# NOAA Atlas NESDIS 65

# CLIMATIC ATLAS OF THE SEA OF AZOV 2008

Silver Spring, MD
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**U.S. DEPARTMENT OF COMMERCE**
**National Oceanic and Atmospheric Administration**
National Environmental Satellite, Data, and Information Service

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National Oceanographic Data Center User Services Team
NOAA/NESDIS E/OC1
SSMC-3, 4th Floor
1315 East-West Highway
Silver Spring, MD 20910-3282

Telephone: (301) 713-3277

Fax: (301) 713-3302

E-mail: services@nodc.noaa.gov

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|---|---|
| - Проектов “Спасение и архивация глобальных океанографических данных” (GODAR) и “База данных Мирового океана”, поддержанных Межгосударственной океанографической комиссией (IOC) ЮНЕСКО | - “Global Oceanographic Data Archaeology and Rescue” (GODAR) and “World Ocean Database” projects endorsed by the Intergovernmental Oceanographic Commission (IOC) UNESCO |
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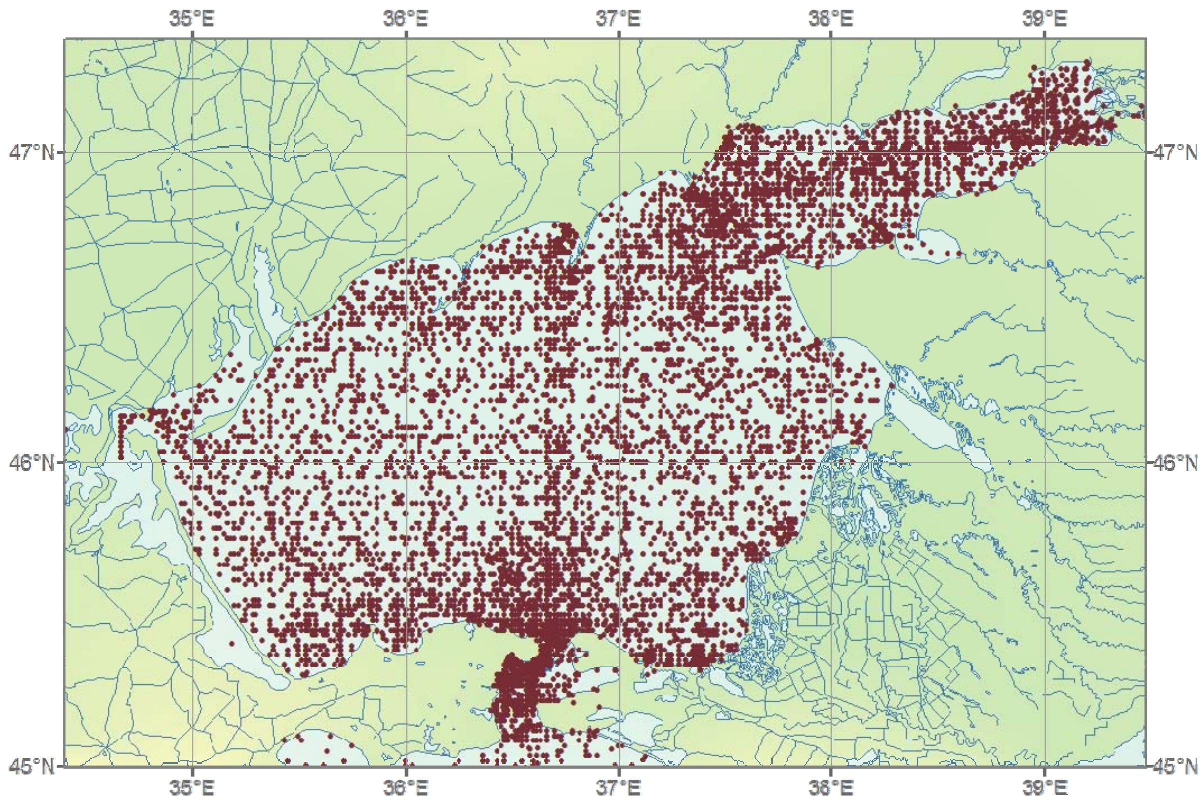
**Time: 1891-2006**
**Marine observations: 35,417 profiles**
**Surface observations in the coastal zone: 89,203 measurements**

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# CLIMATIC ATLAS OF THE SEA OF AZOV 2008

G. Matishov, D. Matishov, Yu. Gargopa, L. Dashkevich, S. Berdnikov
V. Kulygin, O. Arkhipova, A. Chikin, I. Shabas
(Southern Scientific Center, Murmansk Marine Biological Institute,
Russian Academy of Sciences, Russia)

O. Baranova, I. Smolyar
(NOAA/NESDIS/NODC/Ocean Climate Laboratory, U.S.A.)

Editors: G. Matishov, S. Levitus

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**CONTENTS**

## ACKNOWLEDGEMENTS

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The large amount of data in the atlas has been rescued thanks to the support of the UNESCO Intergovernmental Oceanographic Commission (IOC), Global Oceanographic Data Archeology and Rescue project and the IOC World Ocean Database Project.

The sources of historical data for the present paper were the NOAA Central Library, the Don State Public Library of the city of Rostov-on-Don, Scientific Library of the Southern Federal University, and Library of the North Caucasus Hydro-meteorological Centre of Russia. Our special gratitude is to the employees of these libraries – T.A. Sharapova, E.M. Kolesnikova, O.A. Men’shikh, and S.A. Bondarenko – for their help provided searches for the books on the Sea of Azov climate research history.

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We express our gratitude to Roman Mikhalyuk for the Russian-English translation of this paper.

**ABSTRACT**

The present Atlas is a result of international co-operation of the scientists of the Southern Scientific Center and Murmansk Marine Biological Institute of the Russian Academy of Sciences (Russia) and the Ocean Climate Laboratory of the National Oceanographic Data Center (USA).

The Atlas contains oceanographic data presented on CD-ROM and on internet http://www.nodc.noaa.gov/OC5/AZOV2008/start.html. The data collected in the Sea of Azov and the Kerch Strait during 1891-2006 by the Russian Academy of Sciences, the Ministry of Fisheries, and the Hydro-Meteorological Service of Russia. It includes data distribution maps by year and individual month as well as vertical sections of climatological monthly temperature and salinity. A three-dimensional hydrodynamic model of the Sea of Azov was developed. The accuracy of the hydrodynamic model was assessed by comparing the model output with salinity climatic fields calculated from measured salinity data. Interannual air temperature variations for the Sea of Azov and surrounding areas, for the period of 1885-2006, are also reviewed for potential climate change trends. Electronic copies of rare books and articles on the history of the Sea of Azov exploration and climate studies are included, as well as photographs depicting the natural history of the region.

## 1. INTRODUCTION

The Sea of Azov, due to its geographical location, has been at the junction of Euro-Asian trading routes for many centuries. The climate and fertile soils of the areas neighbouring the Sea of Azov, the state of its biological resources have been determining the life conditions and economic activity of the vast region with population of more than 20 million people for centuries. The combination of these factors makes it vital to study the climatic system of the Sea of Azov nowadays.

The present atlas is the continuation of the Climatic Atlas of the Sea of Azov 2006 and aims, first of all, at replenishment and enrichment of the Sea of Azov oceanographic database both by historical and new data, collected by the employees of the Russian Academy of Sciences during the period of expedition researches of 1997-2006.

Primary data, used while preparing the present paper, are available on a CD-ROM and internet are part of the Atlas. They are divided into three categories:

Category A. Measurements of physical and chemical characteristics of seawater over the Sea of Azov water area (vertical profiles). In total 34,517 stations

Category B. Measurements of water surface temperature and meteorological parameters at the coastal hydro-meteorological stations. In total 89,203 measurements.

Category C. Continuous measurements of temperature and salinity by a towed CTD probe. In total 12,830 measurements.

Thus, the database, presented in the previous version of the Atlas 2006 and containing 14,289 marine and coastal stations, has been considerably enlarged with new data, including measurements carried out at the end of the XIX$^{th}$ century.

Significant attention in this paper is paid to the quality control of temperature and salinity measurements because these parameters vary within a very wide range. The temperature varies from -0.8 $^{o}$C to +32 $^{o}$C during a year. The salinity variability is in the range of values close to zero in the mouths of the rivers that enter the Sea of Azov to 39 ‰ in the northeast in the area of Sivash.

## 2. THE HISTORY OF INSTRUMENTAL OBSERVATIONS

The first known instrumental observations in the Sea of Azov were carried out in the Xth century. The squads (bodyguards) of Prince Svyatoslav seized the Sea of Azov eastern coast and established the Tmutarakan Principality there. Later it became the outpost of the Kiev Rus. Prince Gleb was the first to measure the depth of the sea from ice in the direction from Tmutarakan to Korchev (present day Kerch) (Plakhotnik, 1996).

The warriors of Alexander the Great reached the coasts of the Sea of Azov. The Genoas built rich cities on the shores of the Sea of Azov in the XIII-XIVth centuries (Zuev, 1855. p. 4). The importance of the Sea of Azov is also proved by the fact that during the period of XIV-XVth centuries the Genoas made nine maps of the Sea of Azov (Ivanovsky, 1904).

Peter the Great founded Taganrog – a fortress city near the Cape of Taganyi Rog. The Taganrog Bay became the cradle of the Russian Navy. The study of the Sea of Azov also started during the reign of Peter the Great. The supreme attention was given to study sea-level fluctuations'. Because five meter depth passes at a distance of 2-3 kilometers from the shore in the Sea of Azov, the problem of sea-level fluctuations' is of great practical interest. They either block the vessels' passing or, vice versa, favor it. In 1696 the Dutchman Peter Bergman during expedition on Russian military vessel Krepost, with Peter the Great and Vice-Admiral K.I. Kryuis on board, surveyed the Don River from Voronezh to Azov. In 1697 the same Peter Bergman made the first measurements of the depths of the Sea of Azov (Fel, 1960).

According to the dictates Peter the Great, Vice-Admiral K.I. Kryuis made and published an atlas of maps of the Don River from Voronezh to Azov in 1703, with drawings of the Sea of Azov being placed at its back (Salishchev, 1962. p. 52). In 1768-1771 Senyavin published a new map of the Sea of Azov and the Kerch Strait. The weather and sea conditions' records were already made and kept on board the vessels at that time. From them one may learn, in particular, that due to the fresh winds of the eastern points, when the Don Estuary arms became extremely shallow, the squadron could not leave the Don for the Sea of Azov (Blinov, Messer, 1927).

In 1775 to encourage the Russian trading navigation in the Sea of Azov the Government of Ekaterina the Great (Ekaterina II) published a description of the southern ports and seas, prepared by Academician Geldenstedt (Ivanovsky, 1904). In 1808 navigation data and information on the Sea of Azov hydrology and meteorology were collected and generalized for the first time in the Sailing Directions or Travel-Guide on the Black Sea and the Sea of Azov by Captain Budishchev.

The Russian Geographical Society from 1863 to 1866 sent off an expedition to elucidate the reasons for the Sea of Azov becoming shallow (Bulletin of the Russian Geographical Society, 1982, Известия ВГО, 1982). In 1871 the Black Sea and the Sea of Azov Hydrographic Expedition was established being headed by Captain Zarudnyi and worked in the Sea of Azov till 1887. The reports of hydrographic parties of this expedition contain hydrological data as well.

Since 1873 marine hydrological activities were carried out by F.F. Wrangel. In particular, in late autumn he organized observations on the currents in the Sea of Azov and the Kerch Strait at the floating lighthouses of Beglitskaya Spit, Tuzla, and the Peschanye (Sandy) Isles. As a result, it was ascertained that the currents of the Kerch Strait depends on the wind conditions (Wrangel, 1875. p. 25).

From 16 to 25 June 1891 the Sea of Azov was studied in hydrological and biological respects days under the leadership of Captain of 2nd Rank Popov who was on board the schooner Kazbek (Spindler, Wrangel. I899; Tanfiljev, 1931; Alekseev, 1981). A.P. Loidis carried out the hydrological studies of the Kerch Strait in summer 1900 (Loidis, 1901). In 1913-14 the Sea of Azov hydrological studies were carried out by L.V. Antonov (see *Electronic Books* Section on CD-ROM).

In 1922-1926 under the guidance of N.M. Knipovich regular study of the Sea of Azov hydrometeorological regime began with the activities of the Azov-Black Sea Scientific and Fishery Expedition (Knipovich, 1926, 1932, 1938). In total, around 20 cruises were carried out with more than 500 hydrological stations being made. The complete texts of the reports "The Essay on the Azov-Black Sea Scientific and Fishery Expedition Activities in 1925" and "Hydrological Studies in the Sea of Azov" are presented on CD-ROM and internet version of the Atlas in the *Electronic Books* Section.

In parallel with the researches and activities of the Azov-Black Sea Scientific and Fishery Expedition some data on the Sea of Azov hydrology were obtained at eight vessels of the State Trading Fleet cruising the sea (Bulletin …, 1925).

When conducting the Sea of Azov hydrological researches it became obvious that the near constancy of ion composition of waters in the Sea of Azov, typical of the ocean, was significantly disturbed under the conditions of its limited water exchange with the ocean and considerable impact of continental runoff water. For that reason the use of standard marine tables, that enabled the computation of water salinity by the content of chlorine dissolved in it, introduced significant errors. N.M. Knipovich, at the 2$^{nd}$ All-Union Hydrological Congress in 1928, drew attention to the necessity to conduct special experimental researches to determine hydro-chemical constants for the waters of the inner seas, in particular – for the Sea of Azov (Knipovich, 1932).

In 1923—1925 the HMV Kerch cruises became regular. During the cruises the determination of water temperature, its specific weight at various horizons, transparency, roughness and other characteristics were carried out together with the measurements of the currents in the strait. Usually, it was possible to conduct observations at four to six points of the Kerch bay and the narrow area to the south of the Pavlovsky Cape during one cruise. Altogether for three years 246 series of currents measurements were made at 40 points of the strait, thus allowing the understanding of the specific features of currents' change and their character (Rudovits, 1977. pp. 37-38). The goal of those activities was to study the water exchange between the Sea of Azov and the Black Sea via the Kerch Strait. The importance and necessity of such observations increased after the 25$^{th}$ of November 1925 when during a heavy storm the Tuzla Spit was breached and broken through. Due to that, both field and laboratory observations were organized to study the influence of the Tuzla Spit breach and break-through on hydrological regime and depths within the Kerch – Enikal Strait (Ataev, 1927). In the work by P.M. Erokhin (Erokhin, 1929. p. 450) it was shown that if the winds of eastern points over the Sea of Azov led to the sea level decrease in its northern part, then the winds of western points with the speed of about 20-25 m/s for 10 hours contributed to the water increase in the same part of the sea by 150- 200 cm.

In 1928-1932, the Azov-Black Sea Fisheries Station, later reorganized into the Azov-Black Sea Research Institute of Fisheries and Oceanography (AzCherNIRO), conducted regular expeditionary studies.

The results of the Sea of Azov studies were summed up and generalized in the Sea of Azov Hydrological Reference Book, published in 1937 under the editorship of N.M. Knipovich and G.R. Bergman (see CD-ROM and the Internet version of this Atlas in the *Electronic Books* Section).

In 1936, the State Hydro-meteorological Service Administration of the USSR set up a network of standard sections in the Sea of Azov (Fig. 1A). Measurements along those transects were carried out by the State Oceanographic Institute (SOI (GOIN)). By the end of the 1980s there were more than 20 coastal stations in operation for collecting daily hydro-meteorological information.

World War II interrupted studies of the Sea of Azov but in 1944 the restoration of the hydro-meteorological stations on the coast of the sea began. By 1947 all previously existing operating stations and posts took up systematic observations again (Chernyshev, 1962).

In 1947 the Azov-Black Sea Institute of Fisheries and Oceanography (AzCherNIRO) restarted expedition activities in the Sea of Azov with studying its hydro-chemical characteristics (content of chlorine, oxygen, phosphates, nitrogen, silicon, oxydizability) along with hydrological ones.

In the 1950s dependencies between electrical conductivity and salinity of the Sea of Azov waters at various temperatures were experimentally derived at the GOIN Laboratory of the Sea Chemistry (Sopach, 1958). Dependencies between the content of chlorine, salinity and density of water were determined. As it was already known that salinity for the whole sea could not be calculated by a single formula without significant errors. An attempt was made to develop two formulae: for the open sea and one for the freshened sea areas (Taganrog Bay, Prikuban District). By the dependencies determined, the "Correspondence Oceanological Tables for the Sea of Azov Waters, Including its Much Freshened Areas" were calculated and made (Musina, Mikei, 1955; Tsurikova, 1960).

Since 1958 the Azov Research Institute of Fisheries (AzNIIRKh) has been conducting regular expeditions studying the Sea of Azov oceanographic and biological characteristics trough a net of stations presented at Fig. 1B. Together with observations on the state of the fish resources, seasonal studies of physical and biological parameters of the region are carried out annually.

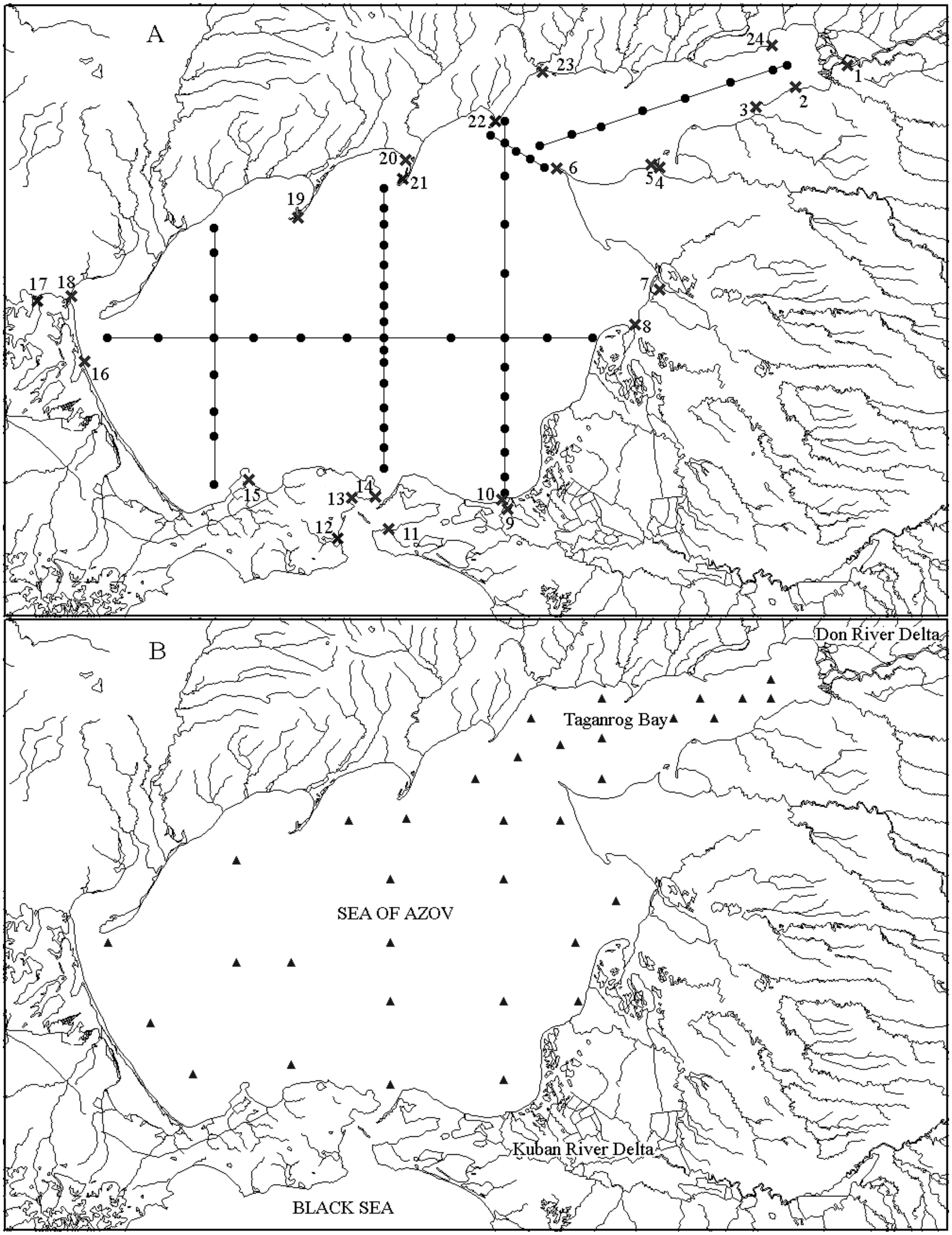



Fig. 1. Chart of hydrological sections and position of stations for coastal observations of the USSR Hydrometeorological service (A), chart of AzNIIRKh stations' location (B) 1-Azov; 2-Ochakov(skaya) Spit; 3-Margaritovo; 4-Eisk Port; 5-Eisk; 6-Dolzhanskaya; 7-Yasenskaya Ferry; 8-Primorsko-Akhtarsk; 9-Temryuk Port; 10-Temryuk; 11-Taman; 12-Zavetnoe; 13-Kerch; 14-Opasnoe; 15-Mysovoe; 16-Strelkovoe; 17-Chongarsky Bridge; 18-Genichesk; 19-Obitochnaya Spit; 20-Berdyansk; 21-Berdyansk(aya) Spit; 22-Belosaraisk(aya) Spit; 23-Mariupol; 24-Taganrog.

In the period of 1950-1990 the employees of the All-Union Research Institute of Fisheries and Oceanography (VNIRO), AzNIIRKh, AzCherNIRO, and various organizations of the USSR State Hydro-meteorological Service Administration conducted numerous expeditions collecting data on the state of the Sea of Azov environment and bioresources. The data obtained were summed up in the reference books and resulted in the publishing of a wide range of literature on studying the Sea of Azov hydro-meteorological regime (The Sea of Azov Hydro-meteorological …, 1962; Hydro-meteorological …, 1986; Hydro-meteorology …, 1991). The papers mentioned, however, did not contain the primary data.

Since 1997 Murmansk Marine Biological Institute has been conducting research expeditions in the Sea of Azov. In 1999 the Azov Branch of the Institute and Research Station were established, being equipped with updated scientific instruments and vessels. Research results are presented in a series of books (Complex …, 1998; Contemporary …, 1999; Regularities …, 2000; Environment …, 2001; Ecosystem …, 2002; Matishov et al., 2003; Complex …, 2004; Ecosystem …, 2005; Matishov et al., 2006; Ecosystem …, 2007).

In 2002 the Southern Scientific Center of the Russian Academy of Sciences was established in Rostov-on-Don. With the Center being established, the observations acquired a more regular character. During seven years (2002 – 2007) more than 60 scientific expeditions were organized thus providing a basis for obtaining new basic knowledge about the Sea of Azov climatic system. The primary data collected during these expeditions are used while training and educating the students of Rostov and Kuban State Universities, as well as handed over to the Universities of Moscow and Saint-Petersburg. Besides, collecting new data a task was set to rescue and preserve historical data and make them available to the world scientific community. The present Atlas is a step in this direction.

## 3. THE SEA OF AZOV CLIMATE INTERANNUAL FLUCTUATIONS

Social-economic progress depends on many factors, including weather and climate. Contemporary long-term prognoses orient mankind to global warming. But an increased interest of the specialists in long-term and still disputable and under discussions climatic trends should be balanced by serious attention paid to weather cataclysms. Their detailed study on the long-term plane can more pragmatically orient the society and economy to the assessment of actual nature risks.

A bright illustration of this thesis is a severe winter of 2006 on the East European Plain from Murmansk to Krasnodar. The weather on the territory of several thousand kilometers was characterized both by very low air temperatures (-20 – -30 °C) and long-lasting period (more than 40 days) of frosts. The extremely cold winter resulted in the arctic ice conditions in the Northern Caspian, Kerch Strait and the Sea of Azov with ice-hummocking as a typical phenomenon. The ice thickness reached 0.5 m, and the height of ice-hummocks – 1.5–2.5 meters. Vineyards and plantations of Lenkoran acacia on the Taman Peninsula, planted around 50 years ago, were frozen and died out. Analogous winters were registered in 1910–1911 and 1952–1954.

Analyzing climatic rhythms it is important to base and rely upon a whole arsenal of methods and approaches that in the aggregate give an integral picture of natural trends. In particular, paleographic methods of sedimentary cores' analysis give important information about the climate chronology (Matishov et al., 2007; Matishov, 2007). An indicator of climatic changes is the change of dominant zoo-benthos complexes on the shelf. Tree rings and fish scales are additional source of information about the habitat of indicated biota for the decades of their lives. In oceanographic practice, regular monitoring at standard hydrological sections is of paramount importance.

Analysis of water temperature seasonal dynamics on the basis of information given in the present Atlas for geographical areas of the Sea of Azov (Fig. 2) showed natural regular (latitudinal) differences of sea weather. From September to April warmer water masses (+2 – +5°C) are formed in the Kerch Strait (Fig 3). Shallow Taganrog Bay, on the contrary, is relatively warmed up (up to 25–30°C) in May – August. It is quite obvious that variations of thermohaline qualities of water in winter are under the influence of both air temperature and wind direction and the advection volumes of relatively warm Black Sea waters into the Sea of Azov basin.

Severe weather for winter season are observed in the Sea of Azov waters' thermal rhythms, for example, in 1891, 1911, 1954, and 2006 (Fig. 4). In relatively warm years (1927, 1933, 1940, 1981, 1997) weather winter conditions practically did not develop. Water temperature achieved typically «autumn» features: +2.5 – +6°C, +3 – +7°C, +4 – +9°C correspondingly in the Taganrog Bay, central part of the Sea of Azov and Kerch Strait.

