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Vertical distribution of zooplankton in the shelf area southwest of Iceland in early May 1991 and 1992

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Abstract

The vertical distribution of zooplankton along a transect extending from the coast and across the shelf southwest of Iceland was studied in relation to hydrographic features and chlorophyll *a* concentration during early May 1991 and 1992. The amount of Coastal water (<35‰) was much more significant in 1991 than in 1992. The distribution of chlorophyll *a* followed hydrographic features, and much higher values were observed in early May 1991 (~0.5-22 mg/m^3) than in early May 1992 (~0.5-1.5 mg/m^3). In May 1991, when the Coastal water was observed in significant amounts, the most numerous zooplankton groups were either confined to the Coastal water or occurred in close association with it. In 1992, when almost no Coastal water was observed, increased abundance of the most numerous groups was recorded somewhat farther offshore, both near the surface and close to the bottom. During both years the biomass and abundance of total zooplankton were of a similar magnitude (<1-~6 g dry weight/100 m^3 and ~200-32 000 individuals/100m^3, respectively). In 1991 the spawning of *C. finmarchicus* (the most abundant species, 45-87% of total number), occurred earlier near the shore than farther offshore while in 1992 the difference in spawning between the nearshore and offshore waters was much less prominent. In early May 1991 both fish eggs and fish larvae were primarily confined to the low salinity Coastal Water near the shore. On the other hand in early May 1992, when there was almost no Coastal water present, both fish eggs and fish larvae had a deeper and more offshore distribution. Irrespective of the hydrography the vertical and horizontal distribution of the fish larvae was thus generally similar to that of their potential prey.

Introduction

The commercially important Icelandic fish stocks spawn mainly on the banks south and southwest of Iceland (e.g. Jónsson 1982, Astthorsson 1994, Vilhjálmsson 1994) and there also the fish larvae begin to feed (Thorisson 1989, Jónsson and Fridgeirsson 1986). In this area the relatively warm and saline (6-8°C, 35.0-35.2‰) Atlantic Water, originating from the North Atlantic Drift, is the main water mass (Stefánsson 1981, Malmberg 1978). However, close to the shore this water is diluted by freshwater run-off from rivers and thus the Coastal Water (<35.0‰, Malmberg 1978) is formed. Due to variable timing and amount of fresh water run-off together with variable wind force (Ólafsson 1985, Thórdardóttir 1986, Gislason et al. 1994) the distribution and magnitude of the Coastal Water may vary considerably from year to year.

Since the early seventies the horizontal distribution of zooplankton south and southwest of Iceland has been monitored in spring as part of a general environmental survey (see references in Astthorsson et al. 1983 and Astthorsson and Gislason 1995). Further, the zooplankton southwest of Iceland has been the subject of several ecological studies in the past years (Fridgeirsson et al. 1979, 1981, Gislason and Astthorsson 1991, 1995a, 1995b). However, information on the vertical distribution of zooplankton in the area is confined to only two studies dealing mainly with fish eggs and fish larvae and considering only the uppermost 35 m of the water column (Fridgeirsson 1984, Jónsson and Fridgeirsson 1986). Nothing is for instance known about the vertical distribution of zooplankton in relation to hydrobiological conditions nor how this may vary from year to year. As part of a multidisciplinary study on the plankton ecosystem south and southwest of Iceland in 1990-1992 investigations on the vertical distribution of zooplankton, fish eggs and fish larvae were therefore undertaken, and in this paper we report on the initial results from one transect during 1991 and 1992.

Material and methods

The investigations were carried out on the Krísuvík transect extending from the south coast of Iceland (63°48'N, 22°04'V-63°20'N, 22°04'V), on May 5th 1991 and May 7th 1992 (Fig. 1). At the shallowest station the bottom depth was 45 m, while at the outermost one it was 220 m. Data on hydrography, phytoplankton and zooplankton were collected at Stns 2, 6, 10 and 12. Additional data on hydrography and phytoplankton were further collected at several other stations along the transect (Figs 2, 3).

Temperature and salinity were recorded with a Sea Bird Electronics SBE-9 CTD. Seawater samples for the measurement of chlorophyll *a* were collected from several depths and filtered through GF/C glass fibre filters. The filters were homogenized in 90% aqueous acetone and the extract measured in a spectrophotometer according to the method described by Strickland and Parsons (1968).

The zooplankton was collected with the BIONESS, a multiple opening and closing net sampler (Sameoto et al. 1980). The BIONESS was fitted with nine 330 μ nets, each with a mouth opening of 0.25 m^2. The filtering efficiency and the volume of water filtered by the nets was monitored with external and internal General Oceanics flowmeters. For sampling the BIONESS was slowly lowered to the greatest depth to be sampled, the first net opened on command from the ship, and the sampler then towed horizontally at a speed of ~1 ms^{-1} for about 5 minutes, thereby filtering ~70-80 m^3 of water. The BIONESS was then raised to the next depth of interest, and on the way a new net was opened which simultaneously closed the first one. Another horizontal tow was then made at the new depth. This sampling procedure was repeated as desired and a series of depth strata from near the bottom and to the surface sampled. The number of samples obtained at each station varied according to bottom depth from 3 to 9.

The zooplankton was preserved in 4% neutralized formalin after collection. In the laboratory the displacement volume of total zooplankton was measured after large gelatinous zooplankton had been removed. Euphausiids and fish larvae were then removed and counted from whole samples. Except on a few occasions, when the sample was very small, the remainder was then split a number of times with a Motoda splitter (Motoda, 1959) and an aliquot containing at least 500 individuals analysed for species or higher taxonomic groups. Further, from each sample ~200 individuals of *C. finmarchicus* were classed to developmental stages.

