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BENEFIT SURVEYS

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Recruitment and reproduction study on horse mackerel and anchovy, 1 - 17 April 2001

by

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TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

1.1 General objectives

An overall goal of BENEFIT is to improve the knowledge and understanding of the important commercial stocks, their environmental condition and the linkage between environmental processes and growth, distribution and abundance of the fish stocks.

The present survey is part of a project that was initiated during the BENEFIT Annual Meeting in Swakopmund, April 1999. It resulted in a BENEFIT project proposal "Horse mackerel, *Trachurus trachurus capensis* and *T. t. trecae* recruitment surveys". The objective of the project is to augment the understanding on the reproductive biology and early life stages of horse mackerel and to explain the spawning and recruitment dynamics of the two horse mackerel species and thereby improve management recommendations. A pilot survey was conducted 16 February – 8 March 2000 where the spawning areas in northern Namibia and southern Angola were targeted and where the vertical distribution of eggs and their buoyancy were measured.

1.2 Specific objectives of the survey

The present cruise is the second field investigation of the horse mackerel project, and covered the region from Sandwich Harbour, Namibia to Tombua, Angola. The specific objectives of the survey are to identify spawning areas of horse mackerel, map the spatial distribution of its eggs and larvae and to investigate the physical properties of eggs with respect to buoyancy. Further it will be studied how the circulation features in combination with the vertical distribution of the eggs influence the spreading and advection.

During the survey we surprisingly discovered substantial numbers of anchovy larvae. The distribution extended over the entire Northern Namibian shelf. A spin-off task of the present surveys became therefore to investigate the early stages of anchovy. We studied the age distribution in order to estimate the spawning time and spawning areas of the anchovy. Further we studied the vertical distribution of the larval anchovy and compared them to earlier findings on larval horse mackerel and sardine.

An additional objective was to sample sediment cores from the mud belt along the mid and northern Namibian shelf in order to study the distribution of sulphur bacteria and anoxic conditions, and to study the distribution of fish larvae in relation to distribution of low oxygen layers, and by on-board laboratory experiments investigate the tolerance of low-oxygen concentrations for the fish larvae.

1.3 Participation

The scientific staff during the cruise was:

From Angola:

Francisco de Almeida, and Miguel André António.

From Namibia:

Rudi Cloete, Bronwen Currie, Alie Gumbo, and Kathie Noli-Peard.

From Norway:

Berit Endresen, Tore Nilsen, Svein Sundby, Erling Kåre Stenevik and Jan Frode Wilhelmsen.

1.4 Narrative

The vessel left Walvis Bay 2 April, 20:00 hours, and headed for Sandwich Harbour where the survey started 3 April, 00:45. East-west sections were made from Sandwich Harbour (23° 30' S) to Tombua (15° 50' S) during the first part of the cruise from 3 – 10 April (Figure 1.1). The distances between the sections were 40 –50 nautical miles. Cross sections from southwest to northeast were made between the east-west sections. Stations were normally taken every 20 nautical miles and every 15 nautical miles in the nearshore region. CTD and Multinet plankton sampler were used on all station. Methot plankton trawl were taken occasionally and only during night time. Bottom trawl were used in regions where there were indications of horse mackerel. ACDP was run all through the cruise. Weather conditions were good during the survey.

During the second part of the cruise (11-14 April) (Figure 1.2) the areas of the highest eggs and larval concentrations were revisited for further detailed investigations in order to identify species and to investigate the vertical distributions in more detail. This was done in the southern Angolan water off Baia dos Tigres and in Namibian waters between 19^{o} 00' S and 20^{o} 25' E. After having located the area of highest concentrations of horse mackerel larvae a 24 hours station was occupied at 20^{o} 00' S 12^{o} 30' E from 14 April 16:30 till 15 April 19:00. The investigation was then terminated and the ship headed for Walvis Bay where it arrived 16 April 17:00. The work on reporting continued onboard until 17 April.

CHAPTER 2 MATERIAL AND METHODS

2.1 Physical measurements

The hydrographic measurements were made with a Seabird SBE 911 CTD with oxygen sensor. The distances between the sections were 40 –50 nautical miles. Cross sections from southwest to northeast were made between the east-west sections. Stations were normally taken every 20 nautical miles and every 15 nautical miles in the nearshore region. The first part of the survey started off Sandwich Harbour 3 April 2001, 00:45 hours, (HD 263) and ended off Tombua 10 April, 06:30 hours (HD 332). The second part of the survey started off Baja dos Tigres, 11 April 2001 13:45 hours (HD 333) and ended off Palgrave Point 14 April 2001 10:00 (HD 357). The investigation ended with conducting a 24 hours station at the position (20 ^{o}S, 12 ^{o} 30`E) northwest of Möwe Point, 14 April 15:30 – 15 April 16:50, (HD 358-366).

Wind speed and direction was measured continuously underway by the Aanderaa weather station. In addition, at each CTD station the wind speed was entered manually from the bridge. By using the programme LOG2UMS, the files were converted to UMS format and then plotted in a similar manner to the current data, described below. The direction was given in tens of degrees, and because this was interpreted as degrees by UMS, each directional value had to be multiplied by 10 in order to obtain the correct result.

2.2 Plankton sampling

2.2.1 Multinet plankton sampler

Ichthyoplankton and zooplankton were sampled with a Multinet plankton sampler from Hydrobios. The plankton sampler has 5 nets with a mesh size of 405 micrometers. The opening of the plankton sampler is 0.5 x 0.5 m. A flow meter was mounted in the entrance of each net. A Scanmar depth recorder with acoustic transmission to the vessel was mounted on top of the Multinet. The plankton sampler was retrieved at a speed of 0.5 -1.0 m/sec while the vessel maintained a speed of 2 - 2.5 knots. During the first part of the survey (Figure 1.1) depth intervals were 0-25 m, 25 – 50 m, 50 – 100 m, 100 – 150 m, 150 – 200 m. When bottom depths were less than 200 m, the deepest net sampled from 10 or 20 m above the bottom to the nearest 50 m depth interval (e.g. from 180 to 150 m depth). During the second part of the survey while the ship was moving southwards and during the 24 hours station at the end of the survey, the depth intervals were 0-10 m, 10-20m, 20-30m, 30-40m, 40-50m, 50-60m, 60-80m, 80-100m, 100-bottom.

2.2.2 Methot fish larvae sampler

A Methot fish larvae sampler was fabricated at Globe Engineering in Walvis Bay. The equipment was produced in stainless steel according to the description of Methot (1986). The opening of the sampler is 2.24 x 2.24 m. The mesh size of the inner nets were 7 mm. The Methot sampler was deployed from the stern gate using a 12 mm cable on one of the trawl net winches.

The experience with operating the new Methot net onboard "Dr. Fridtjof Nansen" was good. The deploying and retrieving through the stern gate seemed to work quite well and the large net winch was perfect for running the cable.

The Methot sampler was only used during night time. A Scanmar depth sensor was mounted on top of the frame, and depth was monitored on the bridge during tows. The sampler was towed horizontally at discrete depth from 40 m to about 10 m.

2.2.3 Processing of ichthyoplankton and early juvenile fish samples

After removing the cups from the Multinet the samples were poured into measuring cylinders to determine the volume of the sample by displacement. The samples were transferred to petri dishes and examined with a stereo microscope. All fish larvae and fish eggs were removed from the sample while the major zooplankton species were noted. The fish larvae were identified using the key of Olivar and Fortuno (1991). All fish larvae were counted and total lengths were measured before storing it in 96% alcohol. Fish eggs were identified, counted, staged and the diameters were measured. Live horse mackerel eggs were transferred to the density gradient columns.
Juvenile fish collected from the Methot net were counted and length measured.

2.3 Trawl sampling

The purpose of the trawl sampling was to collect mature horse mackerel in order to sample the gonads and to conduct artificial fertilisation of mature eggs and subsequently measure the stage development and the buoyancy of the eggs. Therefore, only horse mackerel were collected from the bottom and pelagic trawls. Gonads from the adult horse mackerel were conserved for further investigations on maturity development.

2.4 Buoyancy measurements of fish eggs and larvae

The onboard equipment from Martin Instrument Co. Ltd. (MIC) was used to measure specific gravity of plankton. The equipment consists of three glass cylinders, 50 mm internal diameter and 700 mm high, submersed in a temperature-controlled transparent water container. The temperature was kept constant by a ship-mounted cooling unit. A linear salinity gradient is set up in each column by filling the column from two conical flasks. One of the flasks is filled with (each filled with 830 ml salt water solutions) connected by a plastic tube at the bottom, one with low-salinity and the other with high-salinity. The two solutions were made from natural seawater. The filling of each column takes about 25 min.

The salinity gradients in the three columns were first made before departure on 2 April when the ship was in harbour in Walvis Bay. It is of importance to do the filling in calm conditions because too much motion of ship will cause errors in the filling procedure due to unwanted mixing between the two flasks. Seawater from the Swakopmund Aquarium was used to prepare the salinity solutions for the density gradient columns. The water was filtered through a 90 micron mesh. The low salinity solution was prepared by adding 1.072 l distilled water to 4.0 l of seawater. The high salinity solution was made by adding 42 g sodium chloride to 5.0 l of seawater.

The columns were calibrated by inserting five glass floats in each column, the specific gravities, $\Delta\rho$, ranging from about 1.021 to 1.027 g/cm3. The table shows the Id. number for each float and the exact specific gravities, $\Delta\rho$, at 11. 5 °C and 14 °C . The absolute specific gravity of the floats was given with an accuracy of +/- 0.0002 g/cm3.

Column I			Column II			Column III		
Id. No.	$\Delta\rho$ at		Id. No.	$\Delta\rho$ at		Id. No.	$\Delta\rho$ at	
	11.5 °C	14.0 °C		11.5 °C	14.0 °C		11.5 °C	14.0 °C
23744	1.0214	1.0214	23743	1.0210	1.0210	23742	1.0203	1.0203
22635	1.0233	1.0233	23745	1.0228	1.0228	22633	1.0218	1.0218
20381	1.0243	1.0242	20377	1.0248	1.0247	20380	1.0241	1.0240
20375	1.0255	1.0254	20372	1.0262	1.0261	20374	1.0256	1.0255
20366	1.0270	1.0269	20358	1.0281	1.0280	20362	1.0276	1.0275

The fish eggs to be measured were introduced into the columns with a pipette just below the surface water in the columns, and eggs are allowed to settle for 3-4 hours before first reading of the vertical position in the column. During the present survey only wild caught horse mackerel eggs were measured, and only from one single station. The eggs were first measured 16 hours after they were first inserted in the column. Neutral buoyancy of the eggs was expressed in salinity units by calculating the salinity gradient in the column from the absolute densities of the floats and from the temperature in the columns.

2.5 Mud sampling and experiments on oxygen tolerance in larval and juvenile fish

A separate project on mud sampling and onboard experiments on oxygen tolerance of larval and juvenile fish was conducted by Drs. Bronwen Currie and Kathie Noli-Peard. Mud sampling positions are shown in Figure 1.1. The complete results from the project (Currie and Noli-Peard in prep.) are reported separately from the present cruise report.

2.5.1 Sediment corer

A small multicorer MC 200-4 (Ocean Instruments, San Diego, USA) -encoded “Eagle” on the cruise - holding 4 tubes 32.5cm x 6.25cm, was deployed at 18 stations over the inner shelf mud belt. Successful cores were examined microscopically for abundance of sulphur bacteria.

2.5.2 Onboard experiments on low oxygen tolerance of juvenile fish

Experimental glass aquaria 60cm x 40cm x 40cm, secured in a wooden frame, were set up on deck. They could be sealed with a small circular glass roof-window, and were fitted with stopcock inlets and outlets from the nitrogen gas supply and for water sampling respectively. A nitrogen cylinder was secured next to the aquaria with regulated flow to both aquaria. A large plastic holding container alongside the aquaria was used to receive and hold the experimental fish, serving also as a control tank. Water supply for all the experiments was the same: ambient subsurface water pumped on board to the fish deck. Control water was aerated using the deck air supply. Water in the aquaria was deoxygenated as required by bubbling through nitrogen gas. The DO (dissolved oxygen) content was accurately determined at any stage of the experiment by tapping off a sample for Winkler analysis.

A stock solution of sodium sulphide dissolved in deoxygenated seawater was used to add sulphide as required to the tanks. The ambient sulphide concentration of sulphide in the tanks, as with oxygen, was sampled at intervals throughout each experiment. Sulphide analyses were carried out on board using the Cline method.

Experimental fish were retrieved from trawls immediately they came on board and acclimatized for at least 30 minutes in the holding container. Fish used were 0-1year old juveniles, of uniform size. Experiments using varied combinations of hypoxia, anoxia and sulphide were carried out together with 2 controls.

CHAPTER 3 RESULTS

3.1 Physical measurements

3.1.1 Weather

Wind direction during the survey period 30 March to 13 April 2001was, as normally, quite constant. It was veering between 170 and 210 degrees (Figure 3.0) with a mean direction of 180. Daily mean wind speed was varying between 8 and 27 knots (Figure 3.0). On the days before the survey started (30 March – 1 April) wind speed was declining from 25 to 13 knots. During the first part of the survey (2 – 4 April), in the region from Sandwich Harbour northwards to Cape Cross, the wind speed was on a low level, 8 –14 knots. On the 5 – 6 April, daily mean wind speed was at the maximum of 27 knots with maximum speeds of 35 knots. For the remaining part of the survey daily mean wind speed was varying between 16 and 21 knots.

3.1.2 Hydrography

The horizontal temperature distributions displayed the typical upwelling features of the region with lowest temperatures inshore and increasing towards north and west. At 10 m depth inshore temperatures increased from 17 ^{o}C at Walvis Bay to 19 ^{o}C at Möwe Point (Figure 3.1). A local intensifying of the upwelling was evident around Cape Frio, from Rocky Point to Kunene River (Figures 3.1 – 3.8). This local upwelling cuts through the southward advancement of the warm Angolan water. At 10 m depth the warm-water front had reached 19 to 21 ^{o}S. The warm-water front was most predominant just below the Ekman layer, i.e. at 35 m depth, where it had advanced as far south as 21 – 22 ^{o}S (Figure 3.2).

Similar to earlier eggs and larval surveys (Sundby et al. 2001) mesoscale eddies seems to be present in the subsurface region below the Ekman layer. This was most apparent at 50 m depth (Figure 3.3) where both cold-core and warm-core eddies were found. The cold-core and low-salinity eddy was found in the southern part of the area of investigation, off Walvis Bay, while the warm-core and high-salinity eddies are found further north, off Cape Frio and Dune Point, corresponding with the areas where mesoscale eddies were found during the hake egg survey in September/October 1998 (Sundby et al. 1998).

At 10 m depth, the lowest oxygen concentrations were located nearshore from Henties Bay (22^{o}S) to Dune Point (20^{o}S) with a minimum of 2 ml O_2 l^{-1} off Ambrose Bay at 21^{o}S (Figure 3.9). In the bottom-near layers (Figure 3.11), lowest oxygen concentrations were observed offshore at 150-300m depth. Hydrogen sulphide in the

water column, however, was only found at one nearshore station 10 nautical miles off Pelican Point, Walvis Bay.

3.2 Plankton sampling

3.2.1 Fish eggs

Spawning intensity was very low for all species during April. This is corresponding well with the earlier monitoring programmes in Namibian waters (O'Toole 1999), that show the major spawning season for all species to be during September-April and with a bimodal spawning distribution for some of the species (e.g. hake and sardine). Horse mackerel, hake, sardine and Maurolicus eggs were the main species. No anchovy eggs were found.

Horse mackerel
Horse mackerel eggs were the most abundant species (Figure 3.12). The eggs were mainly found to the north of Cape Frio. Two major spawning patches were found, one off Baia dos Tigres and the other between Kunene River and Cape Frio. Only minor numbers of horse mackerel eggs were found in Namibian waters south of Cape Frio. One smaller patch of eggs were found inshore from Cape Frio extending right southward to 20 ^{o}S. The horse mackerel eggs were found mainly at depths between 50 and 100 m where there is a strong thermocline ranging from about 15 ^{o}C at 100 m and up to 21 ^{o}C at 50 m. According to the measurement on egg buoyancy (see section 3.4) the eggs have been spawned at 150 to 100 m depth where the ambient temperature is ranging from 13 to 15 ^{o}C. Hence, the eggs are spawned below the warm Angolan water. However, as the eggs develop they ascend up into the warm Angolan water that advances southwards. It is uncertain whether the eggs origin from *T. t. trecae* or *T. t. capensis.* However, trawl samples below the egg distributions (see section 3.3) indicate that these are from spawning *T. t. capensis*.

Hake
Very low spawning intensity was recorded for hake (Figure 3.13). Hake eggs were found only at two stations, at the most offshore station off Sandwich Harbour and at an offshore station off Dune Point. Hake larvae were more abundant. It indicates that the beginning of April is the termination of the hake spawning season. All of the eggs were found at depths between 50 and 200 m in correspondence with earlier findings by Sundby *et al*. (1998, 2001).

Sardine
Sardine eggs were practically absent from the samples (Figure 3.14). Only at two stations, one inshore station off Swakopmund and one inshore station off Ambrose Bay had sardine eggs. Similar to the horse mackerel and hake, the sardine larvae were more abundant than the eggs.

Maurolicus
Maurolicus eggs were only found at one station (Figure 3.15). Similar to earlier surveys the eggs were found at offshore stations and at large depth. The present station was the most offshore station off Henties Bay and the eggs were found at 200 - 100 m depth.

3.2.2 Fish larvae

The main species found were horse mackerel, sardine, hake, gobies and anchovy. Surprisingly, the anchovy was the most second most abundant of the species, only slightly exceeded in abundance by horse mackerel. Sardine, hake and gobies were all found at low concentrations.

Horse mackerel
Figure 3.16 shows the distribution of horse mackerel larvae (#/10 m^2). One patch of high concentration is found off Cape Cross. This patch was extending down to 50 m depth (Figures 3.17 and 3.18) with the highest concentration in the upper 25 m (Figure 3. 17). No larvae were found below 50 m depth here (Figure 3.19).
Another patch extending far offshore was found in the Palgrave Point region. Here, large numbers of larvae were found below 50 m depth, and the peak concentration was found from 25 to 50 m depth. The third part of the larval distribution was found rather close inshore in an elongated form from Dune Point to Baia dos Tigres. Here, highest concentrations were in the upper 25 m except in a small patch at Cape Frio where the highest concentration was found below 50 m depth.

Anchovy
Figure 3.20 shows the distribution of anchovy larvae (#/10 m^2). It was the second most abundant species of the fish larvae, and it was found in two large concentrations. The largest one was extending from Ambrose Bay to Rocky Point with a small branch extending down to Henties Bay. In the extended branch the larvae were found in the upper layer above 25 m depth (Figure 3.21). The major fraction of the larvae in this patch was found below 25 m depth (Figure 3.22). A large part of the larvae was even found below 50 m depth (Figure 2.23). The other patch was found between Cape Frio and Kunene River. Also here, the major fraction of the larvae was found below 25 m depth.

Hake
Hake larvae were found at small concentrations in an elongated band from Cape Frio to Palgrave Point (Figure 3.25). The larvae were found mainly below 50 m depth corresponding to earlier findings by Sundby *et al*. (1998, 2001).

Gobies
Gobies were found in four small patches from Walvis Bay to Rocky Point (Figure 3.26). They were mainly found below 25 m depth.

3.3 Trawl sampling

A trawl station (772) conducted in Tiger Bay yielded a horse mackerel catch consisting of 54 % *Trachurus trecae* and 46 % *Trachurus capensis*. However both species were juvenile fish with a mean length of 13 cm for *T. capensis* and 12.5 cm for *T. trecae*. Another trawl station (773) was done outside Tiger Bay in an area with a high density of horse mackerel eggs (Fig. 3.12). This trawl contained a horse mackerel catch consisting of 74 % *T. trecae and* 26 % *T. capensis. T. trecae* had a mean length of 17.5 cm and *T. capensis* had a mean length of 19.5 cm. At these lengths at least 50 % of the fish could be mature (Jens Krakstad – pers. comm.). This implies that most of the eggs outside Tiger Bay probably belonged to *T. trecae.* The rest of the trawls were set in Namibian waters and contained only *T. capensis*. Horse mackerel eggs found in Namibian waters thus definitely belonged to *T. capensis*.