To construct the air temperature graphics, mean data values for December, January, and February for meteorological stations located on the Sea of Azov coast were used. Water temperature in the winter period were computed by averaging the data, presented in the Atlas

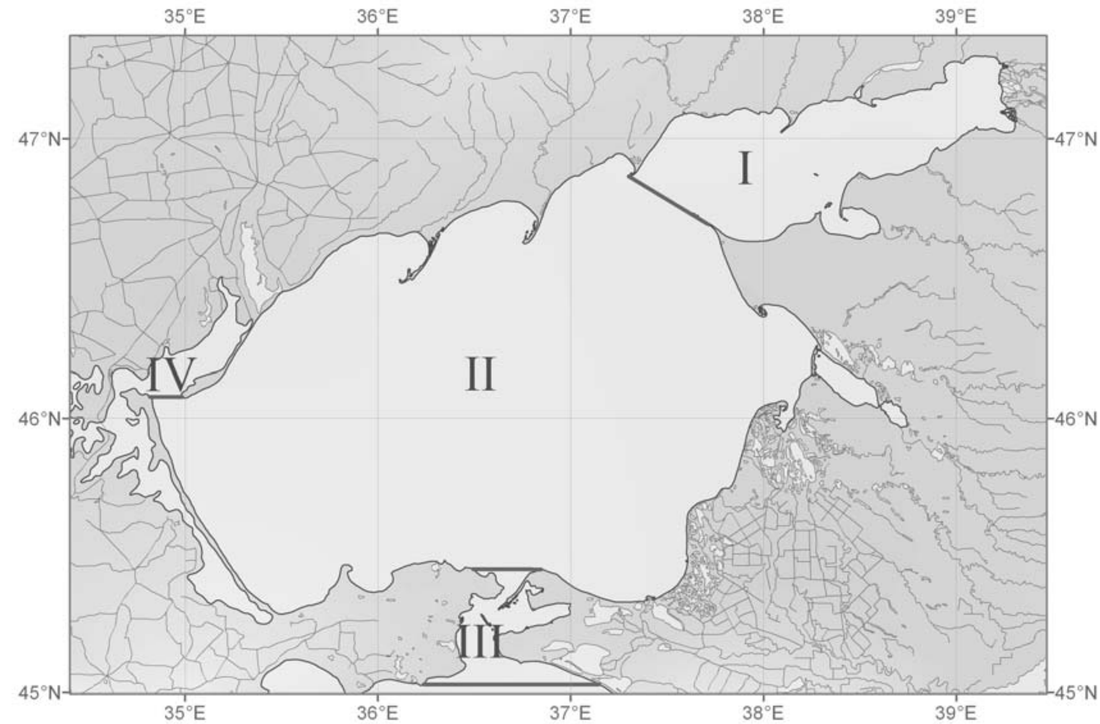



Fig. 2. Regions of the Sea of Azov
I – Taganrog Bay, II – Central Part of the Sea of Azov,
III – Kerch Strait and neighbouring part of the Black Sea,
IV – Sivash and neighbouring part of the Sea of Azov

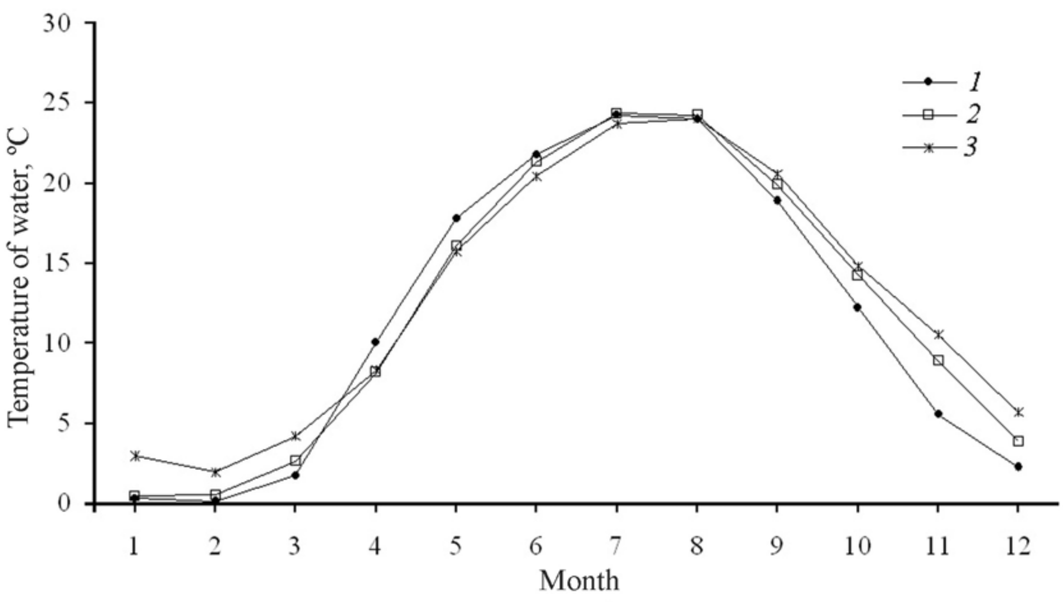
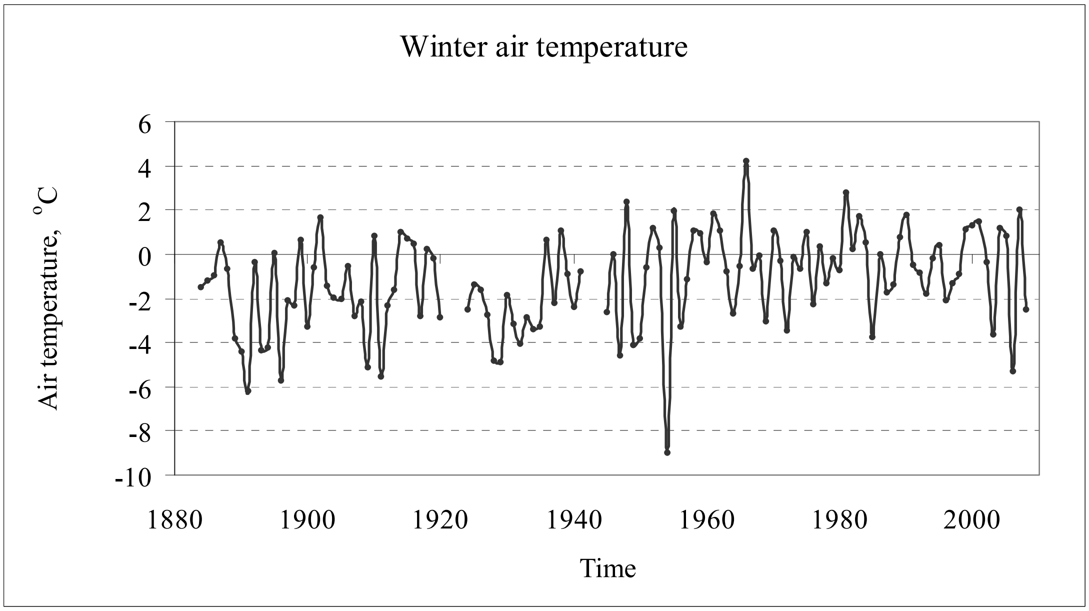



Fig. 3. Seasonal cycle of water temperature.
*1* – Taganrog Bay; *2* – Sea of Azov; *3* – Kerch Strait



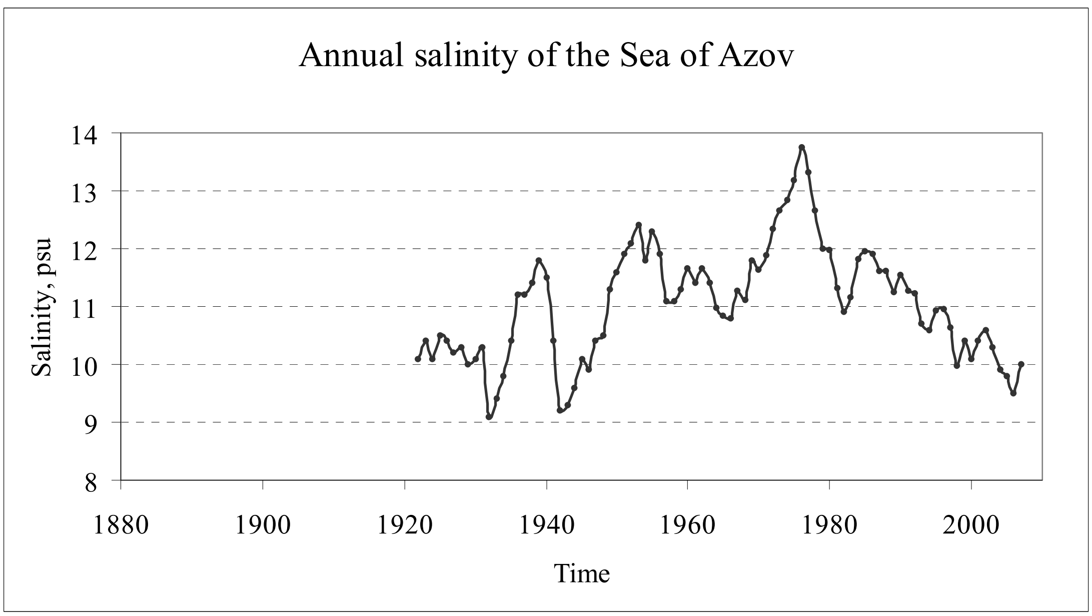




Fig. 4. Interannual weather regime over the Sea of Azov in the winter period

Although, oceanographic data were not available for all winter months for the centennial period. Nevertheless, there is some manifestation of a consistent pattern of severe and warm winters over the Sea of Azov area and their complete synchronicity with atmospheric temperature dynamics on the coast. To get a complete climatic picture, mean daily air temperature for December – February of 1885 – 2006 along the coast were analyzed and mean winter values over the Sea of Azov were calculated. The following pattern of winters' rhythms was determined: severe – with average frosts down to -5 – -10°C in 1885 – 1941; mild – with average temperatures over the sea up to +2 – 4°C in 1942 – 1984; severe – in alternation with mild ones with air temperatures up to +2°C in 1985 – 2006 (Fig. 4). It is typical that after severe winters drifting ice blocks sized several dozens meters are observed in the area till May.

In the aggregate, the conducted data analysis and systematization allows us to make the following preliminary conclusions. In publications connected with the Sea of Azov temperature regime analysis, the major focus is on the presence of positive trends in the last years, which are linked with global warming. But from the results presented here, it is clear that, most likely, we deal with fluctuations of climate, with periodicity of 20–40–60 years. The Sea of Azov climate for 120 years is characterized by cold cycles with freezing and high degree of ice conditions over the whole area alternating with warm ice-free phases during the whole winter. Besides, during various historical times either warm or cold periods may be more pronounced. So far there are no reasons to presume it will be different in the future.

The beginning of the XXI$^{st}$ century is characterized by a series of relatively cold winters. At the moment the present paper was published, not all data for the winter of the year 2008 were available, but it is clear that the winter of 2008 is within the anomalously cold winters' category. Ice cover (35-45 cm thick) was formed in the Sea of Azov. The inflow of cold air from the Arctic area was registered in the first decade of January of 2008 in the South of European Russia. In January in the majority areas of Astrakhan, Volgograd, and Rostov-Don, Krasnodar and Stavropol Regions were extremely cold for the first time for the last 58 years. Such a cold January for the southern region is among the first ten coldest Januaries since 1891. Cold weather (night frosts down to -23°C…-19°C and lower) remained till the middle of January.

It is obvious that polycyclic natural rhythms (from inter-glacial periods to inter-annual variability), even with consideration of progressive influence of human activities, suggest treating the global anthropogenic warming conception with caution. But even if humanity has entered the phase of long-term global warming, the actual on-going life demands more careful attention to any large-scale anomalies of weather and contemporary climate than tendencies that, possibly, will determine our common future in several decades of the specialists. The wreck of 12 vessels in the Kerch Strait on the 11$^{th}$ of November 2007 was the consequence of non-forecast southwestern stormy gusty (up to 30 m/s) wind.

To study and forecast climate, databases containing physical, hydro-chemical, and biological parameters of marine environment are required. Development of such databases is the basis of co-operation between the specialists of the Southern Scientific Centre and Murmansk Marine Biological Institute of the Russian Academy of Sciences and Ocean Climate Laboratory of the National Oceanographic Data Centre NOAA, USA (Matishov *et. al.*, 1998; Matishov *et. al.*, 2000; Matishov *et. al.*, 2004; Matishov *et. al.*, 2006).

# 4. DATABASE

## 4.1. Data Sources

The data for the present Atlas were obtained from the following sources:

- Publications of the employees of the Hydro-meteorological Service of the USSR, Ministry of Fisheries, Academy of Sciences of the USSR.
- Expeditionary cruise reports of the Southern Scientific Center of the Russian Academy of Sciences and Azov Branch of Murmansk Marine Biological Institute of the Kola Scientific Center of the Russian Academy of Sciences, report of the joint expedition of the Technological Institute of the Southern Federal University and Southern Branch of the P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences.
- Internet site of the United (Russian) State System of Information about the Situation in the World Ocean (ESIMO), http://data.oceaninfo.ru

## 4.2. Data Format

The data description format (Table 1), was developed by the employees of the Ocean Climate Laboratory of the National Oceanographic Data Center NOAA jointly with the colleagues from Murmansk Marine Biological Institute. This is the basis for the proposed approach to data formalization. The format has a block structure described in the present paper with slight changes. It consists of three blocks: **STATION, HEADERS,** and **DETAILS.** **STATION** block contains information about the place and time of data collection. **HEADERS** block contains meteorological data and information about the measurements' methods and instruments. **DETAILS** block contains temperature, salinity and other parameters' data.

When formalizing and formatting historical data it is necessary, sometimes, to restore stations' coordinates. Sometimes they are presented in the cruise reports in terms of local geographical names (for example: a pier of Akhtari, nowadays town of Primorsko-Akhtarsk). This is typical of the Sea of Azov as many expeditions of the end of the IXX$^{th}$ century and first half of the XX$^{th}$ century were carried out relatively close to the shore, and it was very easy for a navigator to determine the vessel's location in terms of coastline contours or a settlement's situation.

Inaccuracy definition of a vessel's location is an important part of the data quality in general. The presence of key words **COORD DETERM DESCRIPTION** in the **HEADERS** block indicates the fact of coordinate restoration (Table 2). If these key words are absent then the vessel's location coordinates were determined by instrumental methods.

Table 1. Data format. Sample 1

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **STATION** | | | | | | | | | | |
| LAT DEG | LAT MIN | LAT SEC | LAT HEM | LON DEG | LON MIN | LON SEC | LON HEM | MONTH | DAY | YEAR |
| 46 | 36 | 6 | N | 35 | 23 | 5 | E | 6 | 13 | 2004 |
| | | | | | | | | | | |
| **HEADERS** | | | | | | | | | | |
| TIME | 9 | 30 | | GMT | | | | | | |
| BOTTOM DEPTH | 9.9 | m | | | | | | | | |
| TS PROBE | CTD | | | | | | | | | |
| WIND DIRECTION | se | compass | | | | | | | | |
| WIND SPEED | 9 | m/sec | | | | | | | | |
| CLOUD AMOUNT | 4 | code10 | | | | | | | | |
| CLOUD TYPE | st | wmo0500 | | | | | | | | |
| WAVE TYPE | 1 | code | | | | | | | | |
| WAVE DIRECTION | se | compass | | | | | | | | |
| WAVE HEIGHT | 1 | m | | | | | | | | |
| TRANSPARENCY | 0.6 | m | | | | | | | | |
| | | | | | | | | | | |
| **DETAILS** | DEPTH | TEMP | SAL | | | | | | | |
| UNITS | m | C | | | | | | | | |
| DECIMAL PLACES | 1 | 2 | 3 | | | | | | | |
| | 0.5 | 18.43 | 10.078 | | | | | | | |
| | 1.0 | 18.43 | 10.078 | | | | | | | |
| | … | … | … | | | | | | | |
| | 9.0 | 18.24 | 10.104 | | | | | | | |
| | 9.5 | 18.24 | 10.104 | | | | | | | |

Table 2. Data format. Sample 2

| **STATION** | 46 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| LAT DEG | LAT MIN | LAT SEC | LAT HEM | LON DEG | LON MIN | LON SEC | LON HEM | MONTH | DAY | YEAR |
| 47 | 5 | 22 | N | 37 | 34 | 17 | E | 11 | 13 | 1922 |
| | | | | | | | | | | |
| **HEADERS** | | | | | | | | | | |
| TIME | 0 | 40 | | GMT | | | | | | |
| BOTTOM DEPTH | 2.2 | m | | | | | | | | |
| COORD DETERM | DESCRIPTION | | | | | | | | | |
| | | | | | | | | | | |
| **DETAILS** | DEPTH | TEMP | SAL | | | | | | | |
| UNITS | m | C | | | | | | | | |
| DECIMAL PLACES | 1 | 2 | 2 | | | | | | | |
| | 0 | 5.8 | 3.71 | | | | | | | |
| | 2 | 6.2 | 3.78 | | | | | | | |

Note: Station in the area of Mariupol (Kalmius River) (Knipovich, 1932, p. 431).

## 4.3. Data Access and Inventory

Access to the data as CD-ROM, and online version implemented through the web interface from the main menu Atlas section *Inventory, Access to original data.* Primary data are on CD-ROM in the **DATABASE** section in EXCEL electronic tables format with *.csv extension. They are divided into three categories depending on where and how the measurements were made.

Category A. Section - *Marine observations.* Measurements were made in the period of 1891-2006 in the Sea of Azov area on the surface and at various depth horizons. Data of this category includes 34,517 stations. The database of the Climatic Atlas of 2006 included only water temperature and salinity values. The database of this Atlas includes additional parameters listed in Table 3. All data are archived in one zip-file named MARINE_DATA.zip.

Category B. Section - *Coastal stations.* Measurements of water surface temperature were made in the period of 1937-2006 only at the coastal hydro-meteorological stations. Data of this category includes 89,203 measurements. All data are archived in one zip-file named COASTAL_DATA.zip.

Category C. Section - *Continuous observations.* Measurements of temperature and salinity at the depth of 0.6 meter were made during 17-18 June 2005 in the Taganrog Bay using towed CTD probe. An array of data of this category includes 12,830 measurements. All data are archived in one zip-file named CONTINUOUS_DATA.zip.

Table 3. List of parameters included into the Atlas database

| Parameter | | Units | |
|---|---|---|---|
| Name | Contraction | Name | Indication |
| Temperature | TEMP | Centigrade | C |
| Chlorinity | CL | units of practical chlorinity, mg/l | psu, mg/l |
| Pressure | PRESS | decibar | dbar |
| Electrical conductivity | COND | milliSiemens/cm | ms/cm |
| Salinity | SAL | - | - |
| Absolute content of dissolved oxygen | OXY | mg/l, ml/l, microgram-atom/l | mg/l, ml/l, μg-at/l |
| Relative content of dissolved oxygen | OXY SATUR | Percentage | % |
| pH | PH | - | - |
| Oxygen oxidizability | COD | milligram oxygen per l | $mgO_2/l$ |
| Phosphates | PO4 | mg/l, microgram /l, microgram-atom/l | mg/l , μg/l , μg-at/l |
| Total content of phosphorus | TOTP | mg/l, microgram /l, microgram-atom/l | mg/l , μg/l , μg-at/l |
| Nitrates | NO3 | mg/l, microgram /l, microgram-atom/l | mg/l , μg/l , μg-at/l |
| Nitrites | NO2 | mg/l, microgram /l, microgram-atom/l | mg/l , μg/l , μg-at/l |
| Ammonium nitrogen | NH4 | mg/l, microgram /l, microgram-atom/l | mg/l , μg/l , μg-at/l |
| Silicates | SIO4 | mg/l, microgram /l, microgram-atom/l | mg/l , μg/l , μg-at/l |
| Total alkalinity | ALK | milligram-equivalent/l, mg/l | meq/l , mg/l |

Appendix A contains description of data of all categories. Category A is presented by a table of stations' distribution by years and months. Inventory of Category B data is presented by a map of stations' location in the Sea of Azov coastal zone, at which measurements of water surface temperature and meteorological characteristics were made, and a table containing total information about and from each coastal station. Inventory of Category C data is presented by a map of location of temperature and salinity measurements made by a towed probe.

Gaps in the sea observations in such periods as of 1960-1970 and 1980-1985 (Fig. 5) allows to hope for substantial addition of the database represented here in the later works. In particular, the database does not cover the results of AzNIIRKh expeditionary researches of 1958-2006. The same goes for water temperature measurements at the coastal meteorological stations.

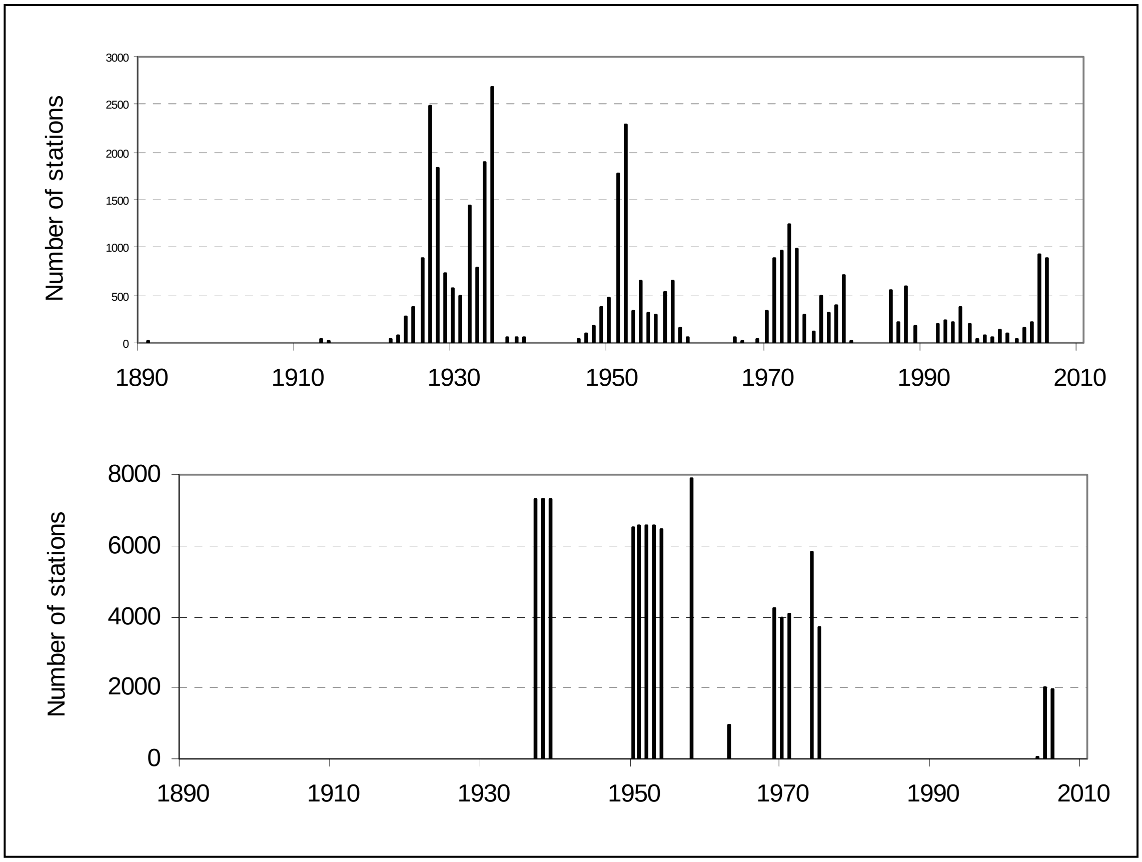



Fig. 5. Total distribution of Category A (upper chart) and Category B (lower chart) stations in the Sea of Azov oceanographic database by years

Appendix B contains maps of Category A stations' location in the Sea of Azov area and adjacent Black Sea by months for each individual year.

## 4.4. Data Quality Control

Data quality control was carried out according to the procedures used by the NOAA Ocean Climate Laboratory. First, gross errors in primary data were determined and corrected if possible. For example, coordinates of a station are on the shore, time interval between two consecutive stations does not coordinate with a reasonable ship speed, etc.

Regularities of annual climatic cycle of temperature and salinity variation for the Sea of Azov were considered at the second step of the data quality control to determine the range of limited values for these parameters.

To describe the pattern of salinity variation in the Sea of Azov four areas were distinguished (Fig. 2). Table 4 lists maximum and minimum salinity values $S_{min}$ and $S_{max}$ for these areas. At Fig. 6 typical data distributions within the considered range are given.

Table 4. Range of salinity variation for the Sea of Azov areas

| **Area** | | **Salinity, ‰** | | | |
|---|---|---|---|---|---|
| № | Name | $S_{min}$ | Interval covering 90% of values | | $S_{max}$ |
| I | Taganrog Bay | 0.0 | 0.60 | 12.14 | 14.42 |
| II | Central part of the Sea of Azov | 1.0 | 8.70 | 13.84 | 17.00 |
| III | Kerch Strait and adjacent part of the Black Sea | 8.57 | 11.61 | 17.21 | 19.96 |
| IV | Sivash and adjacent part of the Sea of Azov | 9.19 | 9.53 | 31.30 | 38.99 |

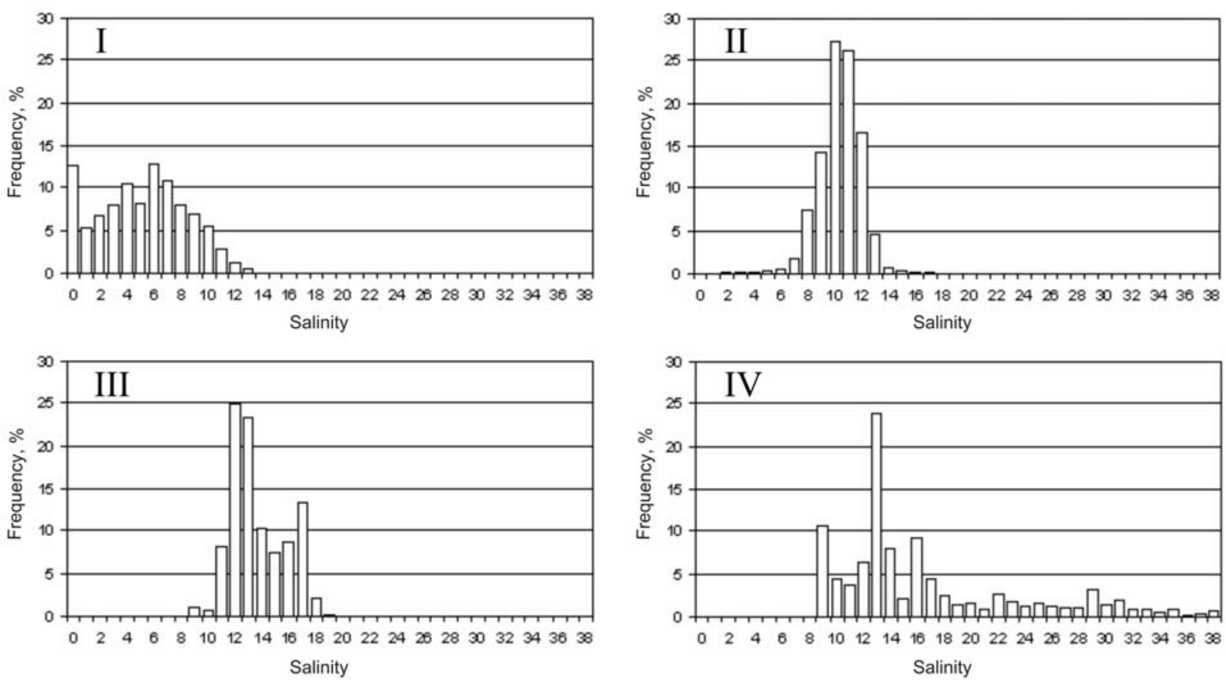



Fig. 6. Density of salinity distribution by four regions of the Sea of Azov

I – Taganrog Bay, II – Central part of the Sea of Azov, III- Kerch Strait and adjacent part of the Black Sea, IV – Sivash and adjacent part of the Sea of Azov

For each individual month, minimum and maximum temperature variation ranges were calculated for the entire Sea of Azov area, $T_{min}$ and $T_{max}$ correspondingly (Table 5). Then, the temperature distribution frequency within $T_{min}$ and $T_{max}$ for each month was calculated (Fig. 7).

Table 5. Ranges of temperature variation for the Sea of Azov

| Month | $T_{min}$ | $T_{max}$ |
|---|---|---|
| January | -0.80 | 7.80 |
| February | -0.80 | 6.60 |
| March | -0.70 | 9.90 |
| April | 0.0 | 18.10 |
| May | 1.16 | 26.50 |
| June | 8.90 | 30.00 |
| July | 10.01 | 31.6 |
| August | 13.70 | 29.61 |
| September | 10.10 | 28.50 |
| October | 4.40 | 22.00 |
| November | -0.26 | 19.50 |
| December | -0.80 | 12.20 |

Values, exceeding the allowable limits of parameters' variation, were not included into the database provided on a CD-ROM and internet version of the Atlas.

Before the researchers acquired CTD-probes, the Sea of Azov salinity was calculated by chlorinity values.

It is known for the N.M. Knipovich expedition of 1922-1927 that salinity values were calculated by the Knudsen tables (for 'normal' seawater). It obviously resulted in getting a significant error, and the fresher the water, the greater the error (Knipovich, 1932). It is quite probable that L. Antonov (data of 1913-1914) also used the Knudson tables.

It is known that for Marine Year-Books of 1947-1956 (Part 2 – Sea Observations) when calculating the Sea of Azov waters' salinity the following formula was applied (Voronkov, 1940):

$$S=1.794 * CL+0.21, \quad (1)$$

where S – salinity, ‰, CL – content of ions of chlorine, ‰,
and for the Kerch Strait the Oceanological Tables of 1940 were applied (author: N.N. Zubov).

Salinity data published in Marine Year-Books of 1957-1960 (Part 2 – Sea Observations) were calculated according to the GOIN Methods Guidelines (Oceanographic Tables of 1960, Tsurikova, Shulgina, 1964).

$$S=0.0294 * CL^2 + 1.664*CL + 0.263, \text{ with } 1‰ < CL < 4‰, \quad (2)$$
$$S=1.792*CL + 0.23, \text{ with } CL \geq 4‰. \quad (3)$$

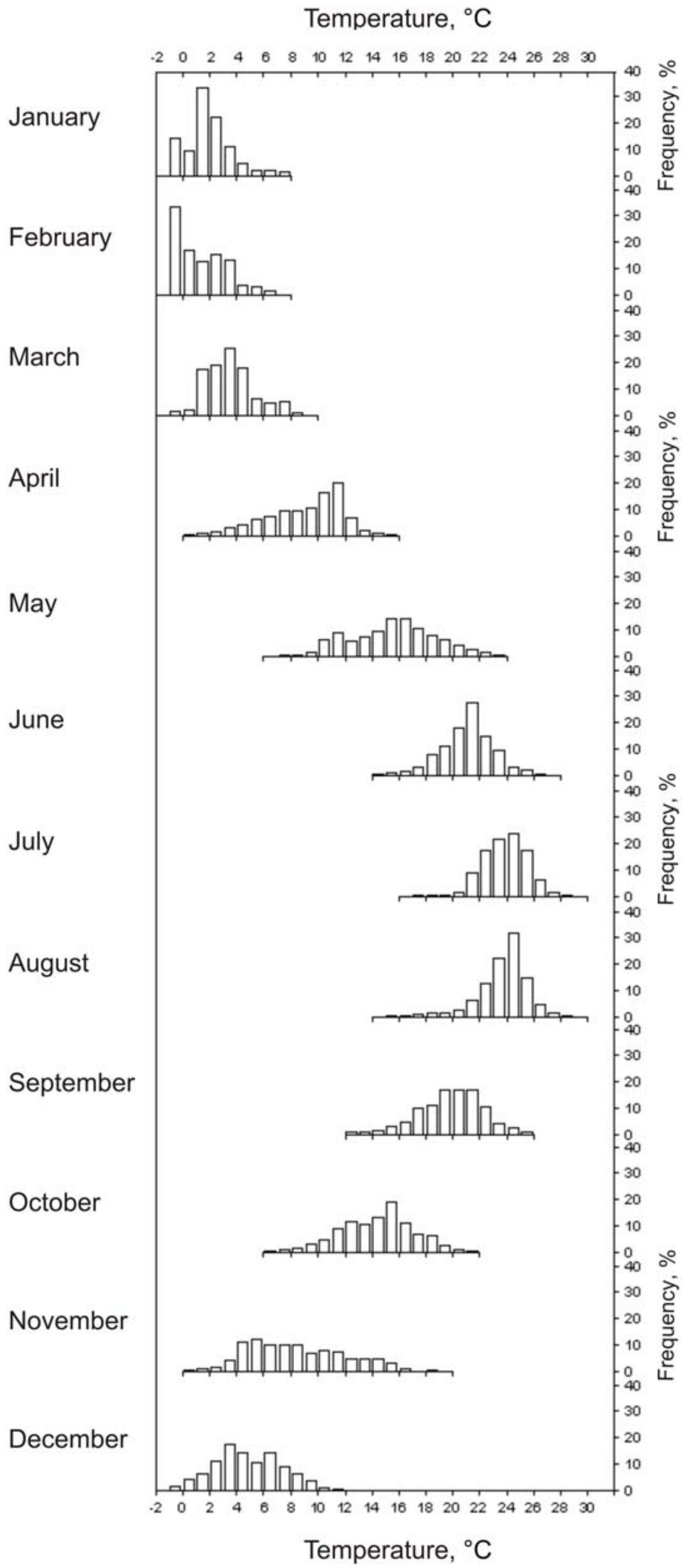



Fig. 7. Density of the Sea of Azov water temperature distribution by months

Apparently, when calculating salinity by chlorinity after 1960, oceanographic tables calculated according to the formulae developed by A.P. Tsurikova, were also applied (Tsurikova, Shulgina, 1964). At the same time, there are no references to the formulae used in some publications, the primary information of which was included into the database.

