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REDUCED OXYGEN CONCENTRATIONS IN HERRING WINTERING AREAS

by

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ABSTRACT

Since 1987 the major part of the adult Norwegian spring spawning herring stock has been wintering in the Ofotfjord and the Tysfjord, two tributaries to the Vestfjord in northern Norway. The herring enter the fjords in August-September, and leave again in January, to start their spawning migration.

The Institute of Marine Research has had regular surveys in the area in November each year since 1975, in which the herring population present has been measured acoustically. Since 1976 environmental parameters have also been recorded, including temperature, salinity, and oxygen and nitrate concentrations.

This time series shows a gradual decrease in oxygen concentration in the Ofotfjord since 1987, when the herring started wintering in the fjord. High concentrations of herring are found in areas with oxygen concentrations as low as 1-2 ml l^{-1}.

This paper presents and discusses the available data.

INTRODUCTION

After the feeding season in summer the Norwegian spring spawning herring migrate to the wintering areas where they form dense concentrations. Here the herring stock is stationary until the spawning migration starts in early winter. Several wintering areas have been located during the past 40 years. In the 1950's, when the stock size was in the order of 10 million tonnes (Dragesund and Ulltang 1978), the herring stock wintered in an area east of Iceland. In the period 1963-66 the stock was reduced to 3-4 million tonnes, and the major part of the stock, consisting of the strong 1959 and 1960 yearclasses, wintered off the Norwegian coast in the northern part of the Norwegian Sea (Devold 1968). After the stock collapsed, near the end of the 1960's, the remaining small herring stock wintered in several fjords along the Norwegian coast. In 1983 the first strong yearclass since the collapse was produced. This yearclass migrated from the nursery areas in the Barents Sea in spring 1986 and stayed in the Vestfjord during the winter 1986/87. From the winter 1987/88 the spawning stock, where the 1983 yearclass makes up about 90 %, has wintered in Ofotfjord and Tysfjord, which are side fjords to the Vestfjord.

The largest part of the spawning stock winters in the Ofotfjord, and in January 1992 the biomass of herring here was acoustically estimated to 2 million tonnes. Such a large concentration of biomass in a limited area can be expected to cause environmental changes, and in the present paper we look at the effects of the overwintering herring stock on the oxygen conditions in the Ofotfjord.

The Ofotfjord is situated at the inner part of the Vestfjord area (Fig. 1). It is 65 km long, with an east-west axis, and has a maximum width of 10 km. It has a sill of about 320 m towards the Vestfjord at Barøy. Just inside the sill there is a 27 km long and narrow basin with a depth of about 550 m. From this basin and inwards the fjord gets wider and its depth decreases gradually to about 100 m in the inner part.

MATERIAL AND METHODS

Since 1975 the Institute of Marine Research has conducted systematic acoustic surveys for young herring and sprat in most Norwegian fjords. Since 1976 environmental parameters have been recorded as well. The Ofotfjord has been covered in November each year. Environmental studies have included hydrography (Neil Brown CTD probe) and oxygen determinations (Winkler method), and since 1981 nutrient levels have also been measured (autoanalyzer). All oxygen determinations have been done on board, while nutrient samples have been conserved with chloroform and analyzed ashore (Hagebø and Rey 1984, Føyn et al. 1981).

During the autumn 1991 and winter 1992 additional cruises were conducted in October, November, and January in order to monitor the herring migration and the environmental conditions in the Ofotfjord.

RESULTS

Occurrence of herring in the Ofotfjord.

Before the collapse of the stock, young and immature herring were reported from the Ofotfjord in varying amounts and at irregular intervals. After the collapse and up to 1987 practically no herring have been reported from the fjord. Although some herring were taken in gillnets in the tributary fjord Skjomen, they most probably belonged to a small local stock.

During the November surveys since 1975 no herring were found prior to 1987. Even in 1983 when a strong yearclass of herring was produced, no 0-group herring was found in the Ofotfjord, although some 0-group herring was generally recorded in the neighbouring fjord Tysfjord and in the Lofoten area.