In the present paper the displacement volume data have been converted to dry weight biomass using the formula of Matthews and Heimdal (1980). Data on biomass and abundance are standardized to per 100 m^3 of water. The distribution of temperature, salinity, density, chlorophyll *a*, as well as the abundance and biomass of zooplankton were contour-plotted with the Kriging method using the SURFER program (Golden Software, Inc.).

Results

Hydrography and chlorophyll *a*

In May 1991 the temperature at the Krísuvík transect increased somewhat with distance from the shore, being ~6-6.5 °C in the vicinity of the shore and ~6.5-7 °C farther offshore (Fig. 2). The near shore water masses were strongly stratified due to a pronounced halocline at a depth of 30-40 m and which extended ~35 km offshore. Above the halocline there was a mixed layer of Coastal water (S<35.0‰), while below it the Atlantic water of higher salinity (S>35.0‰) (Fig. 2). In 1992 the temperature distribution along the whole transect was very similar (~6.5°C, Fig. 2). Further, in contrast to May 1991 very little Coastal water was observed along the transect in 1992 and it was confined to only a thin surface layer extending ~7 km from the shore. As a result of this there was unlike 1991 virtually no stratification observed along the transect in 1992, except at ~30-35 km from the shore where somewhat lower water density was observed near to the surface (Fig. 2).

The concentrations of chlorophyll *a* were much higher in early May 1991 (~0.5-22 mg/m^3) than in early May 1992 (~0.5-1.5 mg/m^3) (Fig. 3). During both years the distribution of chlorophyll *a* was consistent with hydrographic features. Thus, in 1991 the highest concentrations were found in the Coastal water, while in 1992 the highest concentrations were found in the low density surface water ~30-40 km from the shore (cf. Figs 2 and 3). Similar to previous investigations (e.g. Thórdardóttir 1986, Gislason et al. 1994) the present results demonstrate the importance of the freshwater run off for initiating an early spring bloom of the phytoplankton in the nearshore waters south of Iceland.

Zooplankton

Calanus finmarchicus was the dominant species in the samples in early May in both 1991 and 1992 (Table I). At the nearshore stations it constituted 45-63% of the animals, while at the offshore ones it made up 51-87% of the total number. Near the shore several coastal species and groups (*Pseudocalanus* sp., *Temora longicornis*, cirripede larvae) and fish eggs and fish larvae also contributed significantly to the catch. Further, euphausiid eggs were numerous on the central part of Krísuvík transect in 1991 (Table I). The distribution of total biomass and abundance of total zooplankton, together with the distribution of the most important groups, is dealt with in more detail below.

During both early May 1991 and early May 1992 the biomass was of a similar magnitude, ranging from <1 to ~6 g dry weight/100 m^3 (Fig. 4). In 1991 the biomass was highest in the uppermost 50 m in the nearshore regions, and at ~100-150 m depth farther offshore. In 1992 the highest values were observed on the middle of the transect, both near the surface and close to the bottom. The total zooplankton abundance was similar in early May 1991 and 1992, and varied between ~4200 and ~32 000 individuals/100 m^3. In 1991 the abundance was highest close to the surface in a region extending from the shore and beyond Stn 10 or approximately in the area confined to the Coastal Water (<35.0‰). In 1992 the abundance was greatest on the middle and outer part of the transect and also near the bottom relatively close to the shore.

C. finmarchicus was in 1991 found in highest concentrations (~4000-8000 individuals/100m^3) in relatively shallow water in a region extending from the shore and beyond Stn 10 (Fig. 5). Further, there was a concentration of *C. finmarchicus* at ~ 150 m depth farthest from the shore. Individuals of copepodite stages I-IV were found in greatest relative abundance close to the shore, while the proportion of stage VI increased with distance from the shore (Fig. 6). In 1992 the highest densities of *C. finmarchicus* (~16 000-32 000 individuals/100m^3) were slightly greater than in 1991 and also the species had a more offshore distribution along the transect than in 1991 (Fig. 5). The similar proportion of copepodite stages I-IV and stage VI at the different stations in 1992 indicates a more synchronous spawning and development along the transect than in 1991 (Fig. 6).

Pseudocalanus sp. and *Temora longicornis* were in both years primarily caught at the shallowest stations (Stns 2 and 6), with the highest concentrations occurring at 50-130 m depth (Fig. 7). It is worth noting, however, that in 1991 the distribution was generally shallower than in 1992 and the highest densities appeared to occur at the boundary between the Coastal and Atlantic water (cf. Figs 2 and 7). Cirripede larvae (mainly nauplii but a few cyprii were also caught) were in 1991 predominantly found near the surface in the low salinity Coastal water, while in 1992 they had a more offshore distribution and were abundant both near the surface and close to the sea bed (Fig. 7).

Most of the fish eggs found in the samples were from cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) (~80%), while the fish larvae mainly belonged to capelin (*Mallotus villosus*) (>90%). In early May 1991 both fish eggs and fish larvae were primarily confined to the low salinity Coastal Water near the shore (Fig. 8). On the other hand, during early May 1992 the fish eggs were mainly concentrated near the surface at the centre and outer part of the transect and near to the bottom somewhat closer to land (Fig. 7). The larvae showed in 1992 a distribution similar to that of the eggs except that the main concentration near the surface occurred somewhat closer to the land (Fig. 8).

