Some observations of the deep flow in the Bornholm strait during the period June 1973–December 1974

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(Manuscript received April 15, 1975)

ABSTRACT

Preliminary observations of the deep water flow penetrating into the Baltic are presented. An important feature of the measurements is that the distribution of the flux with respect to salinity is resolved. The mean salt and volume fluxes obtained from the observations are checked against the fresh water supply with surprisingly good result.

Introduction

The primary aim of this investigation is to estimate the long-term mean distribution with salinity of the salt water inflow to the Baltic to be used in connection with continuity considerations of the type outlined by Walin (1975). Of great interest as well is to study the character of the time-dependence of the inflow; e.g. the degree of intermittency of the flow, the maximum rate of flow etc. We do however confine our interest to the flow of water with salinity higher than the salinity of the surface layer. This means that the upper 30–40 m (in the southern Baltic) having salinity close to 8‰ have been excluded from the observations. Alternatively we may say that we are only studying the salinity range in which the mean flow is into the Baltic in contrast to the water of the surface layer which is generally moving out of the Baltic.

The difficulties in achieving the above mentioned goal are of course associated with the variability in space and time of flow speed as well as salinity. Furthermore we are naturally interested in minimizing the cross-sectional area that has to be covered. The contradiction we have to face is that a narrow channel such as the Danish sounds generally gives rise to a strong oscillating component of the flow associated with water level variations in the Baltic. We thus want two conditions to be satisfied simultaneously:

(i) A region exists where the flow in the salinity range, $s > s_0$, $s_0 = 8$–10‰, is confined to a relatively narrow crossection.

(ii) The flow in this region is mainly unidirectional (in space and time), i.e. the amplitude of the variations is at most of the same order as the mean flow.

The Baltic is characterized by a narrow entrance region, and the sill depth (~ 18 m) is small compared to the typical basin depth (~ 100 m). The Baltic itself is furthermore divided into a number of basins connected by more or less pronounced trenches. As a consequence regions fulfilling the first condition above can be found in several places in the Baltic. The second condition above rules out the Danish straits and Öresund as suitable measuring sections. Possible remaining sections are then mainly the Bornholm strait and the Stolpe trench (the latter connecting the Bornholm and Gotland basins). Both these regions, while providing a narrow passage for the deep water flow, offers a wide cross-section for the surface water, i.e. we do not expect a strong oscillating component of the flow driven by water level variations. The wide strait south of Bornholm has a mean depth of about 15 m with a narrow passage probably not deeper than 35 m, while the sill depth between Bornholm and Sweden is almost 50 m.