In October 1987 large schools of herring entered the Ofotfjord (Røttingen, 1990). This was mainly 4 years old herring (1983 yearclass). They stayed in the fjord until January 1988 when they started migrating to the main spawning area outside Møre, as recruit spawners. Since then, the major part of the spawners of the Norwegian spring spawning herring have continued to return to wintering areas on the coast of northern Norway. The Ofotfjord is the most important of the wintering areas.

Since 1986 the herring have also taken up the old pattern of feeding in the Norwegian Sea during the summer. After termination of the feeding season in the end of July or beginning of August the herring start migrating into the Vestfjord. They continue moving eastward in the fjord, and by October they enter the Ofotfjord and, some years, the Tysfjord. The herring stay in the inner part of the Ofotfjord during November and December, and in January they start moving out again. This is illustrated by Fig. 2 which shows the distribution of herring in the Ofotfjord in November 1990 and January 1991.

In January 1992 a biomass density of up to 800 grams per cubic meter was recorded in the densest concentrations of herring (Fig. 3).

During the wintering period the herring undertake diurnal vertical migrations of at least 150 m (Fig. 4). Even when the herring schools are stationary, the individual herring are moving continuously. The swimming speed of herring wintering in the Ofotfjord in 1991 was measured with acoustic Doppler techniques to be in the order of one body length per second (Ona, personal communication). The herring do not feed during the wintering period.

When the herring enter the wintering areas their gonads are classified mostly as "maturing" (stage 4, ICES scale), and the same stage is observed throughout the wintering period.

Mean weight of herring in the spawning stock since 1980 has increased as the dominating 1983 yearclass got older. In the winter 1987/88 the mean weight was 199 grams, and in the winter 1991/92 it was 366 grams.

There has been difficulties measuring the abundance of herring in such dense concentrations as are found in the wintering areas. However, new equipment (Simrad EK-500 echo sounder and BEI echo integrator) has almost eliminated problems such as instrument saturation from strong reflected signals which was a disadvantage of earlier equipment. Further, solutions to the problem of sound extinction in dense herring concentrations have been recently developed (Toresen, 1991). Investigations utilizing these new techniques indicate that 2 million tonnes of herring may have wintered in the Ofotfjord from October 1991 to January 1992 (Dommasnes and Holst, 1992). However, a longer time series and studies of behaviour and target strength measurements are needed before this stock level is given full confidence.

The total biomass of the spawning stock has probably not changed very much since 1988. Since that year only weak yearclasses have recruited to the spawning stock, and even if the number of individuals has decreased through natural mortality and fishing, this has been compensated through individual growth.

Environmental conditions.

Temperature, salinity, and oxygen values in November for the years 1976-91 at Station 3 in the Ofotfjord, and nitrate values in November at the same station for the years 1981-91 are shown in Fig. 5. The salinity distribution in the autumn shows large variations, especially in the upper 150 m, that are mainly due to variations in freshwater runoff. Below 150 m the changes are of smaller magnitude and the regular appearance of water masses with salinities higher than 34.9 indicates renewal of bottom water masses with water from outside the fjord. This renewal, seen also in the outer part of the fjord (data not shown), produces an uplifting of the intermediate water masses as indicated by the 34.0 isohaline.

Until 1988 the oxygen concentrations at Station 3 in November showed a typical slow decrease with depth. In the deeper part there was a rough covariation of the 5.5 ml l^{-1} isoline with the 34.5 isohaline. In November 1987 and 1988 oxygen concentrations below 5 ml l^{-1} were observed near the bottom for the first time since the observations started. Further, the

observations in November 1989 showed a dramatic decrease in oxygen concentration in the whole water column below about 100 m to less than 2 ml l^{-1}. This decrease continued in 1990 when values lower than 1 ml l^{-1} were found at 200 m. In November 1991 slightly higher oxygen concentrations were observed but still the values were significantly lower than in the period previous to 1989. Another feature of interest is a second oxygen minimum observed at about 70 m in 1989 and at 50 m in 1991. Although less significant than the deeper one, this minimum also represents a deviation from the situation that was normal previous to 1988.

