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SEASONAL VARIATIONS IN THE PLANKTON COMMUNITY IN EYJAFJÖRÐUR, NORTH ICELAND.

by

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ABSTRACT

Seasonal changes in the plankton were monitored at one station from May 1992 to August 1993 in Eyjafjörður, North Iceland. This is a first report on the plankton community as part of a more extensive interdisciplinary study of the ecosystem of the fjord. Eyjafjörður is like most Icelandic fjords wide and open to the adjacent coastal water, with salinity generally above 34, except in the surface layer during spring and summer. The temperature range is between 0 - 10°C.

Phosphate and nitrate showed typical concentration development from temperate coastal waters with high winter values, decreasing values in spring followed by low values through summer. However, silicate concentration peaked in summer as a result of river run off. The oxygen measurements showed that the water coloumn was aerobic with oxygen saturation above 70%.

Dominating phytoplankton through winter were dinoflagellates, succeeded by a diatom dominating community from March to October with exeption of periodic *Phaeocystis pouchetii* blooms in spring. The phytoplankton biomass measured as chlorophyll *a* showed typical low winter values, increased in March with a maximum in April followed by relatively low summer values. A second biomass peak occurred in September.

A total of 48 species or taxonomic groups were found, but only three copepod species (*Oithona* spp., *Acartia* spp., *Calanus finmarchicus*) together with euphausiids and the cirriped *Verruca stroemia* usually made up 80-90% of the zooplankton population. The zooplankton population showed marked seasonal fluctuations in densities with maximum numbers (> 900,000 ind./100m^3) appearing in autumn. A minor peak in the abundance occurred in spring. These peaks mainly reflect the seasonal reproductive cycle of the more important taxa.

INTRODUCTION

An interdisciplinary study was initiated in Eyjafjörður, North Iceland, in April 1992. Data was collected in 15 cruises on approximately monthly intervals until mid August 1993. The main purpose of the project is to describe and obtain an understanding of the ecology in the fjord. Eyjafjörður is like most Icelandic fjords wide and open to the adjacent coastal water. A broader introduction to the project and the seasonal changes in the physical environment are given byJÓNSSON & GUDMUNDSSON (1994). The salinity was generally above 34 and the temperature range was between 0 - 10°C. The stability of the water coloumn was mainly determined by the change in salinity following variations in river run off.

The objective of this presentation is to give an overview of the plankton community of Eyjafjörður. This includes a description of the seasonal changes in zooplankton abundance, phytoplankton standing crop and the PvsI relationship together with available nutrient concentration and oxygen. Results are based on data from a single station in the inner part of the fjord.

MATERIAL AND METHODS

A description of the topography of the fjord and of the physical environment (hydrography, tides/currents, freshwater runoff, winds, air temperature, light intensity) is given by JÓNSSON & GUDMUNDSSON (1994). Thus, only a short summary will be given here. Eyjafjörður is an approximately 60km long fjord in central north of Iceland (Fig.1). The depth of the fjord gradually deepens to the north from 40m at the innermost station to about 200m at the mouth. The inflow of adjacent water is predominantly on the west side of the fjord and outflow on the east side. The sampling station (65°49'4N,18°08'0W) is located in the inner part of the fjord where the depth is about 90m. The bottom at the sampling station is flat, consisting of fine mud. Samples were collected on 15 cruises from 1. May 1992 to 18. August 1993. Bucket samples were taken weekly from a ferry to increase the sampling frequency during the phytoplankton growth season.

Hydrography data was sampled with a CTD (Seacat from Seabird Electronics) lowered at $1ms^{-1}$. A fluorometer (Sea Tech Instruments) was connected to the CTD for measurement of chlorophyll fluorescence. Sampling interval was 0.5s and data was averaged into 1m depth bins (cf.JÓNSSON & GUDMUNDSSON 1994).

For measurement of available nutrients and oxygen content, water samples were taken at 10 stations in each cruise. The samples for nutrients were filtered and deep frozen for transportation and storage until analysed according to standard techniques (GRASSHOFF *et al.* 1983), nitrate and silicate were analysed in an auto-analyser and phosphate in a spectrophotometer. Samples for determination of oxygen content were brought ashore and titrated according to standard Winkler method as soon as possible.

Light at the surface were recorded continuously during the investigation period at Hjalteyri (Fig. 1). The light was recorded as quantum irradiance (PAR) with a cosinus corrected sensor (LI-COR 190SA). The extinction coefficient of the euphotic zone were calculated from readings of the Secchi depth at the time of water sampling. In this paper, measurements of chlorophyll *a* on filtered samples are presented

