TASMANIAN FARM DAMS
IN RELATION TO FISH CULTURE

DIVISION OF FISHERIES AND OCEANOGRAPHY TECHNICAL PAPER NO. 4

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL
RESEARCH ORGANIZATION, AUSTRALIA 1958

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Technical Paper No. 4

Commonwealth Scientific and Industrial
Research Organization, Australia

Melbourne 1958

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[*Manuscript received March* 31, 1958]

Summary

Farm dams in Tasmania are usually small, shallow, turbid, and subject to rapid and considerable loss and replacement of water. The bottom deposits appear to consume oxygen rather quickly and to give off carbon dioxide, though prolonged depletion of oxygen is unlikely because of the ease with which the contents of the dams may be mixed by wind action. Notwithstanding their disadvantages they possess a sometimes abundant phytoplankton, zooplankton, and bottom fauna. Fish can live in most of them and grow well, production in the better ones being similar to that in unenriched commercial fish ponds elsewhere in temperate climates.

I. INTRODUCTION

Conservatively estimated there are several thousand farm dams in Tasmania, whose areas vary from a small fraction of an acre up to the order of 10 ac (4 hectares) or more. The modal area is probably of the order of $\frac{1}{4}$–$\frac{1}{2}$ ac ($\frac{1}{10}$–$\frac{1}{5}$ hectare). While their main purpose is to store water for stock or irrigation, an attempt has been made to determine whether a suitable freshwater fish could survive and grow in them.

Nine were chosen as typical representatives of farm dams in Tasmania for size, depth, colour, and turbidity, and because of their lack of a permanent water supply. The latter meant that they underwent considerable changes in area and volume during the course of the work. Fish were released in the nine dams, and the chemical and biological features of two were examined in relation to these released fish.

II. THE DAMS

(*a*) *Location*

Two dams (1 and 2) selected for preliminary tests with fish were located in podzolic soil formed from sandstones and shales of Triassic age. Dam 1 was below Dam 2 and both obtained their water mostly from surface run-off from their catchment. Water had the same appearance in both dams, being always brown and very turbid. Dam 1 had a fringe of rushes surrounding a narrow zone of *Potamogeton* sp., which was more noticeable in summer, and inside this was an extensive area of free water. Maximum depth was 6 ft (2 m). Dam 2 had no marginal vegetation and sloped more steeply to a maximum depth of about 10 ft (3 m).

Dams 3 and 4, which are the main basis of this paper, were located in strips of alluvium below dolerite hills, and for their sizes both had large catchments, so that they filled rapidly after heavy rain. Dam 5 lay near the base of a dolerite sill,

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close to the margin of a region of brown soil on dolerite. Dams 6, 7, and 9 were in alluvium, to which dolerite and sandstone had contributed, but Dam 8 was in soil derived entirely from sandstone.

Pasture covered most of the catchment areas of the dams, though that of Dam 5 was mainly under eucalypt forest growing in skeletal soil derived from dolerite.

(*b*) *Construction*

All except Dam 5 were constructed in a manner typical of farm dams in Tasmania. Soil was excavated by means of a bulldozer so that a hollow was produced. The excavated soil was formed into a wall by the bulldozer on the downhill side of the dam. This meant that the bottom of the dam was formed of soil denuded of its surface horizons and it was therefore less permeable, but devoid of organic matter. Thus, the mud bottom usual in a farm dam which is not entirely new is formed from the exposed soil of the original bottom, plus inorganic and organic matter from the catchment, including material from pollution by stock, and from organic matter produced by biological processes in the dam itself. In a dam which is fairly old such mud can be a foot or more deep, very soft—of the consistency of ooze—, and light to dark brown or grey in colour. Dams normally have only sparse communities of higher plants, or even lack them entirely.

In contrast, Dam 5 was built by constructing a wall of earthen sods by means of a front-end loader. The natural grassed bottom was undisturbed, so from the outset the bottom mud must have had quite a different character. A very dense community of higher aquatic plants, dominated by *Myriophyllum* sp., grew in the first two years. It is interesting that another dam, close by and built in a similar manner, also had a very similar plant community.

The dams were suitably screened across their spillways to prevent the escape of fish during floods.

III. Methods and Procedures

(*a*) *Stations*

From November 1955 to April 1957 one station was occupied at approximately monthly intervals in Dams 3 and 4. Each station was located over the deepest part of the dam, samples being collected from near the bottom as well as from the surface, with a brass collecting bottle of 6 l. capacity. It is believed that one station per dam was adequate to give a picture of the chemical and biological constitution of the water mass, since the dams are very small bodies of water, subject to considerable wind action which causes continual mixing. Phytoplankton, zooplankton, and bottom fauna were sampled usually whenever water collections were made, though during the summer of 1956–57 phytoplankton collections were made more frequently than this.

(*b*) *Physical Factors*

Temperatures of surface and bottom were measured at the time of each collection, and additional data were obtained with maximum-minimum thermometers suspended in mid water. A Secchi disk was used to estimate limit of visibility, while turbidity was measured by comparison with silica standards (Welch 1948). Colour was determined by comparison with platinum-cobalt standards (Welch 1948).

Areas of the dams were measured when full and at various other times. Contour lines were drawn through points of equal depth on outline maps of the dams. The area of the whole dam and areas enclosed by contour lines were then determined by means of a hatchet-planimeter as described by Welch (1948), whose formula for volume estimation from these data was also employed.

(c) *Chemical Factors*

Total and fixed solids were estimated by the conventional procedure of evaporating at 180°C for the former, then igniting at 500°C for the latter. Total hardness (calcium and magnesium) was determined by the borate buffer procedure (American Public Health Association *et al.* 1955), calcium alone then being determined as described by Tucker and Bond (1954); magnesium was estimated by difference. Sodium and potassium were estimated by flame photometric comparison with standards.

The unmodified Winkler method served to determine oxygen, and pH was estimated by colour comparison in the field, indicators being bromocresol purple, bromothymol blue, or cresol red. Free carbon dioxide concentration was measured on fresh samples (Welch 1948), as were carbonate and bicarbonate (Association of Official Agricultural Chemists 1950).

Nitrate nitrogen and inorganic and organic phosphorus were estimated according to Rochford (1947, 1951).

(d) *Biological Factors*

Collections were made from November 1955 to April 1957.

(i) *Phytoplankton.*—From the collecting bottle water was run into 100 ml glass jars with screw caps. Samples were examined for living phytoplankton organisms on return to the laboratory. A Sedgwick-Rafter counting cell (Welch 1948) was used for enumeration of the phytoplankton.

(ii) *Zooplankton.*—A Clarke and Bumpus (1950) plankton sampler was used to collect zooplankton quantitatively. Vertical hauls were not feasible because of the shallowness of the dams. Because also of the opacity of the water it was decided to tow the sampler horizontally about $2\frac{1}{2}$ ft below the surface. The depth was a little less than this when the depths of the dams were minimal. Catches were preserved in formalin subsequently to be identified and counted.

(iii) *Bottom Fauna.*—Pairs of samples were collected from opposite sides of the dams, under water of approximately average depth. The grab used and the procedure following collection have already been described by Weatherley and Nicholls (1955).

(iv) *Fish.*—Rates of stocking were approximately 400 per ac (988 per hectare) for Dams 1–9, exclusive of 3–5, for which the rate was 600 per ac (1482 per hectare). The fish used were tench, *Tinca tinca* (L.), which were caught by electro-fishing in Lake Tiberias near Hobart. Numbers released were dependent on areas of the dams at the time.