Discussion

The main hydrographic difference observed on the transect between the two years was that in 1991 the amount of Coastal water was much more significant than in 1992 (Fig. 2). Thórdardóttir (1986) has pointed out that the presence of the Coastal water is an important prerequisite for initiating an early phytoplankton bloom in the nearshore waters south of Iceland. The relatively strong stratification imposed by the fresh water in early May 1991 resulted in high growth of phytoplankton in the surface layers compared to early May 1992 when no such stratification was observed (Gislason et al. 1994, Fig. 3). This somewhat striking difference between years in the extent of the Coastal water and the resulting development of the spring bloom was, to some extent reflected in the distribution of the zooplankton and the development of *C. finmarchicus*. Thus, in early May 1991 the most numerous zooplankton groups were either confined to or occurred in close vicinity of the productive low salinity surface water (cf. Figs. 2 and 4), and it is reasonable to assume that then the distribution of the zooplankton was at least to some extent dependent on the observed gradients in hydrography and phytoplankton. On the other hand, in early May 1992, when there was hardly any Coastal water present and almost no phytoplankton, the zooplankton showed somewhat more offshore distribution both near the surface and close to the bottom (Fig. 4). These gradients in the zooplankton distribution, observed at a time when no structuring was present in the physical or food environment, probably demonstrate that in addition to the physical environment and feeding conditions, factors such as behaviour, predation and competition were also influencing the vertical distributional pattern of the animals.

During early May 1991 the proportion of young copepodite stages (I-IV) of *C. finmarchicus* was greater near the coast than farther from the shore, while the adult individuals showed more offshore distribution than the younger stages and in contrast to them were also abundant in deep water (Fig. 6). This probably demonstrates that in 1991 *C. finmarchicus* spawned earlier and developed faster in the Coastal water where the feeding conditions where favourable than in the offshore water where almost no phytoplankton was present. In 1992, however, when hardly any phytoplankton growth had started, neither in the Coastal nor in the Atlantic water, an inshore-offshore gradient such as this in the development was not as evident.

In early May 1991, when the Coastal water was observed in significant amounts (Fig. 2) the distribution of both fish eggs and fish larvae were mainly confined to it (cf. Figs 2 and 8). These findings for 1991 accord with those of Ólafsson (1985), who also demonstrated that the greatest densities of cod and haddock eggs tend to be in the Coastal water. Similarly the eggs and larvae of the Arcto-Norwegian cod stock are initially carried by the Norwegian Coastal current from the spawning areas to the nursing grounds (Ellertsen et al. 1989, Suthers and Sundby 1993). Coastal fronts have often been reported as areas of high zooplankton abundance and productivity (Owen 1981, Kiørboe and Johansen 1986, Mann and Lazier 1991), and therefore they may be providing favourable feeding conditions for fish larvae. Our results demonstrate, however, that both in the presence of the Coastal water and when there was almost no Coastal water present there was good correspondance between zooplankton abundance on one hand and egg and larval abundance on the other (cf. Figs 4 and 8). Possibly this demonstrates that the larvae are attracted to areas of high zooplankton abundance. However, in this context it is important to bear in mind that our findings are only "snapshots" at a given time, and in addition to the physical structuring of the water column at the time of sampling the previous history of the water masses must also be considered when interpreting data such as presented here.

More detailed understanding of the complex dynamics of the planktonic ecosystem south of Iceland requires much further research with serial stratified sampling during the whole growth season. Such studies we hope to undertake as part of the TASC program (Trans-Atlantic Study of *Calanus finmarchicus*) which is planned to start early next year.

Acknowledgements

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Table 1. Relative abundance of zooplankton groups (% of total abundance) along Krísuvík transect southwest of Iceland in early May 1991 and 1992. Total abundance is also given as numbers/m².

	Krisuvik							
	1991 Distance (km)				1992 Distance (km)			
Group	2,8	12	34,3	54,6	2,8	12	34,3	54,6
C. finmarchicus	62,9	52,2	50,8	81,2	44,7	60,6	84,7	86,5
Pseudocalanus spp.	11	24	1,7	0,9	7,3	5,5	0,1	0,2
Temora longicornis	12,5	5,4	0,1	0,1	2,4	5,7	0,7	1,9
Euphausiid eggs	0	5,8	45,2	3,2	0	0,2	0,1	0,2
Cirripede larvae	6,7	3,8	0,2	0,1	10,2	15,8	8,7	6,8
Fish eggs and fish larvae	4	1,9	0,1	0	7,4	7,3	4,5	2,7
Other groups	2,9	6,9	1,9	14,5	28	4,9	1,2	1,7
Total abundance	14811	9604	7746	5711	244	14554	20375	6603

