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IRON METABOLISM IN TWO BASINS OF A LAKE NEAR OSLO, NORWAY

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Langlivann and Himtjern are two basins in a lake situated on rocks poor in lime and with coniferous forest and bogs in the surroundings. The lake is fundamentally oligotrophic. The influence of allochthonous organic matter is shown by lake colours which are different shades of brown, and by water colours which at the surface are from 15 to 25 on the mg Pt/l scale.

Some differences in hydrology and morphology make the thermal and oxygen stratifications different in the two basins. At certain periods iron is accumulated in great quantities in the deep water. The differences, both in time and depth, in oxygen concentration make it possible to study the influence of this element on the reduction/oxidation of iron. An attempt has been made to find the critical concentration of oxygen. The value found by Einsele (1940) in eutrophic lake water seems also to be valid in this dystrophic lake.

The development of dichotomous pH stratifications is shown. They seem to confirm the above statement.

In a district north of Oslo, Nordmarka, investigations on iron metabolism in some lakes have been done. Kjensmo (1962, 1964, 1967) has shown that in some of these lakes the accumulation of iron in the deep waters is great enough to render the lakes meromictic.

In the following the iron metabolism in two basins in a lake in the abovementioned district will be discussed. Some factors which are important for the oxidation and reduction of iron are also mentioned. In addition, the effect of iron accumulation on active reaction in the deep waters is discussed.

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MORPHOLOGY, GEOLOGY, MORPHOMETRY, AND HYDROLOGY

The topography of Nordmarka depends largely upon the tectonics of the area. Rounded hills with steep sides are characteristic topographical features. A network of fissures and dislocations form zones of weakness in the underground, which consists of Permian intrusives (Halvorsen 1935). Along some of these zones of weakness valleys have been formed by ice and water erosion. Langlidalen (Langli Valley) is formed along such a zone in NNW-SSE direction (Fig. 1). To the south the valley is narrow but is more open in the northern part. Earlier,

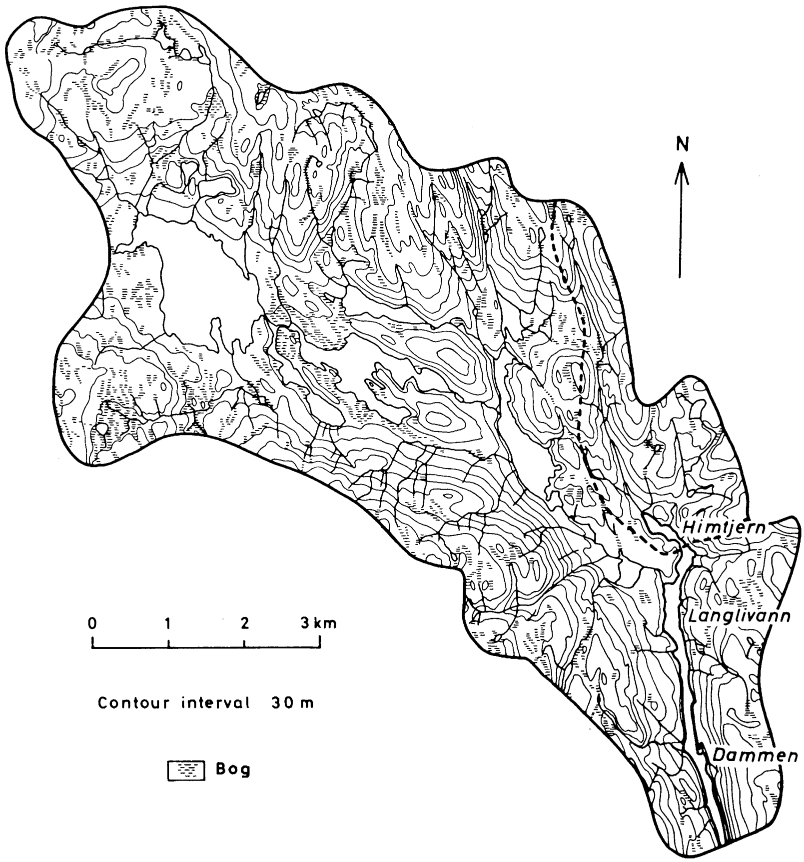

Fig. 1.
Topography of drainage area.

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there were two lakes in this northern part of the valley, Langlivann and Himtjern, the latter farther to the north. The basin of Langlivann is an overdeepening in the Langli Valley and the basin of Himtjern is an overdeepening in a continuation of this valley along a zone of weakness in ESE-WNW direction.

By means of a dam at the outlet of Langlivann the two lakes were transformed into one lake with two separate basins. Later (in 1941) a part of the Langli Valley south of Langlivann was also dammed by a 30 m high dam with the top at 315.2 m above sea-level, that is *ca.* 3 m higher than the old dam (Fig. 2).

In the following, observations only from the two northernmost basins will be discussed. The names which will be used are in accordance with the names of the earlier separate lakes: Himtjern is the northernmost basin and Langlivann is the basin in the middle of the present lake.

Langlivann is especially sheltered to the east and west. Himtjern is more exposed to these directions but it is largely sheltered by the hills which surround the basin. The most frequent wind directions are north and south.

Geologically the drainage area of the lake consists predominately of Permian intrusives, mainly Normarkite and Kjelsåsite. In the highest plateaus to the west some trachyandesitic lavas (rhomb porphyries) are also found. All these rocks are poor in calcium. The drainage area is further covered with coniferous forest and the water which enters the lake drains many bogs. The main drainage passes through Langlivann and southwards, whereas the inlets to Himtjern only consist of smaller brooks (se Fig. 1).

With the 315 m contour as surface basis, the morphometrical data in Table 1 are obtained.

The average depths are small compared with the maximum depths.

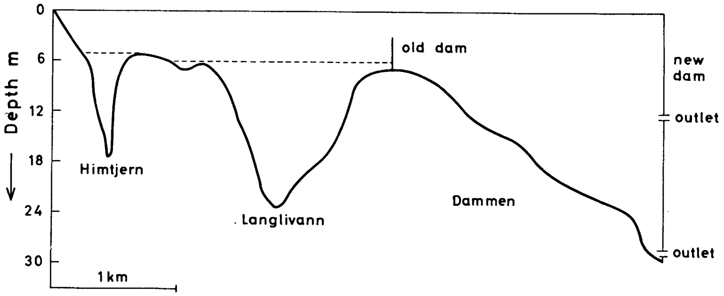

Fig. 2.
Longitudinal section through Himtjern, Langlivann, and Dammen.

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Table 1.
Morphometrical values

	Langlivann	Himtjern
Height above sea-level (m)	315	315
Surface area (km^2)	0.36	0.11
Maximum depth (m)	23.5	17.5
Volume (m^3 × 10^4)	258.8	51.6
Average depth	7.2	4.7

The drainage area of the whole lake (including the southernmost part) is 52.2 km^2. The theoretical renewal of the lake water (according to Strøm 1938) is high, 1.8 months (calculated for the whole lake). As mentioned above, the main part of the water drains through Langlivann and southwards, leaving Himtjern outside this drainage.

The variation in water level in this artificially dammed lake is not greater than in many natural lakes. Maximum variation in the period November 1961 – November 1962 was 2.2 m.

The climate of the district is continental.

