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Hydrographical investigations in the Baltic Sea area before the founding of ICES

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Few investigations exist from the Baltic Sea from the 1700s. Many scientists speculated on the changes in sea level in the Baltic Sea. T. O. Bergman analysed surface waters and some scientists measured density and water temperature. In the early 1800s, Forchhammer carried out chemical analysis of samples from different sea areas, including the Baltic. He confirmed Marcet's statement on the constant relation between chemical elements in seawater. Several other scientists analysed seawater samples chemically. Salinity determinations using chemical methods and density measurements were carried out by Danish, Finnish, German, Russian, and Swedish scientists. Two important expeditions were carried out in the Baltic Sea, the first in 1871 by the German "Pommerania" and the second by the Swedish "Alfhild" and "G. af Klint" in 1877. The deep circulation and stagnation of the Baltic deep water were explained using the results from these expeditions. International cooperation between the Scandinavian countries and Germany was established. Hydrographical methods and results are described and discussed. Hydrographical tables for salinity determination using density measurements were published by Ekman, Makarov, Krümmel, and others at the end of the 1800s.

Keywords: density, expeditions, hydrographical methods, international cooperation, salinity, sea level, water temperature.

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Introduction

The Baltic Sea is an intra-continental, mediterranean sea with very narrow and shallow connections to the open ocean. Average depth is only 60 m, and the water balance is positive with an annual outflow of brackish surface water and an inflow of higher saline water along the bottom from the Kattegat through the Danish Sounds. The Baltic Sea consists of a series of deep basins separated by sills. In some of the deep basins, the bottom water may become stagnant and lose all its oxygen, and hydrogen sulphide may develop. The stagnant water is occasionally renewed during special meteorological conditions through the inflow of higher salinity water through the Sounds.

Sea-level changes

The first investigations in the Baltic Sea area were made in the 1700s. The Swedish scientist and philosopher E. Swedenborg (1719) speculated on the sea-level changes observed as old shore lines along the Swedish coast of the Baltic and tried to attribute these to very high tides in ancient times. A. Celsius (1743) and O. von Dalin (1747) discussed this question and suggested that the water level along the coasts was sinking. C. von Linné (1741, 1746, 1749) claimed that the sea level was sinking in all oceans. Finnish scientists also participated in this research (Homén, 1907). J. Browallius (1755), bishop of Turku, suggested that the sea level in the oceans was still sinking after the great flood recorded in the Bible. Celsius and von Dalin started series of observations in 1731 and 1752. On the initiative of Celsius, sea-level marks were cut on cliffs along the coasts in the Gulf of Bothnia. The British geologist Charles Lyell (1835) visited the Celsius mark made in 1731 at Lövgrund 104 years later. The sea level was already 0.78 m below the Celsius mark in that year, and had dropped an additional 0.22 m (Sieger, 1893) in 1849. Lyell explained the change as a rising of the land.

E. Biese (1902) reported monthly means of sea-level variations along the Finnish coasts from 1888 to 1900. M. Rykashev (1898) studied flooding in St. Petersburg and possibilities for predicting them by means of meteorological observations. R. Sieger (1893) published a very extensive account of the different ideas and theories on sea-level variations in Scandinavia beginning in the 1700s.

Temperature, density, salinity measurements, and chemical analysis of seawater

The oldest observations on the properties of the water itself were made by Muschenbroek (cited by von Etzel, 1874), by J. C. Wilcke (1771), who also constructed a deepwater sampler (Figure 1), and by P. J. Bladh (1776), who measured the density and temperature of the seawater in the Öresund, at different points on the Swedish Baltic Sea coast, in the Åland Sea, and in the Gulf of Bothnia. J. Catteau-Calleville (1815) reported on temperature, salinity, density, currents, tides, ice, colour, sea bottom, and sea levels in the Baltic Sea. Density was mostly measured by different types of hydrometers. Salinity was first determined by evaporation of the water and different extraction methods with precipitated salts. A relation between density and salinity was observed, and salinity was thereafter generally calculated from density. Tables for the relationship were prepared.

