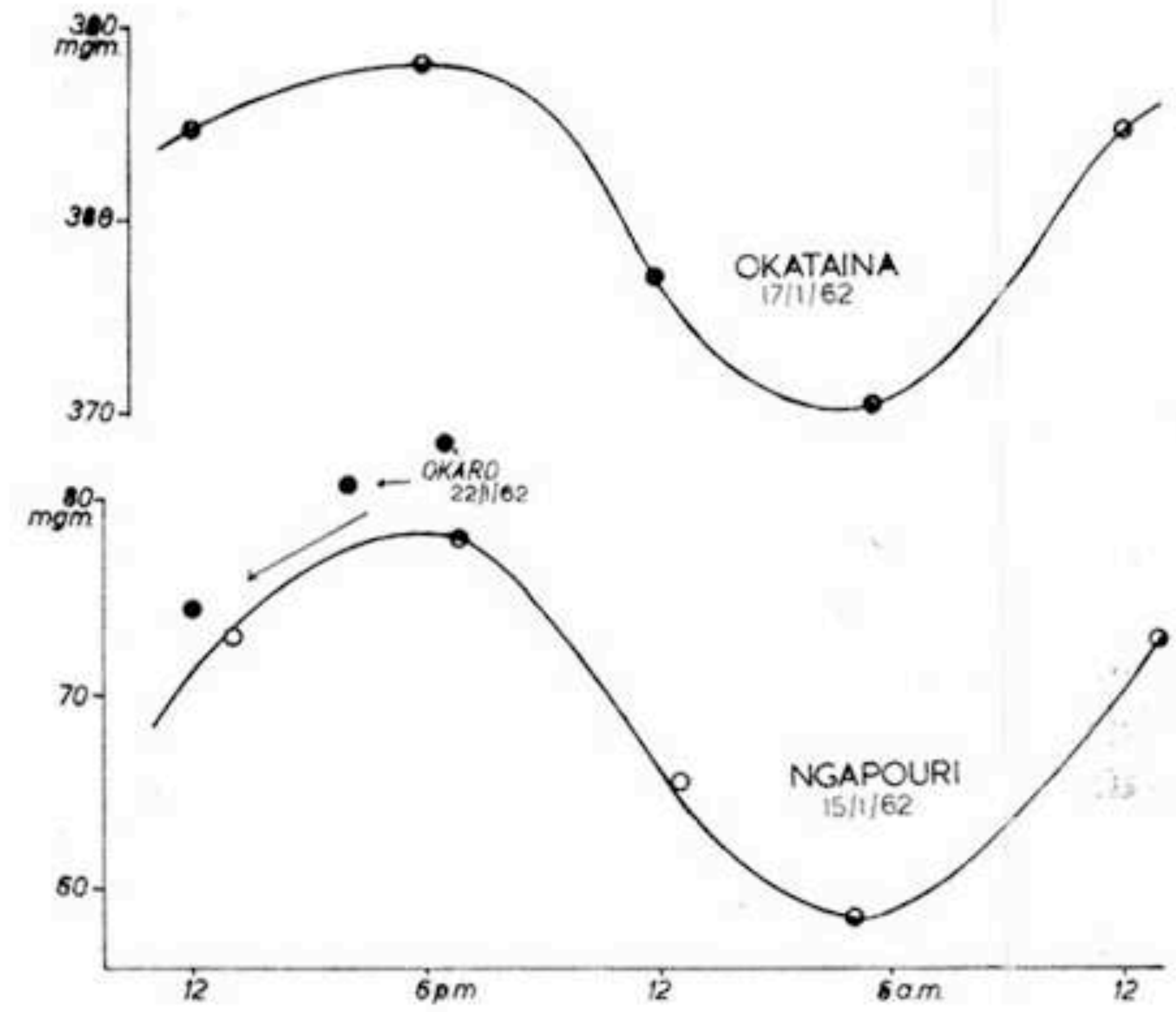


FIGURE 2. *Diurnal fluctuations in total dissolved oxygen per sq. metre in lakes Okataina and Ngapouri.*

are shown in Figure 2. Unfortunately, the series for Okaro was interrupted after three readings had been taken. At this time, when the spring bloom of phytoplankton was still active, the oxygen content of the 42 m. water column in Okataina varied from about 370 to 387 g./sq. m. During the period of 24 hours, production in the entire water column was equivalent to 18 g. oxygen per sq. m. (Fish, 1958) or 0.43 g./cu. m. The similar series in Ngapouri showed a fluctuation in the 24 m. water column of 20 g. oxygen per sq. m. or 0.83 g./cu. m., which was nearly double that in the larger lake. As summer progressed, the size of the standing crop of phytoplankon was expected to fall considerably and, during the period 12-20 February, the daily production was found to be equivalent to only 0.19 g. oxygen/cu. m. in Okaro and 0.071 g./cu.m. in Okataina.

