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Phytoplankton at the Ocean Quahog Harvesting Areas off the Northwest Coast of Iceland 1994

Svifþörungar á kúfiskmiðum út af norðvesturströnd Íslands 1994

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Þórunn Þórðardóttir and Agnes Eydal

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(Icelandic summary)

Vegna fyrirhugaðs útflutnings á kúfiski til Bandaríkjanna, voru gerðar viðamiklar rannsóknir á veiðisvæðum kúfisks samkvæmt kröfum bandarískra yfirvalda.
Meðal rannsóknaþátta voru rannsóknir á plöntusvifi og umhverfi þeirra.
Frá 28. mars og út október 1994 var yfirborðssýnum safnað vikulega á þremur stöðvum, í **Önundarfirði**, á **Aðalvík** og **Fljótavík**. Háfsýni og talningarsýni voru tekin úr yfirborði. Einnig var mæld blaðgræna, selta, næringarefni og hiti í yfirborði. Eitt af markmiðum þessarar rannsóknar var að kanna tilvist þörunga sem hugsanlega geta framleitt eiturefnin: PSP (Paralytic shellfish poison) sem er hættulegt taugaeitur og skoruþörungar af ættinni *Alexandrium* geta framleitt, DSP (Diarrheic shellfish poison) sem veldur magaeitrun og skoruþörungar af ættinni *Dinophysis* geta framleitt og að lokum ASP (Amnesic shellfish poison) sem er einnig taugaeitur og getur m.a. valdið minnisleysi, kísilþörungar af ættinni *Pseudonitzschia* geta framleitt þetta eitur. Mánaðarlega var safnað sýnum úr kúfiskafla til að kanna hvort þessi eiturefni væru mælanleg, var mælingin framkvæmd af Rannskóknastofnun fiskiðnaðarins.

Þegar sýnatakan hófst í lok mars var hitastig sjávar um 1 °C og jókst hægt eftir það í 10 °C í ágúst, lækkaði síðan aftur og var 4-5 °C í nóvember (myndir 2b, 3b og 4b). Mælingar sýndu talsverðar sveiflur í seltu, aðallega að vorinu og fram á sumarið þegar leysingavatn rann af landi (myndir 2a, 3a og 4a). Í Aðalvík og Fljótavík voru greinileg vetrargildi næringarefna við upphaf mælinganna en upptaka svifþörunga á næringarefnum var sýnilega hafin á Önundarfirði í lok mars. Styrkur næringarefna minnkaði ört frá miðjum apríl fram í miðjan maí og héldust gildi fosfats og nítrats lág fram í september. Gildi kísils voru einnig lág í maí en aukningar varð vart smhliða seltulækkun. Kísill varð aldrei uppurinn né heldur fosfat, en nítrat gekk til þurrðar í júlí og ágúst aðallega á Önundarfirði og Aðalvík (myndir 2, 3 og 4). Þess ber þó að geta að nítrat var eina köfnunarefnissambandið sem mælt var, og ekki útilokað að önnur form köfnunarefnis hafi verið til staðar.

Á Önundarfirði varð aðalhámark vorsins í lok apríl en u.þ.b. tveimur vikum seinna á Aðalvík og Fljótavík (mynd. 5). Í lok mars var þegar kominn nokkur gróður í Önundarfirði (myndir 2-c-d-e-f, 5). Sömu tegundir urðu ríkjandi í svifinu á öllum stöðvum, þó tímamunur væri á hámarki á hverjum stað. Fyrst um vorið voru það *Thalassiosira gravida, Th. nordenskioeldii, Chaetoceros socialis* og *Phaeocystis pouchetii.* Á eftir fylgdu þrír gróðurtoppar á tímabilinu júlí til september (mynd 5), ríkjandi tegundir í hverju tilviki voru, í réttri tímaröð

Leptocylindrus minimus, Skeletonema costata og að lokum *Pseudonitzschia pseudodelicatissima* (myndir 6 og 7). Í lok september var gróðurtímabilinu lokið á Aðalvík og Fljótavík en örlítillar aukningar varð vart að nýju á Önundarfirði í október og bar þá mest á *Pseudonitzschia seriata/fraudulenta*. Á heildina litið voru kísilþörungar ríkjandi tegundir allt sýnatökutímabilið.

Blaðgræna jókst mest um vorið (myndir 2e, 3e og 4e). Fall varð síðan í blaðgrænu að afloknu vorhámarki, en jókst svo og féll á víxl fram á haustið þar til gróðurtímanum lauk.

Þær þörungategundir sem komu fyrir og geta myndað eitrin PSP, DSP og ASP eru tilgreindar á bls. 6 í enska textanum. Þessar tegundir fundust á öllum sýnatökustöðvunum og birtust í eftirfarandi tímaröð, *Alexandrium spp, Dinophysis spp* og *Pseudonitzschia pseudodelicatissima* (myndir 7 og 10, töflur 2, 3 og 4). Fjöldi þessarra eitruðu þörunga á rúmmálseiningu segir til um hættumörk, en viðmiðunin er þó mismunandi eftir löndum, í þessari skýrslu var stuðst við norskar og danskar vinnureglur. Hættumörkin sem miðað var við eru eftirfarandi *Alexandrium spp.* 500 frumur/lítra, *Dinophysis spp.* 300 frumur/lítra og *Pseudonitzschia pseudodelicatissima* $5x10^5$ frumur/lítra. *Alexandrium spp.* fór einu sinni yfir þessi hættumörk, en *Dinophysis spp.* og *P. pseudodelicatissima* fóru nokkrum sinnum yfir hættumörkin (töflur 2 og 4, myndir 7 og 10).
Alexandrium sást fyrst í júní og var aðallega áberandi í júní og júlí (mynd 10), fjöldi fruma á líter var alltaf undir hættumörkum utan einu sinni á Önundarfirði. Mælingar á PSP-eitri í kúfiskinum voru alltaf undir hættumörkum. Engu að síður er vitað að *Alexandrium spp.* getur valdið skelfiskeitrun hér við land, það hafa aðrar mælingar á skelfiski sýnt. *Alexandrium* tegundir eru nokkuð algengar í háfsýnisprufum við Ísland, en yfirleitt í litlu magni.

Í kjölfar *Alexandrium* komu *Dinophysis* tegundir, þær voru áberandi í svifinu alveg fram í október (mynd 10). Fjöldi *Dinophysis spp.* fór nokkrum sinnum yfir hættumörkin, einkum á Aðalvík. DSP-eitur mældist ekki yfir hættumörkum í kúfiskinum. Það er vitað um nokkur tilfelli hér við land þar sem *Dinophysis spp.* hafa valdið skelfiskeitrun. *Dinophysis spp.* eru nokkuð algengar tegundir í sýnum við Ísland, en sjaldnast er mikið af þeim.

P. Pseudodelicatissima fannst í svifinu allt sumarið og fram á haust (mynd 9). Yfirleitt var um nokkur hundruð frumur á lítra að ræða, en í ágúst varð mikil fjölgun, fjöldinn fór í nokkrar milljónir á lítra. Þrátt fyrir mikinn fjölda mældist ekki ASP-eitur í kúfiskinum.

Hvort svifþörungategundir sem hugsanlega geta framleitt eiturefni eru staðbundnar eða berast inn með straumum er erfitt að segja. Sú vitneskja sem til er um svæðin er það takmörkuð að erfitt er að segja til um hvaða tegundir eru staðbundnar. Tegundir sem mynda dvalargró og mikill fjöldi verður af á ákveðnu svæði eru líklegar til að koma fram aftur. Það er vitað að *A. tamarense* getur myndað dvalargró, en ekkert er vitað um hugsanlega veru þeirra á Önundarfirði, Aðalvík eða Fljótavík. Sömu sögu er að segja um *Dinophysis*, en nýlega var staðfest að ættin getur myndað dvalargró í og eftir blóma. Okkur er hins vegar ekki kunnugt um að *Pseudonitzschia* geti myndað dvalargró. Þær upplýsingar sem til eru sýna að *Pseudonitzschia* er algeng síðsumars á strandsvæðum við vesturströnd Íslands og því reiknum við með því að hún sé árviss á svæðinu.

Það hefur verið sýnt fram á að kísilþörungar hafa betur í samkeppni við aðrar þörungategundir þegar næringarefni eru næg og kísill yfir 2µM. Kísill var yfirleitt yfir 2µM allan sýnatökutímann m.a. vegna ferskvatnsflæðis af landi og gæti það skýrt góða afkomu kísilþörunga og einnig hvað lítið var af skoruþörungum á svæðinu sumarið 1994. Mikið kísilmagn yfir sumartímann þarf ekki að vera árvisst og virðist háð ferskvatnsflæði af landi sem getur verið mismunandi.
Það er niðurstaða þessara rannsókna að svifþörungar sem vitað er að geta framleitt eiturefnin PSP, DSP og ASP voru til staðar á veiðisvæðum kúfisksins norðvestur af landinu 1994. Eitur mældist ekki yfir hættumörkum í kúfiskinum, en þar sem þessar tegundir fundust á sýnatökusvæðunum er æskilegt að fylgjast með svifþörungunum yfir sumartímann. Ástæða er til að gæta fyllstu varúðar og mæla reglulega möguleg eiturefni í kúfiskförmunum.