The fish for Dams 1 and 2 were probably all 2 years old having just passed their second winter as revealed by scale readings. They were released in September 1954, 85 in Dam 1 and 57 in Dam 2. In May 1955 these populations were netted with seines (1 in. stretched mesh) and those recovered were measured, weighed, and sexed, a sample of scales being removed from each; the results of reading these scales will be reported elsewhere. The fish were returned to the dams. The populations were netted again in March and November 1956. This method was eventually realized to be rather less efficient than was originally believed, so certain adjustments have been made in calculating production values for Dams 1 and 2 because a small number of additional fish were captured from them after November 1956. However, these adjustments hardly affected the overall picture.

In November 1955, 336, 210, and 168 small tench were released in Dams 3, 4, and 5 respectively. The first two were netted in March 1956 to ascertain the success of the releases. As a result of the netting operations it was decided to remove all the fish from Dam 3 in April 1956 and restock it later. However, the onset of colder weather caused the fish to become sluggish, and it proved impossible to remove them all with a net. It was therefore decided to poison the remainder with rotenone. So, late in June, after a simple laboratory test of the effectiveness of rotenone in killing tench, sufficient powdered derris was broadcast into the dam as a watery paste to make a concentration of approximately 1 p.p.m. Because of the low water temperature it required a week for all the remaining fish to be disabled or killed by the rotenone, and some considerable time elapsed before a residual effect had disappeared and the zooplankton had recovered (Section IV (*d*) (ii)). The mean length and weight of the comparatively few fish obtained by poisoning in June were very similar to those removed earlier, which indicated that those remaining had not grown since April. Their weight and number were therefore added to those recovered in April. In September 1956 the dam was restocked.

The reason for removing the fish from Dam 3 and restocking it was that it was considered likely that the heavy mortality found in March–April was caused by bird predation. However, despite the destruction of all cover near the dam before the second release of fish, and a watch kept for bird predators thereafter, a comparatively high rate of mortality was again encountered with the second release.

In December 1956 the population of Dam 4 was again netted, examined, and replaced, while in April 1957 the populations of both Dams 3 and 4 were very completely netted out, measured, weighed, and sexed.

In April 1956 Dam 5 was fished electrically, since it was far too weedy to net. It was divided into several sections with vertical partitions of netting and each section worked over thoroughly. Only 2 of the 168 fish released were recovered, and restocking was not attempted.

In September 1956 Dams 6–9 were stocked with 54, 62, 16, and 22 fish respectively. Dam 8 was netted in February 1957 as it was feared that great loss of water from this dam might have prejudiced survival. The fish recovered were replaced. In April 1957 the four dams were thoroughly netted.

(*e*) *Chemical Enrichment*

Following a 9 week laboratory experiment on the effects of adding four fertilizing substances (sodium nitrate, disodium hydrogen phosphate, potassium chloride, and calcium carbonate) singly, and in their possible combinations, to jars containing water and mud from Dam 3, it was decided to add a fertilizer mixture to the dam.

After a wet winter and spring in 1956, during which Dam 3 discharged almost continuously, though usually at a slow rate, the chemical composition of the water had changed considerably from a year earlier, as Section IV(*b*) reveals. It was water of this earlier composition which was used in the experiment mentioned above. Nevertheless, it was decided to try the effects of a fertilizer mixture based upon the experiment, since the water was simply more dilute, rather than changed in any fundamental or qualitative sense.

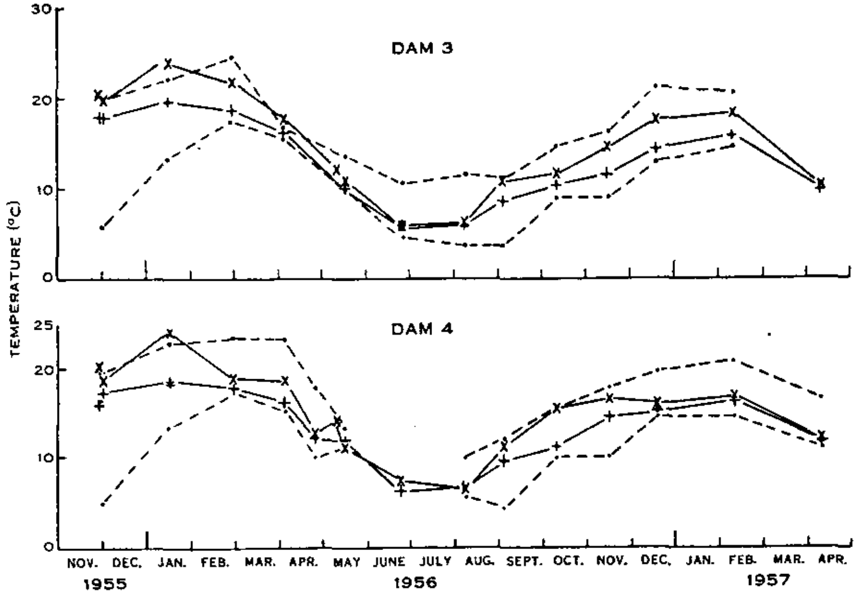

Fig. 1.—Temperature in Dams 3 (upper) and 4 (lower). ×——× surface; +——+ bottom; - - - - - maximum (upper curve) and minimum (lower curve).

A fertilizer mixture of the following composition was therefore prepared:

29 parts sodium nitrate,
66 parts superphosphate (20·5 per cent. water soluble),
5 parts potassium chloride.

A quantity of 419 lb (190 kg) of the mixture was made up to be broadcast evenly over the dam in eight additions at approximately fortnightly intervals. The amounts were based on recommendations of Swingle and Smith (1939), calculated to give concentrations of 8, 2, and 2 p.p.m. of nitrogen, phosphorus, and potassium, respectively, if all had been added to the dam at once and gone into solution. The first addition was on October 15, 1956.

IV. Results

(*a*) *Physical Factors*

(i) *Temperature.*—Figure 1 shows the temperature records for Dams 3 and 4. Surface, bottom, maximum, and minimum temperatures are included. The maximum temperatures were usually somewhat higher than those taken with reversing thermometer, the minimum somewhat lower. The few occasions when the surface temperatures exceeded the maximum are explained by the fact that the positions are different, the maximum-minimum thermometer being midway between surface and bottom. The few instances of bottom temperatures being lower than recorded minima are similarly explained.

There was apparently not more than about 3–5°C difference between surface and bottom during summer days, and in winter there was hardly any. About 25°C is the highest temperature likely to occur in any normal year.

Table 1

EXTREMES IN AREA AND VOLUME FOR DAMS

Dam	Area (ac)		Minimum as % of Maximum	Volume (gal)		Minimum as % of Maximum
	Maximum	Minimum		Maximum	Minimum	
1	0·278	0·109	39·2	—	—	—
2	0·143	0·069	48·3	—	—	—
3	0·680	0·431	63·4	575,681	338,563	58·8
4	0·569	0·275	48·3	479,075	206,794	43·2
6	0·138	0·071	51·4	102,800	29,100	28·3
7	0·164	0·086	52·4	121,188	47,300	39·0
8	0·040	0·008	20·0	16,250	875	5·4
9	0·050	0·008	16·0	24,700	1,100	4·5

(ii) *Light Penetration.*—Limit of visibibility, as indicated by the Secchi disk, was usually low, for most dams are turbid and coloured. Minima are most likely to be found after prolonged rain, when large quantities of suspended materials have been washed in. Thus in August 1956 the Secchi readings were at minima in Dams 3 and 4 of about 7 cm in the former and several times this in the latter.

