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EFFECTS OF ORGANIC WASTE FROM MARINE FISH FARMS ON THE SEABOTTOM BENEATH THE CAGES

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ABSTRACT

Seven fish farms and a control station were investigated four times during one year. The farms represented a gradient of increasing accumulation of organic waste on the sea bottom. The thickness and the organic content of the waste increased up to 20 cm with increasing sedimentation. When the thickness of the accumulated waste exceeded 20 cm the larger fauna (> 5 mm) disappeared, and the decomposition rate of the material as a function of the accumulated amount decreased.

The spontaneous gas ebullition from the waste increased linearly with increasing accumulation.

Preliminary analysis of stable carbon isotope ratios of the sediment suggests that there is a return to original background isotope ratios within 30 m of a well-run fish farm.

INTRODUCTION

The effect of fish farming on their surrounding environment has been subject to increasing attention during the past years. Various studies have looked at the sediment chemistry (Enell 1982, Hall & Holby 1986, Blackburn et al. 1988, Kaspar et al. 1988, Hall et al. 1990), bottom fauna (Brown et al. 1987, Aure et al. 1988, Weston 1990), sedimentation (Aure et al.1988, Weston & Gowen 1988, Gowen et al. 1989), mass balance (Penczak et al. 1982, Hall et al. 1990) and calculated impact (Bergheim et al. 1984, Gowen & Bradbury 1987, Acherfors & Enell 1990). However, fish farms are difficult to generalize about, due to differences in operating procedures, stocking density, feeding regimes, bottom topography, current around the farm and depth.

Thus, an investigation was conducted comparing seven fish farms and a reference station located far from any aquaculture activities. The main concern was the fate of the organic waste consisting of feed and fecal pellets that escapes from the farms. The sites did not differ much in depth, bottom current and primary sediment and were therefore comparable.

The organic input to the sediment was measured by means of sediment traps. To calculate the degradation rate of the waste oxygen consumption by the sediment was measured and compared with the organic content of the sediment.

The release rates of ammonia, nitrate and phosphate from the sediment were measured.

Gas release from the sediment is often noticed in fish farms (Braaten et al. 1983) and was measured here simultaneously with the other flux rates.

Stable carbon isotopes (^{12}C and ^{13}C) is found in all organisms in a characteristic ratio. The higher an organism is positioned in the food chain the more of the heavy ^{13}C will it accumulate. Thus the isotope ratio can be used as a food chain tracer (Fry & Sherr 1984). Fish feed, fish (muscle), macro algae and macro fauna from each farm and the reference station were analyzed for stable isotope ratios. The sediment was analyzed for water and organic content, and stable carbon isotope ratios were measured in the sediment along a transect from the edge of the farm and 30 m out.

MATERIALS AND METHODS

Study area

Seven fish farms (B, C, D, E, F, G, H) and a control station (A) were investigated four times during a thirteen month period. All sites were located in Hordaland County, Western Norway, and had shellsand as the primary sediment. The bottom current was weak on all locations, from 0 to 10 cm/sec. The bottom temperature varied between 4 and 12 degrees celsius annually, and the salinity between 33 and 35 ppt. Depths under the farms varied between 7 and 21 m.

Equipment

Fluxes of oxygen and nutrients (ammonia, nitrate and phosphate) were measured by the means of parallel diffusion chambers containing up to 160 litres. The chambers were placed over a fixed (0.28 m2) area of the sea bottom, and a rotation device ensured constant movement of the enclosed water to avoid the creation of concentration gradients.
An oxygen electrode was fixed in one of the chambers for continuous monitoring of the oxygen concentration.

Gas escaping from the sediment was trapped at the top of the chambers by an inverted graduated cylinder.

Four parallel PVC - sediment traps (height: 32 cm, diameter: 4.3 cm) were deployed during the fall measurements on five of the farms. The traps were placed under the farms 3 to 5 m above the sediment.

Methods

Oxygen was measured with the Winkler method. Ammonia was measured according to Koroleff (1983). Nitrate and phosphate were analyzed automatically in accordance with Chem Lab Instruments Continuous Flow Analysis.

Waste accumulation was measured by employing a graduated stick into the sediment several places under the fish farms. The accumulated waste was very soft and the underlying sediment consisted of shell sand and was rather compact.