Scientists of the Southern Scientific Center and Murmansk Marine Biological Institute apply formulae (2)-(3), when calculating salinity by chlorinity for the Sea of Azov. Also, formulae (2)-(3) were used for calculating salinity by chlorinity for all stations included in the present Atlas.

To determine possible errors in the tables of primary data, salinity calculations and correlation with primary information were made by formulae (2)-(3).

Table 6 contains the range of limits for hydro-chemical parameters, included in the database of the Atlas, applied when conducting data quality control (Aleksandrova et al., 2005; Hydrometeorological…, 1962; Hydrometeorology…, 1991; Tsurikova, Shulgina, 1964).

Table 6. Hydro-chemical parameters. The range of limits

| Parameter | Units | Min. value | Max. value |
|---|---|---|---|
| OXY | mg/l, ml/l | 0 | 15 |
| OXY SATUR | % | 0 | 181 |
| COD | $mgO_2/l$ | 0.8 | 12.8 |
| pH | | 7.6 | 9.05 |
| NO3 | mg/l | 0 | 0.75 |
| NO3 | µg/l | 0 | 500 |
| NO2 | mg/l | 0 | 0.047 |
| NO2 | µg/l | 0 | 47 |
| NH4 | mg/l | 0 | 0.93 |
| NH4 | µg/l | 10 | 1000 |
| TOTN | mg/l | 0.012 | 0.409 |
| TOTN | µg/l | 12 | 409 |
| PO4 | mg/l | 0 | 0.16 |
| PO4 | µg/l | 0 | 160 |
| PON | mg/l | 0.42 | 2.05 |
| TOTP | µg/l | 5 | 900 |
| SIO4 | mg/l | 0.049 | 5 |
| SIO4 | µg/l | 49 | 5000 |
| ALK | meq/l | 1.701 | 3.964 |

## 5. ALGORITHM OF THE CLIMATIC FIELDS CONSTRUCTION

The procedure for the climatic fields construction (objective analysis of data), utilized in this paper, corresponds to the pattern proposed by Barnes (1973) and the methods of data spatial distribution calculation and chart construction (Levitus and Boyer, 1994).

To construct the climatic fields the Sea of Azov was divided into squares sized 10x10 km. Temperature and salinity values were calculated for each month in the regular grid points (middle of a square). Mean monthly values for each grid point were calculated by all measurements within a radius of 20 km of the point, if the number of oceanographic stations exceeded three. Data absence was flagged by a special code. For averaging by space, the following approach is applied:

$$X_{cp} = [\Sigma_i(X_i/(R_i+d)^\gamma ]/[\Sigma_i(1/(R_i+d)^\gamma], R_i \leq R_{max}, \quad (4)$$

where:

$X_{cp}$ = mean value in the considered grid point;

$X_i$ = value of the considered characteristics at i station;

$R_i$ = distance from grid point to i station, km;

$R_{max}$ = radius of influence, km;

d, $\gamma$ = parameters, d=5 km, $\gamma$ = 1.4.

Appendix C provides climatic charts of temperature and salinity for each individual month for the surface and standard horizons of 5 and 10 meters. They coordinate and agree well with climatic charts and maps developed by specialists on the basis of experience and intuition (Hydrometeorology and Hydrochemistry of the Seas of the USSR, 1991). This fact confirms the right choice of methods used for objective analysis for the algorithm of the Sea of Azov climatic fields' construction procedure and provides the basis for application of formal procedures to analyze the Sea of Azov climatic systems.

The vertical climatic transects were constructed for the first time along the line crossing the deepest part of the Sea of Azov from the Don mouth to the Kerch Strait with the total length of 350 km.

The climatic transects construction procedure is similar to the procedure of climatic fields' construction with the averaging of water temperature and salinity values in the regular grid points with the distance of 5 km along the profile line and 1 m in depth. Data absence was flagged by a special code. When averaging, all stations located within a radius of 20 km of the rated grid point, were considered. Vertical climatic transects of temperature and salinity, constructed for every month, are given in Appendix D.

## 6. SALINITY FIELDS MODELING

A series of hydro-physical mathematical models, directed at studying the specific features of water circulation, influence of meteorological, climatic, and anthropogenic factors on hydrological regime formation was developed for the Sea of Azov (Filippov, 1972; Surkov *et al.*, 1989; Krukier, 1991).

One of the approaches is proposed in the works (Chikin, Shabas, 2001; Chikin, 2001, 2005) and presumes calculation of 3-dimensional fields of currents and salinity as a result of the influence of wind, river water inflow and water- and mass exchange with the Black sea via the Kerch Strait. The calculation procedure is carried out in such a way so that to get the maximum similarity between the calculations by model and data of salinity measurements for each month of a range of June – September and each year of an interval of 1924-2004. The monthly salinity fields for June, July, August, September, and October for all considered years obtained as a result of calculations were averaged to construct monthly climatic salinity fields. After that, the results of calculations by a model were compared to the charts constructed on the basis of the measurements' data.

Let's mark salinity field constructed for $i^{th}$ month applying the model as Model ($S_i$) and climatic fields constructed by the results of observations as Observations ($S_i$). The result of comparison of two fields Comparison ($S_i$) is the difference by absolute quantity of salinity values in points having similar coordinates.

To compare salinity climatic fields and construct the chart of differences Comparison ($S_i$) programme modules are developed with the application of the ArcInfo (geographical information system) instruments.

At Figure 8, as an example for July, charts Model ($S_7$), Observations ($S_7$) and Comparison ($S_7$), are given, and analogous charts for the rest of the months are given in the section *Climatalogical Modeling* on CD-ROM and Internet version of the Atlas.

Thus, the elements of one cycle of the Sea of Azov climatic system modeling include the following stages:

1) Construction of the Sea of Azov climatic system model and formulation of the accepted assumptions.

2) Development of methods to solve the equations that form the basis of the model and algorithms to visualize the results of climatic fields' calculations.

3) Assessment of model adequacy (that is documenting the differences between the fields obtained applying the model and fields constructed on the basis and by the results of the in-situ observations).

4) Analysis of the determined differences to correct and improve the Sea of Azov model.


Fig. 8 a)

Fig. 8 b)

Scale differences

>2 - ≤3

>1 - ≤2

>0 - ≤1

0

Fig. 8 c)

Рис. 8. Climatic maps of salinity: Model vs. Observations.
a) Climatic maps of salinity for July based on *in situ* data, b) Climatic maps of salinity for July based on the model, c) Comparison maps a) and b).

## 7. ELECTRONIC BOOKS

The *Electronic Library* section on a CD-ROM and internet version has electronic copies of books on the history of the Sea of Azov exploration that contain primary data and description of the measurements' methods. The majority of these publications belong to the category of rare books and almost always inaccessible for a wide audience. Though the text quality in a PDF format does not always correspond to the generally accepted standards due to imperfect book scanning technique used, the authors, nevertheless, believed it was reasonable, expedient, and appropriate to include such books into this section for their scientific significance. Below is a list of publications arranged in alphabetic order:

Antonov, L. (1926). Notes on Hydrography. V. 51. Leningrad. p. 195-224. (In Russian)

Bogachev, V.V. (1910). Geographical Development of the Don River Delta due to its Settling. In: Collection of the Scientific-Literary Society at the Imperial Yurjev University. vol. XVI. p. 205-265. (In Russian)

Endros, A. (1932). Die Seiches des Schwarzen und Asowschen Meers, Annalen der Hydrographie und Maritimen Meteorologie, November 1932, p. 442-455. (In German)

(1937). Hydrological Reference Book of the Seas of the USSR. V. III. The Sea of Azov. Issue 2. Hydrometizdat, Leningrad – Moscow. p. 227-465. (In Russina)

(1937). Hydrological Reference Book of the Seas of the USSR. V. III. The Sea of Azov. Issue 3. Hydrometizdat, Leningrad – Moscow. p. 466-732. (In Russian)

Ivanovsky, A.V. (1904). Transactions of the Trading Ports Department. Issue XII. The Sea of Azov. Technical and Economic Review. Saint-Petersburg. 171 p. (In Russian)

Klossovsky, A. (1890). The Level and Temperature Fluctuations in the Coastal Line of the Black Sea and the Sea of Azov. Saint-Petersburg. 70 p. (In Russian)

Knipovich, N.M. (1926). The Essay on the Azov-Black Sea Scientific and Fishery Expedition Activities in 1925. Moscow. p. 75-106. (In Russian)

Knipovich N.M. (1932). Hydrological Studies in the Sea of Azov. In: Transactions of the Azov-Black Sea Scientific and Fishery Expedition. Issue 5. Moscow. 497 p. (In Russian)

Mendeleev, V.D. (1899). The Project of the Sea of Azov Level Increase by the Kerch Strait Damming. Saint-Petersburg. 33 p. (In Russian)

Sovinsky, V. (1898). Scientific Results of the Atmanaya Expedition. In: The News of the Imperial Academy of Sciences. Saint-Petersburg. May. V. VIII. № 5. p. 359-400. (In Russian)

Spindler, I.B., and Wrangel, F.F. (1899). Materials on Hydrology of the Black Sea and the Sea of Azov from Expeditions of 1890-1891. Saint-Petersburg. 70 p. (In Russian)

Zuev, N. (1855). The Sea of Azov with its Seaside and Port Towns, their Dwellers, Industries, and Trade in and outside Russia, with the Sea of Azov Map as an Appendix. Saint-Petersburg. 92 p. (In Russian)

## 8. PHOTO GALLERY

The sources of materials in the *Photo Gallery* section on a CD-ROM and internet version of the Atlas are the photographs made by the staff of the Southern Scientific Center of the Russian Academy of Sciences and Murmansk Marine Biological Institute of the Kola Scientific Center of the Russian Academy of Sciences. The historical photocopies of the Rostov-on-Don were obtained from the archives of the public library.

*Phenomenal Winter* section presents pictures made in winter of 2005 – 2006 during an expedition on board the icebreaker Captain Demidov and illustrates some extreme meteorological conditions that may be observed in this southern sea. *History* section gives idea of the historical development of the city of Rostov-on-Don and its port. It has comparative photographs of the early XX and XXI centuries, which allow see the changes occurred for the last 100 years.

## 9. CD-ROM DISC CONTENT

The major sections of the disc are as follows:
**DATABASE** – contains data files.

**DOC** – contains the text of the Atlas with Appendixes in Russian and English in PDF format.

**E-BOOKS –** contains electronic copies of the books.

**HTML** – contains HTML files, stations' distribution plots, and climatic maps. Access to the information is via HTML Menu that has the following main sub-sections:

*Text of the Atlas* - The sub-section contains the text of the Atlas with Appendixes in Russian and English in PDF format.

*Historical and Bathymetric Maps* - The sub-section contains the maps of the Sea of Azov made in XVI century, 1855, 1932, and 2006 years.

*Access to Original Data, Inventory* - The sub-section contains Category A, B, and C data and inventory tables.

*Monthly Climatology* - The sub-section contains monthly climatic fields of temperature and salinity presented as transects and charts for the surface and horizons of 5 and 10 m.

*Climatologic Modeling* - The sub-section contains monthly climatic charts of salinity constructed applying the mathematical model of the Sea of Azov hydro-physical processes, methods of observations' data objective analysis and comparison results of these two charts with the use of the GIS-technologies.

*Electronic Library* - The sub-section contains complete copies of the books and articles on the Sea of Azov studies.

*Photo Gallery* - The sub-section contains photographs made during expeditions in the Sea of Azov by the employees of the Southern Scientific Center and Murmansk Marine Biological Institute of the Russian Academy of Sciences, as well as modern photographs and historical photocopies of Rostov-on-Don of the early XX century received from the archives of the public library.

*Authors* - The sub-section lists the authors and bibliographic references of the present paper.

## 10. CONCLUSION AND FUTURE ACTIVITIES

The present Atlas incorporates data taken from more than 34 thousand stations for the period of 1891-2006, more than 89 thousand measurements of water surface layer temperature at the coastal hydro-meteorological stations and more than 12 thousand measurements of temperature and salinity that were made by a towed CTD-probe.

The climatic vertical sections and charts of temperature and salinity on the surface and at horizons/profiles of 5m and 10m are constructed applying the objective analysis method. A three-dimension mathematical model of hydro-physical processes in the Sea of Azov and its application for salinity climatic fields construction are considered. To assess the adequacy of the model climatic fields, fields constructed by the objective analysis method are compared with the fields calculated on the basis of the model.

Inter-annual air temperature variations in the areas neighboring the Sea of Azov and variations of water temperature in winter months of 1885-2006 are discussed to describe the climate change trends.

In the future it is planned to increase the database with hydrological and hydro-chemical data for the time periods not presented in this Atlas to analyze inter-annual variability of the Sea of Azov for a 100-year period.

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# APPENDICES

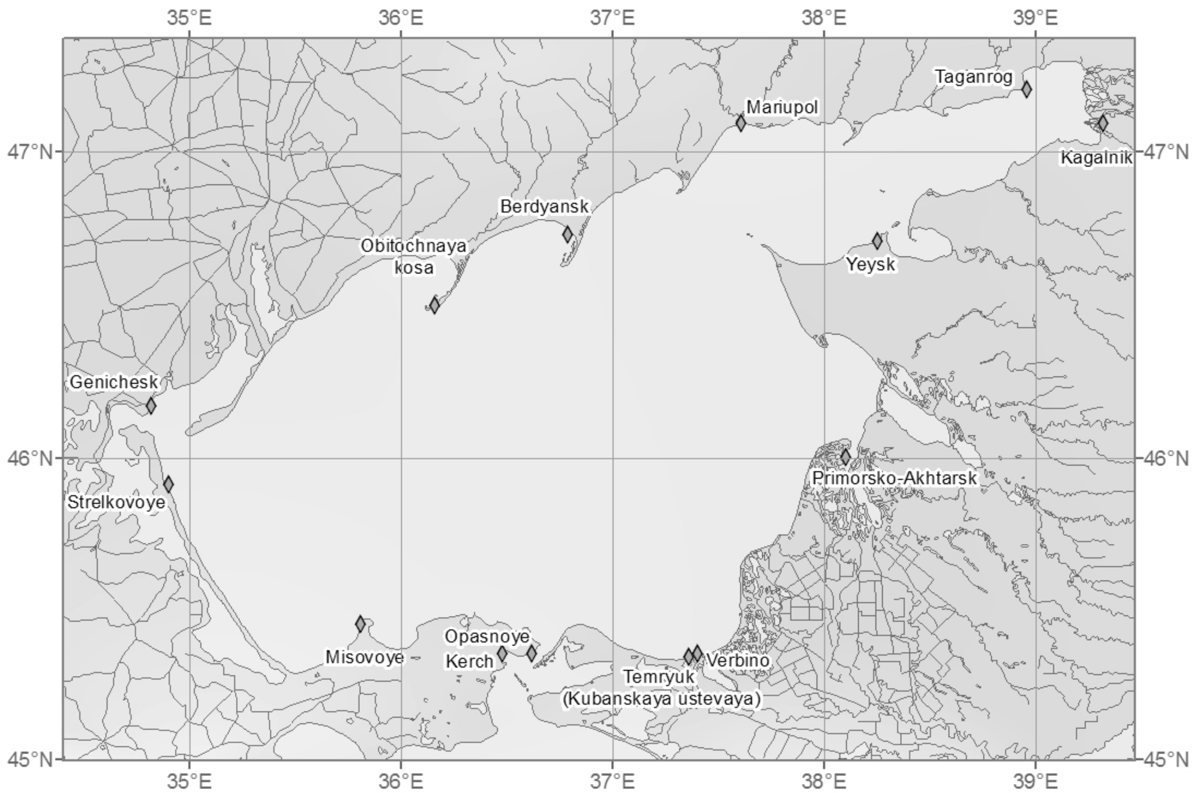
# Appendix A. Inventory

## Appendix A1. Marine observations.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1891 | | | | | | 9 | 10 | | | | | | 19 |
| 1913 | | | | | | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 34 |
| 1914 | 10 | | 5 | | | | | | | | | | 15 |
| 1922 | | | | | | | | | 14 | 7 | 11 | | 32 |
| 1923 | | | | | | | 18 | 11 | 23 | | 9 | 16 | 77 |
| 1924 | | | 11 | 4 | 62 | 35 | 40 | 29 | 37 | 46 | 12 | 10 | 286 |
| 1925 | | | 8 | 10 | 22 | 69 | 26 | 70 | 61 | 59 | 34 | 21 | 380 |
| 1926 | 2 | 9 | | 49 | 85 | 105 | 93 | 172 | 139 | 99 | 67 | 62 | 882 |
| 1927 | 18 | | 5 | 62 | 239 | 355 | 321 | 374 | 398 | 333 | 308 | 68 | 2481 |
| 1928 | 3 | | 26 | 82 | 66 | 30 | 560 | 544 | 382 | 71 | 34 | 36 | 1834 |
| 1929 | 13 | | 2 | 13 | 24 | 52 | 86 | 217 | 215 | 57 | 35 | 19 | 733 |
| 1930 | 26 | 11 | 22 | 23 | 32 | 131 | 59 | 128 | 43 | 40 | 36 | 12 | 563 |
| 1931 | 1 | | | 19 | 71 | 126 | 83 | 65 | 79 | 41 | 13 | | 498 |
| 1932 | | | | 1 | 170 | 202 | 205 | 297 | 291 | 188 | 48 | 32 | 1434 |
| 1933 | | | | 54 | 45 | 91 | 49 | 210 | 132 | 162 | 40 | 15 | 798 |
| 1934 | | | 1 | 51 | 89 | 229 | 268 | 213 | 332 | 364 | 354 | 2 | 1903 |
| 1935 | | | 1 | 128 | 371 | 532 | 576 | 617 | 206 | 236 | 14 | 5 | 2686 |
| 1937 | | | 5 | | 4 | 7 | 24 | 16 | 6 | 3 | | | 65 |
| 1938 | | | | | 10 | 10 | 14 | 13 | 4 | 16 | | | 67 |
| 1939 | | | | | 16 | 15 | 20 | | | | | | 51 |
| 1941 | | | | | | 2 | | | | | | | 2 |
| 1946 | | | | | | | | | 46 | | | | 46 |
| 1947 | | | | 26 | | | 30 | | 25 | 21 | 5 | | 107 |
| 1948 | | | | 36 | 91 | 46 | | | | 6 | 8 | | 187 |
| 1949 | | | | 93 | 25 | 53 | 42 | 133 | 15 | 6 | 7 | | 374 |
| 1950 | 5 | 12 | 8 | 65 | 68 | 60 | 99 | 73 | 32 | 22 | 19 | 15 | 478 |
| 1951 | 4 | 5 | 10 | 120 | 181 | 218 | 96 | 342 | 238 | 231 | 178 | 160 | 1783 |
| 1952 | 85 | 47 | 43 | 164 | 132 | 284 | 283 | 376 | 262 | 345 | 200 | 75 | 2296 |
| 1953 | 6 | 5 | 42 | 37 | 21 | 24 | 45 | 63 | 32 | 25 | 23 | 3 | 326 |
| 1954 | 2 | 1 | 3 | 15 | 111 | 172 | 169 | 31 | 34 | 93 | 26 | 3 | 660 |
| 1955 | 13 | 42 | | 69 | | | 106 | 23 | | 61 | 6 | | 320 |
| 1956 | | | | 51 | 86 | | 54 | 47 | 8 | 53 | | | 299 |
| 1957 | | | | 31 | 43 | 31 | 177 | 5 | 36 | 208 | | | 531 |
| 1958 | 53 | 29 | 39 | 61 | 38 | 111 | 87 | 60 | 36 | 20 | 97 | 22 | 653 |
| 1959 | | 8 | 8 | 27 | 7 | | 44 | 43 | 30 | | | | 167 |
| 1960 | | | | | 21 | | | | 9 | | 20 | 17 | 67 |
| 1961 | | | | | | | 2 | | 1 | 1 | | | 4 |
| 1962 | | | | | 1 | | | | | | | | 1 |
| 1966 | | | | 20 | 9 | 10 | 15 | 13 | | | | | 67 |
| 1967 | | | | | | | | | 18 | | | | 18 |
| 1969 | | | | 8 | | 8 | | | 17 | 8 | | | 41 |
| 1970 | | | 17 | 15 | | 26 | 92 | | 13 | 27 | 62 | 91 | 343 |
| 1971 | | | 19 | 83 | | 205 | 59 | 35 | 35 | 428 | 15 | 17 | 896 |
| 1972 | | | | | 94 | 307 | 13 | 23 | 344 | 180 | | | 961 |
| 1973 | | | | 14 | 282 | 449 | 49 | 24 | 178 | 216 | 23 | | 1235 |
| 1974 | | | | 29 | 152 | 136 | 122 | 48 | 143 | 199 | 118 | 35 | 982 |
| 1975 | | | | | 37 | 12 | 72 | 59 | 30 | 41 | 43 | | 294 |
| 1976 | | | | 7 | 6 | 6 | 44 | 14 | 44 | | | | 121 |
| 1977 | | | | 41 | 112 | 85 | 83 | 62 | 42 | 45 | 25 | 6 | 501 |

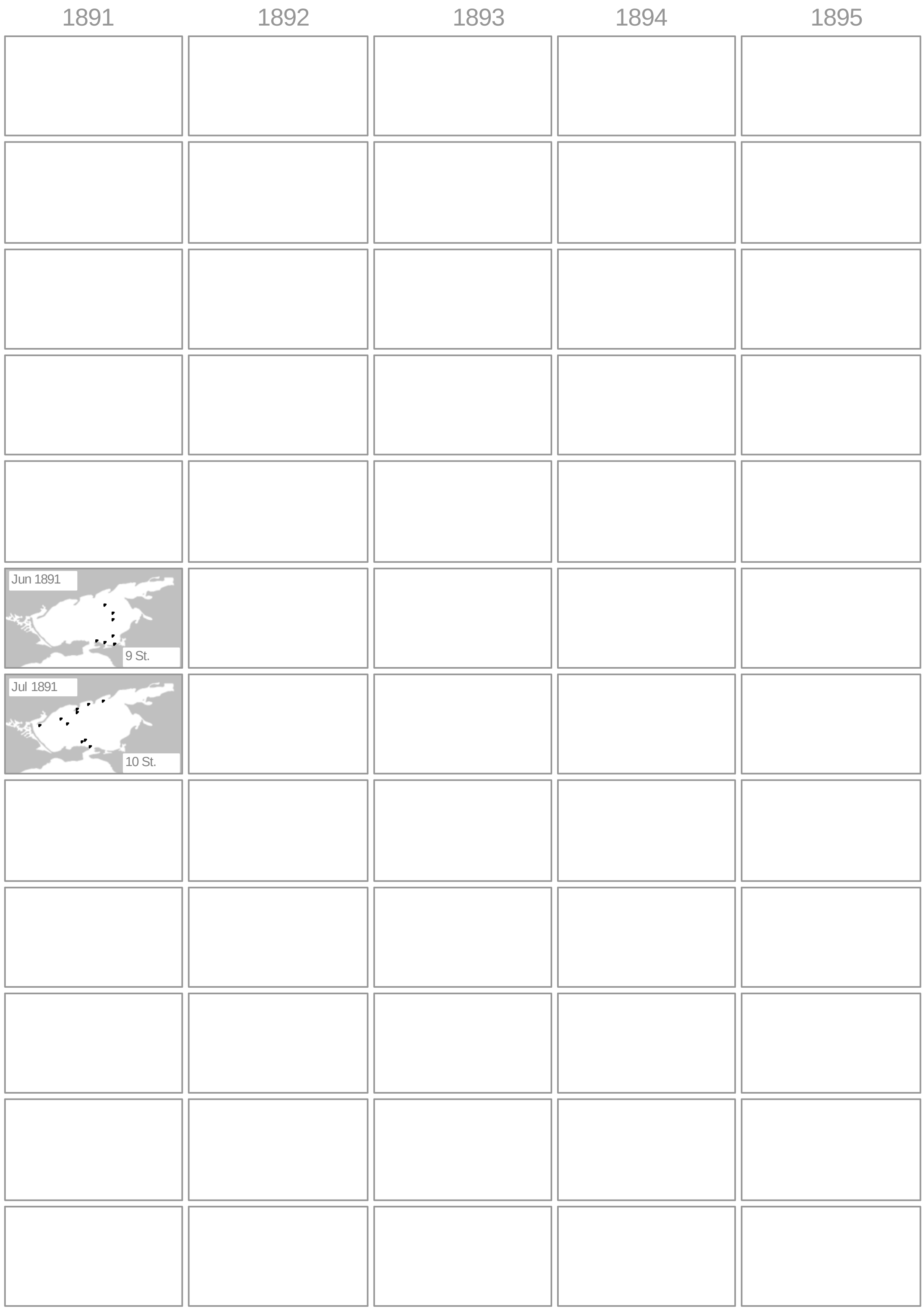
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1978 | | | | 147 | 39 | 22 | 36 | 7 | 44 | 5 | 7 | | 307 |
| 1979 | | | 46 | 26 | 28 | 66 | 38 | 46 | 52 | 38 | 58 | | 398 |
| 1980 | | | | 125 | 163 | 41 | 85 | 6 | 31 | 112 | 86 | 56 | 705 |
| 1981 | | | | | | | 8 | 11 | | | | | 19 |
| 1984 | | | | | 3 | | | | | | | | 3 |
| 1986 | | | 14 | 125 | 70 | 111 | 38 | 102 | 71 | | 12 | | 543 |
| 1987 | | | | | 33 | 186 | | | | | | | 219 |
| 1988 | | | | | 38 | 49 | 79 | 115 | 86 | 75 | 84 | 62 | 588 |
| 1989 | | | | 80 | 40 | 53 | | | | | | | 173 |
| 1992 | | | | | | | 13 | 100 | 7 | 70 | 9 | 7 | 206 |
| 1993 | | | | 33 | 3 | 54 | 37 | 36 | 34 | 42 | | | 239 |
| 1994 | 7 | 7 | 7 | 47 | 2 | 50 | 29 | 55 | 6 | | | 9 | 219 |
| 1995 | 16 | 12 | 12 | 36 | | 31 | 93 | 99 | | 63 | 5 | | 367 |
| 1996 | | | | | | | 48 | 52 | 46 | 28 | 9 | 12 | 195 |
| 1997 | | | 13 | | | | | | 34 | | | | 47 |
| 1998 | | | | | | 72 | | | | | | | 72 |
| 1999 | | | | | | 53 | | | | | | | 53 |
| 2000 | | | | | | 89 | | 54 | | | | | 143 |
| 2001 | | | | | | 25 | 44 | 28 | | | | | 97 |
| 2002 | | | | | | 46 | | | | | | | 46 |
| 2003 | | 21 | 1 | 8 | 10 | 54 | 14 | 31 | 6 | 5 | | | 150 |
| 2004 | 7 | | 3 | | 25 | 149 | 6 | | 16 | 10 | 3 | 5 | 224 |
| 2005 | 7 | 19 | 17 | 47 | 85 | 301 | 99 | 13 | 286 | 17 | 7 | 26 | 924 |
| 2006 | 74 | 108 | 9 | 148 | 145 | 276 | 16 | 34 | 11 | 17 | 17 | 27 | 882 |
| Total | 352 | 336 | 397 | 2330 | 3507 | 5976 | 4923 | 5244 | 4765 | 4444 | 2192 | 951 | 35417 |

Appendix A2.  Coastal stations.




| Station name | Latitude | Longitude | Time period | Number of observations |
|---|---|---|---|---|
| Berdyansk | 46.7319 | 36.7944 | 1937-1939, 1950-1954, 1958, 1963, 1969-1971, 1974, 1975 | 15752 |
| Genichesk | 46.1744 | 34.8192 | 1937-1939, 1950-1954, 1958, 1974, 1975 | 14055 |
| Kagalnik | 47.0786 | 39.3050 | 2004-2006 | 4024 |
| Kerch | 45.3475 | 36.4803 | 1937-1939, 1950-1954, 1958 | 13143 |
| Kubanskaya ustevaya | 45.3375 | 37.3653 | 1963, 1969-1971, 1974, 1975 | 2899 |
| Mariupol | 47.0919 | 37.6089 | 1963, 1969-1971, 1974, 1975 | 2426 |
| Mysovoe | 45.4500 | 35.8100 | 1963, 1969-1971, 1974, 1975 | 2916 |
| Obitochnaya kosa | 46.4958 | 36.1606 | 1958 | 364 |
| Opasnoe | 45.3514 | 36.6158 | 1958, 1963, 1969-1971, 1974, 1975 | 2409 |
| Primorsko-Akhtarsk | 46.0000 | 38.1000 | 1937-1939, 1950-1954, 1958, 1963, 1969-1971, 1974, 1975 | 14256 |
| Strelkovoe | 45.9056 | 34.8975 | 1969 | 244 |
| Taganrog | 47.2000 | 38.9600 | 1937-1939, 1950-1954, 1958, 1963, 1969-1971, 1974, 1975 | 13316 |
| Verbino | 45.3500 | 37.4000 | 1958 | 243 |
| Yeysk | 46.7131 | 38.2503 | 1963, 1969-1971, 1974, 1975 | 3156 |

# Appendix B. Data distribution plots, 1891-2006


1891
1892
1893
1894
1895
Jun 1891
9 St.
Jul 1891
10 St.