Nitrate concentrations at Station 3 since 1981 also show large variations which in the upper 50 m seem to be closely related to the variations in salinity. In the deeper part of the station high nitrate concentrations were observed in the years previous to the appearance of high salinity water masses. The maximum observed concentrations were just over 20 µM during 1983 and 1990.

DISCUSSION

When evaluating the impact of the large herring biomass in the Ofotfjord, one should be aware that there are possible other sources of influence as well. The city of Narvik, situated at the landtip close to station 3 (Fig. 1), has a population of about 13.000, and presumably all sewage goes into the upper layers of the fjord after some treatment. The town has a port from which large quantities of iron ore are shipped, and the storage and loading areas are potential sources from which iron oxides and other metal compounds may leak into the fjord waters. These sources of influence on the environment have not been investigated or evaluated by the authors. However, these influences, to the extent that they exist, have been present long before 1987/88, which is the "point of change" for the oxygen concentrations in the deeper layers of the fjord.

The oxygen concentration at Station 3 in the Ofotfjord was between 5 and 7 ml l^{-1} until 1987 (Fig. 5), when large quantities of herring first appeared in the fjord. But the change in oxygen concentration was not very large in 1987, as the herring arrived in October and the measurements of environmental parameters were done in November, so that the herring had only been present one month when the measurements were done. Also for the years 1988-1990 the measurements of environmental factors were done approximately one month after the herring had arrived. Still the oxygen concentrations became rapidly lower for each year. The reason for that can only be that there has been a cumulative effect - the water in the fjord has not been exchanged each year, or only partly exchanged. When the herring returned to the fjord, they were returning to more or less the same body of water that they left earlier in the year. In 1991 there had been an influx of new deep water from the Vestfjord, as is evident from the salinity values, and consequently the oxygen concentration in the deep water was also higher.

The oxygen minima that can be discerned at two depths in 1989 and 1991 fit well with the diurnal migration pattern of the herring. During daylight they are found at 150-200 m (sometimes deeper), coinciding with the deeper minimum. At night the herring are found mostly at 50-100 m depth (Fig. 4), coinciding with the shallower minima at 70 m and 50 m in 1989 and 1991, respectively. It is also natural that the shallower minimum is less pronounced, as the renewal of water is better in the upper layers, and the cumulative effect can be expected to be small. (The vertical migration does not always follow this pattern, as seen from Fig. 3, which shows biomass distribution along the Ofotfjord at nighttime when the migration out of the fjord is just starting.)

The higher concentration of nitrate since 1989 at the same depth as the deeper oxygen minimum substantiates the assumption that the low oxygen concentration is due to the metabolism of the wintering herring. Again, the somewhat lower value of nitrate in 1991 can be ascribed to an influx of new deep water.

The cumulative effect, with a "carrying over" of the oxygen minimum from one year to the next, is demonstrated in Fig. 6, which shows the oxygen concentrations in a section along the Ofotfjord during 3 surveys in the 1991-92 wintering season. The first section, from October, shows that there is an oxygen minimum at 200 m in the inner part of the fjord already at the start of the wintering season when the herring is arriving. There is no oxygen minimum at 50-100 m in October. The next two sections show that the deeper minimum becomes more pronounced through the wintering season, and a shallower minimum becomes established at 50 m depth. The section from January is taken just as the herring were leaving the inner part of the fjord fjord to start their spawning migration, and shows well developed oxygen minima at 50 m and 200 m.

The section in Fig. 3 showing the biomass distribution of herring in the Ofotfjord and the lowermost section in Fig. 6 showing the oxygen concentrations in the same section were taken only a couple of days apart. Comparison of the sections shows that the densest concentration of herring at nighttime is found at an oxygen concentration of about 2 ml l^{-1}. As the herring had started moving out the fjord at this time, it is likely that they earlier stayed in oxygen concentrations even somewhat lower, indicating that the herring may be able to tolerate oxygen levels as low as ml 1 ml l^{-1}.