(iii) *Turbidity and Colour.*—As indicated by the low penetration of light, values were very high in Dams 3 and 4. On two occasions turbidity in the former was about 1000 p.p.m. and colour 1500 p.p.m. Corresponding values in Dam 4 were less than half.

(iv) *Area and Volume.*—Area and volume changes were governed mainly by local precipitation and evaporation, though according to their owners several of the dams were fed by seepage water, and indeed it was pointed out that where possible dams are located so that they are in water courses. Table 1 gives the area and volume maxima and minima for eight dams and expresses the minimum as a percentage of the maximum. The relation of the changes to the chemistry and biology of the dams will be considered in the following subsections. Figure 2 shows the shapes and depth contours of Dams 3 and 4 when full.

(*b*) *Chemical Factors*

(i) *Total and Fixed Solids.*—Table 2 gives maximum, minimum, and mean values for total and fixed solids. The maxima were summer values and occurred when the water contents of the dams were minimal. The minima occurred in the winter and spring of 1956 when the water contents were maximal and much dilution had occurred owing to prolonged winter rain. The dams were full to overflowing from March–April until the end of 1956. Values were similar for surface and bottom, though the latter tended to be a little higher.

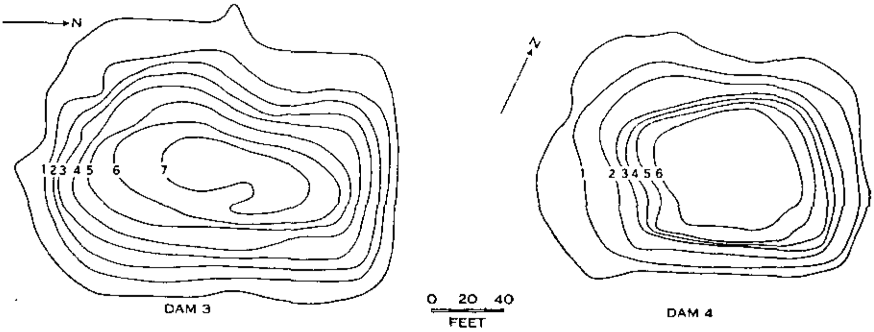

Fig. 2.—Maps of Dams 3 and 4 showing depth contours.

TABLE 2

RANGES AND MEANS FOR TOTAL AND FIXED SOLIDS, CALCIUM, MAGNESIUM, SODIUM, AND POTASSIUM IN DAMS 3 AND 4

No. of observations in each dam, 25; values in p.p.m.

	Dam 3		Dam 4	
	Range	Mean	Range	Mean
Total solids	458–1981	1047	400–2060	1066
Fixed solids	362–1678	813	296–1528	820
Calcium	8–62	26	14–74	39
Magnesium	7–93	35	18–143	67
Sodium	40–380	150	60–460	212
Potassium	3–10	5	2–12	7

Run-off water carried heavy loads of suspended materials into the dams, but these settled rapidly and the effect of the water was to dilute that already in the dams.

To judge from Chu (1942) and Welch (1952) the values for total solids and fixed solids were higher than is usually found in lakes, especially in the summer when maximal values occurred.

(ii) *Calcium, Magnesium, Sodium, and Potassium.*—The trends for these four elements were similar to those for total and fixed solids. Differences between surface and bottom were not large. Such great changes occurred with time that means alone are not very significant, so again ranges are also given in Table 2.

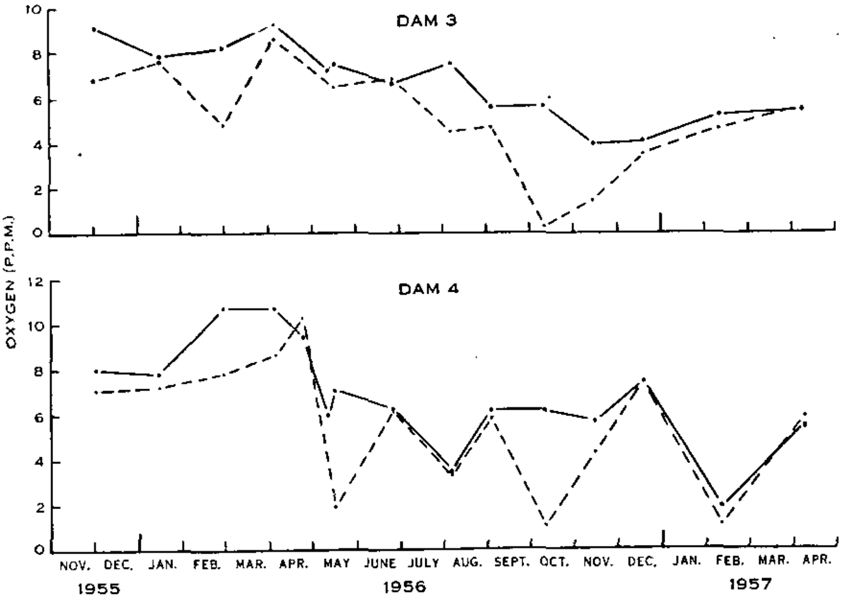

Fig. 3.—Oxygen values for Dams 3 (upper) and 4 (lower). ———— surface; – – – – – – bottom.

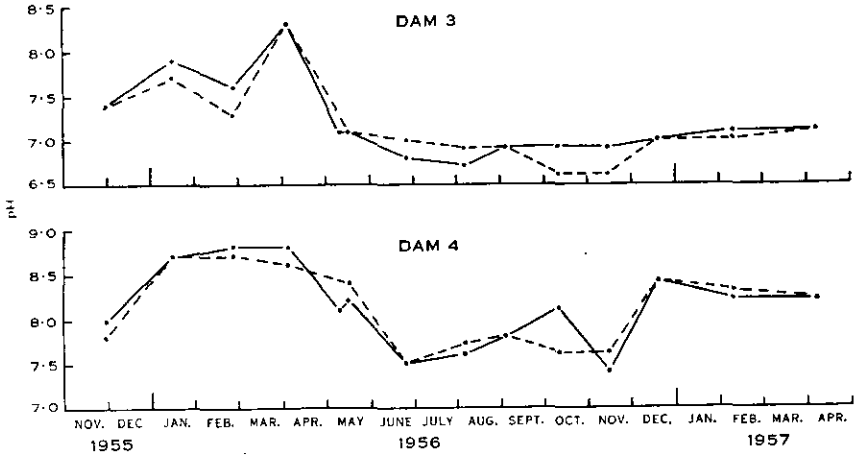

Fig. 4.—pH values for Dams 3 (upper) and 4 (lower). ———— surface; – – – – – – bottom.

Chu (1942) tabulated data which show the very large range of these elements occurring in natural freshwaters. Though generalizations should be cautious it appears that values for the dams are not atypical, except perhaps for sodium which appear high.

(iii) *Oxygen.*—Oxygen values (Fig. 3) revealed a remarkably variable picture, lacking the orderly seasonal changes normally associated with larger bodies of water. But there was a distinct tendency for surface values to be higher than bottom, and several times the latter were quite low. Values seem to have declined somewhat overall, during the course of the observations. It appears that the bottoms of the dams consume oxygen rapidly, though stratification is normally short-lived, probably because of the prevalence of wind action and the ease with which such small bodies of water can be mixed.