| 1896 | 1897 | 1898 | 1899 | 1900 |
|---|---|---|---|---|
| 1901 | 1902 | 1903 | 1904 | 1905 |
| 1906 | 1907 | 1908 | 1909 | 1910 |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
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| | | | | |
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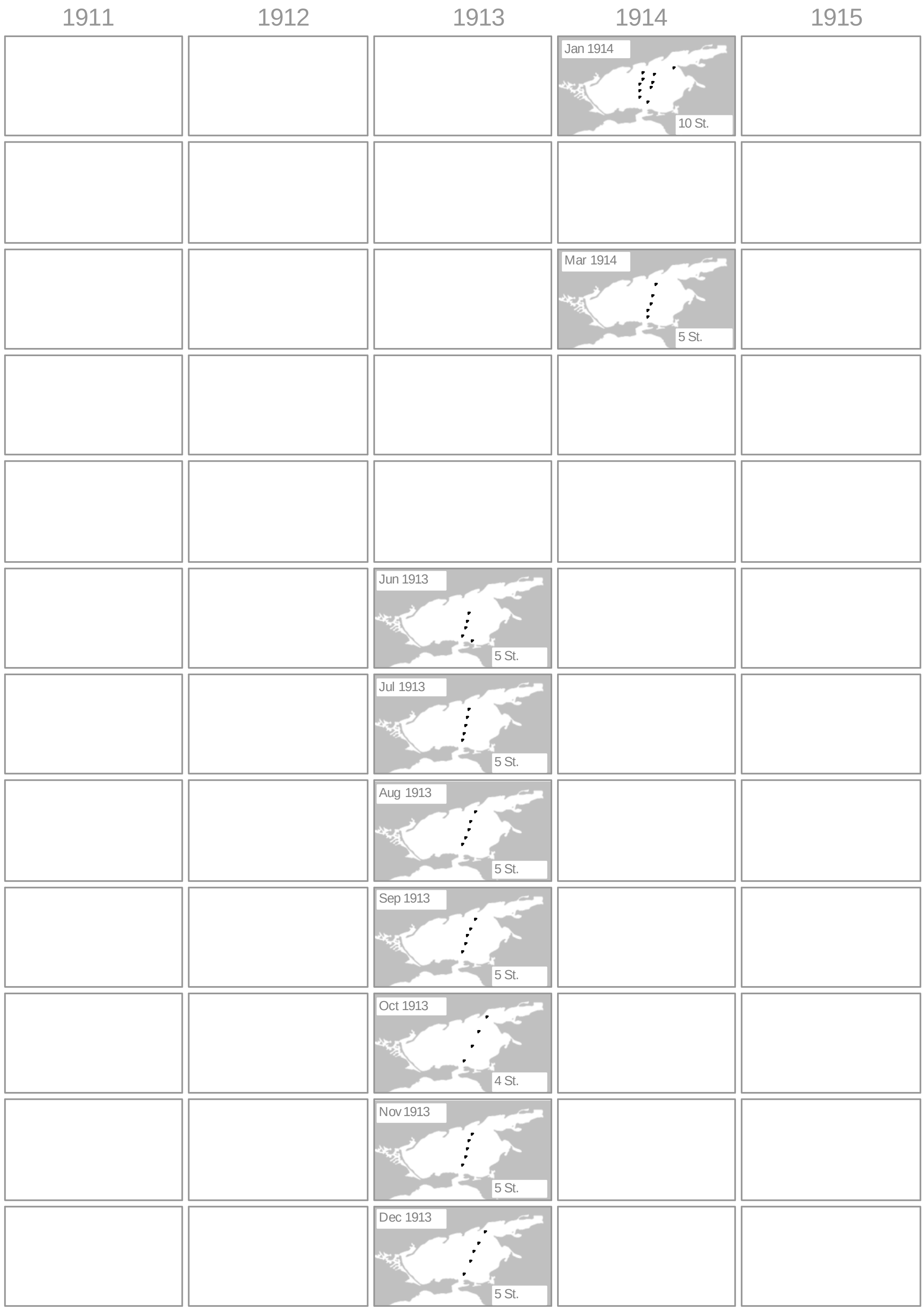
1911
1912
1913
1914
1915
Jan 1914
10 St.
Mar 1914
5 St.
Jun 1913
5 St.
Jul 1913
5 St.
Aug 1913
5 St.
Sep 1913
5 St.
Oct 1913
4 St.
Nov 1913
5 St.
Dec 1913
5 St.

| 1916 | 1917 | 1918 | 1919 | 1920 |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
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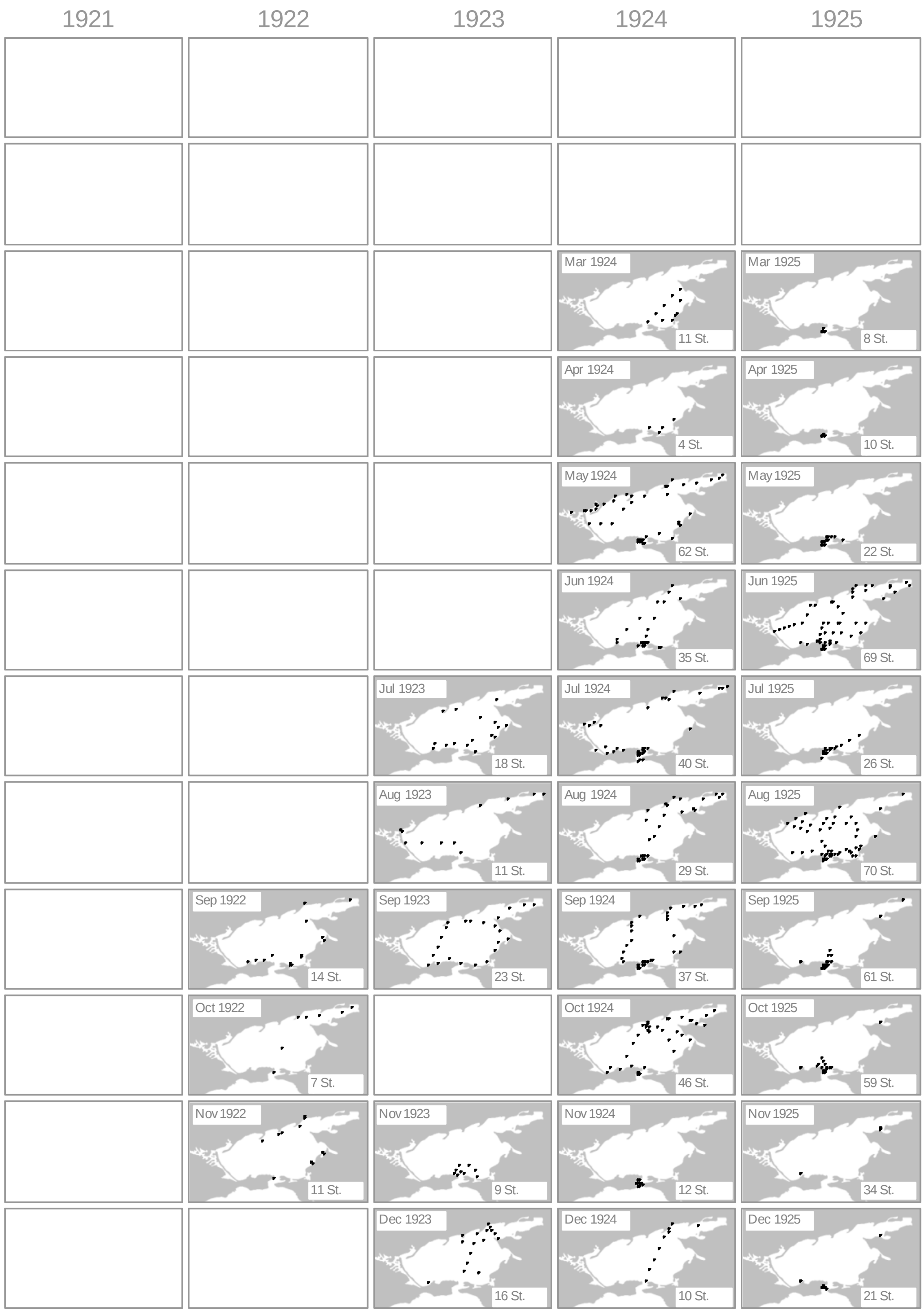
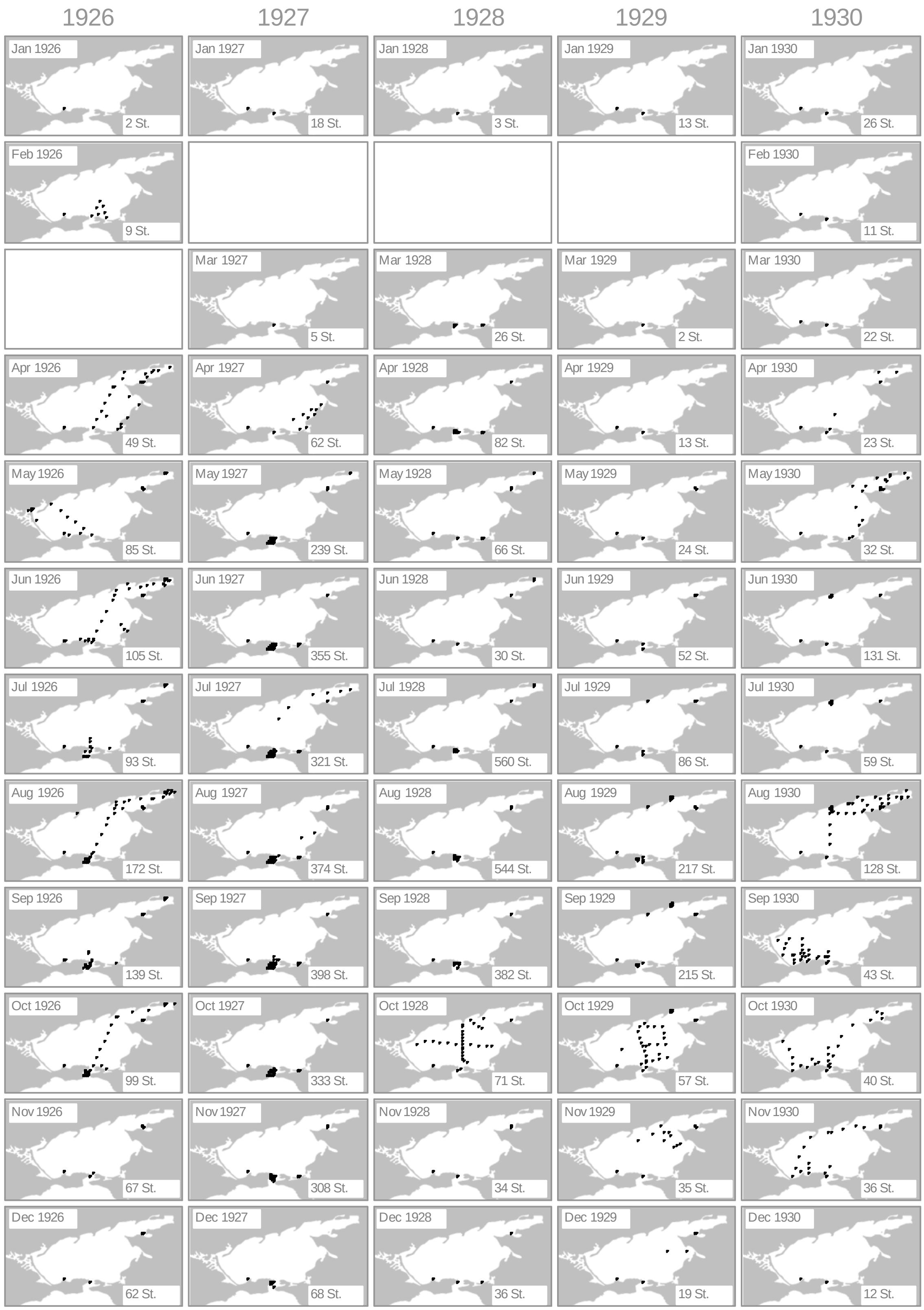
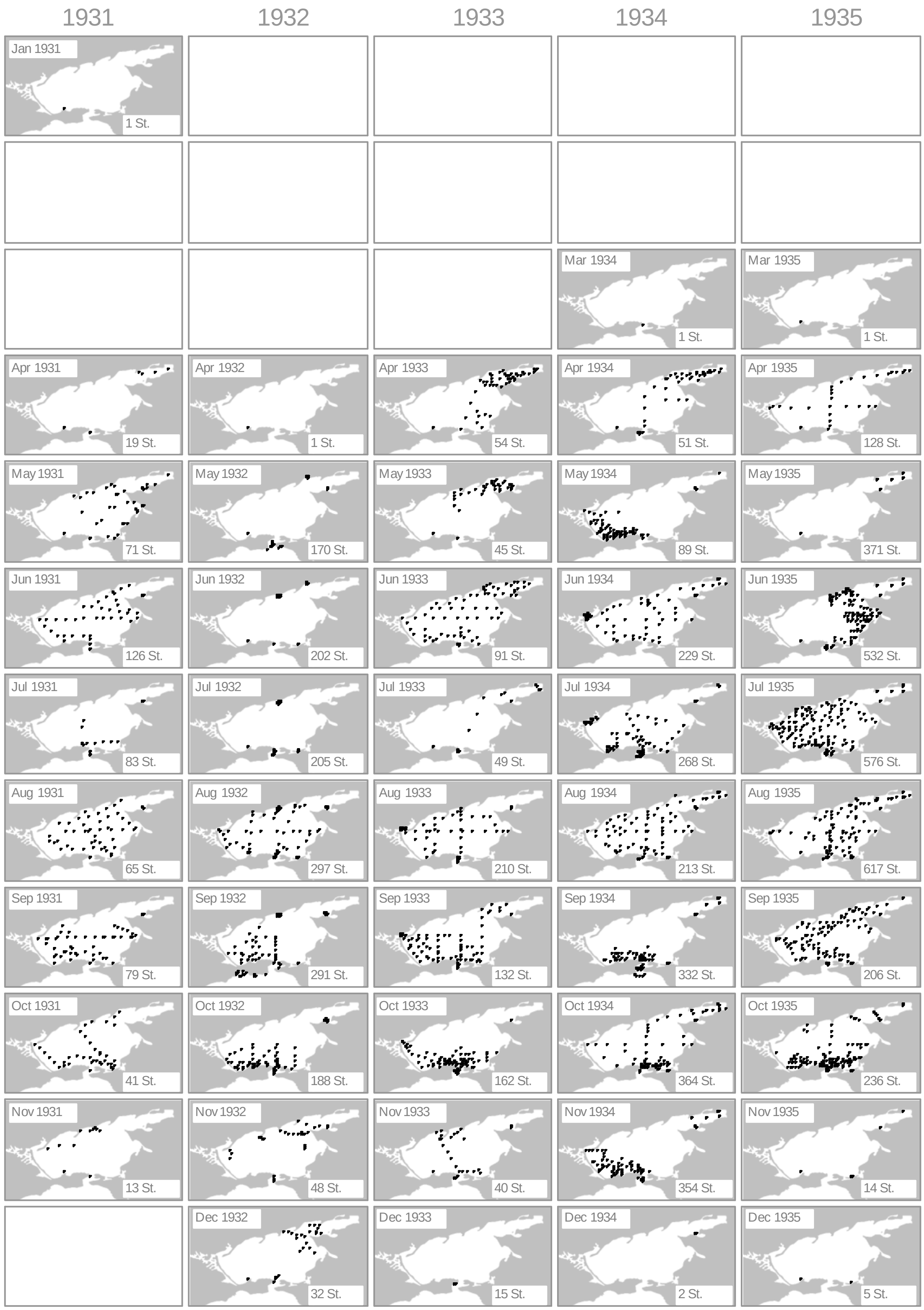
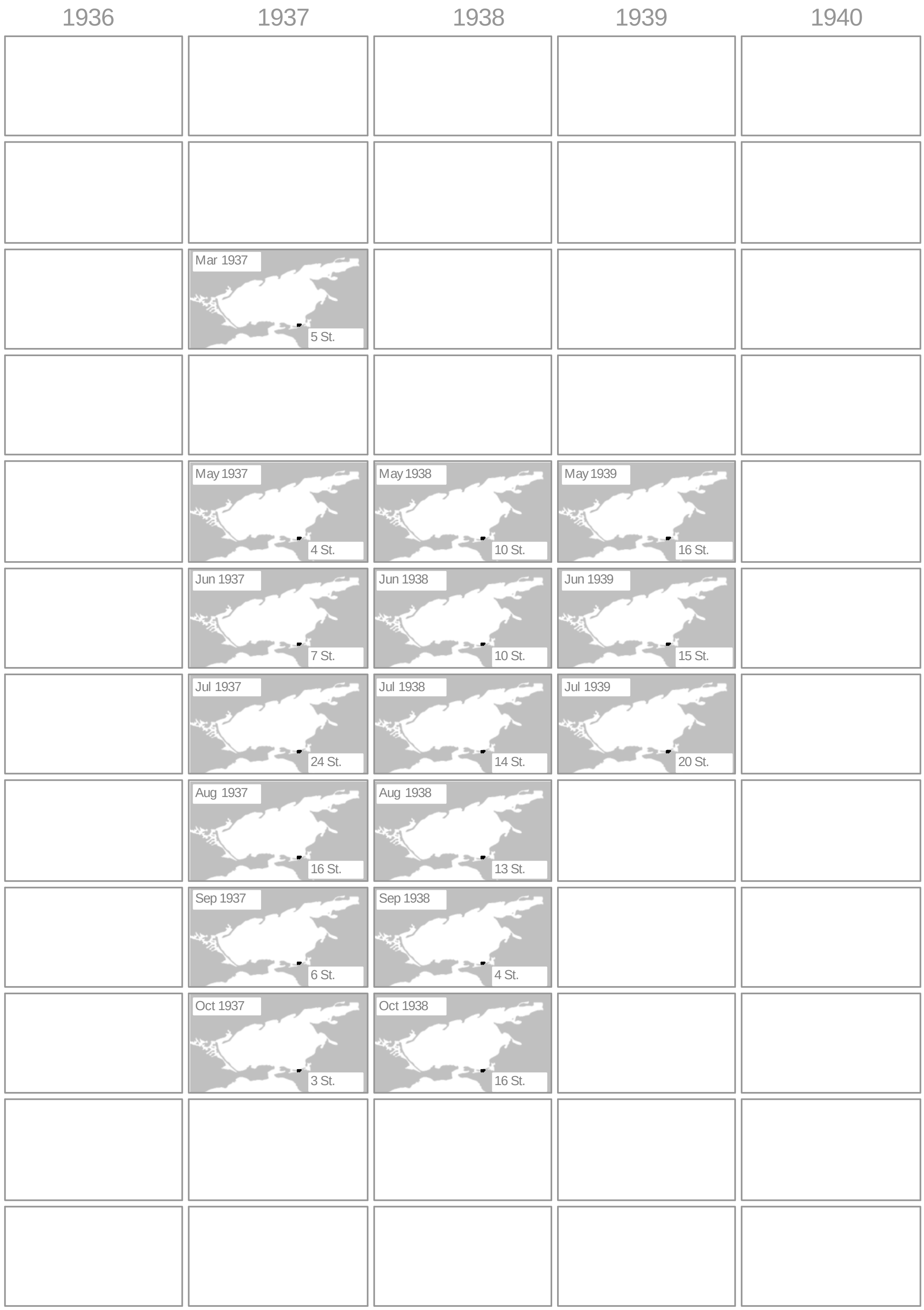
| | | | | |
| | | | | |
| | | | | |
| | | | | |


1921
1922
1923
1924
1925
Mar 1924
11 St.
Mar 1925
8 St.
Apr 1924
4 St.
Apr 1925
10 St.
May 1924
62 St.
May 1925
22 St.
Jun 1924
35 St.
Jun 1925
69 St.
Jul 1923
18 St.
Jul 1924
40 St.
Jul 1925
26 St.
Aug 1923
11 St.
Aug 1924
29 St.
Aug 1925
70 St.
Sep 1922
14 St.
Sep 1923
23 St.
Sep 1924
37 St.
Sep 1925
61 St.
Oct 1922
7 St.
Oct 1924
46 St.
Oct 1925
59 St.
Nov 1922
11 St.
Nov 1923
9 St.
Nov 1924
12 St.
Nov 1925
34 St.
Dec 1923
16 St.
Dec 1924
10 St.
Dec 1925
21 St.


1926
1927
1928
1929
1930
Jan 1926
2 St.
Jan 1927
18 St.
Jan 1928
3 St.
Jan 1929
13 St.
Jan 1930
26 St.
Feb 1926
9 St.
Feb 1930
11 St.
Mar 1927
5 St.
Mar 1928
26 St.
Mar 1929
2 St.
Mar 1930
22 St.
Apr 1926
49 St.
Apr 1927
62 St.
Apr 1928
82 St.
Apr 1929
13 St.
Apr 1930
23 St.
May 1926
85 St.
May 1927
239 St.
May 1928
66 St.
May 1929
24 St.
May 1930
32 St.
Jun 1926
105 St.
Jun 1927
355 St.
Jun 1928
30 St.
Jun 1929
52 St.
Jun 1930
131 St.
Jul 1926
93 St.
Jul 1927
321 St.
Jul 1928
560 St.
Jul 1929
86 St.
Jul 1930
59 St.
Aug 1926
172 St.
Aug 1927
374 St.
Aug 1928
544 St.
Aug 1929
217 St.
Aug 1930
128 St.
Sep 1926
139 St.
Sep 1927
398 St.
Sep 1928
382 St.
Sep 1929
215 St.
Sep 1930
43 St.
Oct 1926
99 St.
Oct 1927
333 St.
Oct 1928
71 St.
Oct 1929
57 St.
Oct 1930
40 St.
Nov 1926
67 St.
Nov 1927
308 St.
Nov 1928
34 St.
Nov 1929
35 St.
Nov 1930
36 St.
Dec 1926
62 St.
Dec 1927
68 St.
Dec 1928
36 St.
Dec 1929
19 St.
Dec 1930
12 St.


1931
1932
1933
1934
1935
Jan 1931
1 St.
Mar 1934
1 St.
Mar 1935
1 St.
Apr 1931
19 St.
Apr 1932
1 St.
Apr 1933
54 St.
Apr 1934
51 St.
Apr 1935
128 St.
May 1931
71 St.
May 1932
170 St.
May 1933
45 St.
May 1934
89 St.
May 1935
371 St.
Jun 1931
126 St.
Jun 1932
202 St.
Jun 1933
91 St.
Jun 1934
229 St.
Jun 1935
532 St.
Jul 1931
83 St.
Jul 1932
205 St.
Jul 1933
49 St.
Jul 1934
268 St.
Jul 1935
576 St.
Aug 1931
65 St.
Aug 1932
297 St.
Aug 1933
210 St.
Aug 1934
213 St.
Aug 1935
617 St.
Sep 1931
79 St.
Sep 1932
291 St.
Sep 1933
132 St.
Sep 1934
332 St.
Sep 1935
206 St.
Oct 1931
41 St.
Oct 1932
188 St.
Oct 1933
162 St.
Oct 1934
364 St.
Oct 1935
236 St.
Nov 1931
13 St.
Nov 1932
48 St.
Nov 1933
40 St.
Nov 1934
354 St.
Nov 1935
14 St.
Dec 1932
32 St.
Dec 1933
15 St.
Dec 1934
2 St.
Dec 1935
5 St.


1936
1937
1938
1939
1940
Mar 1937
5 St.
May 1937
4 St.
May 1938
10 St.
May 1939
16 St.
Jun 1937
7 St.
Jun 1938
10 St.
Jun 1939
15 St.
Jul 1937
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Jul 1938
14 St.
Jul 1939
20 St.
Aug 1937
16 St.
Aug 1938
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Oct 1937
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Oct 1938
16 St.