## TROUT GROWTH

A precise number of hatchery-reared trout fingerlings about 14 cm. long are stocked into these lakes each year. Before release, the fish are measured and tagged. When these tagged fish are recaptured later, their age is known and their growth serves as an index of the growth of the whole population of trout in that particular lake. No evidence of any adverse effect of the tags on the fish was found from an examination of the catches from lakes supporting both a natural and an introduced trout population. Satisfactory numbers of tagged fish were recaptured by routine gill-netting from Ngapouri (311) and Okaro (83). Since only 47 recaptures were made in this way from Okataina, a further 48 tagged fish recorded by anglers have been studied. These data show that a definite and individual pattern of growth occurs in each lake.

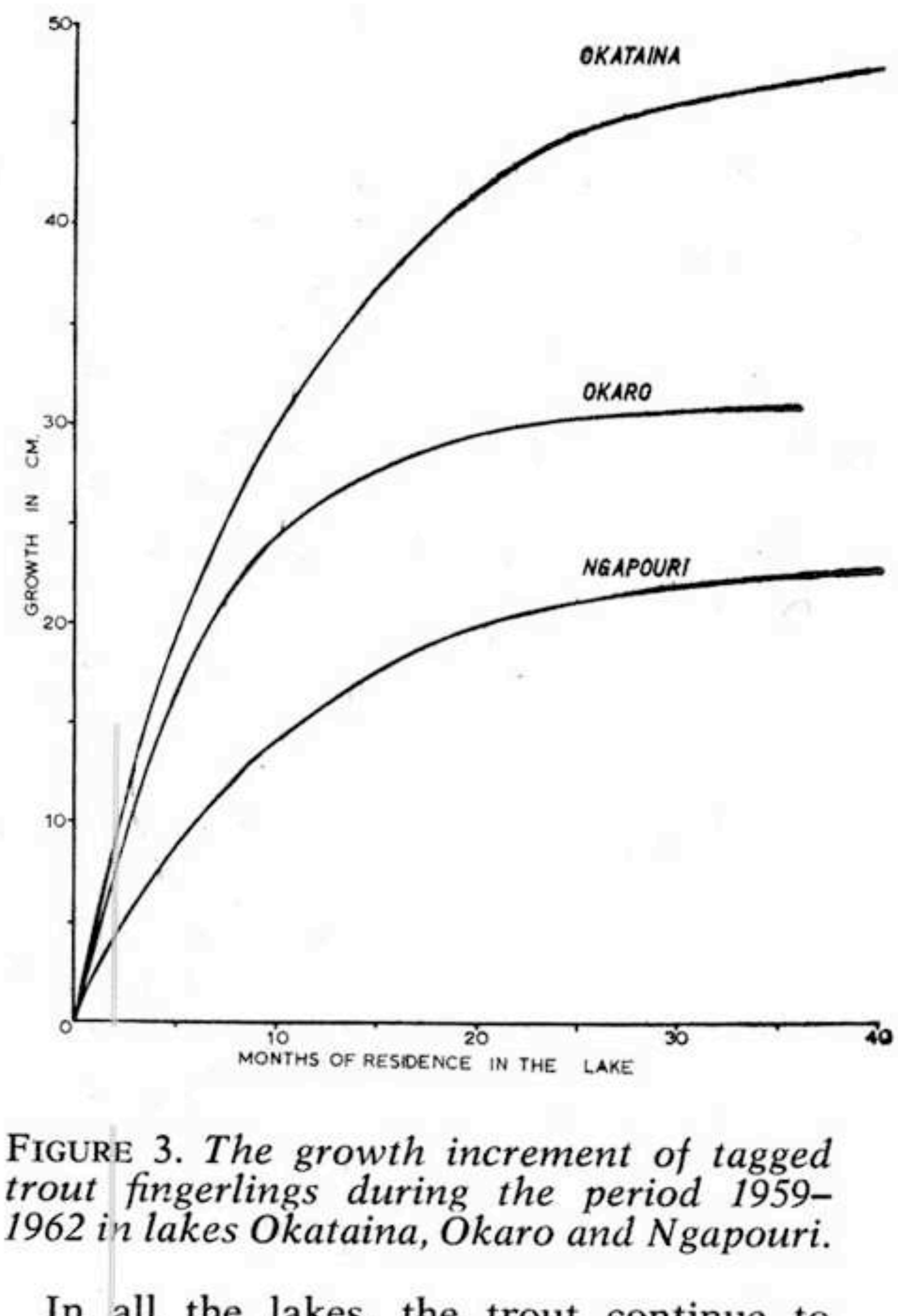


FIGURE 3. *The growth increment of tagged trout fingerlings during the period 1959–1962 in lakes Okataina, Okaro and Ngapouri.*