T. O. Bergman (1788) carried out qualitative and some quantitative analyses of surface waters from different parts of Europe. In 1819 and subsequent years, A. Marcet (1819) made areometric density determinations and chemical analyses of seawater from different oceans, including some samples from different depths in the Baltic Sea, and found that the water had almost the same composition in all seas.

The most important contribution was made by G. Forchhammer (1865) who analysed several hundred seawater samples over a period of 20 years for calcium, magnesium, chloride, and sulphate from different areas, including five samples from the Baltic Proper and five from the Gulf of Finland. He calculated the salinity from these components, confirmed Marcet's finding that the proportion between the main components of seawater was nearly constant, and concluded that salinity could be calculated from a single component. He proposed that chlorine would be easy to determine by Mohr titration and calculated that salinity could be found by multiplying the chloride content by 1.812. Forchhammer was the first scientist to observe the existence of hydrogen sulphide in seawater rich in organic matter. He observed that the ratio of sulphate to chloride was apparently lower in such water and explained that, "In this kind of decomposition where sulphuretted hydrogen is formed, the organic matter is changed into carbonic acid and water while the oxygen which this change requires is taken from the sulphates."

Several scientists at the Academy of Sciences in St. Petersburg determined the salinity of seawater samples.

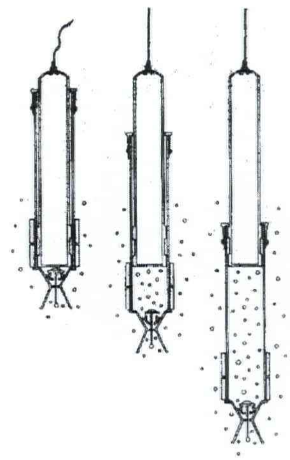

Figure 1. Piston water sampler according to Wilcke. The sampler is thrown over the ship's rail together with the length of rope needed. When the line is stretched, the sampler fills with water (Svansson, 2000).

H. Struve (1864) analysed some samples from different parts of the Baltic Sea and the Gulf of Finland in 1852 and five samples from the Gulf of Bothnia in 1864. A. F. von Sass (1867) published a longer series of salinity results determined from density.

Current observations

J. Nordenankar (1795) presented a paper on the currents in the Baltic Sea at the Swedish Academy of Sciences in 1792. A. Stjerncreutz (1861), Finland, published a report from 1857 on surface current observations carried out in different parts of the Baltic Sea.

A. W. Cronander (1898) conducted current observations on Danish and Swedish lightships. He constructed a current meter and measured currents on board lightships as well as smaller boats in the Baltic Sea and in the Öresund. He calculated the annual mean ingoing and outgoing currents through the Belts and the Sound (Öresund) by means of current observations taken on board the lightships "Schultz' Grund" and "Drogden". He compared current observations from the "Drogden" during the periods 1850–1859 and 1864–1873. The current observations did not cover the whole year and, therefore, the conclusions were uncertain. I have not been able to determine how current speed was measured on the Danish lightships in 1850.

R. Engelhardt (1889) calculated the sea level of the Gulf of Finland to be about 18 cm above the level of the Sound and 30 cm above the level of the Skagerrak. He also found that the Baltic surface water moved cyclonically.

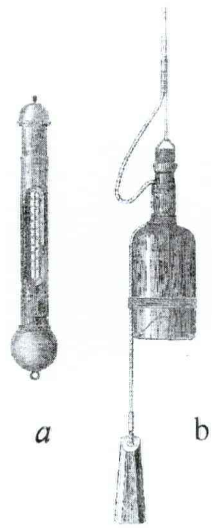

Figure 2. a) Thermometer isolated with thick hard rubber, used on the "Pommerania". It had to be kept submerged for one hour and then quickly raised to the surface for reading the temperature. b) Arrangement for sampling water close to the surface.

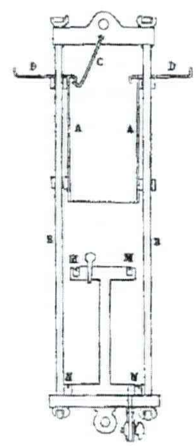

Figure 3. Deep-sea sampler according to Ekman, used on the "Pommerania". The sampler was kept open by water resistance during lowering and closed when it was stopped.