TEMPERATURE

Figs. 3 and 4 show the temperature variations in Langlivann and Himtjern in the period November 1961 – November 1962. There are marked thermal differences in the two basins. Himtjern was ice-bound on 15 November and Langlivann a week later. The water in the deeper part of Himtjern is not cooled below 4 ° C, whereas in Langlivann the water has been cooled somewhat below this temperature, in spite of its greater depth. Both the later formation of ice and lower temperature in Langlivann are primarily caused by the higher flow-through rate and wind exposure.

The bottom water in both basins is warmed during winter. This is probably mainly due to heat given off from the sediments. The great area of sediments compared with the volume of water in the deeper part of the basins (see Fig. 2) may contribute to a comparatively high rise in temperature in the water, although the sediments are not warmed much during summer.

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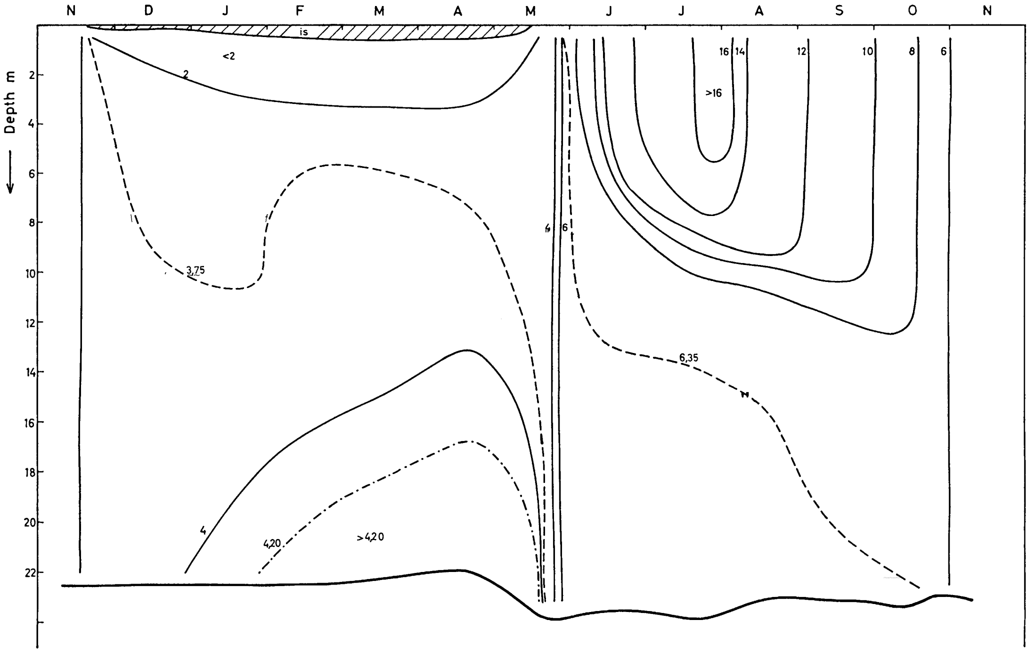

Fig. 3.
Depth-time diagram of temperature in Langlivann, November 1961 – November 1962.

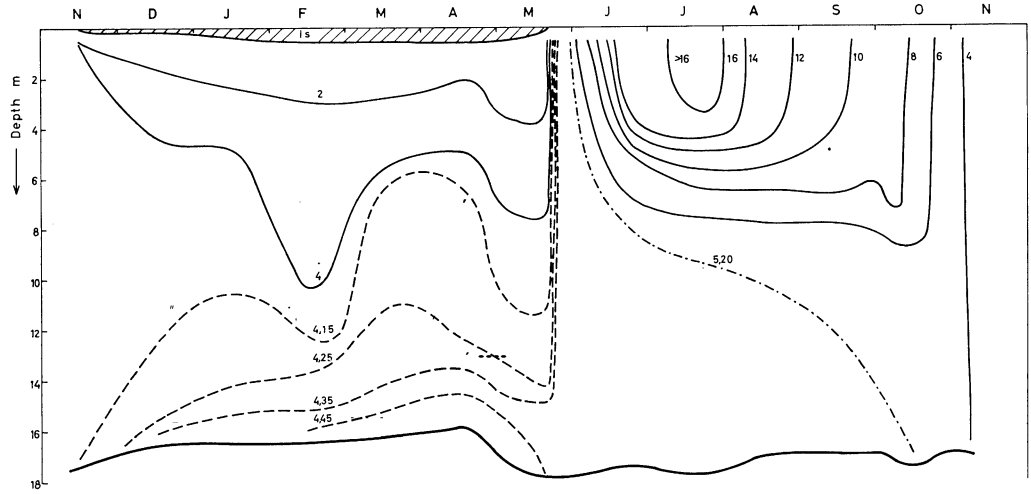

Fig. 4.
Depth-time diagram of temperature in Himtjern, November 1961 – November 1962.

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Meltwater affects the temperature of the warmer water in Himtjern more than that in Langlivann during February. The different courses of the isotherms in the two basins at this time may either be due to meltwater being warmer than the lake water at 4-12 m depth in Langlivann but colder than 4° C (note the depression of this isotherm in Himtjern). There is also the possibility that the meltwater drains at the surface of the more stable Langlivann water, thus permitting the warming from the sediments to continue undisturbed by the meltwater.

In spite of the 4° C isotherm lying in the middle of Himtjern's waters during winter, calculations have shown that the water is stable. Accumulation of salts in the deeper part of the lake is the reason for the stability.

Langlivann was ice-free one week earlier than Himtjern, where the ice broke on 23 May. A combined effect of shelter against wind, low flow-through rate, late ice-break, together with a rapid warming of the surface water at this time, and a stable chemical stratification in the deep water made the spring circulation in Himtjern only a partial circulation. In Langlivann, however, where the ice broke earlier, the flow-through rate is greater, and the water is more exposed to wind, the circulation continued until the whole water mass reached *ca.* 6° C. The lower flow-through rate and the slighter wind exposure are also the main causes of the shallow site of the thermocline in Himtjern during summer stagnation.

Also, the autumn full circulation commenced earlier in Langlivann than in Himtjern, in spite of the greater depth of Langlivann. The temperature at the beginning of this circulation was 6° C in Langlivann and 4° C in Himtjern.

The differences in thermal stratifications in the two basins are thus mainly due to different hydrological and morphological features.

COLOUR AND TRANSPARENCY

Colours in the lake were determined in two ways, subjectively against the Secchie disc in half its vanishing depth (lake colour), and quantitatively as mg Pt/l (water colour). The lake colour is described according to Strøm (1943). Lake colour and Secchie disc transparency were determined in the period November 1961 – November 1962 and water colour in the period April 1962 – November 1962.

Table 2 gives the observed data of lake colours, water colours half a metre below the surface, and Secchie disc transparency.

