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Impact of Atlantic salmon cage culture on sediment chemistry in Mjoifjordur, Iceland

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Abstract: Impact of Atlantic salmon (*Salmo salar*) cage culture in Mjoifjordur, Eastern Iceland on the chemistry of the sediment was investigated. Sediment samples were collected using a Shipek grab in December 2003. A core sub-sample was taken from each grab for analyzing total organic matter, total organic carbon, total nitrogen and phosphorus in different depths from three stations at various distances from the cage. These parameters were analyzed in the top layer of additional four stations. The results showed significant increase in all analyzed parameters in station 1, at 5m from the cage ($P<0.05$). The difference between reference station (600 m from the cage) and station 2 at 95 m to the cage was insignificant ($P>0.05$), indicating localized impact of cage farming to the vicinity of cage. The analyzed parameters in various depth did not show significant differences ($P>0.05$). The value of analyzed parameters in the perimeter of the cage and their differences with reference stations showed small magnitude and localized impact on the chemistry of sediment. It might be due to deep water and moderate velocity of water current in this fjord. The magnitude of impact may differ during the summer season when biomass and feeding rate would be at the maximum level.

Keywords: Cage culture, Atlantic salmon, Environmental impact, Sediment, Iceland

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Introduction

Cage culture is widespread around the world. Salmon is the most important group of cage farmed species, cultivated in various environments from freshwater lakes to offshore oceanic areas. Atlantic salmon (*Salmo salar*), with annual production of more than 1 million tons has the greatest contribution (FAO, 2005).

Environmental impact of salmon aquaculture is well studied due to its expansion in developed countries or with the financial investment of developed countries in developing countries like Chile. A number of reports on environmental impact assessment of salmon cage farming in several countries are available, among them studies in Australia, Canada, Chile, Norway, United Kingdom and the United State could be pointed out (EAO, 1996 ; Winsby *et al.,* 1996 ; ASI, 1999 ; Nash, 2001 ; Buschmann, 2002 ; Crawford *et al.,* 2002 ; SECRU, 2002 ; Brooks & Mahnken, 2003 ; Carroll *et al.,* 2003 ; Weber, 2003). Although the risks and degree of effects are site specific and may vary from place to place, all of these studies have pointed out similar risks and impacts. Chemical changes in the sediment are the most important impact of the cages.

Iceland is a new entrant to the world aquaculture. Atlantic salmon with annual production of some 3700 tons contributes to more than 50% of total aquaculture products of the country (FAO, 2005). Production of cage farmed salmon is expected to reach to 4000 tons by 2005-2006 (Johansson, 2001).

Mjoifjordur is a deep and narrow fjord in east Iceland. It is about 18 km in length and a width that decreases gradually from 3.5km at the mouth to 600m at the end. Farming operation in this fjord was started in late July 2002 when the cages were stocked with Atlantic salmon smolts. Being a relatively new activity in this fjord, salmon cage culture should be assessed from all aspects before it expands further beyond its controllable scale. This requires a wide range of field investigations. The present study has been aimed at assessing the impact of Atlantic salmon cage culture on the chemistry of sediments in Mjoifjordur. Such studies will provide us with scientific tools and reasons in manipulating the fast growing cage farming industry in the sensitive fjord ecosystem.

Materials and Methods

Location

The farm is located at 65° 12′ 027″ N and 13° 46′ 632″ W (coordinate of farm's center) close to the opening of the fjord (Fig. 1).The minimum distance of the farm from the northern coast is approximately 300m. The farm is composed of 14 circular cages moored in two rows. The maximum surface temperature is about 9°C during the summer and decreasing to 1°C in winter season (MRI, 2004). The area is rather windy. Average wind speed in autumn for the past 10 years has been 6.8ms^{-1} with the maximum speed of 12.3ms^{-1} (IMO, 2004). Prevailing current at the farm site is from the east into the fjord along the northern shore. The average velocity at 10 m depth is 4.1cms^{-1} and the recorded maximum 36.6cms^{-1} (Samherji hf., farm log sheet 2003).

Farming operation started in late July 2002 when the cages were stocked with Atlantic salmon smolts. Considering the total contribution of feed, total carbon and nitrogen input from the feed was estimated 2625 and 278 tons, respectively. Based on minimum rate of feed waste (EAO, 1996; Winsby *et al.,*. 1996; Pearson & Black, 2001; Nash, 2001), some 305 tons of carbon and 31.4 tons of nitrogen have been released in to the fjord as faecal matter and uneaten feed.