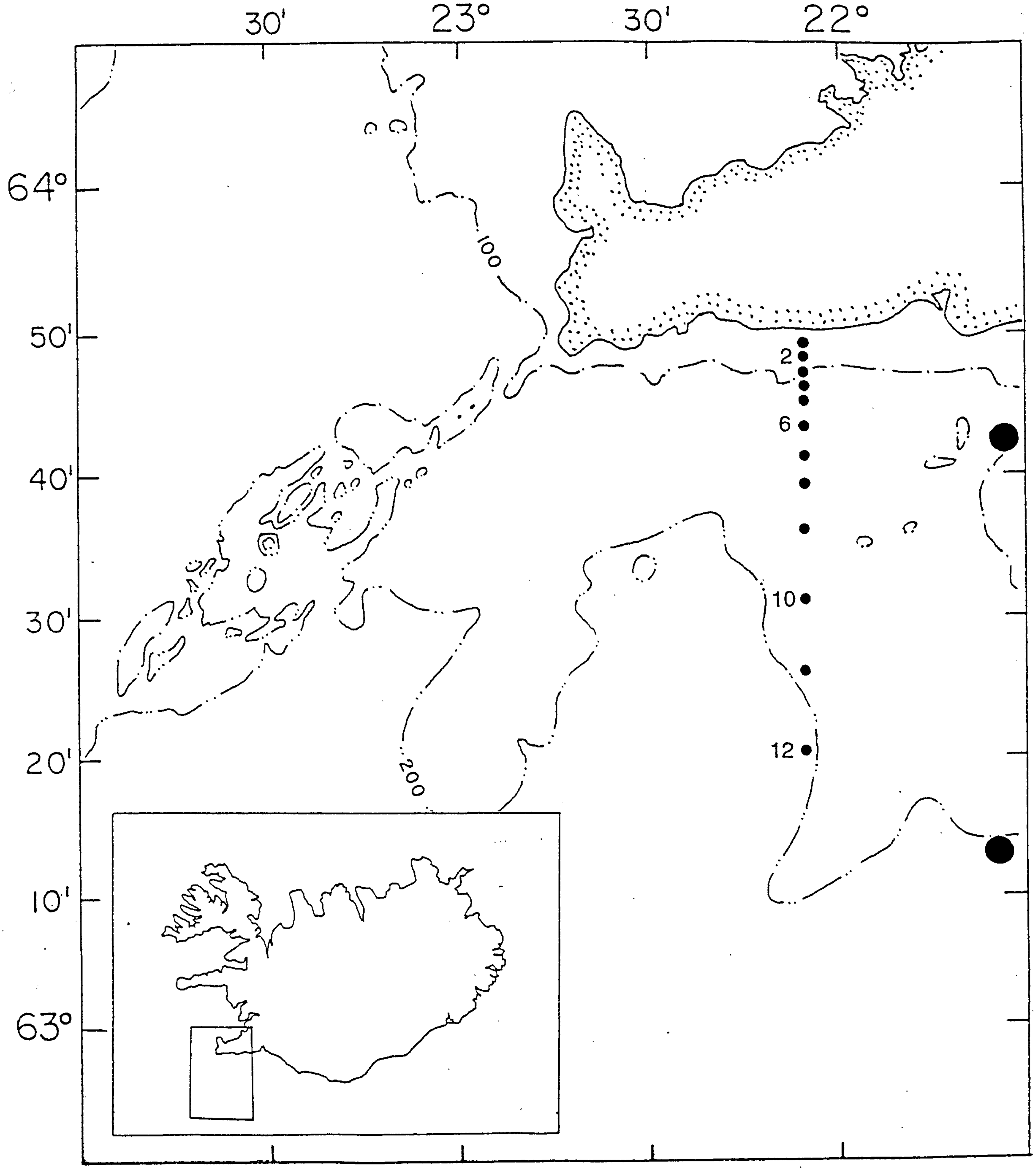

Figure 1. Bathymetric chart showing location of the Krísuvík transect southwest of Iceland. Stations are indicated by black dots.