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Table 2.
Lake colour, water colour, and transparency in Himtjern and Langlivann

Date	Lake colour	Water colour as mg Pt/l	Transparency m
1961	*Himtjern*		
10 November	Yellowish-brown		4.0
15 November	Yellowish-brown		4.1
1962			
17 January	Brownish-yellow		4.0
15 February	Brownish-yellow		3.5
20 March	Brownish-yellow		2.3
17 April	Yellowish-brown	20	2.2
1 May	Greenish-yellow	17	4.2
21 May	Greenish-yellow	20	5.2
20 June	Brownish-yellow	15	4.0
22 July	Brownish-yellow	15	5.1
18 August	Brownish-yellow	15	5.5
15 September	Yellowish-brown	17	4.7
30 September	Yellowish-brown	17	5.0
9 October	Yellowish-brown	17	4.9
15 October	Brownish-yellow	13	4.3
24 October	Brownish-yellow	22	4.7
10 November	Brownish-yellow	20	4.4
1961	*Langlivann*		
9 November	Yellowish-brown		4.0
16 December	Yellowish-brown		4.2
1962			
18 January	Brownish-yellow		4.2
16 February	Brownish-yellow		3.2
22 March	Brownish-yellow		3.0
19 April	Yellowish-brown	20	2.5
22 May	Brownish-yellow	27	5.2
20 June	Brownish-yellow	25	4.2
25 July	Brownish-yellow	15	5.2
18 August	Brownish-yellow	15	5.5
16 September	Yellowish-brown	17	4.5
15 October	Brownish-yellow	17	4.8
24 October	Brownish-yellow	20	4.8
9 November	Brownish-yellow	25	4.5

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The drainage areas of both Langlivann and Himtjern are covered with coniferous forest and many bogs. This influences both lake and water colour. All the lake colours observed *may* indicate a dystrophic character of the lake caused by allochthonous organic matters from the drainage area (Strøm 1943). The variations of lake colours during the observation period are very similar in the two basins. In May, however, there is a difference inasmuch as the colour in Himtjern is greenish yellow but in Langlivann it is brownish yellow. At this time Himtjern was still covered with broken ice and the spring circulation had just begun. Langlivann had been icefree for a week and the overturn was complete. During winter, measurements have shown that the water colours in both basins increase with depth. The different lake colours may thus be due to the fact that the upper waters of Langlivann are affected to a higher degree than those of Himtjern by these colouring matters from the deeper part because of the difference in circulation.

As for the lake colour, the water colour was mainly determined by the amount and character of the organic matters in the water. Several regional researches (e. g. Birge & Juday 1934, Åberg & Rodhe 1942, Hutchinson 1957, Kjensmo 1967) have shown that water colour is determined to a high degree by the allochthonous organic matter (humic substances). Certain inorganic materials, such as iron and manganese, may also give the water the same characteristic colours.

In accordance with the lake colour, the water colour at the surface of Himtjern is lower than in Langlivann in May. In both basins there is a decolorization during summer and an increase again towards the autumn turnover. This may be due to lower precipitation during summer and a combined effect of higher percipitation together with circulation of the more coloured deep water towards the autumn. The decolorization, however, may also be due to formation and precipitation of colloidal ferric hydroxide and organic ferric complexes. Åberg & Rodhe (1942) have shown experimentally that such precipitation takes place in humic water when iron and light are present. Iron acts as a catalyst in this process.

Transparency, which is determined mainly by the water colour and the turbidity (absorption and scattering of light), varies similarly in the two basins. There was a decrease during winter to a minimum in April (2.2 m in Himtjern and 2.5 m in Langlivann). In the summer the transparency was greatest and a maximum was observed in August in both basins (5.5 m). The increase in lake colour and decreasing transparency during winter may indicate an increase of the contribution of allochthonous organic matter in this period. This has proved to be characteristic of lakes with bogs in the drainage area. Dominating drainage from bogs in winter is probably the reason (Kjensmo 1961, 1965).

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The high transparency during summer may indicate rather low primary production in the lake.

OXYGEN

Winkler's unmodified method (Gaarder 1915-16) was used in determination of oxygen concentrations in the water.

Depth-time diagrams (Figs. 5 and 6) show the variations in oxygen concentrations (ml/l) in the observation period (Nov. 1961–Nov. 1962).

In December there is already a considerable oxygen depletion in both basins. During winter the lowest oxygen concentration is found in the deep water of Himtjern. The greater depth, the higher water volume/bottom area-ratio, and the fact that Langlivann was ice-bound later than Himtjern are the main causes of this difference.

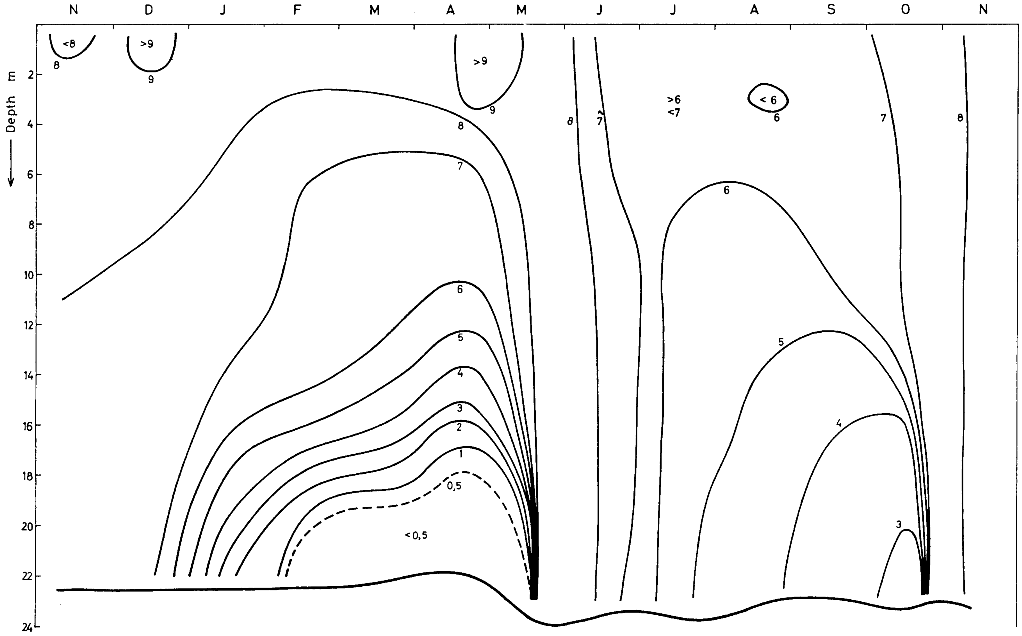

Fig. 5.
Depth-time diagram of oxygen (ml/l) in Langlivann, November 1961 – November 1962.

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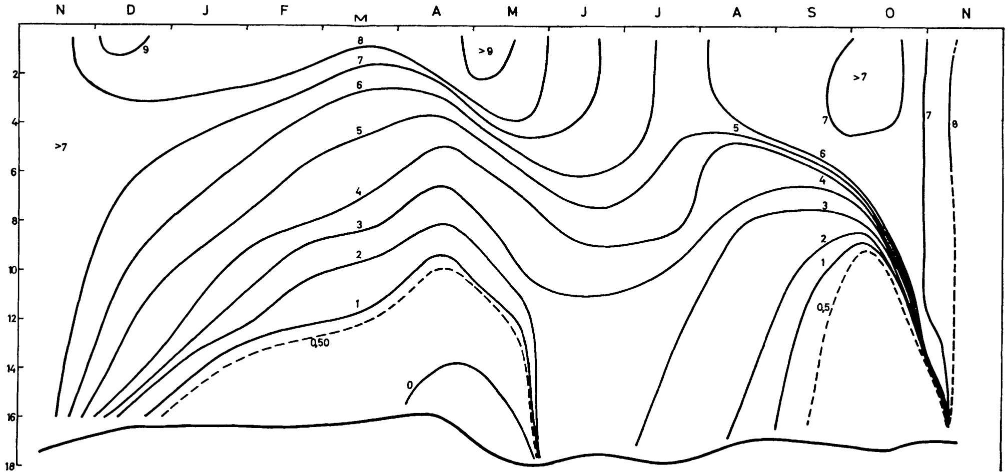

Fig. 6.
Depth-time diagram of oxygen (ml/l) in Himtjern, November 1961 – November 1962.