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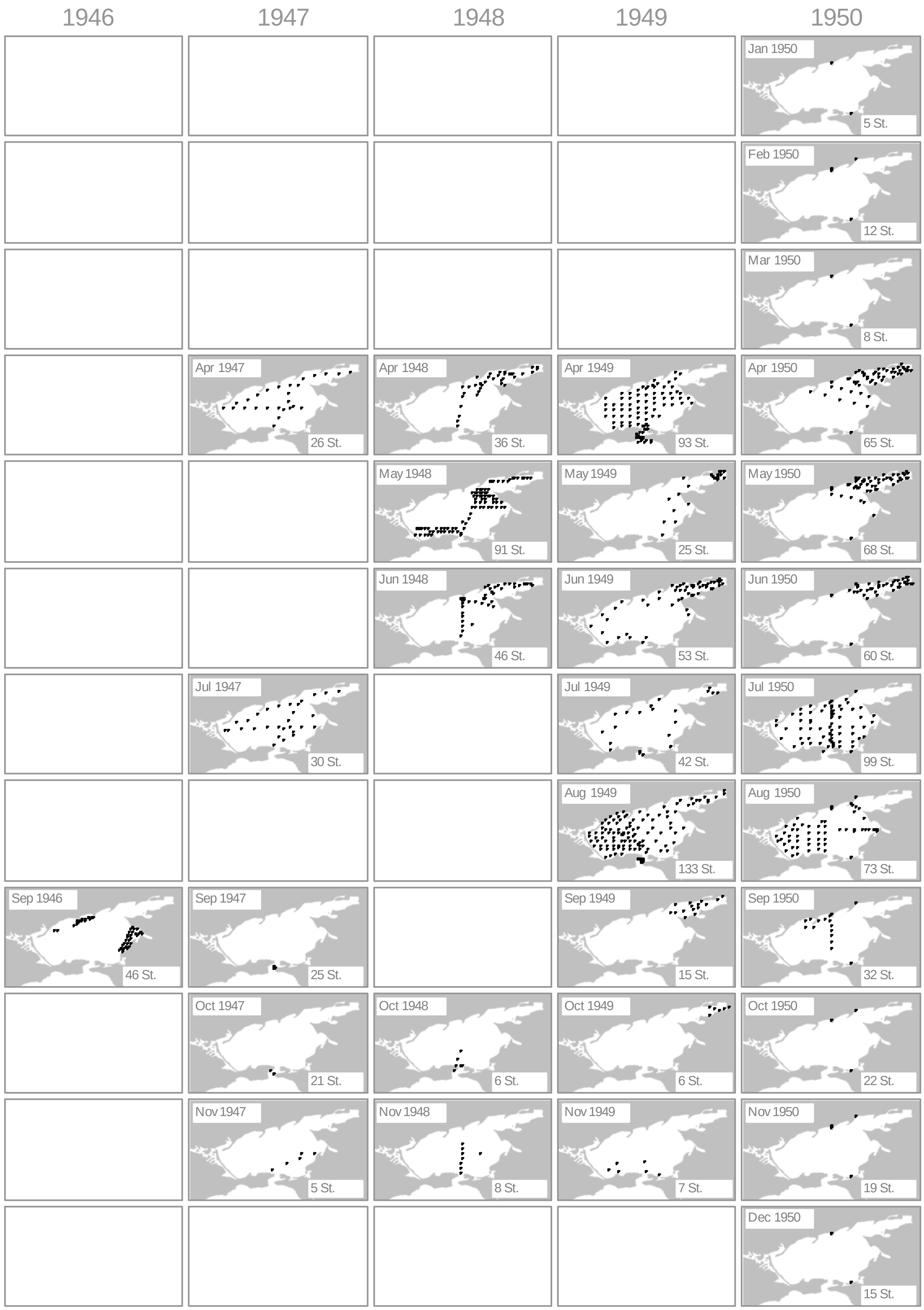
|---|---|---|---|---|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Apr 1950
65 St.
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May 1949
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May 1950
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Jun 1948
46 St.
Jun 1949
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Jun 1950
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Jul 1947
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42 St.
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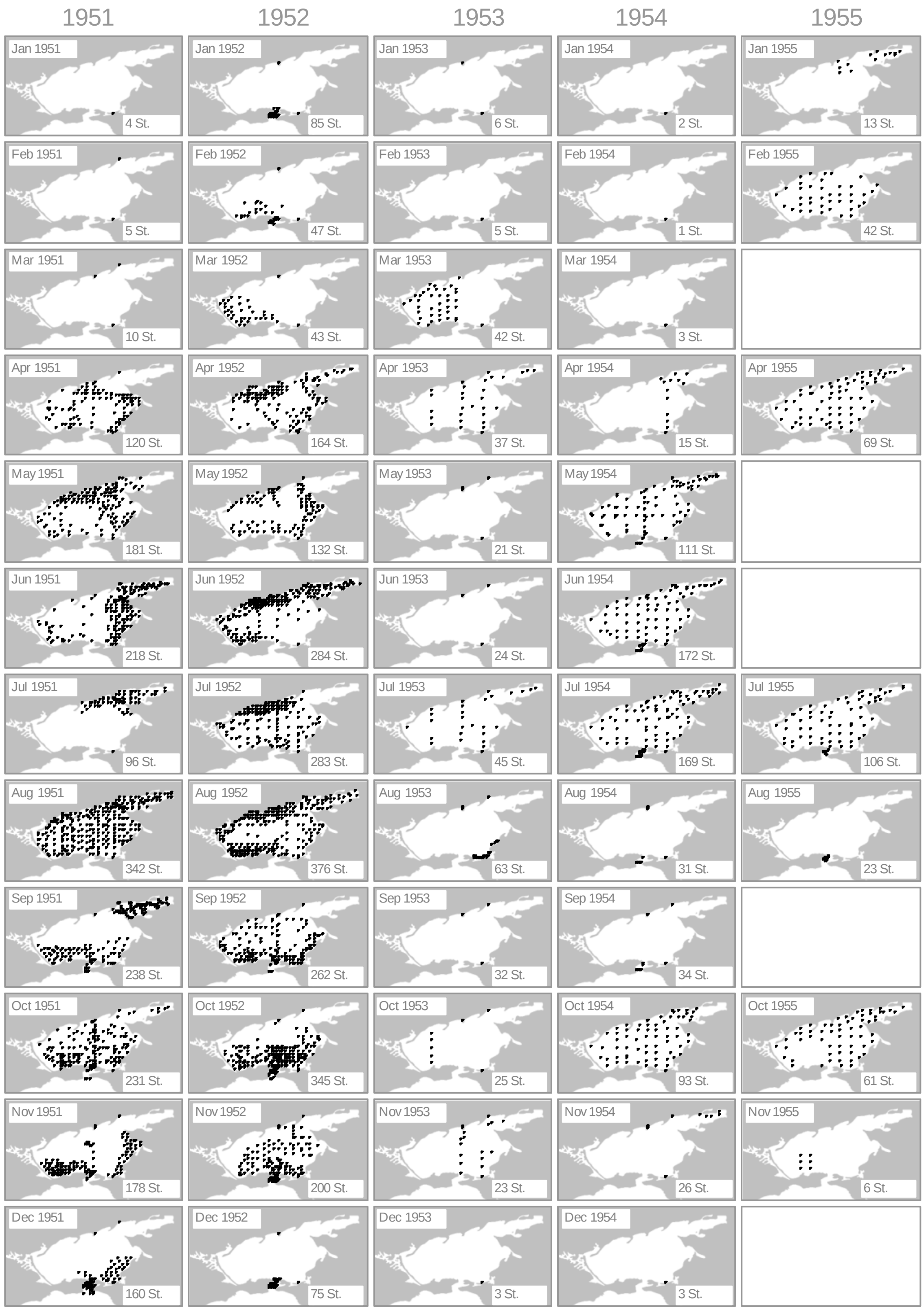
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Feb 1954
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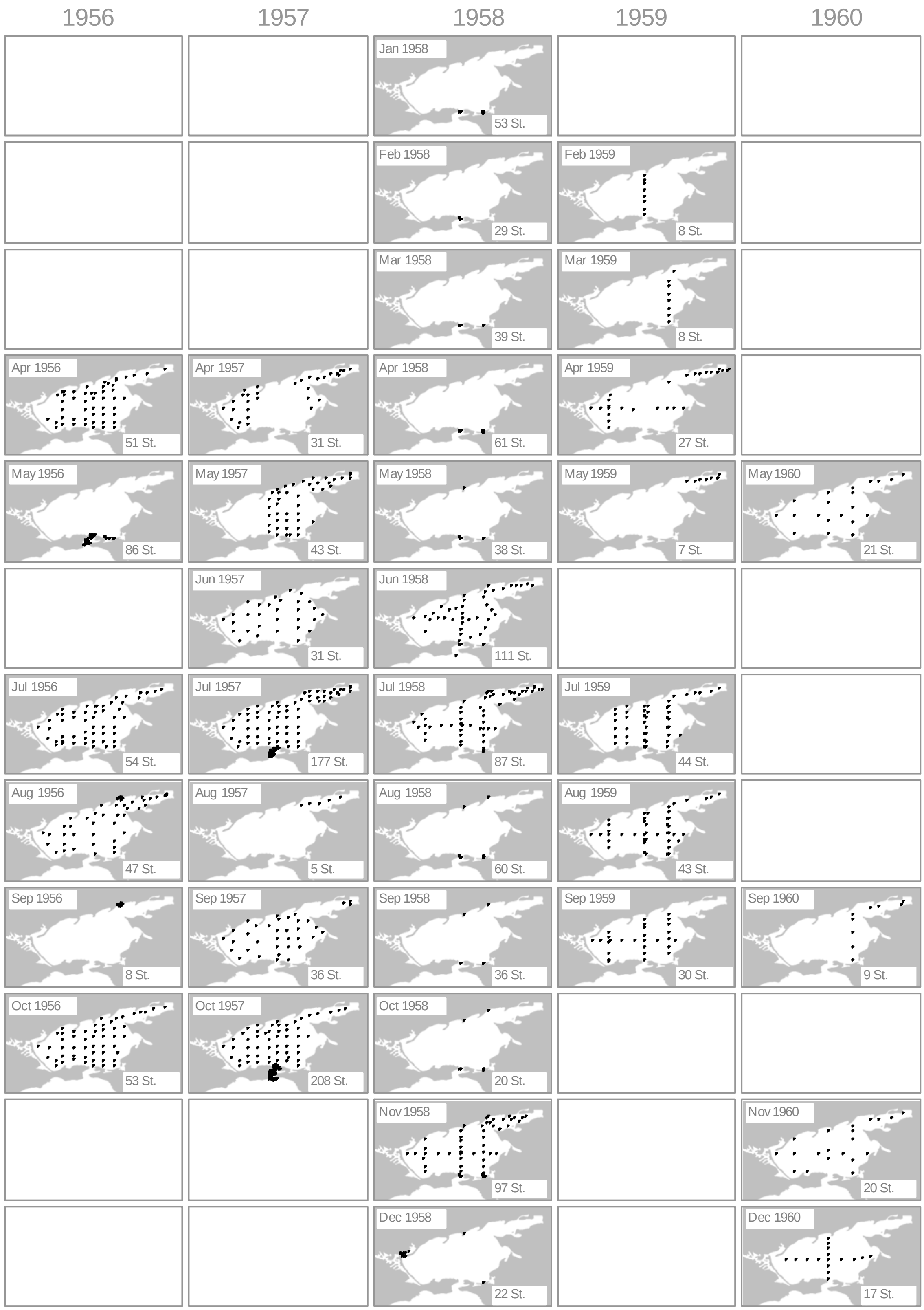
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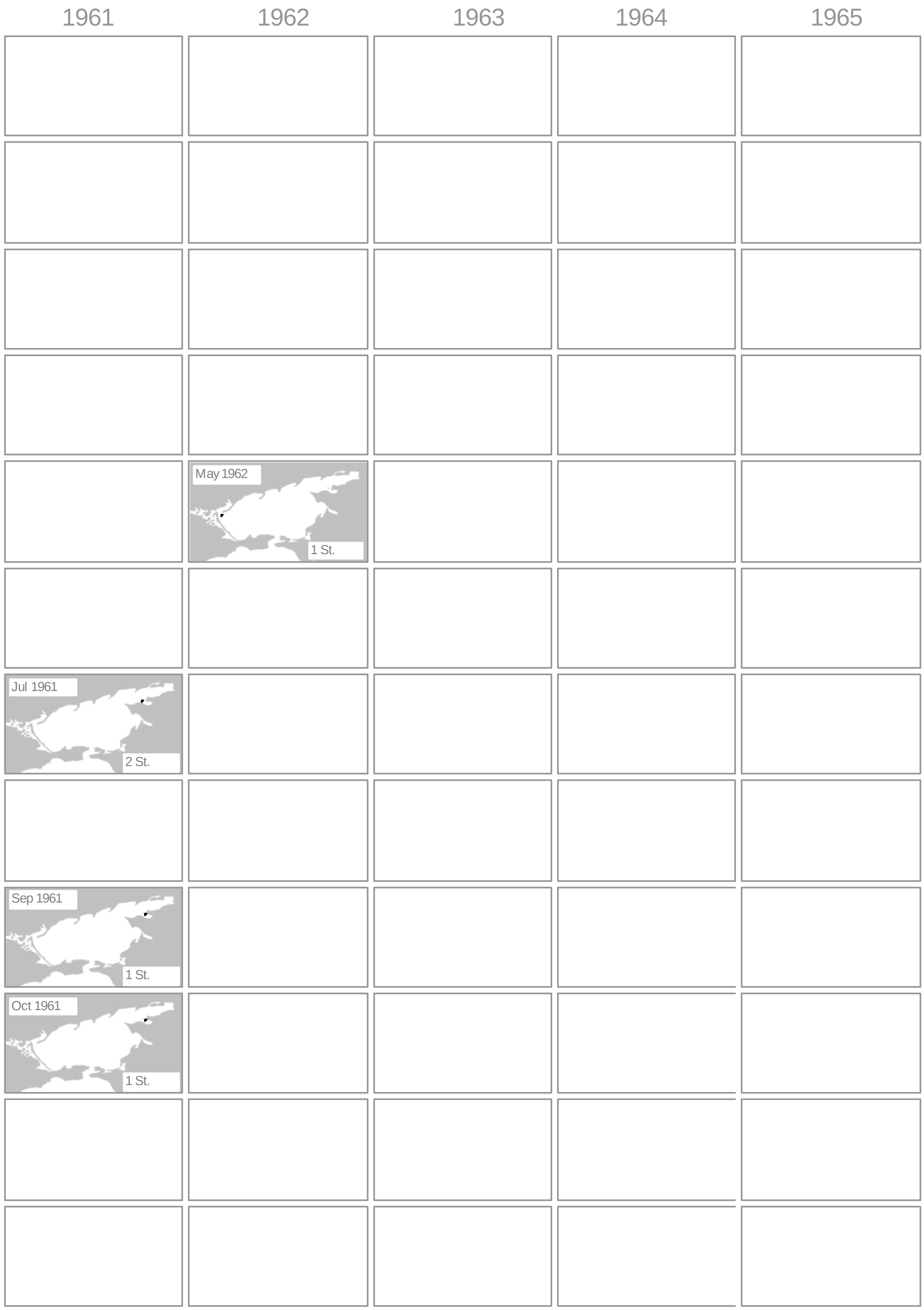
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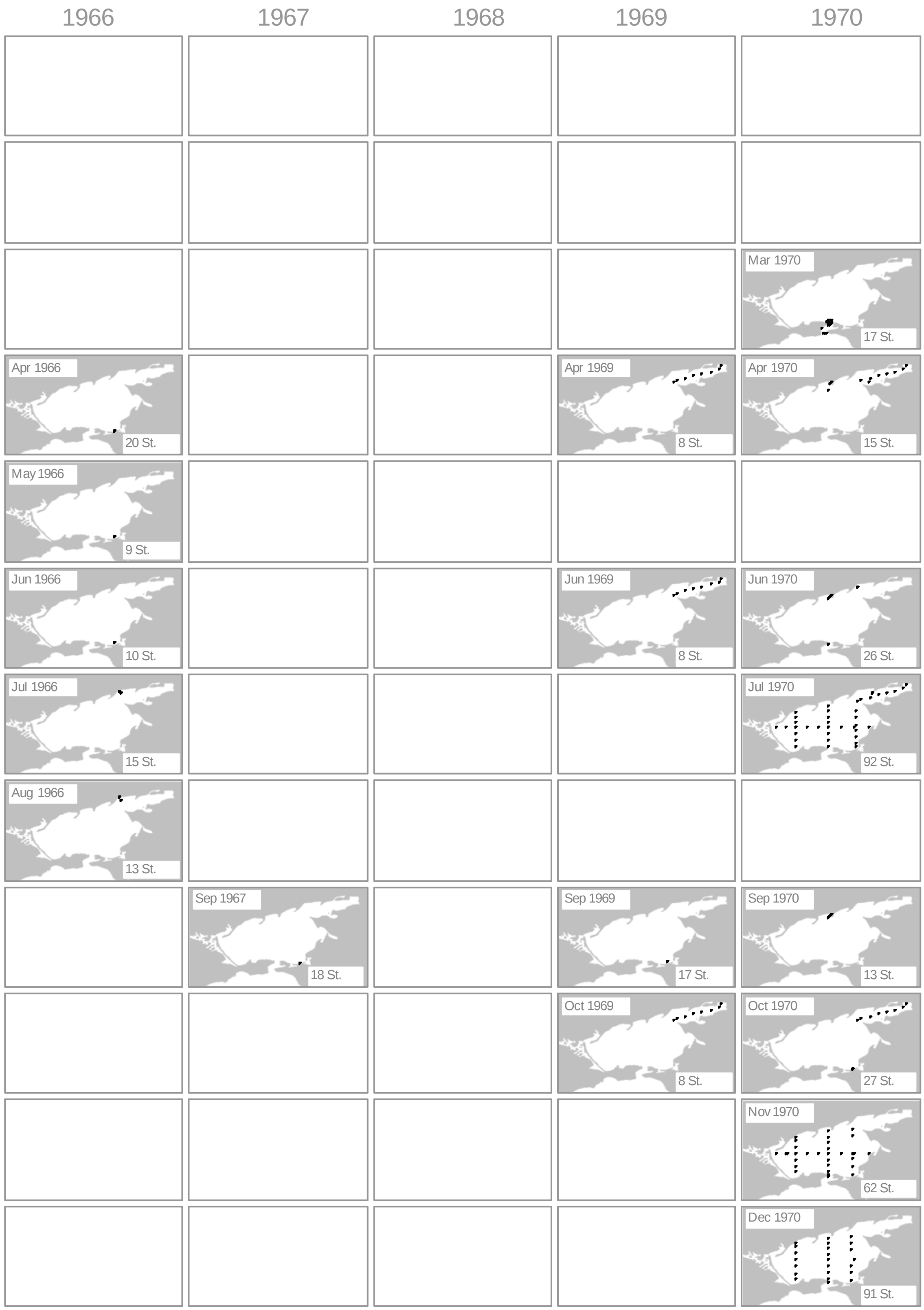
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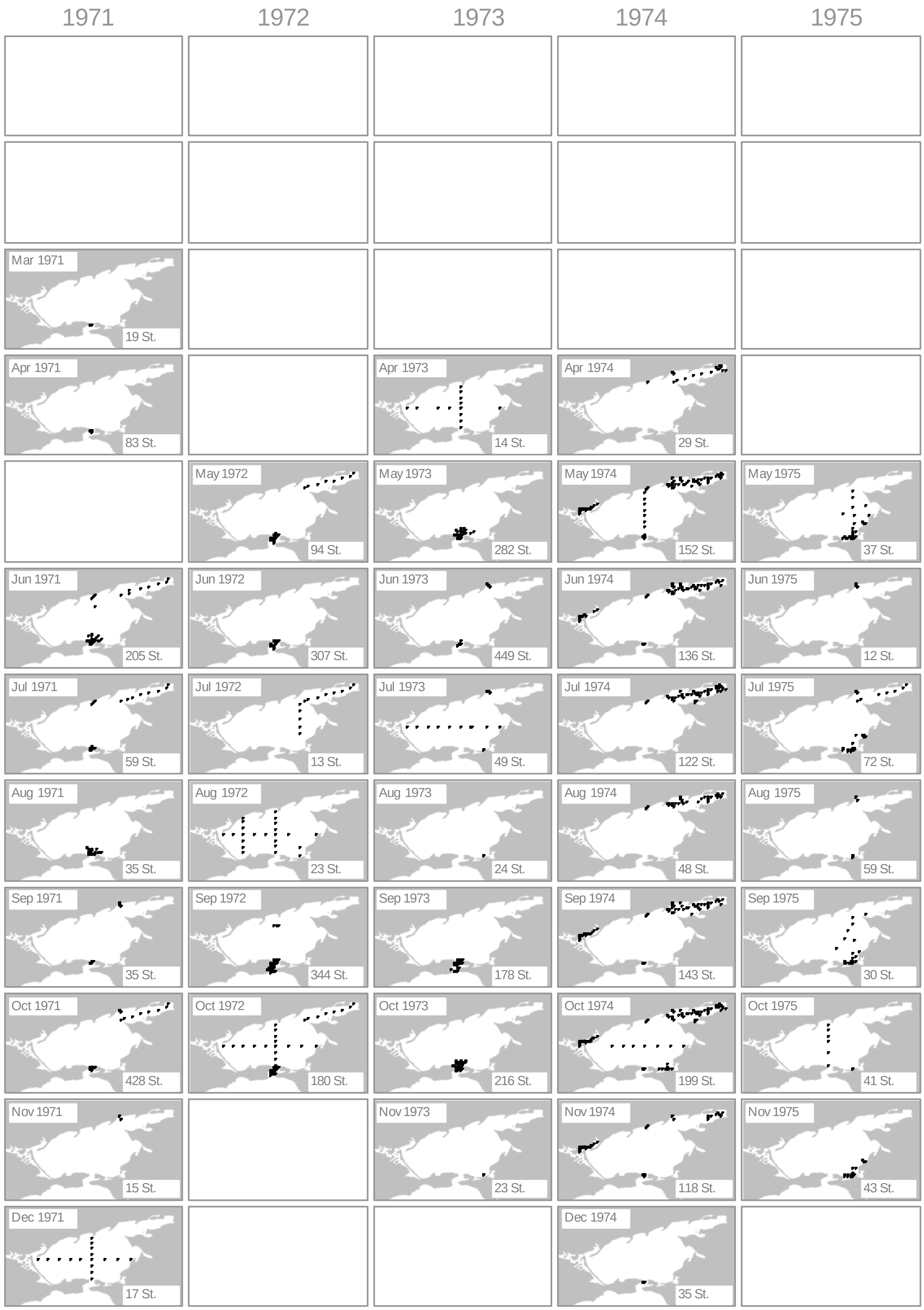
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Jul 1971
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Aug 1972
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Oct 1974
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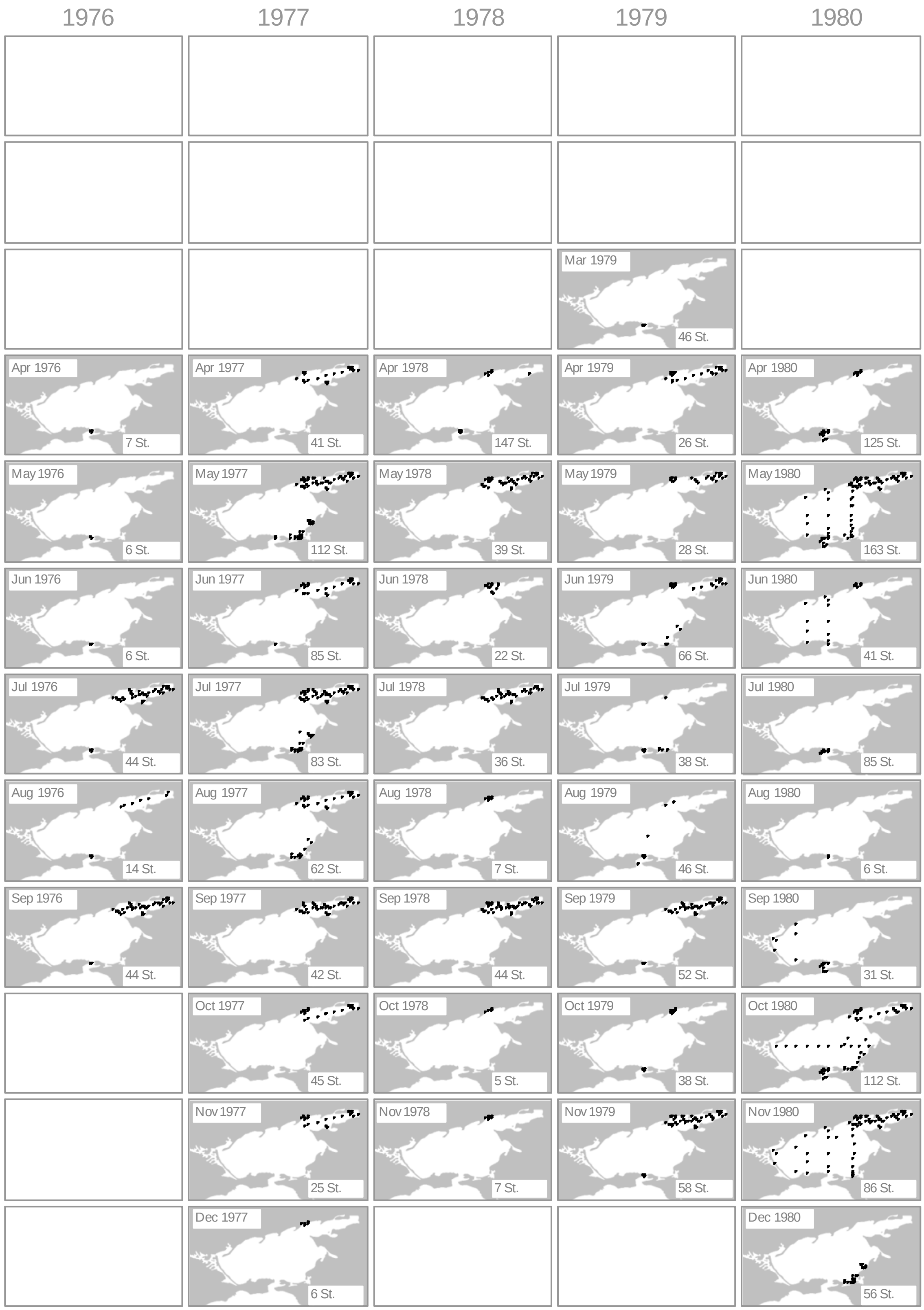
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May 1977
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May 1978
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May 1979
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May 1980
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Jun 1977
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Jul 1977
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Oct 1979
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Dec 1980
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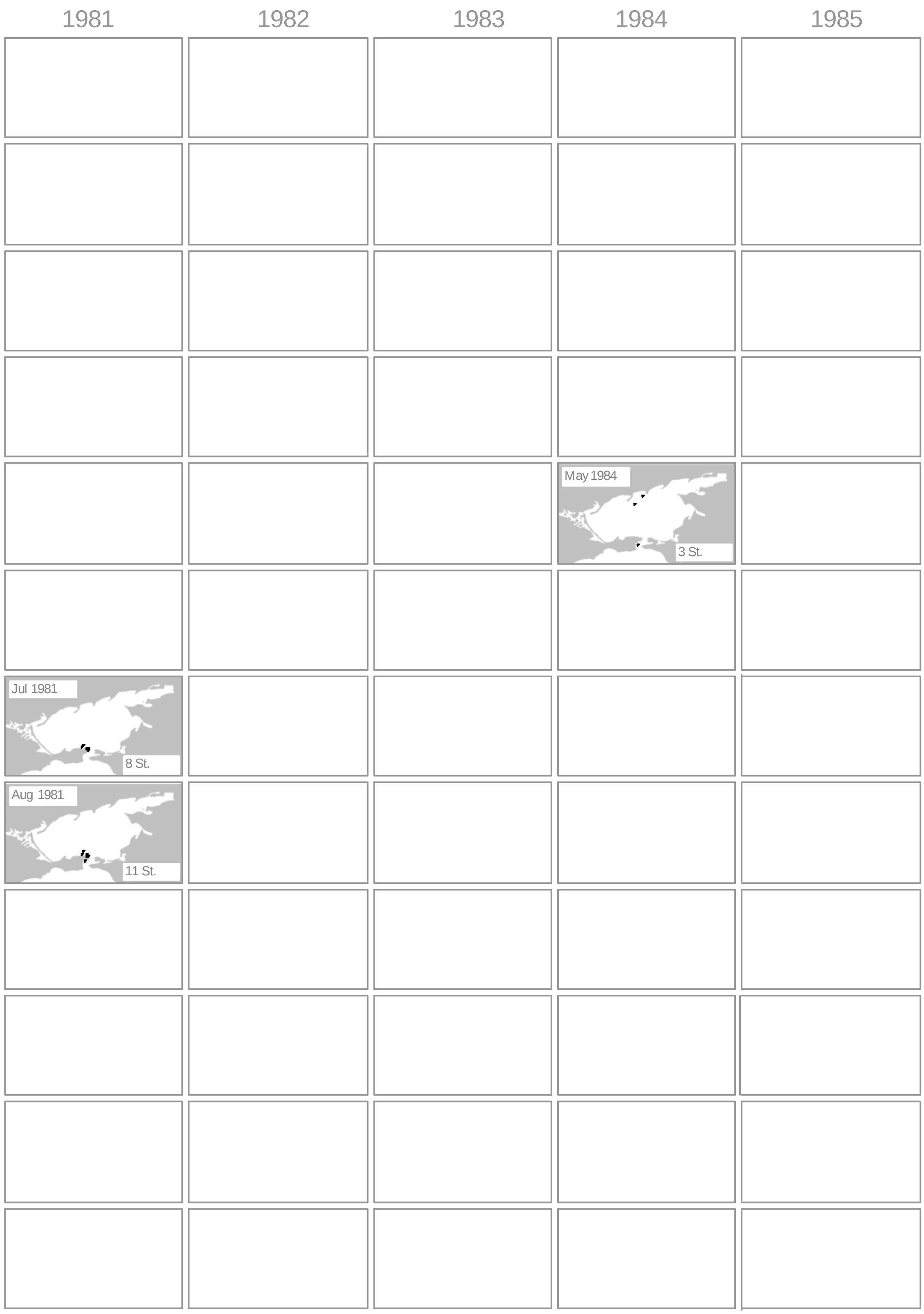
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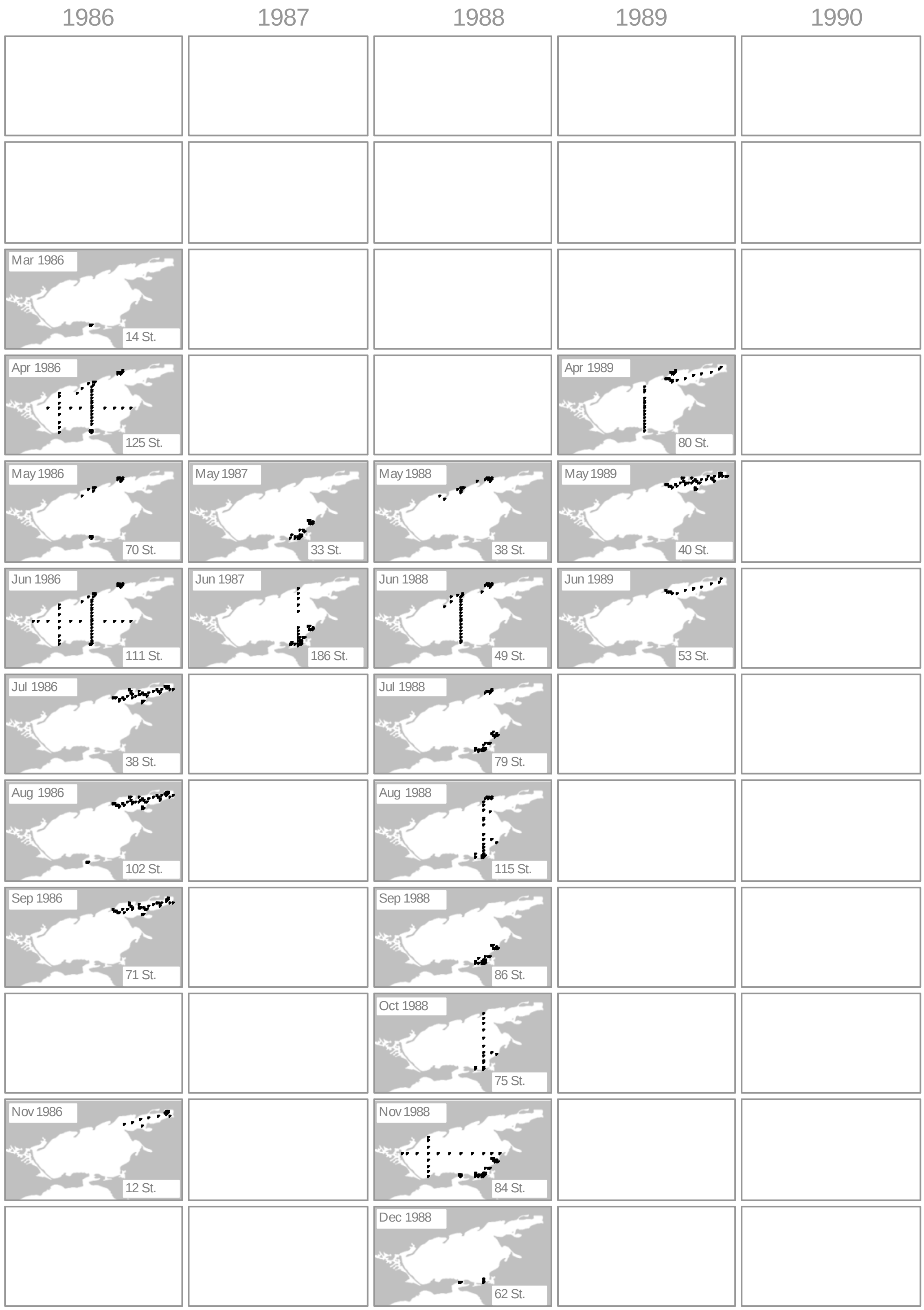