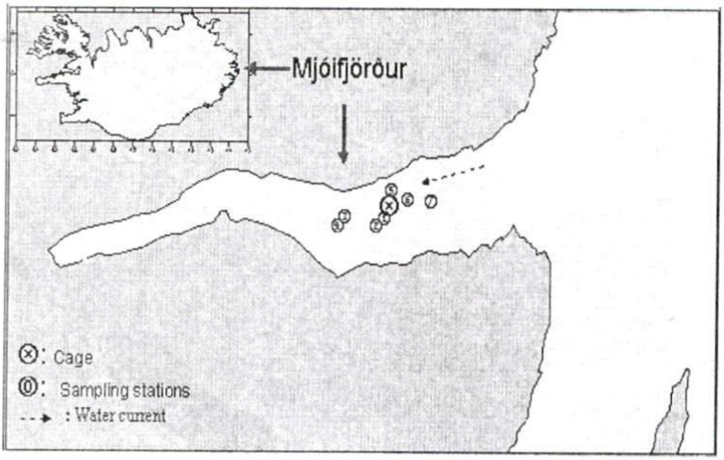

Figure 1: Position of the farm and sampling station in Mjoifjordur (not in scale)

Sampling

One of the 14 cages in the middle of the block was selected as the target cage. Seven sampling stations were selected based on depth, prevailing current in the fjord, specification of the waste materials and distances of the cage from the coast and the next farm. The farthest station (S7) upstream of the cages was chosen as the reference station. Depth of water and position of the sampling station were read on the GPS screen of the sampling vessel (Fig. 1 and Table 1).

Table1: Depth of water and distance from the coast at sampling stations

Station	Depth (m)	Approximate distance in meter		
		From the edge of cage	From the reference station (No.7)	From the north coast
1	85.5	5	600	410
2	88.1	95	650	470
3	85	320	900	380
4	88	350	930	400
5	74	150	570	270
6	66	200	580	450
7	87.3	600	0	480

Sediment samples were collected in December 2003 using a Shipek grab sampler with a foot print of $0.044m^2$. Almost all the grabs were in good quality with minimum leakage or flushing out the sediment. Low quality samples were discarded. The weather was calm, partly cloudy and temperature was about -5.7 °C at the time of sampling. The wind speed varied between $2.5ms^{-1}$ in early morning to $4.1ms^{-1}$ at the end of sampling period. Wind direction changed from 340° to 250° during the same period (IMO, 2004).

A sub-sample was taken from each grab using Plexiglas corers (inner diameter: 6cm). The length of the sediment in cores was 9 to 10cm. The cores were packed immediately and kept at minus zero degrees centigrade on deck. When at shore the cores were frozen at –20°C (Karakassis *et al.*, 2000; Zitko, 2001; Carroll *et al.*, 2003) until transported to the Icelandic Fisheries Laboratories in Reykjavik by air. In the laboratory, the top 0.5cm layers of all the core samples were cut by stainless steel saw and placed in plastic bags. Three cores from station No. 1 (at the edge of cage), No.2 (at 95 meter of cage) and No.7 (reference, at 600m from the cage) were selected for complete layer analysis and those cores were dissected in 1 cm thick slices. Sub-samples were placed in plastic bags and kept frozen (at –20°C).

Sample analysis

The samples were analyzed for dry weight, total organic matter (TOM), total organic carbon (TOC), total phosphorus (TP), and total nitrogen (TN) according to the following methods:

TOM was determined by loss on ignition method. A 500mg sample from each dissected layer was oven dried for two hrs, at 105°C, weighed and subsequently placed in a furnace at 550°C for 2 hrs., then reweighed. Dry weight was determined as the difference between weight of wet sample and oven dried one. TOM was calculated from the difference between the oven dried weight and weight after being in the furnace. TOM is expressed as the percentage of the oven dried weight (% DW).

The determination of TOC was based on chemical oxygen demand (COD). Two samples, approximately 100 and 200mg wet weight from each layer were digested in 250ml flask containing 10ml dichromate 4M, 30ml sulphuric acid (95-97%) and 20ml Milli-RO/Milli-Q water for 2 hours. Some 200mg of mercury sulfate was added to the flask in order to prevent interference of natural chloride in the sediment. COD was calculated based on volume of standardized ferrous ammonium sulfate (FAS) used in the titration and then converted to percentage of organic carbon content based on the chemical balance of carbon oxidation.