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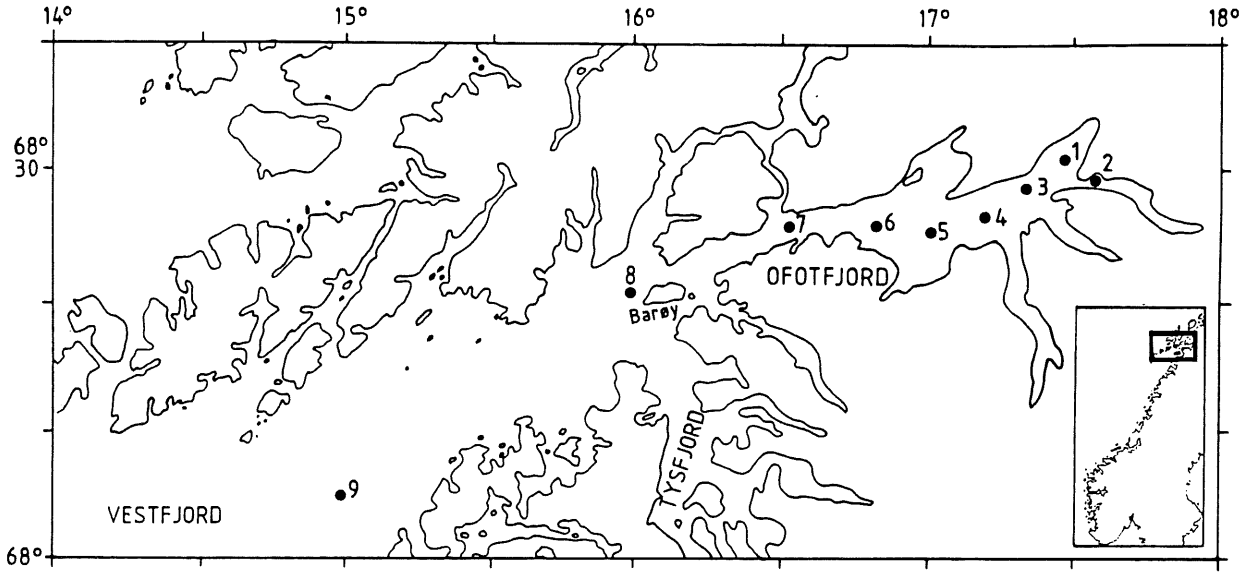

Figure 1. The Ofotfjord. Sampling stations for environmental parameters are shown.