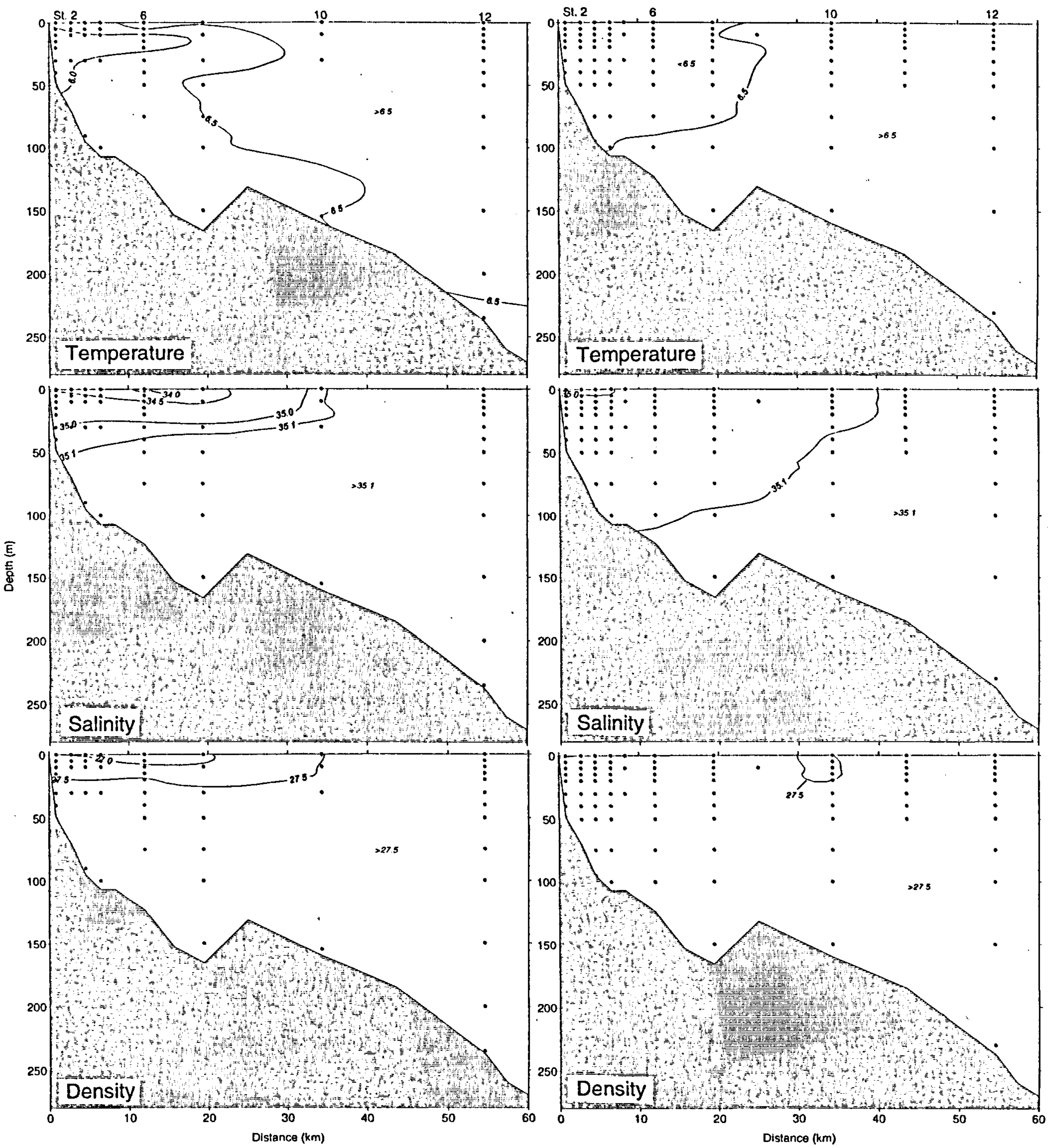

Figure 2. Vertical distribution of temperature (°C), salinity (PSU) and density (σ_t) along Krísuvík transect in 1991 (left) and 1992 (right).

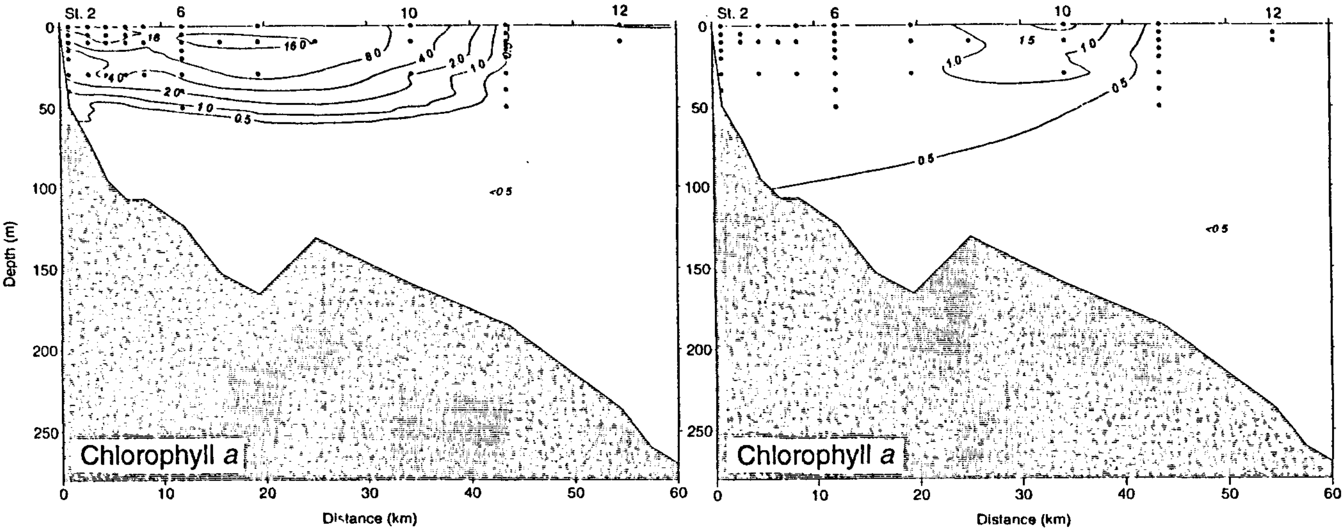

Figure 3. Vertical distribution of chlorophyll *a* (mg/m^3) along Krísuvík transect in 1991 (left) and 1992 (right).