Material for stable carbon isotope analysis was dried, sorted, homogenized and acidified with 1 % hydrochloric acid, before weighing into prewashed tin cups. All samples were then analyzed on a Carlo Erba CHN analyzer coupled to a Finnigan Mat Mass Spectrometer. Results are given relative to the PDB standard, according to the formula:

$$d^{13}C\ (\text{ppt}) = \frac{(^{13}C/^{12}C)\text{sample} - (^{13}C/^{12}C)\text{standard}}{(^{13}C/^{12}C)\text{standard}} * 1000$$

An oil standard NBS-22 was used to calibrate the sample values. All values given are means of duplicate sample measurements.

Material from the sediment traps were filtered on GF/C filters and dried for 18 hours at 60 degrees celsius (TPM) and then burned for three hours at 450 degrees celsius in a muffle oven (POM).

The water content of the sediment was measured by drying it for 24 hours at 105 degrees celsius. Organic content of the sediment was obtained by burning at 450 degrees celsius for 24 hours.

The sediment was visually inspected for macrofauna, but since microscopes were not employed only animals larger than 5 mm were registered.

All results shown are annually means apart from the sedimentation measurements which were only conducted during fall.

RESULTS

Table 1 shows certain characteristics of the investigated sites. A is the control station and therefore has no accumulated waste on the bottom. The rest of the stations are arranged after increasing accumulation of organic waste on the sea bottom under the farms. The content of organic matter and water in the sediments increased with increasing accumulation. Fauna larger than 5 mm is present in the sediments with a waste accumulation less than 7 cm, but absent when the accumulation exceeds 20 cm.

Fig.1 shows the rate of sedimentation on five of the seven fish farms. The farms are arranged in order of increasing accumulation of organic waste. As the sedimentation rate increases so does the accumulation. From 70 to 85 % of the total particulate matter in the sediment traps consists of organic matter.

Fig.2 shows the relationship between the thickness of the accumulated waste and the sedimentation rate. The accumulation of organic waste on the bottom is increasing some with increasing sedimentation up to 7 cm. But further sedimentation gives a much heavier accumulation.

The oxygen uptake by the sediments are shown on Fig.3. The stations are arranged after increasing accumulation of organic waste on the sediment. The more accumulated organic matter the higher the oxygen consumption by the sediment.

On Fig. 4 the oxygen consumption of the sediment is shown as a function of the thickness of the accumulated waste. For lower accumulations (under 7 cm) the oxygen consumption is linearly correlated with increasing accumulation. For higher accumulations the oxygen consumption only increases slightly.

The relationship between the ammonia and the phosphate release from the sediments are shown on Fig. 5. The ammonia and phosphate fluxes are not high at the same stations, which may partly be explained by the use of different feed types. Nitrogen and phosphate are supplied to the sediment as waste food and fecal pellets which have N/P ratios around 15 and 4 respectively (Stigebrandt 1986). Since most of the value points on the figure lie above these lines it indicates that nitrogen is not released in the proportion in which it is supplied.

In Table 2 the decomposition rate per litre accumulated waste per year is calculated, and compared with the thickness of the accumulated waste. The decomposition rate decreases dramatically when the depth of the accumulated waste exceeds 20 cm and the larger fauna (> 5 mm) disappears.

Fig.6 shows the gas ebullition from the sediment as a function of the thickness of the accumulated waste. The five fish farms with the most accumulated organic waste all had spontaneous release of gas with the highest release rates during fall. One station is omitted in this figure since it was only visited during spring and summer where ebullition rates were low. The other four stations show a linear increase in gas release with increasing waste accumulation.

Fig.7 show the stable carbon isotope (^{12}C and ^{13}C) ratios of fish, feed, macro algae and macro fauna on all stations. The feed is distinctively lightest (most negative) on all farms and the isotopic composition of the fish seems to mirror the feed.

The preliminary results from isotope analysis of sediment from seven transects are shown on Fig.8. On three of the farms (D, F and G) the isotope ratio remains almost constant during the transect whereas the ratios on station B and C increases with increasing distance from the farm.