1. Introduction

This investigation is a part of a one year interdisciplinary sanitary survey preceding planned export of ocean quahog (*Arctica islandica* L.) to the USA market. The survey was conducted in accordance with the requirements of U.S. authorities as regards control of the sanitary conditions in shellfish harvesting areas in the year before the harvesting begins. Among items to be surveyed was the content of the algal toxins PSP, DSP and ASP in the ocean quahog at intended harvesting sites. Because of the remoteness of two of the harvesting areas it proved to be difficult to monitor the toxins in the shellfish more often than once a month. Therefore it was decided to monitor phytoplankton weekly for the occurrence of potentially toxic algae. When numbers were above risk level more frequent measurements of algal poison in the ocean quahog would be taken for as long as necessary.

Another aspect of the weekly monitoring of phytoplankton was considered. Very little is known of the composition and seasonal progress of phytoplankton in the areas where harvesting is planned. By weekly monitoring it would be possible to gain knowledge of the role of different algal groups within the vegetation as well as the distributional pattern of potentially toxic algae eventually present. This information might be useful in future monitoring and control of algal toxins in the ocean quahog.

Data on oceanographic variables were collected concurrent with the phytoplankton sampling to help interpret the results of the phytoplankton monitoring.

2. Material and Methods

Sampling took place at three locations, Önundarfjörður 66°04,26´N-23°41,55´W (ÖN), depth 13-14 m, Aðalvík 66°22,24´N-23°08,74´W (AL), depth 30-32 m and Fljótavík 66°26,59´N-22°57,19´W (FL), depth 15-17 m. The stations occupied are located in shallow areas close to land. Surroundings differ in that, ÖN is within a sheltered fjord, whereas both AL and FL are situated in fairly open and exposed areas (Fig. 1).

Surface samples which were taken weekly from March 28 to November 5 1994, were collected with a bucket. Temperature was measured immediately after collection. Samples for measuring salinity, nutrients (P, N, Si), chlorophyll a (1 liter), and for quantitative analysis of phytoplankton were taken from the bucket. Netsamples were collected with a phytoplankton net (mesh size 20 µM).

The sampling and sample pretreatment prior to shipment to Reykjavík, were carried out at the local branch laboratories of the Icelandic Marine Research Institute (MRI) and the Icelandic Fisheries Laboratories (IFL) at Isafjördur. The fishing plant at Flateyri in Önundarfjörður provided vessels for the collection of samples.

The salinity and nutrients (P, N, Si) were measured at the hydrography laboratory at the MRI using standard analytical methods (Strickland and Parsons 1968; Grasshoff *et. al* [eds] 1983). Other work was performed by the phytoplankton laboratory at the same institute.

Chlorophyll a was filtered, stored and measured as described in Anon. 1966. The phytoplankton samples were conserved with neutralized formalin. The final concentration of formalin in the 100 ml samples for quantitative analysis were 0.4%. All phytoplankton samples collected were analysed. Species were identified in the net samples before the quantitative analyses were performed. The counting procedure was as follows. After thorough shaking of the bottle (150 times), a subsample was poured into a sedimentation chamber (50 ml). The settling time was usually 24 hours. The counting was carried out with an inverted microscope at 200 times magnification. The numbers of the species of *Alexandrium* and *Dinophysis* were counted over the whole bottom of the 50 ml chambers, whereas all other species were counted on 2 or 4 diagonal stripes which corresponded approximately to 1 and 2 ml on a volume basis, respectively.

A few net samples were sent to professor G.R. Hasle, Oslo University, in order to confirm the identification of *Pseudonitzschia pseudodelicatissima* (Hasle) Hasle as well as identifying a *Pseudonitzschia* species which occurred together with *Pseudonitzschia seriata* Cleve during September and October at ÖN. The species proved to be *Pseudonitzschia fraudulenta* (Cleve) Hasle. Because of difficulties in distinguishing between the species in the quantitative samples, they are listed as *P. seriata/fraudulenta* in the counting lists. A similar problem was encountered when identifying species of *Alexandrium.* In netsamples two species of *Alexandrium* were identified, *i.e. Alexandrium tamarense* (Lebour) Balech and *Alexandrium ostenfeldii* (Paulsen), Balech & Tangen. According to the results of netsamples, *A. ostenfeldii* and *A. tamarense* are restricted to different periods (Table 1). In the sedimentation chamber, however, it was difficult to distinguish between the two species with certainty. Therefore, *Alexandrium sp.* includes both species in the counting lists (Table 3).

Table 1. *Alexandrium ostenfeldii and A.tamarense*, identified in netsamples at ÖN, AL and FL.

Date	Species	ÖN	AL	FL
09.06	*Alexandrium ostenfeldii*	r	r	c
15.06	*A. oststenfeldii*	r	r	r
22.06	*A. tamarense*	+	+	r
30.06	*A. tamarense*	c	r	r
08.07	*A. tamarense*	r	r	r
14.07	*A. tamarense*	r	r	r
20.07	*A. tamarense*	+	+	+

+=found, r=rare, c=common

3. Results

3.1. Seasonal variations in the physical and chemical environment.

Available information on currents in the study area indicates that the northward flow of the Irminger Current is over the slope and banks off the Northwestern peninsula and that a branch of it rounds the corner of the peninsula (*e.g.* Stefánsson and Ólafsson 1991). The low salinity coastal current is believed to flow into the fjords at the southern side and out along the northen side (Svend-Aage Malmberg pers. comm.)

The seasonal variation in temperature, salinity, nutrients (N, P, Si), and chlorophyll a are shown in Figs. 2, 3 and 4. The main trend in the variations is similar at all locations, but with certain deviations.

3.1.1 Temperature. The temperature by the end of March was around 1 °C and increased slowly to 10 °C in August. After that the temperature decreased to 4-5 °C in November (Figs. 2b, 3b and 4b).

3.1.2 Salinity. Considerable fluctuations occurred in salinity at all locations. The range was 28.4-34.6, 32.4-34.6 and 27.9-34.6 at ÖN, AL, and FL, respectively. The fluctuations are, however, more conspicuous at ÖN and AL than at FL (Figs. 2a, 3a and 4a). Two main freshwater affluxes were indicated at ÖN and FL and three at AL. The timing of floods was at least 14 days earlier at ÖN than at the two other locations.

3.1.3 Nutrients. At AL and FL, high winter values with an average of 13.6 and 14.2 µM nitrate respectively, lasted until April 12, whereas at ÖN the utilization had already begun on March 28. (Figs. 2, 3 and 4). Generally there was a rapid decrease in nutrients during spring. After a minimum during May, a period of low concentration of nitrate and phosphate continued until September when the recycling of nutrients started. Phosphate was never quite exhausted, whereas nitrates were exhausted during July and August, especially at ÖN and AL. The values of silicate concentrations showed aberrant trends as compared to those of phosphate and nitrate. After the minimum in May, there were several considerable increases in silicate values, which mostly coincided with the fresh water affluxes mentioned above (Figs. 2a and c, 3a and c, 4a and c).

3.2 The vegetation at ÖN, AL and FL.

The vegetation in all three localities was similar as was the main trend of changes in species composition with time. However, there was a delay, in the timing of the spring bloom as well as the succession of plant communities at the two exposed stations, AL and FL, as compared to the more sheltered station ÖN. At ÖN a considerable stock of *Thalassiosira spp.* was already establisted by March 28. The number decreased in the following weeks, but the main peak of the spring bloom was on April 30 or two weeks earlier than at AL and FL (Fig. 5). At all stations the characteristic species of the spring maximum were *Thalassiosira gravida* Cleve, *Th. nordenskjöldii* Cleve, *Chaetoceros socialis* Lauder and *Phaeocystis pouchetii* (Hariot) Lagerheim. *P. pouchetii*, however, did not reach very high numbers. The spring maximum was succeeded by a poor vegetation during June, but after that the cell number, especially of diatoms, increased intermittently during the rest of the growth season. Three main peaks were noticable during the period July - September (Fig. 5), and the species which dominated the successive peaks were *Leptocylindrus minimus* Gran, *Skeletonema costata* Cleve, and *P. pseudodelicatissima*, respectively (Figs. 6 and 7). By the end of September the vegetation period was over at AL and FL whereas at ÖN there was yet another, but small, peak in October. During this peak *P. seriata/fraudulenta* outnumbered other algae, but *P. pseudodelicatissima* was also present in considerable number. A number of species, belonging to diverse groups of phytoplankton, contributed for periods of varying duration to the vegetation.

In general, diatoms were a dominating group in the vegetation during the entire period. Representants of other groups never reached as much as 15% of the total number of cells (Figs. 5, 8 and 9).

3.2.1 Chlorophyll a. The seasonal variation of chl a at ÖN, AL and FL is shown in Figs. 2e, 3e and 4e. The changing values correspond only to a certain degree to the changes in the number of cells. There was a restricted spring increase of chl a which coincided with a rise and fall in cellnumbers (Fig. 5) as well as the almost complete utilization of the winter resources of nurtients. After minima, which lasted for varying periods depending on locality, a period of irregularities in chl a concentration followed and lasted until the end of the phytoplankton growing season. The changing values did not match the changes in cellnumbers. This was not unexpected in view of the large size variation of species participating in the plankton from one week to another. However, this difference in the seasonal pattern of cellnumbers and chl a needs a closer study.

3.2.2 Potentially toxic algae. Of species which have been shown to produce the algal toxins DSP, PSP or ASP the following have been found at ÖN, AL and FL.