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May 1988
38 St.
May 1989
40 St.
Jun 1986
111 St.
Jun 1987
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Jun 1988
49 St.
Jun 1989
53 St.
Jul 1986
38 St.
Jul 1988
79 St.
Aug 1986
102 St.
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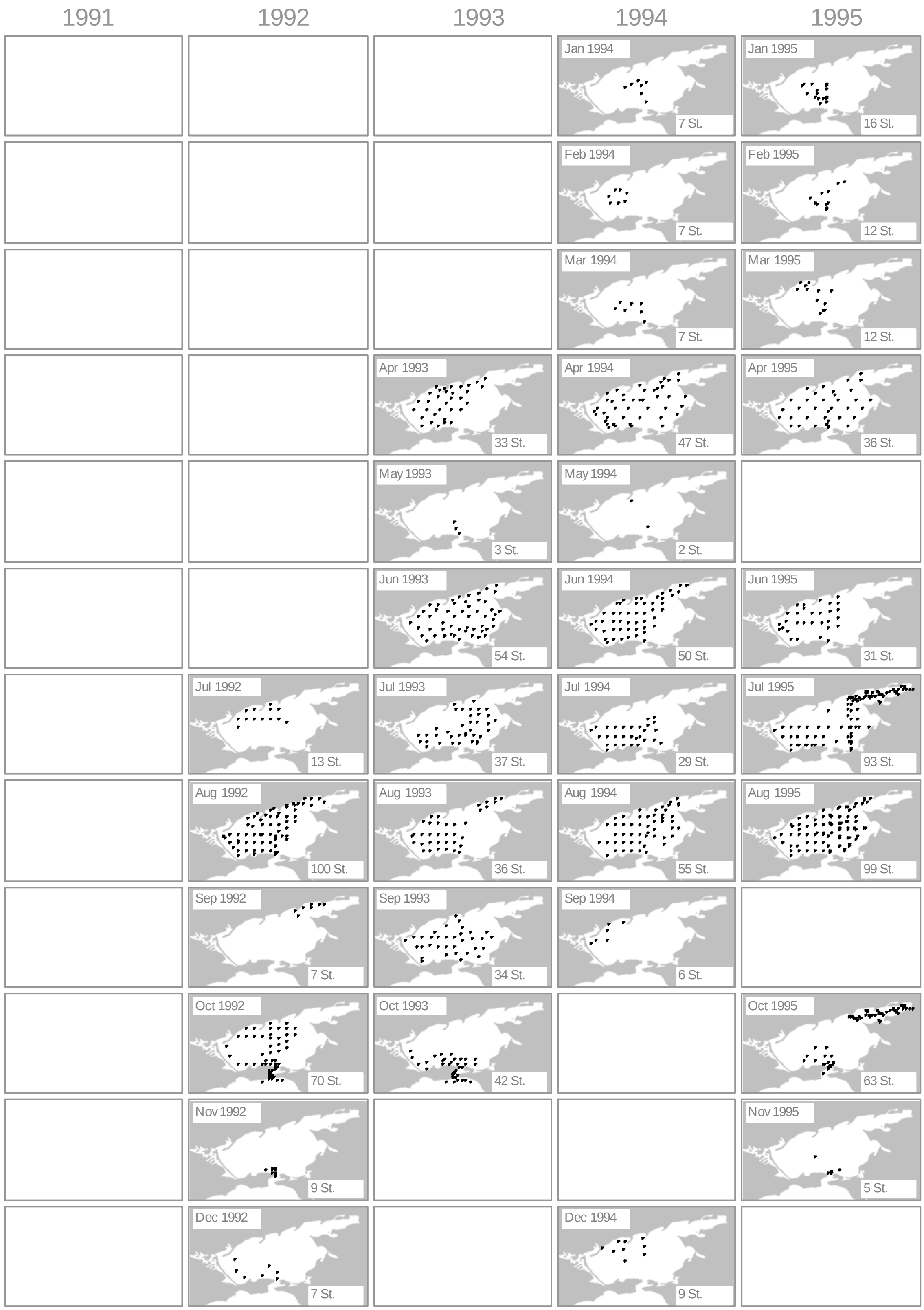
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Apr 1993
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Apr 1994
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Apr 1995
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May 1993
3 St.
May 1994
2 St.
Jun 1993
54 St.
Jun 1994
50 St.
Jun 1995
31 St.
Jul 1992
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Jul 1993
37 St.
Jul 1994
29 St.
Jul 1995
93 St.
Aug 1992
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Aug 1993
36 St.
Aug 1994
55 St.
Aug 1995
99 St.
Sep 1992
7 St.
Sep 1993
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Sep 1994
6 St.
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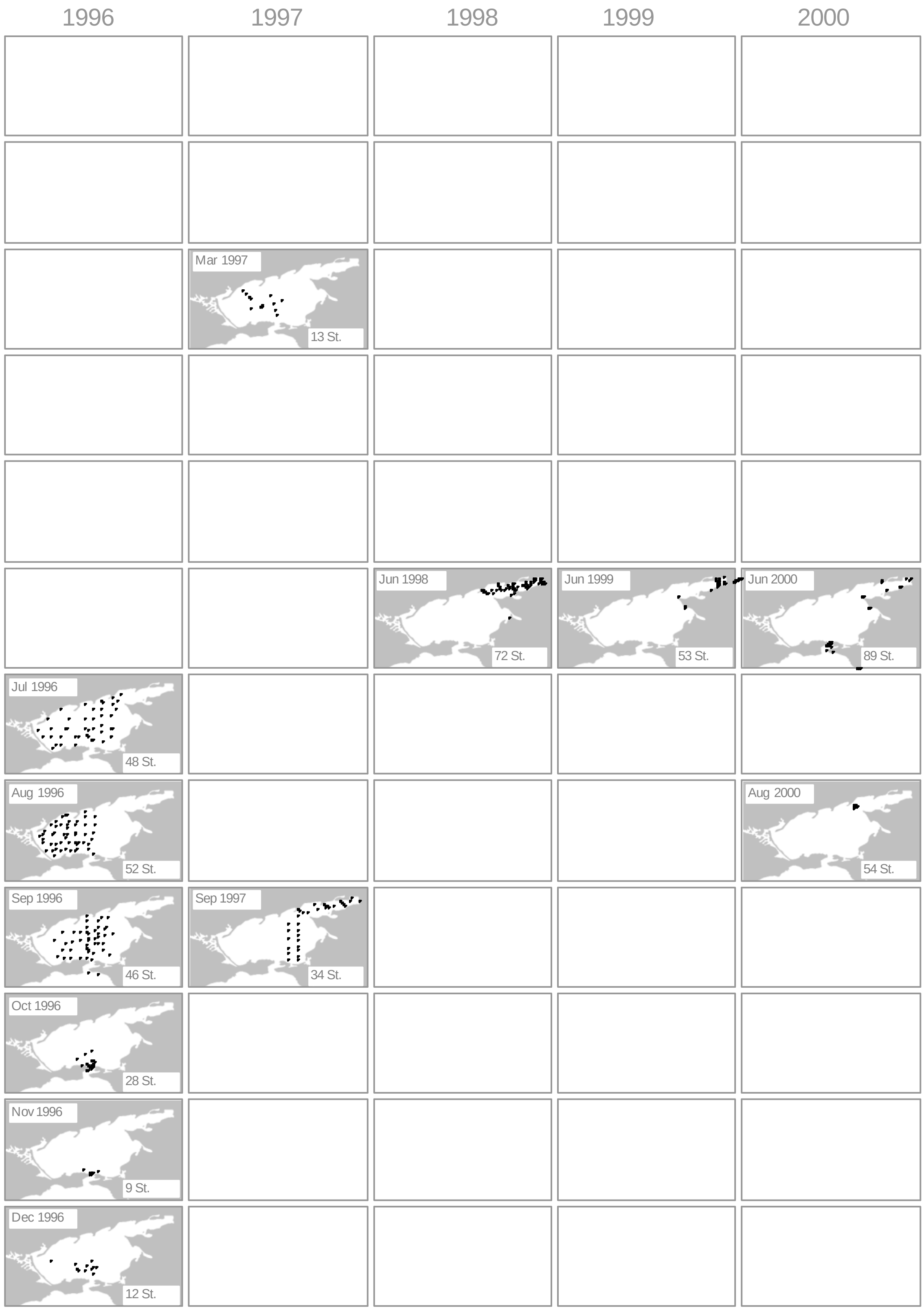
9 St.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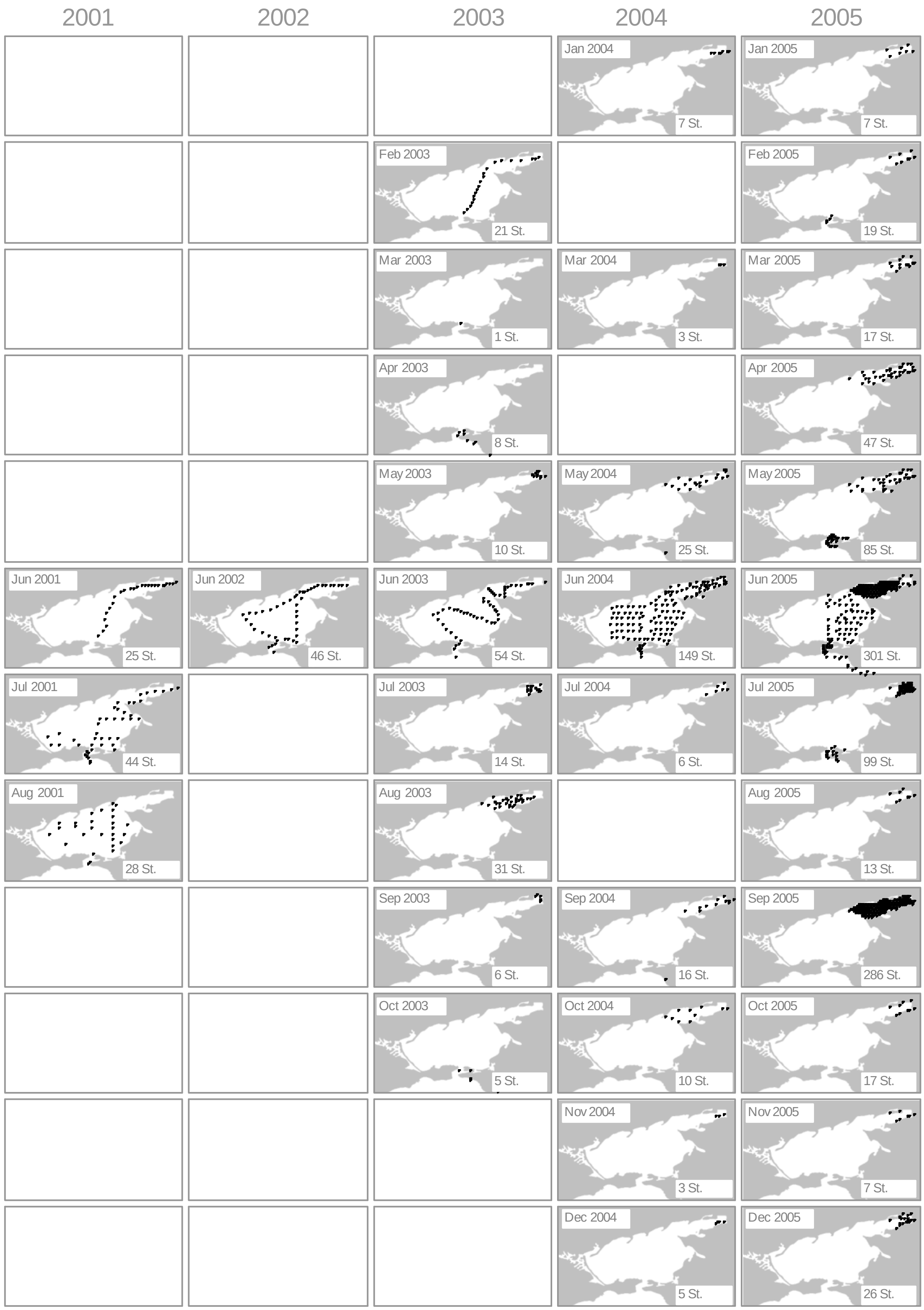

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3 St.
Mar 2005
17 St.
Apr 2003
8 St.
Apr 2005
47 St.
May 2003
10 St.
May 2004
25 St.
May 2005
85 St.
Jun 2001
25 St.
Jun 2002
46 St.
Jun 2003
54 St.
Jun 2004
149 St.
Jun 2005
301 St.
Jul 2001
44 St.
Jul 2003
14 St.
Jul 2004
6 St.
Jul 2005
99 St.
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28 St.
Aug 2003
31 St.
Aug 2005
13 St.
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Sep 2005
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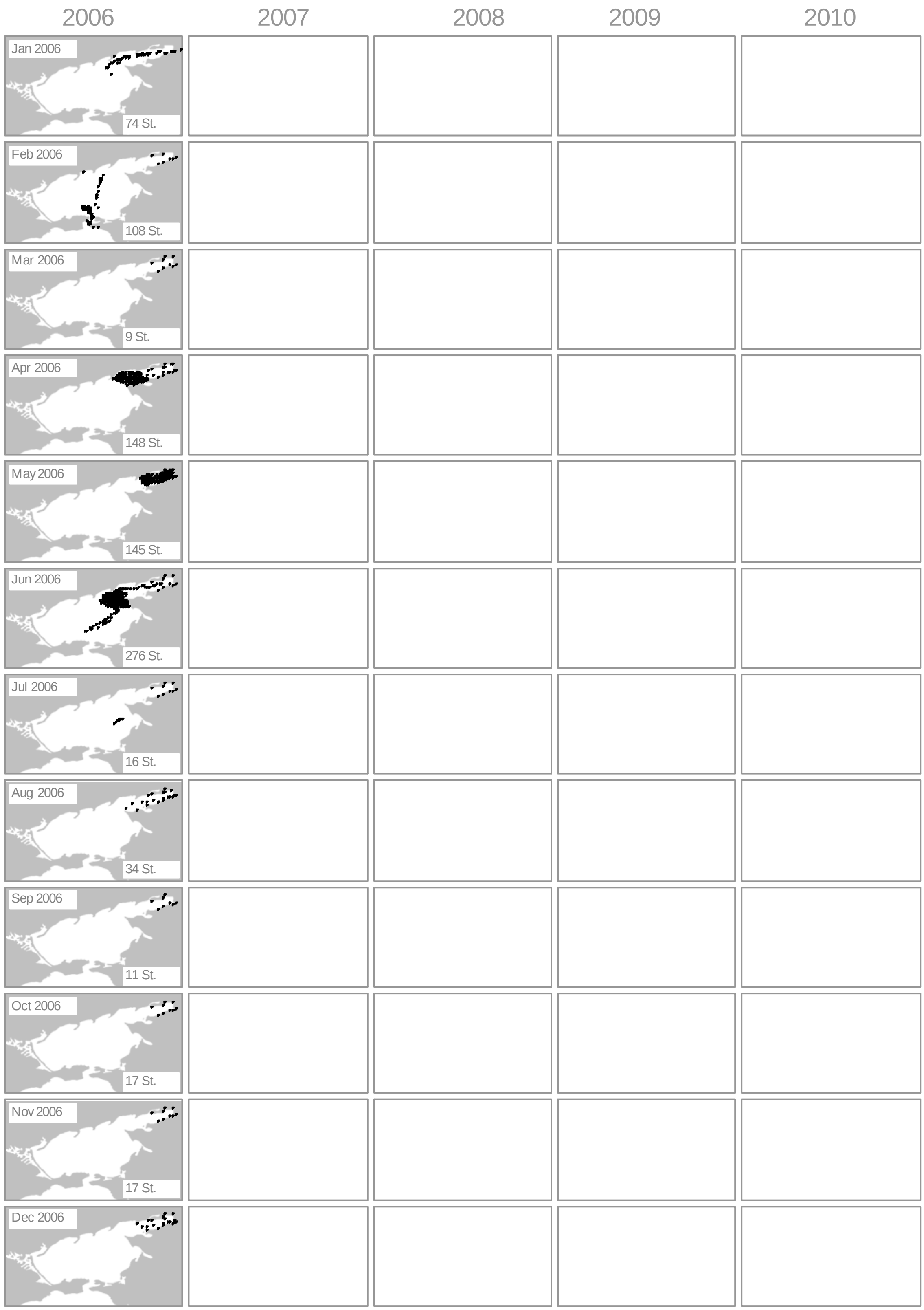
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Jul 2006
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Dec 2006

## Appendix C. Monthly climatic maps of temperature and salinity

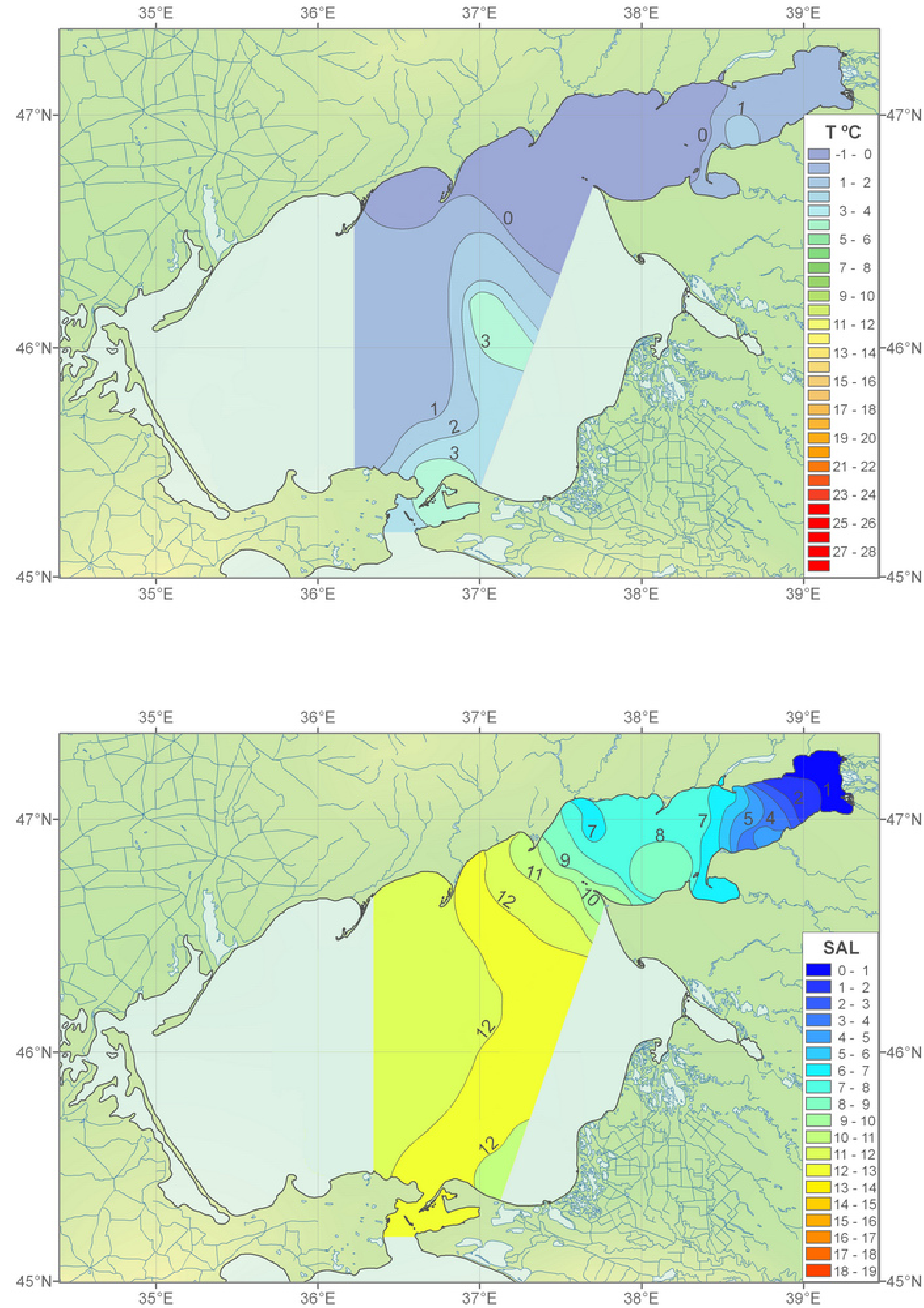



Fig. C1. Temperature ($^{o}$C) and Salinity (below). January. Depth 0 m.

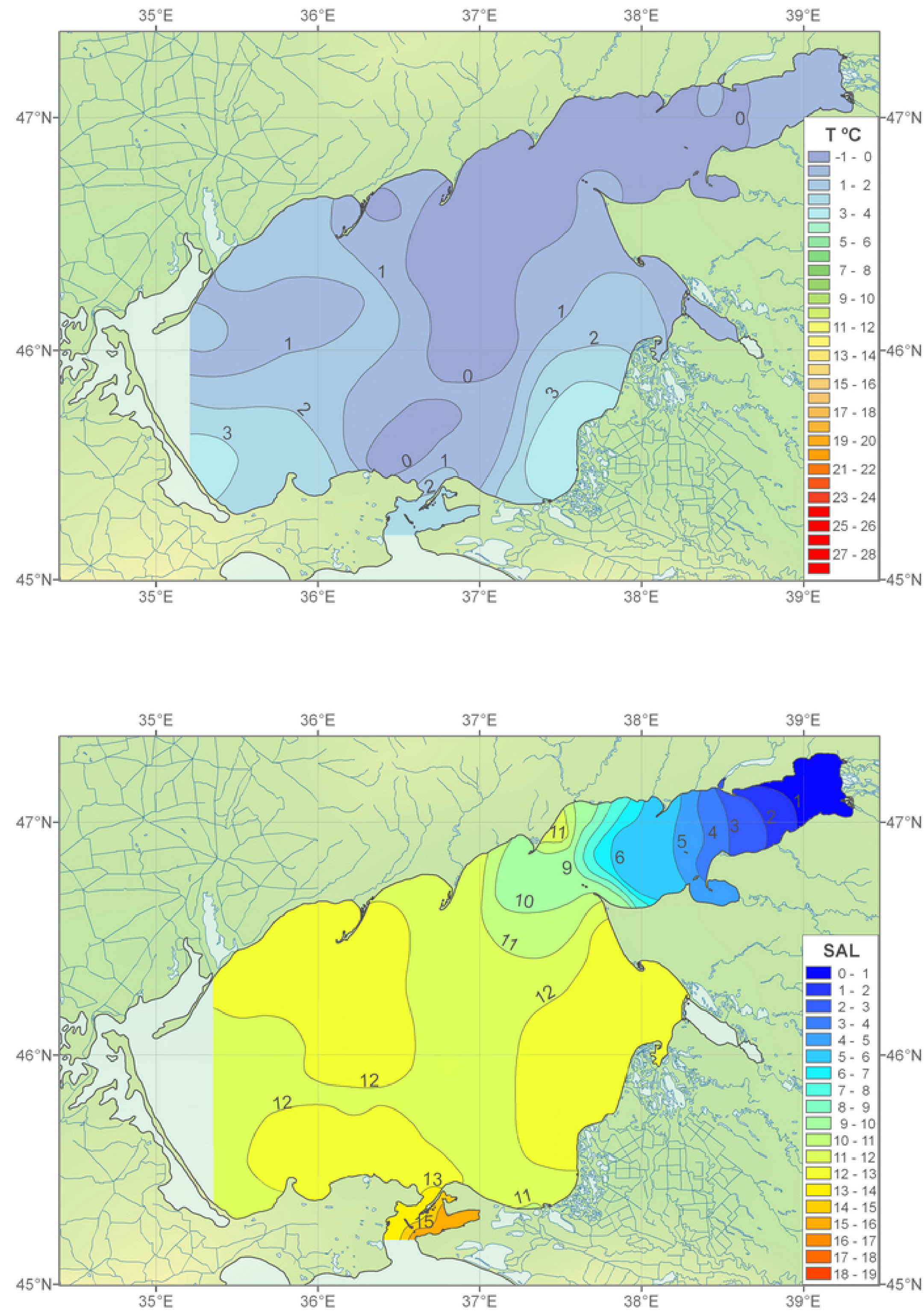



Fig. C2. Temperature ($^{o}$C) and Salinity (below). February. Depth 0 m.

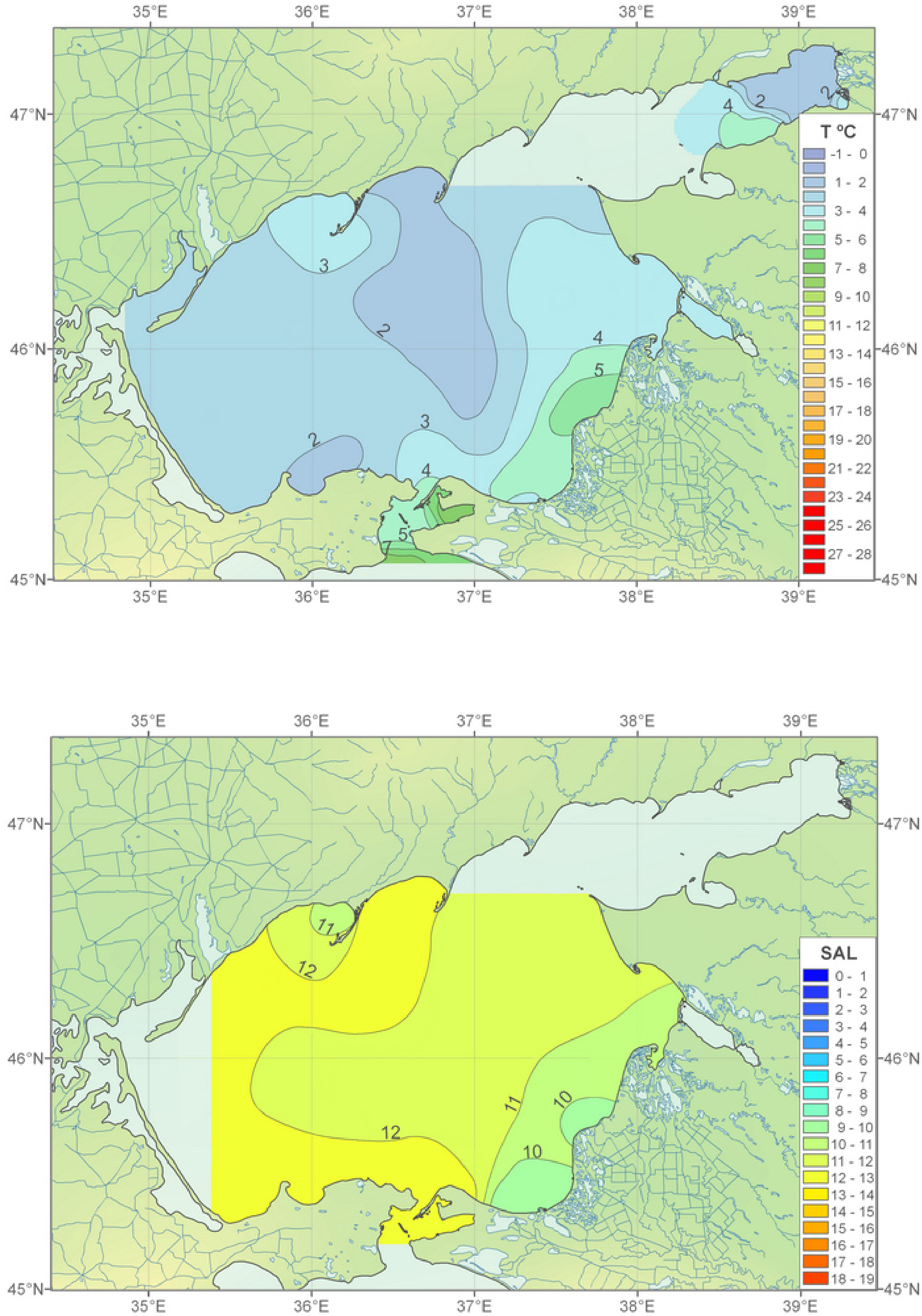



Fig. C3. Temperature ($^{o}$C) and Salinity (below). March. Depth 0 m.

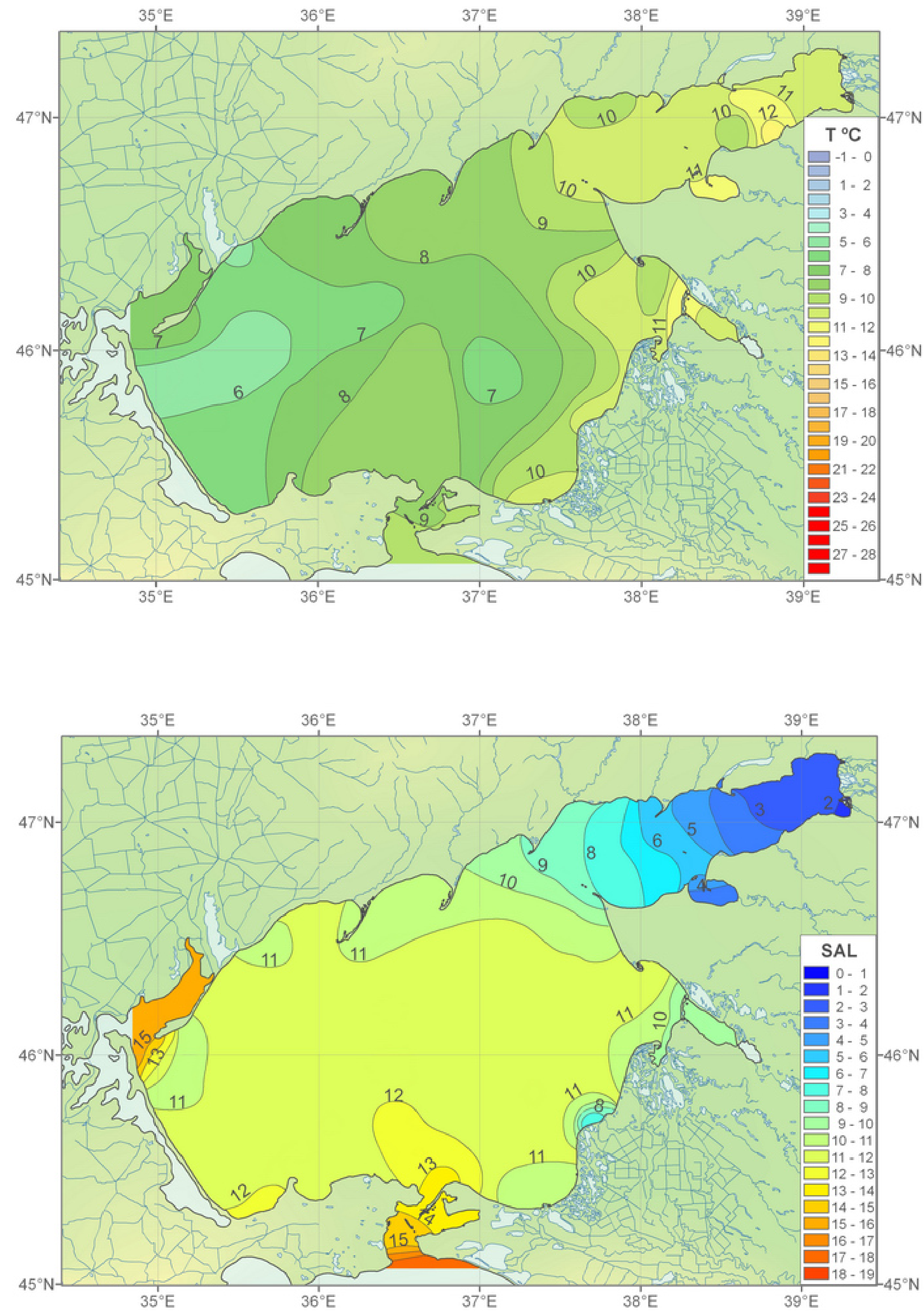
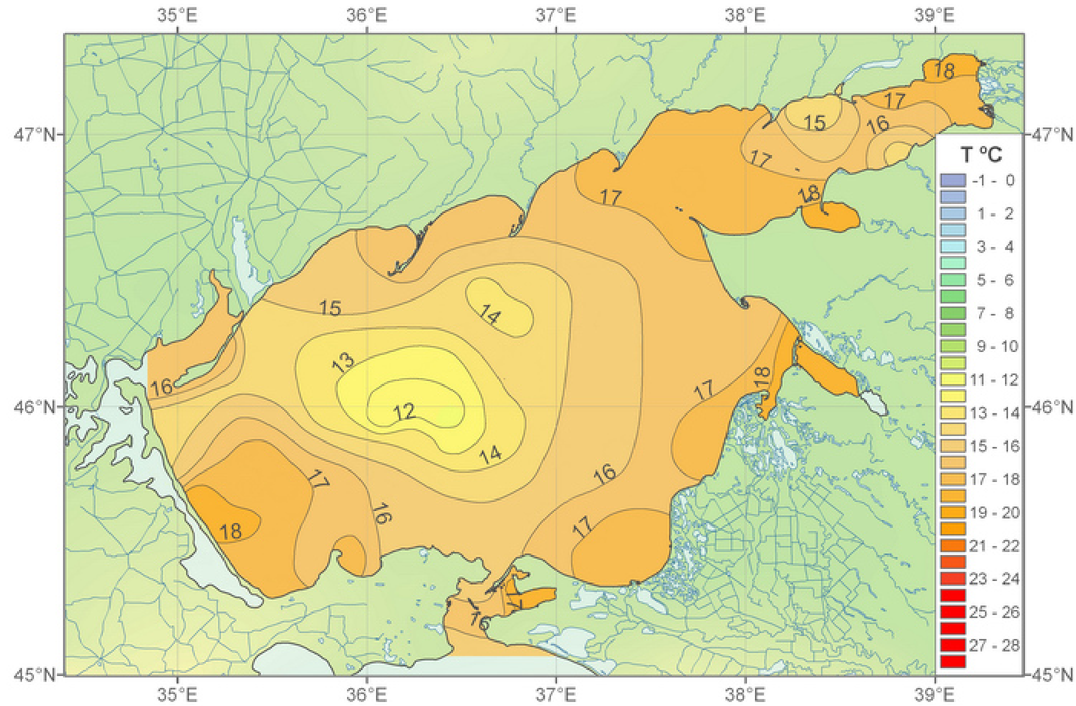



Fig. C4.Temperature ($^{o}$C) and Salinity (below). April. Depth 0 m.