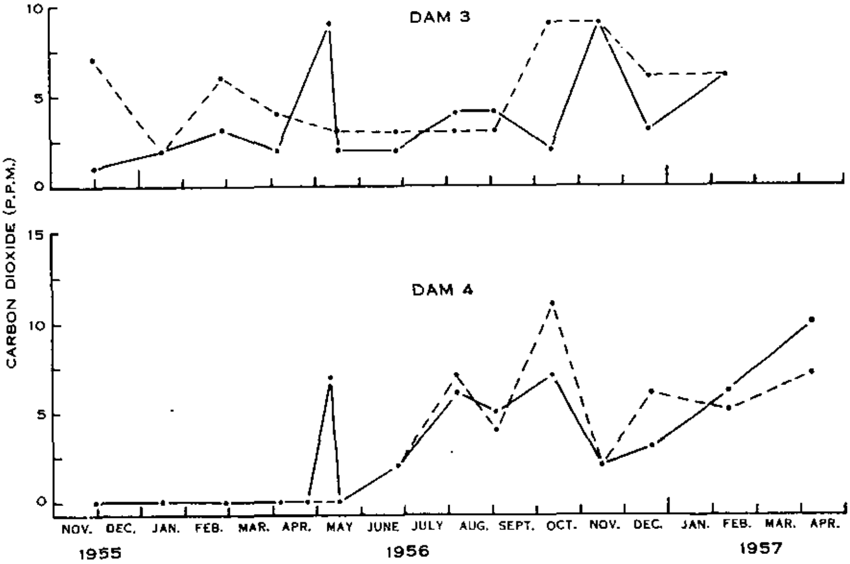

Fig. 5.—Carbon dioxide values for Dams 3 (upper) and 4 (lower). ——— surface; – – – – – – bottom.

(iv) *pH.*—Figure 4 gives the pH changes. Surface and bottom values did not change greatly or systematically, and in both dams tended to fall during winter and rise again with the onset of drier, warmer weather, this being more marked in Dam 4 than Dam 3. In Dam 3 pH fluctuated somewhat on either side of 7, but Dam 4 was always distinctly alkaline.

(v) *Carbon Dioxide.*—Considering Dam 3 alone (Fig. 5) it is seen that bottom values were generally somewhat higher than surface, with a notable exception on May 10, 1956. About this time the surface water must have been comparatively heavily charged with carbon dioxide, apparently acquired in its journey over and through the soils of the catchment as run-off from flood rains. Otherwise high carbon dioxide tended to coincide with low oxygen values for bottom water, which strengthened the view that the metabolic demands of the bottom are heavy, and responsible for the low oxygen values noted.

In contrast, Dam 4 had no free carbon dioxide until May 1956, when 7 p.p.m. were detected in the surface water, an occurrence analogous to that in Dam 3.

Thereafter carbon dioxide was always detected and, as with Dam 3, the values for the bottom water were inversely related to oxygen values. The appearance of carbon dioxide, where before there was carbonate, is directly attributed to the effects of the flood on the hydrology of the dam.

(vi) *Carbonate.*—Carbonate was present in Dam 4 until May 1956, when carbon dioxide appeared (Figs. 5 and 6). From then on carbon dioxide was always found, and of course carbonate was no longer detected. None of the other dams contained carbonate.

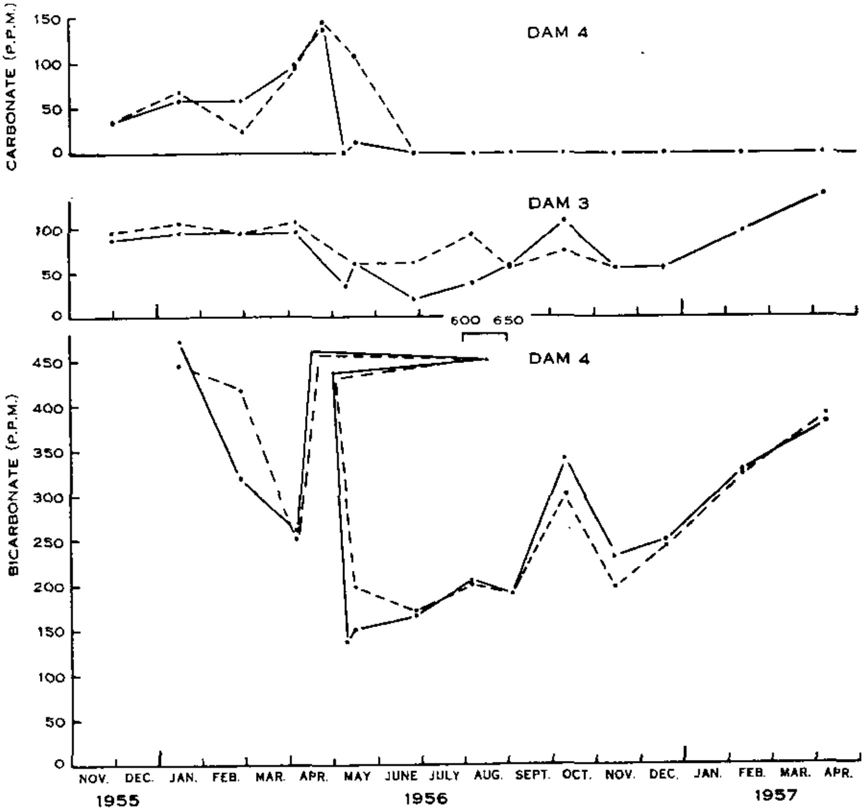

Fig. 6.—Carbonate and bicarbonate values. Carbonate, Dam 4 (upper); bicarbonate, Dams 3 (middle) and 4 (lower). ———— surface; – – – – – – bottom.

(vii) *Bicarbonate.*—Most of the carbon dioxide in Dams 3 and 4 was combined in the form of bicarbonate, values in the latter, however, being far the higher (Fig. 6). During the 1956 winter, values became severely reduced, especially in Dam 4, carbon dioxide becoming evident just as bicarbonate reached a minimum.

(viii) *Nitrogen.*—Before May 1956 nitrogen values were comparatively low in Dam 3, but during run-off from the May flood large quantities appeared (Fig. 7) and values were generally higher thereafter. There were declines in October and February, and since they coincided with phytoplankton maxima, rate of biological utilization of nitrogen may sometimes have been very high. The minimum, in February 1956, was also associated with an algal maximum. The generally high values from October 1956 onwards were no doubt mainly the result of artificial chemical enrichment.

The position is not so clear in Dam 4. However, before the May flood, values were low, corresponding again with high phytoplankton levels, while afterwards they became and remained higher, perhaps because there were no further significant increases in phytoplankton production.