3.4 Buoyancy and development of horse mackerel eggs and larvae caught in the Multinet plankton sampler.

Most of the larger horse mackerel caught at the bottom trawl stations were dissected and the gonads inspected in order to try to conduct artificial fertilisation of the eggs. However, no ripe and running fish were found during the present survey. Also, egg concentrations found in the Multinet plankton sampler were low compared to the cruise in February/March 2000. Only at one single station wild caught live horse mackerel eggs were found that could be used for measuring the egg buoyancy. This was during the second part of the survey at Multinet station 80 off Möwe Point. Most of the horse mackerel eggs died very quickly when retrieved from the plankton net at this station, most probably due to the high temperature of the surface water, 22.5 ^{o}C. However, we managed to put 10 live eggs sampled from the 100 –150 m depth layer into the density gradient column, which was cooled at a temperature of 11.5 ^{o}C. They were all newly spawned, stage 1 eggs, when they were inserted into the density gradient column # 2 on 14 April 01:30. The staging was according to King *et al*. (1977). The temperature in the depth layer from where they were collected was below 15 ^{o}C.

The specific gravity of the 10 horse mackerel eggs were measured 5 times during the period from insertion until the experiment was stopped on 16 April 10:00 hours, 57 hours after they were caught in the Multinet. One of the eggs had then hatched. The measurement of specific gravity are shown in Appendix I. Figure 3. 27 shows mean specific gravity through development.

Time	Temp.	No. eggs	Mean egg buoyancy sal. Units	Mean egg spec. gravity	No. larvae	Mean larval buoyancy sal. Units	Mean larval spec. gravity
14.04.01 17:15	11,5	9	32,55		0		
14.04.01 23:45	11,5	9	32,77		0		
15.04.01 08:40	11,5	10	33,12		0		
15.04.01 17:10	11,5	9	33,44		1	31,45	
16.04.01 09:30	11,5	4	33,26				

3.5 Vertical distributions of eggs and larvae

Horse mackerel
The horse mackerel eggs and larvae had a relatively wide vertical distribution and were found in all the depth strata from 200 m to the surface. When data from all stations except the 24-hour station were pooled, horse mackerel eggs were mainly found deeper than 50 m (Figure3.28). The highest fraction was observed in the 100-150 m interval (51.7 %) while 37.2 % were observed in the 50-100 m interval. The vertical distribution of horse mackerel larvae was opposite to the eggs (Figure 3.28). The highest fraction of larvae was found in the upper 50 metres (42.6% in 0-25 m and 30.3 % in 25-50 m) while only 5.1 % were found in the 100-150 m interval.

The diurnal pattern in vertical distribution of horse mackerel larvae was different for the 24-hours station and the survey stations. The data from the other stations than the 24-hours station, showed that the larvae were distributed deeper during the night than during the day (Figure 3.29). The fraction of larvae found in the upper 25 m decreased from 52.9 % during the daytime stations to 30.0 % during the night-time stations. However, this pattern was different from the data of the 24-hour station (Figure 3.30). The fraction of larvae in the upper depth intervals did also decrease during night time for these data, but the picture was not as clear-cut as for the other stations.

Anchovy
No anchovy eggs were found during the survey. The vertical distribution of the anchovy larvae was different than for the horse mackerel larvae (Figure 3.31). Anchovy larvae had a narrower distribution (no larvae found deeper than 150 m), but still a large fraction was found deeper than 25 m. Only 28.0 % were observed in the upper 25 m while more than 70% were found between 25 and 100 m. For anchovy the diurnal pattern was more clear-cut and there was correspondence between the data collected at the 24-hour station and at the other stations (Figures 3.32 and 3.33). During daytime the larvae were higher up in the water column than at night when they were deeper and more widely distributed.

Sardine
Only 63 sardine larvae and 3 eggs were found, but when the larvae data was split into day and night stations, the pattern was the same as for the anchovy larvae. The sardine larvae were concentrated towards the surface during daytime and more widely and deeper distributed during night time (Figure 3.34).

3.6 Mud sampling and experiments on low-oxygen tolerance

3.6.1 Sulphur bacteria

All three species of large sulphur bacteria *Thiomargarita namibiensis*, *Beggiotoa* sp.and *Thioplaca* sp were found in the inner shelf surface sediments between 19 ^{0}S and 23^0 30'. Their distribution was mapped according to relative abundance (fig. 3.35).

3.6.2 Hydrogen sulphide

CTD rosette bottom-water samples containing hydrogen sulphide were found only in the sample at station 268 (off Walvis Bay, approx.100m. water depth).

3.6.3 Experiments on low-oxygen tolerance

Eight experiments were carried out: fish were exposed to varying concentrations and combinations of DO and sulphide. Anoxic (< 0.2 ml O_2 $l^{-1)}$ to severe hypoxic conditions (< 0.5 ml O_2 l^{-1}) resulted in death of all fish within 28 minutes with a 50% mortality time (T50) of 15 minutes. When sulphide was added to hypoxic water T50 was reduced to 9 minutes. For smaller fish < 9 cm, T50 was consistently less. Exposed to hypoxia (< 1ml O_2 l^{-1}) only, the larger fish > 12cm survived for up to180 minutes whilst the smaller fish died within 20 minutes. When sulphide was added to water containing the ambient oxygen concentration, the rate of mortality was 58 minutes. During this experiment deoxygenation of the water occurred due to the presence of sulphide, so that the cause of death could have been the resultant hypoxia, or sulphide, or the combination. In all experiments there was a marked discrepancy in the time of survival between larger > 12cm and smaller <10cm fish. Behaviourally the fish exhibited frantic and rapid escape swimming when exposed to severe hypoxia and/or sulphide. During each experiment the plastic holding container served as a control tank, and in addition two independently-run controls using untreated water were run in the aquaria: in both 80%+ of the fish survived for 5 hours before being discarded. Unfortunately no very young stages (<6 cm) were available for experimentation.

CHAPTER 4 DISCUSSION AND CONCLUSIONS

The second cruise of the BENEFIT horse mackerel recruitment project, presented in this cruise report, confirmed the results of the pilot survey in February/March 2000 that horse mackerel is a mesopelagic spawner in Namibian waters. The eggs are found at highest concentrations in the depth layer from 100 to 150 m depth. Only a very small fraction of the eggs are found in the offshore-moving Ekman layer (i.e. 0-25 m depth). The measurements on buoyancy of eggs and larvae were also consistent with the measurements made during the first cruise. The neutral buoyancy, expressed in salinity, ranges from about 32.5 to 35.0. This implies that the eggs ascend at a relatively slow speed and that a large fraction of the larvae will hatch below the surface layer. Consequently, spawning, ascending of the eggs, and the resulting onshore transport of eggs and larvae by the circulation below the Ekman layer is largely similar to Namibian Cape hake (Sundby *et al.*1998, Sundby *et al.* 2001). It, therefore, seems that the many of the environmental conditions for the early stages of Cape hake and horse mackerel are similar.

Even though it is not possible to part between the early stages of *T. t. capensis* and *T. t. trecae*, the observations of mature fish from the trawl hauls indicate that the eggs to the north of the Kunene River were spawned by *T. t. trecae*, while the eggs to the south of Kunene River originated from *T. t. capensis*. Most probably, the Angolan warm water front is a natural borderline between the two species.

The egg concentrations of all species were generally low during the survey, and much lower than during the pilot cruise in February/March 2000. It supports earlier observations (O´Toole 1999) that April is the time of the year in Namibian water when spawning terminates. Only horse mackerel eggs were found at significant numbers and only in the northern part of the survey area.

The vertical distribution of larval horse mackerel, anchovy and pilchard were studied and the pattern was similar for all three species. A high fraction of the larvae were always found deeper than 25 meters which means that they will be in the inshore moving layer which is observed under the offshore moving Ekman layer and they will therefore not be subjected to offshore loss. This is in correspondence with results obtained for hake during earlier investigations (Sundby *et al.* 1998; Sundby *et al.* 2001) and sardine larvae during a survey in 1999 (Stenevik *et al*. 2001). Slight variations in this pattern were however observed. For horse mackerel larvae, a higher fraction of the larvae was observed in the upper 25 m than for anchovy larvae. For pilchard larvae during daytime, more than 90% of the larvae were observed in the upper 25 m. This was, however, based on relatively few larvae found on only one rather shallow station. The diurnal pattern in vertical distribution was also studied for the three species. For horse mackerel and anchovy, data were available from a 24-hours station in addition to the pooled data from all the other stations. For pilchard, no data from the 24-hours station was obtained. The pattern in diurnal vertical distribution is also consistent. During daytime the larvae were found higher up in the

water column than during night-time. During night-time the larvae were deeper and had a wider vertical distribution. This pattern was consistent between species and also when data from the 24-hours station was compared with data from all the other stations for each species. The diurnal variations in vertical distribution observed here has also been observed for sardine in Australia (Fletcher, 1999) and Gray (1998) found the same pattern of vertical migration in 80% of the investigated taxa sampled in unstratified coastal waters off Sidney, Australia.

The horizontal distribution of the horse mackerel larvae was more southerly and slightly more inshore distributed than the horse mackerel eggs. This pattern is consistent with the general horizontal circulation pattern below the Ekman layer (Sundby et al. 2001) which will carry plankton inshore and southwards towards the central parts of Namibian waters. It is also consistent with the observations from the Methot net hauls during the cruise in February/March 2000 when large concentrations of pelagic juvenile horse mackerel were found at the innermost stations around Palgrave Point.

During the cruise period the bottom water on the Namibian central inner shelf was relatively well ventilated, as shown by the presence of oxygen at most stations and very limited bottom-water sulphide. Sulphur bacteria were not found densely at any of the cored stations. This contrasts strongly with the conditions in August 2000 (Meteor M48/2 cruise report). Research into the ecology of these bacteria is in its early stages; it is thought that the presence and relative abundance of the different species could relate to the intensity of the sulphidic environment in which they are found.

Tolerances of young (0-1 year-old) horse mackerel revealed that they are able to survive DO concentrations of <1 ml O_2 l^{-1} for up to 3 hours. DO concentrations of < 0.5 ml O_2 l^{-1} result in death within 20 minutes. Sulphide together with hypoxia results in quicker death. This remarkably high tolerance of young fish could help to explain the presence of this species where both hypoxia and hydrogen sulphide naturally occur. Behaviourally, horse mackerel react violently to both sulphide and extreme hypoxia, showing rapid dashes (a probable escape mechanism when they come into contact with affected water).

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Captain Sangolt and his crew onboard R/V “Dr. Fridtjof Nansen” are thanked for their helpful assistance and, particularly, for making the variety of equipment functioning excellent during all kind of weather conditions.

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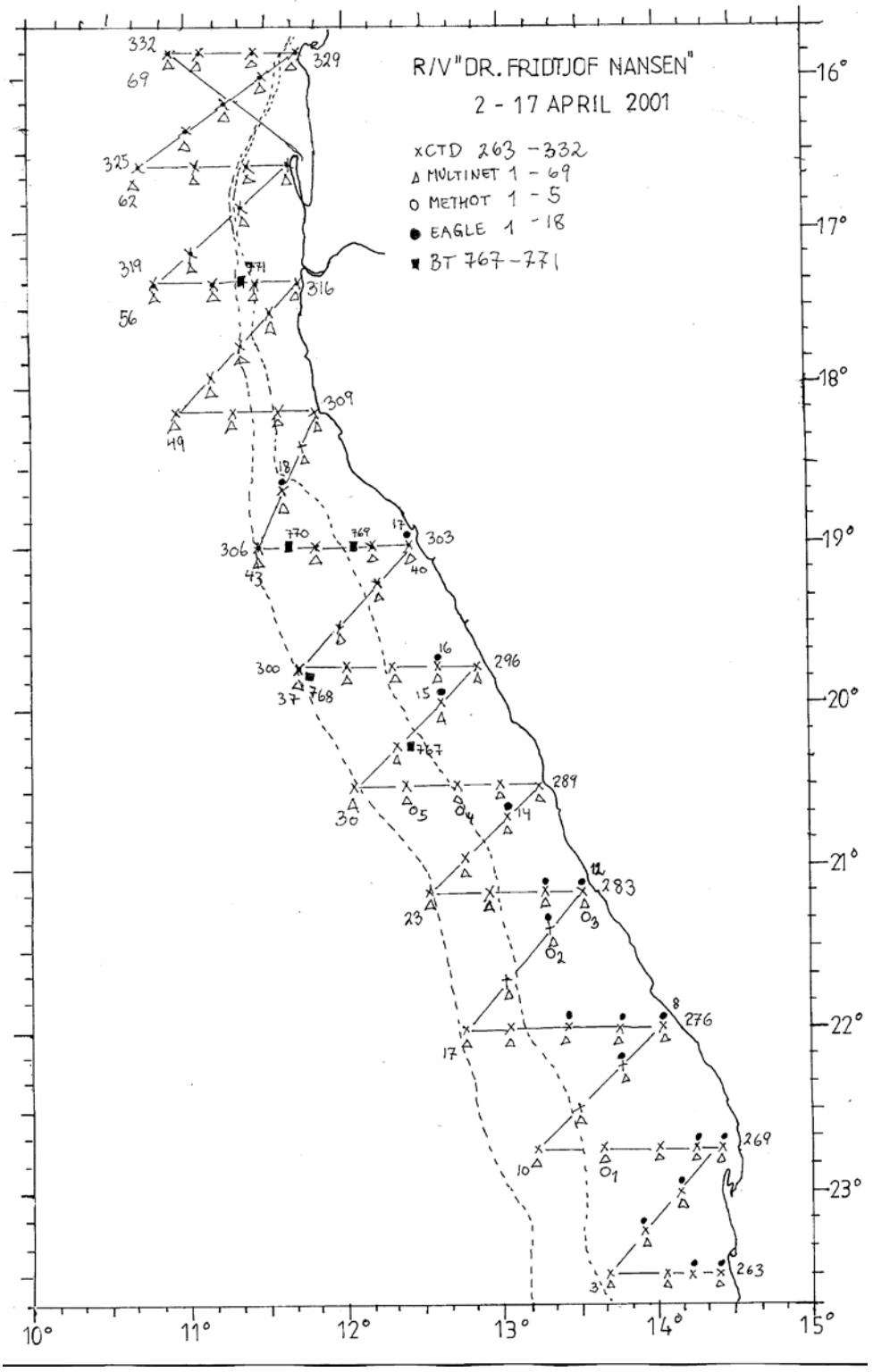

Figure 1.1 Cruise track, 2 – 10 April 2001.

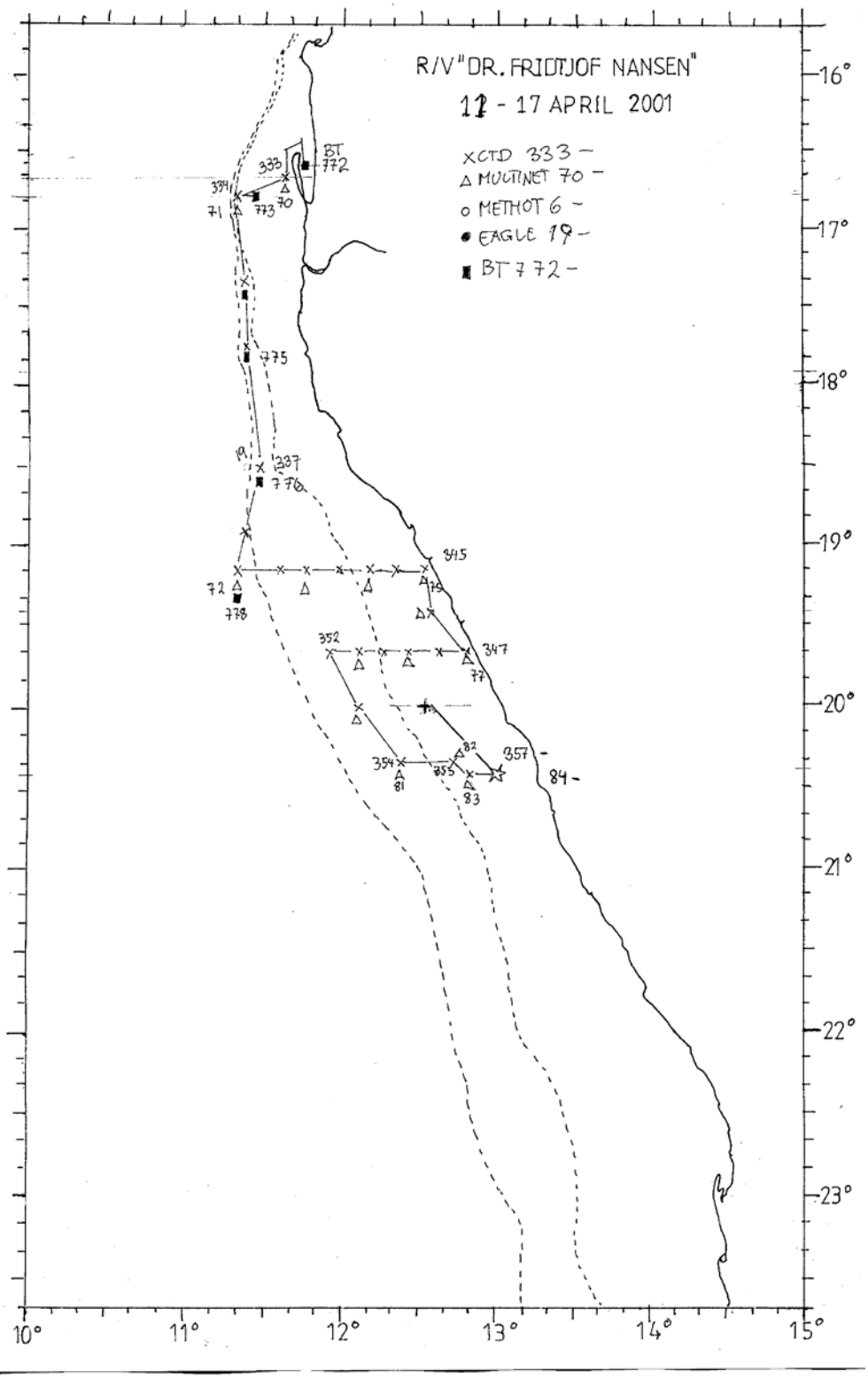

Figure 1.2 Cruise track, 11- 15 April 2001.

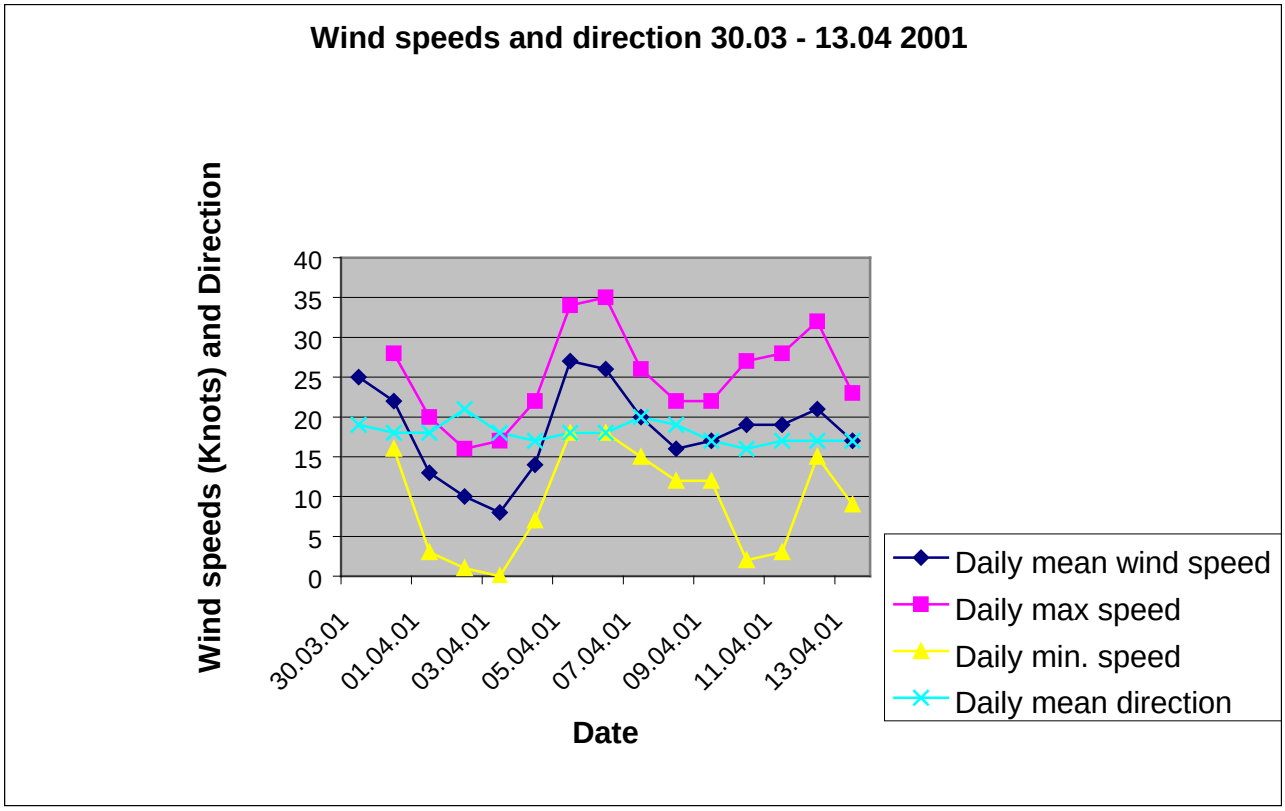

Figure 3.0 Daily mean, max. and min. wind speed and direction along the cruise track of “Dr. Fridtjof Nansen” 30 March –13 April 2001.