For TP and TN, 200 and 400mg wet weight of samples were digested in 6ml sulphuric acid (36M) for 5 minutes and then oxidized by adding 15ml hydrogen peroxide (30%) using HACH Digestdal instrument. The solution was diluted to 100ml and left overnight for precipitation of suspended material.

• *Total phosphorus*

Exact volume of 0.5ml of prepared sample solution were pipetted into 50ml flask and diluted to 25ml with water. TP was determined by spectrophotometery (Cary 1E, 880nm) after formation of the molibdate complex and reduction by ascorbic acid.

• *Total nitrogen*

Due to low concentration when using 0.5ml of the solution, the initial volume of sample was increased 10 times and 5ml of processed sample was pipetted to 50ml flask. 3ml of NaOH (4M) was added to adjust the pH. TN determined by spectrophotometery (Cary 1E, 630nm) by the phenate method.

Statistical analysis

To determine the significant differences between the stations and between the layers within a station one way analysis of variance (ANOVA) and ANOVA single factor was used respectively. Duncan Multiple Range Test (DMRT) was applied for comparison of the means between three stations at 95% level of confidence using SPSS version 10 and Excel software. Correlation between variables were analyzed using Pearson 2 tailed test in two level of confidence (a = 1% and 5%).

Results

Percentage of all analyses studied in top layers (0-0.5cm depth) was the highest at station 1 (Fig. 2). ANOVA single factor analysis showed TN and TOC at this station were significantly different from the other stations. Total phosphorus and TOM did not, however, show any significant differences in the top layer of station 1 as compared with the other stations (a = 5%).

One way analysis of variance (Table 2) revealed no significant difference between means of analyzed parameters in different depths of sediments at station 1, 2 and 7 (P>0.05). Although the TOM, TOC, and TP all showed a decreasing gradient with depth at station 1, they were however, approximately at the same level in the other two stations at all depths of sediments.

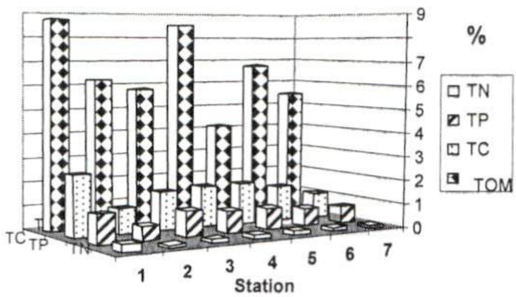

Figure 2: Analyzed parameters in top layers of different stations

Table 2: Mean and standard deviation of analyzed compounds in different layer of sediments in 3 stations

Sediment depth (cm)	Nitrogen (mgg^{-1})	TOC (%)	Phosphorus (mgg^{-1})	TOM (%)	C:N ratio	C:P ratio
0- 0.5	0.1735± 0.1146	1.5588± 0.8543	0.8377± 0.3285	6.7930± 1.7099	9.4053± 1.0389	1.8047± 0.3073
0.5-1.5	0.2243± 0.1653	1.4748± 0.4996	0.7706± 0.2326	5.8667± 1.0788	8.0872± 4.0306	1.9009± 0.2575
1.5-2.5	0.1253± 0.0116	1.309± 0.1085	0.6777± 0.08427	6.1137± 0.05816	10.4584± 0.3125	1.9416± 0.07492
2.5-3.5	0.1162± 0.215	1.3718± .103	0.6503± 0.0379	5.8593± 0.3185	12.125± 2.7470	2.117± 0.2524
3.5-4.5	0.2444± 0.2133	1.2756± 0.1453	0.6675± 0.0601	5.8193± 0.3304	11.5310± 6.6527	1.9191± 0.1935
4.5-5.5	0.1762± 0.1214	1.3986± 0.0866	0.6395± 0.06627	5.1637± 1.0512	9.8587± 3.6113	2.2118± 0.2181

The mean and standard deviations of the parameters analyzed at these 3 stations are presented in Table 3. One way analysis of variance revealed significant differences between the stations in terms of the means of all parameters ($P<0.05$).

DMRT showed that difference of mean of analyzed parameters at station 7 and 2 were insignificant (P>0.05).

However, station 7 and 1 were significantly different, except in the mean of TOC. Mean of TOC at station 7 was higher than S2. Station 1 and 2 showed significant differences in TOC, TN and TP. Difference of the mean of TOM between two stations was insignificant. TOM value was the highest at the station closest to the cage.

(C:N) ratio at station 1 was significantly different from other two stations (P<0.05). However, carbon, phosphorus (C:P) ratio in all three stations was very similar and did not show significant differences (P>0.05).