In all the lakes, the trout continue to grow until maturity, after which growth rates diminish considerably. This trait seems particularly characteristic of rainbow trout (Allen 1962). The rate of growth is slowest in Ngapouri and the total increase in growth was calculated from the data above for each of the three lakes. The growth curves can be reasonably well described by an equation of the von Bertalanffy type as written by Beverton and Holt (1957), *i.e.* $L_t = L_{\infty} (1 - e^{-Kt})$, where $L_t$, in the present instance, is the increment in growth after liberation, t is the time in in months and $L_{\infty}$ is the asymptotic increment. K was estimated by the first approximation method given by Stevens (1951) and $L_{\infty}$ was obtained from a linear regression through the origin between $(1 - e^{-Kt})$ and $L_t$. The equations obtained for the three lakes were:

$L_t = 48.9\ (1 - e^{-0.094t})$ for Okataina,
$L_t = 31.0\ (1 - e^{-0.150t})$ for Okaro,
$L_t = 23.2\ (1 - e^{-0.094t})$ for Ngapouri.

The results are shown in Figure 3.

## DISTRIBUTION OF TROUT

A large proportion of the animals sought by trout for food are found in moderately shallow water and often near the shoreline. The winter spawning of trout is also limited, as far as is known, to shallow waters. It is here that angling for trout is most successful and the routine nettings in the three lakes were made with one end of the net secured to the shore. On occasions, nets have been set some distance offshore but the catch was always much smaller. The inshore and offshore catches in Ngapouri, Okaro and Okataina during the 1961-62 summer were 35 and 4, 33 and 1, and 54 and 7 respectively. The fish caught offshore were only in the surface nets in the two lakes with a deoxygenated hypolimnion, whilst, of the 7 caught in Okataina, 6 were from bottom nets and only one from the surface. During the succeeding winter, proportionally more fish were found offshore. In Okataina, 6 nets offshore caught 25 fish and 3 nets inshore caught 79; but all the offshore fish were caught in surface nets, none in nets set on the bottom. Similarly, negligible catches were made by bottom nets set in the deep waters of Ngapouri and Okaro although these waters were well oxygenated at this time. The deeper waters are probably of value to trout during the summer if cool and well oxygenated but the evidence here indicates that, at all times, the greatest activity is in the shallower waters bounding the lakes.

This conclusion is supported by those of other limnologists. Rawson (1955) considered the fish production in a number of Canadian lakes and showed that depth rather than area controlled production. Similar findings were made from lake and pond surveys by Benson (1961) and Newell (1960). These data show that the major contribution to the total fish production in a lake is made by its shallow littoral regions and this is particularly true for rainbow trout which is typically a fluvial species.

## RELATIVE DENSITIES AND NUMBERS OF TROUT

Netting operations during 1960 and 1961 were carried out using the same fleet of gill nets, set for a single night at the same place in each of the three lakes. The total catch from these nets in each lake (Table 1) shows that roughly equal numbers of fish were caught in Okataina and Ngapouri and about half as many in Okaro. Such data, from operations which are standardised as far as possible, can indicate the approximate density of the population in different lakes (e.g. Smith 1959). However, owing to certain changes in the netting operations during the last two years, further data

TABLE 1. *Total fish catches from netting operations using the same gill net fleet at standard positions in each lake*

| | *Okataina* | *Ngapouri* | *Okaro* |
|---|---|---|---|
| Winter 1960 ...... ...... | 63 | 61 | 29 |
| Summer 1961 ...... | 35 | 41 | 13 |
| Winter 1961 ...... ...... | 92 | 65 | 33 |

concerning fish numbers are confined to the proportion of tagged fish in each catch. A crude calculation of proportionality, even if refined by a correction for the probable annual mortality rate in the population of 33% (Smith 1959), is unlikely to produce a reliable quotient except within very wide limits. However, such figures are presented in Table 2, more to enable a rough comparison to be made of densities of fish in the various lakes than for their absolute value. As indicated above, the length of shoreline rather than the total area or volume of water is likely to be the most important factor controlling the density of fish supported by a deep lake. This conclusion was also reached by Smith (1959) from a study of gill net catches in these lakes over a number of years. He found that population estimates based on shoreline length formed a more reliable index than numbers per unit area. In Table 2, therefore, the number of fish per mile of shoreline is used as the basis for comparison. These figures show that the density of fish in Ngapouri and Okataina is of the same order whilst that in Okaro is rather smaller.