Dinoflagellates	Toxins
Alexandrium tamarense	PSP
Alexandrium ostenfeldii	PSP
Dinophysis acuminata Claparéde & Lachmann	DSP
Dinophysis acuta Ehrenberg	DSP
Dinophysis norvegica Claparéde & Lachmann	DSP
Dinophysis rotundata Claparéde & Lachmann	DSP?

Diatoms	
Pseudonitzschia pseudodelicatissima	ASP

P. seriata is also a possible producer of ASP since recently ASP has been detected in *P. seriata* kept in culture (G. R. Hasle, pers. comm.).

The three genera in question appear at about the same time in all three localities and their time of proliferation is in the order *Alexandrium spp.*, *Dinophysis spp.* and *Pseudonitzschia pseudodelicatissima.* Furthermore, the cellnumbers of each genus as well as the duration of their contribution to the vegetation, is quite similar in three localities (Figs. 7 and 10). On a species level there were, however, some variations in occurrences at all localities, especially in the case of *Dinophysis*. Of the *Dinophysis* species, *D. acuminata* was most frequent and numerous as shown in Table 2.

Table 2. The occurrence of *Dinophysis* species at ÖN, AL and FL, cells/l.

ÖN.

Date	*D.acuminata*	*D.norvegica*	*D.acuta*	*D.rotundata*	Total
14.07			20		20
21.07	40				40
03.08	60				60
10.08	360	120			480
19.08	180			20	200
24.08	40	20	40	20	120
31.08	380	120			500
08.09	80				80
14.09	80	60			140
21.09	80				80
29.09	120	20			140
07.10	120	20			140
13.10	80				80
19.10	80				80
27.10	260				260
05.11	100				100

AL.	*D.acuminata*	*D.norvegica*	*D.acuta*	*D.rotundata*	Total
08.07	40				40
20.07				20	20
28.07	280	320		20	620
03.08	360	40			400
12.08	280	220		20	520
18.08	180				180
24.08	80				80
30.08	300	40			340
08.09	100			20	120
15.09	140				140
20.09	200	20			220
28.09	380			20	400
07.10	140				140
11.10	80				80
20.10	40				40

28.10	20				20
05.11	20				20

FL.	*D.acuminata*	*D.norvegica*	*D.acuta*	*D.rotundata*	Total
08.07	20				20
20.07	20				20
28.07	20	20			40
03.08	320	40	60		420
12.08	60	280			340
24.08		40			40
30.08	260	20	20	20	320
08.09	20				20
15,09	140				140
20.09	80				80
28.09	80	20			100
07.10	40				40
11.10	40				40

Table 3. The number of *Alexandrium spp.* at ÖN, AL and FL. Cells/l.

Date	ÖN	AL	FL
06.05	20		20
03.06		40	20
09.06	20		140
15.06	120	160	320
22.06	140	460	440
30.06	240	260	
08.07	760	340	500
14.07	40	420	300
21.07	20	140	80
28.07		80	140
03.08		40	40
10.08	40	100	

Table 4. The number of *Pseudonitzschia pseudodelicatissima* at ÖN, AL and FL. Cells/l.

Date	ÖN	AL	FL
08.06		3.061	
22.06	27.551		3.061
30.06	11.224	2.041	
08.07			12.245
20.07	134.693	223.468	123.468

28.07	173.468	313.263	43.877
03.08	268.365	1.255.092	1.320.398
12.08	235.712	792.851	314.283
18.08	5.105.061	6.099.951	4.136.702
24.08	1.453.050	6.333.623	169.386
31.08	16.326	218.366	258.161
08.09	26.530	28.571	
14.09	81.632	386.732	76.530
21.09	83.673	306.120	37.755
29.09	120.407	42.857	64.285
07.10	385.711	12.245	
12.10	292.855	18.367	
20.10	127.550	7.143	6.122
27.10	39.796	6.122	
05.11	7.143		

4. Discussion

Definitions of the limits, at which there is a risk because of species producing the algal toxins PSP, DSP and ASP, differ considerably amongst countries monitoring the potentially toxic algae (van Egmond *et al.* 1992). In this survey, we have used Norwegian and Danish work rules as a frame of reference (Einar Dahl pers. comm). These referent limits are as follows:

Alexandrium spp.	*500 cells/l*
Dinophysis spp.	*300 cells/l*
Pseudonitzschia spp.	*$5x10^5$ cells/l*

During this survey the number of *Alexandrium* spp. exceeded the limit once (Table 3) whereas both *Dinophysis spp.* and *P. pseudodelicatissima* exceeded the limits several times (Tables 2 and 4, Figs. 7 and 10). In the case of *P. pseudodelicatissima* the cellnumbers exceeded the risk referent number many orders of magnitude times during August at all locations.

Species of *Alexandrium* are the first to appear in early June, a small increase is notable during June 15 to July 15 when their number was consistently at 300-500 cells/l at AL and FL. At ÖN the number was lower except on July 8 when 760 cells/l were found. No *Alexandrium* cells were found after August. *Alexandrium spp.* are commonly found in netsamples from our monitoring surveys of the waters around Iceland in May-June and August, mostly in small number. Only a few cases are known where considerable number of *Alexandrium spp.* cells have been observed (max 200.000 cells/l) or indicated by poisoning of shellfish (2 cases, unpublished data). The known cases occurred in the period from late May through June. These occurrences, as well as the slight increase in early summer at ÖN, AL and FL, are in accordance with the most frequent occurrences of PSP poisoning in North European coastal waters (Tangen 1983, Sakshaug 1972, Gaard & Poulsen 1988, Wyatt 1993).

Concurrently with the decrease in the number of *Alexandrium* in the latter half of July, *Dinophysis* appeared and increased in numbers during August (Fig. 10). *Dinophysis spp.* are common in Icelandic waters according to results from netsamples, but are generally in low numbers. However high numbers have been reported, *i.e.* $177x10^3$ cells/l of *D. norvegica* in Hvalfjördur in September 1986 (Thórarinsdóttir 1987). Cases of diarrhea in a group of people who had eaten mussels from a nearby locality occurred in early September that year. In June 1994 DSP was found in horse mussels *(Modiolus modiolus)* in the inner part of Faxaflói. At ÖN, AL and FL, numbers exceeding the alarm limits occurred in August, but the species were present in the vegetation at all stations from late July until October. The highest number noted was 600 cells/l at AL, where numbers exceeding the limits were also most frequently found (Table 2).

P. pseudodelicatissima was found in the phytoplankton during the whole summer and autum period. Usually it counted several hundreds cells pr. liter, the main peak being in the latter half of August (Fig. 7). *P. pseudodelicatissima* is a prominent component of the diatom flora in the Atlantic proper as well as the Atlantic type waters off the south and west coasts of Iceland. It may be the dominating species during the spring bloom in the ocean part of the region and during summer it is an important member of the vegetation within the coastal area. In years when there is a large influx of Atlantic water to the area north of Iceland, it has been found to be the most prominent species of the diatom vegetation during August (Thórdardóttir 1956 and unpublished data).

To our knowledge occurrences of *P. pseudodelicatissima* have never been connected with harmful events in Icelandic waters. The weekly monitoring during 1994 showed that *P. pseudodelicatissima* contributed in considerable number from early July and onwards. The maximum number was found on the same date at all locations. There was a difference, however, with regard to cellnumber. Thus, *P. pseudodelicatissima* was far more abundant at AL than at the two other localities. The reason for this difference between the stations is not known.

A common feature of the phytoplankton at the three locations is the close relationship in the vegetation both with regards to species contribution as well as the sequential apperance of plant communities. The earlier onset of growth as well as a longer vegetation period at ÖN, as compared to AL and FL, may be attributed to the more exposed nature of AL and FL than the ÖN station. Another feature worth mentioning is the dominating role of diatoms, larger species during spring and smaller ones in summer. The nutrient data seem to explain this, since considerable quantities of silicate throughout the growing season would favour the growth of diatoms. Furthermore, the low concentrations of the other nutrients during summer would favour small cells as compared to larger ones. Since the available information is scanty it is not known whether the results reflect the usual progress in the vegetation pattern within the nearshore area of this region.

The similarity of the vegetation is also evident in the seasonal pattern of potentially toxic genera. The genera which are potential producers of the algal toxins PSP, DSP and ASP are all represented in the vegetation at about the same time at ÖN, AL and FL, *Alexandrium* and *Dinophysis* with modest populations whereas *Pseudonitzschia* occurred in large quantities. The three genera contribute in highest numbers one after the other in the same order at all stations.

There were weekly changes in biomass (chl a), cellnumber and in contribution of the different species which the present data do not explain. Additional data, for instance on the possible load of grazing as well as information on stratification versus mixing during the period, might possibly have explained some of these changes.

The main concern of this monitoring of phytoplankton, however, is the participation of potentially toxic algae within the vegetation at the harvesting areas of ocean quahog. As mentioned above, the genera which are known to be the main producers of the algal toxins PSP, DSP and ASP are all represented at the three locations. The recent findings of shellfish poisoning in Iceland show that *A. tamarense* as well as *Dinophysis* species may be toxic, whereas there is no information on possible harmful effects of ASP-producing algae in Icelandic waters. The monthly monitoring of PSP, DSP and ASP in the ocean quahog from the same study area, has showed that the toxins were not present in the shellfish in concentration above the detections limits of the methods used (Guðjón Atli Auðunsson, pers. comm.).