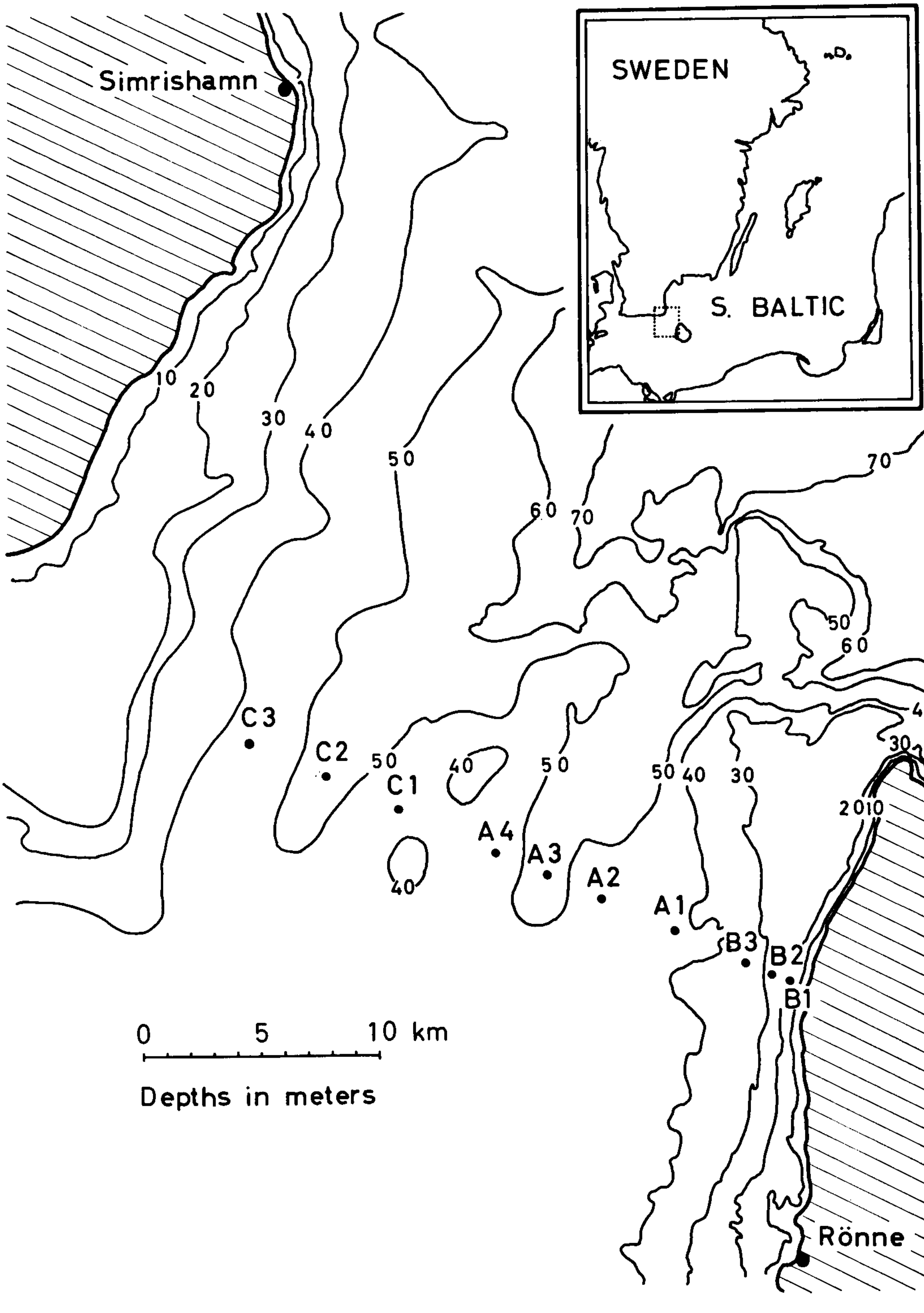
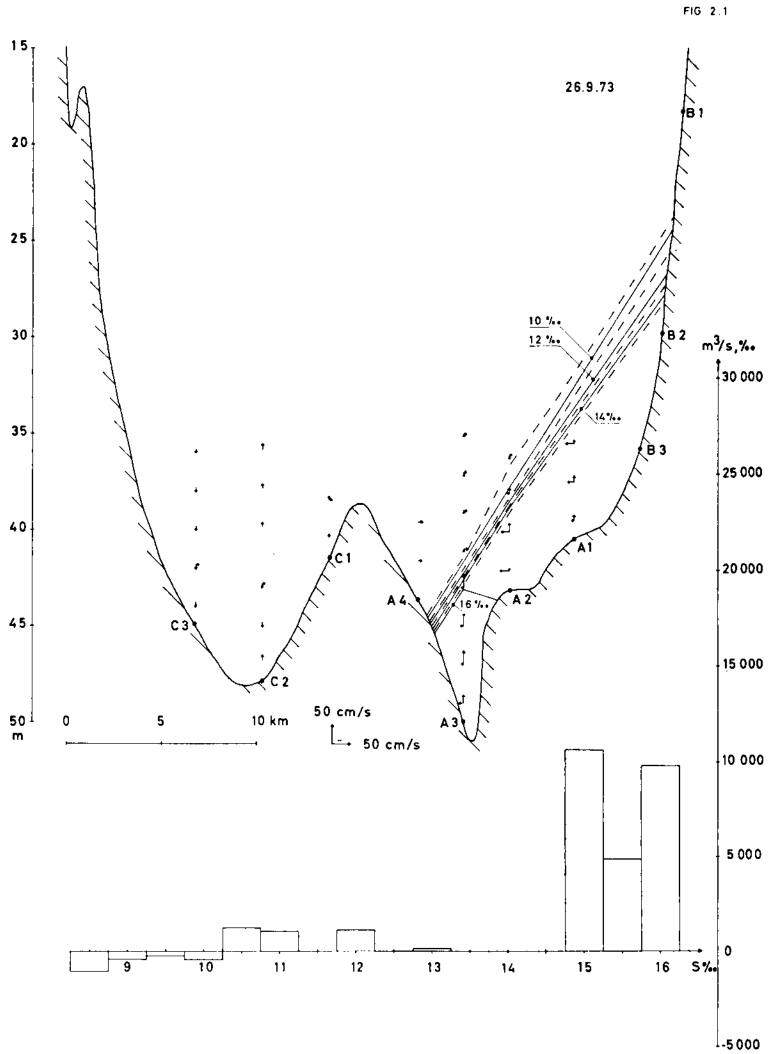


Fig. 1. Map of the Bornholm Strait showing the stations on which observations have been taken.



Figs. 2:1–2:10. Part of the observations illustrated by the position of isohalines in the crosssection (Bornholm being to the right in the figures). The components of the current are indicated by the small arrows at some of the points of observation. The length of the vertical and horizontal arrows indicate the strength of current along and perpendicular to the channel respectively (upwards meaning into the Baltic). In the lower half of the figure the instantaneous shape of the inflow function $m(s, t)$ as obtained from the observations is shown.

We presently believe that this restricts the inflow of interest to occur in the deeper strait on the northwestern side of Bornholm.

The cross-section from Bornholm to Sweden has thus been chosen for the measurements. From the Arkona basin the bottom is sloping monotonically downwards through the Bornholm strait, and the depth to the halocline is usually substantially larger inside the Bornholm basin than in the Arkona basin. As a consequence the deep flow in the Bornholm strait is mainly driven by the internal pressure gradients associated with the sloping isohalines, i.e. the strait provides a hydraulic constraint on the flow.

According to our observations the inflow through the cross-section at Bornholm is restrict-