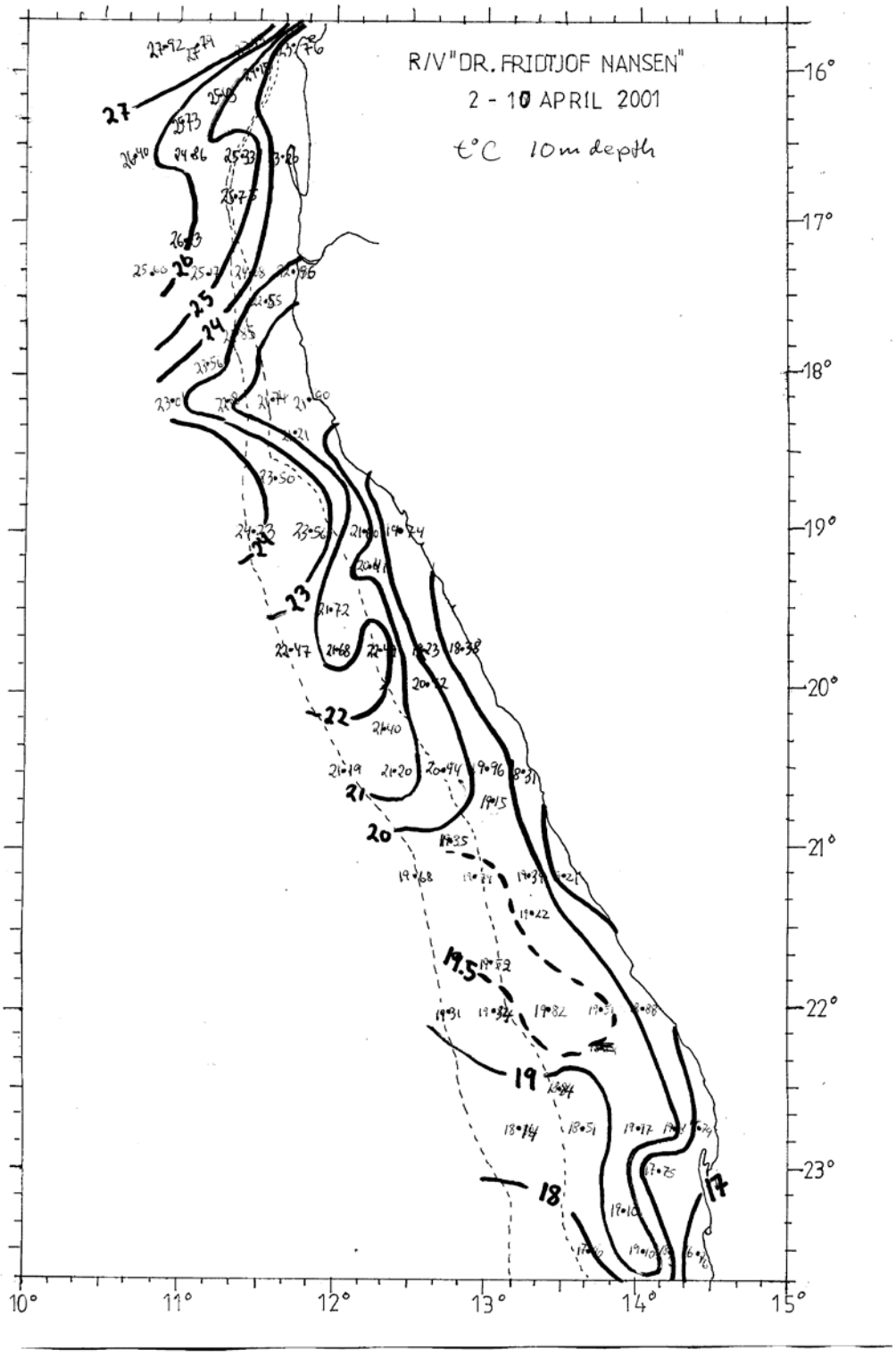

Figure 3.1 Temperature (°C) at 10 m depth, 2 – 10 April 2001

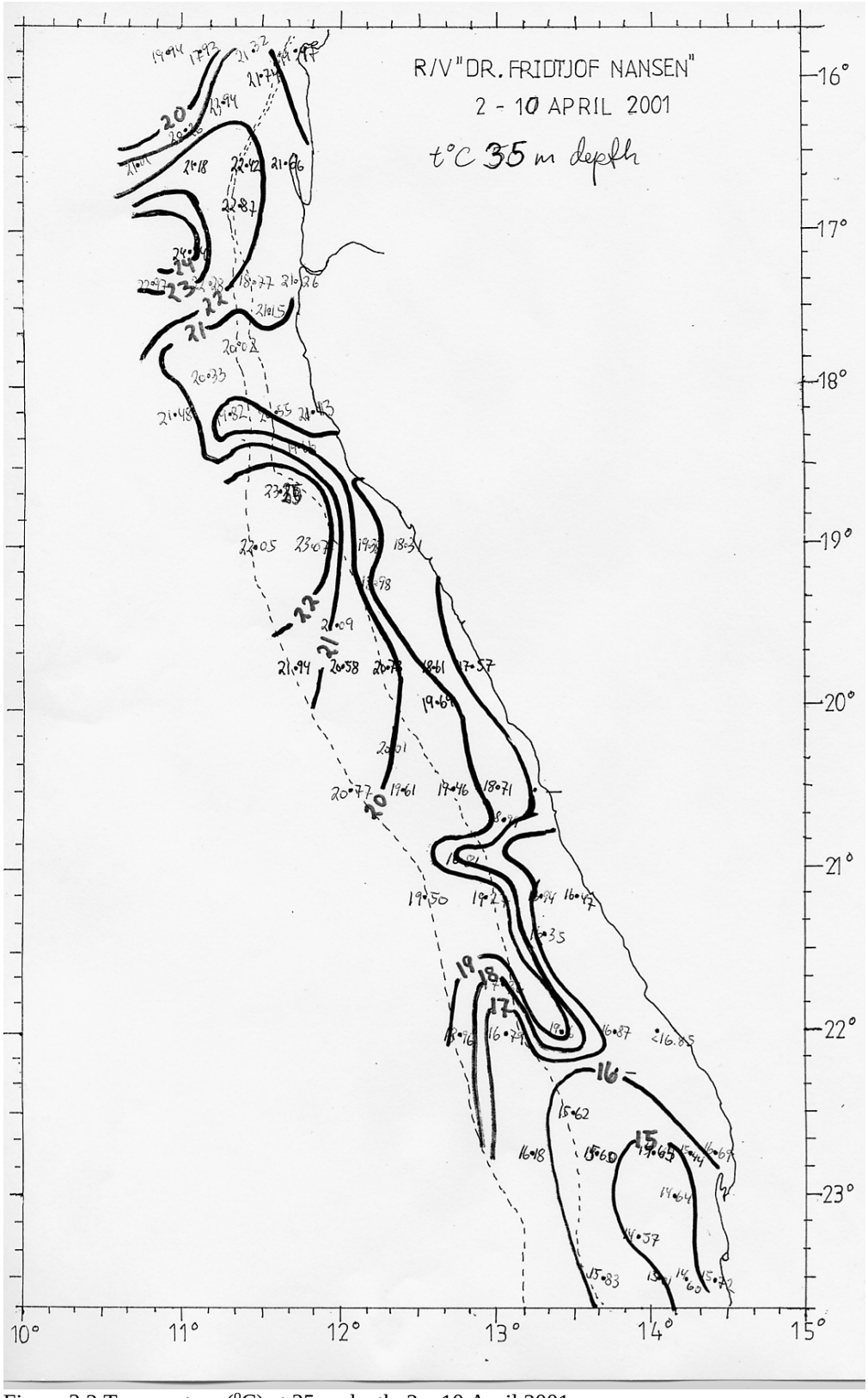

Figure 3.2 Temperature (°C) at 35 m depth, 2 – 10 April 2001

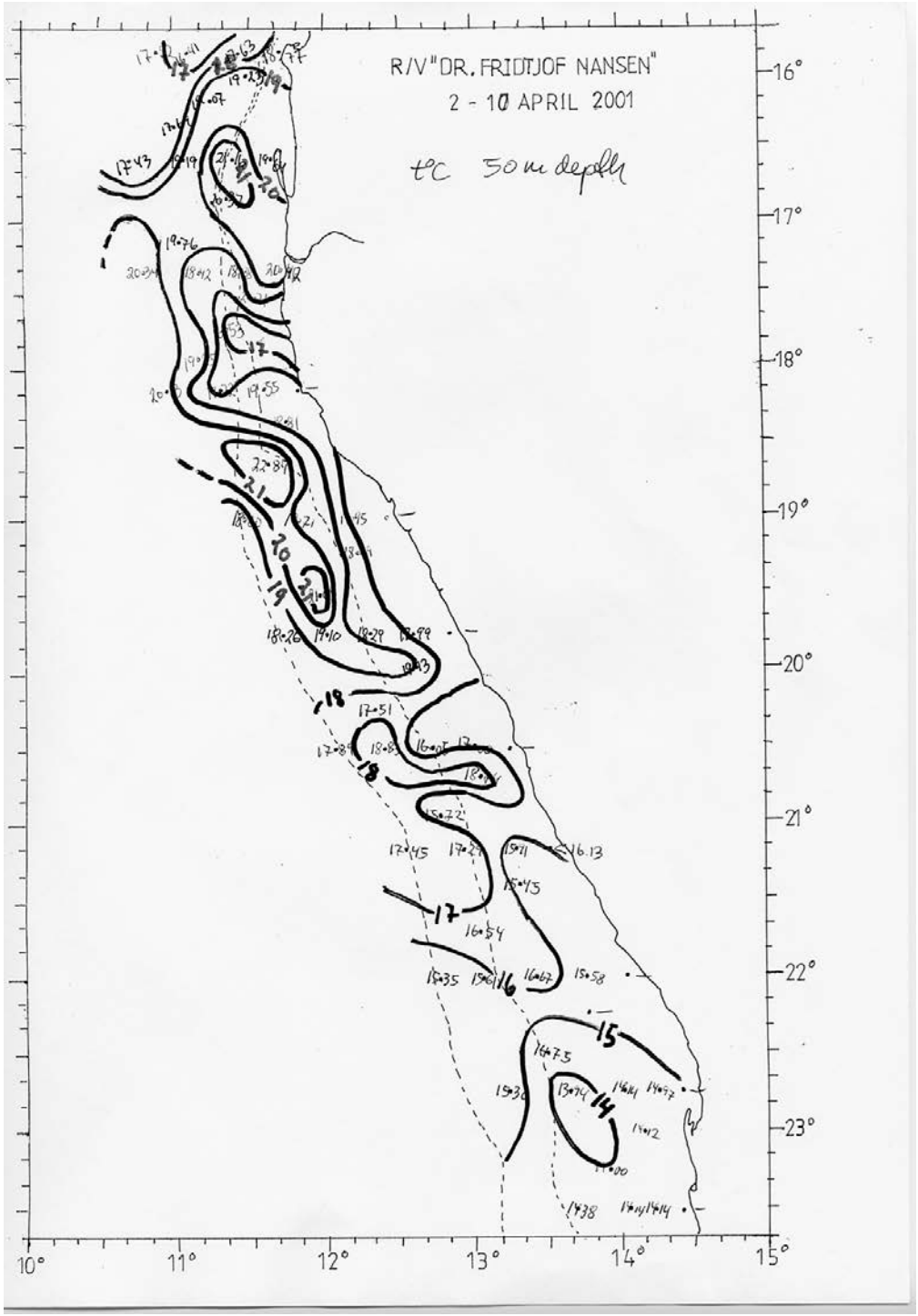

Figure 3.3 Temperature (°C) at 50 m depth, 2 – 10 April 2001

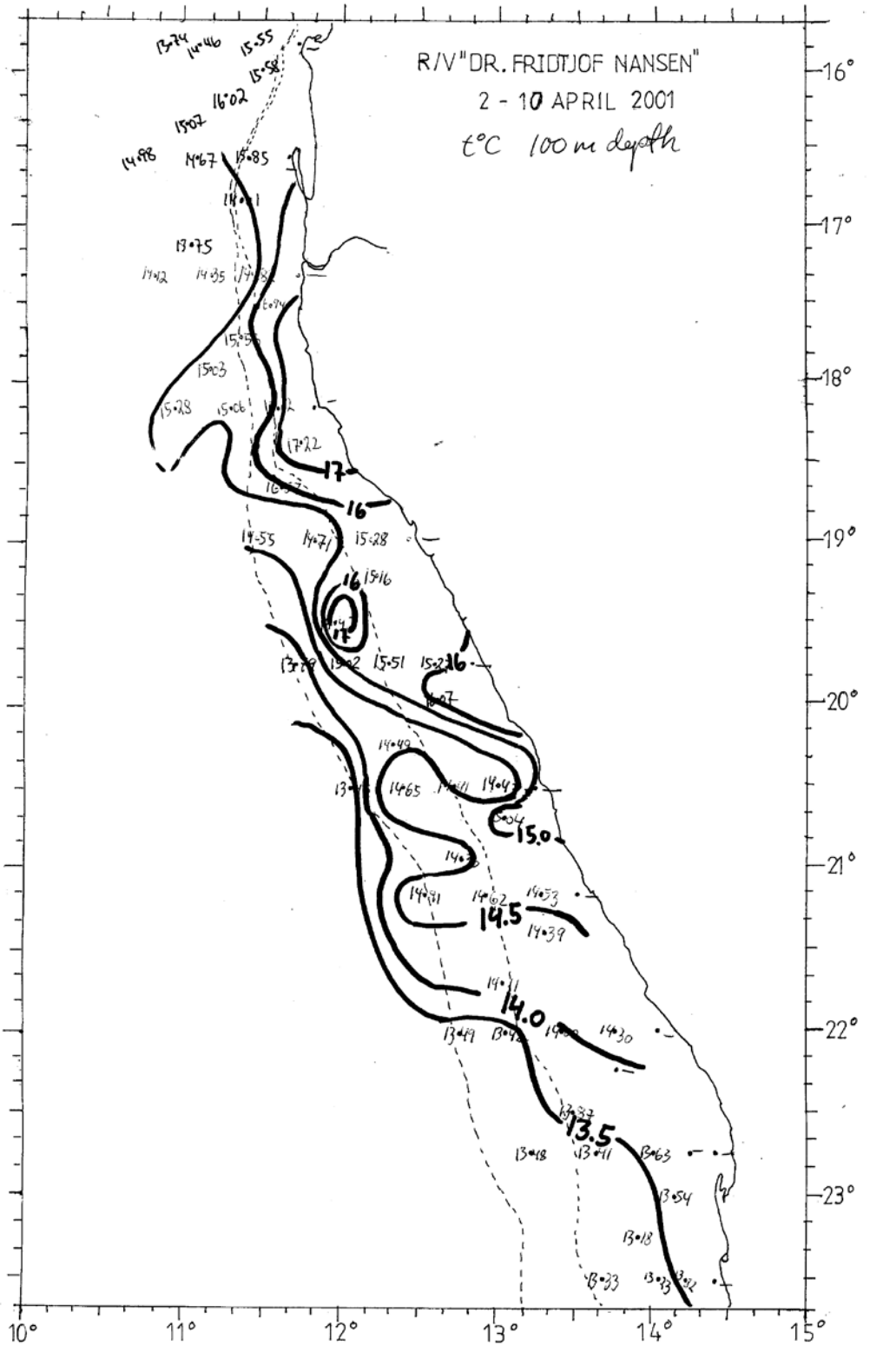

Figure 3.4 Temperature (°C) at 100 m depth, 2 – 10 April 2001

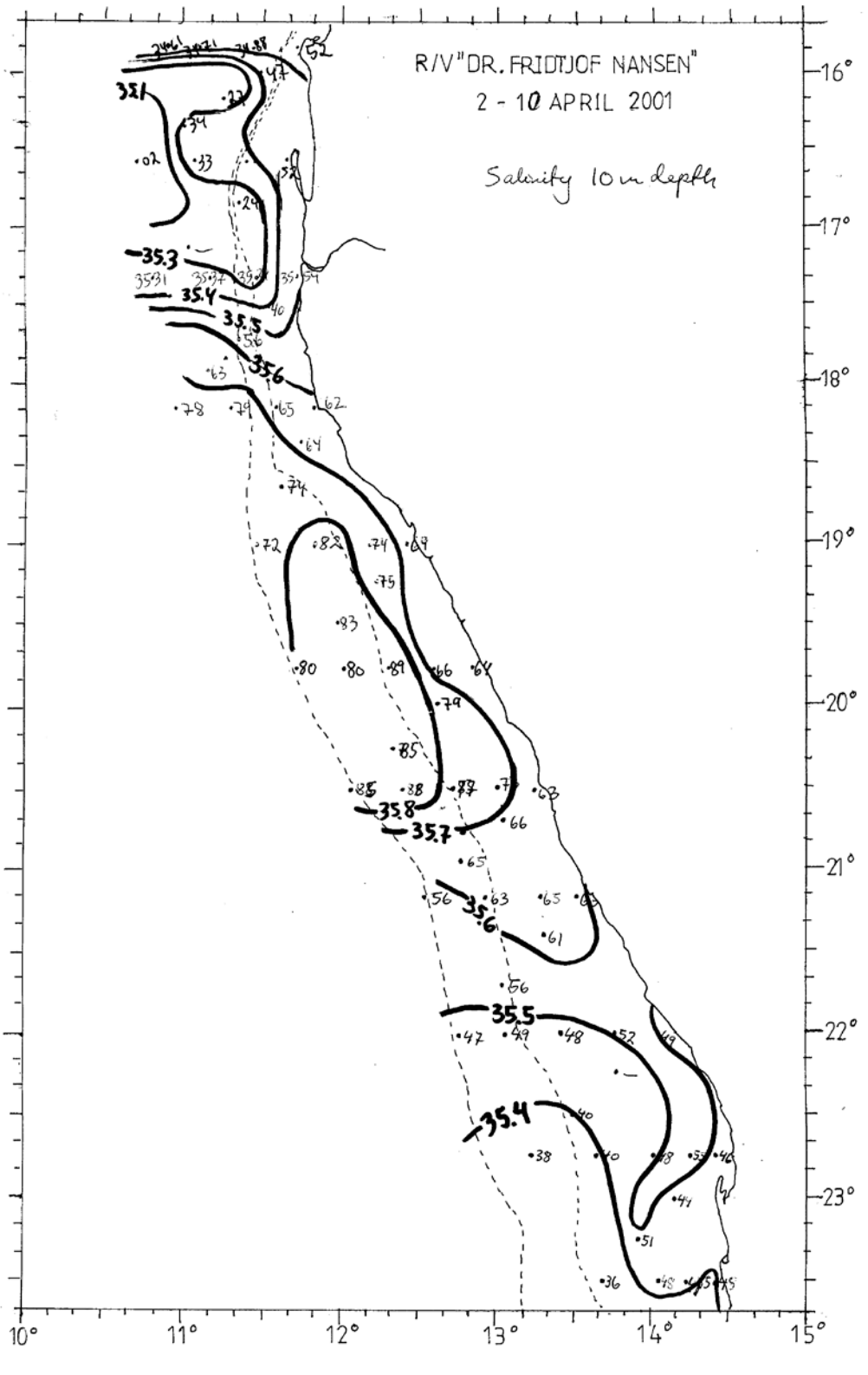

Figure 3.5 Salinity at 10 m depth, 2 – 10 April 2001

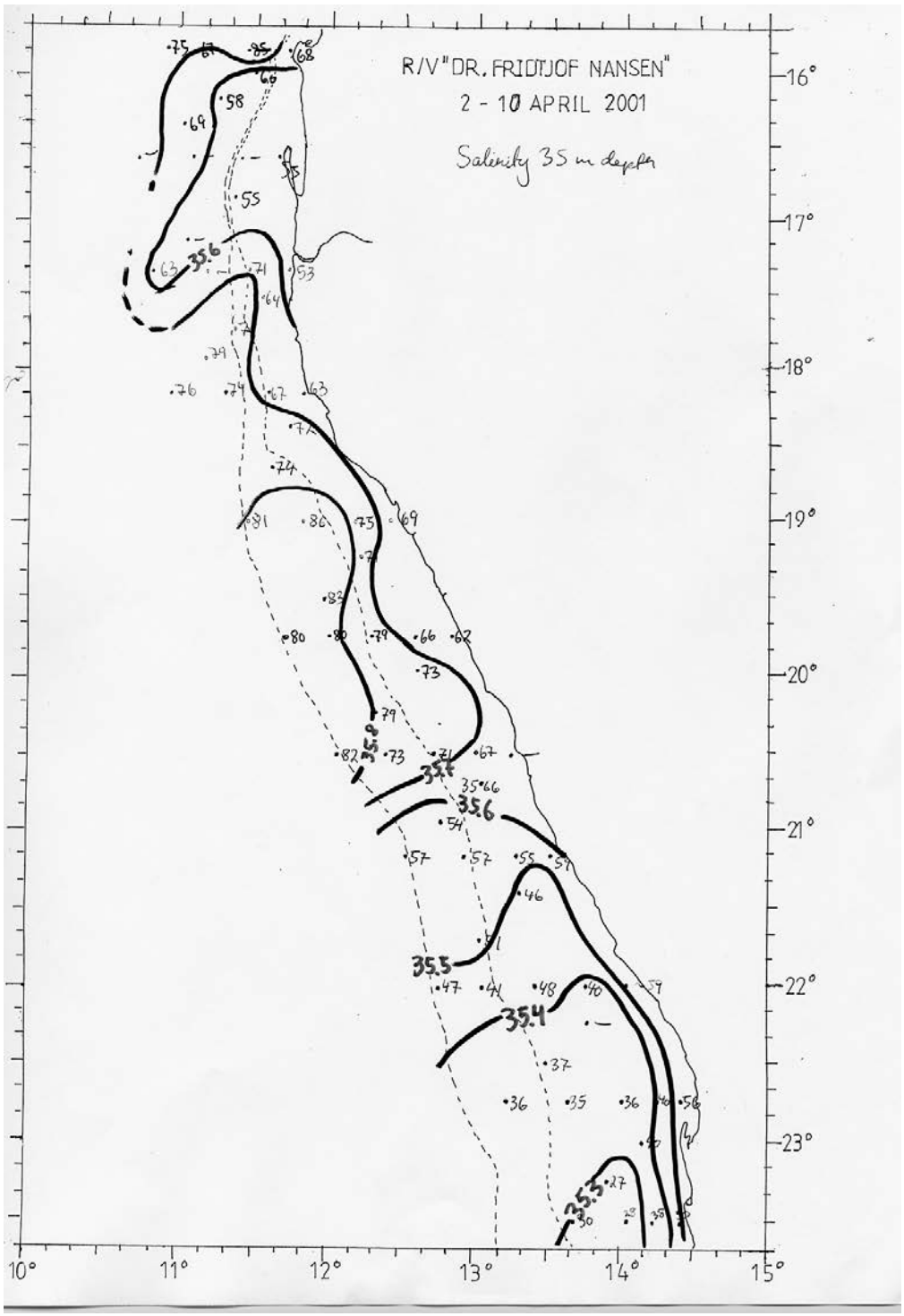

Figure 3.6 Salinity at 35 m depth, 2 – 10 April 2001

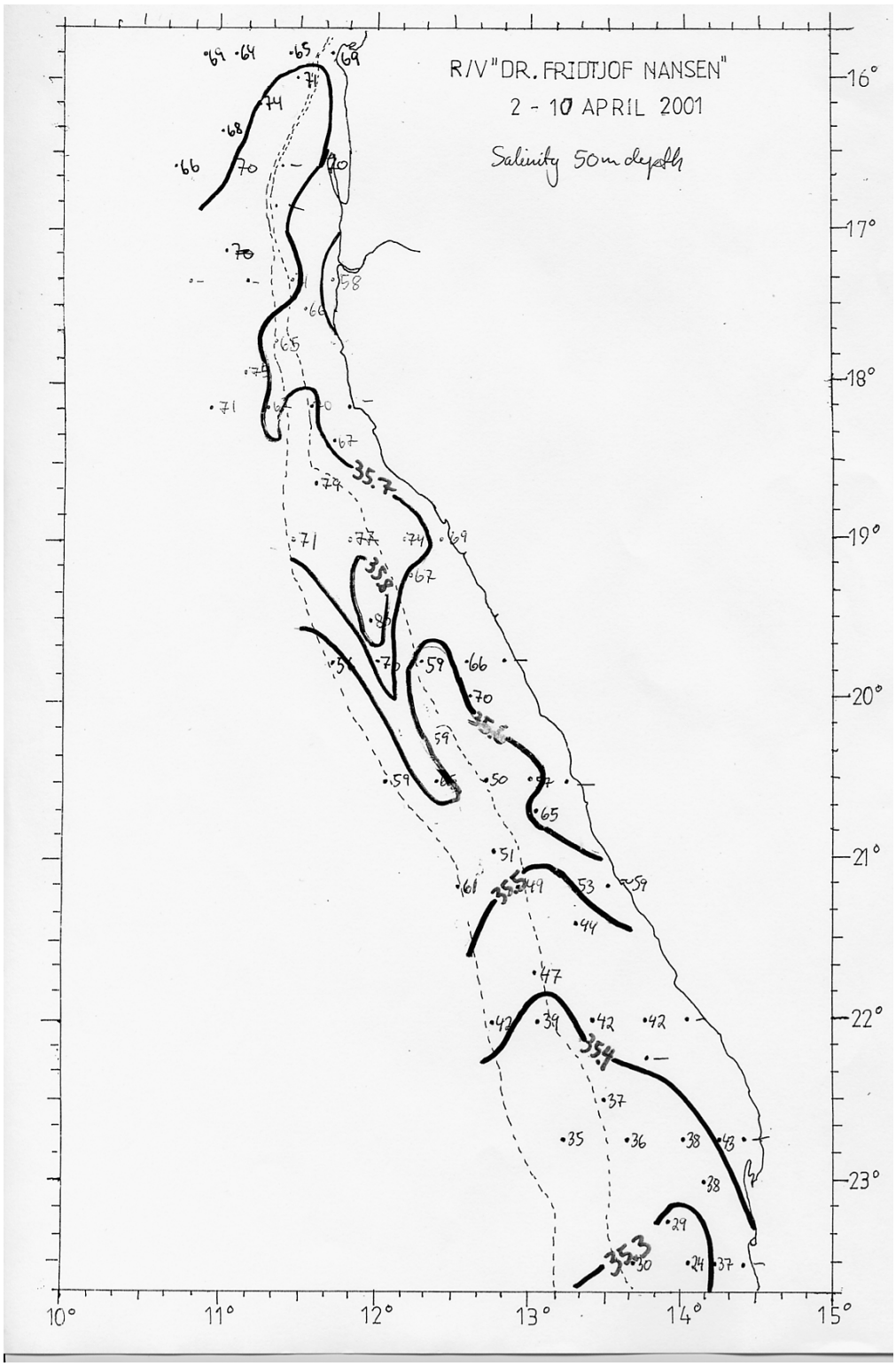

Figure 3.7 Salinity at 50 m depth, 2 – 10 April 2001

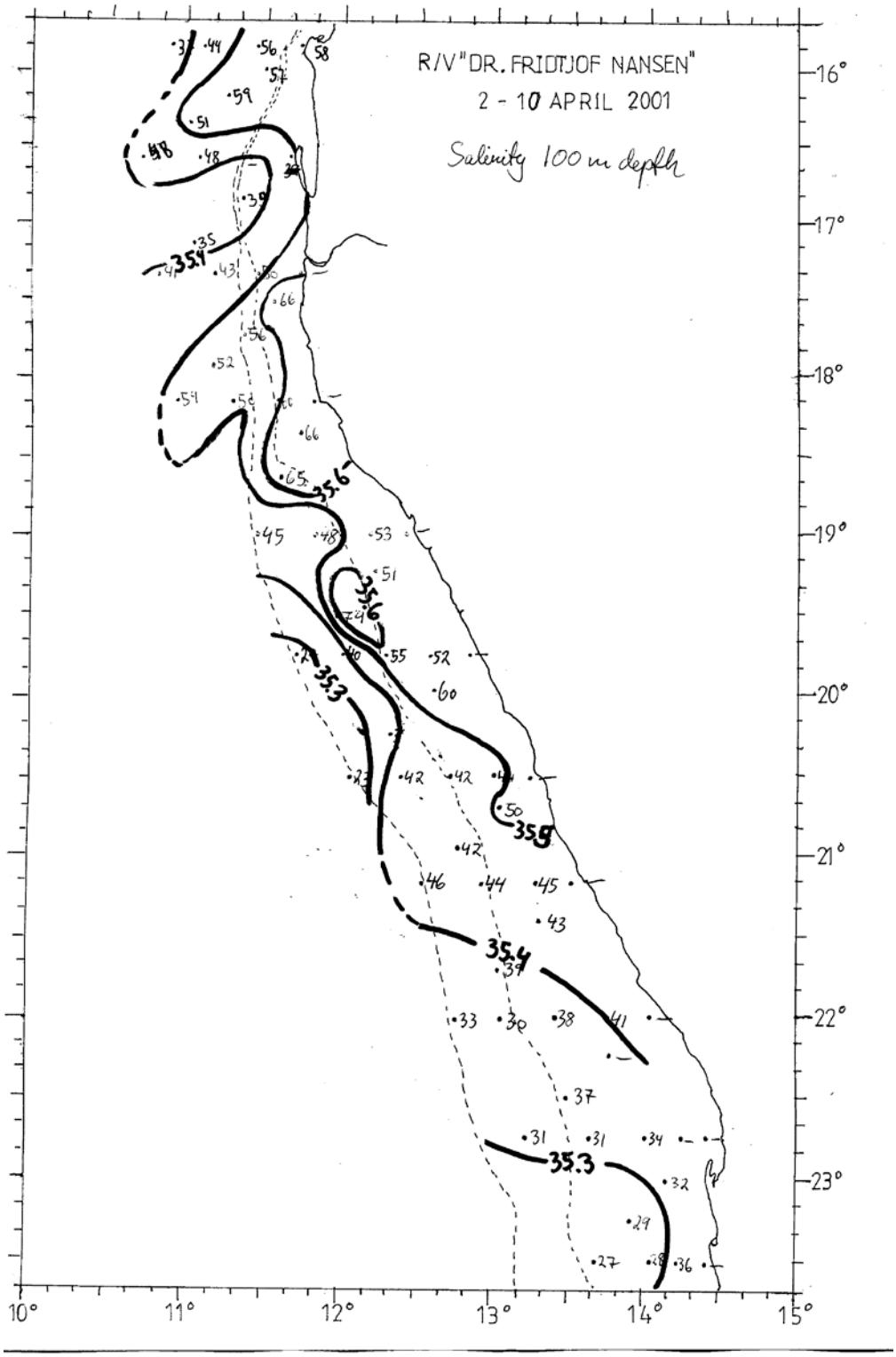

Figure 3.8 Salinity at 100 m depth, 2 – 10 April 2001

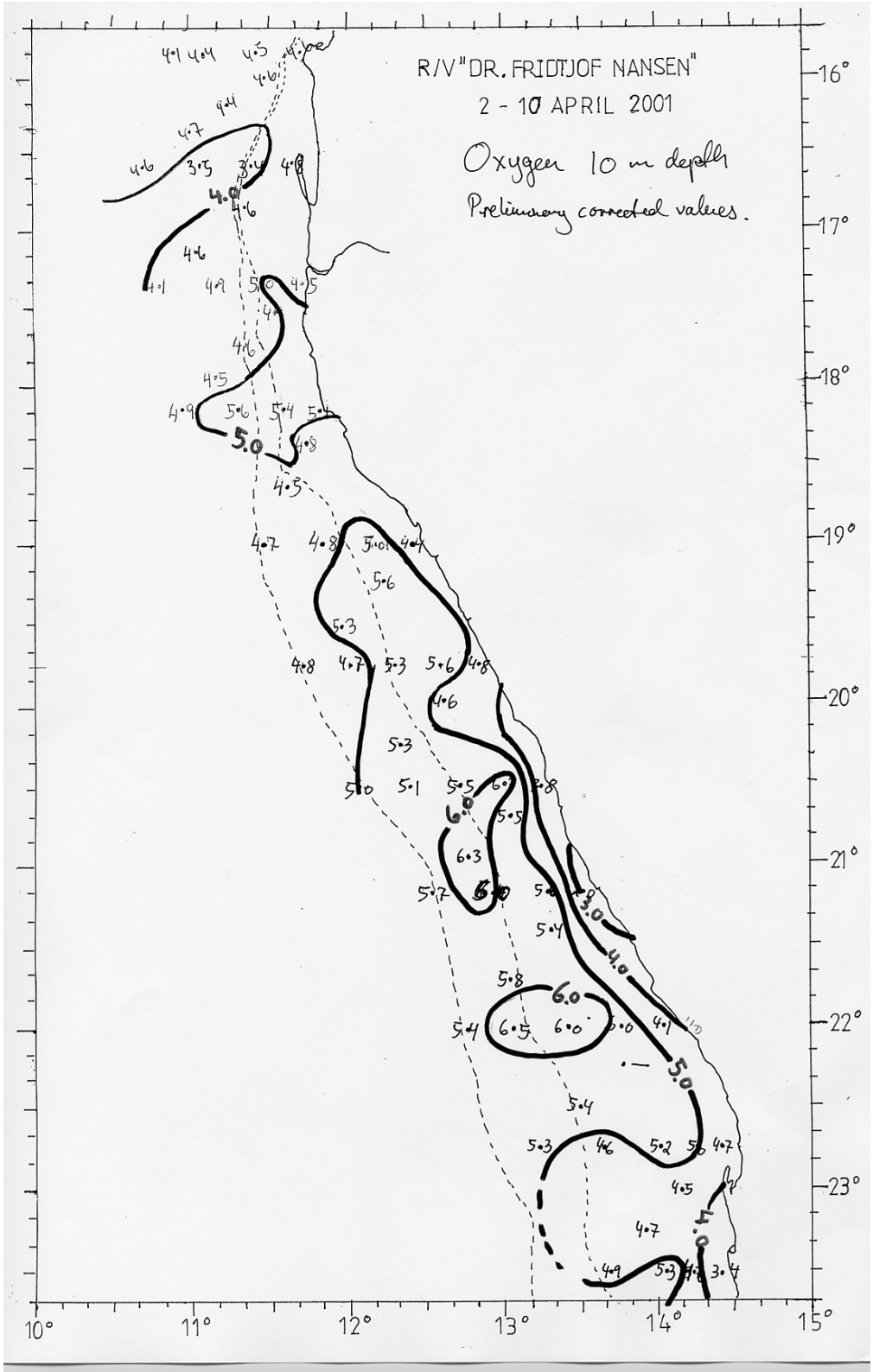

Figure 3.9 Oxygen concentration (ml/l) at 10 m depth, 2 – 10 April 2001

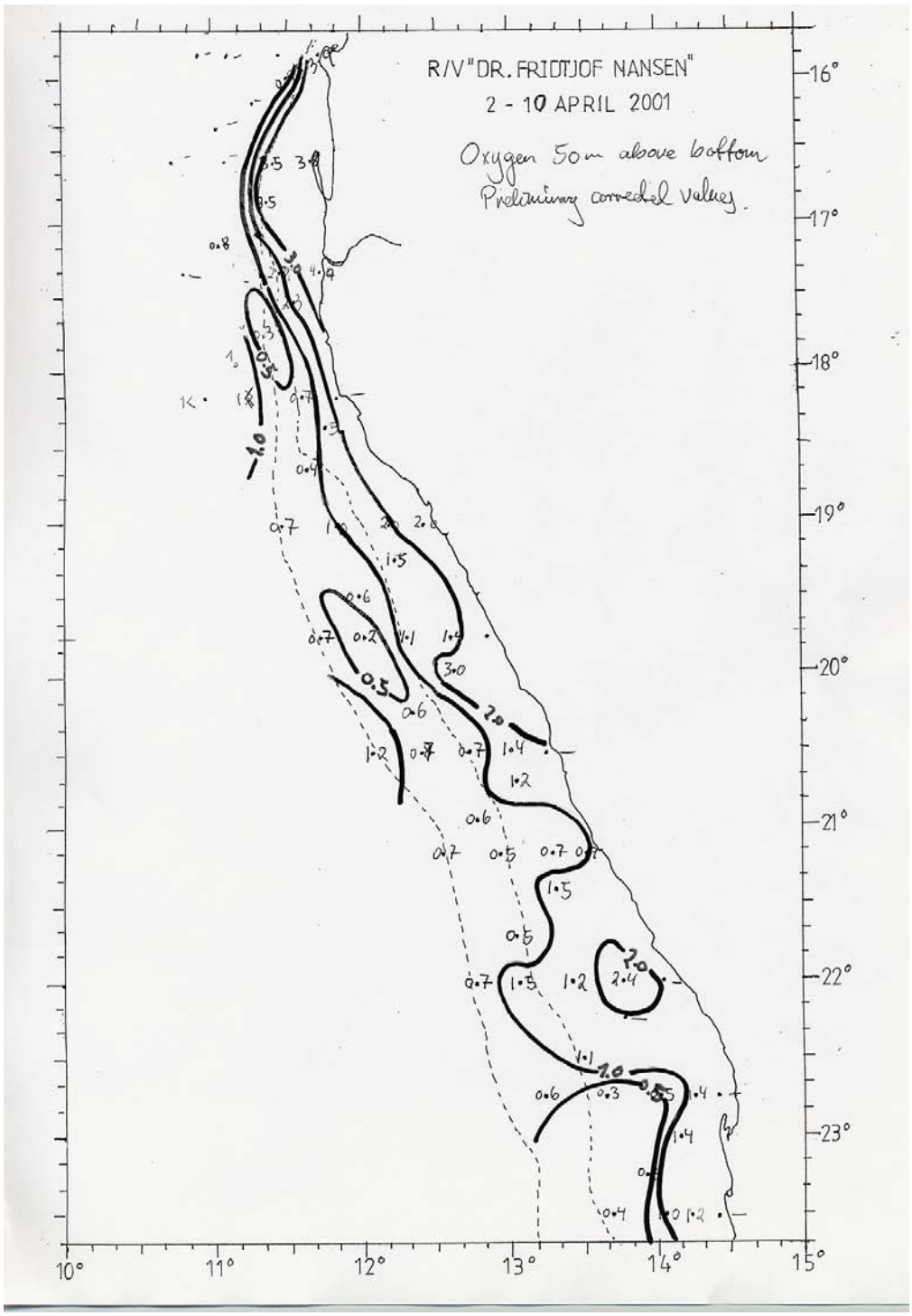

Figure 3.10 Oxygen concentration (ml/l) at 50 m above the bottom, 2 – 10 April 2001