DISCUSSION

The investigated fish farms differed mainly in the amount of organic waste that accumulated on the sea bottom under the farms. This accumulation will mainly be a function of the amount of 1) the organic waste that is being produced by the farm 2) the current and 3) the depth. The fish farms in question did not differ much in current which was between 0 and 10 cm/sec on all stations. The depth under the

farms varied between 7 and 20 m and could not account for the all differences in waste accumulation. The accumulation therefore seems mainly to be a function of the waste output from the farm.
Sedimentation measurements were only conducted on five of the seven fish farm investigated. One farm was abandoned before the initiation of the sedimentation investigation, and another one was temporary abandoned during that period. These two sites had heavy accumulations of organic waste on the sea bottom (30 cm and 35 cm respectively).
When the sedimentation rates increased from station to station the accumulation of organic waste increased with it. But it might be possible that the bioturbation and comsumption of organic matter by the fauna prevented too much waste to build up. A large waste accumulation (35 cm) was seen on a station with a sedimentation rate not too much higher than the one that gave an accumulation of 7 cm. On this station the fauna was absent.

When the oxygen consumption is seen against the waste accumulation there is an initial linear increase. But with further accumulation (above 7 cm) the oxygen uptake only increases slightly.
It is also seen that the larger fauna (> 5 mm) disappear somewhere between an accumulation of 7 to 20 cm. The lack of fauna under fish farms has been found by others (Brown et al. 1987, Ervik pers. com.) and may be attributed to the loose consistency of the sediment together with the decreasing oxygen concentrations and increasing concentrations of sulfide in the pore water. The lack of bioturbation prevents oxygen from getting into the deeper layers of the sediment and the mineralization becomes anaerobic.
The three stations with the thickest accumulation of organic matter (F, G and H) therefore has a much slower degradation rate of the waste than the other stations.

Both ammonia and phosphate are released in high amounts compared to other investigations (Hall & Holby 1986). Nitrate is neither consumed nor released from the sediment in any noticeable amount. Generally, too little ammonia is released compared to phosphate when the N/P ratio of the input to the sediment is considered. Another investigation (Hall et al. 1986) have found that the main part of the nitrogen in the sediment is released as dissolved organic nitrogen, and it is possible that this can explain the missing nitrogen. Nitrification and denitrification seems to be unimportant in fish farm sediments (Hall et al. 1986, Blackburn et al. 1988, Kaspar et al. 1988).

Gas release from the sediments is a well known phenomenon in fish farming (Braaten et al. 1983). Five of the seven fish farms in this investigation had spontaneous gas ebullition all year. The more waste accumulated on the bottom under the farm the more gas release. Samuelsen et al. (1988) analyzed the gas from five fish farms and discovered that it consisted from 68 to 89 % methane, from 10 to 30 % carbondioxyde and 1 to 2 % hydrogensulfide. These compounds are produced during anaerobic decomposition of organic material, and they seem to be released in accordance with the increasing thickness of the accumulated matter.

The difference in isotopic composition of the fish muscle and the fish feed is of the same order of magnitude on all farms. This corroborates the findings of Fry & Sherr (1984) and others where the organism is isotopically heavier (less negative) than its food, usually by 1-2 per mil. When we additionally take into consideration the overall values from fish farms and compare them to those from the reference station, it suggests the possibility of using the isotopic ratio of the fish feed as a natural tracer around the fish farms.

The stable carbon isotope ratios show two different trends in the transects. One grouping consists of sites where the isotope values are relatively constant along the transect, and one grouping where isotope values seem to return to those associated with the original sediment (shellsand) Craig (1953). The last group of sites corresponds with the two farms that have the least sedimentation and therefore the least accumulation of waste. It is likely that the impact of these two farms on the surrounding benthic environment should be limited and the stable isotope ratios indicate that most of the waste is eliminated within 30 m of the farm.
The higher accumulation of sediment in the group of sites with constant isotope ratios along the transect is also associated with higher rates of oxygen consumption and eventually loss of bottom fauna. If an increasing accumulation suggests a higher output of waste feed and fecal pellets from the farm, then it follows that the area of impact is similarly larger. It is therefore suggested that a combination of high sedimentation rates and reduced secondary conversion may have led to the relatively constant isotope values along these transects. Similar values on transects from a fish farm have been obtained by other investigators (Li-Xun Ye et al. submitted). Unfortunately, the transects from the reference station are not yet analyzed so the final confirmation of this type of impact from fish farming activities remains to be seen.
An annual mean stable carbon isotope ratio for each point along the transect for each farm may give a better indication of the general impact of farm waste on the bottom sediments.