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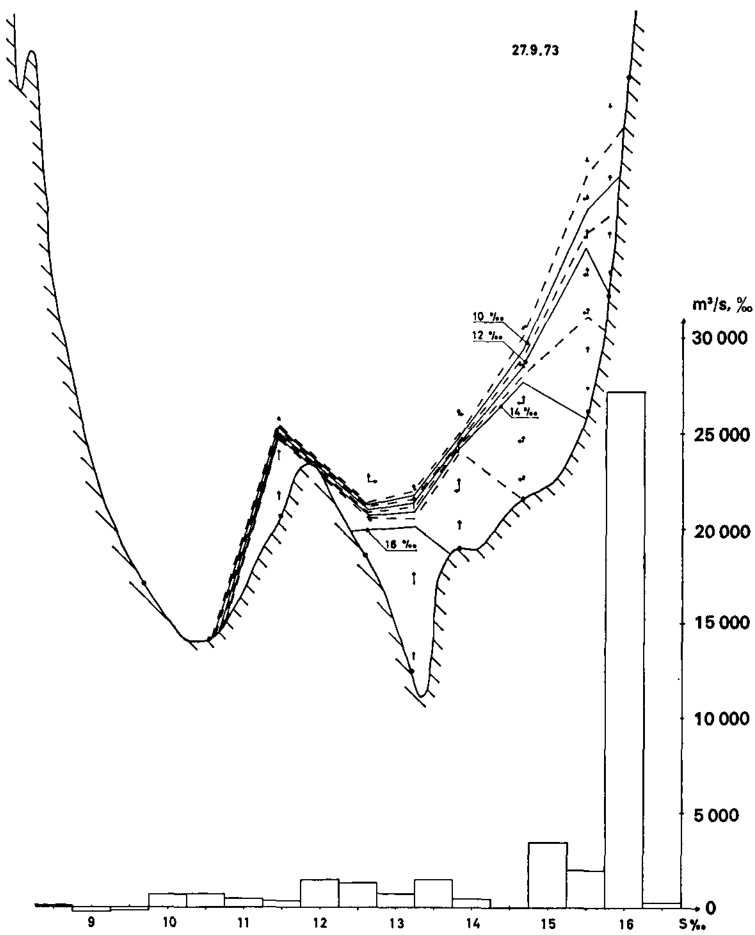


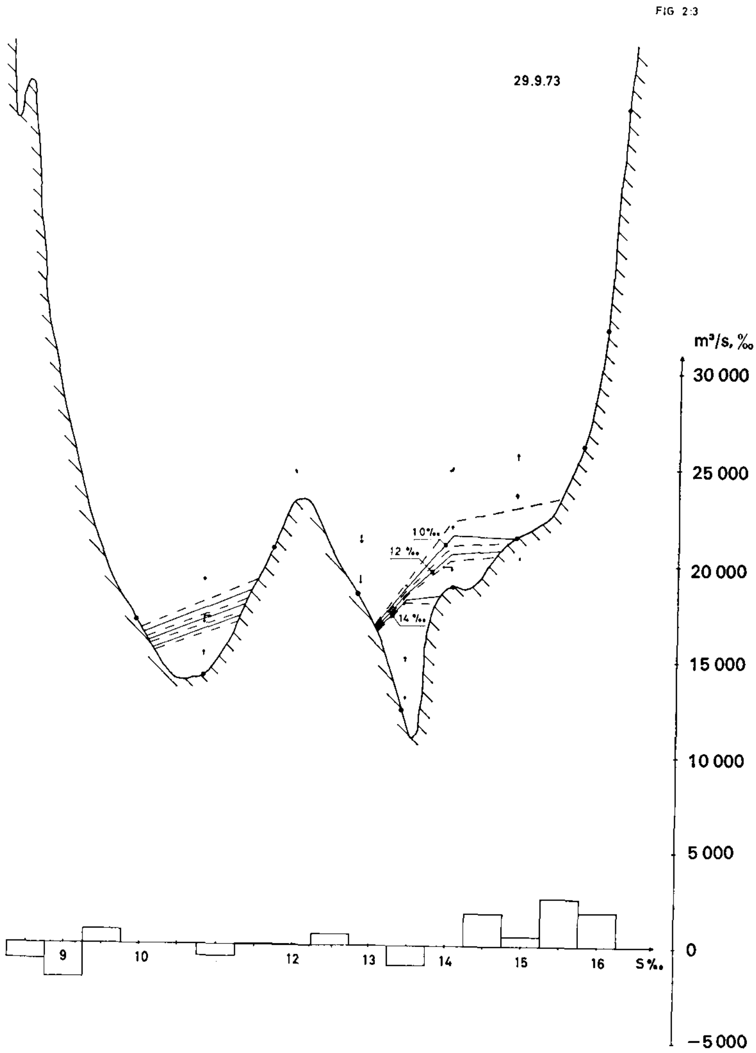
ed to a bottom layer about 20 m thick and 10 km wide. See Fig. 1. A single survey, including observations of current, salinity and temperature in the bottom layer, can thus be completed in a few hours. Rapid current profile measurements have been made possible by a new gelatine pendulum current meter (Haamer, 1974).

Methods

Our intention has been to obtain a near synoptic picture of the velocity and salinity distribution on each measuring day. As usual in connection with hydrographic observations the work has been strongly hampered by bad weather conditions which in fact are unusually difficult in this particular area.

An array of ten stations (with a typical separation of 1 km) has been used. On each station vertical salinity and temperature profiles are recorded. Whenever water with a salinity greater than a certain value (commonly 8.5‰) is found, current measurements are taken in this water with depth increments of 1–2 m. The cross-section is thus divided into typically 100 cells, where the area of each is known from echo-sounding surveys.

In each cell the water flow and the salinity is computed. When current data are missing for certain cells, values are interpolated from adjacent cells with similar salinity. All the cells are



grouped according to their salinity in classes with a width equal to 0.5‰, starting at 8.5‰ (mid-point). Finally the fluxes are added for each salinity class separately. The result of the computations is an approximate representation of the instantaneous form of the function $m(s, t)$ describing the inflow; $m(s, t)$ being defined in such a way that $m \cdot ds$ equals the volume flux in the salinity interval $(s, s + ds)$.

In the period Sept. 26, 1973, to Oct. 23, 1974, such distributions have been obtained on seventeen occasions.