Open-sea expeditions

Two important open-sea expeditions were conducted in the Baltic Sea in the 1870s. The first was the German expedition with the paddle wheeler "Pommerania" in the summer of 1871, organized by the "Kommission zur wissenschaftlichen Untersuchung der deutschen Meere in Kiel" (Commission for Scientific Investigations of the German Seas in Kiel). Scientists involved were H. A. Meyer, K. Möbius, G. Karsten, and V. Hensen. The expedition covered the Skagerrak, the Kattegat, and the Baltic Proper up to Stockholm and the island of Gotland. At the Landsort Deep, the maximum depth sampled was only 210 m, while at the Gotland Deep, the maximum sampling depth was 176 m. Altogether, 170 stations were worked (Meyer *et al.*, 1873).

A thermometer isolated with thick hard rubber was used for the temperature measurements (Figure 2a). The thermometer had to be kept submerged for one hour before being quickly raised to the surface for reading. At shallow depths, a glass bottle was used for water sampling (Figure 2b). Several models of metallic samplers equipped with different closing systems were used for deep sampling (Figure 3). One sampler type was submerged closed and then opened at the sampling depth by a messenger. After the opening was observed by air bubbles rising to the surface, the sampler was closed and lifted to the surface. Salinity was determined partly by evaporating the water and weighing the residue and partly by gravimetric chlor analysis. Areometric determination was also used, but the areometer was not designed for the lowest salinities encountered (Jacobsen, 1873). Currents were observed by means of a large current cross made of zinc sheets. The earlier observed differences in salinity and the inflow of surface water along the Baltic east coast were confirmed. The inflow of bottom water with high salinity was observed on the Rügen-Ystad line.

The second expedition was carried out by Swedish scientists in the summer of 1877 (Figure 4). The work consisted of two parts. The first sampled 96 stations, with the gunboat "Alfhild" covering the Skagerrak, the Kattegat, and the Baltic Proper up to the island of Gotland; F. L. Ekman was the chief scientist. The second part sampled 112 stations with the survey ship "G. af Klint" covering the Gulf of Bothnia, the Åland Sea, the mouth of the Gulf of Finland, and the northern Baltic Proper; participating scientists were F. S. Malmberg and A. Cronander. Ekman had constructed five different types of water samplers for the expedition. His isolated water sampler was used for temperature measurements on the "Alfhild" (Figure 5). On the "G. af Klint", Miller-Casella maximum-minimum thermometers were mainly used. The water samplers were closed by different arrangements as soon as they moved upwards. The reason was that messengers did not function properly when hemp rope was used for lowering the sampler.