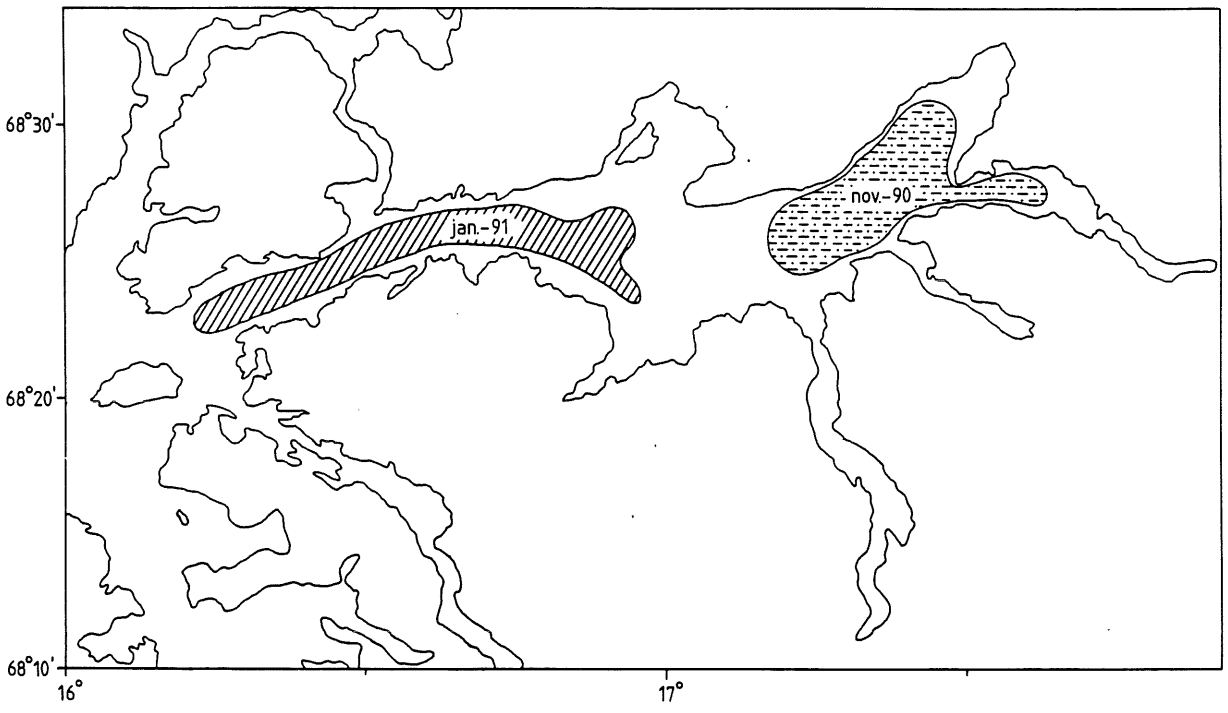

Figure 2. Distribution of maturing herring in the Ofotfjord in November 1990 and January 1991.

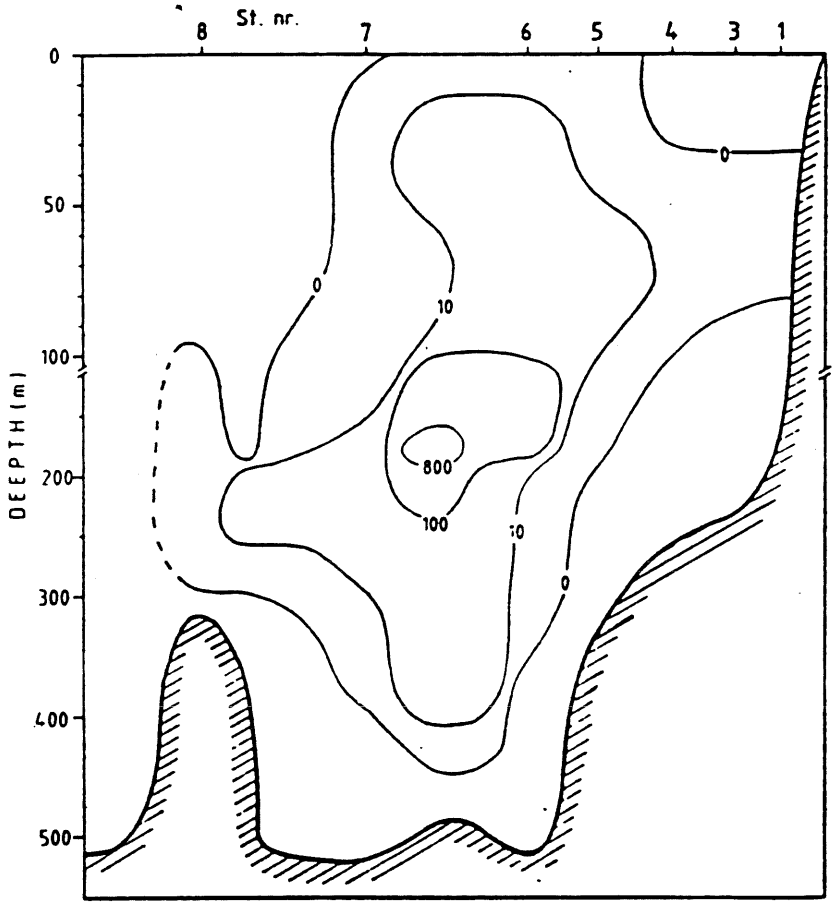

Figure 3. Biomass density of herring (grams per cubic meter) in a section through the Ofotfjord during the night 8-9 January 1992, based on echoes integrated with the Simrad EK500 echosounder. From Dommasnes and Holst, 1992.