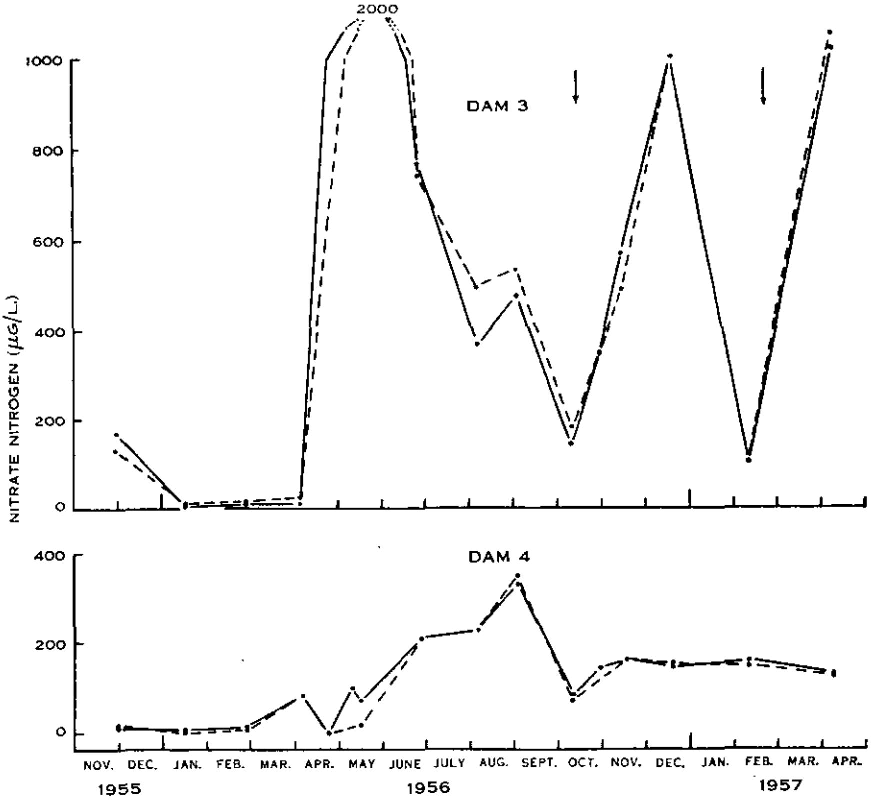

Fig. 7.—Nitrogen values for Dams 3 (upper) and 4 (lower). ———— surface; - - - - - - bottom. Arrows indicate times of first and last chemical enrichment of Dam 3.

Consistently low values for nitrogen were not encountered in any of the dams. Chu (1942) listed values for nitrogen in natural waters ranging from a trace to about 11 mg per l.; most were less than 1 mg per l. Allowing for the great range found, the dams seem to have about "typical" amounts of nitrogen for natural freshwaters.

(ix) *Phosphorus*.—From November 1955 to May 1956 inorganic phosphorus ranged from 6 to 310 and from 1 to 152 μg per l. in Dams 3 and 4 respectively, while corresponding ranges of organic phosphorus were 11–90 and 111–258 μg per l.

Welch (1952) cited a range of 0–15 μg per l. "soluble" phosphorus and 5–100 μg per l. organic phosphorus for 479 Wisconsin lakes. Again, consideration of the data of Chu (1942), Smith (1946), Barrett (1953), Cunningham *et al.* (1953), Weatherley and Nicholls (1955), and Rigler (1956) on lakes, and Zeller (1953) on farm fish ponds, gives an indication of the vast range of phosphorus values found in both natural and phosphorus-enriched freshwaters. Several of the above studies have stressed the rapid changes in values which may occur. All that may be said of the dams is that there does not appear to have been a shortage of phosphorus in the ordinary limnological sense, which is reflected in their ability to support phytoplankton "blooms".

TABLE 3

PHYTOPLANKTON GROUPS FOUND IN DAMS 3, 4, AND 5

Dams in which forms are found signified by numbers in parentheses

Chlorophyta	*Carteria* sp. (3, 4)
	Palmella sp. (5)
	Pediastrum sp. (5)
	Ankistrodesmus sp. (3, 4, 5)
	Kirchneriella sp. (3)
	Scenedesmus sp. (5); other unindentified Oocystaceae
	Closterium sp. (4, 5)
Chrysophyta	*Botryococcus* sp. (4)
	Cyclotella sp. (4)
	Rhizosoleniaceae (5)
	Synedra sp. (5)
	Cymbellaceae (5)
	Naviculaceae (3, 4, 5)
Cyanophyta	*Synechococcus* spp. (3, 4, 5)
	Pluto sp. (3)
	Anabaena sp. (3, 5); other unindentified Cyanophyta
Pyrrophyta	Unidentified forms (3, 4, 5)
Euglenophyta	*Trachelomonas* sp. (3, 4)
	Unidentified forms (3, 4, 5)

Unfortunately after May 1956 the heavy load of suspended materials and high turbidity entering with the run-off from flood rains interfered with the method of analysis, so that all subsequent analyses had to be discarded. In 1954, however, before the main period of observations, several analyses were performed which indicated a similar order of values to those obtained subsequently.

(*c*) *Effects of Chemical Enrichment*

The relation of the large bloom of *Trachelomonas* sp., observed in Dam 3 in February 1957, to chemical enrichment, will be considered in Section IV (*d*) (i).

(*d*) *Biological Factors*

(i) *Phytoplankton*.—Various algae found in Dams 3 and 4 are given in Table 3. Algae from Dam 5 are also included.

In Dam 3, three distinct phytoplankton maxima occurred during 1956–57 in late summer–early autumn of 1956, at a similar time in 1957, and in the spring of 1956 between these times (Fig. 8). The first maximum was made up of *Ankistrodesmus*, *Kirchneriella*, and *Pluto* spp., Naviculaceae, Pyrrophyta, and some unidentified cells. The second was mainly *Trachelomonas* and *Carteria* spp. and branching Cyanophyta, and the third, in 1957, was due to *Trachelomonas* sp. μ-Flagellates* were nearly always present, but their numbers did not compare with the larger cells, and because of their smallness their total bulk seemed unimportant.

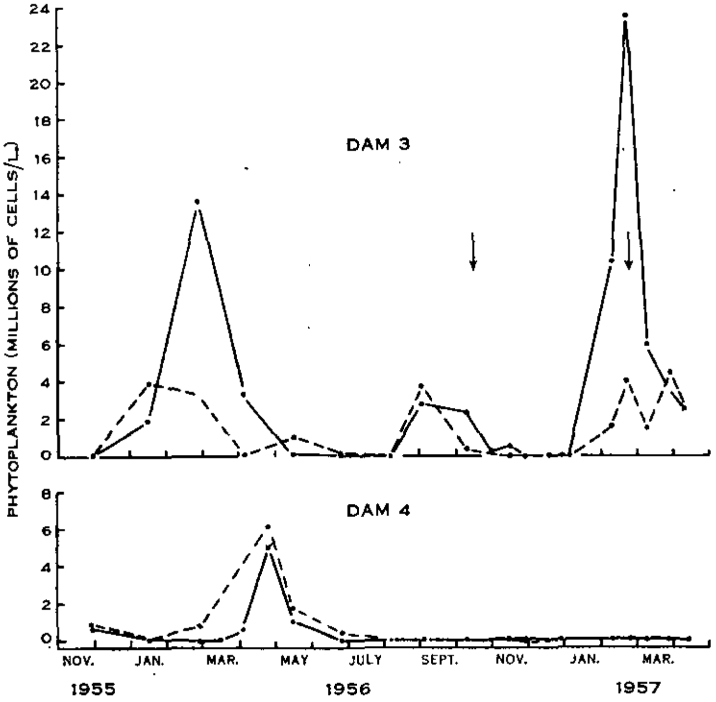

Fig. 8.—Phytoplankton in Dams 3 (upper) and 4 (lower). ———— surface; – – – – – – bottom. Arrows indicate times of first and last enrichment of Dam 3.

The increasing volume of water in Dam 3 in late 1955 and early 1956 must have tended to lower the population density of the phytoplankton by dilution, while the 1956 spring maximum occurred despite outflow of water from the dam which had been going on for some 8 months. On the other hand, the very high maximum in February 1957 was probably somewhat exaggerated by the shrinking area and volume at that time. This makes it difficult to decide whether chemical enrichment made

*The term μ-flagellates is used here in the sense of Marshall (1947) to describe tiny flagellates of which the nannoplankton is largely composed.

more than a slight contribution to this bloom, especially as there was a bloom almost exactly a year earlier, and a smaller one in the preceding spring, both without benefit of artificial enrichment. It almost seems as if this dam displayed the classical picture of phytoplankton abundance, featuring spring and autumn maxima. The large bloom of February 1957 seemed to make inroads on the large amount of nitrogen then in the dam as a result of enrichment.