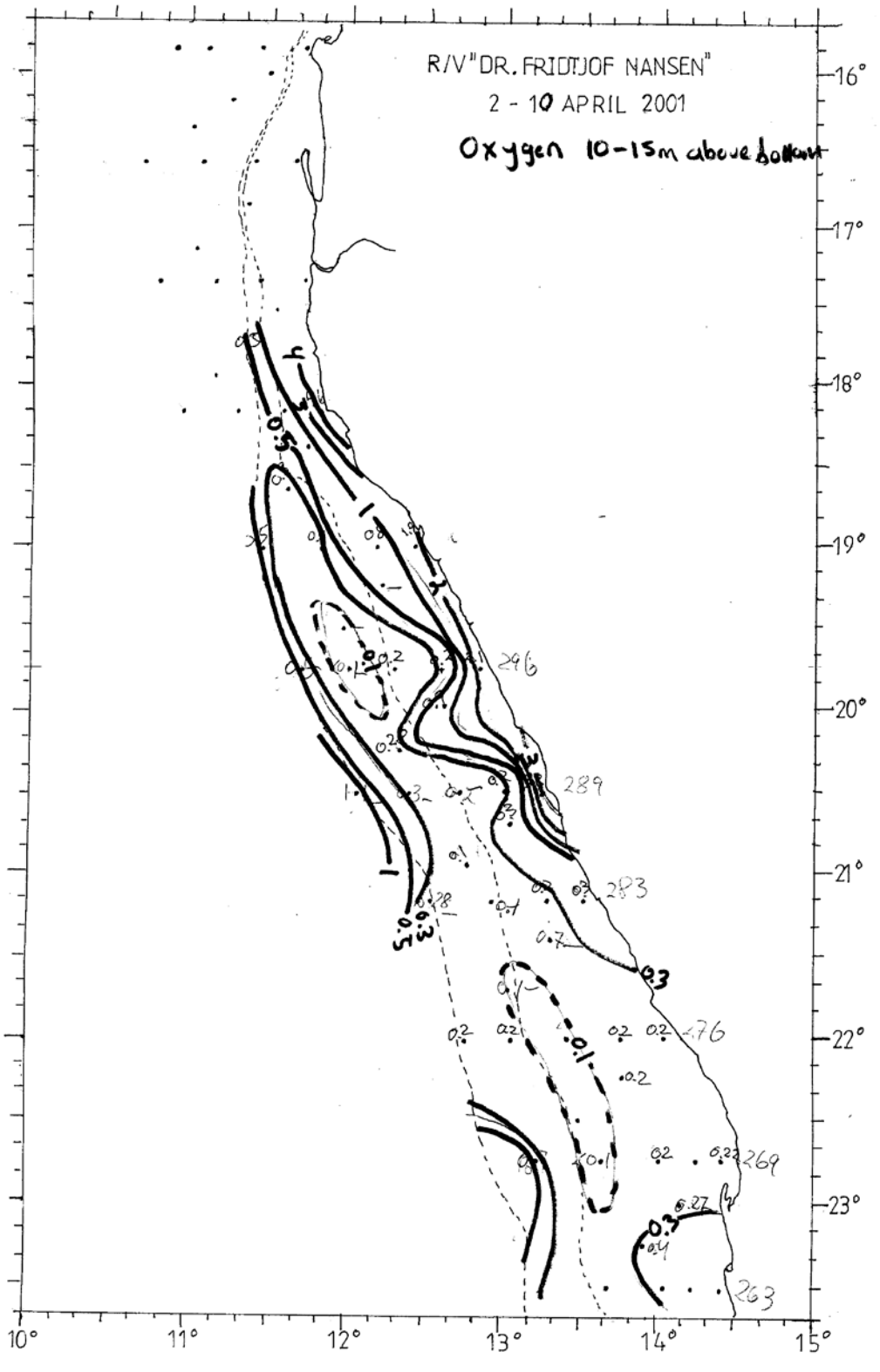

Figure 3.11 Oxygen concentration (ml/l) at 10 – 15 m above the bottom, 2 – 10 April 2001