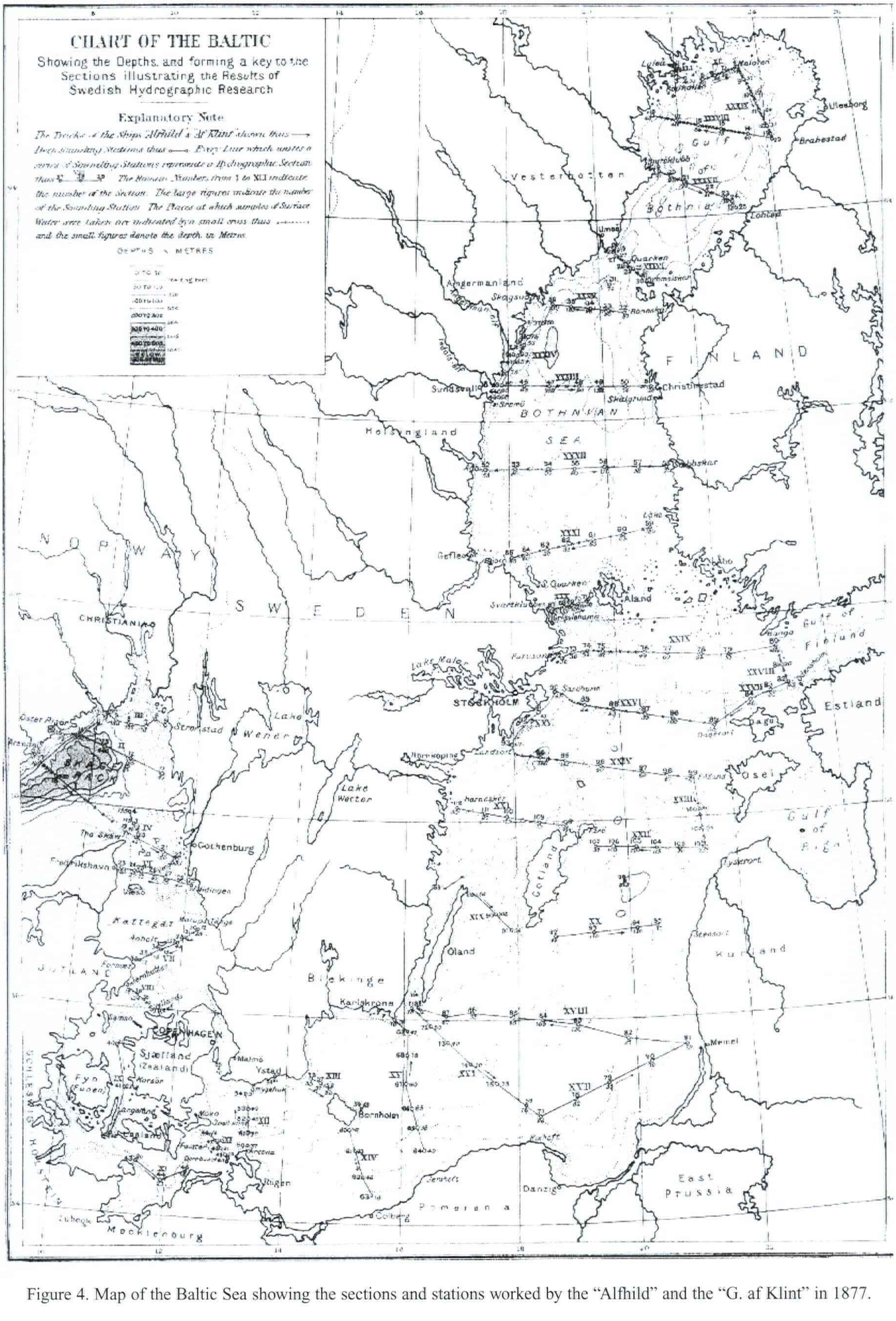

Figure 4. Map of the Baltic Sea showing the sections and stations worked by the "Alfhild" and the "G. af Klint" in 1877.

The minimum temperature layer below the warm surface water was discovered and caused much speculation. O. Krümmel (1895) explained that the phenomenon was caused by vertical convection of the surface water in winter and warming of the surface water during spring and summer. Cold surface water from the previous winter was preserved between the thermocline and the halocline.

O. Pettersson (1893), who worked out and published the Swedish results after the death of Ekman, compared them with the results from the "Pommerania". He found that the results were generally similar in the southern part of the Baltic Proper, but different in the Landsort Deep. Pettersson concluded that deep stretching changes in the deep water had occurred between 1871 and 1877 (Table 1). The Swedish expeditions in 1877 were the most important and detailed investigations in the Baltic Sea during the century.

Long-term regular measurements at coastal stations and lightships

H. A. Meyer (1871), Kiel, started regular observations of water temperature and density at different depths and of surface currents at 10 stations in the western part of the Baltic Sea in 1868–1870. In 1870, the German Kiel Commission was established, took responsibility for continuing the measurements, and established 13 hydrographical stations along the south coast of the Baltic Sea from Hela to Sonderburg. The measurements continued until 1893, but owing to high costs and the increasing interest for deep-sea expeditions, the 13 stations were replaced with four well-equipped stations.

In Denmark, 28 hydrographical stations were established between Bornholm and Skagen in 1876–1883. Current observations were carried out on Danish light-

Table 1. Distribution of salinity, temperature, oxygen, and carbon dioxide in the Landsort Deep between 1871 and 1893.