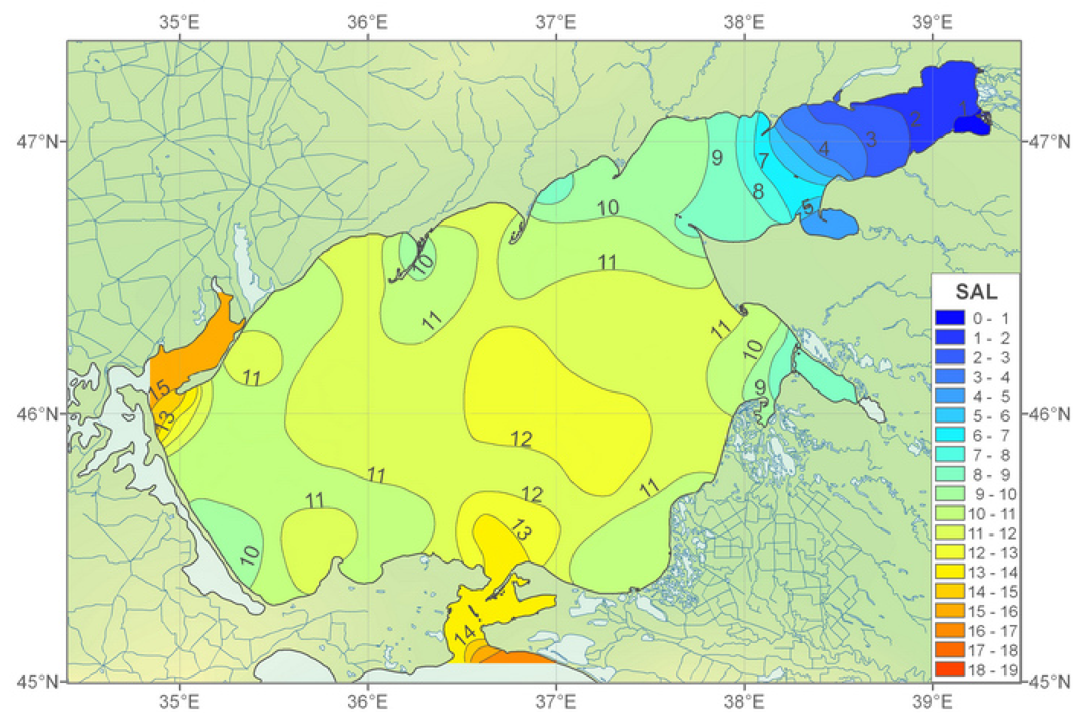




Fig. C5. Temperature ($^{o}$C) and Salinity (below). May. Depth 0 m.

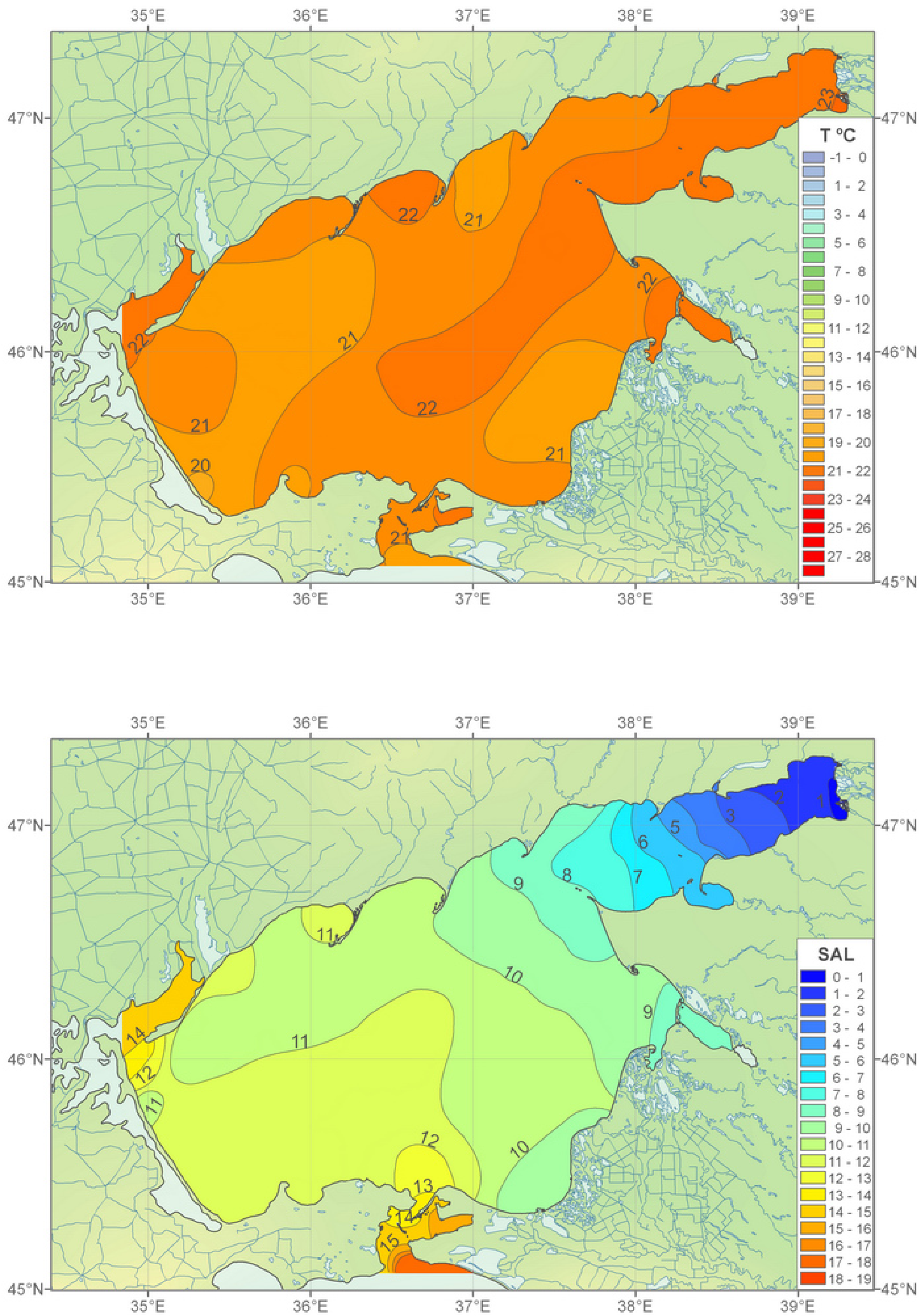



Fig. C6. Temperature ($^{o}$C) and Salinity (below). June. Depth 0 m.

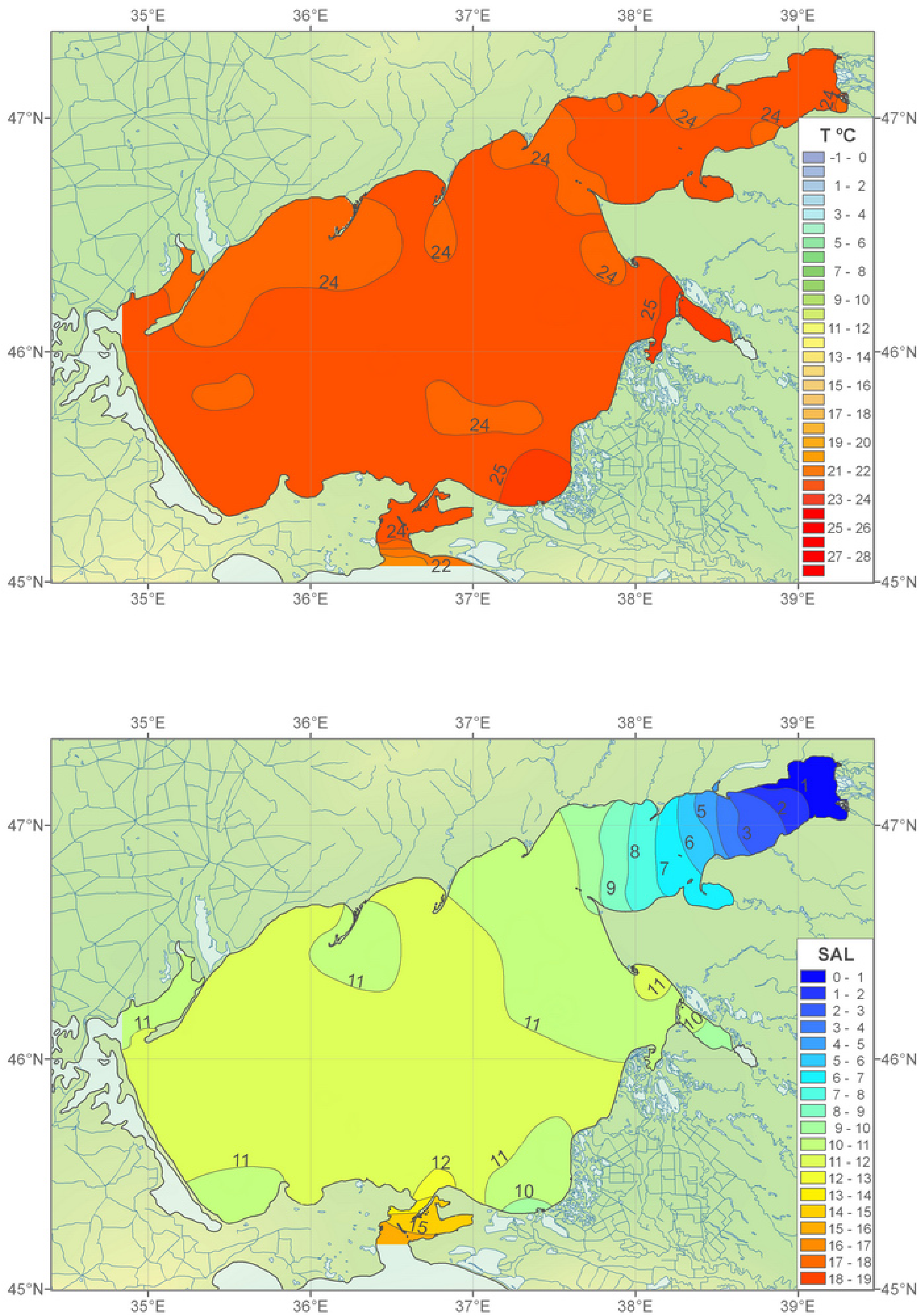



Fig. C7. Temperature ($^{o}$C) and Salinity (below). July. Depth 0 m.

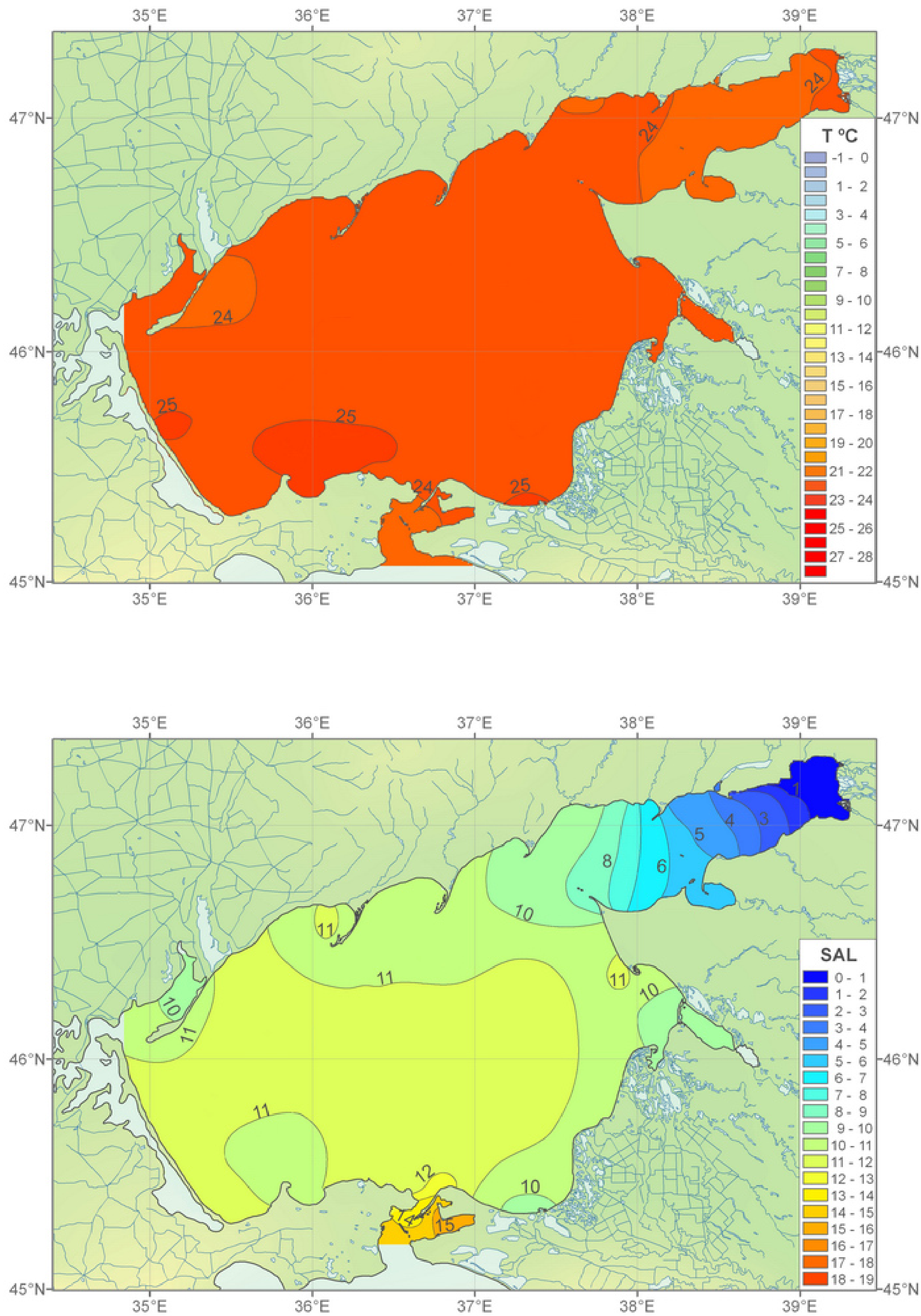



Fig. C8. Temperature ($^{o}$C) and Salinity (below). August. Depth 0 m.

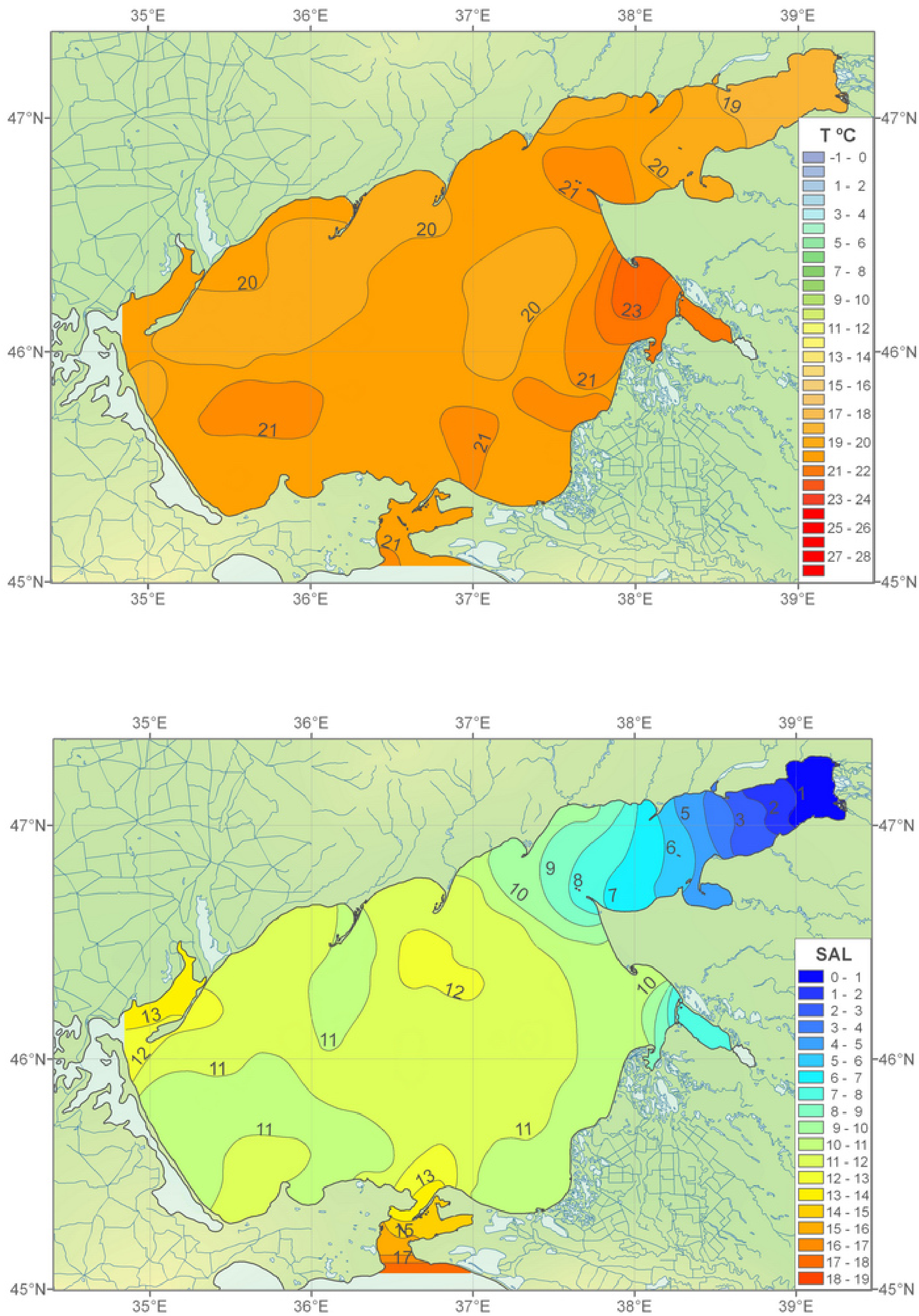



Fig. C9. Temperature ($^{o}$C) and Salinity (below). September. Depth 0 m.

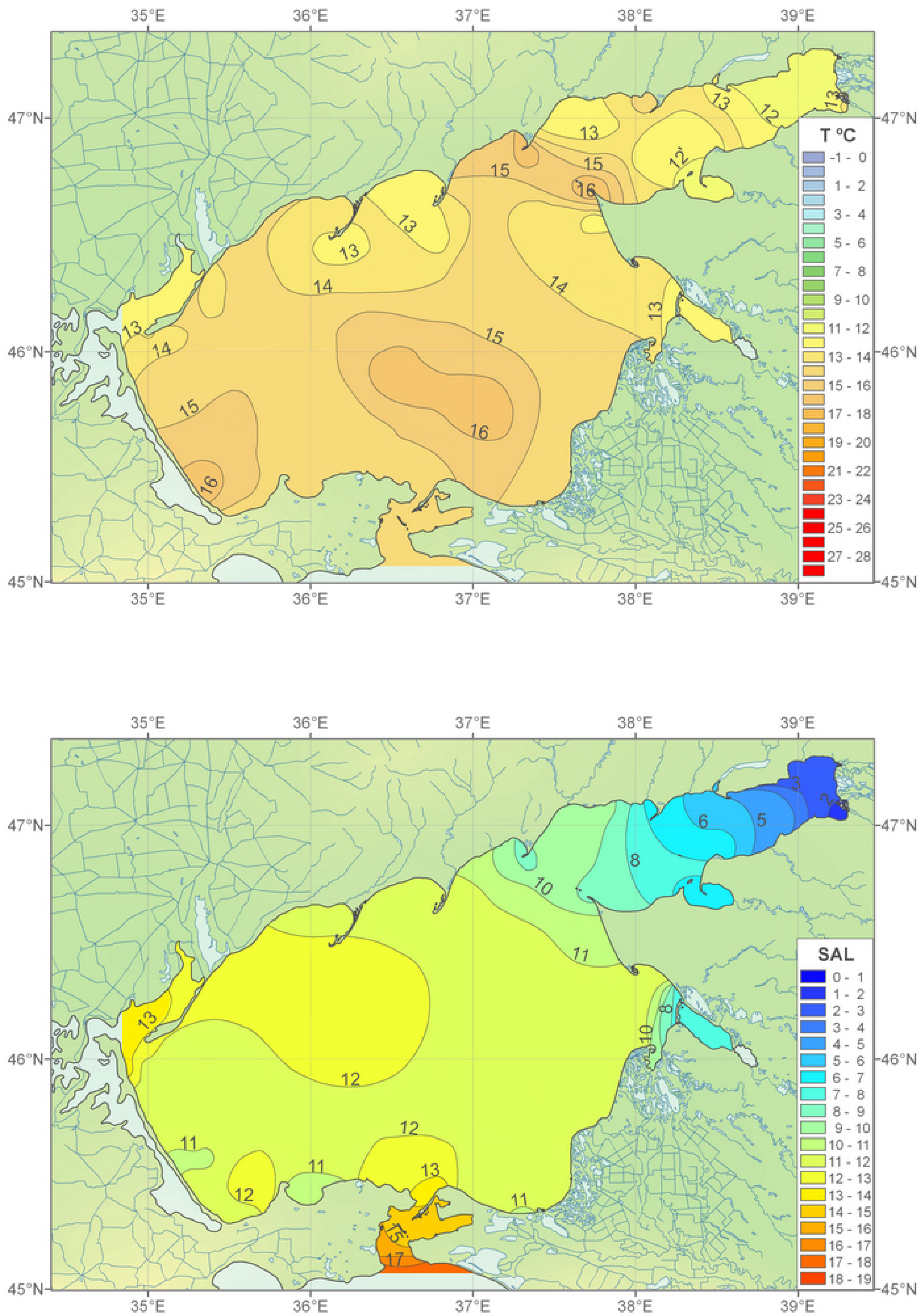



Fig. C10. Temperature ($^{o}$C) and Salinity (below). October. Depth 0 m.

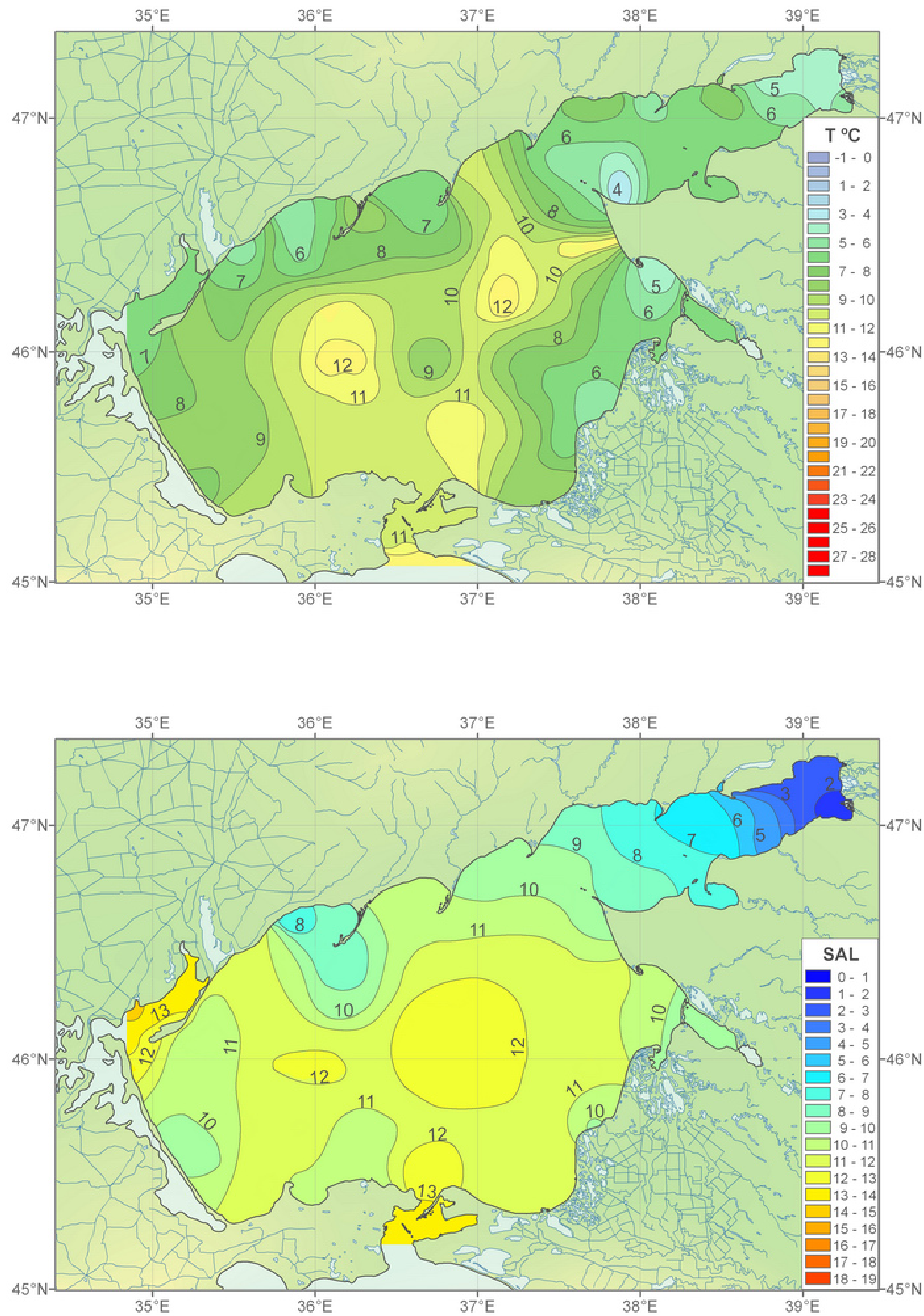
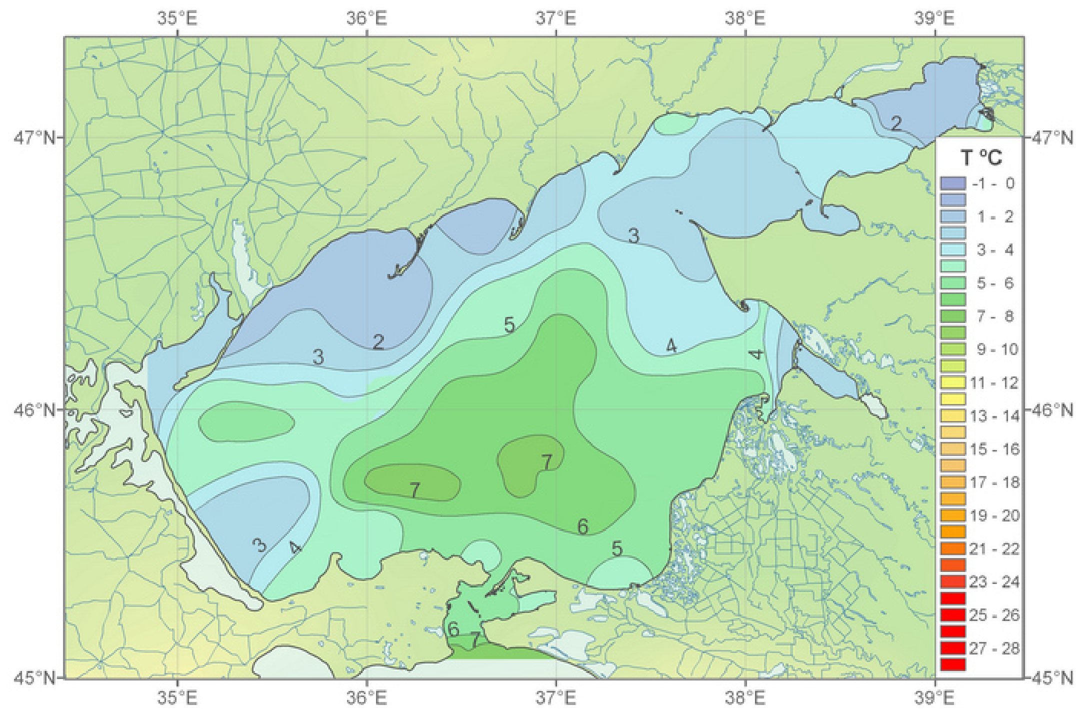



Fig. C11. Temperature ($^{o}$C) and Salinity (below). November. Depth 0 m.