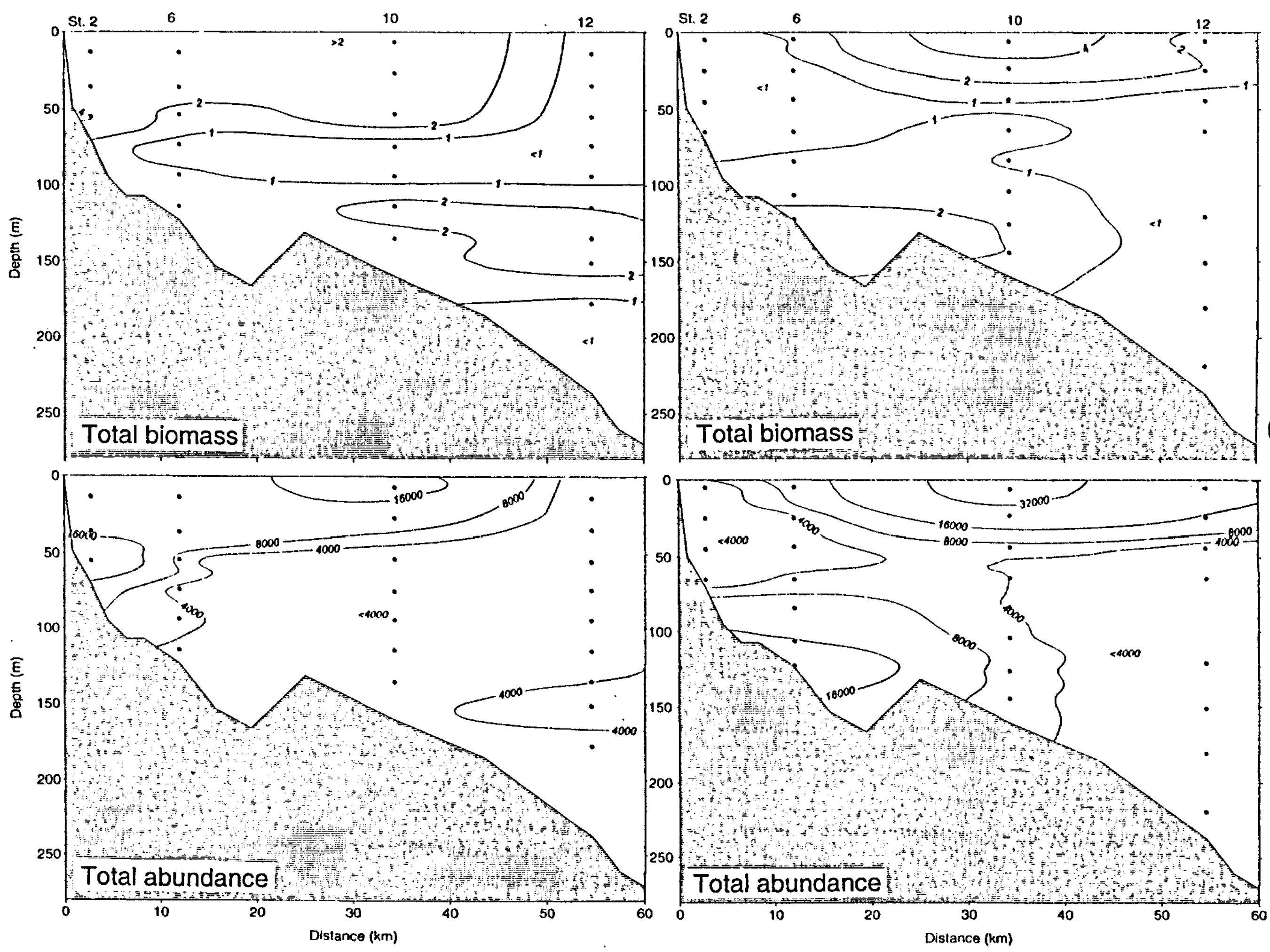

Figure 4. Vertical distribution of biomass (g dry weight/100 m^3) and abundance (numbers/100m^3) of total zooplankton along Krísuvík transect in 1991 (left) and 1992 (right).

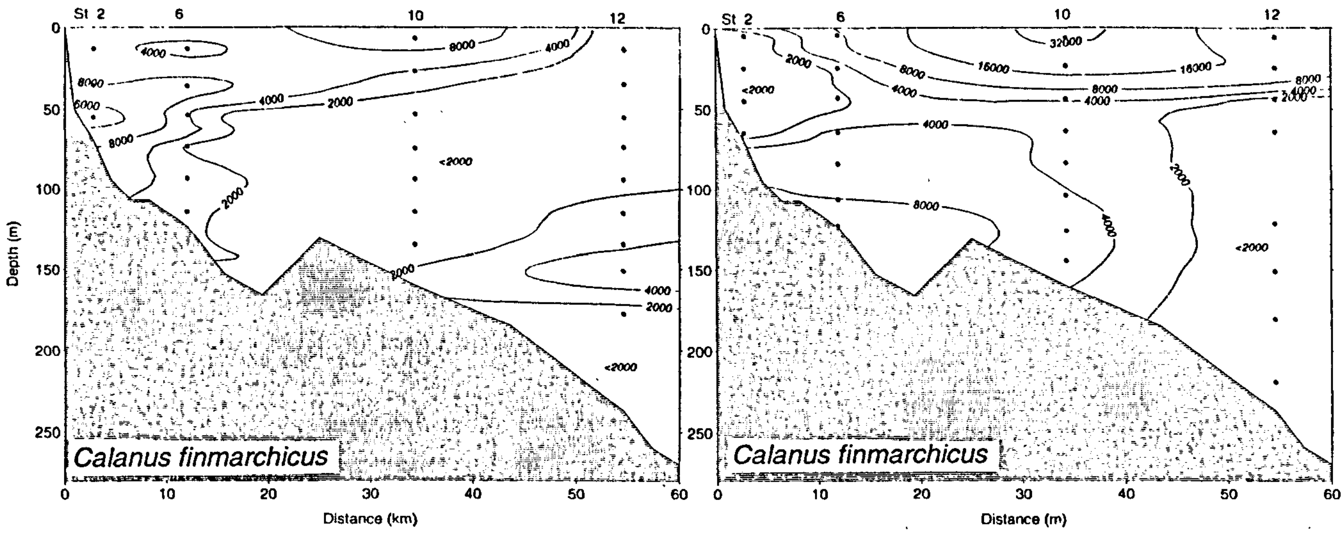

Figure 5. Vertical distribution of *Calanus finmarchicus* along Krísuvík transect in 1991 (left) and 1992 (right). Isolines illustrate abundance in numbers/100 m^3.