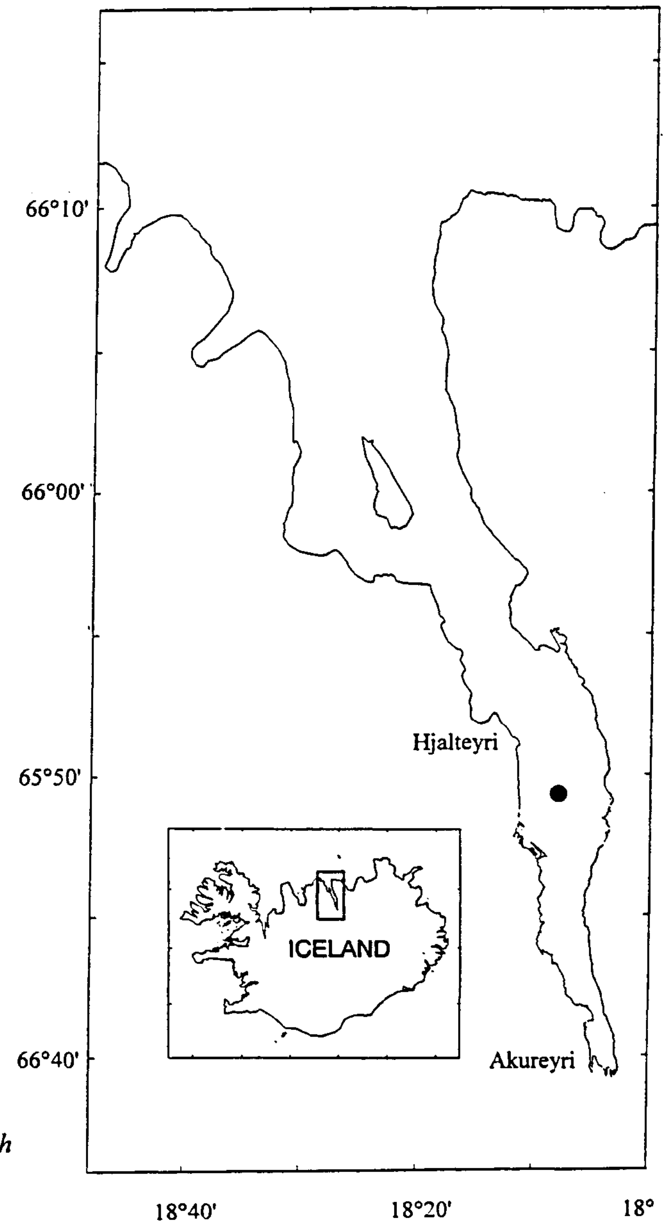

Fig. 1: Map of Eyjafjörður with sampling station marked.

as phytoplankton biomass. The chlorophyll*a* measurements were made in accordance with the standard trichromatic method (ANON. 1966) filtering approximately one liter sea water per sample.

For later calculations of the primary production, experiments were performed to evaluate the PvsI relationship at selected stations. The samples were illuminated for four hours in an incubator with white fluorescent tubes (Philips TLF 20W/33). A more detailed description of the procedure is given in THÓRDARDÓTTIR *et al.* (1991). Preliminary results calculated according to PLATT *et al.* (1980) are given. Water samples for counting and net samples for identification were preserved in a 4% neutralised formaldehyde sea water solution.

Zooplankton samples were collected with a WP-2 net of 0.57m mouth diameter ($0.25m^2$) and fitted with a 200µm mesh net (ANON. 1968). The net was hauled vertically at $1ms^{-1}$, usually from 3m above the bottom (90m) to the surface giving a total volume of filtered sea water of approximately $21m^3$. The material was preserved in a 4% neutralised formaldehyde sea water solution. The overall taxonomic

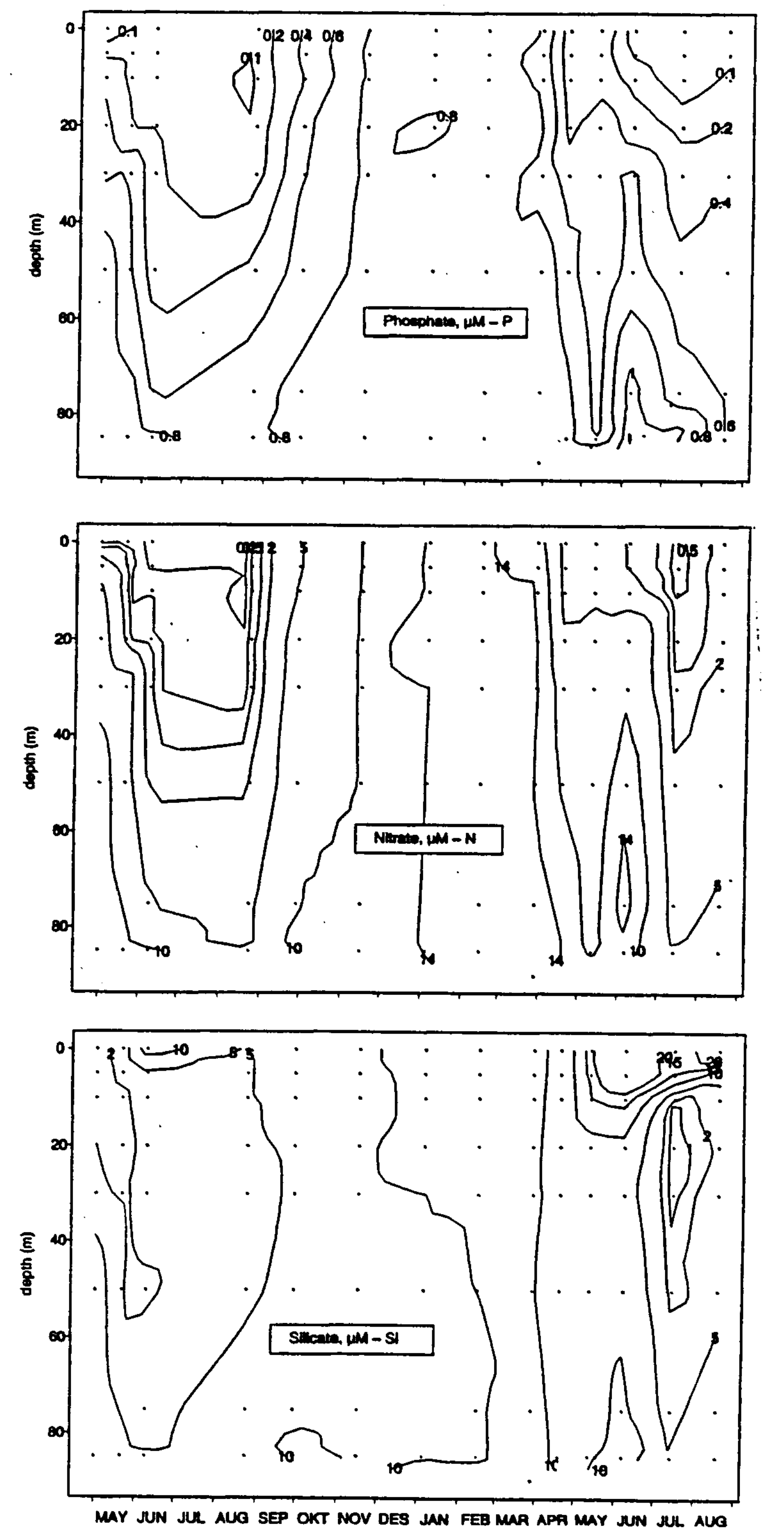

Fig. 2: Seasonal variations in phosphate, nitrate and silicate at station 10, Eyjafjörður, May 1992 to August 1993