Dam 4 had only one maximum (Fig. 8); a bloom of *Botryococcus*, *Cyclotella* sp., Pyrrophyta, and some unidentified cells, in April and May 1956. The bulk of the bloom was *Botryococcus*, because the colonies were so large, though the numbers involved were comparatively modest (maximum 805,000 per l.). The *Botryococcus* imparted a definite greenish hue to the water, despite the brownness and turbidity of the latter. The run-off from the May flood destroyed the bloom. In January and February 1956, μ-flagellates were present in rather large numbers, and in April and May they paralleled the larger cells in numbers, though not, of course, in volume. Though their overall numbers were greater than in Dam 3 their contribution to the phytoplankton still seemed small.

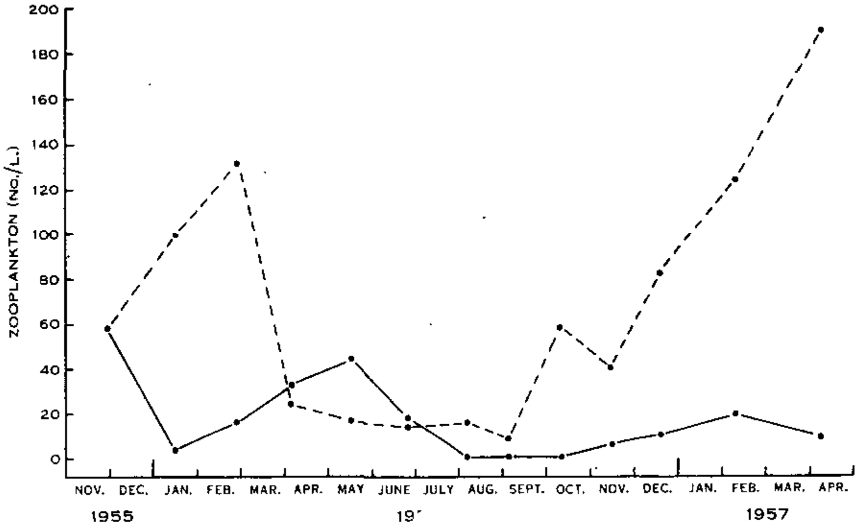

Fig. 9.—Zooplankton in Dams 3 and 4. ———— Dam 3; – – – – – – Dam 4.

Swingle and Smith (1950) in particular have written of the ability of high turbidity to prevent phytoplankton blooms through reduction of light penetration, the idea being almost axiomatic in limnology. But blooms of considerable magnitude occurred in these dams. As further evidence, large phytoplankton populations were found in Dams 5–9, though admittedly the number of samples collected from the latter four was small. These four seem to resemble Dam 3 rather than 4; in February 1957 10,000,000 *Trachelomonas* sp. per l. were found in Dam 6. Again, large quantities of green filamentous alga (*Microspora* sp.) were found on the bottom of Dam 3, and bottom-living algae were also noted in Dams 7 and 8—colonial diatoms among a mass of filaments of *Hormidium* sp. in the former, and *Zygnema* and *Anabaena* spp. in the latter.

Algae capable of flourishing in such turbid waters as the dams must be well adapted to carry out photosynthesis in low light intensities.

Taken as a whole the phytoplankton in the dams seems fairly rich. Thus *Asterionella*, the colonial diatom, may reach a population density of 50,000,000 per l. in certain reservoirs, though from several million to about 10,000,000 per l. is about the order of its numbers in the spring maximum in the English lakes (Lund 1950). The fifth annual report of the Supervisory Committee for Brown Trout Research (1954) referred to phytoplankton values from 500,000 to 5,000,000 per l. resulting from the addition of phosphate fertilizer to Scottish lochs, and Weatherley and Nicholls (1955) noted maxima in excess of 1,000,000 cells per l. accompanying the chemical enrichment of a Tasmanian highland lake, with a subsequent decline to only a few thousand per l. Bainbridge (1957), summarizing data on marine phytoplankton populations, gave maxima of 10,000,000 per l. for diatoms and 50,000,000 per l. for flagellates, but indicated that more common maxima are 500,000 and 2,500,000 per l. respectively. Thus it appears that farm dams are not unproductive measured in terms of their ability to produce large phytoplankton populations.

There was a considerable amount of detrital material in addition to the phytoplankton.

(ii) *Zooplankton.*—The mean zooplankton population of Dam 3 was less than that of Dam 4 (Fig. 9). Neither stood in any obvious close relation to the phytoplankton standing crop values. The disappearance of zooplankton from No. 3 after June 1956 is ascribed to toxic effects of rotenone. It is well known that while rotenone does not greatly affect bottom fauna it is destructive of zooplankton and fish (Krumholz 1948).

Low values in Dam 4 in autumn, winter, and spring in 1956 were attributable to the water flowing out of the dam over this period; Brook and Woodward (1956) showed that Scottish lochs lose much plankton because of high rates of water replacement. Apart from this period of minimum values zooplankton of Dam 4 was at a much higher level.

Copepoda were much the most important organisms of the zooplankton, though after June 1956 Cladocera became of about equal importance in Dam 4.

The Supervisory Committee for Brown Trout Resarch (1954) mentioned a zooplankton population for a chemically enriched loch of 12 organisms per l. immediately after the disappearance of ice cover, with a subsequent increase to 60 per l. Borecky (1956) cited a range of 0–70 Cladocera per l. for a number of lakes, but reported peak values herself of more than 3000 per l. for a large Pennsylvanian reservoir, though densities of a few hundred per litre were more usual. Marshall (1947) and Gauld (1950) provided data on zooplankton in salt water lochs, including two which had been chemically enriched. The former reported Copepoda ranging from 0 to about 800 per l. while the latter gave means of 70 animals per l. (unenriched water) and about twice as many (enriched water). Dams 3 and 4 had mean populations of 20 and 54 per l. respectively. These, then, appear to be in the normal ranges for lakes, lochs, and other standing waters, though both could have been appreciably higher if the low values of winter, apparently caused mainly by rotenone and dilution in Dam 3, and by dilution alone in Dam 4, had not occurred.

(iii) *Bottom Fauna.*—The bottom fauna in Dams 3 and 4 was similar in quantity and kind. Figure 10 shows the principal changes in the bottom fauna of Dam 3, the picture for Dam 4 being substantially similar.

When tench were released in November 1955 the fauna was abundant, but it decreased rapidly and remained low. However, the bottom fauna was not always rich before the release of fish. A few samples taken before November 1955 indicated values similar to those to which it declined in 1956–57. Apparently the bottom fauna in both dams reached a midsummer peak in 1955–56. The weight of the fauna then declined rapidly, evidently because of consumption of its molluscs by tench. It has been shown that tench consume molluscs readily (Schaeperclaus 1933) and confirmed by the present writer, as will be reported elsewhere. After molluscs had been reduced to very low levels in both dams Oligochaeta and Chironomidae formed the major part of the bottom fauna by weight and numbers. Weatherley (1958) found a situation apparently rather analogous to this in a large dam in northern Tasmania in which trout had been released.