The depth-time diagram shows clearly the incomplete circulation in spring in Himtjern. The bottom water only reached the concentration of 2.5 ml/l. The addition of oxygen to the deeper waters was probably greater than this value indicates. Some of the oxygen added is used in the oxidation of iron and the formation of iron hydroxide which is precipitated.

This incomplete circulation in Himtjern against the good ventilation of Langlivann is the main cause of the comparatively great difference in hypolimnetic oxygen concentration during summer stagnation. These differences in hypolimnetic oxygen concentrations and their influence on iron solution will be discussed in the section "Oxygen and Iron in the Deep Water".

The decreasing epilimnetic oxygen content during the first part of summer in both basins is thermally conditioned. The water temperature is also the cause of increasing concentration after July, when the temperature reached a maximum.

The autumn overturn was complete in both basins.

During the whole period of investigation the oxygen concentration as a percentage of saturation was below 100, even in the upper part of the water. This indicates low primary production. The highest value, 98.4 per cent, was found 0.5 m below the surface in Himtjern in June. *Ca.* 90 per cent was common in both basins. The proportionately low epilimnetic oxygen content in relation to

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saturation during the whole period is probably mainly due to a supply of allochthonous organic matter.

IRON

Total iron was determined by means of a Hilger-Spekker photoelectric colorimeter and orthophenanthroline was used as indicator (American Public Health Association 1949).

Figs. 7 and 8 are depth-time diagrams showing total iron as p. p. m. in Langlivann and Himtjern.

The concentration of iron is high throughout the whole period and at all depths. The richness of iron in the upper and circulating part of the water must to a large extent be attributed to the humic influence on the water. Several in-

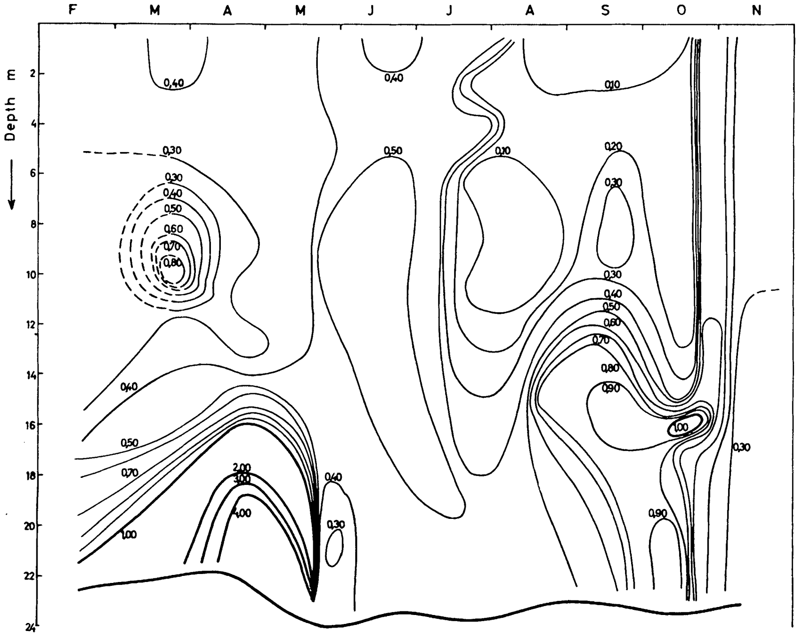

Fig. 7.
Depth-time diagram of total iron (mg/l) in Langlivann, February–November 1962.

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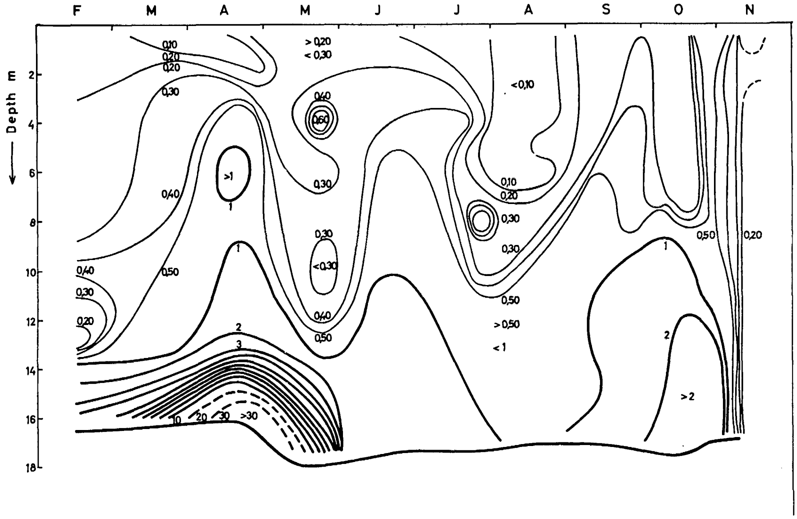

Fig. 8.
Depth-time diagram of total iron (mg/l) in Himtjern, February–November 1962.

vestigations have shown such interdependence (e. g. Yochimura 1936, Einsele 1940, Åberg & Rodhe 1942, Järnefelt 1963, Kjensmo 1967).

The variation in the concentration of iron is great in both basins. As early as in February the concentration in the water near the bottom in Himtjern was 4.3 p. p. m. and in Langlivann 1.5 p. p. m. The concentration in the deep waters reached a maximum in Langlivann in April and in Himtjern on 1 May. Half a metre above the sediments it was 35.3 p.p.m. in Himtjern and 4.6 p.p.m. in Langlivann. The circulation in spring caused ventilation of the deep water; the ferrous iron was oxidized and precipitated.

The proportionately greater supply of humic substances in winter (see above) is probably partly the reason for the high concentration of iron in the middle and upper waters at this time. A maximum at 6 m depth in Himtjern and 10 m depth in Langlivann in April and March respectively may be caused by density currents from the shallow and flatter parts of the basin. A tapping of water at this time may have amplified such currents.

At the end of the winter stagnation the iron concentration is lowered near the surface owing to dilution by meltwater. These waters become richer in iron at the beginning of spring circulation. Oxidized iron has, at this time, been brought from the deeper waters to the higher by the circulation.

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During summer stagnation there is a decrease in the epilimnetic iron concentration probably for the same reason as for the decolorization mentioned above. The increase from August on is in full accordance with the assumed increase in humic substances (see "Colour and Transparency"). In October the precipitation was low. The iron concentration decreased in the first part of this month but increased again in the last part. At this time, the autumn circulation had reached down to the waters richer in iron.

At a depth of 15-16 metres in Langlivann there is a marked maximum of iron in the period from August to October. The most probable reason is the supply of groundwater, rich in iron, at this depth.

OXYGEN AND IRON IN THE DEEP WATER

The influence of oxygen concentration on the iron metabolism in lakes has been described by several scientists (e. g. Birge & Juday 1911, Ohle 1934, Einsele 1940, Mortimer 1941-42). In Norway, Kjensmo (1962, 1964, 1967) has studied this relationship in some lakes in Nordmarka and in Vingersjøen (Kjensmo 1965).

Einsele (1940) describes the conditions which are necessary to permit reduction of ferric to ferrous iron and thus the solution of iron as ferrous bicarbonate. The critical concentration of oxygen to permit the reduction at pH 7 he found to be 0.5 p. p. m. or between 0.3 and 0.4 ml/l. In addition, reducing substances must be present in the water. Decomposing organic substances are good reducing agents.