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Station	**Depth** m	**Org.cont.** % (top 2 cm)	**Waste acc.** cm	**Water cont.** % (top 2 cm)	**Fauna** (>5 cm)
A	10	4	0	35	+
B	12	15	2	59	+
C	15	16	2	61	+
D	7	26	5	80	+
E	14	31	7	80	+
F	9	44	20	87	-
G	11	47	35	89	-
H	20	40	30	85	-

Table 1 Various parameters from the sampling stations.

STATION	**DECOMPOSITION RATE/ LITRE WASTE/YEAR(%)**	**WASTE ACCUMULATION** (cm)
B	45	2
C	-	2
D	39	5
E	51	7
F	15	20
G	11	35
H	15	30

Table 2 Decomposition rate of the accumulated organic waste at the stations (except the reference) and the depth of accumulation.

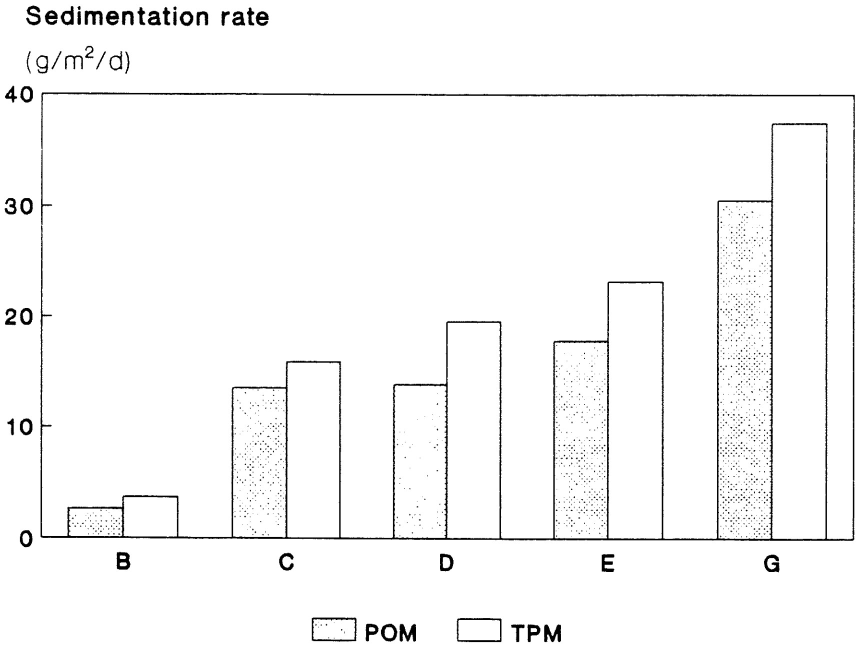

Fig.1 Total particulate matter (TPM) and particulate organic matter (POM) from five stations in the fall.

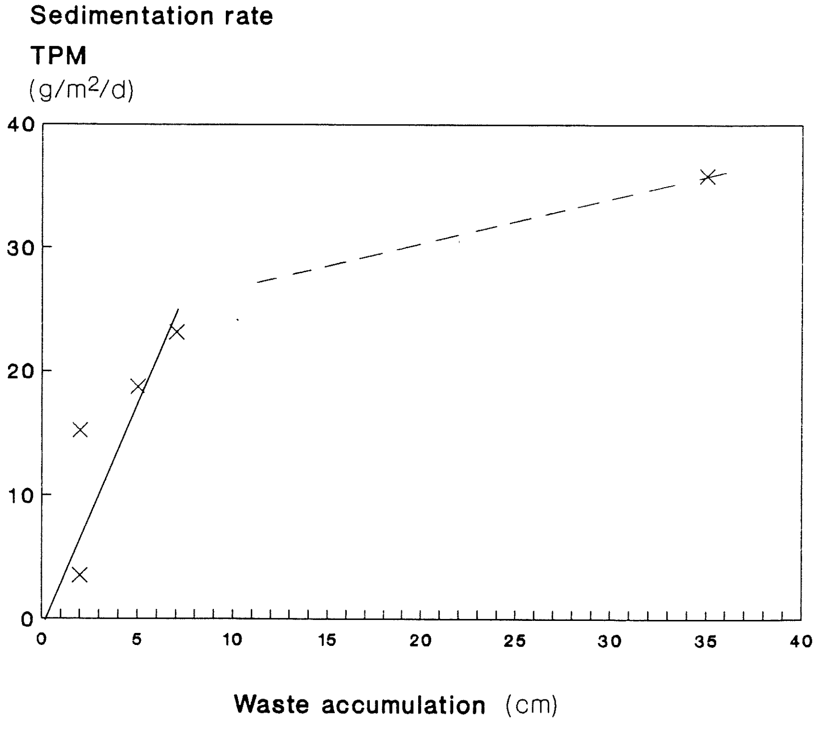

Fig.2 The relationship between the sedimentation (TPM) and the thickness of the accumulated waste.