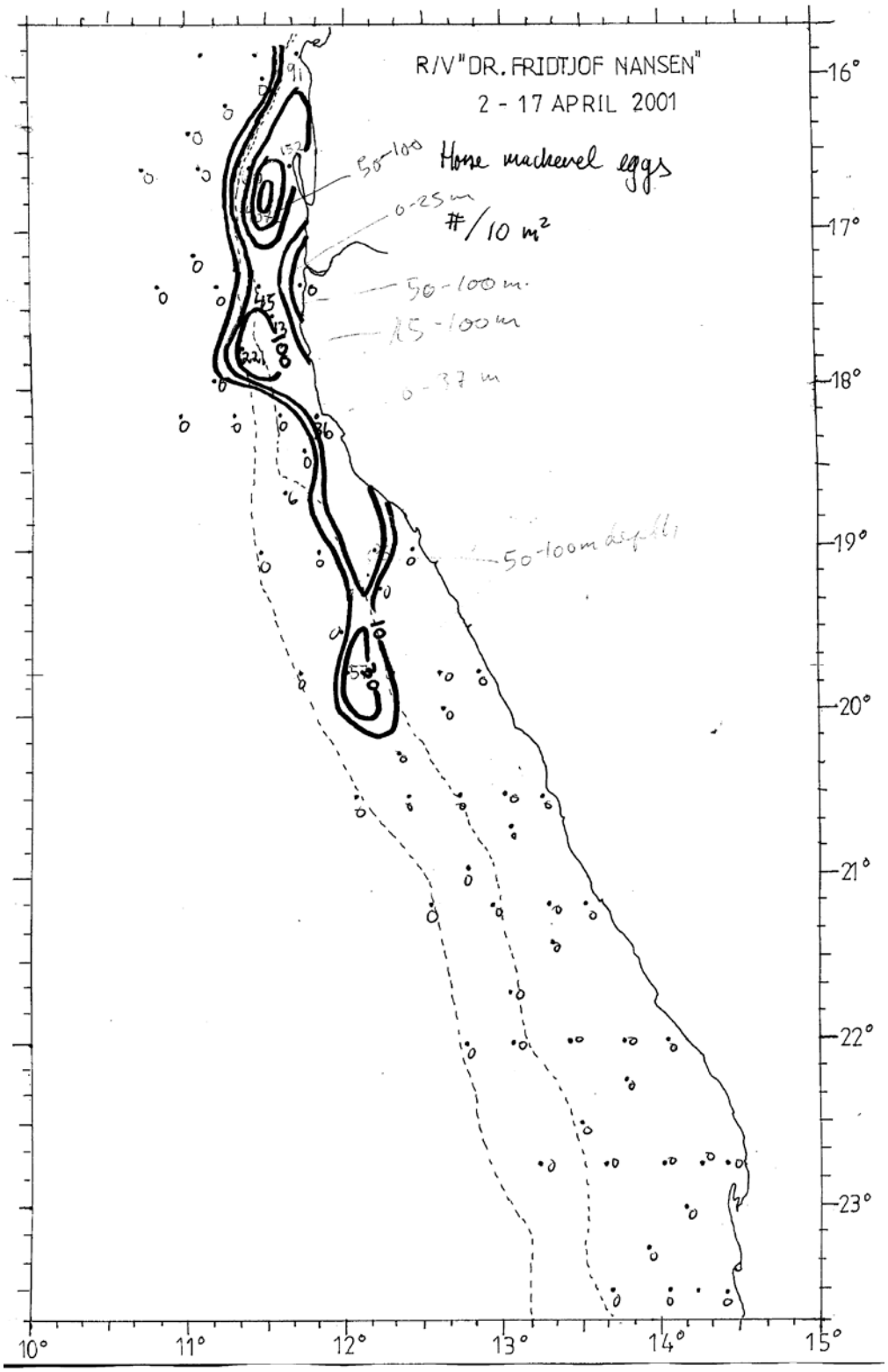

Figure 3.12. Distribution of horse mackerel eggs (#/10 m^2), 2 – 10 April 2001

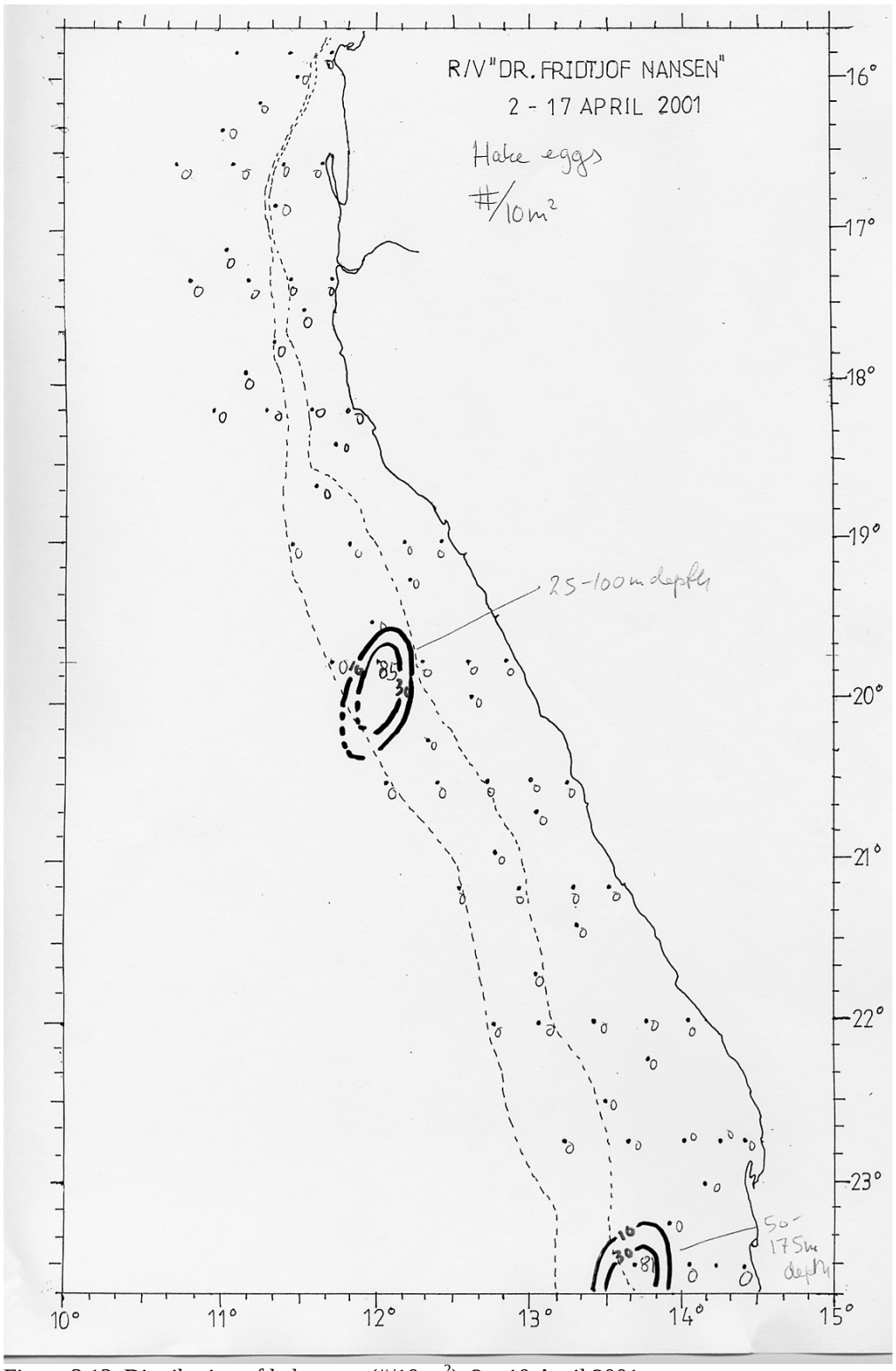

Figure 3.13. Distribution of hake eggs (#/10 m^2), 2 – 10 April 2001

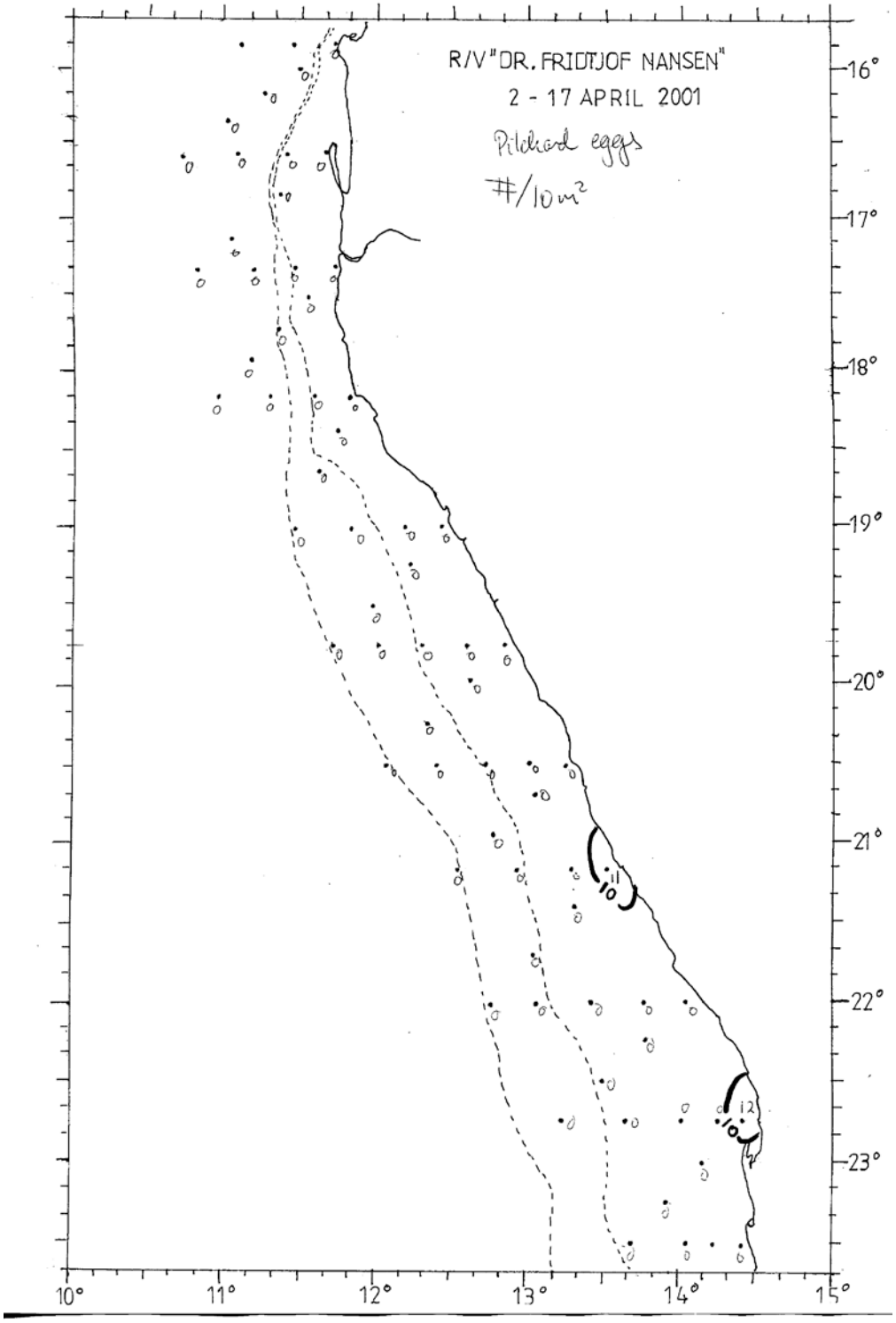

Figure 3.14. Distribution of sardine eggs (#/10 m^2), 2 – 10 April 2001

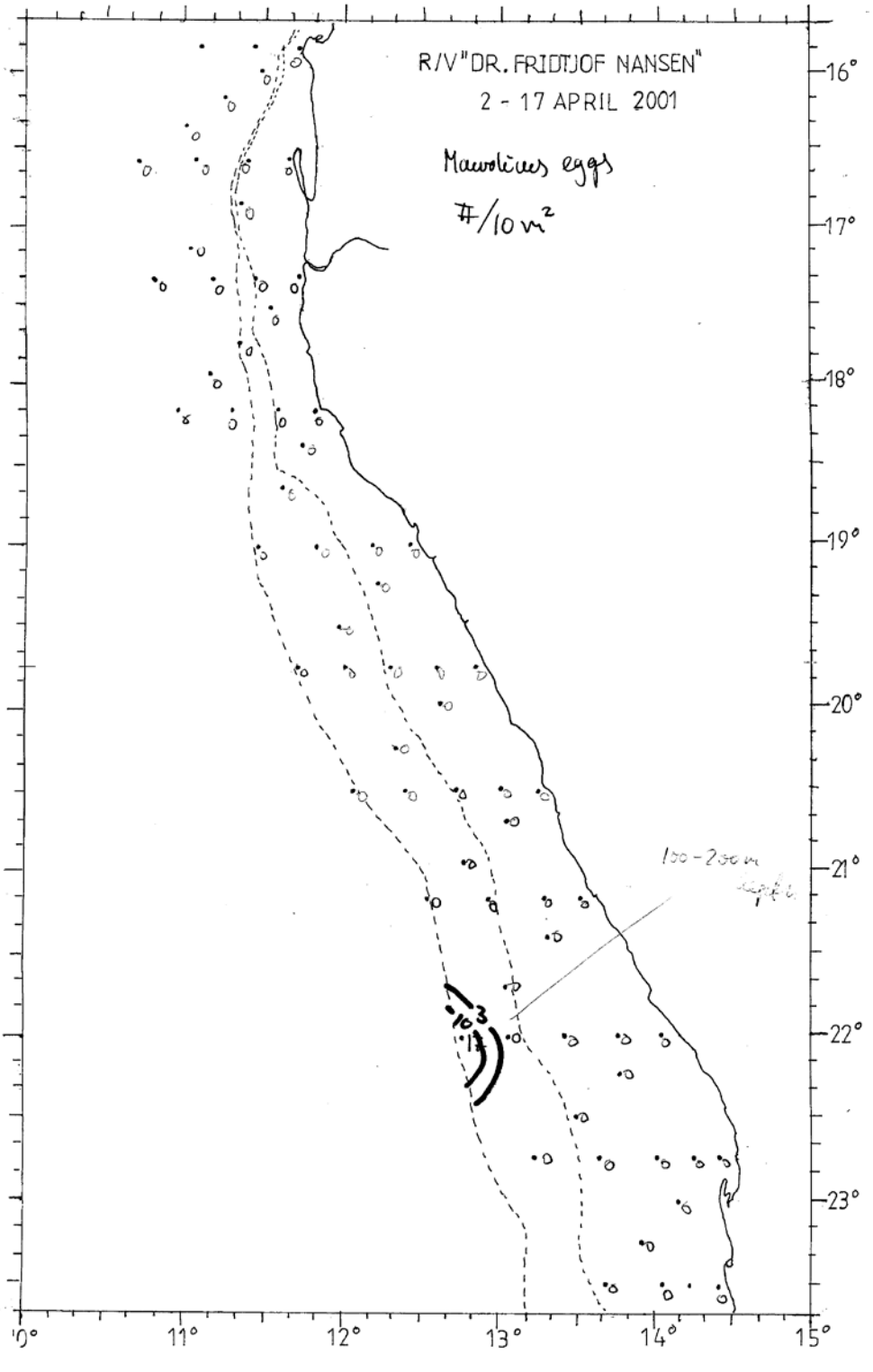

Figure 3.15. Distribution of *Maurolicus* eggs (#/10 m^2), 2 – 10 April 2001

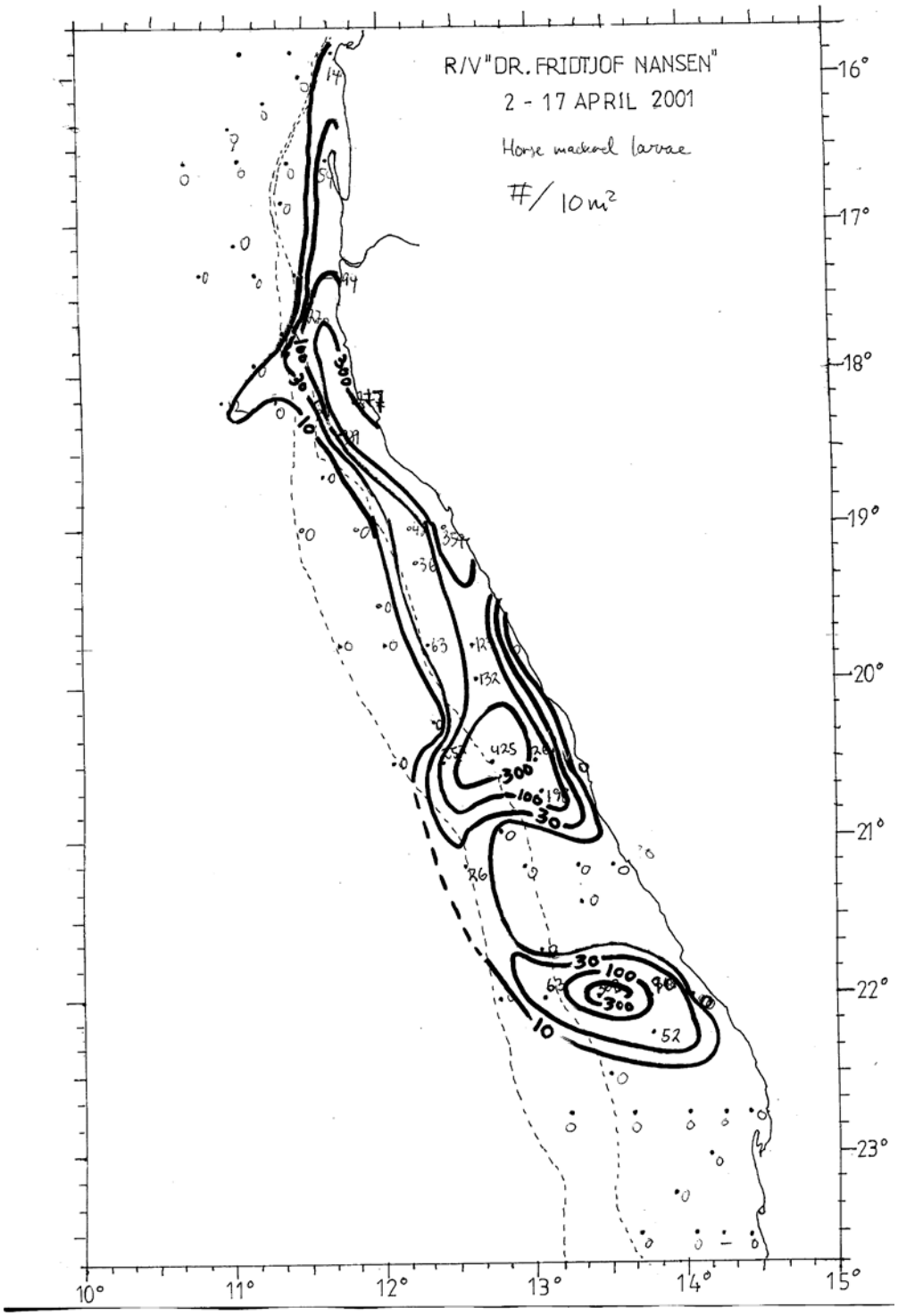

Figure 3.16 Distribution of horse mackerel larvae (#/10 m^2), 2 - 10 April 2001

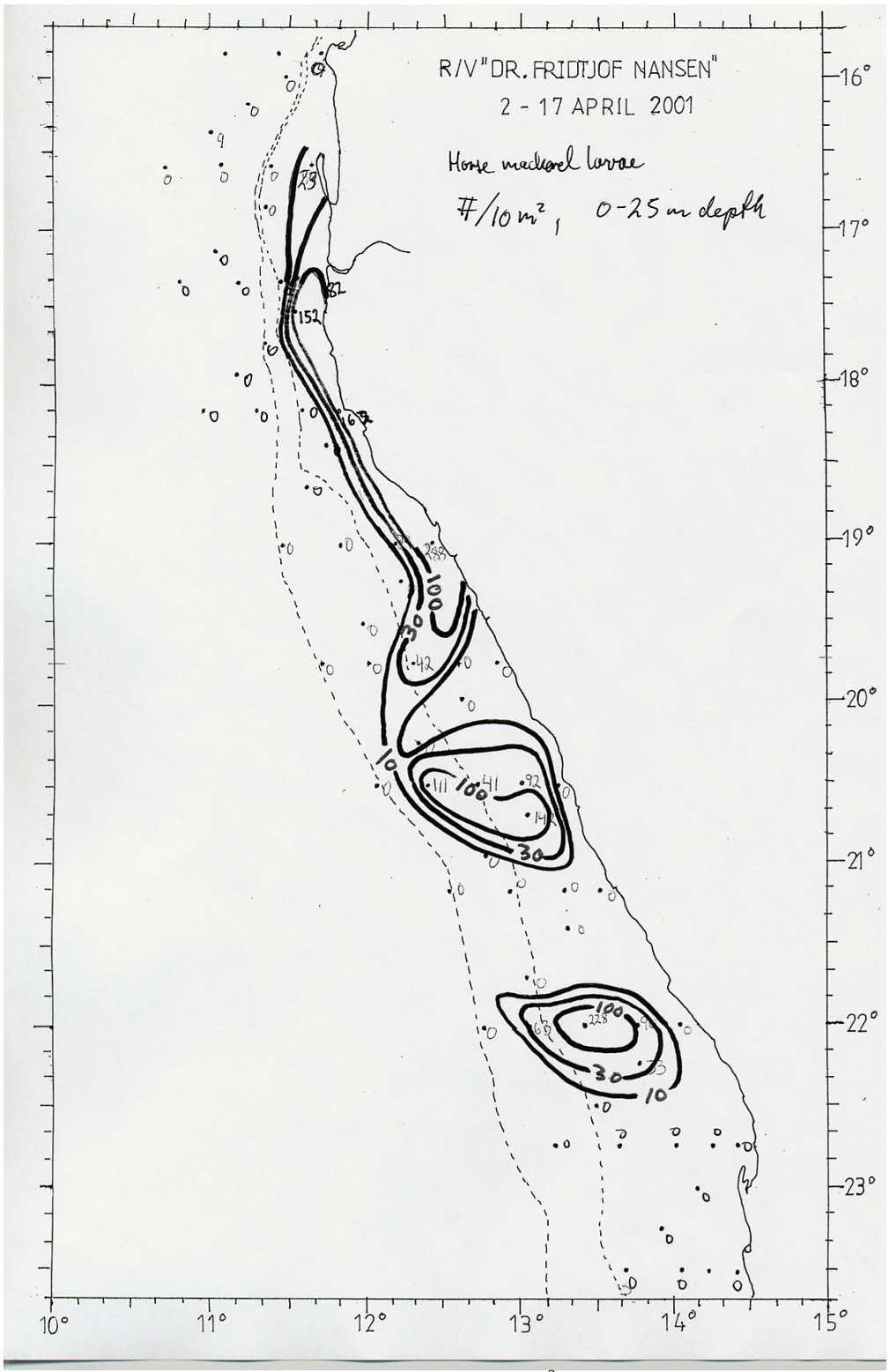