Results

The main part (i.e. 10 out of 17 sections) of our observations are shown in Figs. 2.1–2.10 in the form of cross-sections of salinity and velocity and the estimated shape of the function $m(s, t)$ at the time of the observation. Furthermore in Figs. 3.1–3.4 the instantaneous representations of $m(s, t)$ have been combined into a mean function giving an approximate picture of the time averaged distribution $\bar{m}(s)$ of the inflow. As described below the average has been formed in different ways partly since it is not obvious how the mean value should be formed and partly to

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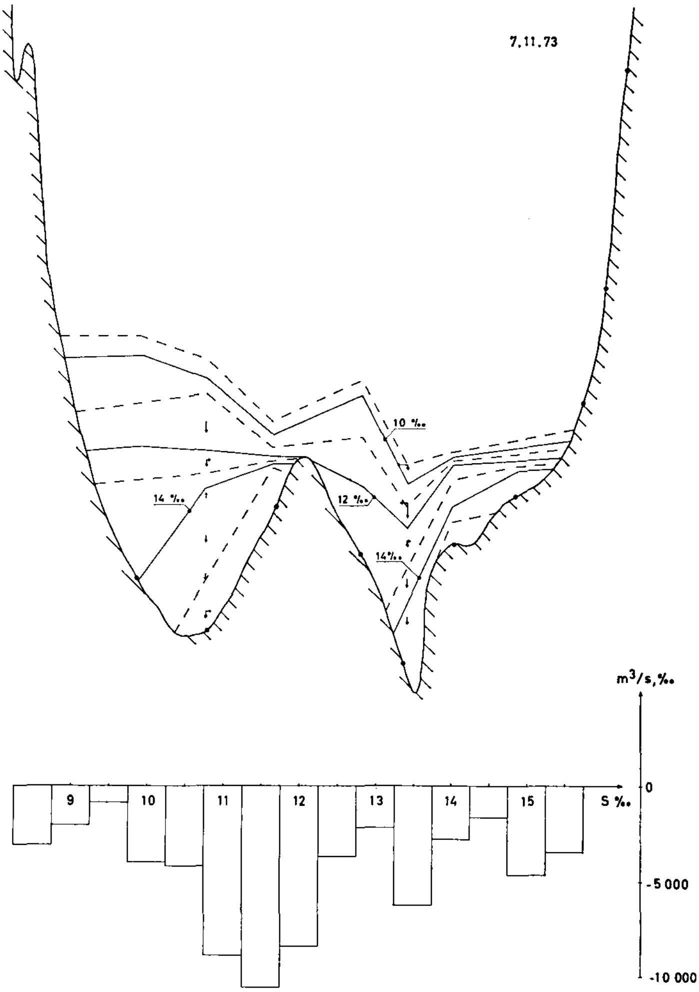

obtain an idea of the uncertainty in our result considered as an approximate representation of the true long term average $\overline{m}(s)$. Since we plan to continue the observations we hope to obtain more reliable results in the future.

Unfortunately some of the measuring days are clustered in periods of two or three days. In such cases a certain degree of correlation between different days of observations may be expected and consequently a weighting procedure should be used. Each period including one, two or three sets of observations has thus been averaged separately, whereupon a second average has been formed with equal weight given to each period. See Fig. 3.1.

For comparison an average with equal weight on each day of measurements has been computed, see Fig. 3.2. As a further estimate of the influence on the mean distribution from the relatively low number of observations the corresponding mean values have been computed with one of the extreme days (Nov. 7, 1973) excluded, Fig. 3.3 and 3.4.

Check of results against fresh water-supply

The measured water and salt fluxes together with an estimated upper layer mean salinity can be applied to Knudsen's relation in order to

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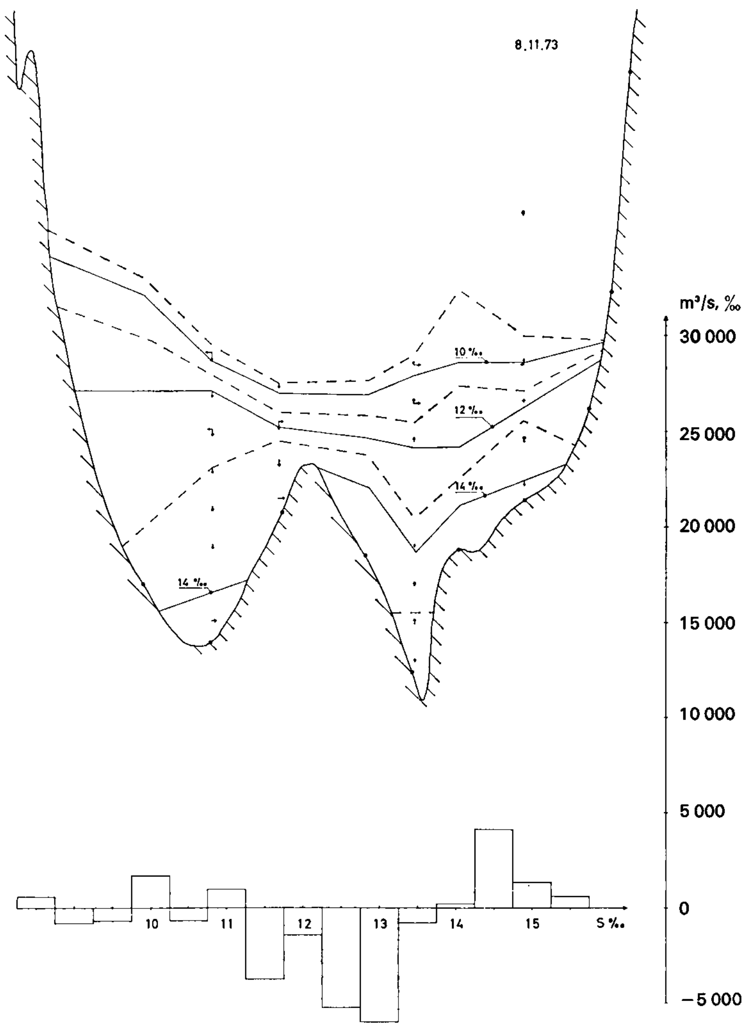