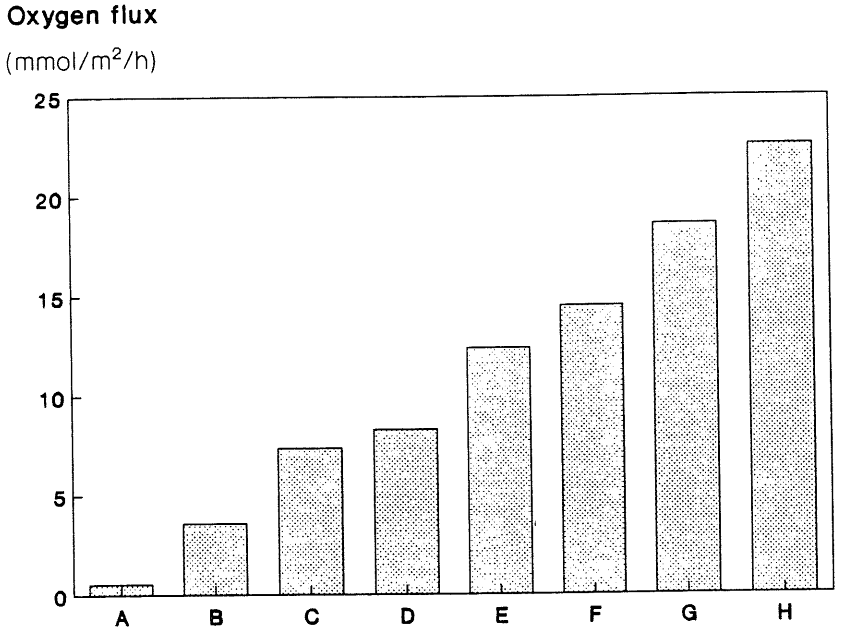

Fig.3 The annual mean oxygen consumption at the stations.

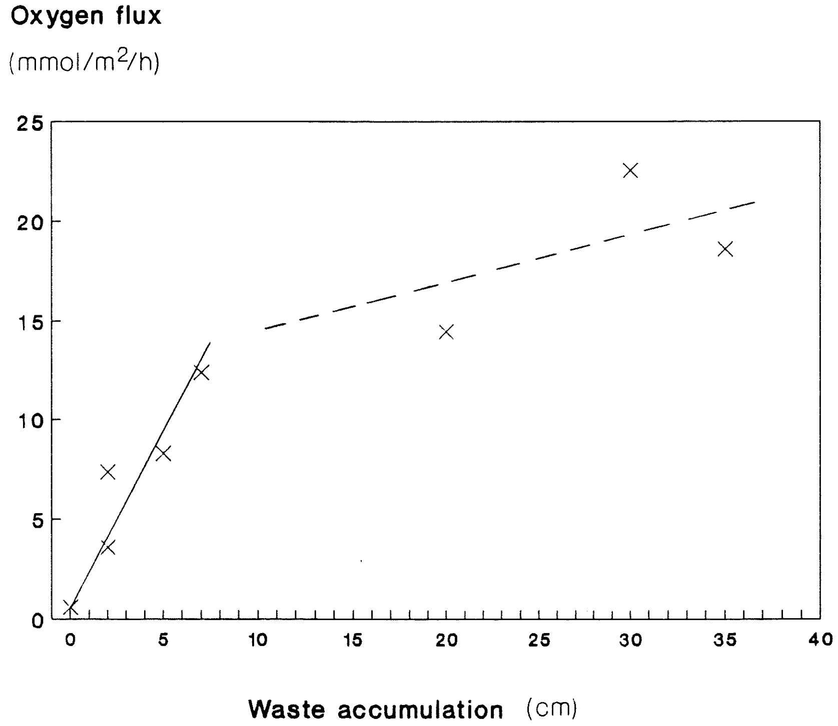

Fig.4 The relationship between the oxygen consumption and the thickness of the accumulated waste.