Figure 3.17 Distribution of horse mackerel larvae (#/10 m^2) in 0 – 25 m depth, 2 - 10 April 2001

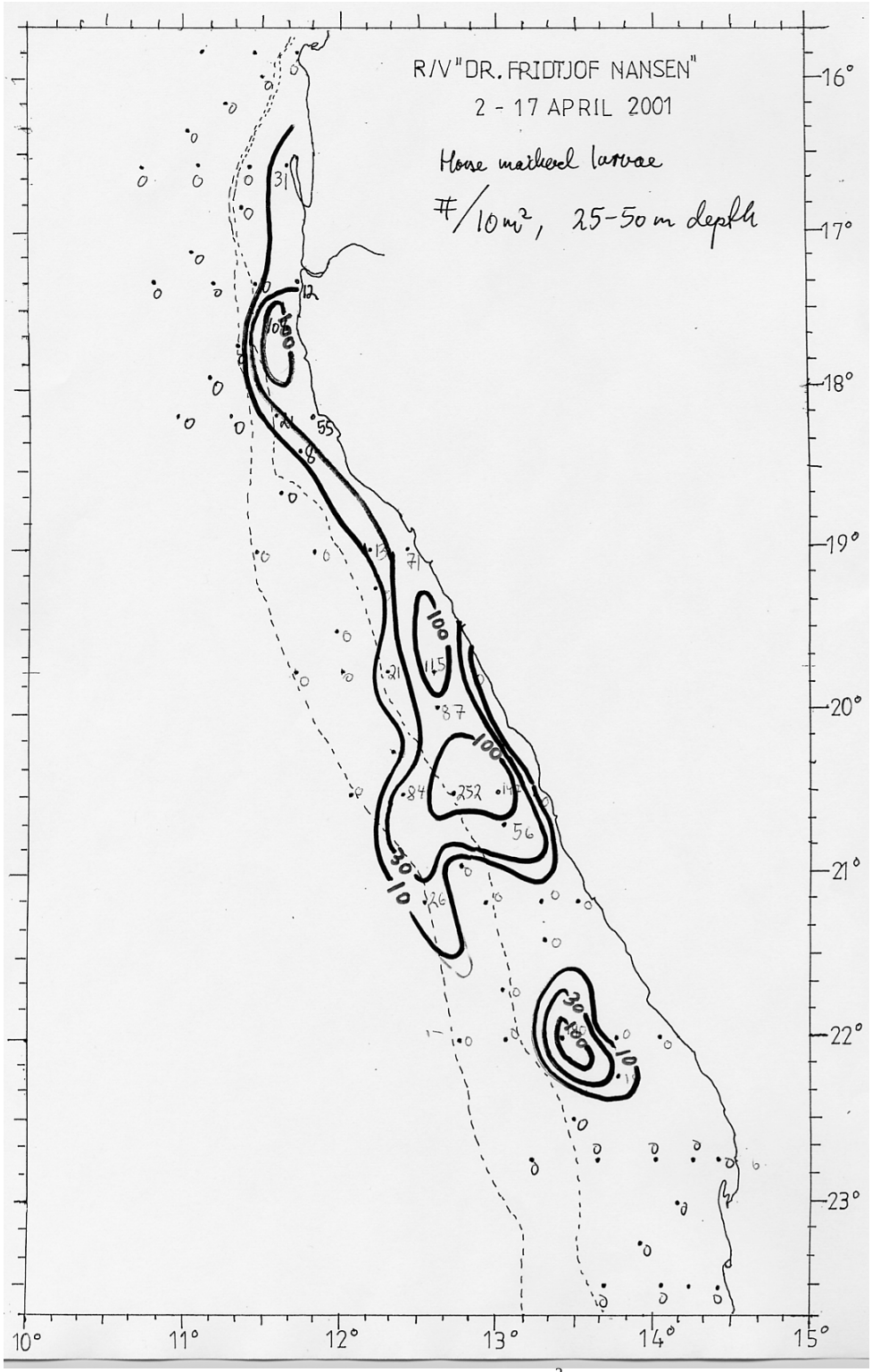

Figure 3.18 Distribution of horse mackerel larvae (#/10 m^2), in 25– 50 m depth, 2 - 10 April 2001

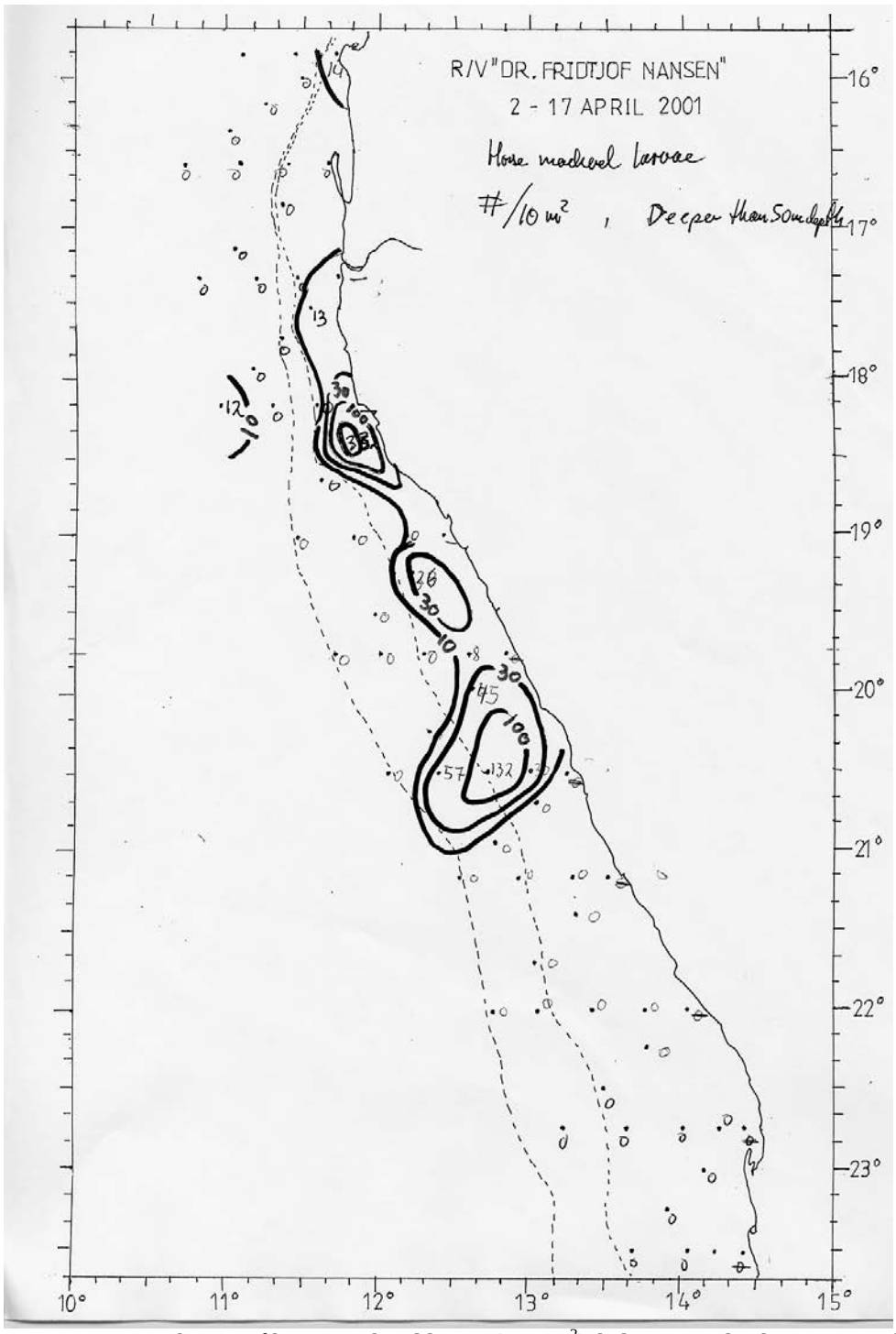

Figure 3.19 Distribution of horse mackerel larvae (#/10 m^2), below 50 m depth, 2 - 10 April 2001

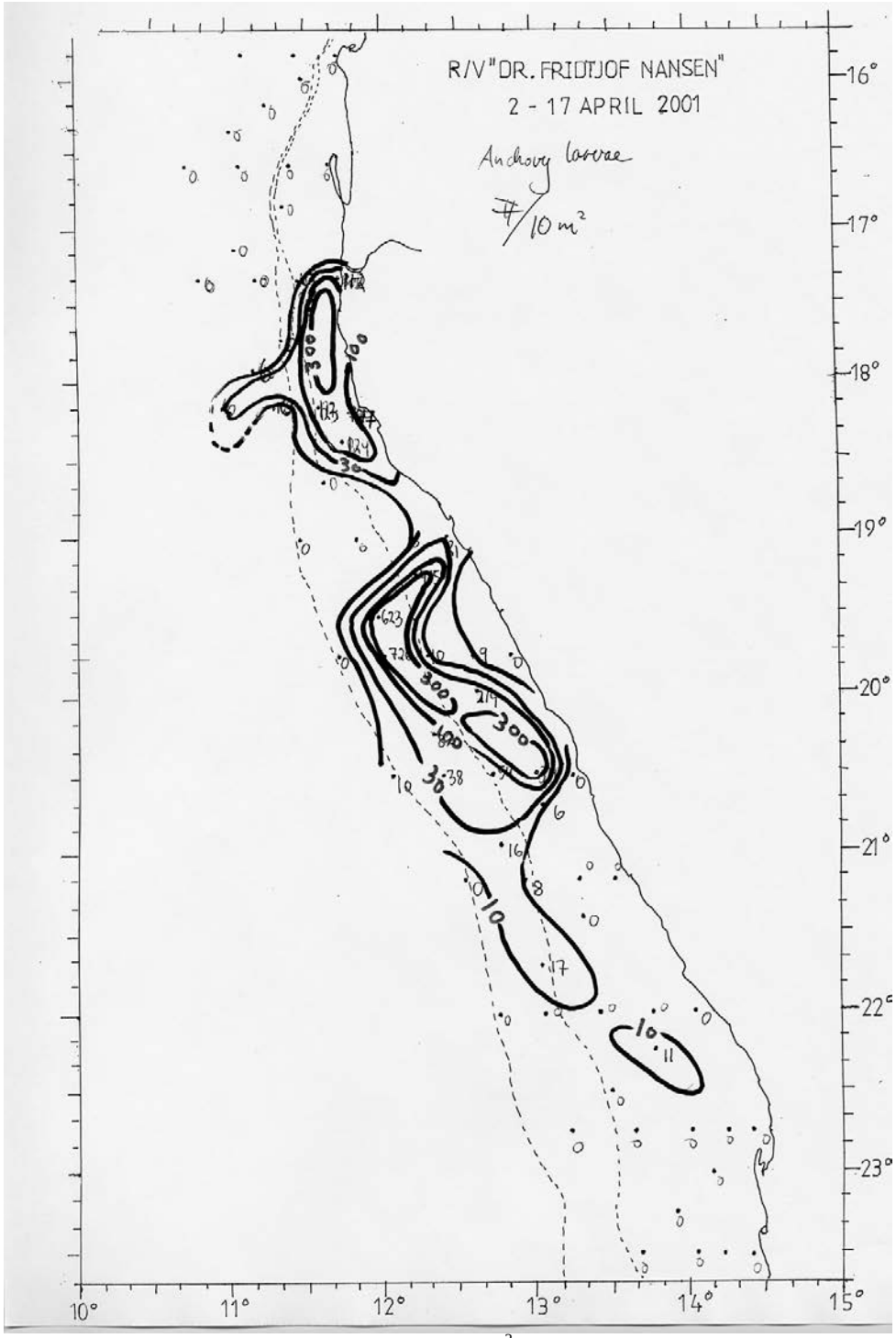

Figure 3.20 Distribution of anchovy larvae (#/10 m^2), 2 - 10 April 2001

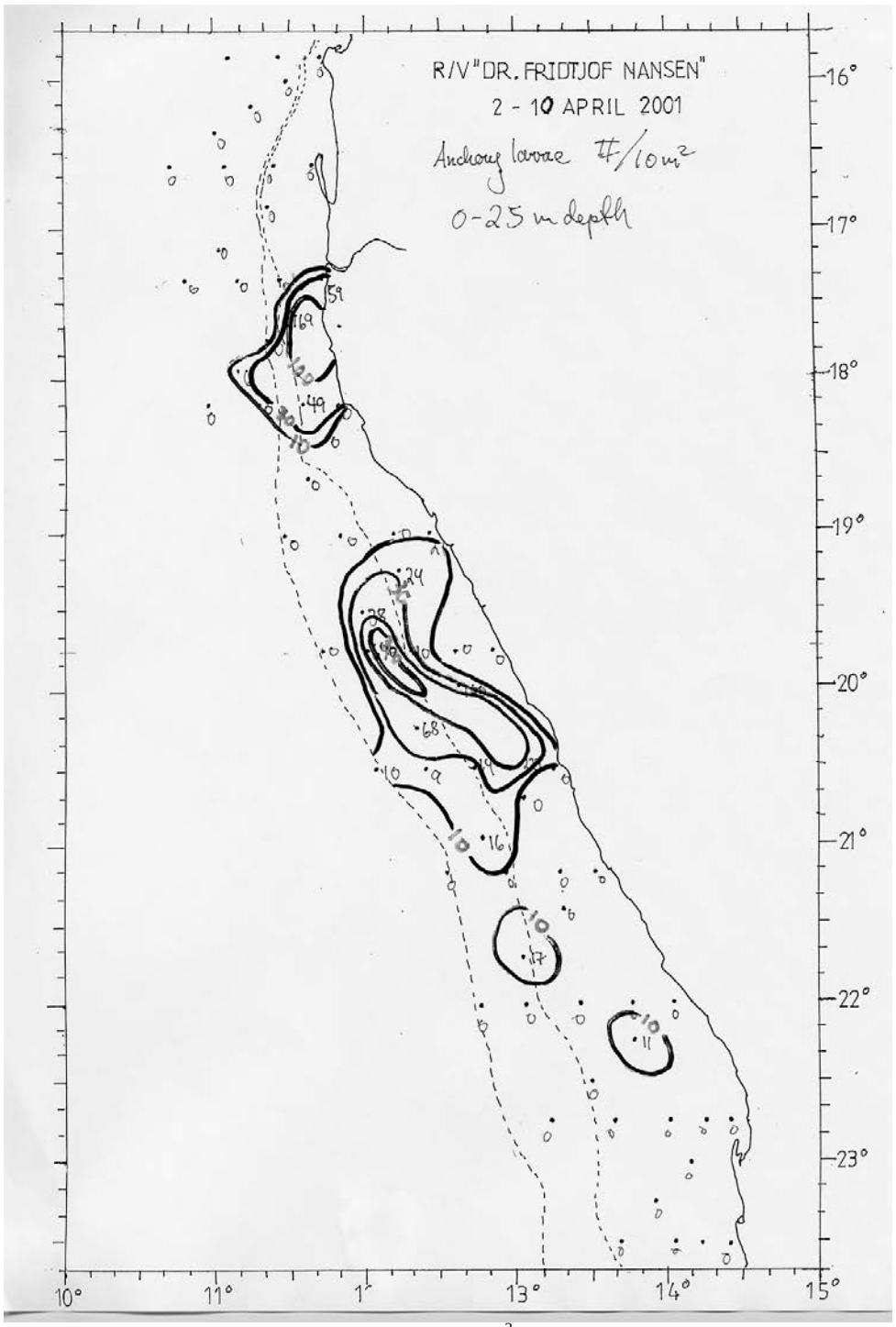

Figure 3.21 Distribution of anchovy larvae (#/10 m^2) in 0 – 25 m depth, 2 - 10 April 2001