Both of the above conditions are present in Langlivann and Himtjern during winter stagnation, although the oxygen concentration is not low enough in Langlivann during the summer. pH is always on the acid side in both basins, but rarely lower than 6.0.

In Esthwaitweater, Mortimer (1941-42) found a great increase of iron in the bottom water at a redox potential of 0.2 volt at the mud surface. According to Mortimer, this increase in iron was caused by reduction of the mud surface so that ferrous iron could diffuse outward from the sediments unobstructed by the oxidized barrier. He also found enrichment of iron in water with high oxygen content. He assumed that this was caused by increased diffusion of ferrous iron from sediments with low oxygen content at the surface and its oxidation at a higher level.

Kjensmo (1964, 1967) found a good relation between increase of iron in the

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water and decrease of the same element in the oxygen-free sediment surface (upper 5 cm).

The sediments have thus proved to be an important source of iron in the water when the conditions mentioned above are present. If the iron is to accumulate to any degree in the water, it is not sufficient that the water in the water-sediment interface exhibits the above-mentioned conditions and thus permits diffusion of iron from the sediments to the water. The iron will oxidize and be precipitated if the water above is rich enough in oxygen. The precipitation will take some time and the supply of ferrous iron to the oxygenated water will continue. Einsele (1940) has shown that in water containing ferrous iron and being oxygenated the oxidation may take more than a day at pH 6.0. Altogether this will cause an increase in total iron, even in relatively oxygen-rich water. However, the increase in iron will accelerate when the conditions necessary to reduce iron are present in the water. The different oxygen concentrations in Langlivann and Himtjern at different times and depths thus permit a study of the influence of the concentration of this element on the reduction of iron.

Fig. 9 shows variations in total iron and oxygen 2 and 6 metres from the bottom in Himtjern and Fig. 10 the same variations in Langlivann.

From February to March there was an increase in iron concentration in both basins and at both depths. The gradient was greater at 2 m and somewhat greater in Himtjern than in Langlivann. The oxygen concentration decreased from 0.50 ml/l to 0.45 ml/l at 2 metres from the bottom in Langlivann and it was constantly 0.50 ml/l in Himtjern in the period. Between March and April the gradient of the increase of iron at 2 metres definitely increased in both basins, whereas at 6 metres the gradient is not greater than at 2 metres the month before. The oxygen concentration at 2 metres in Langlivann decreased to 0.27 ml/l and in Himtjern to 0.18 ml/l. In this period the water 2 metres above the bottom probably lost its oxidizing ability.

The oxygen concentration at 2 m in Himtjern decreased to 0.00 ml/l from the middle of April to 1 May, and the iron concentration increased with a gradient somewhat greater than between the earlier observations (no observation in Langlivann 1 May). Six metres from the bottom in Himtjern the oxygen content decreased to 0.60 ml/l. There was, however, no further increase in iron content at this depth.

On 21 May the oxygen concentration 2 metres from the bottom in Himtjern was increased to 0.25 ml/l. Great quantities of iron were precipitated. The oxygen supply may have been greater and used in the precipitation of iron hydroxide and in oxidation of organic matter. In Langlivann the circulation was complete. The oxygen concentration increased to 8.5 ml/l on 21 May and pro-

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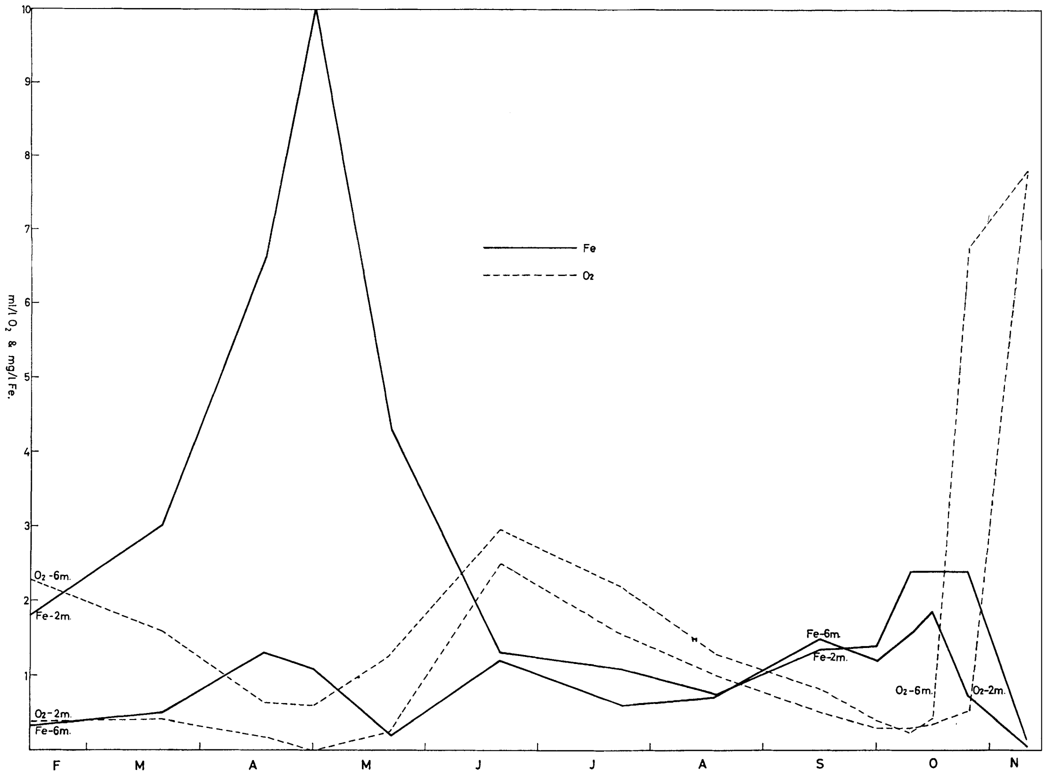

Fig. 9.
Oxygen and total iron concentrations 2 and 6 metres from the bottom in Himtjern.

bably all iron had been oxidized. In this basin there was little variation in iron concentration in the two depths during summer stagnation. In September there was a small increase at both depths and in October at only 2 metres above the sediments. This may be due to a supply of allochthonous iron from surface drainage or ground water, or increased diffusion from the sediments on account of lower oxygen concentration in the sediment surface. The decrease of iron 6 metres above bottom from September on and 2 metres from bottom from October on was a result of the autumn circulation.