composition of the zooplankton community was established by enumerating all zooplankton to lowest possible taxa following the procedure of ASTTHORSSON & GISLASON (1992) with the exception that when necessary the rest of the material was sub sampled by using Lea's whirling vessel (WIBORG1951) before identification.

RESULTS AND DISCUSSION

Nutrients

The nutrients, phosphate, nitrate and silicate, are presented in Figure 2. The concentration of nitrate and phosphate show a marked decrease following the spring bloom in both 1992 and 1993. Phosphate and nitrate values were quite low in the stratified surface layer during the summer 1992. In the post bloom situation in 1993, phosphate is the most likely nutrient to limit the phytoplankton growth in the surface layer. The silicate concentration was, on the contrary, never critical to the phytoplankton growth. The lowest values, found at the end of blooming situations and in late summer to early winter, were still high. Obviously the runoff of silicate from land is more than counteracting the utilization by the phytoplankton. There were no apparent burst of water inflow with consequent renewal of nutrients in the euphotic zone during the growth season.

Oxygen.

The results on the oxygen content (Fig. 3) show quite high oxygen saturation during the whole investigation period. The highest values follow the spring blooms each year but the lowest values are found near the bottom after a bloom culminated. Generally the fjord seems to be well aerated. However, the lowered values following the heavy blooms may indicate sedimentation and subsequent increase in bacterial activity on the decaying biomass.

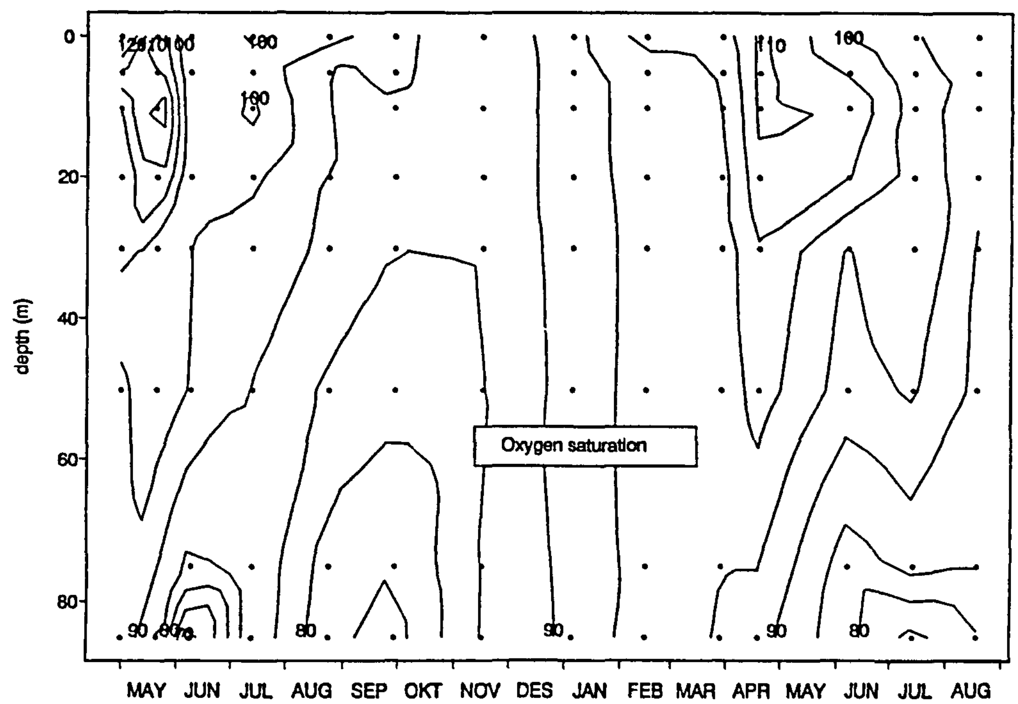

Fig. 3: Seasonal changes in oxygen saturation at station 10, Eyjafjörður, May 1992 to August 1993.

Table 1: Dominant phytoplankton species recorded from net samples at station 10, Eyjafjörður, May 1992 to August 1993.