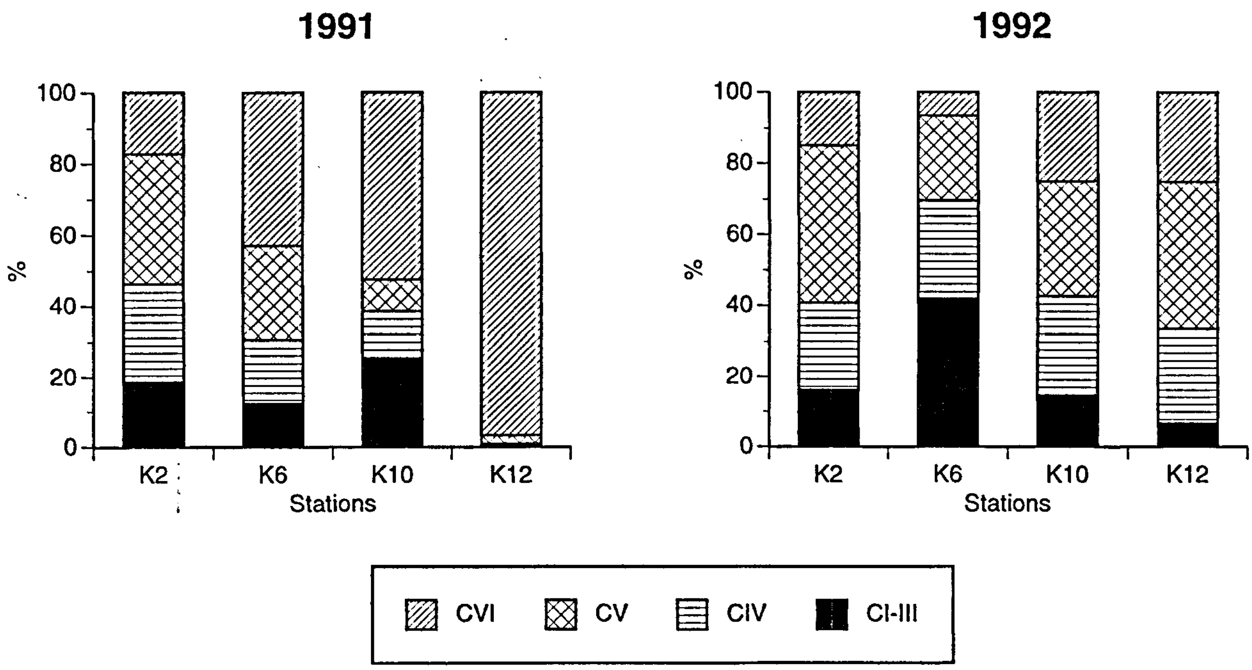

Figure 6. Relative abundance of developmental stages of *Calanus finmarchicus* on four stations along Krísuvík transect in 1991 (left) and 1992 (right).