The spring circulation, which was incomplete in Himtjern, had, however, supplied the deep water with oxygen in quantities great enough to oxidize iron. The total iron concentration was still high in June (*ca.* 1 p. p. m.). This may either be due to ferric iron not precipitated or to iron which was not yet oxi-

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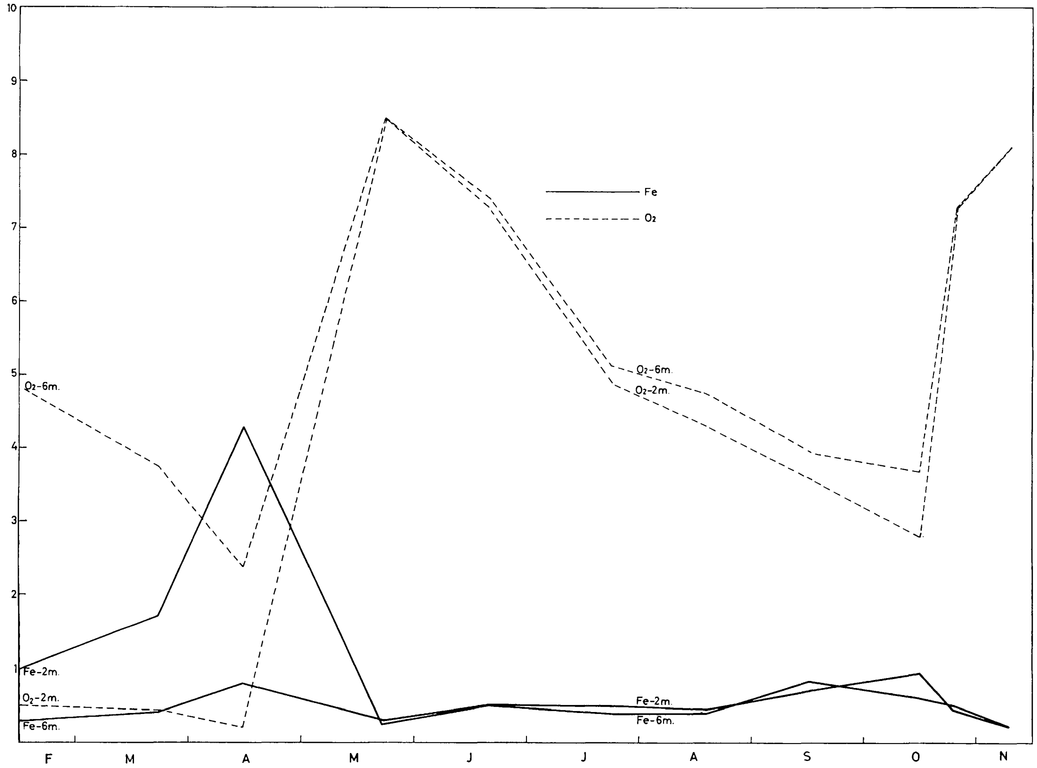

Fig. 10.
Oxygen and total iron 2 and 6 metres from the bottom in Langlivann.

dized (see above). Sedimentation continued until August. From this month on there was a steady increase in iron content 2 metres above bottom until 30 September. That the increase in iron concentration was higher in this basin than in Langvann may either be due to the smaller water volume in Himtjern or the different oxygen concentration in the deep water.

From 30 September to 9 October there was again a marked increase in iron 2 metres above bottom and a smaller increase 6 metres above bottom. The oxygen concentration 6 metres from bottom decreased from 0.40 to 0.25 ml/l in this period. Two metres above bottom the concentration was 0.30 ml/l on both observation dates.

The increase in iron concentration regressed as the autumnal partial circu-

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lation continued and later it decreased until, at the time of full circulation on 10 November, it reached a value similar to that in Langlivann.

The critical values of oxygen in reduction/oxidation of iron found by Einsele (1940) in eutrophic lake waters seem to be valid in these dystrophic lake waters as well.

ACTIVE REACTION AND IRON

The water in Langlivann and Himtjern is poor in lime. On 24 October the concentrations of Ca in the circulating water of Langlivann and Himtjern were 7 and 9 p. p. m. as $CaCO_3$ respectively.

The active reaction in the whole period of observation was on the acid side. At the beginning of the winter stagnation, pH decreased with depth and time as decomposition products increased. In February a change occurred in the stratification as the pH near the bottom started to increase in both basins.

Such a stratification in pH (dichotomous stratification) was first described by Yochimura (1932). In lakes poor in lime, and with drainage from bogs and forest, it is not unusual to find this stratification when iron and/or manganese are present and the oxygen deficit is great enough to permit reduction of these elements (Åberg & Rodhe 1942, Kjensmo 1961, 1962, 1965, 1967). The acid reaction in the beginning of the stagnation period is mainly caused by increasing CO_2 concentration. In the environments near the sediments the iron and manganese are reduced when the oxygen concentration is low enough as is seen in the foregoing section. The reduced ions pass into solution as bicarbonates. The CO_2/HCO_3 ratio decreases and the result is an increase in pH.

Figs. 11, 12, 13, and 14 show the progress and result of the above mechanism in Langlivann and Himtjern during winter stagnation and in Himtjern also during summer stagnation (note the greater scale for p. p. m. Fe in Figs. 13 and 14 as compared with Figs. 11 and 12).

The redox potential for the reduction of manganese is somewhat higher then that of iron. Manganese may, accordingly, diffuse from the sediments to the water at a higher oxygen concentration than iron. In the first part of the stagnation, manganese may play a proportionately greater part in the increase of pH. The high concentration of iron, however, probably makes this element predominant.

In February the iron in the deep water of both Langlivann and Himtjern seems to be dissolved as ferrous bicarbonate. In Himtjern there is a minimum in pH at 10-12 m depth in April (pH 5.8). From this depth to the deepest ob-

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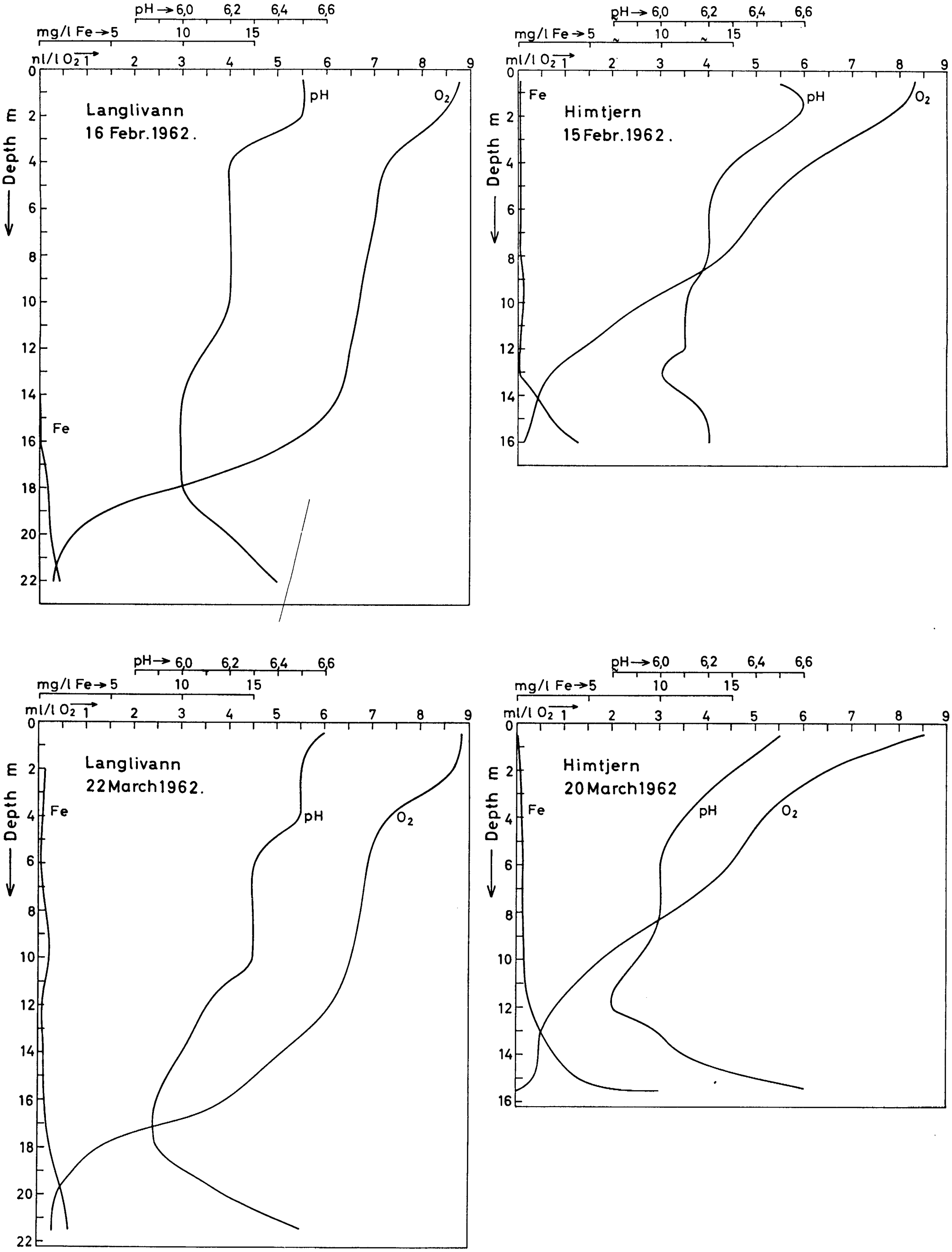