compare with the fresh water supply, which is a relatively well-known quantity. At this stage we have to assume that the salt flux for salinities *lower* than δ_0 is mainly advective, i.e. that the salt flux out of the Baltic carried by the surface layer may be approximated by the expression $M \cdot s_m$ where M is the volume outflux in the salinity range $s < s_0$ and s_m a mean salinity in the surface layer. The fresh water supply may be derived from the mean water and salt balances as expressed by

$$M(s_0) + M_0 = M$$

$$Q(s_0) = Ms_m$$

where $M(s_0) = \int_{s_0}^{\infty} \bar{m}\, ds$ is the volume flux into the Baltic of water with salinity larger than s_0 and $\bar{m}$ is the time average of $m(s, t)$. Furthermore $Q(s_0) = \int_{s_0}^{\infty} \bar{m} \cdot s ds$ equals the salt supply carried by water with salinity larger than s_0 and M_0 is the net fresh water supply to be computed. Considering the salt flux to be advective as in the above given equations means that we ignore the turbulent flux of salt in the surface layer, which in turn will give us an underestimate of the fresh-water supply M_0.

A check on the uncertainty in our computations is obtained by repeating the calculation of fresh-water supply with different choices of

FIG 2:6

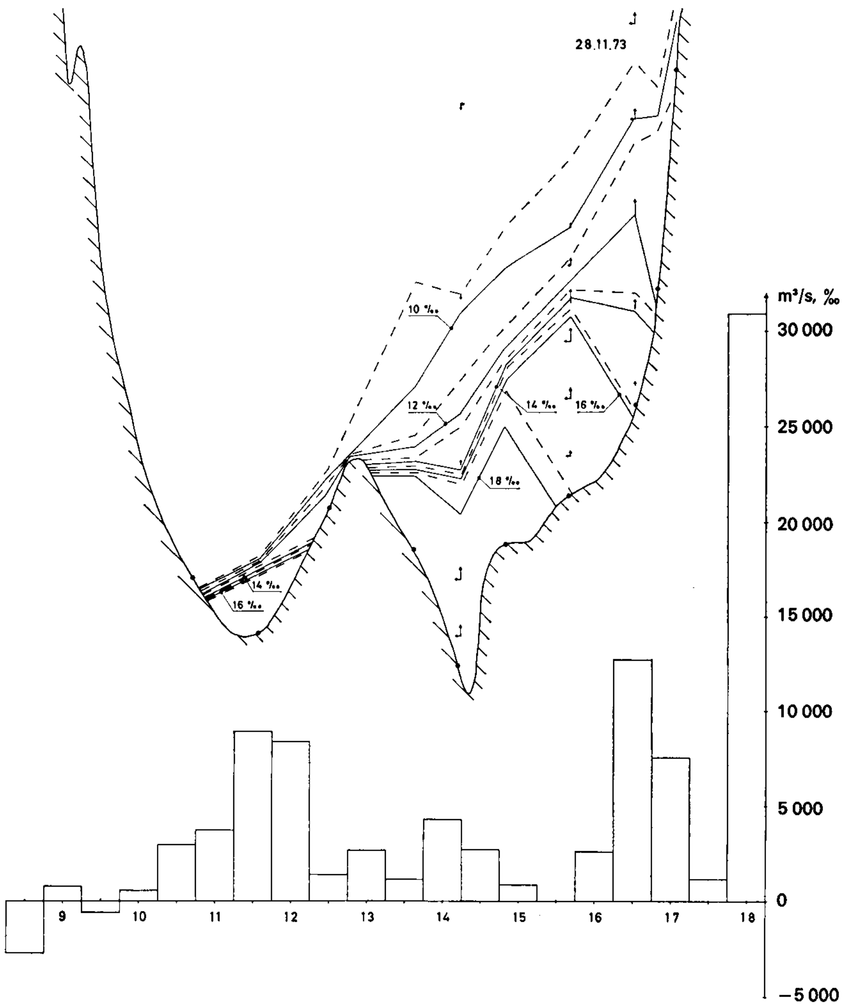
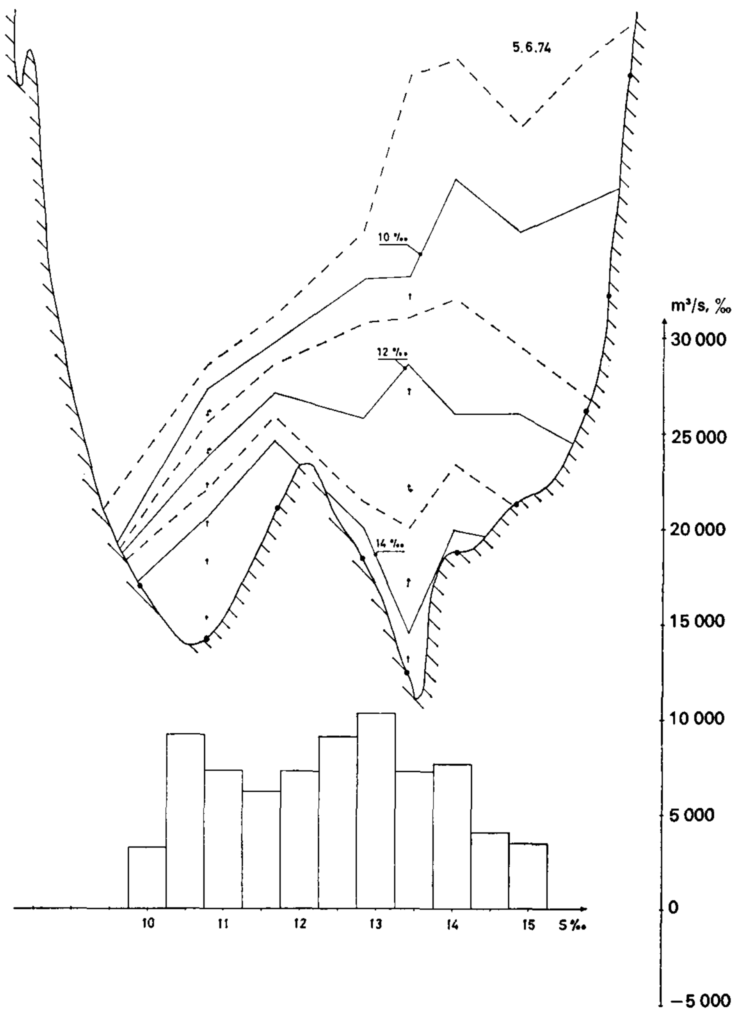