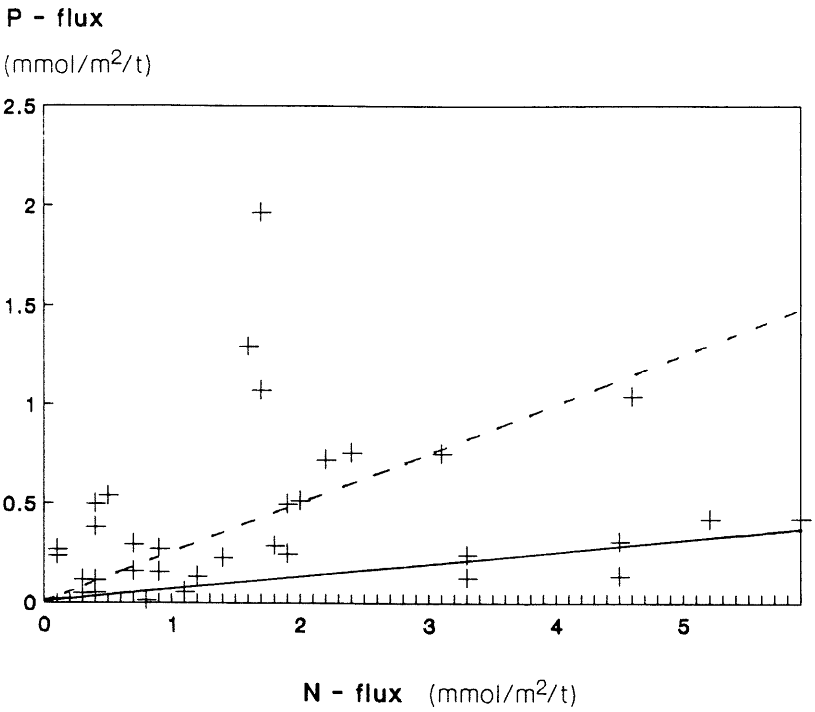

Fig.5 The relationship between the nitrogen and phosphate release from sediments on all stations. Solid line represents a N/P ratio of 15 (fish feed) the dashed line represents a N/P ratio of 4 (fecal pellets).

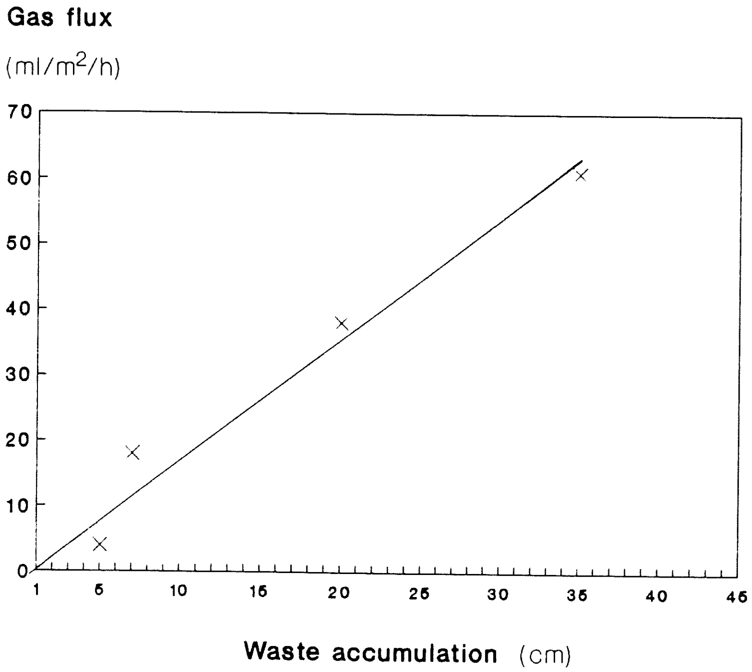

Fig.6 The release of gas from the sediment in relation to the thickness of the accumulated waste.