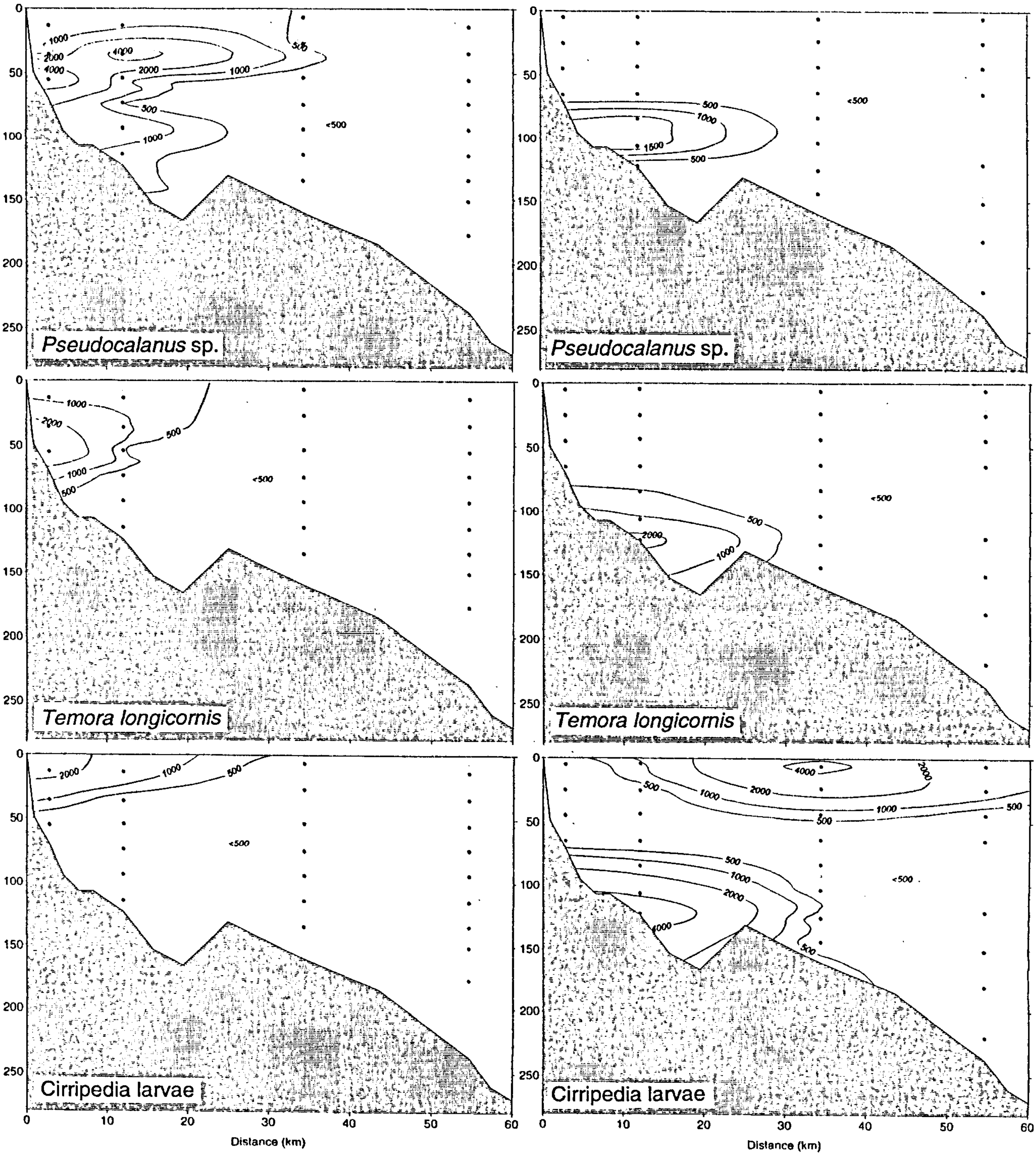

Figure 7. Vertical distribution of *Pseudocalanus* sp., *Temora longicornis* and cirripede larvae along Krísuvík transect in 1991 (left) and 1992 (right). Isolines illustrate abundance in numbers/100 m^3.

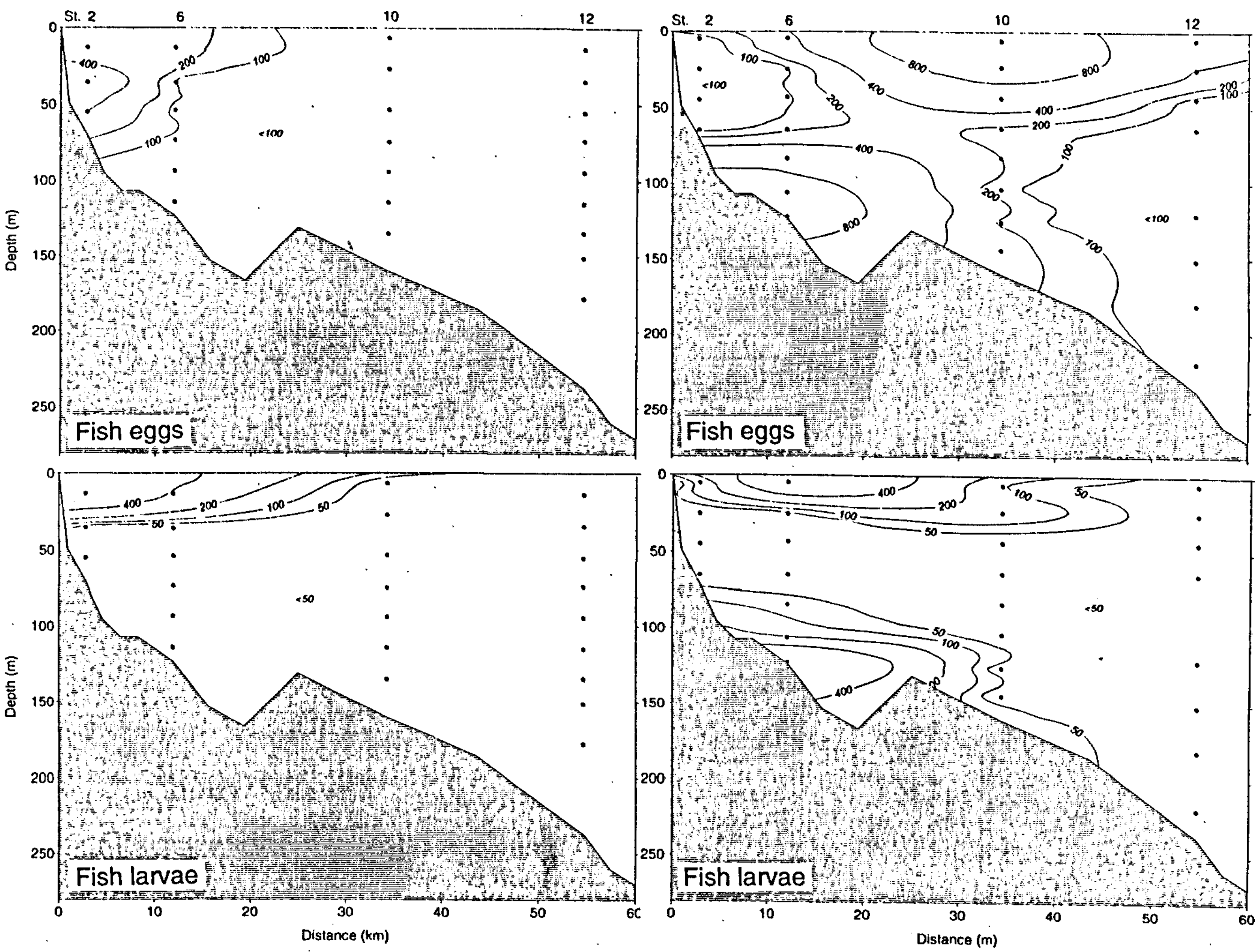

Figure 8. Vertical distribution of fish eggs and fish larvae along Krísuvík transect in 1991 (left) and 1992 (right). Isolines illustrate abundance in numbers/100 m^3.