Depth	Pommerania 1871		F. L. Ekman 1877		O. Pettersson 1891			Swedish Commission 1893			
m	Sal.	Temp.	Sal.	Temp.	Sal.	Temp.	O_2 cc.	Sal.	Temp.	O_2 cc.	CO_2 cc.
0	6.46	6.46	6.13	15.4	–	10.4	–	6.52	13.55	–	–
10	–	–	6.60	11.3	–	–	–	6.63	13.65	8.17	–
20	–	–	6.54	3.9	–	8.00	–	6.78	7.85	–	–
30	–	–	7.12	2.0	–	5.05	–	7.08	4.00	–	–
40	–	–	7.48	2.1	–	–	–	7.12	3.25	–	–
50	9.12	3.0	7.48	–	–	3.00	–	7.35	2.35	8.58	32.31
60	–	–	7.62	2.3	–	2.60	–	7.84	2.10	6.67	33.73
70	–	–	–	–	–	2.80	–	–	–	–	–
80	–	–	9.52	3.4	–	3.10	–	9.43	3.45	–	–
100	–	–	9.52	–	–	3.30	4.41	9.86	4.80	3.09	38.26
110	–	2.8	–	–	–	–	–	–	–	–	–
120	–	–	10.48	3.7	–	3.60	–	10.04	3.75	–	–
140	–	–	10.41	–	–	–	–	10.09	3.85	–	–
160	9.20	2.2	10.20	3.7	–	–	–	–	–	–	–
180	–	–	10.28	–	–	–	–	–	–	–	–
200	9.96	0.8	10.35	3.7	–	3.70	–	10.22	3.90	2.73	38.36
220	–	–	10.35	3.7	–	–	–	–	–	–	–
240	–	–	10.41	3.7	–	–	–	10.32	3.90	–	–
260	–	–	10.45	3.7	–	–	–	10.32	3.90	–	–
280	–	–	10.48	3.7	–	–	–	10.32	3.95	–	–
300	–	–	10.48	3.7	–	3.70	3.51	10.32	3.85	2.82	–
320	–	–	10.51	3.8	–	–	–	10.32	3.85	–	–
340	–	–	10.51	3.7	–	–	–	–	–	–	–
360	–	–	10.54	3.8	–	3.75	3.04	10.34	–	–	–
380	–	–	10.61	3.9	–	–	–	10.36	–	–	–
400	–	–	10.73	4.6	–	3.80	3.19	10.36	3.90	1.33	40.65
411	–	–	–	–	–	3.80	3.21	–	–	–	–

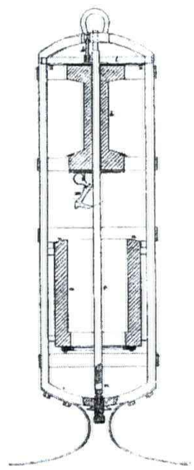

Figure 5. Isolated deep-sea sampler according to Ekman, used on the Swedish expedition in 1877. The plug at the top was removed on deck after the sampling. A common thermometer was inserted through the opening and the temperature was read.

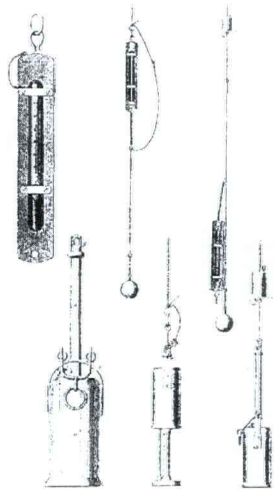

Figure 6. Reversing thermometer and water sampler used on the Swedish lightships in 1879. No auxiliary thermometer was used.

ships as early as 1850. Temperature was measured with the same kind of thermometers as those used on the "Pommerania". At the end of 1879, Sweden established five stations along the coasts of the Baltic Proper and the Gulf of Bothnia. By 1897, there were 14 Swedish stations, of which 10 were on lightships.

A Nautical-Meteorological Conference on Regular Hydrographical Measurements on Ships on Regular Routes, Lightships, and Coastal Stations was held in Copenhagen in 1878, with participants from Denmark, Norway, and Sweden. The establishment of nautical-meteorological institutions in the Scandinavian countries resulted from a division of work and the introduction of common principles for observations, performance, data processing, and publication of results. Measurements and observations of different parameters in air and water were discussed (Anon., 1878).