	1 MAY	21 MAY	9 JUN	13 JUL	28 AUG	29 SEP	16 NOV	5 JAN	15 FEB	29 MAR	19 APR	12 MAY	7 JUN	14 JUL	18 AUG
DIATOMS:															
Chaetoceros decipiens														c	
Chaetoceros furcellatus	r	c+			r										
Chaetoceros laciniosus	+	++										+	c	+	
Chaetoceros simplex				c	+							+			
Chaetoceros socialis										cc	c	r			
Chaetoceros subsecundus	r	r	r									++	cc	++	
Leptocylindrus danicus		r		r+									+	r	
Pseudonitzschia closterium	+	+	+	c	+	++	++		r					+	cc
Pseudonitzschia granii		c													
Pseudonitzschia grunowii		+								c	c				
Pseudonitzschia delicatissima				cc		++					+				
Pseudonitzschia seriata	+	r	+	+			+						r	c	
Rhizosolenia hebetata			r									r	r	c	+
Skeletonema costata	+				++	c	++		+	c	c	r+		+	cc+
Thalassiosira auguste-lineata	r	++				+						r			
Thalassiosira gravida	cc	c							+		r+	r	+		
Thalassiosira nordenskioldii	cc	r		+						r	c	++			
DINOFLAGELLATS:															
Alexandrium cf. *tamarense*	+	+	r+	++	++							+	+		++
Ceratium longipes					r		r								+
Dinophysis acuminata			+		r	r+	r+	+	r			+			
Dinophysis norvegica					r	r+	r+	+	r						
Gonyaulax spp.			r												r
Gymnodiniacea spp.		r	r+	+		++							+		+
Ensiculifera/Scrippsiella		+	c	r+	c	r			+			+	c		r+
Protoperidinium brevipes		+	r+		r							+	r	r	r
Protoperidinium ovatum		++	r+	r	r		r	+	+				+		r
Protoperidinium pellucidum	+	+			++		r		+			+	+	r	r
Protoperidinium spp.			r				r		r				r	r	r
OTHERS:															
Phaeocystis pouchetii	++	ccc	r						+		ccc	cd	++	r	
Dinobryon spp.			++	r+	r+	r+							++		

+: very rare; r: low numbers; c-ccc: common, 50% -100% of total abundance

Dominating phytoplankton species.

In order to acquire a general picture of the phytoplankton succession in Eyjafjörður net samples were studied (Table 1). A total of 69 phytoplankton species and genera were recorded, the table and the following text is constricted to the most prominent. In early May 1992*Phaeocystis pouchetii* was the dominant species in a otherwise highly diverse sample. *Pseudonitzschia granii* which frequently co-exists with *P. pouchetii* was also present. The diatoms generally dominated the phytoplankton from March to October. *Chaetoceros* spp. and *Thalassiosira* spp. were the most prominent in spring, but during summer *Pseudonitzschia* species of some different genera were numerous. Dinoflagellates dominated the phytoplankton during winter, but are more diverse and of higher abundance in summer. The phytoplankton succession in 1993 resembled the pattern of the foregoing year. Diatoms became dominant in late March. *Skeletonema costata* were more prominent than in 1992 and had a second bloom in late August 1993.

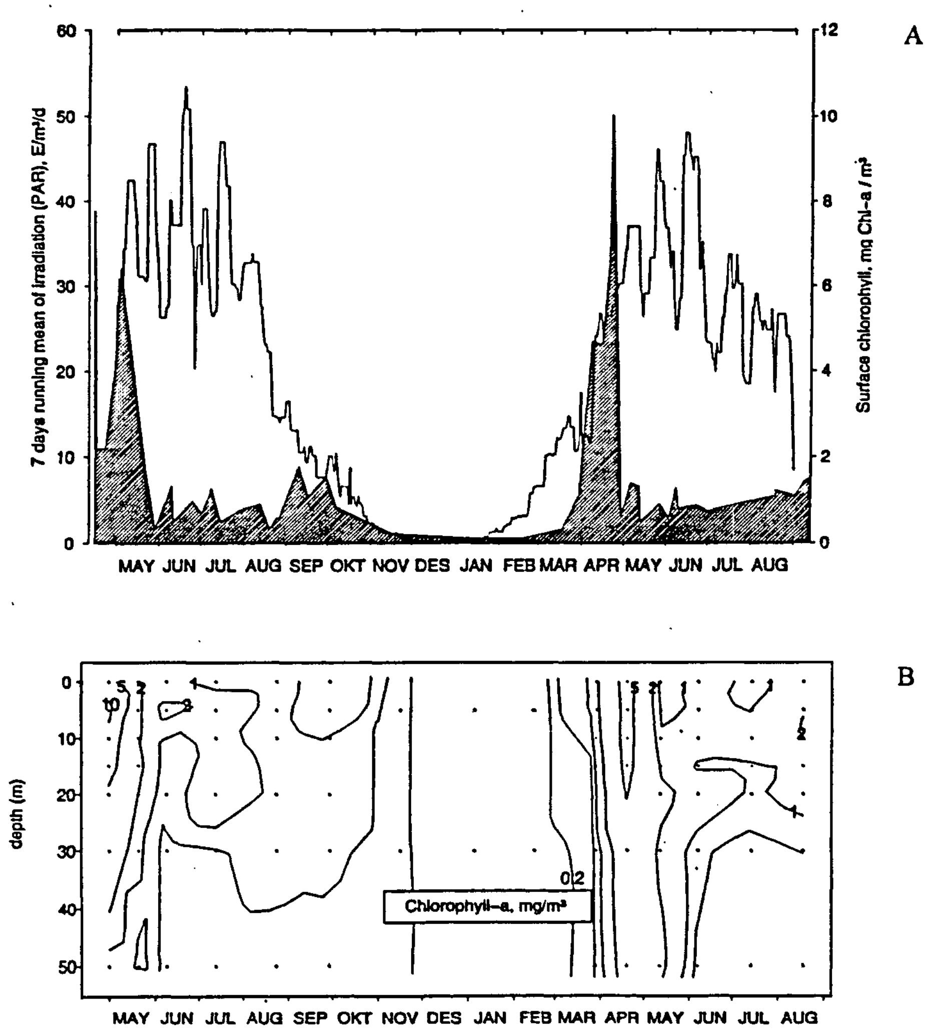

Fig. 4: Seasonal changes in A: *surface irradiation and surface chlorophyll* a *(shaded) based on weekly ferry samples and* B: *chlorophyll* a *isoplets, from station 10, Eyjafjörður.*

Phytoplankton standing crop

The phytoplankton growth cycle (Fig. 4; A & B) show typical development for temperate coastal waters with defined spring bloom maximum and smaller increase in the autumn. According to ERGA (1989) surface irradiation of approximately 10 $Em^{-2}d^{-1}$ for a week should be sufficient to initiate the spring bloom in a fjord. This implies that the spring bloom in Eyjafjörður could start in late March (Fig. 4A). Chlorophyll *a* measurements showed increasing values in mid March, but in spite of improving illumination the phytoplankton did not form a bloom until April. The bloom apparently coincides with the stabilization of the surface layer (see JÓNSSON & GUDMUNDSSON 1994). As the stratification is mostly determined by the lowering of the salinity, i.e. the runoff water, it makes the flooding from land a important factor for the timing of the spring bloom. Autumn peaks were registered in mid September both years and the growing season seems to end in October.