However, the relevant genera contributed to the vegetation during 1994 and therefore the possibility of harmful events exists. The probability of such an event may depend on several factors. Two possibly relevant scenarios will be discussed presently. The first is whether the species in question are autochthonous and, therefore, possibly recurring. The second concerns the specific environmental conditions prevailing in the areas.

The available information on phytoplankton composition in these waters is a meagre basis for evaluating which of the species are autochthonous and which are brought to the areas from outside. Species forming resting stages and occurring in considerable quantities within a locality are likely to recur. Of the potentially toxic species participaiting at ÖN, AL and FL, *A. tamarense* is known to form resting cysts (Dale 1977) but nothing is known of their possible occurrence at ÖN, AL and FL or elsewhere within the Icelandic area.

There was a modest increase in cellnumbers of *Alexandrium spp.* in early summer during a period of 4 weeks. At that time of year we suspect

Alexandrium sp. to be mainly *A. tamarense* (cf Table 1). The similar numbers for such an extended period at all localities may indicate that *A. tamarense* might be an autochthonous species in these waters. The investigations of Paulsen from the beginning of this century (Paulsen 1904) support this assumption. He described a new species, *Gonidoma ostenfeldii*, from Icelandic waters. To him it seemed to be a neritic form distributed from Önundarfjörður along the north and east coasts to Berufjörður (Southeast Iceland). Later, in a posthumous paper (Paulsen 1949), he emended the epithet *Gonidoma* and called the species *Goniaulax ostenfeldii* which he thought had similarities in common with *Goniaulax tamarensis* Lebour. According to Paulsen (1949) the species was distributed all around Iceland and often occurring abundantly. Critical examination of Paulsens findings has suggested that his *Goniaulax ostenfeldii* may have involved three species, *i.e. Gonidoma ostenfeldii* Paulsen, *A. tamarense*, and *A. ostenfeldii* (Gaarder 1954, Balech & Tangen 1990).

With regards to species of *Dinophysis*, we have no evidence whether they may be autochthonous within these waters, although the consistent presence of *D. acuminata* during late summer may indicate this. Recently, resting cysts were reported for the first time in the genus of *Dinophysis* (Moita & Sampayo 1993). The species involved were *D. tripos* and *D. acuta* and formed cysts during and after a bloom. Furthermore a gamete formation in *D. cf acuminata* has also been demonstrated (McLachlan 1993). However, there is little information on the biological cycle of *Dinophysis* since they are difficult to culture and are most often found in modest numbers in nature.

To our knowledge, *Pseudonitzschia* is not known to form resting cysts but we expect it to be recurrent in these waters. The available information shows that it is never absent in the inner coastal waters at the west coast during the summer, although their number may fluctuate between areas and years (Thórdardóttir unpublished data). The number of *P. pseudodelicatissima* cells at ÖN, AL and FL were above $2x10^5$ from July 20 until the end of August and peaked with several million cells/l in late

August (Fig. 9). In the Bay of Fundy, *P. pseudodelicatissima* has been shown to produce the domoic acid, the ASP toxin (Martin *et al.* 1990). Our numbers were considerably higher than those found in the southwestern Bay of Fundy in 1988 and rendered the shellfish poisonous in that area (Martin *et al.* 1990). However, the factors inducing the production of domoic acid are not well understood (Bates *et al.* 1991). In an experiment with a batch culture of *P. pungens f. multiseries* (Hasle) Hasle, Bates *et al.* (1991) found that it was only during the stationary phase that the cells produced domoic acid and for this it was essential that nitrogen sources were available as well as the presence of light. Martin *et al.* (1993) did not find any obvious correlation between *P. pseudodelicatissima* and the nutrient concentrations, when investigating distribution of *P. pseudodelicatissima* and its domoic acid content in southwestern Bay of Fundy. As stated above, the monthly analysis for the detection of domoic acid in the ocean quahog at ÖN, AL and FL did not reveal any presence of the toxin, although *P. pseudodelicatissima* occurred in high numbers during several weeks.

As shown in Fig. 5, there was a considerable increase in cellnumber especially of diatoms, in June and July which may be an indication of improved environmental conditions. However, it is difficult to pinpoint the reason for this improvement from the available data. It has been shown (Egge and Aksnes 1992) that diatoms are more successful in competiton with other algal groups, when nutrients are available and silicate above 2 μM. According to Egge (1993) diatoms do not seem to be able to achieve dominance when phosphate is deficient, although nitrate and silicate are in excess. Concurrent with the freshwater affluxes during early summer at ÖN, AL and FL, there was an increase in the silicate concentration and during the rest of the vegetation period the silicate was on the average above 2 μM except, at AL where it was 1.92 μM. Phosphate was never deficient whereas the nitrate concentration became very low at ÖN and AL during July and August. Nitrate was the only form of nitrogen measured but other forms of nitrogen were probably present, since high cellnumbers occurred from June-July to September. Restoration of nutrients from time to time by mixing is also probable as shown by the fluctations in some of the environmental factors (Fig. 2, 3 and 4). Anthropogenic loading on nutrient conditions is unlikely since the surrounding are very sparsely populated.

The possible improvement in environmental conditions mentioned above did not lead to any proliferation of *Alexandrium spp.* which were consistently at the level of 300-500 cells/l at that time. The increase in the number of *Dinophysis* spp. was also modest at the time when *P. pseudodelicatissima* was found in several millions cells/l. Thus, the availabe information indicates that the competitive ability of diatoms may have hampered further proliferation of *Alexandrium* and *Dinophysis* (Egge and Aksnes 1992).

The noticable annual fluctuations in hydrographic features in the study areas may alter the conditions for growth of phytoplankton between years (Thórdardóttir 1977, 1984). Accordingly, the specific nutrient conditions which are considered to have hampered the proliferation of dinoflagellates during the summer of 1994 may not recur each year. In this connection it is worth mentioning that the different timing of fresh water run off from land in warm and cold years may result in alteration of vegetation pattern during the summer.

5. Conclusions

The results of this study revealed the presence of algae having the potentiality for producing the algal toxins PSP, DSP and ASP at planned harvesting areas of ocean quahog off the northwest coast of Iceland. However their presence did not make ocean quahog poisonous during 1994. Because the potentially poisonous algal species were found during a period of several weeks, and are possibly recurrent within these waters, it is strongly recommended that the toxic species be monitored in the harvesting areas. Alternatively the toxins should be monitored in each shipment of the ocean quahog. The latter would be the most reliable way of protecting the consumers.

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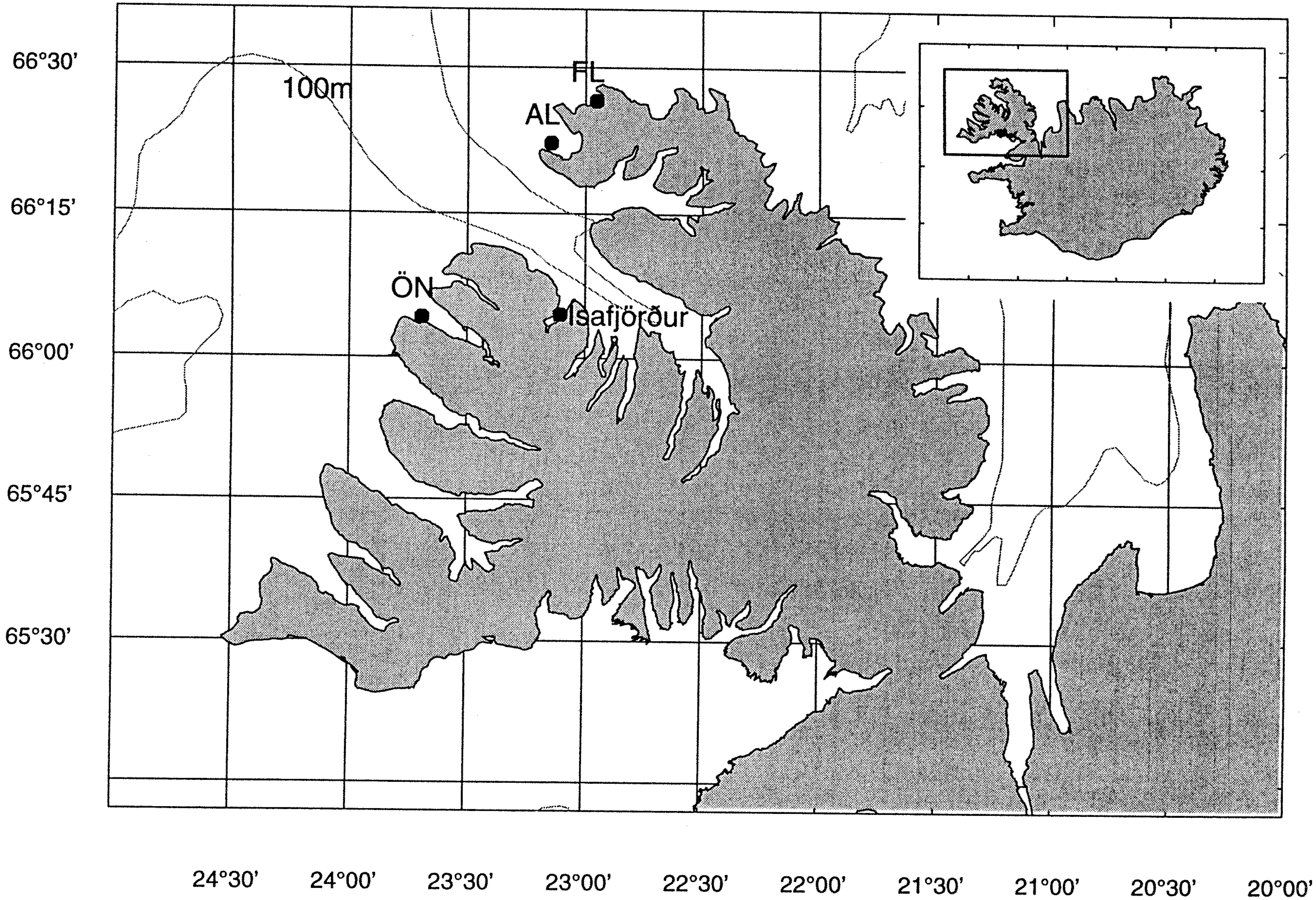

Fig. 1. Location of sampling stations northwest of Iceland; Önundarfjörður (ÖN), Aðalvík (AL) and Fljótavík (FL).