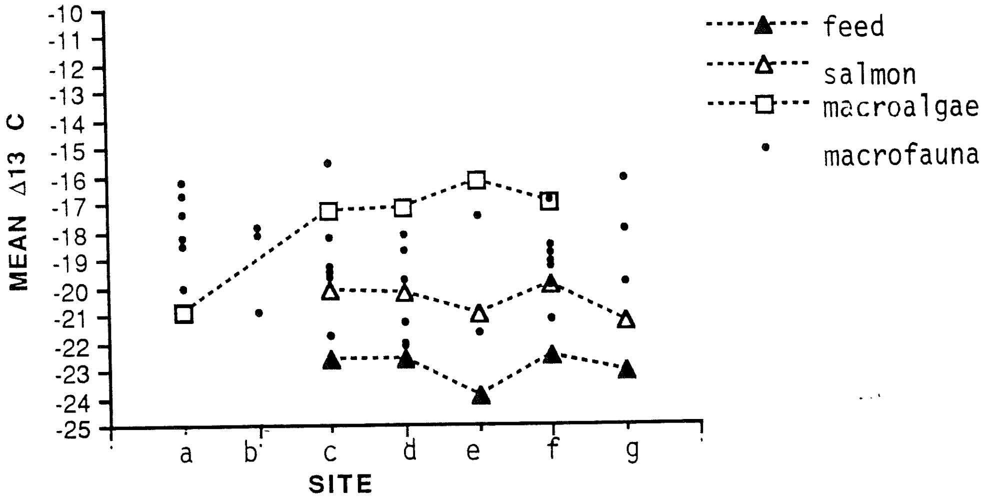

Fig.7 The stable carbon isotope ratios of fish feed, salmon, macroalgae and macrofauna at the stations.

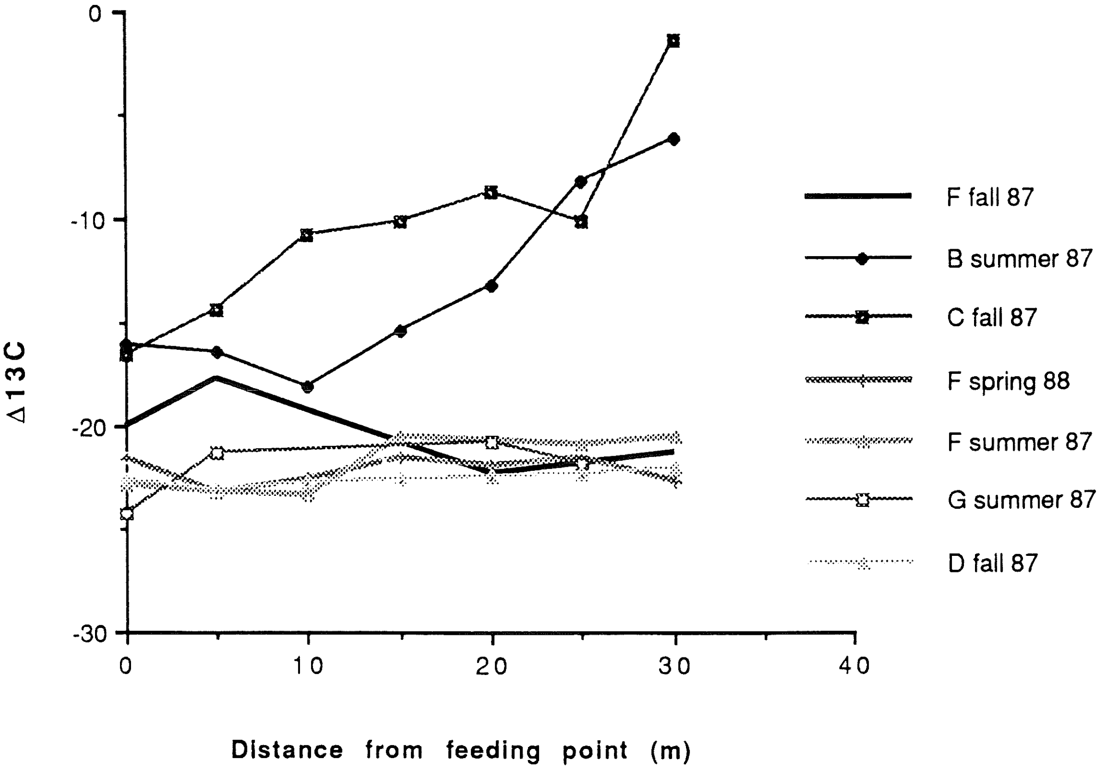

Fig.8 The stable carbon isotope ratios of the sediment along a transect at five of the seven fish farms.