Chlorophyll *a* shows a distinctive peak in April/May, followed by relative low values mostly below 1 mg chl*a*·m^{-3} (Fig. 4B). The low values during the summer months are probably due to the low concentration of available phosphate and nitrate at that time and possible effects of grazing by zooplankton which had increased numbers at that time.

Measurement of phytoplankton productivity

Productivity experiments, PvsI relationship, were performed at selected stations in order to facilitate calculations of primary production. Preliminary results of calculated PvsI variables are given in Table 2. The mean P^B_{max} (N=10) at station 10 were 3.5 mgC m^{-3}(mg chl*a*·$m^{-3})^{-1}h^{-1}$. The α, reflecting the assimilation efficiency of photosynthesis at subsaturation light intensities had a mean value of 0.06 mgC (mg chl$a^{-1}h^{-1}$)(μE $m^{-2}s^{-1})^{-1}$. The saturation light intensity of photosynthesis was in the range 40-80 $\mu Em^{-2}s^{-1}$ and the calculated mean of the 10 PvsI experiments was 58 $\mu Em^{-2}s^{-1}$. The mean of optical light intensity

Table 2: Parameters derived from photosynthetic rate versus light relationships and Secchi depths (D_s).

Cruise no.	P^B_{max}	α	Iopt	D_s (m)
1				5
2				9
3	3.8	0.052	195	11
4	2.8	0.06	120	7
5	3.4	0.048	124	11
6	2.6	0.066	107	14
7				15
8				11
9				14
10	4.9	0.094	170	11
11	3.5	0.054	277	4.5
12	6.1	0.076	218	4.5
13	2.2	0.033	184	5
14	2.9	0.045	234	5
15	2.6	0.05	174	6
Average	3.5	0.06	180	
Standard deviation	1.2	0.02	54	
Counts	10	10	10	

for photosynthesis for the same experiments was 180 $\mu Em^{-2}s^{-1}$. These numbers resembles earlier reported values from Icelandic waters (THÓRDARDÓTTIR *et al.* 1991). Given a similarity in efficiency of photosynthesis, and that the light regime does not differ considerably, one can by comparing the biomass at different localities make a rough guess of whether the production is higher or lower. Thus it appears that the primary production in Eyjafjörður was considerably lower than THÓRDARDÓTTIR & STEFÁNSSON (1977) found for Faxaflói, a bay in south west Iceland.

Zooplankton composition and population density

During the investigations on the zooplankton of Eyjafjörður, 48 species and taxonomic groups were recorded (Table 3). The copepods *Oithona* spp., *Acartia* spp. and *Calanus finmarchicus* together with the cirriped *Verruca stroemia* and euphausiids usually comprised 80-90% of the total zooplankton (Fig. 5). The small copepods *Acartia* spp. and *Oithona* spp. totally dominated the winter plankton by numbers.

The zooplankton population showed marked seasonal fluctuations with maximum numbers appearing in autumn (Fig. 6). Two peaks occurred each year in the zooplankton population. In 1992 a minor

Table 3: Species or taxa identified at station 10 from Eyjafjörður, May 1992 - August 1993.

Coelenterata	Cirripedia
Aurelia aurita	*Balanus balanoides*
Unidentified	*Verruca stroemia*
Ctenophora	Amphipoda
Pleurobrachia pileus	*Parathemisto abyssorum*
Bolinopsis infundibulum	Unidentified
Beroë cucumis	Euphausiacea
Annelida	*Thysanoessa inermis*
Unidentified	*Thysanoessa raschi*
Bivalvia	Decapoda
Unidentified	*Ealus pusiolus*
Gastropoda	*Spirontocaris* sp.
Unidentified	*Pandalus borealis*
Cladocera	*Sabinea septemcarinatas*
Podon leucarti	*Munida rugosa*
Evadne nordmanni	*Pagurus pubescens*
Copepoda	*Hyas coarctatus*
Calanus finmarchicus	Chaetognatha
Calanus glacialis	*Sagitta elegans*
Calanus hyperboreus	Larvacea
Pseudocalanus elongatus	*Oikopleura* sp.
Euchaeta norvegica	Echinodermata
Scolecithricella minor	Unidentified
Temora longicornis	Fish larvae
Metridia longa	*Mallotus villosus*
Acartia longiremis	*Gadus morhua*
Acartia clausi	Ammodytidae
Microcalanus pygmaeus	*Pholis gunnellus*
Oithona similis	Lumpenidae
Oithona spinostris	*Hippoglossoides platessoides*
Caligus sp.	*Limanda limanda*
Unidentified	

peak occurred in May which mainly was composed of *Oithona* spp., *Calanus finmarchicus* and euphausiids, followed by a marked maximum in late September (> 900,000 ind./100m³). In September *Oithona* spp. and *Acartia* spp. comprised the major part of the plankton. In 1993 a minor peak was recorded in April/May mainly due to *Oithona* spp. and Cirripedia, whereas a major build up occurred in August. This latter peak in 1993 was due to *Oithona* spp., Cirripedia and *Acartia* spp. Maximum density numbers were ca 10 times higher than reported from Ísafjord-deep (ASTTHORSSON & GISLASON 1992). It is apparent that especially the smaller individuals were caught in much higher numbers in our investigation. The difference in the density numbers can most likely be explained by the use of a more fine meshed net (200µm compared with 335µm).