Pearson test indicated a positive and significant (P<0.05) correlation between the parameters analyzed. Total organic matter, carbon and phosphorus showed higher correlations (P<0.01) (Fig. 3 and Table 4).

Table 3: Mean and standard deviation of analyzed compounds in different station

Sampling station	Nitrogen (mgg^{-1})	TOC (%)	Phosphorus (mgg^{-1})	TOM (%)	C:N ratio	C:P ratio
S1	0.3014± 0.1460^{a}	1.6646± 0.5016^{a}	0.8475± 0.2236^{a}*	6.6743± 1.1007^{a}	6.7182± 3.2058^{a}	1.9594± 0.1090^{a}
S2	0.1181± 0.0191^{b}	1.2327± 0.2082^{b}	0.6393± 0.0 4402^{b}	5.7827± 0.4114^{ab}	10.7968± 3.2149^{b}	1.9217± 0.2518^{a}
Reference (S7)	0.109± 0.01142^{b}	1.2969± 0.1417^{ab}	0.6349± 0.05315^{b}	5.9359± 0.7214^{b}	12.0612± 2.2397^{b}	2.0664± 0.3257^{a}

* The same letter indicate insignificant difference (P<0.05)

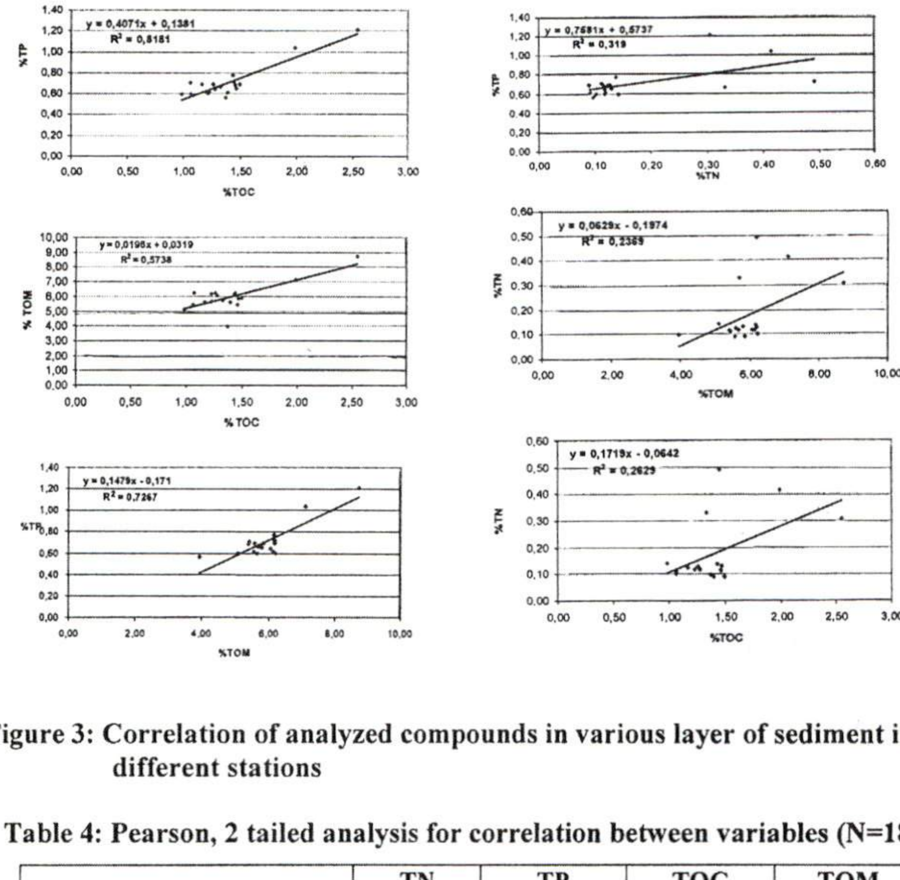

Figure 3: Correlation of analyzed compounds in various layer of sediment in different stations

Table 4: Pearson, 2 tailed analysis for correlation between variables (N=18)

		TN	TP	TOC	TOM
TN	Pearson Correlation	1.000	0.565(*)	0.513(*)	0.487(*)
	Sig. (2-tailed)	.	0.015	0.030	0.041
TP	Pearson Correlation	0.565(*)	1.000	0.904(**)	0.852(**)
	Sig. (2-tailed)	0.015	.	0.000	0.000
TOC	Pearson Correlation	0.513(*)	0.904(**)	1.000	0.758(**)
	Sig. (2-tailed)	0.030	0.000	.	0.000
TOM	Pearson Correlation	0.487(*)	.852(**)	0.758(**)	1.000
	Sig. (2-tailed)	0.041	0.000	0.000	.