Fig. 11.
Vertical distribution of oxygen, total iron, and pH during winter stagnation in Himtjern and Langlivann.

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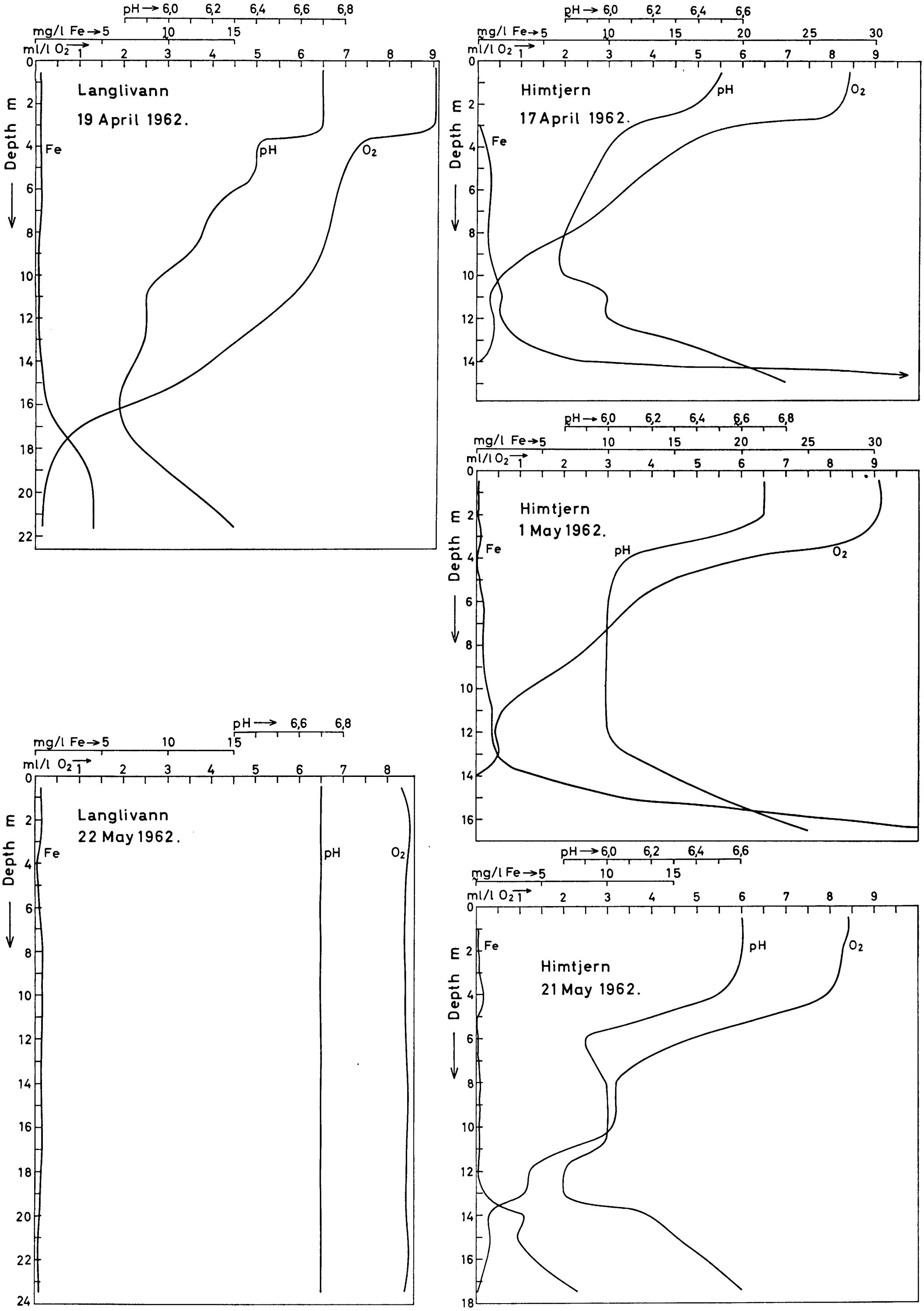

Fig. 12.
Vertical distribution of oxygen, total iron, and pH in last part of winter and spring in Himtjern and Langlivann.

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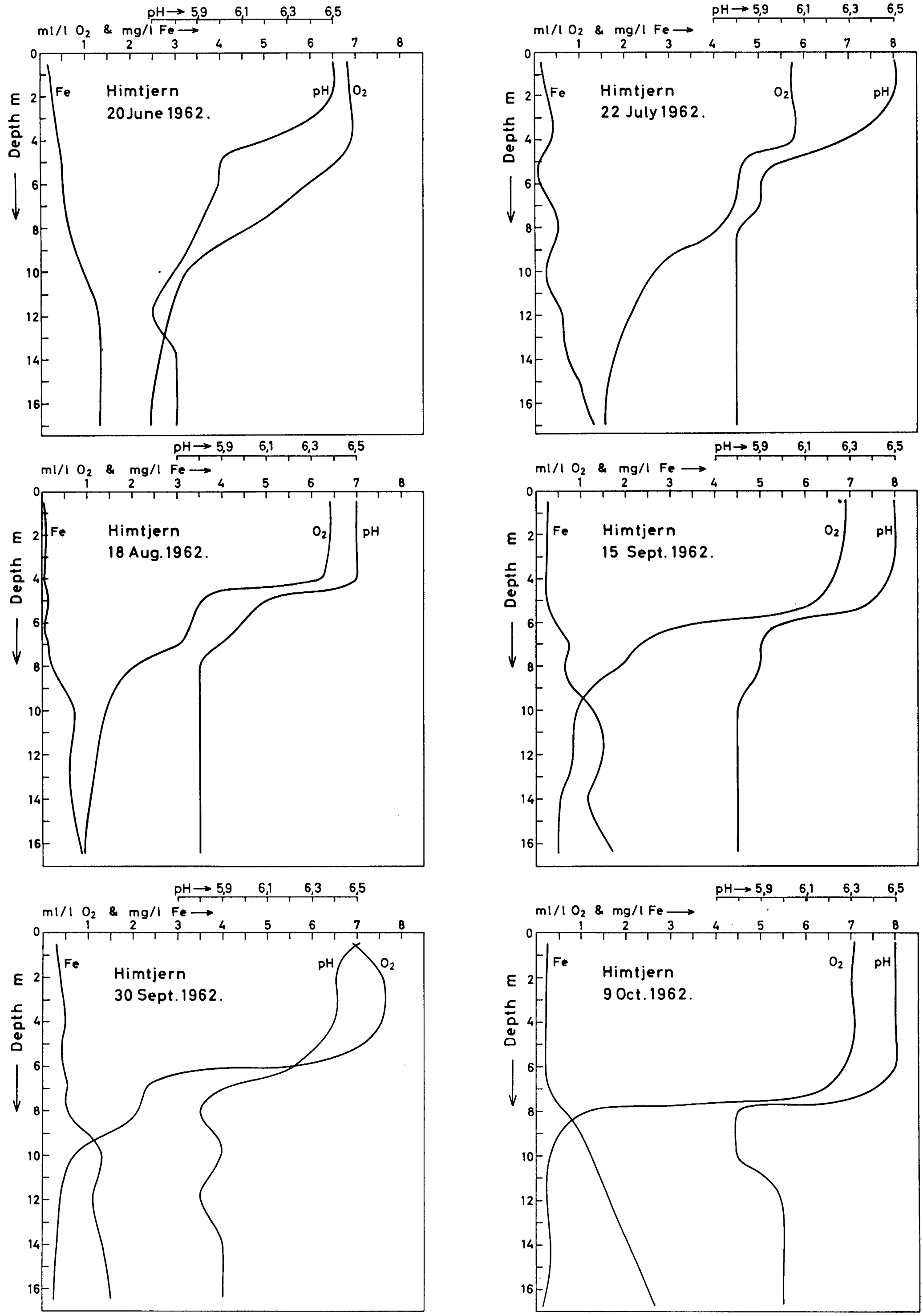