Table 1. *Mean values of salt supply $Q(s_0)$ and water supply $M(s_0)$ in the salinity range $s > s_0$, and the fresh water supply M_0 obtained from $Q(s_0)$ and $M(s_0)$ by requiring steady state salt and water balance*

Comment on how $\bar{m}$ has been obtained	Limiting salinity (‰) s_0	Salt water inflow (m³/s) $M(s_0)$	Salt inflow (tons/s) $Q(s_0)$	Calculated fresh water discharge (m³/s) M_0
(A) Mean value with equal weight on each period of measurements	8.25	15 400	210	11 000
(B) Mean value with equal weight on each day of measurements	8.25	12 200	173	9 400
(C) As A but with most deviating day excluded	8.25	17 200	231	12 000
(D) As A	9.75	11 500	167	9 400

FIG 2:7



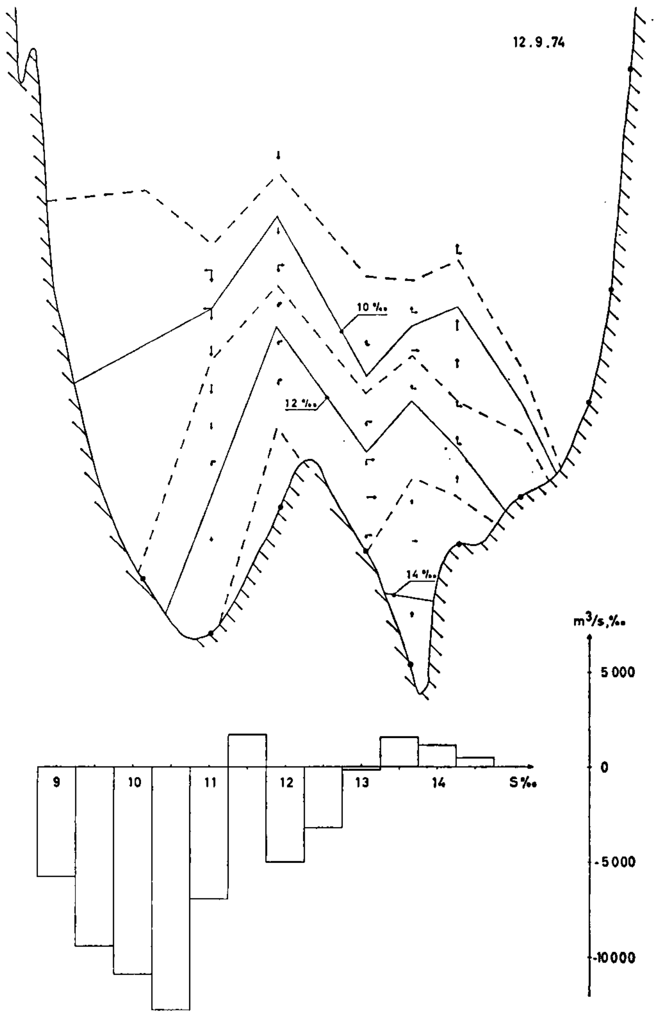
s_0. In all our calculations we have used $s_m = 8$ ‰ which closely approximates the surface layer salinity in the Bornholm area. The results are found in Table 1. The measured mean fresh water supply for the period 1951–1970 is 14 000 m³/s (Falkenmark & Mikulski, 1974).

As seen from Table 1 the values calculated from our observations are somewhat lower than the Mikulski value, but in view of the limited observational material the difference is surprisingly small. Note also that the deviation has the right sign to be accounted for by the assumption of advective saltflux in the surface layer.

Acknowledgement

We appreciate the competent work done by Kristina Hansson in handling the data presented in this report. The selfsacrificing work at sea under typically dangerous or at least uncomfortable conditions by assistants and technicians of the institute is also gratefully acknowledged.