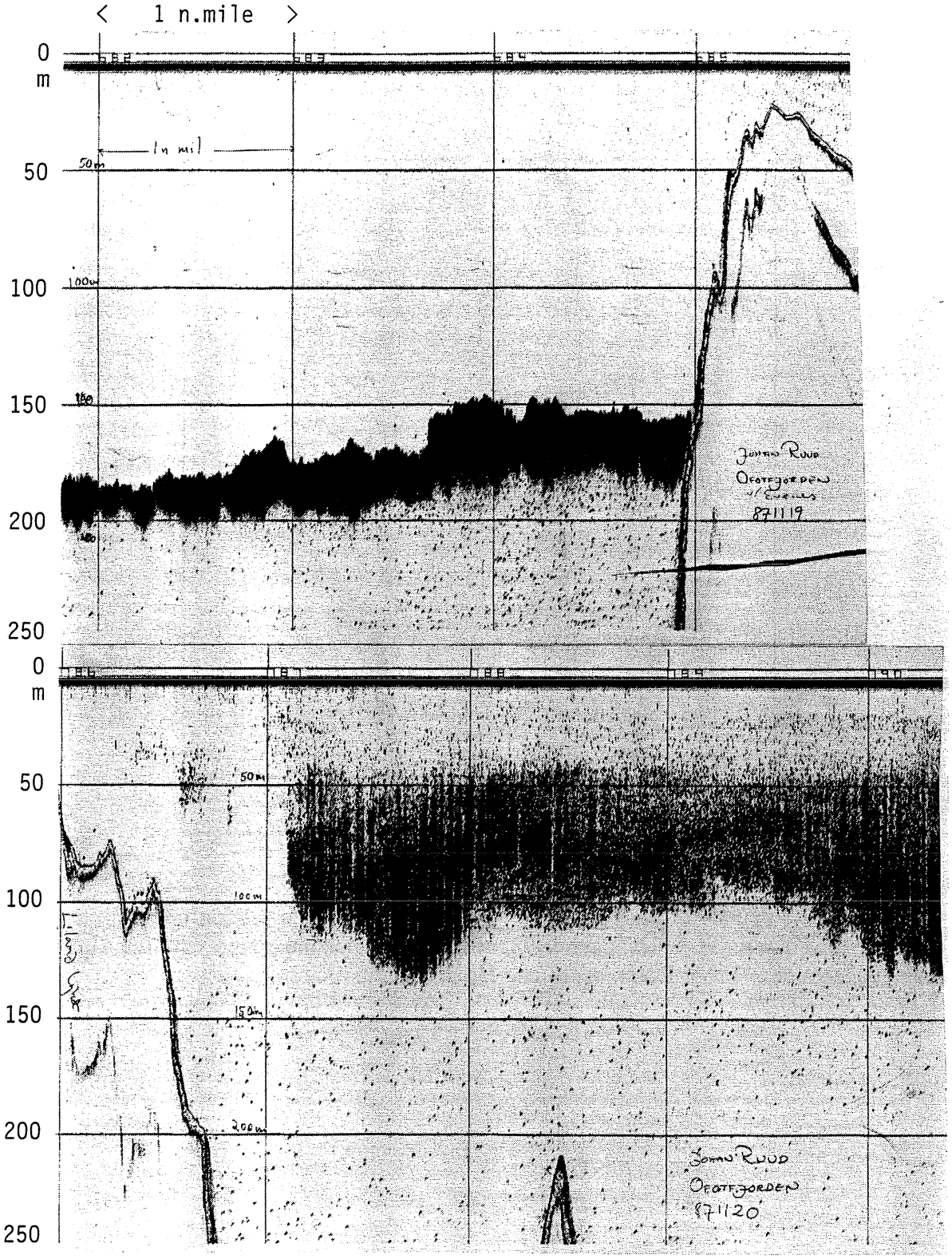

Figure 4. Echosounder recordings of wintering herring in the Ofotfjord in November 1987. The upper recording is from a daytime situation, and the lower one from a nighttime situation. Both recordings are from approximately the same location. From Røttingen, 1990.