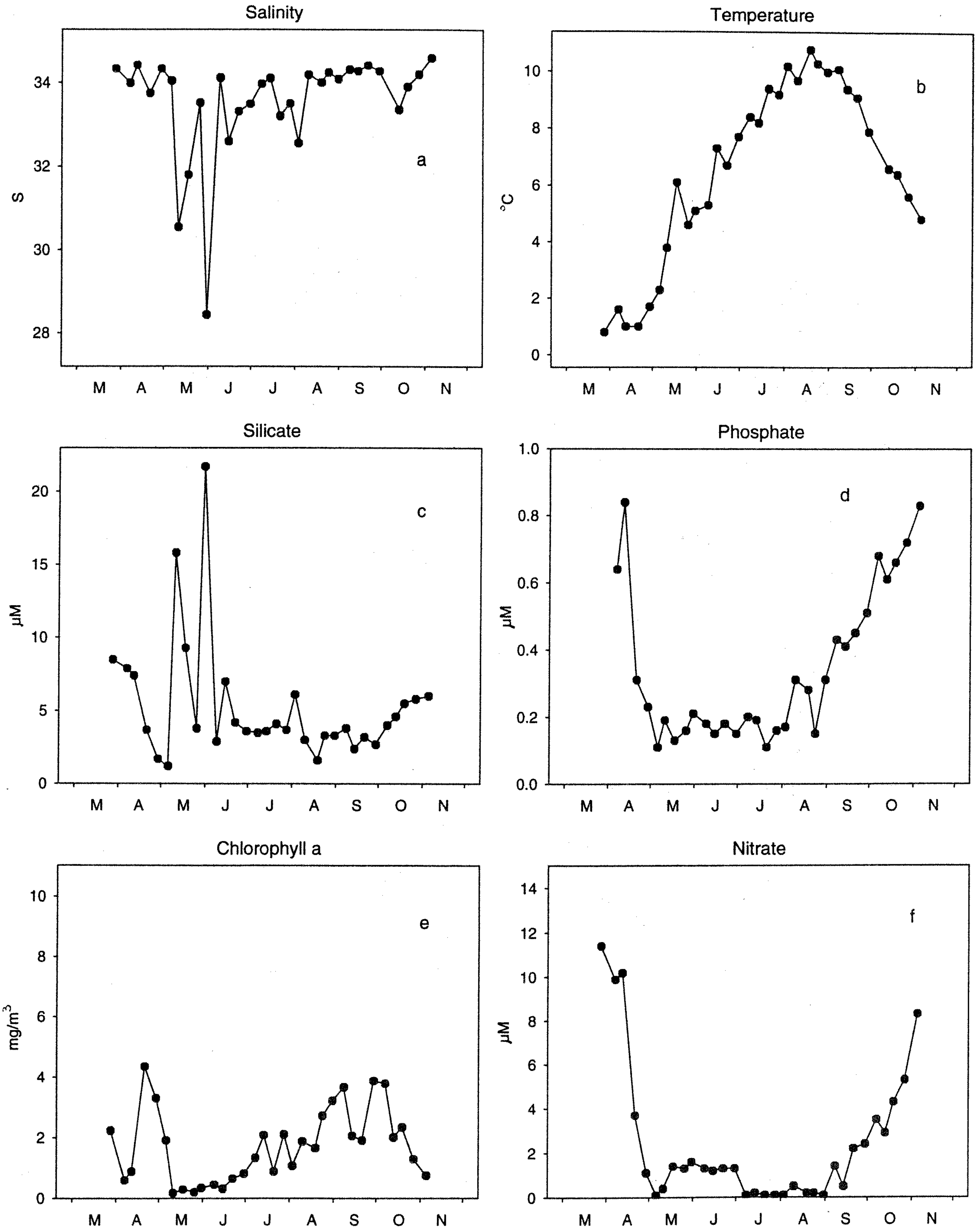

Fig. 2. Seasonal variations in salinity (a), temperature (b), silicate (c), phosphate (d), chlorophyll a (e) and nitrate (f) at the station in Önundarfjörður (ÖN).

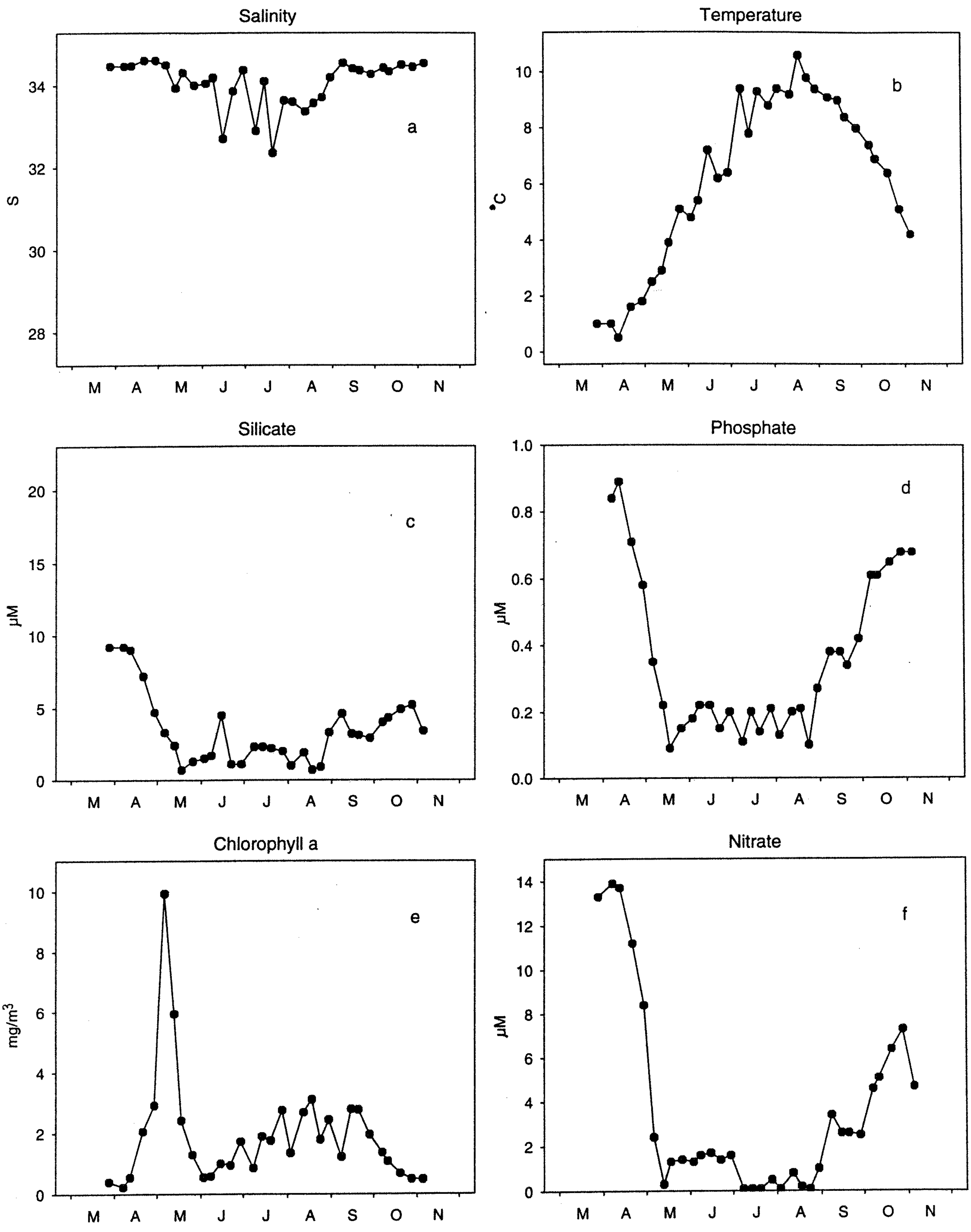

Fig. 3. Seasonal variations in salinity (a), temperature (b), silicate (c), phoshpate (d), chlorophyll a (e) and nitrate (f) at the station in Aðalvík (AL).