FIG 2:8



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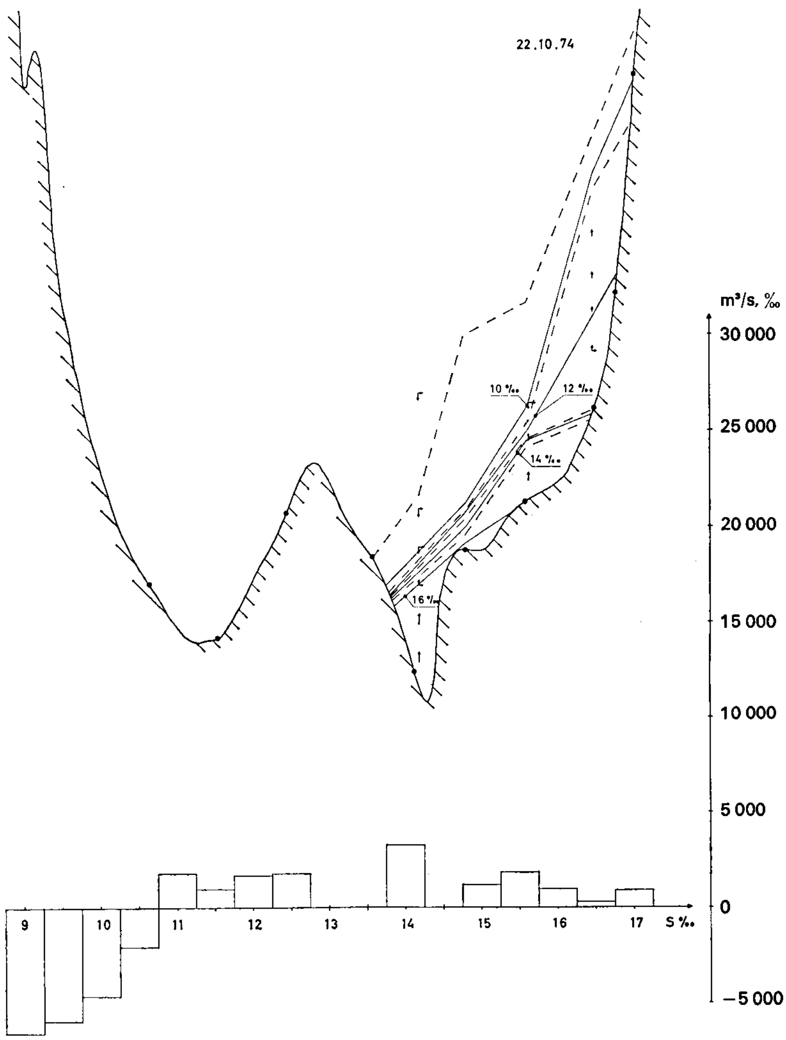

22.10.74
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FIG 2:10

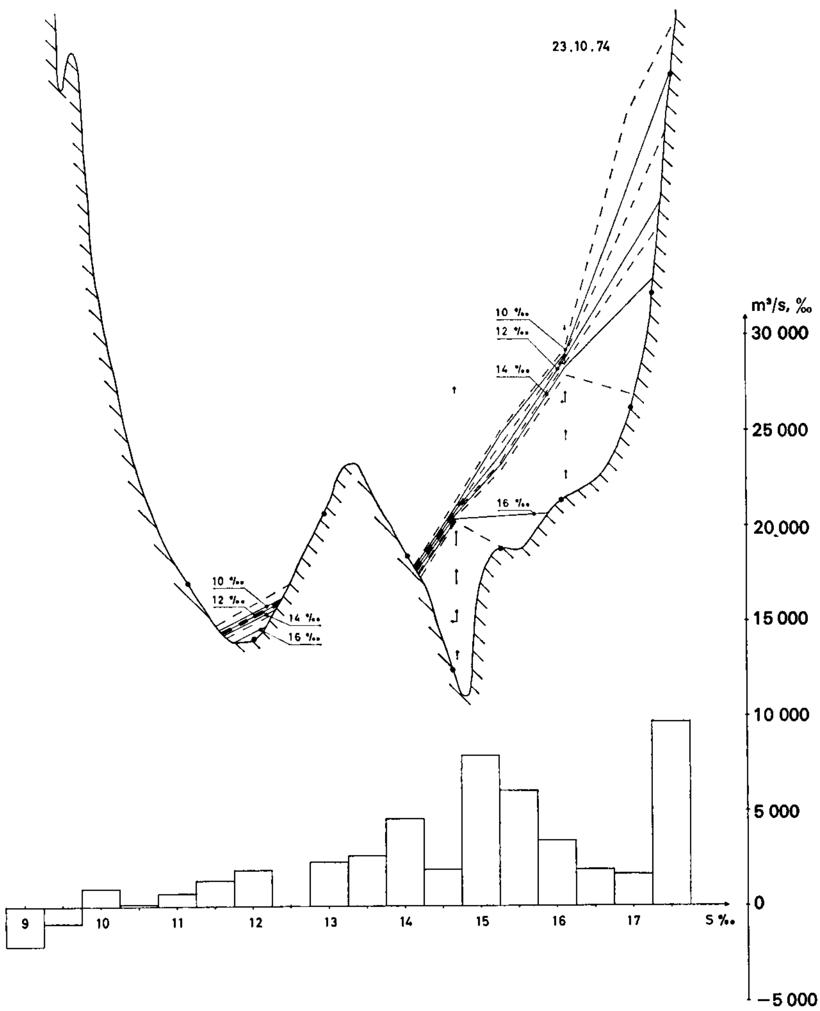

Fig. 3. The mean distribution function $\bar{m}(s)$ during the period of observation computed from the individual distributions such as those shown in Figs. 2.1–2.10.

Figs. 3.1 and 3.3 show the result when equal weight is given to each period of measurements, Figs. 3.2 and 3.4 are obtained by giving each day equal weight. In Figs. 3.3 and 3.4 the most extreme day (Nov. 7, 1973) has been excluded.