Holoplankton

The population structure of *Calanus finmarchicus* throughout the study period indicates a two generation per year cycle (Fig. 7). Copepodites I-III dominated the population in May and June 1992, in September/October 1992 , and in 1993 April/May. Copepodites I-III were also present in July/August 1993. ASTTHORSSON & GISLASON (1992) discusses the time span from spawning to first appearance of smallest copepodites in Isafjord-deep which has a temperature regime much alike Eyjafjörður (see JÓNSSON & GUDMUNDSSON 1994). They found the span to be approximately one month, but can vary with temperature and area. In Eyjafjörður *C. finmarchicus*, which are another indicator of breeding, increased in abundance approximately one month before high copepodites I-III numbers. This indicates a spring spawning in March/April and a summer spawning in July in 1992. In 1993 both spring and

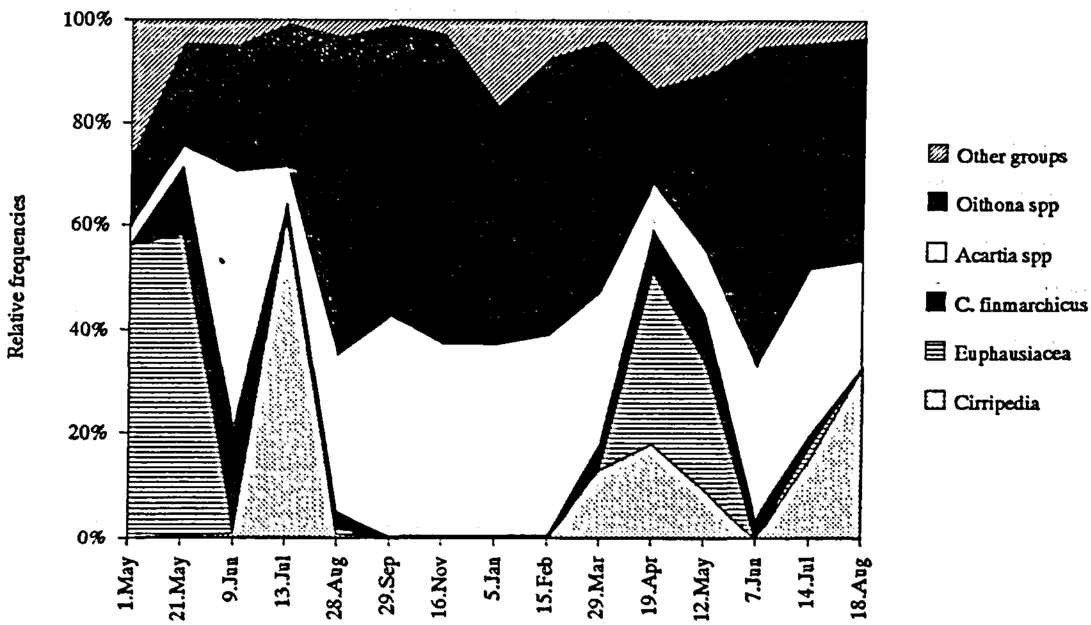

Fig. 5: Relative abundances of the most numerous zooplankton groups at station 10, Eyjafjörður, May 1992 to August 1993. Notice that the x-axis is not continous in time.

summer spawning appeared to be a month earlier. This production cycle pattern seems to be in accordance with other reports from Icelandic waters (ASTTHORSSON & GISLASON 1992, GISLASON *et al.* 1994)

The spring spawning clearly explains the spring increase in the *Calanus finmarchicus* population abundance (Fig. 8). When sampling started in May 1992 the *C. finmarchicus* population was at its minimum, but in late May a sharp increase in abundance was observed. In June maximum numbers (46,000 ind./100m³) during the study period were recorded, wheras numbers dropped to 5,400 ind./100m³ in July and continued to decline through the autumn and winter. In March 1993 the population started to increase and reached maximum numbers, one fourth of those observed in 1992, in May. In June, numbers decreased, but a small increase was recorded in July. Thus, the second spawning both years did not result in any significant increase in total numbers. This deviates from the pattern found both in Isafjord-deep and in ongoing investigations off south west Iceland, were there is a minor May/June peak, but maximum numbers in August (ASTTHORSSON& GISLASON 1992, GISLASON *et al.* 1994).

The two small copepods *Acartia* spp. and *Oithona* spp. were by far the two most abundant species in the samples. They showed nearly identical development pattern for abundance throughout the study period, but a quite different one compared to *Calanus finmarchicus*. While *C. finmarchicus* showed spring maxima both years, *Acartia* and *Oithona* typically reached their maximum numbers in the autumn (Fig. 8). After a small increase from low May 1992 values the numbers were quite stable during the summer until September 1992 where a maximum of 390,000 and 520,000 individuals per 100m³ were recorded for *Acartia* and *Oithona* respectively. In November 1992 the population again showed