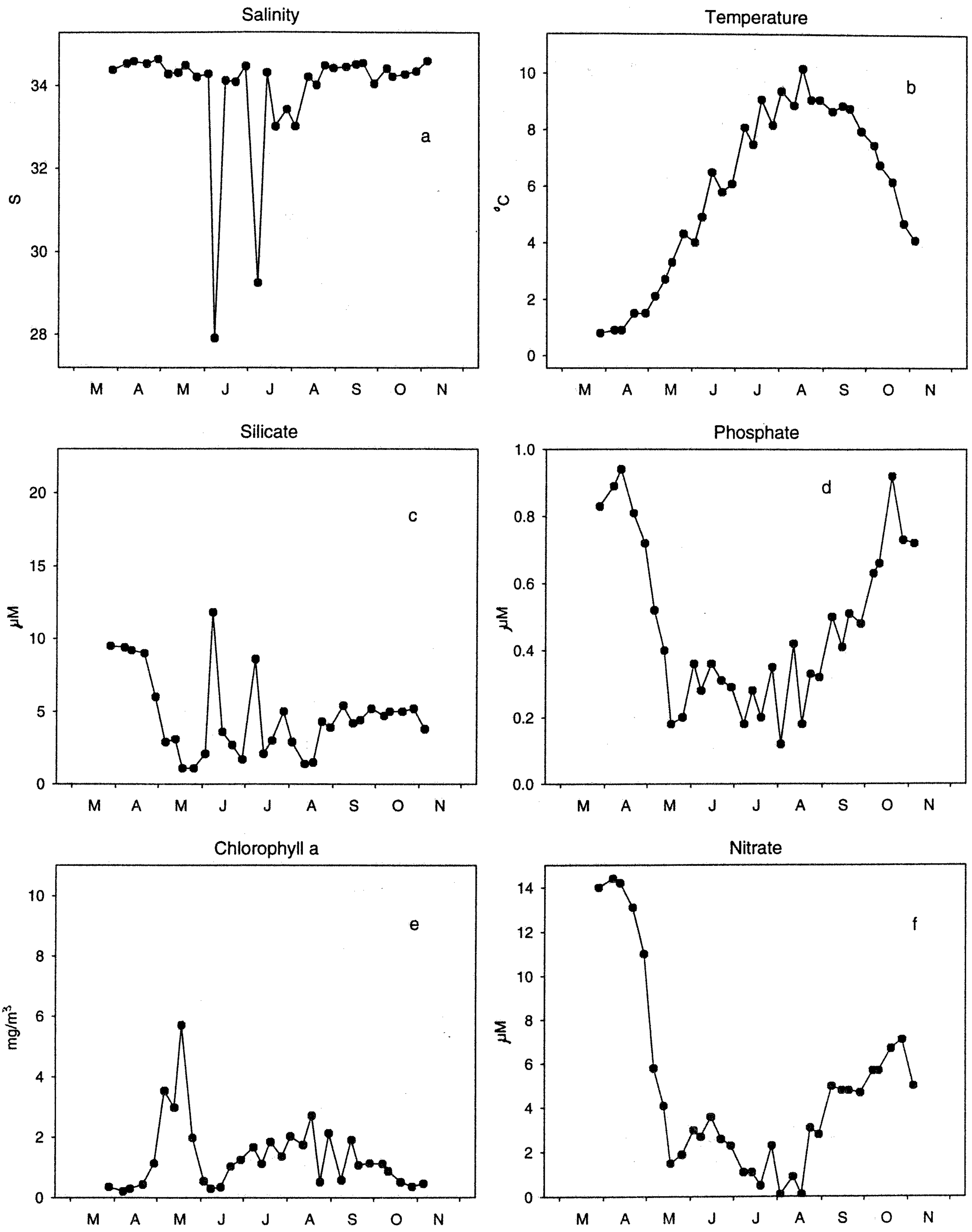

Fig. 4. Seasonal variations in salinity (a), temperature (b), silicate (c), phosphate (d), chlorophyll a (e) and nitrate (f) at the station in Fljótavík (FL).

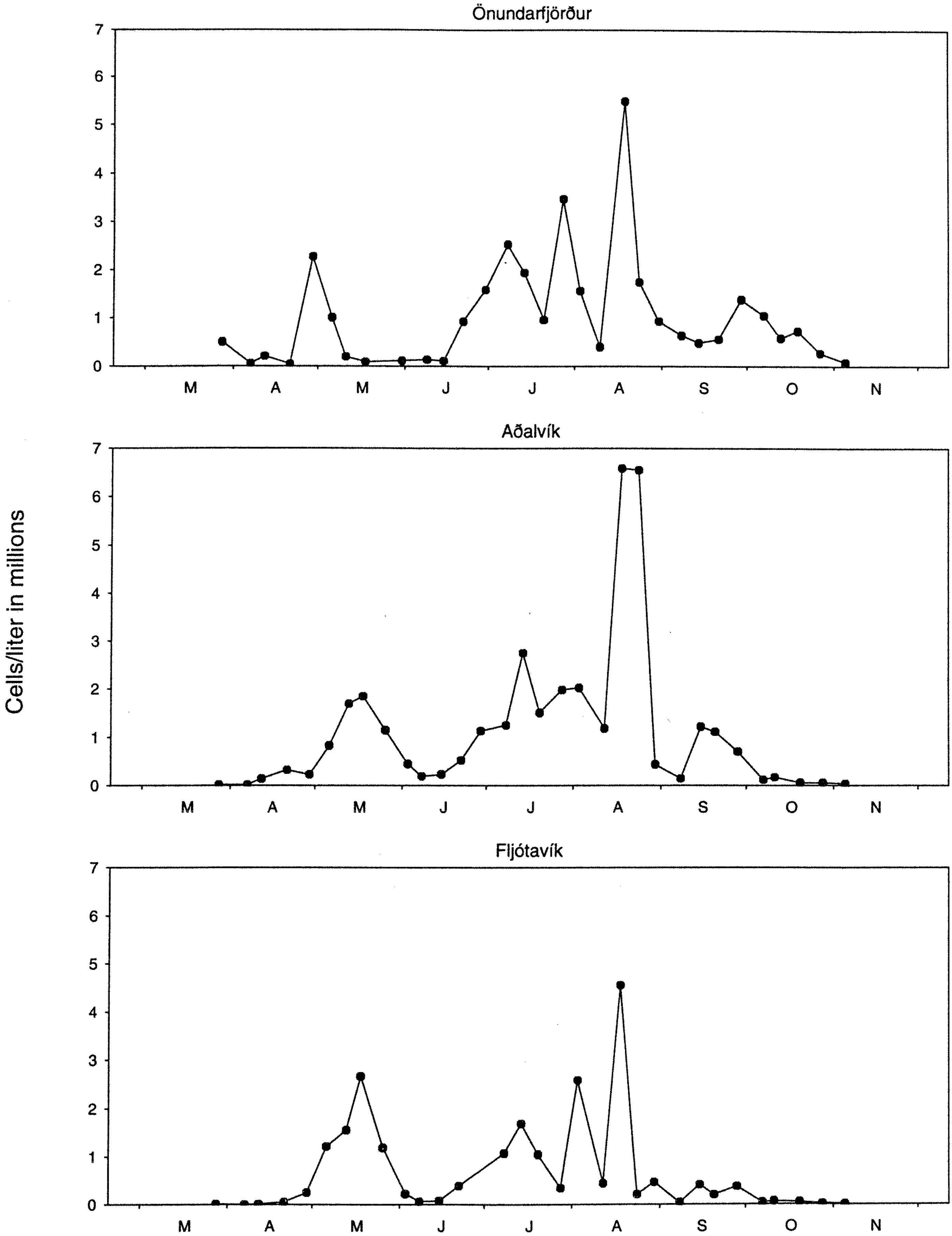

Fig. 5. Seasonal variations in total number of phytoplankton cells at the three sampling stations, Önundarfjörður (ÖN), Aðalvík (AL) and Fljótavík (FL).