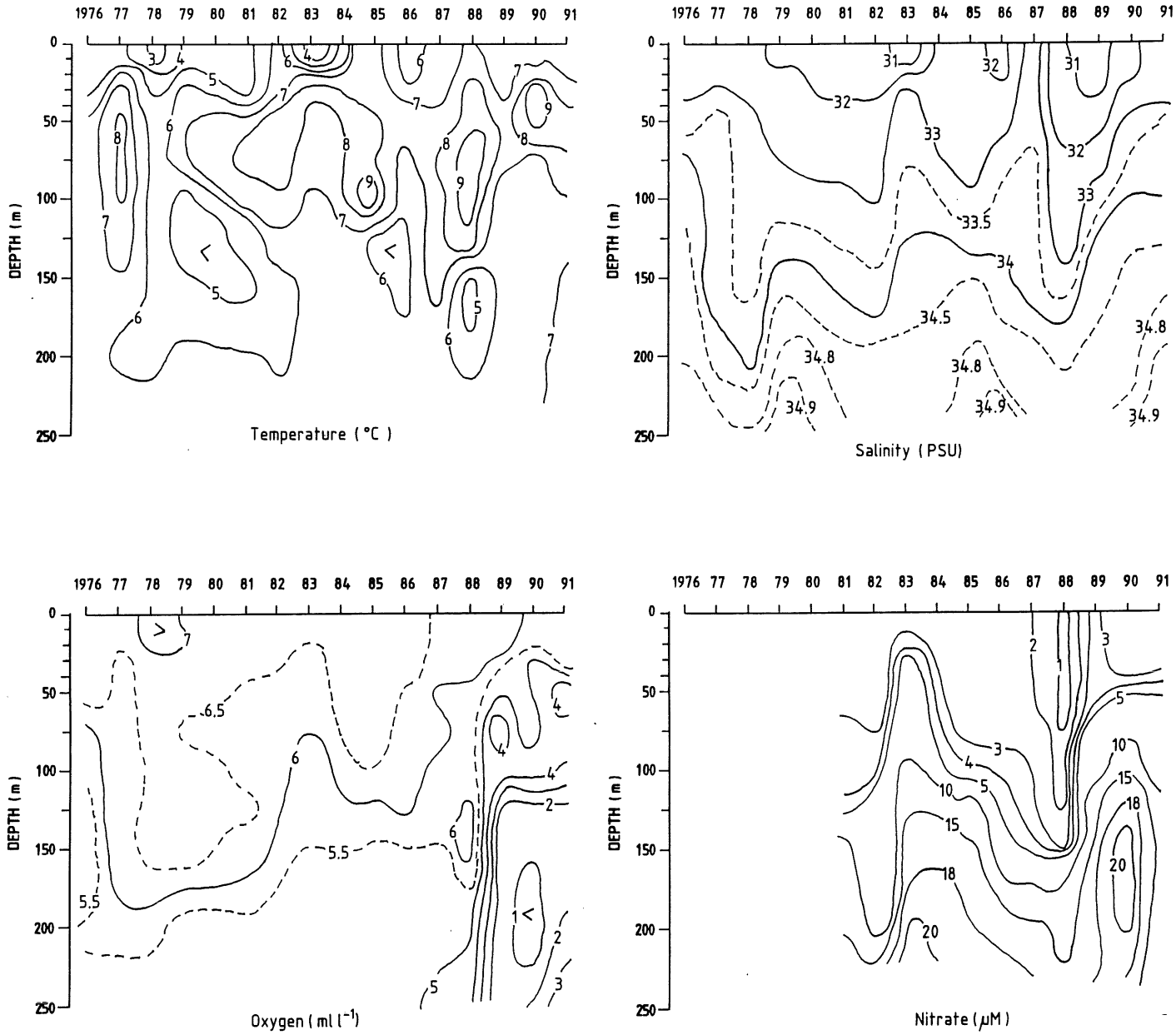

Figure 5. Values for temperature, salinity and oxygen at Station 3 in the Ofotfjord in November for the years 1976-1991, and values for nitrate at the same station in November for the years 1981-91.