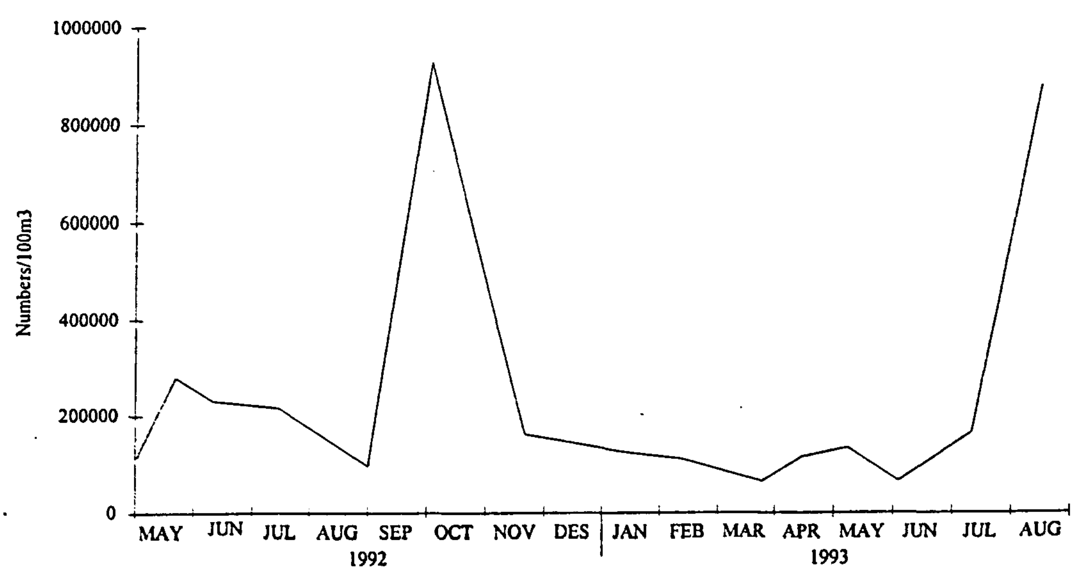

Fig. 6: Seasonal changes in total zooplankton density at station 10, Eyjafjörður, May 1992 to August 1993.

pre peak levels which further declined until April 1993. A large build up had again started when sampling ended in August 1993.

Pseudocalanus elongatus showed greater fluctuations during the study period than the above mentioned copepods (Fig. 8). Two major peaks in the abundance were recorded both years with the highest numbers (9,300 ind./100m^3) found in May 1993.

The very small copepod *Microcalanus pygmaeus* showed a totally different distribution pattern than any of the other copepods during this investigation. Not recorded in the samples during the summer months either in 1992 or 1993, it showed high winter densities and a spring peak both years with a maximum occurring in early May 1992 (27,000 ind./100m^3). This small copepod was not reported from Isafjord-deep most likely due to sampling methods.

Euphausiids were mainly registered in the samples in the spring both years with a maximum abundance of 160,000 individuals per 100m^3 in late May 1992 (Fig. 8). Ninety percent of the countings were euphausiid eggs in early May 1992. The percentage of naupleii and juveniles increased in late May an June (35% and 60% respectively) and by mid July and through September only juveniles and a few adults were recorded. In 1993 eggs appeared in mid April, the first larvae and juveniles appeared in mid May.

Calanus glacialis and *Calanus hyperboreus* were also registered in the samples and had a very similar distribution pattern as *Calanus finmarchicus* (Fig. 8), only juveniles occurred in the samples. ÁSTÞÓRSSON *et al.* (1983) found *C. hyperboreus* to be highly oceanic and only in north icelandic waters. According to RAYMONT (1983) both are mainly oceanic and arctic species.

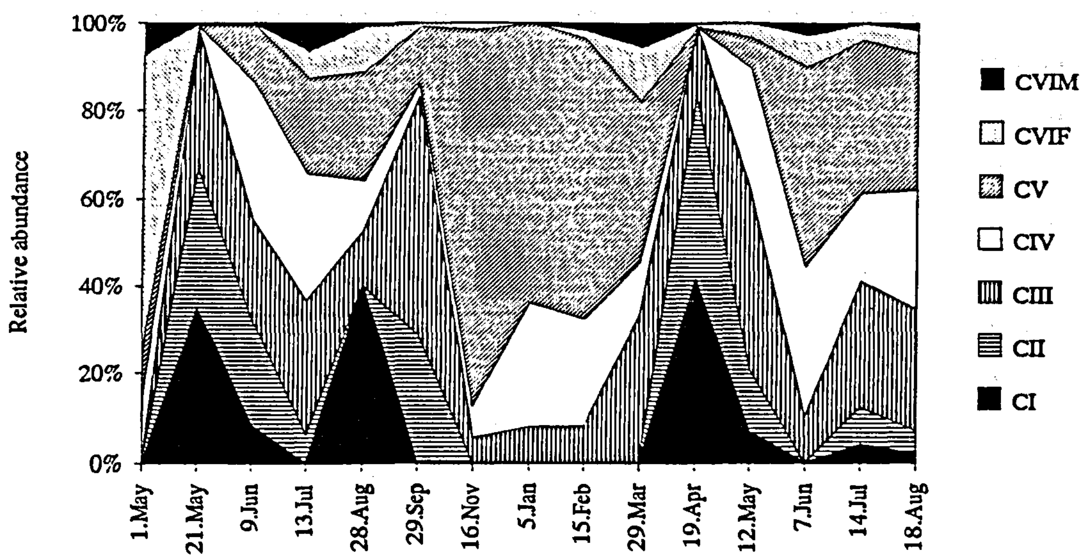

Fig. 7: Development stages of Calanus finmarchicus *at station 10, Eyjafjörður, May 1992 to August 1993. Notice that x-axis is not continous in time.*