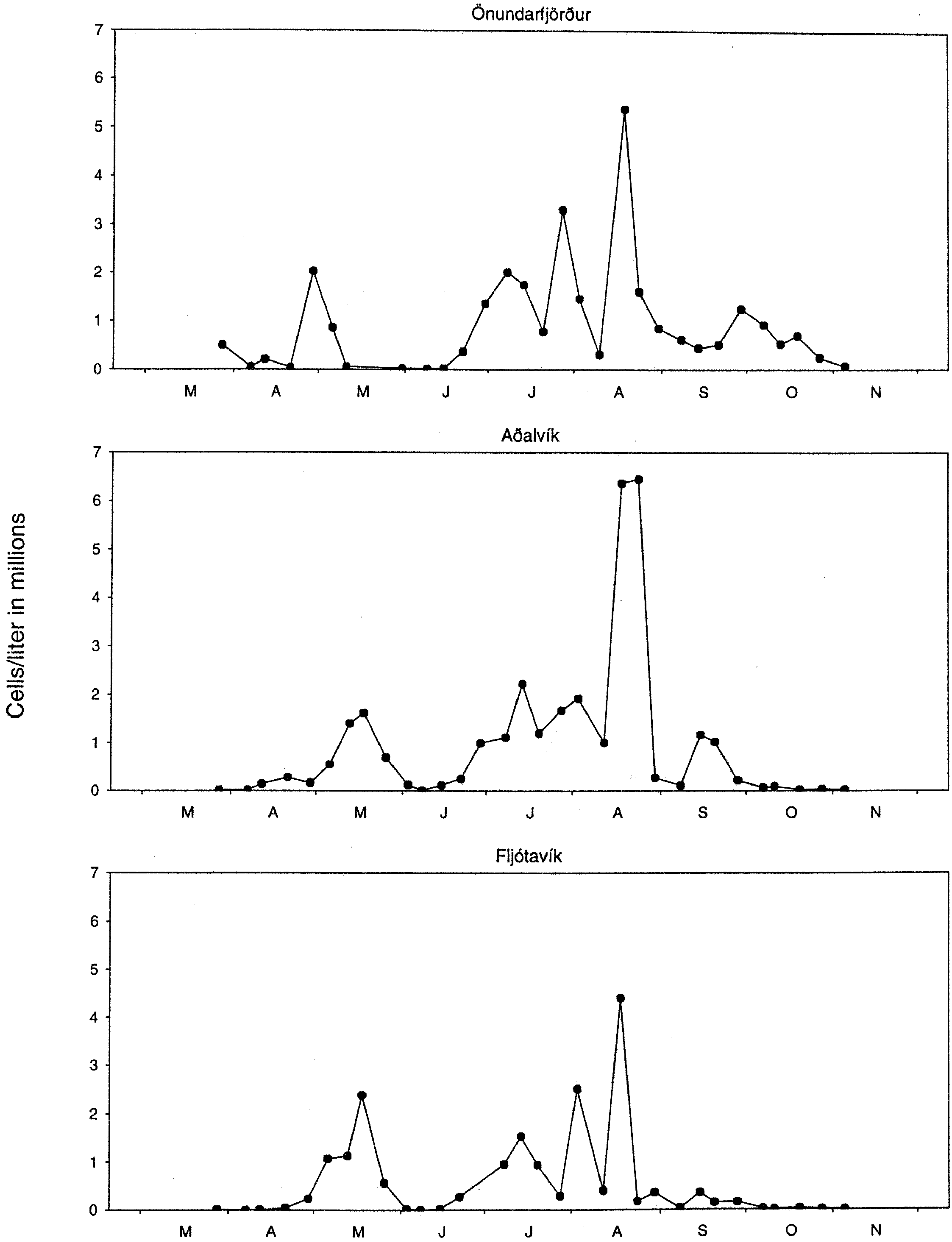

Fig. 6. Seasonal variations in number of diatom cells at the three sampling stations, Önundarfjörður (ÖN), Aðalvík (AL) and Fljótavík (FL).

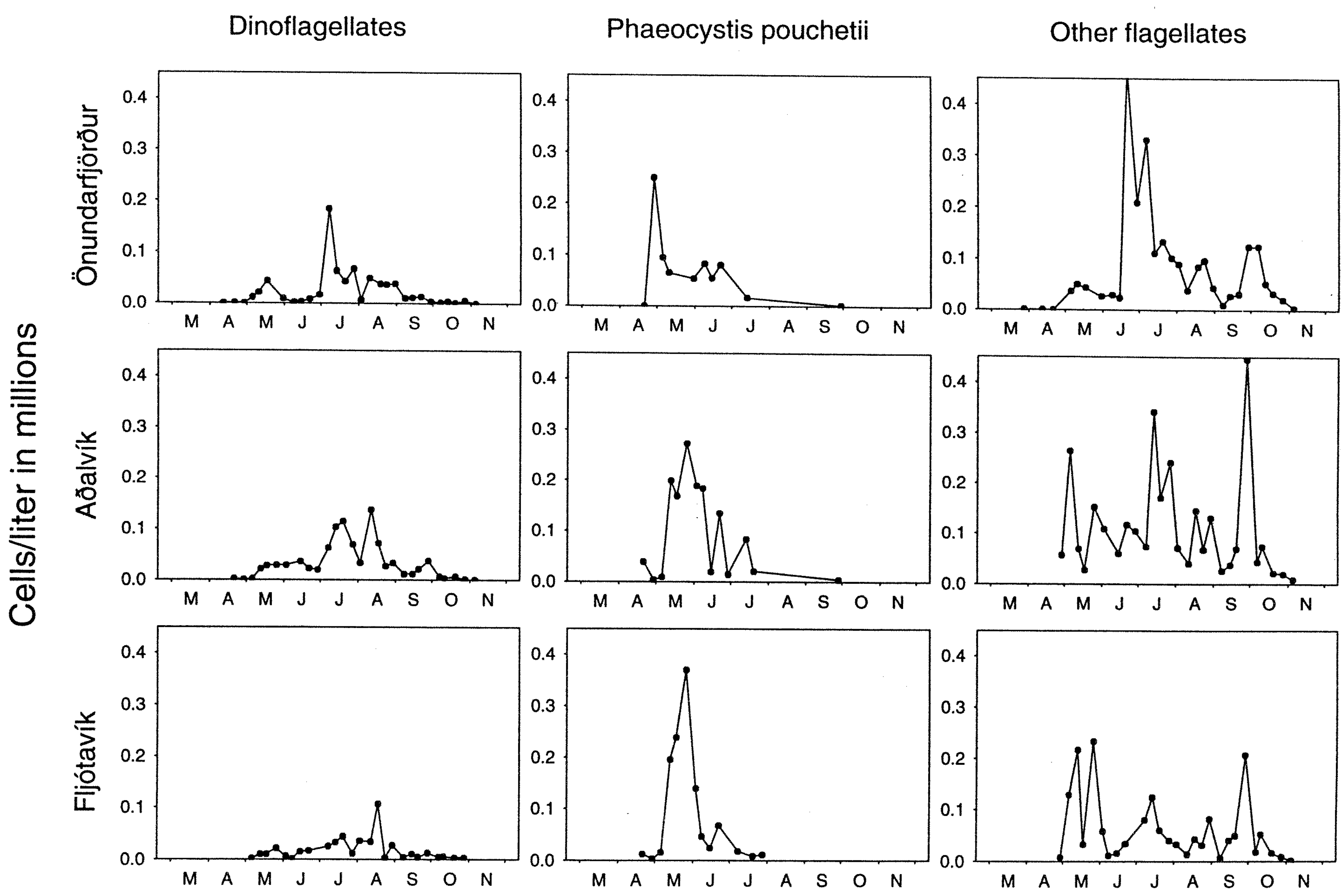

Fig. 7. Seasonal variations in number of dinoflagellate cells, *Phaeocystis pouchetii* and other flagellates than *P. pouchetii* at the three sampling stations, Önundarfjörður (ÖN), Aðalvík (AL) and Fljótavík (FL).

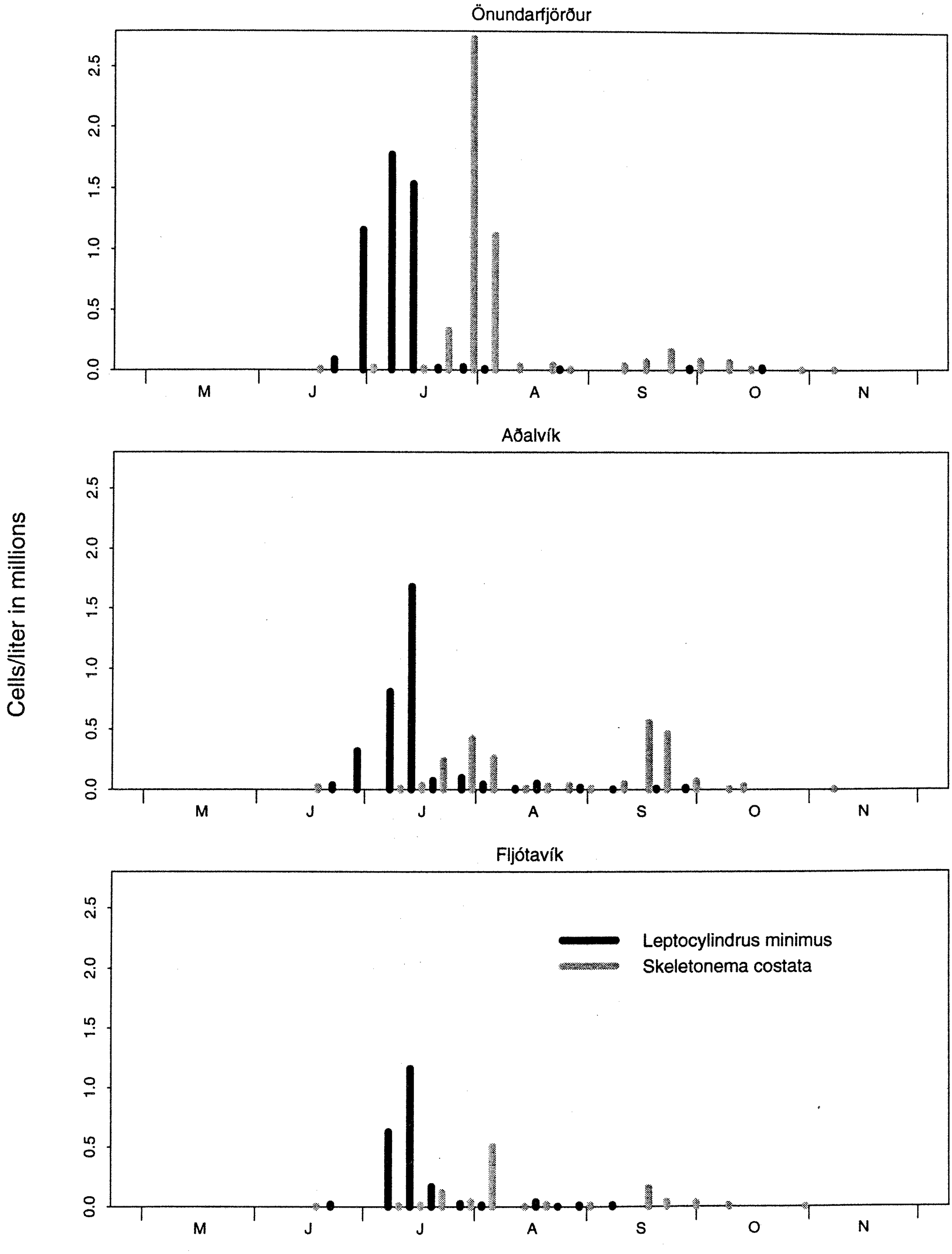

Fig. 8. Seasonal variations in cellnumber of *Leptocylindrus minimus*, dark bars and *Skeletonema costatum*, light bars at the three sampling stations, Önundarfjörður (ÖN), Aðalvík (AL) and Fljótavík (FL).