## FISH SIZE

Totals of 512, 401 and 146 fish have been caught and measured from lakes Ngapouri, Okataina and Okaro respectively. The length/weight relationship of all these fish was similar on the whole although those from the two more fertile lakes tended to be lighter for their length than those from the oligotrophic lake, Okataina. The approximate average ratios between the weight (grams) and the cube of the length (cm.) were 0.0117, 0.0125 and 0.0132 for Ngapouri, Okaro and Okataina respectively. These correspond to condition factors in units of pounds and inches of 42, 44 and 49 respectively. These factors are in the reverse order to those of primary productivity.

The average weight of a fish caught in Ngapouri, Okaro and Okataina was 0.7, 1.6 and 3.7 lbs. and these figures have been used in Table 3 in conjunction with the mean population estimates to discover the relative weight of the fish stock in these lakes. The weight of stock per acre is higher in Okataina than in Okaro but equivalent to that in Ngapouri. This conclusion is doubtful in view of the similarity of the two smaller lakes both in their excessive fertility and growth rates of trout. However, it has been shown above that the littoral regions of a lake are of major importance as far as the trout population are concerned. Therefore, the weight of fish is also expressed in terms of shoreline. These data now form a logical sequence according to the quality of the environment provided. Ngapouri and Okaro have a similar and low productivity. Both these lakes have poorly oxygenated water and it is probable that the weight of stock of 700-

TABLE 2. *Population and density estimates based on the recapture of tagged fish in gill net catches made in each lake.*

| *Date of netting* | Okataina *Population* | Okataina *Fish/mile* | Ngapouri *Population* | Ngapouri *Fish/mile* | Okaro *Population* | Okaro *Fish/mile* |
|---|---|---|---|---|---|---|
| April 1960 | 14,000 | 800 | 2,400 | 1,500 | 1,200 | 800 |
| March 1961 | | | 1,600 | 1,000 | | |
| Sept. 1961 | 20,000 | 1,140 | 1,800 | 1,100 | 600 | 440 |
| Feb. 1962 | 8,000 | 500 | 1,600 | 1,000 | 400 | 270 |
| July 1962 | 13,000 | 740 | 600 | 400 | 630 | 420 |

NOTE: In March 1961, only one tagged fish was found in the catch from Okataina and the whole catch only totalled 13 from Okaro. These data were insufficient for population estimation.

800 lbs. of fish per mile is near the maximum possible. As a result, the higher density of fish in Ngapouri is naturally balanced by their lower weight and smaller size. The environment for trout in Okataina is more suited to this species and so the stock in this lake is correspondingly higher.

## DISCUSSION

The biology of any lake is largely controlled by the rate of supply of nutrient material from its catchment. Drainage into Okataina passes through an area of undisturbed and thick bush which is unlikely to supply more than a minimum of useful dissolved salts to the lake. The farmland surrounding Okaro and Ngapouri, on the other hand, undoubtedly supplies a considerable amount of fertilizing material to the lakes. Sewage from farm animals is far stronger than even domestic sewage (Anon. 1962) and extensive topdressing with superphosphates applied to the pastures ensures an ample supply of nutrients for utilization in these lakes. Regular analyses of these waters during 1962 showed the presence of up to 0.2 p.p.m. of free phosphate, especially in the hypolimnion of the two lakes. The stimulating effect of phosphate is well known (Mortimer 1954) and so the higher primary production in Ngapouri and Okaro compared with Okataina is understandable.

Greater primary production may lead to an increased supply of bottom fauna and other potential trout food (Brook and Holden 1952) but at the cost of increased oxygen consumption in the water. In deep lakes, this usually leads to suboptimal conditions of aeration for trout. Trout avoid severely reduced and lethal oxygen concentrations (Whitmore *et al.* 1960) but little is known about the effects of only moderate oxygen concentrations over long periods. These could hardly be favourable, however, for Davidson *et al.* (1959) found growth of certain Salmonidae was depressed when exposed to 6.0 p.p.m. of dissolved oxygen over a period of 20 days.