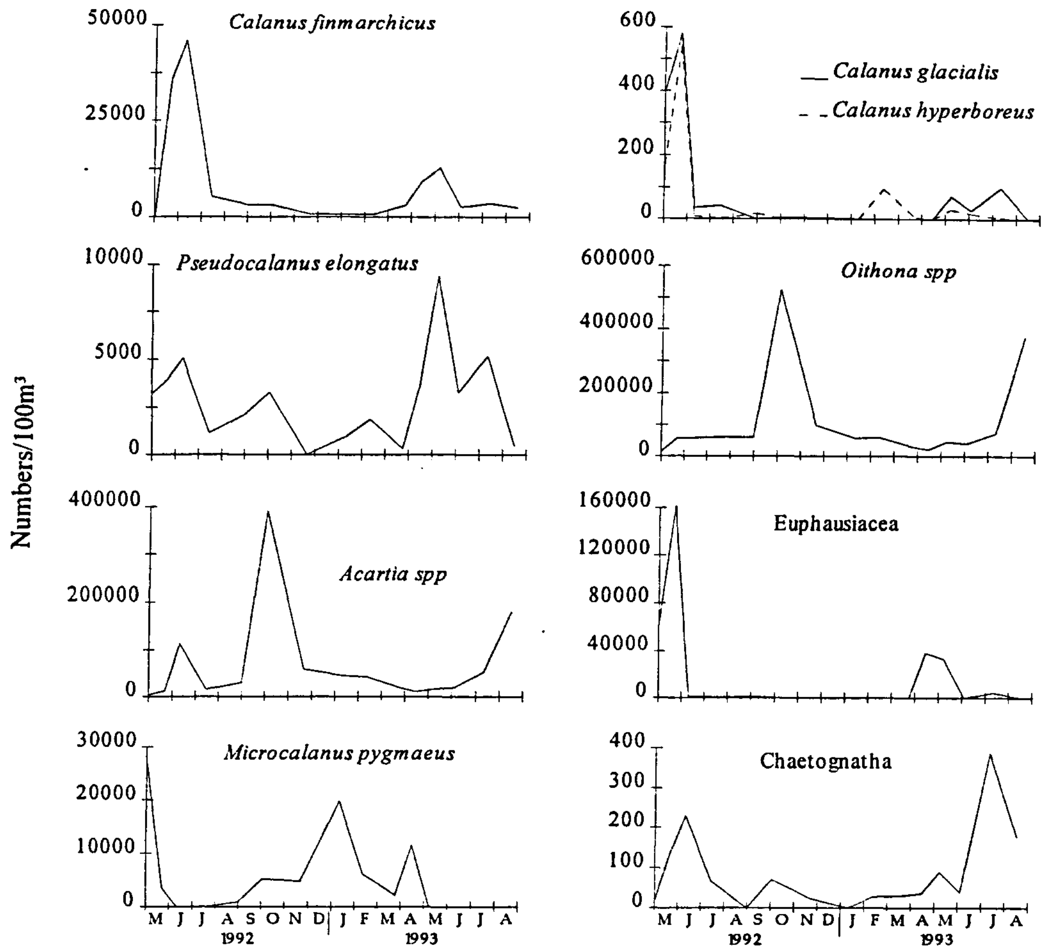

Fig. 8: Seasonal changes of some holoplankters at station 10, Eyjafjörður, May 1992 to August 1993.

Chaetognaths mainly *Sagitta* had highest densities during spring/early summer both years (Fig. 8). These peaks appear to be associated with recruitment since the major part identified were small individuals which disappeared later in the period and thus indicated a one spawning per year cycle.

Besides the holoplankters mentioned above, Larvaceans appeared sporadically in the samples (maximum 2,000 ind./100m³), while Coelenterates and Ctenophores never were very prominent.

Meroplankton

The meroplankton were a substantial part of the zooplankton community at times. Cirriped larvae accounted for up to 62% of the total numbers of zooplankton (Fig. 6). Two species were recorded in the samples, *Balanus balanoides* which occurred in the spring and *Verruca stroemia* which appeared during the summer and were by far the most abundant of the two (Fig. 9).

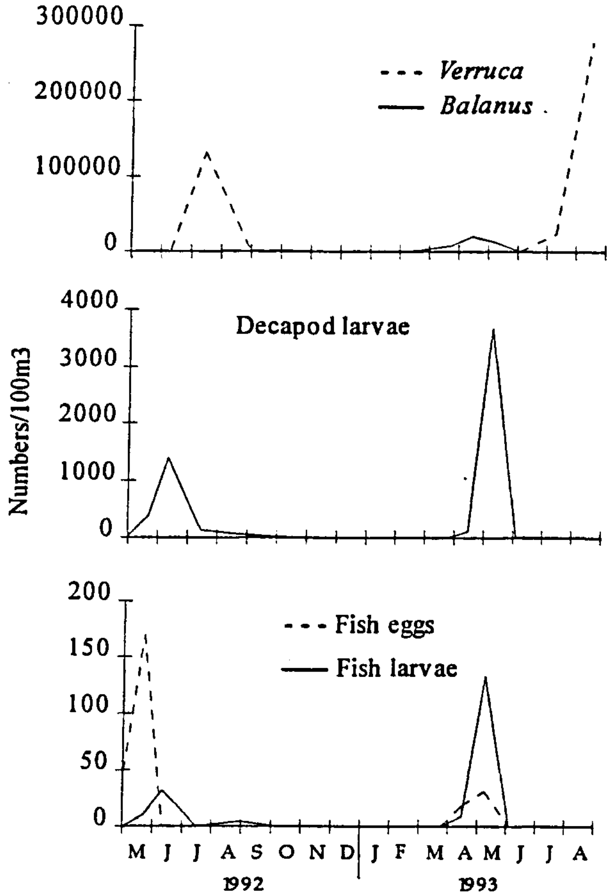

Fig. 9: Seasonal changes of some meroplankters at station 10, Eyjafjörður, May 1992 to August 1993.

Besides Cirripedia larvae, decapod larvae and fish larvae were of the more abundant meroplankton groups. Both had a density maximum in May (1992) and April (1993) with declining numbers during summer, while fish eggs appeared in the samples slightly earlier (Fig. 9).

Of other meroplankton, Gastropod larvae which occurred sporadically in the samples, could reach substantial numbers (22,000 ind./100m^3) in August 1993.

This presentation of the ecology of Eyjafjörður show a habitat with a diverse pelagic community. There are obvious coastal characters, but also there are apparent some influences from adjacent oceanic waters in the fjord both in the species composition of the phytoplankton and the zooplankton.

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