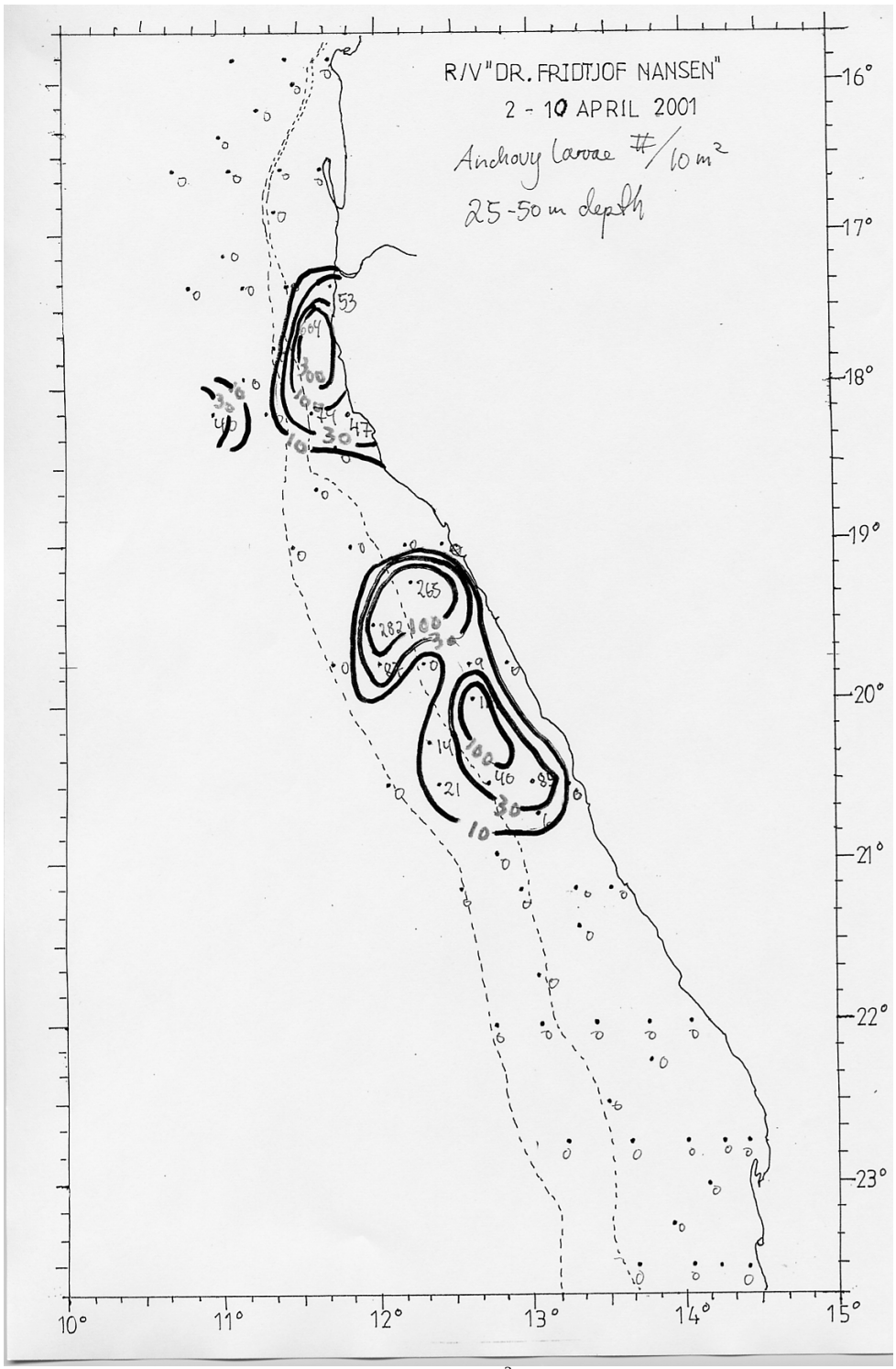

Figure 3.22 Distribution of anchovy larvae (#/10 m^2) in 25– 50 m depth, 2 - 10 April 2001

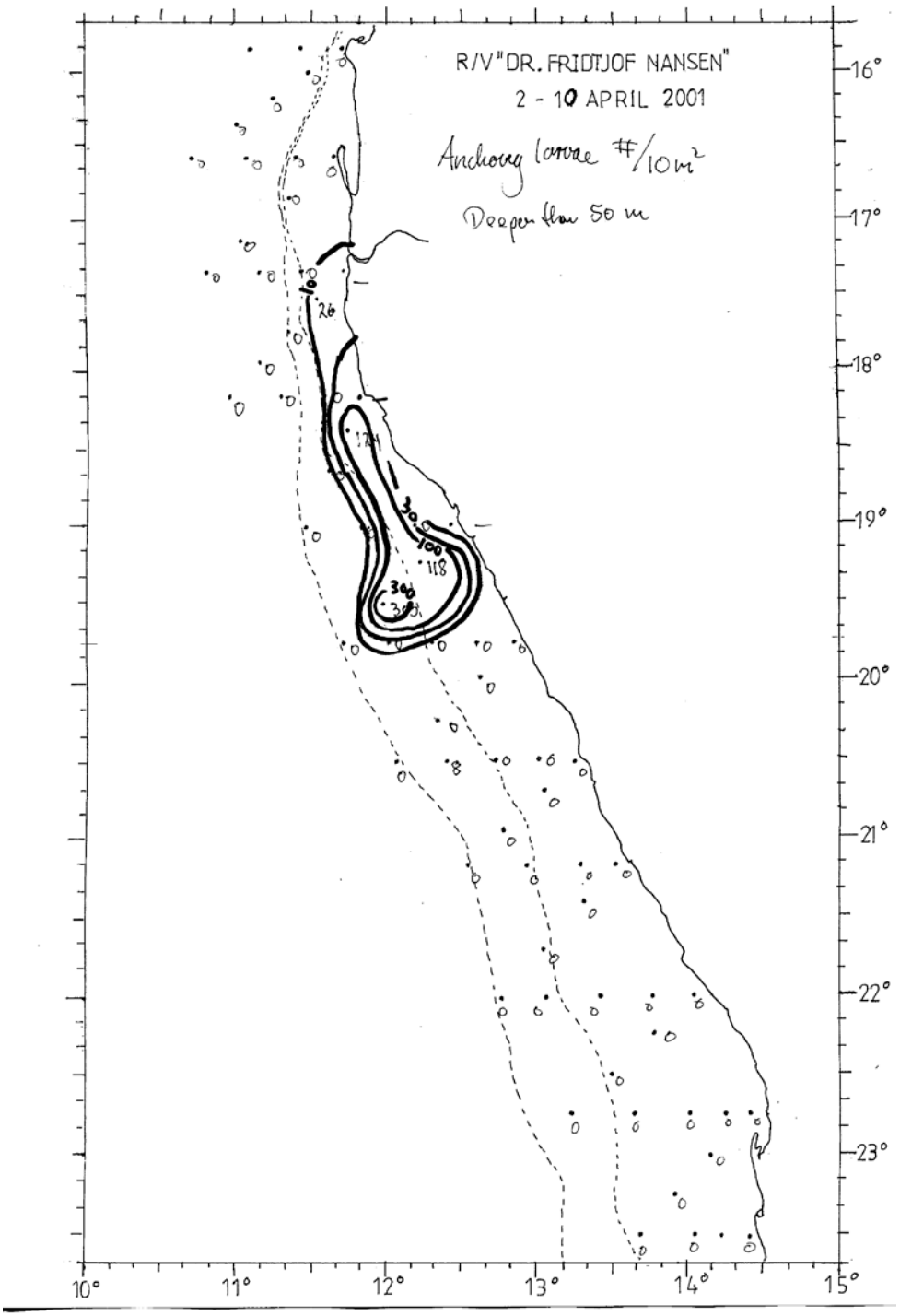

Figure 3.23 Distribution of anchovy larvae (#/10 m^2) below 50 m depth, 2 - 10 April 2001