Fig. 13.

Vertical distribution of oxygen, total iron, and pH during summer stagnation in Himtjern.

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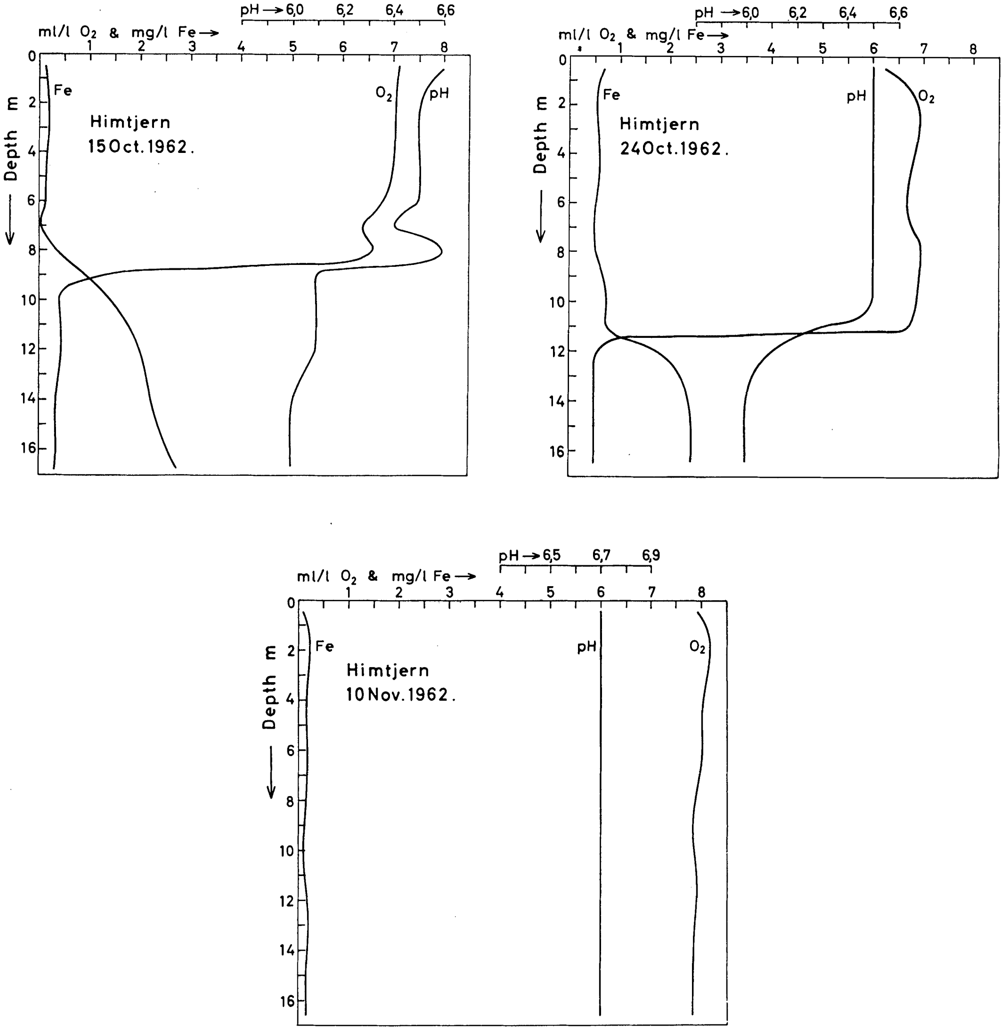

Fig. 14.
Vertical distribution of oxygen, total iron, and pH during autumn partial and full circulation in Himtjern.

servation pH increases, and a maximum was reached on 1 May (pH 6.9). In Langlivann the minimum is at 15-17 m depth in April. Near the bottom pH increased to 6.3-6.4. The point from which pH increases downwards is some-

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what higher in the water of both basins in April than in February. It is, however, never higher than 6 m from the bottom during winter stagnation. This is in agreement with the statement given above that at this depth the oxygen concentration is too high to permit reduction of iron which is thus not soluble as bicarbonate. Two metres from the bottom there is also an increase in pH earlier than April. This may be caused by manganous bicarbonate. As mentioned earlier, there is also a possibility that iron may, for some time, be dissolved as ferrous bicarbonate, even if the oxygen concentration is too high.

The dichotomous pH stratification in Langlivann disappeared at the spring full circulation and it was not re-established during summer stagnation.

After the spring circulation, which was not complete in Himtjern, there is still a dichotomous pH stratification in this basin. This is strange, since the oxygen concentration at the bottom is 2.5 ml/l. Acid water may have entered the 12 m deep horizon. There is also the possibility that some manganese was not yet oxidized. The increasing iron content towards the bottom is probably ferric iron not yet sedimented.

During the months of July, August, and September there is little change in pH in the hypolimnion of Himtjern (pH in the deeper part *ca.* 5.8). On 30 September there is again an increase to 5.9 in the water near the sediments, and on 9 October pH increased to 6.0. On the last date pH also increased higher above the sediments. This is in accordance with the oxygen concentration at this time, which permits ferrous iron in solution.

The minimum at 8-9 m depth is absent on October 15. The somewhat deeper thermocline and supply of oxygen to the upper part of the hypolimnion is probably the reason. The dichotomous stratification thus also disappeared. The observation data on 24 October reflect a deeper partial autumn circulation, which is complete on 10 November.

Both the pH stratification and iron metabolism in the two basins indicate that the critical oxygen concentration for the solution of ferrous bicarbonate coincides with the values given by Einsele (1940).

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