* **Correlation is significant at the 0.05 level (2-tailed).**

** **Correlation is significant at the 0.01 level (2-tailed).**

Discussion

Based on the feed quality and site characteristics, spatial dispersion of the major part of uneaten feed and faecal matter in the studied area in Mjoifjordur should be restricted to 55 m downstream from the edge of cage. Uneaten feed accumulates at closer distances to the cage than faecal mater, since faeces have a lower sinking rate and should therefore settle further away. The current at the farm area will probably interfere with the sedimentation behavior of solid wastes.

The nitrogen content of the sediment is often used as a good indicator of sediment enrichment, due to the fact that this is mostly derived from external inputs (CSIRO, 2000; Telfer & Robinson, 2003). At station 1, total nitrogen in the surface layer and the mean of TN in the whole sediment exceeds 0.3%, which is in accordance with the results of other studies. Karakassis *et al.* (2000) and Kempf *et al.* (2002) reported concentration of organic nitrogen as low as 0.3% in sediments in close vicinity of the marine fish cages in both shallow, slow current and steep bottom, strong current areas. McGhie *et al.* (2000) indicated higher value of TN in Huton Estuary, Tasmania as great as 1.3%. They found that TN did not decrease to less than 0.4% after 12 month farming had ceased. On the other hand, Crawford *et al.* (2002) reported very low nitrogen content (0.15 to 0.4%) in the sediment in the vicinity of salmon farms in Nubeena, Tasmania. In Mulroy Bay, UK, nitrogen content showed that a range from 0.14 to 1.73% in different sites and distances from salmon farms (Telfer & Robinson, 2003). These results point to the influence of both site and farm conditions on the magnitude of accumulation of waste material and their impact on the environment.

Crawford *et al.* (2002), in their evaluation of techniques for environmental monitoring of salmon farms, concluded that nitrogen was a proper indicator in highly impacted sediments. In our case, where the water is deep and the moderate current may flush out the waste materials, nitrogen might be a less qualified index. According to the Shaanning pollution index (Table 5) and considering the mean nitrogen concentration at station 1, 2 and 7 these stations should be classified as undisturbed sites (less than 2 mgg^{-1} N).

Table 5: Shaanning Pollution Index of sediment (Carroll *et al.* 2003)

Degree	Index	pH	pS	pE	N (mgg^{-1})	P ($mg\ g^{-1}$)	Zn ($\mu g\ g^{-1}$)	Cu ($\mu g\ g^{-1}$)
Large	3	<6.9	<2	<-2	>16	>10	>650	>150
Moderate	2	6.9-7.2	2-4	-2 – 0	8-16	2-10	150-650	25-150
Small	1	7.21-7.7	4-7	0-2	2-8	0.5-2	5-150	5-35
No	0	> 7.7	>7	>2	<2	<0.5	<5	<5

pH: alkalinity, pS=-log H_2S, pE: redox potential=-log {e} =Eh (V)/0.059

Total organic carbon in the surface layer of the sediment at station 1 was considerably higher than at the other six stations (Fig. 2), indicating an external input of carbon and accumulation of organic matter on the seabed. The mean of TOC in station 1 was 1.66%, some 28% greater than at the reference site 600 meter from the cage. However, the difference between the two stations was insignificant. McGhie *et al.* (2000) reported high TOC value (4.05%) at a reference site in the Huton Estuary, Tasmania, where TOC was almost 30% lower than underneath the cage. Hargrave *et al.* (1997) obtained a similar result in their study on cage farming in New Brunswick. Carroll *et al.* (2003) in their study on Norwegian salmon cage farming concluded that in approximately 10% of 168 samples, TOC values had increased because of natural processes. Sara *et al.* (2004) found that 47.9% of carbon in sedimentary organic matter in Mediterranean area originated from cage farming and the rest was of terrigenous (about 33%) and autochthonous (about 19%) origins.

C:N ratio can be a useful indicator of the source and age of organic matter in estuaries and coastal areas (Winsby *et al,* 1996; CSIRO, 2000; Telfer & Robinson, 2003). C:N ratio of 6 to 10 is generally reported for autochthonous marine- derived organic matter (CSIRO, 2000; Sutherland *et al.*, 2001) whereas values greater than 11 (Telfer & Robinson, 2003) and/or 12 (CSIRO, 2000) are usually found in terrestrially derived organic matter and external input of nitrogen.