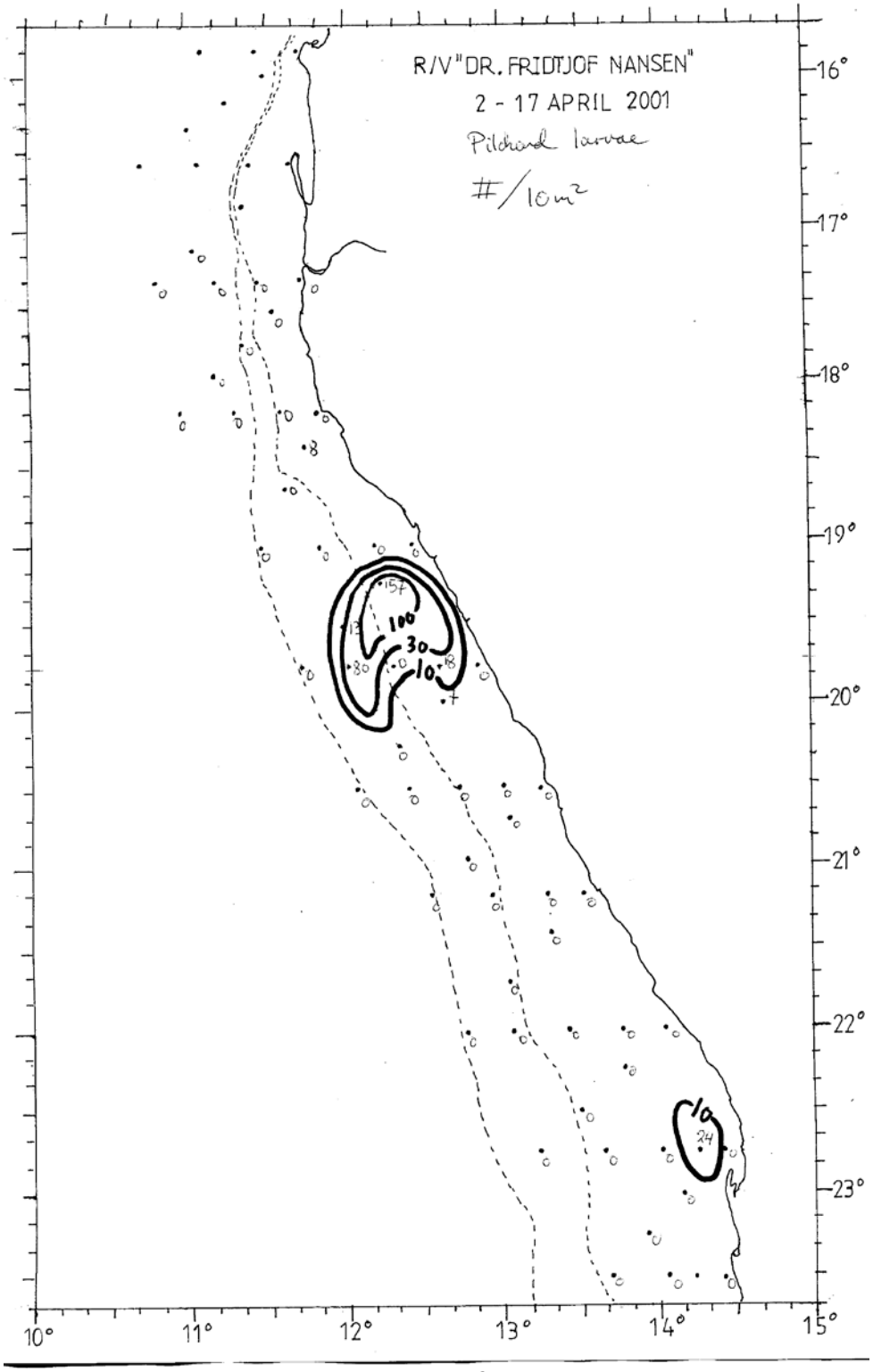

Figure 3.24 Distribution of sardine larvae (#/10 m^2), 2 - 10 April 2001

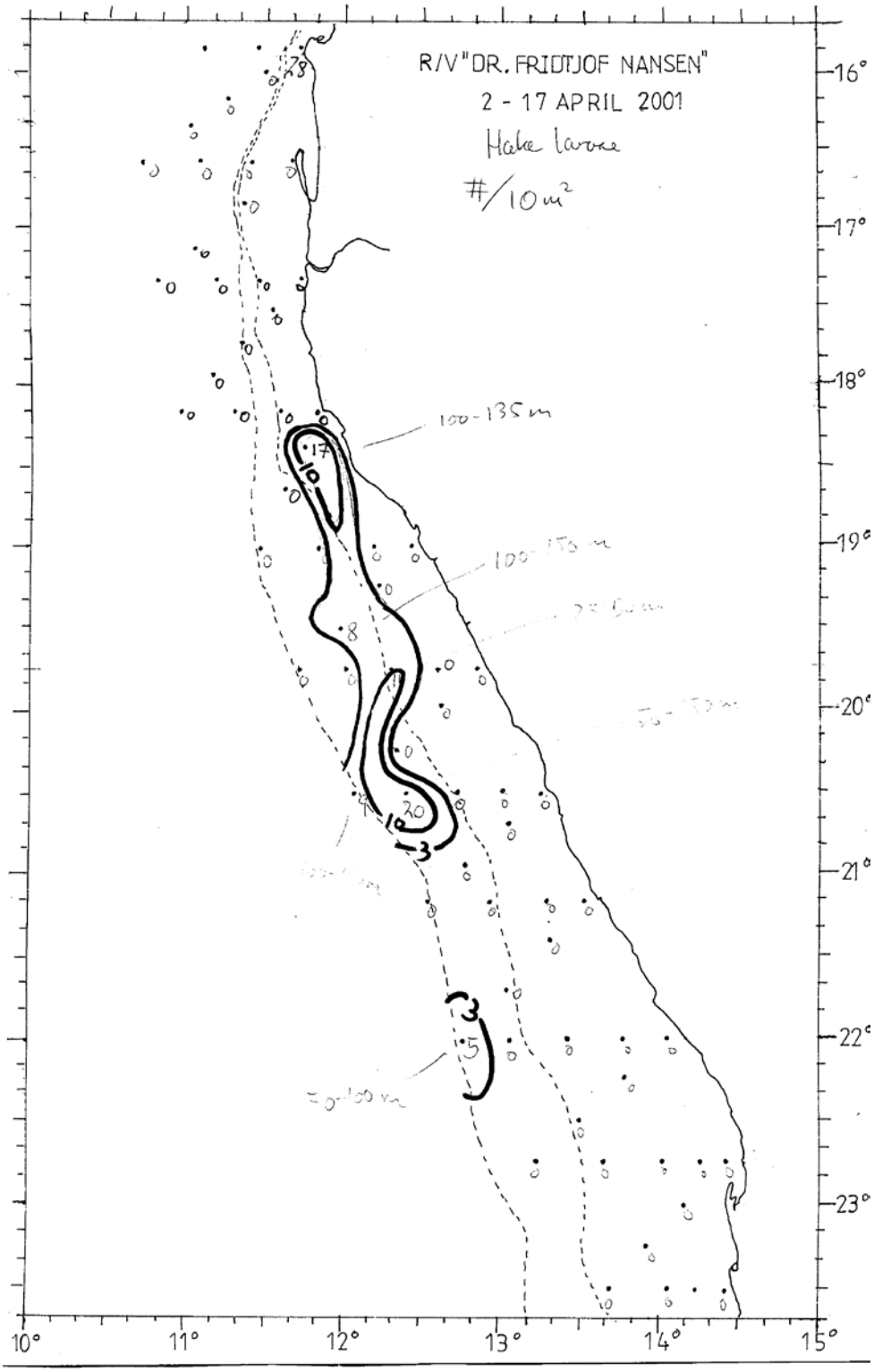

Figure 3.25 Distribution of hake larvae (#/10 m^2), 2 - 10 April 2001

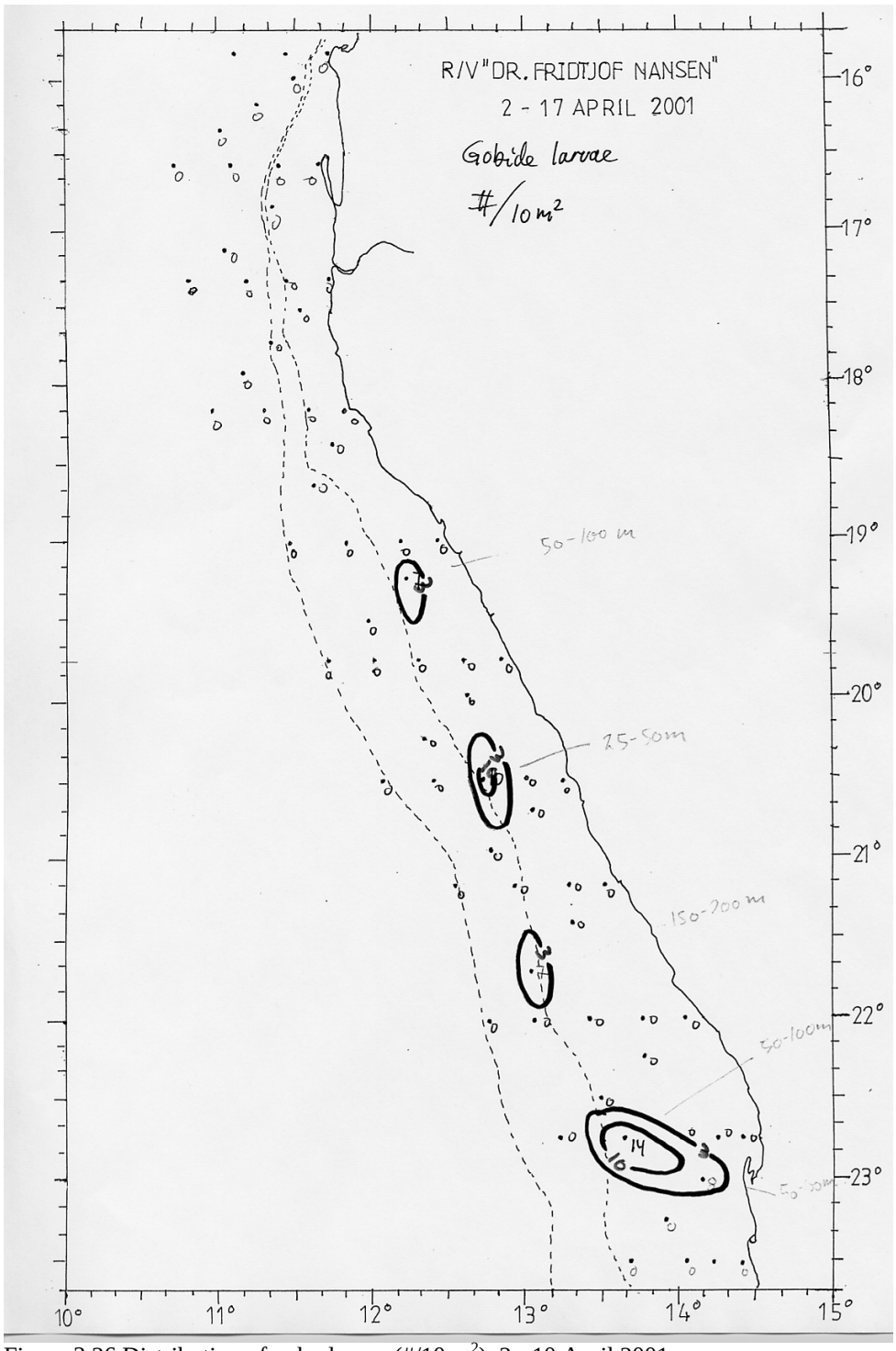

Figure 3.26 Distribution of goby larvae (#/10 m^2), 2 - 10 April 2001

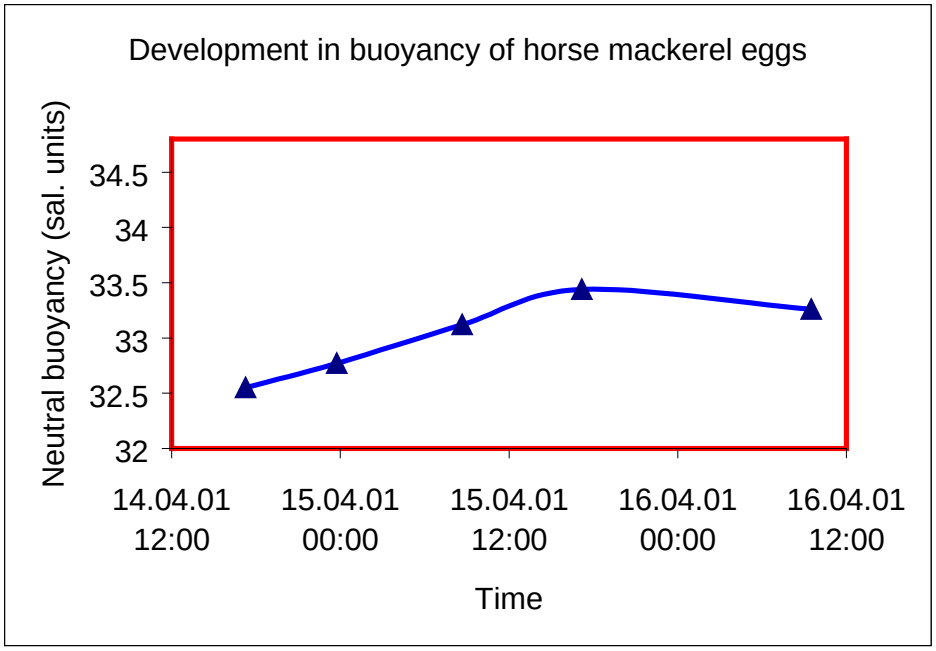

Figure 3.27 Development in mean buoyancy (expressed in salinity) of 10 horse mackerel eggs caught as stage I eggs in Multinet, 100 –150 m depth, at station 80.

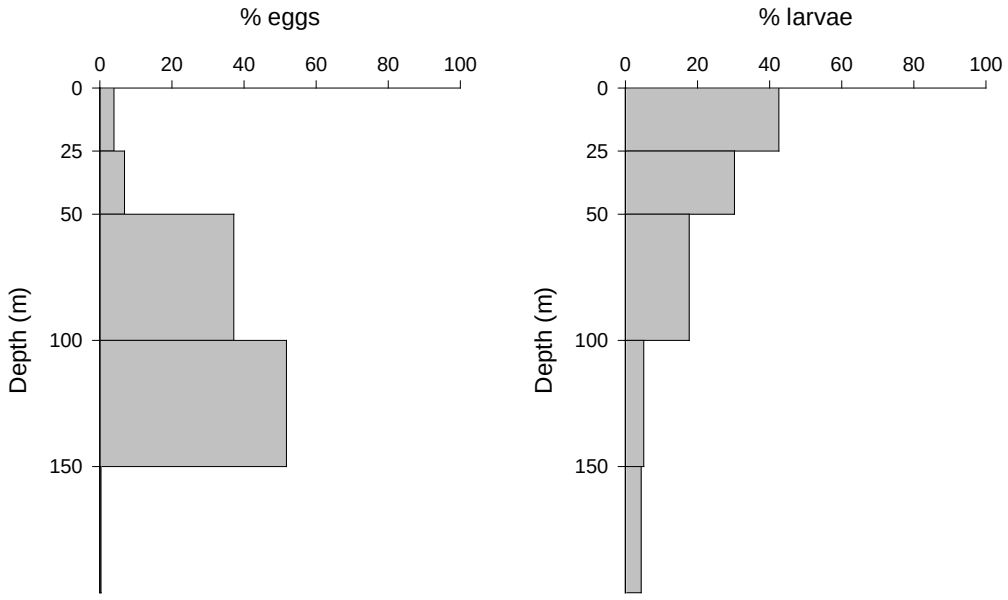

Figure 3.28. Vertical distribution of horse mackerel eggs (left panel) and larvae (right panel) from all stations except the 24-hour station.

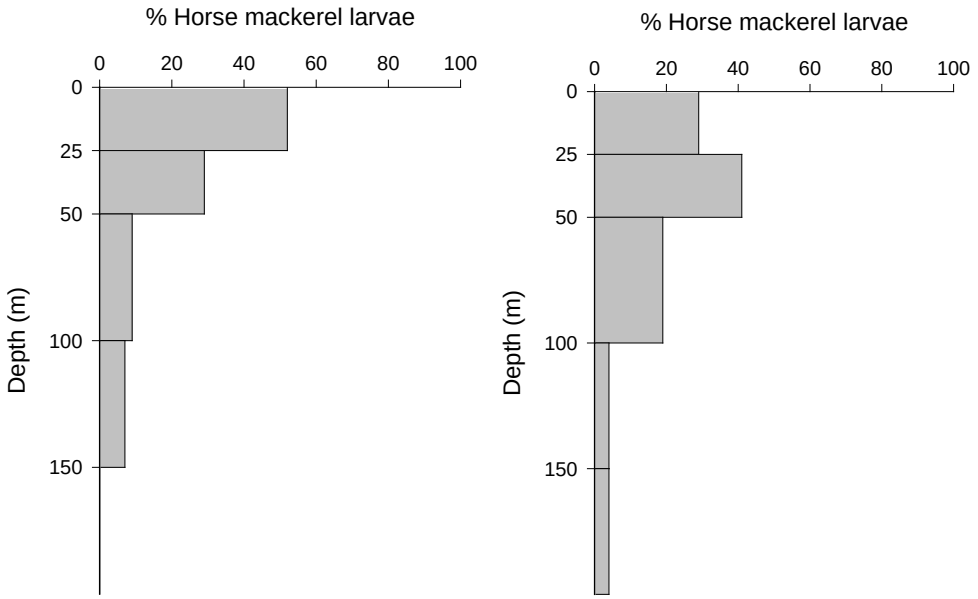

Figure 3.29. Vertical distribution of horse mackerel larvae during daytime (left panel) and nighttime (right panel) from all stations except the 24-hour station.

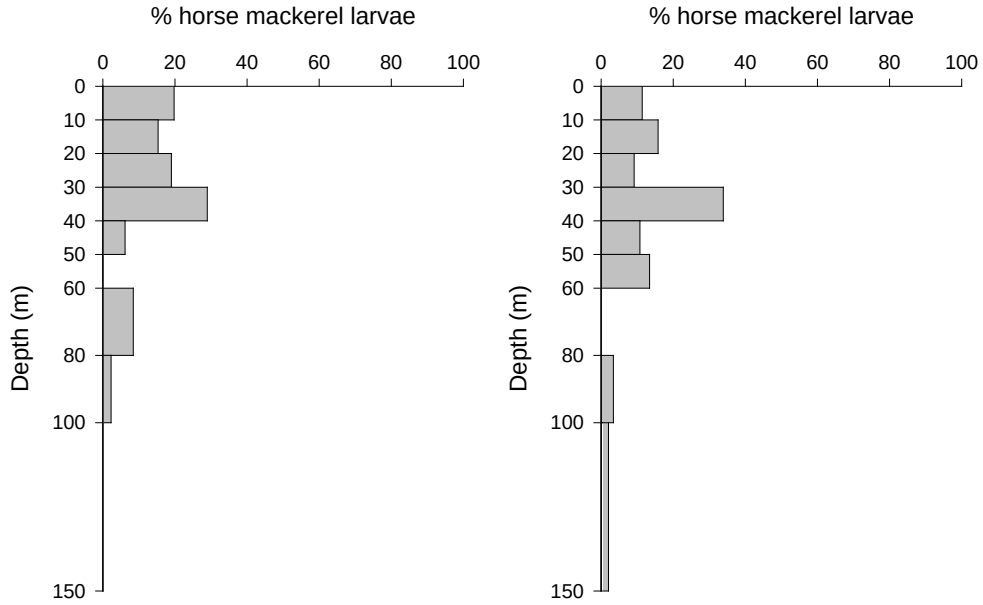

Figure 3.30. Vertical distribution of horse mackerel larvae at the 24-hour station during daytime (left panel) and nighttime (right panel).

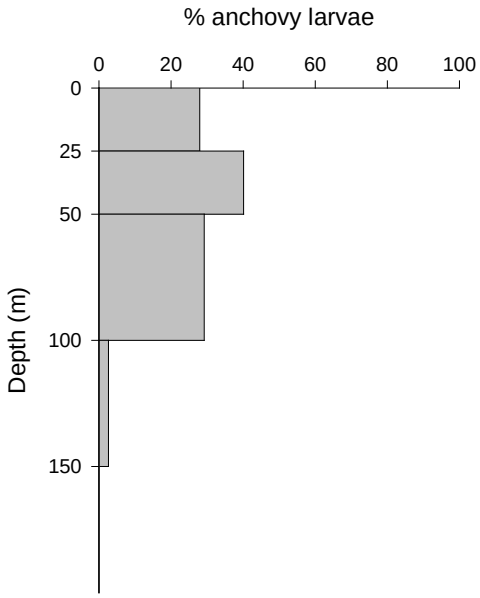

Figure 3.31. Vertical distribution of anchovy larvae from all stations except the 24-hour station.

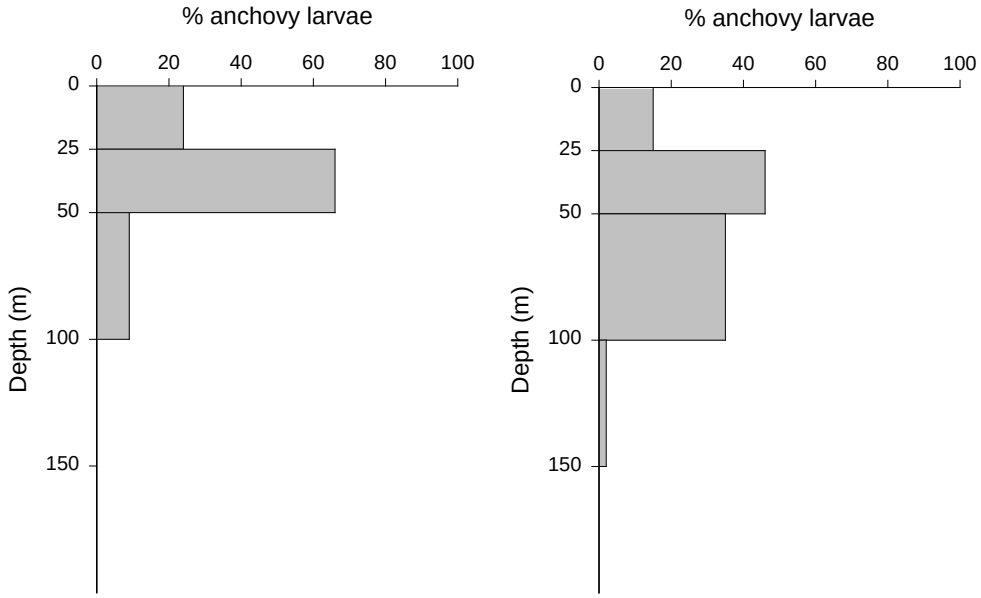

Figure 3.32. Vertical distribution of anchovy larvae from all stations except the 24-hour stations at daytime (left panel) and nighttime (right panel).

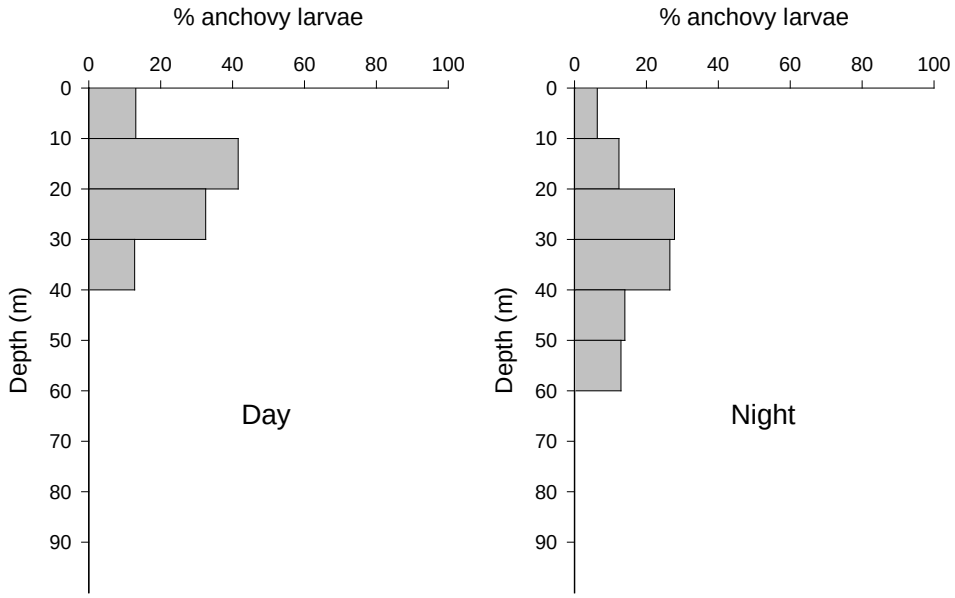

Figure 3.33. Vertical distribution of anchovy larvae from the 24-hour station at daytime (left panel) and nighttime (right panel).

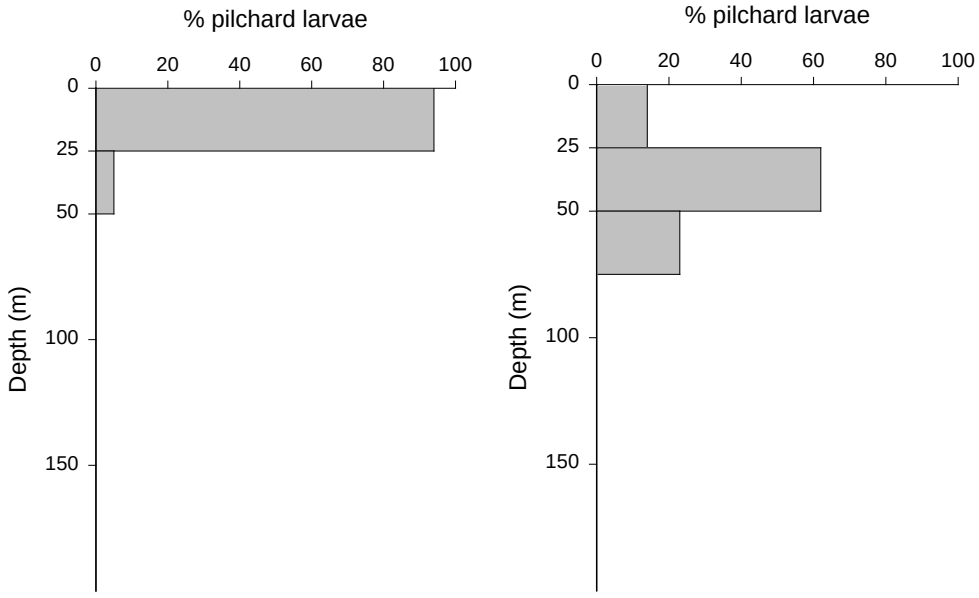

Figure 3.34. Vertical distribution of pilchard larvae from all stations except the 24-hour stations at daytime (left panel) and nighttime (right panel).

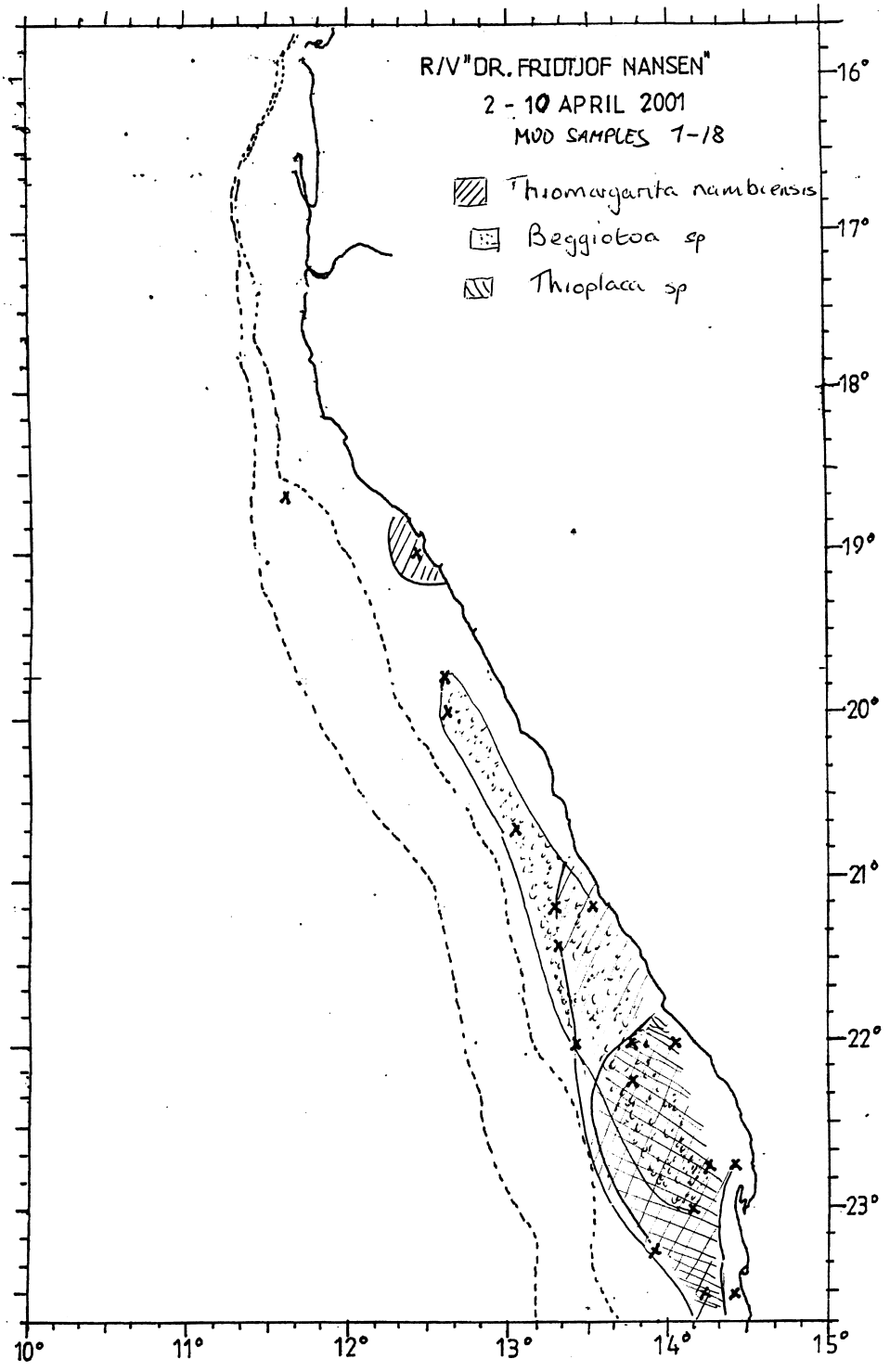

Figure 3.35. Distribution of sulphur bacteria.