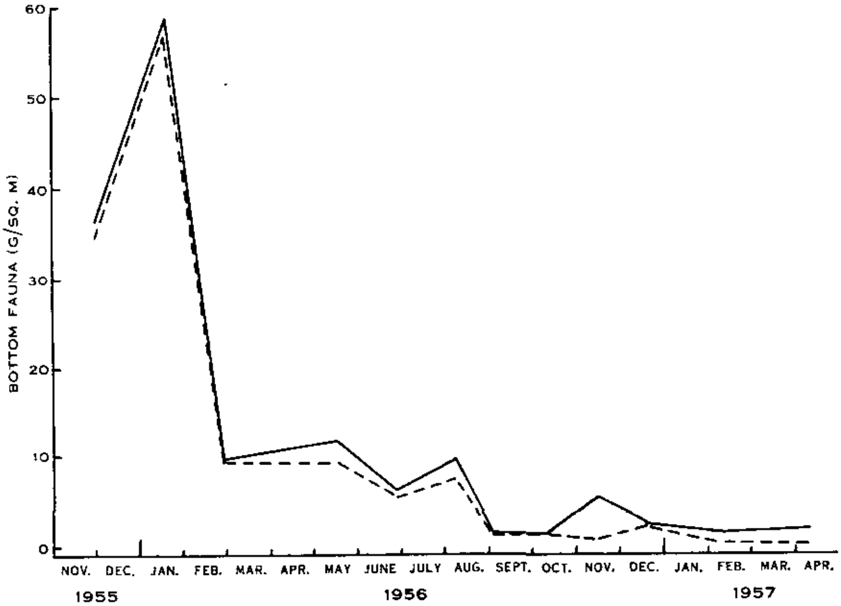

Fig. 10.—Bottom fauna changes in Dam 3. ———— total weight; – – – – – – weight of molluscs.

(iv) *Fish.*—Swingle and Smith (1940) were among the first to appreciate clearly the implication behind the fact that the bluegill (*Lepomis macrochirus* Raf.), a species which usually grows slowly in nature, can sometimes grow much more rapidly. They showed that rapid growth was possible in ponds if population density was kept within certain bounds and adjusted to the food available. It was also important that the fish released be of uniform size, so as to reduce unequal competition and make for uniform growth of the members of the population. These principles were kept in mind in stocking dams with tench, since preliminary examination of their scales had indicated slow growth in nature, yet it was known (Yarrell 1841; Lunel 1874; Maxwell 1904) that under certain conditions tench could achieve rather large size, and that good growth could be obtained in European fish ponds (Schaeperclaus 1933; Mortimer and Hickling 1954).

Table 4 summarizes data from eight dams. Dam 5 has been omitted, since only two fish were recovered after about 4 months and there was no further release.

Dams 1–4 provided the most interesting data; the former two because the fish populations were observed for more than 2 years, the latter because they were studied most intensively as environments. Figure 11 shows rate of increase in length, and increase in weight of populations in relation to *mean* area of dams (production).

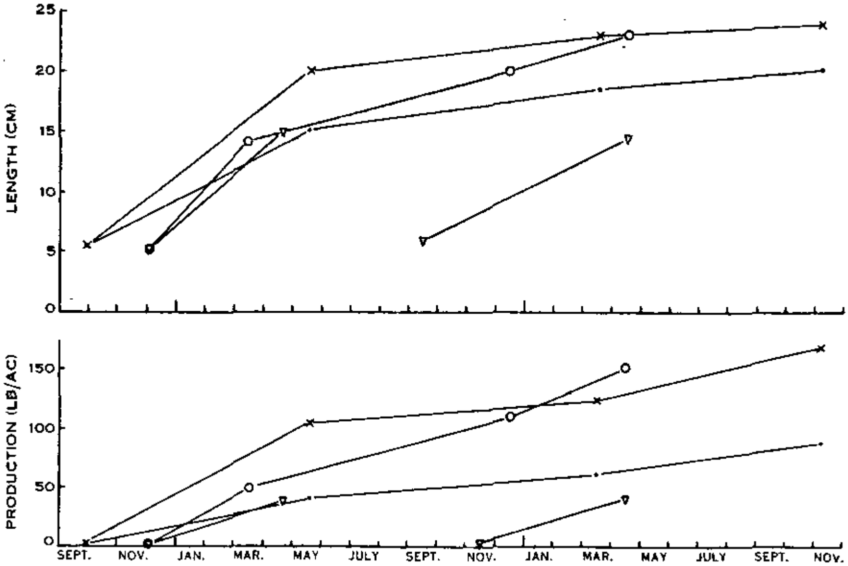

Fig. 11.—Mean increase in length (upper), and production (lower) for Dams 1, 2, 3, and 4. × Dam 1; ● Dam 2; ▽ Dam 3; ○ Dam 4.

Mean growth rate was similar in Dams 1, 3, and 4, though because of a higher mortality in Dam 3 (Table 4) its production resembled that in Dam 2 rather than Dams 1 or 4. Moreover, it is likely that mean growth rate was high in Dam 3 *because* of the higher mortality (and therefore lowered density of population). The second release of fish in Dam 3 resulted in a rather slower growth rate though with a rather higher rate of survival, while production was no better, even though there were about $2\frac{1}{2}$ more months for the fish to grow than following the earlier release. The diminished bottom fauna probably partly accounted for the poorer growth after the second release. Wild tench grew much more slowly than those in Dams 1 and 2, as will be reported later, and the same applied to Dams 3 and 4. Even in Dams 6–9 growth rate was somewhat more rapid than in nature, though slower than in Dams 1–4.

Table 4 shows that results in Dams 6 and 9 were much inferior to those in Dams 1–4. The fish grew and survived poorly; indeed the standing crop of fish in Dam 9 was *lower* after about 7 months than when they were released. Production in

TABLE 4

PERCENTAGE RECOVERY, MEAN INCREASE IN LENGTH AND WEIGHT, STANDING CROP, AND CONDITION OF TENCH IN EIGHT FARM DAMS

R, percentage recovery; *L*, mean total length (cm); *W*, mean weight (g); *S*, standing crop (lb per ac); *K*, mean condition factor

Dam:	1	2		3	4		6	7	8	9
	29.ix.54			3.xii.55			21.ix.56			
L	5·5	5·5	*L*	5·2	5·2	*L*	7·7	7·7	7·4	7·8
W	1·9	1·9	*W*	1·6	1·6	*W*	6·1	6·3	5·8	6·8
S	1·9	2·1	*S*	1·8	1·9	*S*	7·7	7·5	11·2	15·0
K	1·10	1·10	*K*	1·12	1·13	*K*	1·30	1·30	1·36	1·32
	17.v.55			12.iii.56			25.ii.57			
R	85·9	68·4	*R*	—	92·9	*R*	—	—	75·0	—
L	20·0	15·2	*L*	—	14·1	*L*	—	—	13·5	—
W	113·9	49·2	*W*	—	49·3	*W*	—	—	33·5	—
S	105·5	40·8	*S*	—	53·8	*S*	—	—	49·2	—
K	1·38	1·37	*K*	—	1·76	*K*	—	—	1·29	—
	14.iii.56			20.iv.56			24.iv.57			
R	80·9	70·5	*R*	58·0	—	*R*	44·4	83·3	0·0	18·2
L	22·9	18·6	*L*	15·0	—	*L*	12·4	13·2	—	12·6
W	157·9	83·4	*W*	57·0	—	*W*	27·4	32·3	—	22·9
S	125·0	61·2	*S*	38·0	—	*S*	15·4	34·9	—	9·1
K	1·35	1·27	*K*	1·70	—	*K*	1·37	1·32	—	1·45
	7.xi.56			14.ix.56						
R	53·5	44·9	*R*	—	—					
L	24·0	20·3	*L*	6·0	—					
W	232·8	142·3	*W*	2·2	—					
S	166·9	86·9	*S*	3·5	—					
K	1·67	1·67	*K*	0·98	—					
				14.xii.56						
			R	—	65·2					
			L	—	20·0					
			W	—	158·1					
			S	—	111·5					
			K	—	1·88					
				16.iv.57						
			R	55·0	65·2					
			L	14·5	23·1					
			W	47·9	198·4					
			S	40·4	152·1					
			K	1·33	1·54					

Dams 7 and 8 was of a similar order to that in Dam 2, though all the fish had disappeared from Dam 8 by April 1957.