Although there is evidence that the environment for trout is somewhat more favourable in Okaro than Ngapouri, the difference in fish size between these two lakes is probably due to differences in population density (e.g. Allen 1962). But the difference in the trout population between these two lakes and Okataina is difficult to understand in terms of the concept of production per unit area. This concept is applicable where conditions are fairly uniform as in a shallow lake or fish pond but such cannot be so in a deep lake or even in a shallow one if deoxygenated water covers the bottom mud as in certain dystrophic lakes with swampland inflows. However, water conditions are usually uniform in the shallow littoral regions of lakes regardless of their depth, except for the short lengths where inflows or outflows exist. In the present instance, therefore,

TABLE 3. *Estimates of the mean total population weight, and density per acre of total area and per mile of shore.*

| | *Mean Population* | *Total weight* | *lbs. fish/acre* | *lbs. fish/mile* |
|---|---|---|---|---|
| Okataina ...... ...... | 13,900 | 52,000 | 21.1 | 4,400 |
| Okaro ...... ...... | 720 | 1,150 | 14.5 | 771 |
| Ngapouri ...... ...... | 1,500 | 1,050 | 20.8 | 700 |

the data on trout are related to the length of shoreline for comparative purposes and it has been shown that, whilst the density of fish in Okataina is similar or higher than that in Ngapouri or Okaro, fish size and growth are much greater. The absolute sizes of the lakes concerned may be important in controlling the growth of the resident fish. However, fish culture experiments, using *Tilapia* reared in ponds similar in all respects except size, have shown that only ponds smaller than half an acre restrict the size of the fish (Anon. 1960). In addition, trout culture work generally has shown that large fish can be reared in relatively small ponds. Apparently, therefore, the size of the lakes in the present instance is unlikely to be important in controlling the growth of fish. The relative degree of eutrophication in these lakes, however, does explain the fact that the trout grow more rapidly in Okataina than in both Ngapouri and Okaro.

## ACKNOWLEDGMENT

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## SUMMARY

Lakes Okaro and Ngapouri have a higher primary production and a lower dissolved oxygen content than Lake Okataina. In addition, the density of the trout population is approximately the same or lower than in Lake Okataina. On the other hand, the rate of growth is higher and the ultimate size of adult trout is considerably larger in Okataina than in Ngapouri or Okaro.

The observations are correlated to show that eutrophication, resulting from development of farmland in the catchment, has produced an inferior environment for trout in Lakes Okaro and Ngapouri.

## REFERENCES

ALLEN, K. R., 1962. The natural regulation of the population in the Salmonidae. *N.Z. Sci. Rev.* 20, 58–62.

ANON, 1960. Tropical Fish Culture Research Institute, Malacca. Report for 1959–1960. *H.M.S.O.* 1–28.

ANON, 1962. Waste waters from farms. *D.S.I.R. Notes on Water Pollution*, No. 17: 1–4.

BENSON, N. G., 1961. Limnology of Yellowstone Lake in relation to the cutthroat trout. *U.S. Fish & Wildlife Service, Res. Rep.* 56: 1–33.

BEVERTON, R. J. H., and HOLT, S. J., 1957. On the Dynamics of Exploited Fish Populations. *Fish. Invest. Ser.* 2, 19.

BROOK, A. J., and HOLDEN, A. V., 1957. Fertilization experiments in Scottish freshwater lochs. 1. Loch Kinardochy. *Sci. Invest. Freshw. Fish. Scot.* No. 17: 1–30.

DAVIDSON, R. C., BREESE, W. P., WARREN, C. E., AND DOUDOROFF, P., 1959. Experiments on the dissolved oxygen requirements of cold water fishes. *Sewage & Industrial Wastes* 31: 950–966.

FISH, G. R., 1958: The productivity of certain fishponds in Malaya. *Proc. Cent. & Bicent. Congr. Univ. Malaya*: 187–191.

HASLER, A. D., 1958. Eutrophication of lakes by domestic drainage. *Ecology* 28: 383–395.

MORTIMER, C. H., 1954: Fertilizers in fishponds. *Colonial Office Fish. Publ.* No. 5: 1–155.

NEWELL, A. E., 1960. Biological survey of the lakes and ponds in Coos, Grafton and Carroll Countries. *New Hampshire Fish & Game Dept. Surv. Rep.* 8a: 1–297.

RAWSON, D. S., 1955. Morphometry as a dominant factor in the productivity of large lakes. *Proc. Int. Ass. Theo. Appl. Limnol.* 12: 164–175.

SMITH, D. C. W., 1959. The biology of the rainbow rout (*Salmo gairdnerii*) in the lakes of the Rotorua district, North Island. *N.Z. J. Sci.* 2: 275–312.

STEVENS, W. L., 1951. Asymptotic Regression. *Biometrics*, 7: 247–267.

WHITMORE, C. M., WARREN, C. E., and DOUDOROFF, P., 1960. Avoidance reactions of salmonid and centrachid fishes to low oxygen concentrations. *Trans. Amer. Fish. Soc.* 89: 17–26.