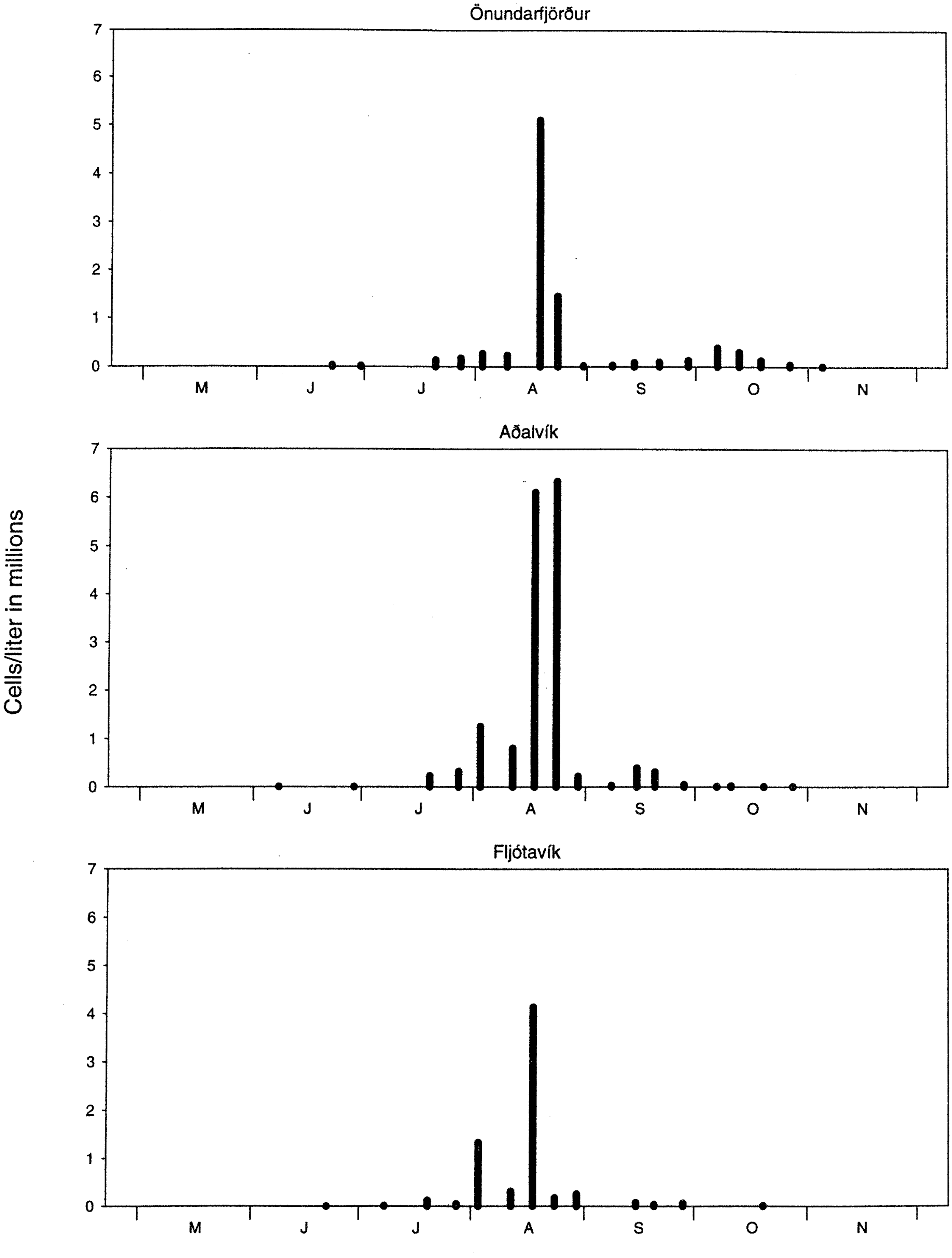

Fig. 9. Seasonal variations in cellnumber of *Pseudonitzschia pseudodelicatissima* at the three sampling stations, Önundarfjörður (ÖN), Aðalvík (AL) and Fljótavík (FL).

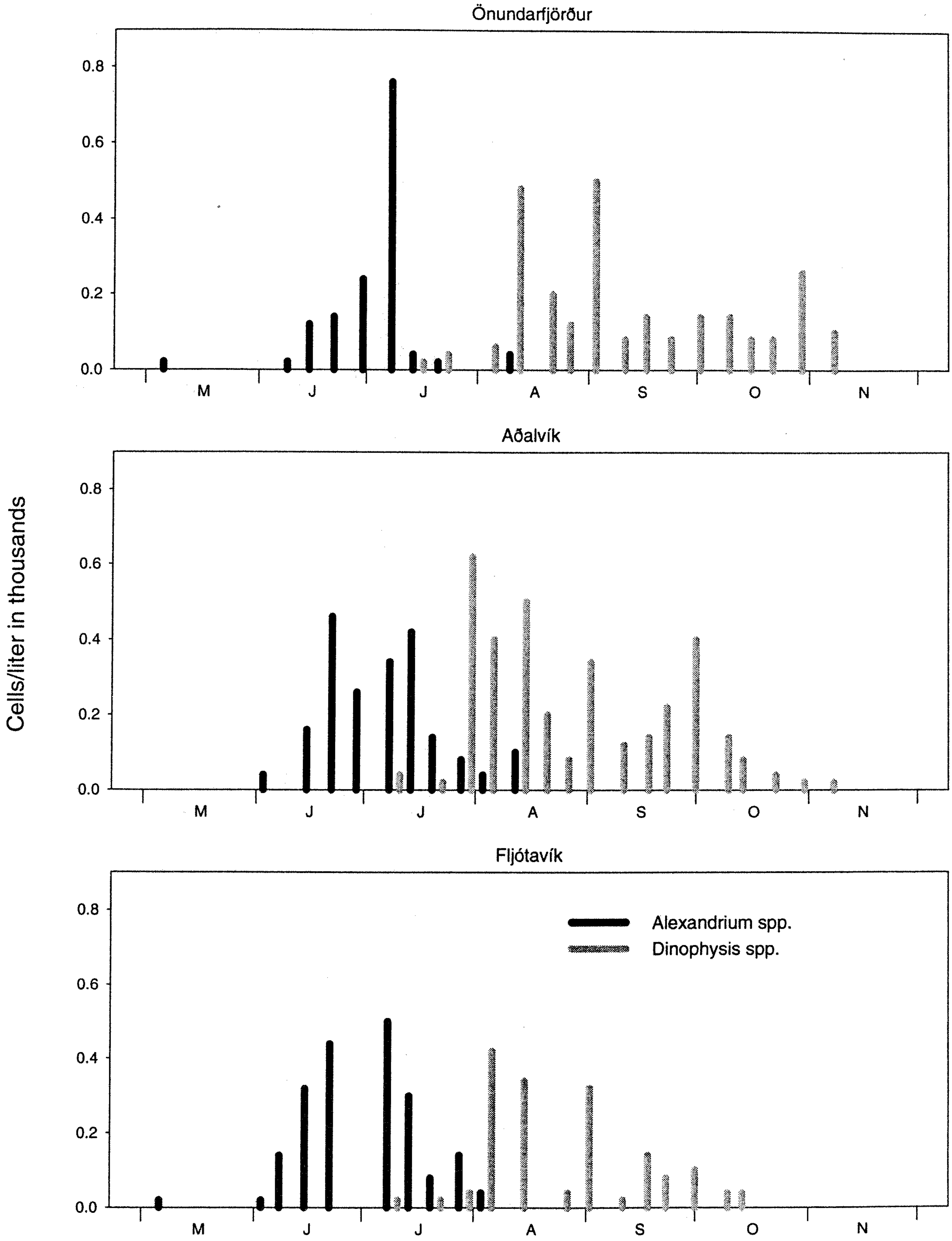

Fig. 10. Seasonal variations in cellnumber of *Alexandrium spp*, dark bars and *Dinophysis spp.*, light bars at the three sampling stations, Önundarfjörður (ÖN), Aðalvík (AL) and Fljótavík (FL).

Fjölritunarstofa
Daníels Halldórssonar