Table 4 also gives the mean condition ($K = W \times 10^2/L^3$) for the fish at the times of their release and on subsequent occasions when the populations were examined. The high condition in Dams 1 and 2 in November 1956 indicates that most of the fish were approaching spawning condition, as examination of them showed, but the similarly high condition in Dams 3 and 4 in March 1956 is not so readily explained. Generally condition was higher after the fish were released. Condition nearly always exceeded the value 1·3 which Schaeperclaus (1933) gave as normal for tench in European fish ponds—especially about spawning time. Moreover, the range at any given time was greater than implied by him. In Dams 3 and 4, from which sufficient data were obtained to construct good scatter diagrams, the same tendency of condition to increase with length was seen as for wild tench, as will be described elsewhere.

V. Note on Reproduction in Dams

Tench spawn in summer, and in 1955 and 1956 males and females of Dams 1 and 2 became ripe and obviously capable of spawning. Yet, as a result, only two fish were added to the population of Dam 1 and none to Dam 2. This was possibly because large (parent) fish preyed on eggs and fry. Probably the ideal way to prepare conditions for successful spawning would be to remove all but a few mature fish of each sex. Schaeperclaus (1933) recommended one pair of spawners per pond, but unfortunately failed to indicate the size of such ponds.

In 1956 an attempt was made to reduce the populations of Dams 1 and 2 each to two ripe females and three ripe males. Subsequent netting operations unfortunately showed that not all the other adult fish had been recovered before releasing the spawners, and there was no evidence of young fish. In netting for young tench the usual nets of 1 in. stretched mesh were used, also a net with a large central panel of $\frac{1}{4}$ in. stretched mesh, and even mosquito netting in the shallower water.

An explanation of the failure, alternative to cannibalism, lies in the fact that in nature tench appear to deposit ova among weeds. Weeds were present in Dam 1 but were not luxuriant, and so may have been too sparse or otherwise unsuitable, while Dam 2 lacked weeds.

VI. Discussion

Meagre additional physical, chemical, and biological data obtained from Dams 6–9 suggest environments similar to those of Dams 3 and 4. It has already been shown that they can support considerable algal populations, but their bottom faunas seemed poorer than those of the latter two dams.

The data from Dam 5, although substantially less than from Dams 3 and 4, make it clear that it differs from the other dams in several fundamental aspects. Values for total and fixed solids were much lower and the various nutrient elements were in much lower concentrations. Turbidity was low even after the May flood and the bottom could almost always be seen wherever it was not obscured by the dense weed growth; Welch (1952) refers to the function of plants in suppressing turbidity. The bottom values for carbon dioxide were often much higher than for other dams, though it will be shown elsewhere that this did not apparently mean that they were particularly lethal to tench.

Apparently because of high metabolic requirements of their bottoms the deeper water in dams tends to become depleted of oxygen rather rapidly, though depletions are of short duration because of the frequency of wind action. Oxygen depletion is usually associated with higher levels of carbon dioxide. However, tench, or other fish with similar respiratory tolerances, would only rarely be affected by such conditions, nor would they be distressed by temperatures up to 25°C (Rosa 1958) which would be about the maximum expected under Tasmanian conditions.

As the available food will probably be the principal limiting factor in the growth of fish populations in dams, its abundance and the factors affecting it must be considered. Dams are dynamic environments, being subject to large changes in area (and therefore volume) within a few months. This means that much of the bottom fauna will be exposed and destroyed in dry summers, while prolonged heavy rain will seriously diminish the plankton. On the other hand, most dams seem capable of supporting considerable phytoplankton blooms or growths of bottom-living algae. Thus, while allochthonous detritus is almost constantly present and abundant, and would undoubtedly form part of the food of the zooplankton and bottom fauna (Welch 1952), much of their food is apparently produced in the dams themselves. This surprises, in view of their high turbidity and colour. However, algal nutrients are present in limnologically adequate amounts, though these are considerably lower than those recommended in fish pond practice (Schaeperclaus 1933; Mortimer and Hickling 1954). Nitrogen was probably important in algal nutrition, since its value was usually inversely related to phytoplankton abundance. While the effect of artificial chemical enrichment was difficult to evaluate, the great decrease in nitrogen in February 1957 accompanying the phytoplankton bloom of that time suggests that the algae utilized added nitrogen at a high rate. Data are lacking on phosphorus over this period, but it seems certain that if the algae were using nitrogen they must also have been using phosphorus. While the role of nannoplankton (μ-flagellates) is rather obscure, to judge from Marshall (1947) and Welch (1952), it would have needed to be enormously more abundant to be important as food.

In spite of the greater and more constant abundance of algae in Dam 3 than in 4 the zooplankton was, on the average, several times more abundant in the latter. Therefore other sources of food must have served the zooplankton of Dam 4 as well as phytoplankton; detrital material was presumably of great importance here.

In six of the nine dams, survival of fish was successful, though production was variable. In two of them it exceeded 100 lb per ac (112 kg per hectare) per annum. It is probable that extremes of production—high or low—were not encountered in this study. However, production in those dams where mortality was not too heavy was within the normal range for unenriched fish ponds in Europe and America (Mortimer and Hickling 1954).

Heavy mortality in Dams 5, 8, and 9, and to a lesser extent Dam 3, may probably be ascribed to more than one cause. Predation is possible for Dam 5, since herons were frequent visitors, though there was abundant plant cover for young fish. In Dam 8 prolonged exposure of the fish population to unfavourable conditions associated with drastic decrease in area, such as high summer temperatures and excessive amounts of materials in suspension, may have been to blame. In Dams 3 and 9 the possible explanations are obscure.

Although rate of production (of fish) in Dam 1 was far above that in Dam 2, after nearly 2 years the standing crop in the latter had approximately equalled that attained in the former after only one growing season (Fig. 11). The curves for Dams 1, 2, and 4 show clearly that, though production rate was most rapid during the first season of growth, it continued and showed no sign of stopping. However, where the rate of production in a dam was high it would probably be sound practice to remove all the fish after not more than one year, and then restock it. But two years or more might be required for the crop to reach worth-while weight in a dam where the production rate was low. The fish taken from Dam 1 in November 1956 are shown in Figure 12.

Fig. 12.—Fish captured from Dam 1, November 1956. Mean length and weight at release, 29.ix.54—5·5 cm, 1·9 g, respectively; mean length and weight at recovery, 7.xi.56—24·0 cm, 232·8 g, respectively.

Fish culture in farm dams could apparently be a successful venture, though unaccountable failures might occur.

VII. ACKNOWLEDGMENTS

The author wishes to thank Messrs. G. T. Boss-Walker, A. McKay, F. C. Fergusson, and A. R. Bowen, and Mrs. B. S. Hore-Lacey, who made dams on their properties available for experiments.

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Printed by C.S.I.R.O., Melbourne