Similar data as those presented are available from the following days of observation: 23.10.73, 26.10.73, 29.3.74, 2.7.74, 12.8.74, 17.8.74, 21.10.74. These sections may be found in the report by Petrén & Walin (1975).

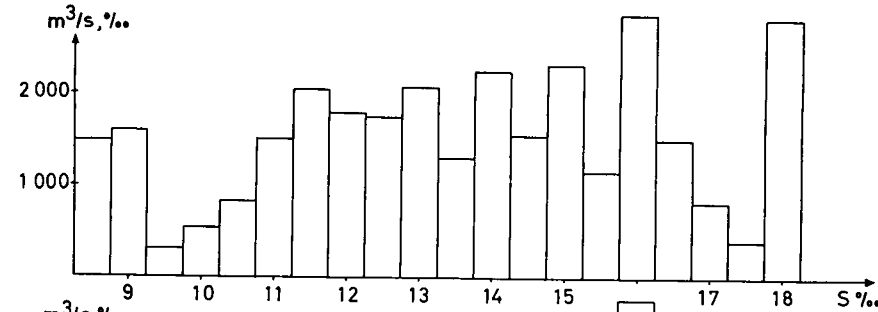

FIG 3:1

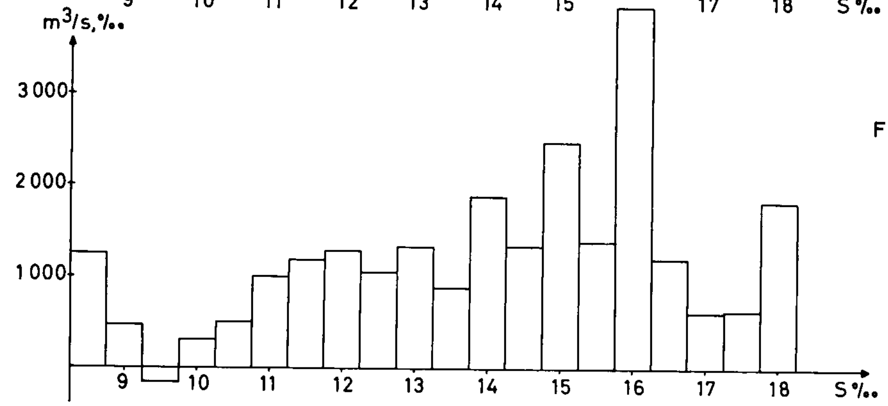

FIG 3:2

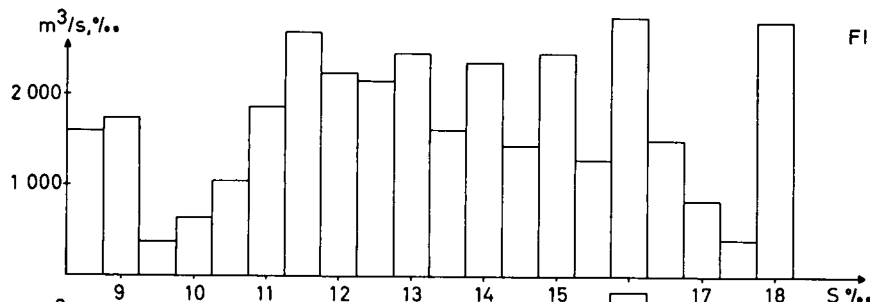

FIG 3:3

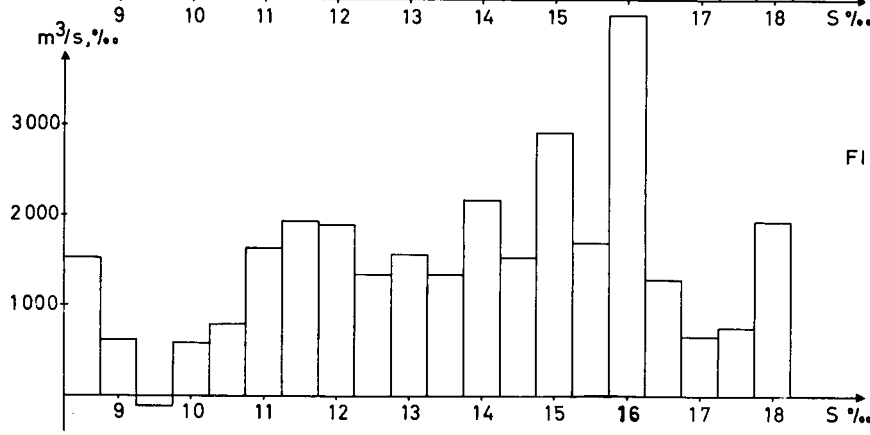

FIG 3:4

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Walin, G. 1975. On the description of the hydrographic state and the circulation in the Baltic deep water. Report 11, Inst. of Oceanography, Univ. of Gothenburg.

НЕКОТОРЫЕ НАБЛЮДЕНИЯ ГЛУБОКОВОДНОГО ТЕЧЕНИЯ В БОРНХОЛЬМСКОМ ПРОЛИВЕ В ТЕЧЕНИЕ ПЕРИОДА С ИЮНЯ 73 ПО ДЕКАБРЬ 74 гг.

Представлены предварительные результаты наблюдений глубоководного течения, проникающего в Балтийское море. Важной особенностью измерений является выделение потока солености. Средние потоки соли и массы, полученные из наблюдений, сопоставлены с притоком пресной воды и результаты сопоставления оказались удивительно хорошими.