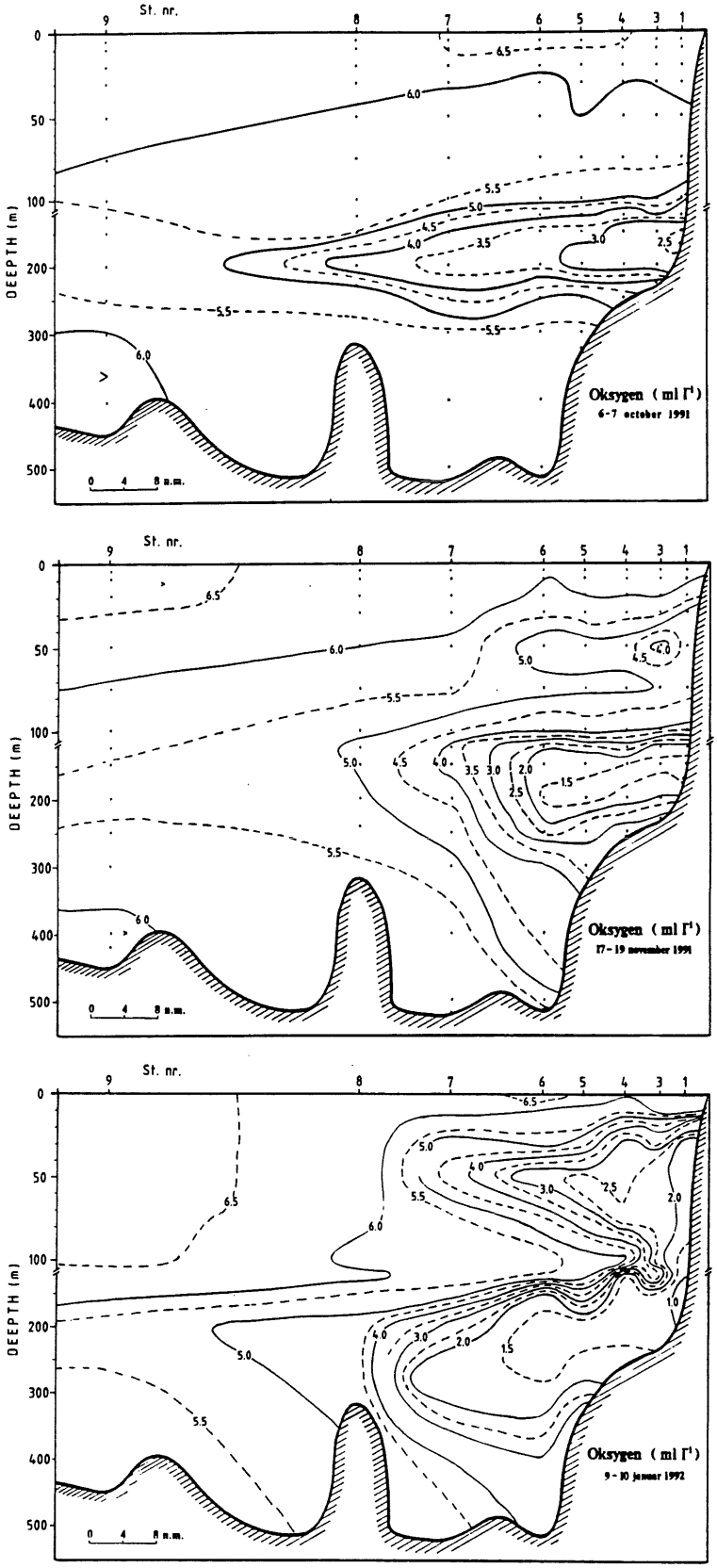

Figure 6. Vertical distribution of oxygen in the Ofotfjord in October 1991, November 1991, and January 1992.