In present study, mean of C:N ratio in different depths at station 1 was 6.7182± 3.2058, showing accumulation of highly labile material. This is lower than calculated C:N ratio of the feed (9.4). Deep water at this station provides a condition for leaching of nitrogen during sinking and decomposition of uneaten feed results in the increase in C:N ratio. It is as high as 8.32 in the top layer at this station. High C:N ratio at station 2 and the reference site indicated the presence of poorer quality of organic material.

A number of studies have shown a wide range of TOC value in the vicinity of cage farms. Heliskov and Holmer (2001) reported values for organic carbon as 1.2 to 2.2% of dry weight in affected sediments near a trout cage farm in shallow coastal waters of Denmark. In Tasmania, organic carbon contents in the sediments around the salmon cage farms varied from less than 1% to more than 6%, depending on the site and farm condition (Crawford *et al.*, 2002). The variability of TOC can be accounted for the varying proportion of fine clays and silts (CSIRO, 2000). Svavarson and Helgason (2002) reported that sediment grain size in Mjoifjordur varied along the fjord. The fraction of fine particle (<0.063mm) changed from 47.5% 1300 m upstream from our reference site (S7) to 27.9% 1300 m downstream. However, the organic carbon was very high (5.7-5.9%) and did not show considerable changes in different places. The results of the present study are closer to the average organic carbon content in the sediment of the coastal area of Iceland.

Microscopic examination of the sediment showed a difference in grain size between the three stations 1, 2 and 7. The second station looked more salty than station 1 while reference station had finer grains. Total phosphorus at station 1 was significantly higher than at stations 2 and 7, reflecting the disturbance of the sediment at this station. The reference station and station 2 were not significantly different, which meant that the impact of the cage culture was restricted to a short distance from the cage. TP showed high correlation with total organic carbon ($r^2 = 0.904$). Carbon: phosphorus ratio in the feed was almost 56.5, while the C:P ratio in the sediments was approximately two and the difference between the three stations was insignificant. Nickell *et al.* (2003) in their study of impact of salmon cage culture in moderately deep (25m) water of Loch Creran, Scotland, found that C:P ratio could describe the quality of carbon in the sediment as phosphorus is more sensitive to degradation. The result of our study does not show such a correspondence.

Holmer *et al.* (2002) found large accumulation of phosphorus in the sediment nearby a milkfish cage farm in moderately shallow water. They suggested that phosphorus was either buried with the organic matter or bound to carbonates. In our study, we observed high level of phosphorus in surface layers of all samples. Therefore, the probability for burying of phosphorus was very low. Available information is not sufficient to discuss the binding capacity of the sediment in this area. Guo and Li (2003) found that solid wastes of cage farming would lose their phosphorus content in the first 50m depth of water. Leaching and decomposition rate depended on temperature, salinity and environmental parameters. So it might be concluded that the difference between the average phosphorus content originated from other source of pollution and waste materials from the farm do not significantly impact phosphorus in the sediments. According to the Shaanning pollution index (Table 5), station 1 would be classified as slightly impacted group and two other stations are very close to being in the undisturbed category.

TOM in station 1 was significantly different from reference station. Higher TOM at station 1 showed an accumulation of organic material nearby the cage. The reference site and station 2 did not show considerable differences. Several researchers have found organic matter measurements by loss on ignition to be accurate only if the sediments were highly enriched or the carbonates and clay concentration were in low levels (Crawford *et al.*, 2002). That is because of ignition of carbonate and interference with the loss of organic carbon.

Karakassis *et al.* (1998) found no significant difference between sites 5m, 10m, and 25m from the cage and the reference site. In our study, the magnitude of enrichment is low. The results show a high correlation between TOC and TOM indicating a similar source of carbon and organic material.

In conclusion, the results of this study revealed that Atlantic salmon cage farming in Mjoifjordur has affected the chemistry of the sediment close to the farm, however low in magnitude. It might be due to moderate current velocity and great depth of the fjord, which provides a suitable condition for leaching and decomposition of organic material during the sinking period and flushing out the deposited waste from the fjord as well. The result also indicated localized impact of cage culture, restricted to few tens of meters from the cage. It should be noted that samples were not taken from underneath the cage. The impact on the sediment below the cage might be higher than observed at the station nearby the cage.

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