Ekman reported, in an appendix to the report, on the Swedish activities and suggested the use of a common log for surface current measurements. Instructions for hydrographical measurements at Swedish lighthouses and pilot stations (Anon., 1879) were published and also adopted in Denmark. Reversing thermometers and water samplers, closed by means of a propeller device or messengers, were used (Figure 6). Salinity was determined from density measurements using an areometer. A current meter constructed by T. Arwidsson was used for deep measurements (Figure 7).

Various smaller investigations

The Russian Admiralty carried out some hydrographical investigations in the Gulf of Finland and the Baltic Proper. Four revenue cutters made hydrographical measurements along the coasts of the present Baltic

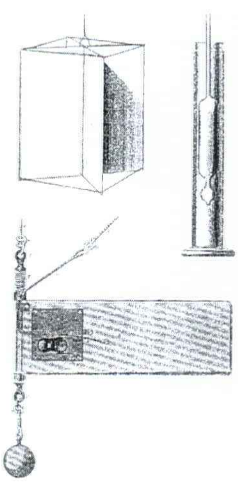

Figure 7. Current cross, hydrometer, and current meter used on Swedish lightships in 1879.

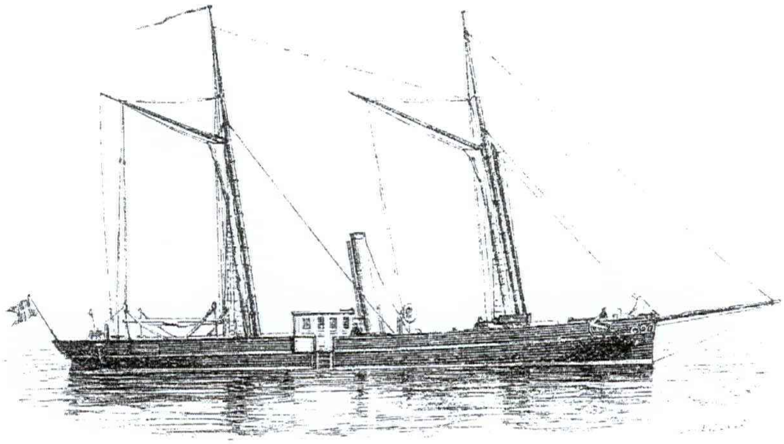

Figure 8. The Danish gunboat and fishery protection ship "Hauch" in 1889.

states in 1876 using methods recommended by the German Kiel Commission. Admiral S. O. Makarov made observations on density and temperature in 1886 on the corvette "Vitiaz" in the Gulf of Finland and the Baltic Proper while leaving Kronstadt for his long scientific expedition to the Pacific and also when returning in 1889 (Makarov, 1894). In addition, Makarov carried out daily measurements of temperature and density in the port of Kronstadt until 1890. In May 1899, Makarov also determined surface water temperature and density at 18 stations during a cruise from Kronstadt to Öresund on the icebreaker "Jermak" (Makarov, 1901).

It is difficult to locate records of investigations from the Baltic countries and Poland because these countries were part of Russia or Germany until the end of World War I. S. Schweder (1881, 1882, 1883, 1885, 1886, 1887) from Riga measured daily salinity in the Gulf of Riga and several other places along the coast from 1881 to 1887. M. Braun (1884) from the University of Tartu in Estonia, carried out several expeditions with revenue cutters along the Estonian coast between 1881 and 1883. His main interest was concentrated on biological problems, but temperature and salinity were also measured. K. von Baer (1862) published the results of four analyses of surface water collected in 1854, 1855, and 1860 in the Gulf of Riga, the Hapsal Bight, and around the island of Hiiumaa (Ösel).

Finland was under Russian rule, but had a much more independent status. The Finnish Inspector of Fisheries, O. Nordqvist (1888), conducted investigations in Bothnian Bay, the Bothnian Sea, the Åland Sea, and the Archipelago Sea in the summer of 1887 on two revenue cutters, the "Falken" and the "Vartia". In addition to biological observations, he measured salinity and temperature at different depths at 44 hydrographical stations. E. Hjelt (1888) chemically analysed several of Nordqvist's water samples for chloride, sulphuric acid, calcium, and magnesium and also determined the total amount of solid substances. A. Moberg published yearly observations of the ice conditions around Finland from 1859 to 1893, and O. Kihlman from 1894 (Homén, 1907).

Two expeditions were carried out by the German RV "Holsatia", the first in 1887, with V. Hensen as chief scientist, and the second in 1901 (Reibisch, 1902). The expeditions covered the Baltic Proper up to the southern tip of Gotland. The main focus was on marine biology, but hydrographical measurements were also carried out at the stations.

The Danish gunboat "Hauch" (Figure 8) worked in Danish waters in the 1880s measuring salinity as well as conducting biological investigations (Petersen, 1889). Swedish hydrographers carried out several smaller expeditions in the Baltic Sea in 1891 and 1893 in the Gotland Deep and the Landsort Deep.

International cooperation in the open Baltic Sea

The years 1892 and 1893 were of great importance for hydrographical investigations in the Baltic Sea. Pettersson compared his measurements in the Landsort Deep from 1891 and the Swedish results from 1893 with Ekman's results from 1877 and found that the water

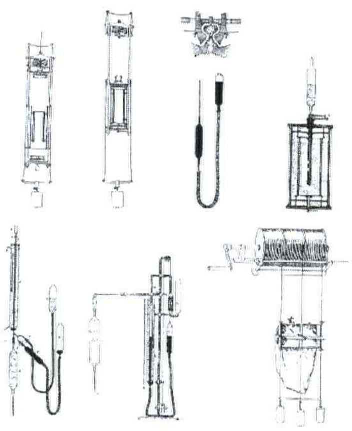

Figure 9. Water sampler, equipment for oxygen, nitrogen and carbon dioxide analysis, and a plankton sampler used by O. Pettersson in the 1890s.

from 150 m to the bottom at 400 m had nearly the same temperature and salinity. Unfortunately, the salinity measurements from 1891 were lost, but not before a diagram showing the salinity distribution was drawn. A similar diagram from the 1893 expedition gave nearly the same distribution. Oxygen content had decreased around 30% from 1891 to 1893, and carbon dioxide had increased proportionally (Figure 9). Pettersson concluded that water with higher density occasionally streamed in along the bottom and filled the deep basins. This water caused stagnation for many years (Table 1); oxygen in the stagnant basins decreased through oxidation of dead organic matter and carbon dioxide was formed. It is admirable that Pettersson could draw the right conclusions from very few and partly questionable data.

The first cooperation between hydrographers from different countries was established with the aim to conduct a rational investigation of the Baltic Sea. At the 14th Scandinavian science meeting in Copenhagen (Anon., 1892), a resolution on international cooperation suggested by Pettersson was adopted. The resolution stated that "due to the great importance of a satisfying knowledge of the hydrographical conditions in the Scandinavian waters, both scientifically and practically, and due to the difficulties in carrying out such research without cooperation between concerned countries, the meeting proposes that the Scandinavian countries together and according to a common plan, should carry out investigations in the waters outside their coasts." In that year, the Danish and Swedish hydrographical commissions were established and hydrographical-biological investigations were started in both countries. When Krümmel in Kiel heard about this cooperation, he contacted Pettersson and joined in the work with the Imperial transport ship "Pelikan" and carried out five expeditions in the western Baltic Proper, and as far as the Gotland Deep in July 1894 (Smed, 1992).

At the Scandinavian science meeting in Stockholm in July 1898, it was agreed between the Danish, Finnish, and Swedish hydrographers that simultaneous investigations should be carried out in different parts of the Baltic Sea on a regular basis. The first Finnish expedition on the "Suomi" began at the end of August 1898 (Homén, 1907). The cooperation between the Scandinavian countries and Germany obviously helped give Pettersson the idea of a larger-scale cooperation between European countries and the founding of ICES.

Hydrographical tables

At this time, it was generally agreed that salinity calculated from specific gravity determined by hydrometer measurements and from chloride titration showed good agreement. Hydrographical tables for reduction of the specific gravity to some standard temperature had been published by Ekman, Makarov (1891), Krümmel, and Knudsen, but had to be revised by an international commission.

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