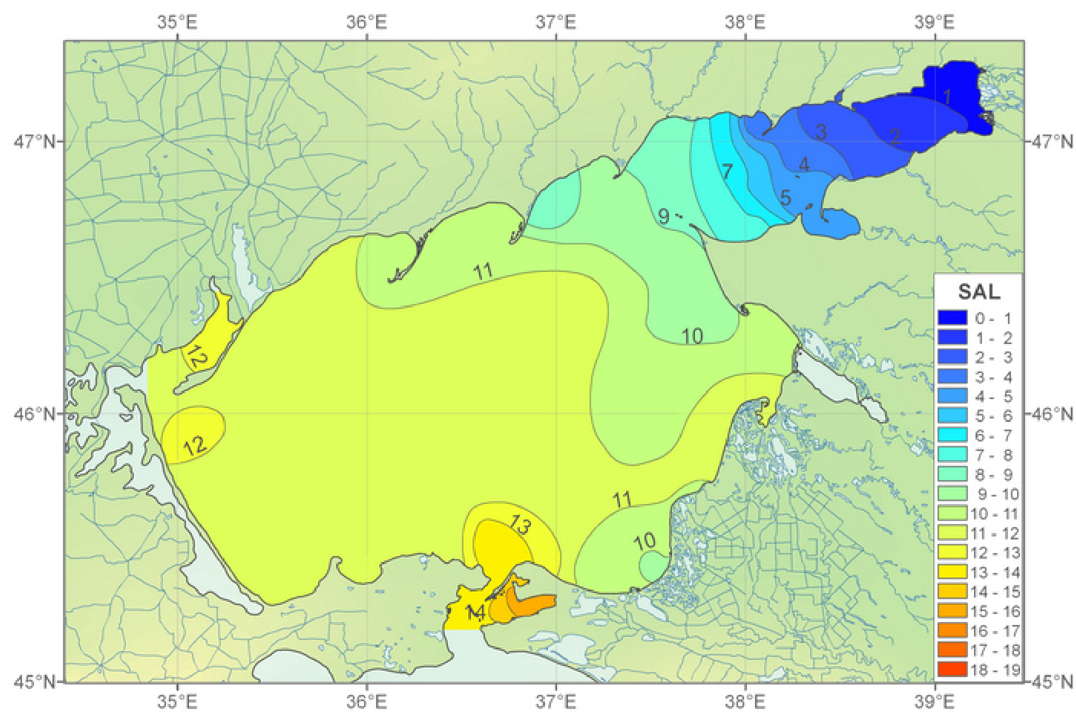




Fig. C12. Temperature ($^oC$) and Salinity (below). December. Depth 0 m.

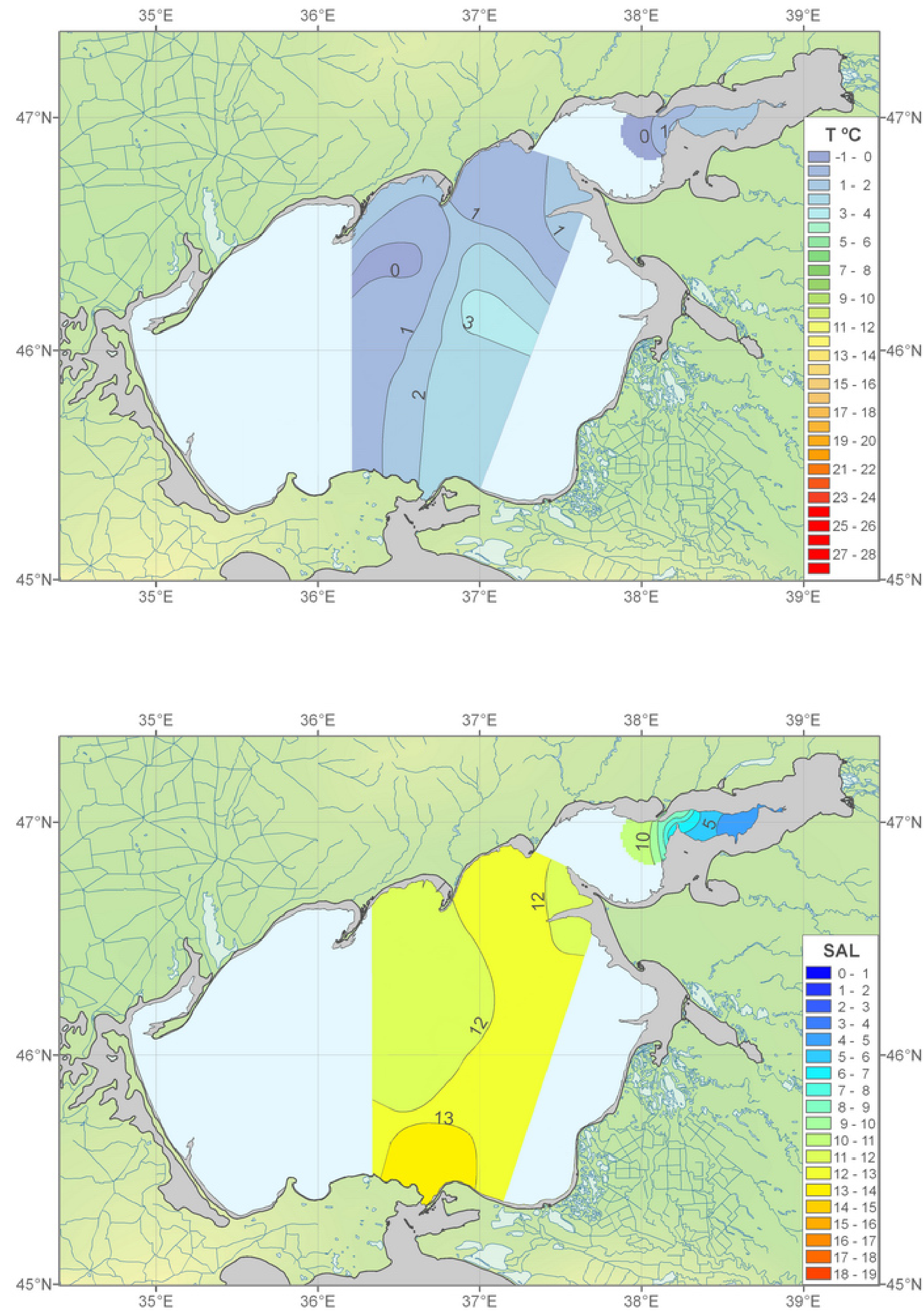



Fig.C13. Temperature ($^oC$) and Salinity (below). January. Depth 5m.

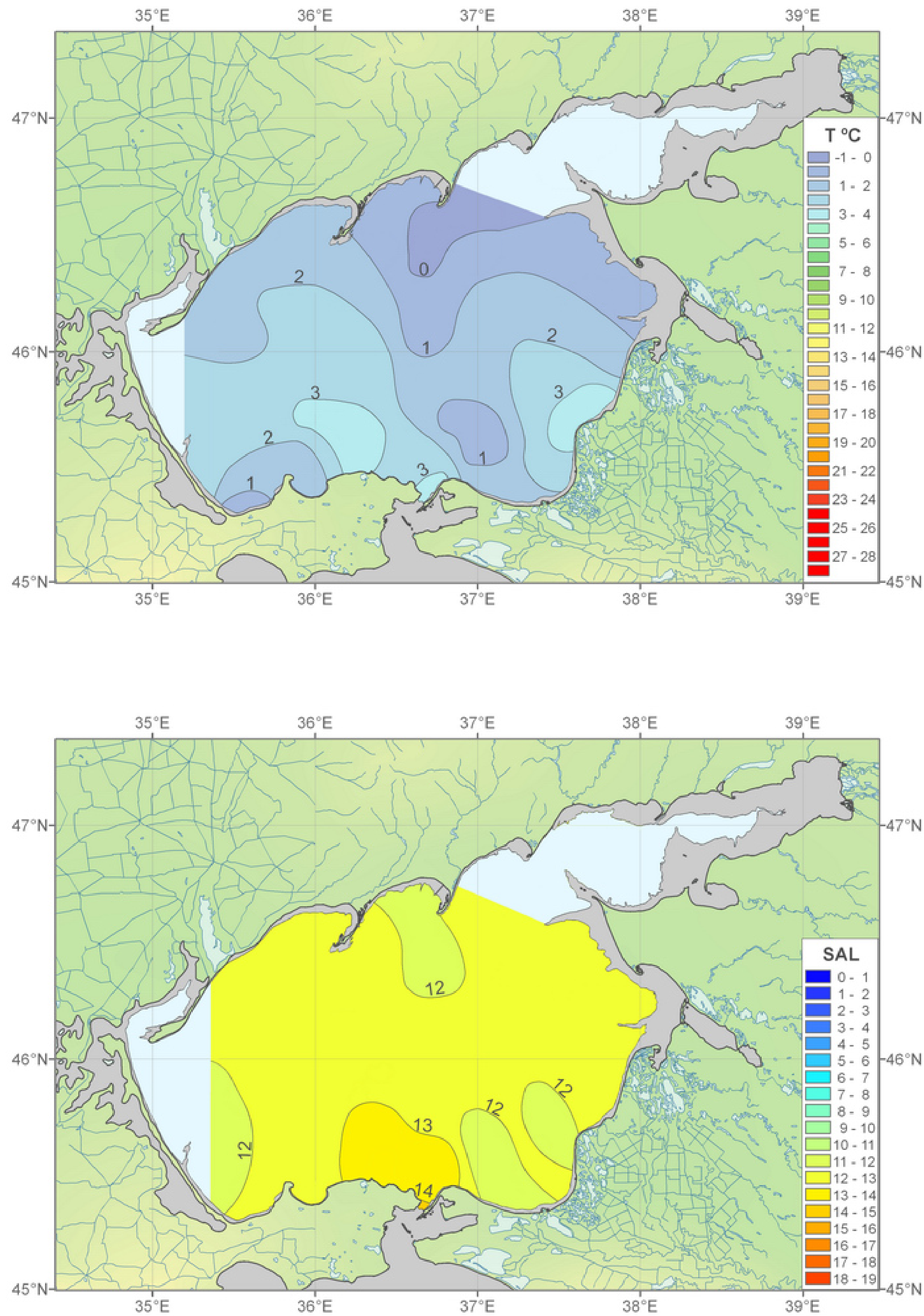



Fig. C14.. Temperature ($^{o}$C) and Salinity (below). February. Depth 5 m.

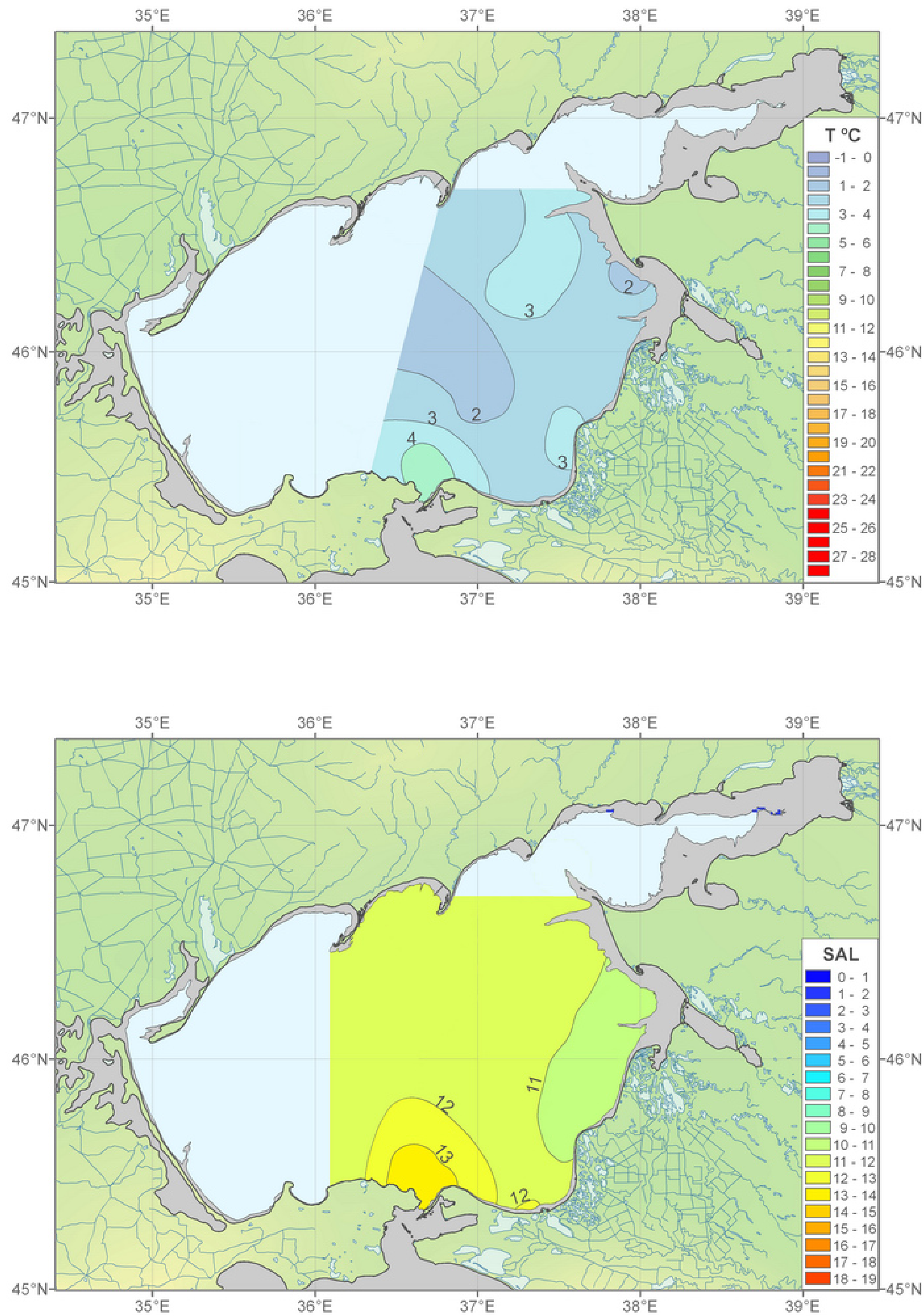



Fig. C15. Temperature ($^{o}$C) and Salinity (below). March. Depth 5 m.

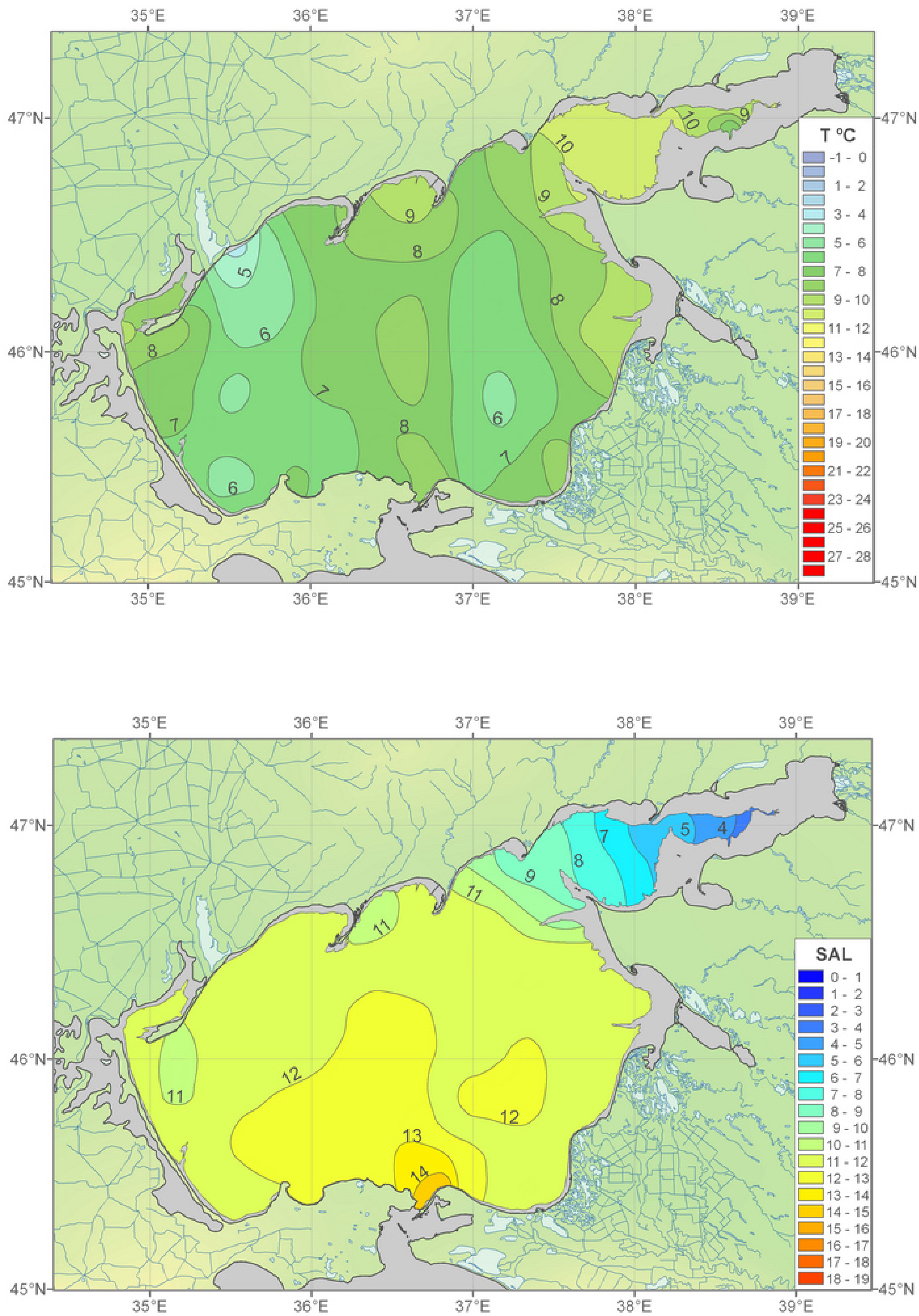



Fig. C16. Temperature (°C) and Salinity (below). April. Depth 5 m.

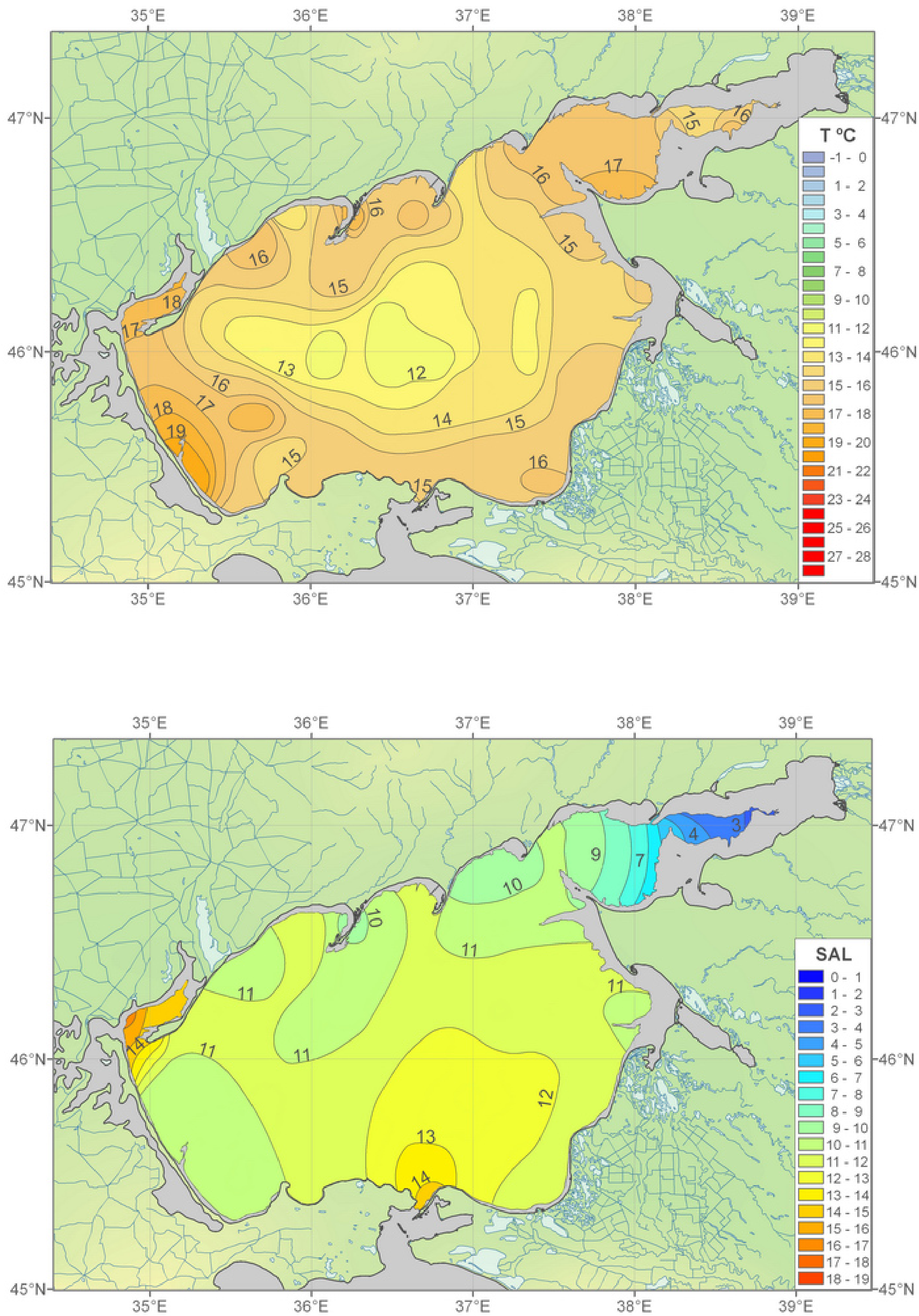
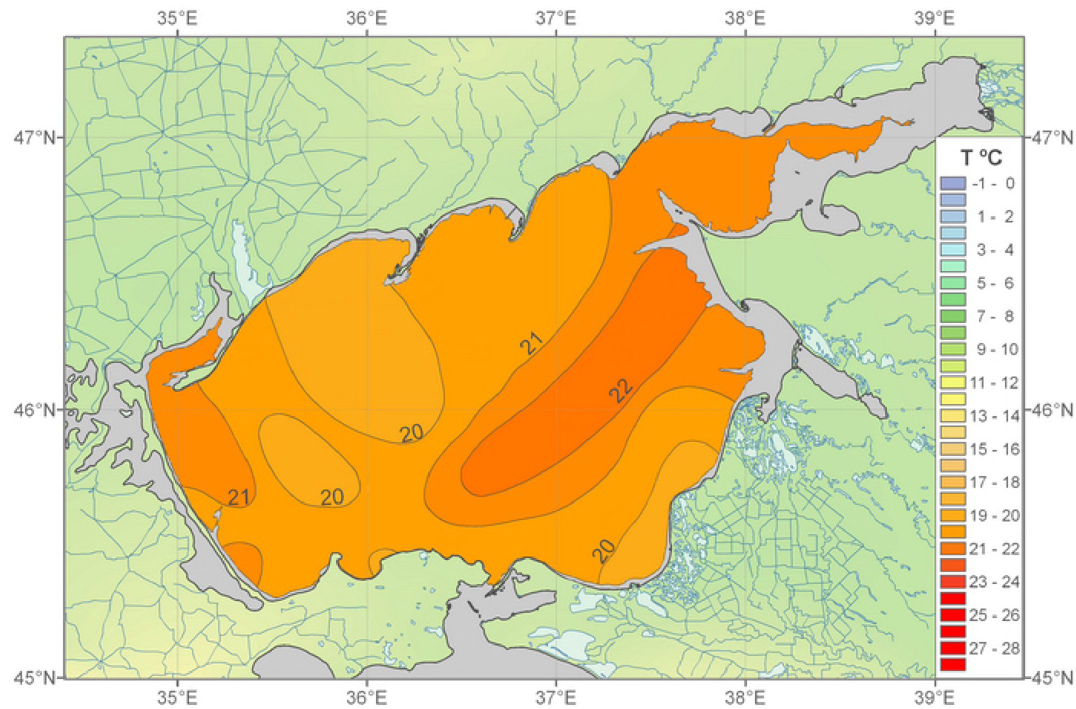



Fig. C17. Temperature ($^oC$) and Salinity (below). May. Depth 5 m.



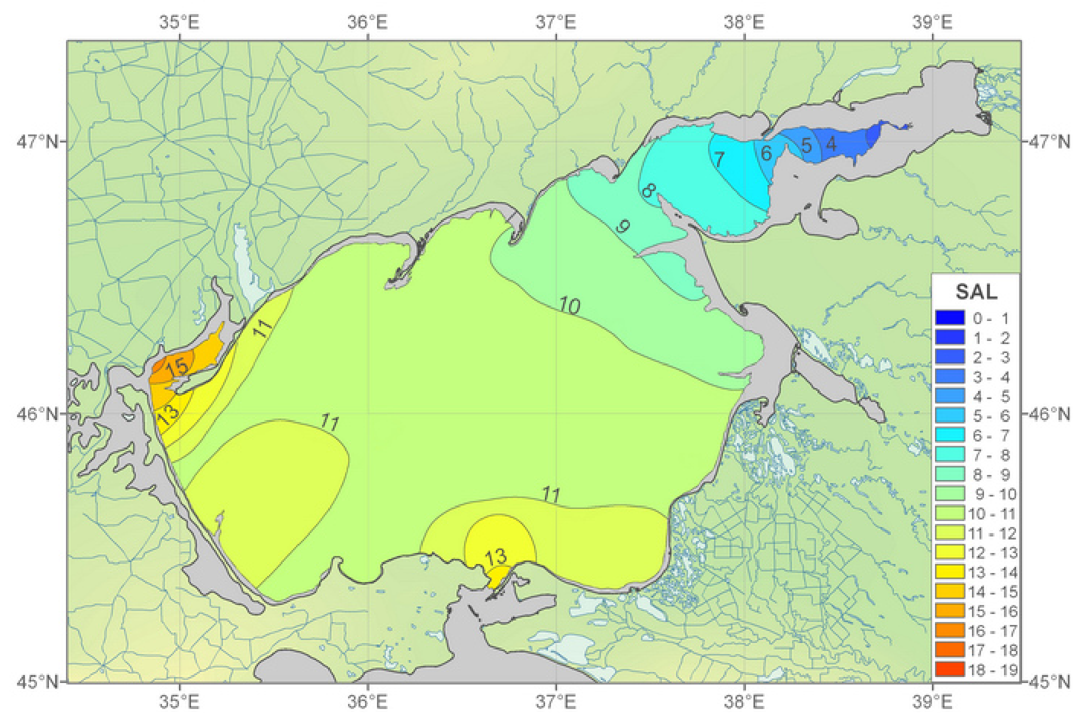
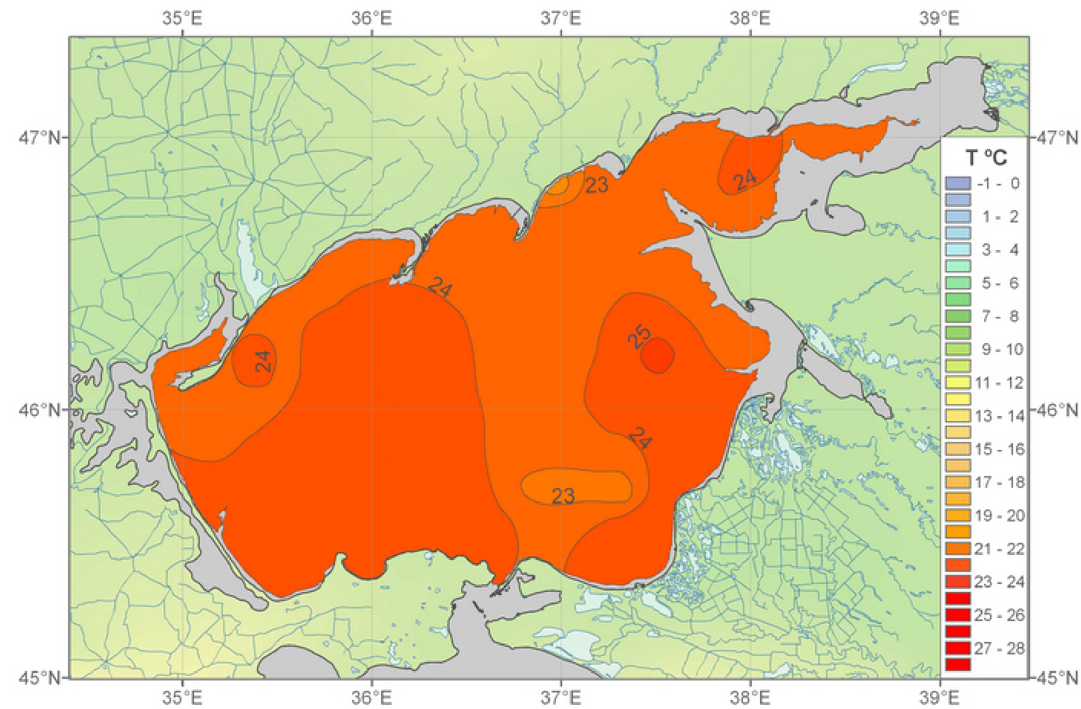




Fig. C18. Temperature ($^{o}$C) and Salinity (below). June. Depth 5 m.



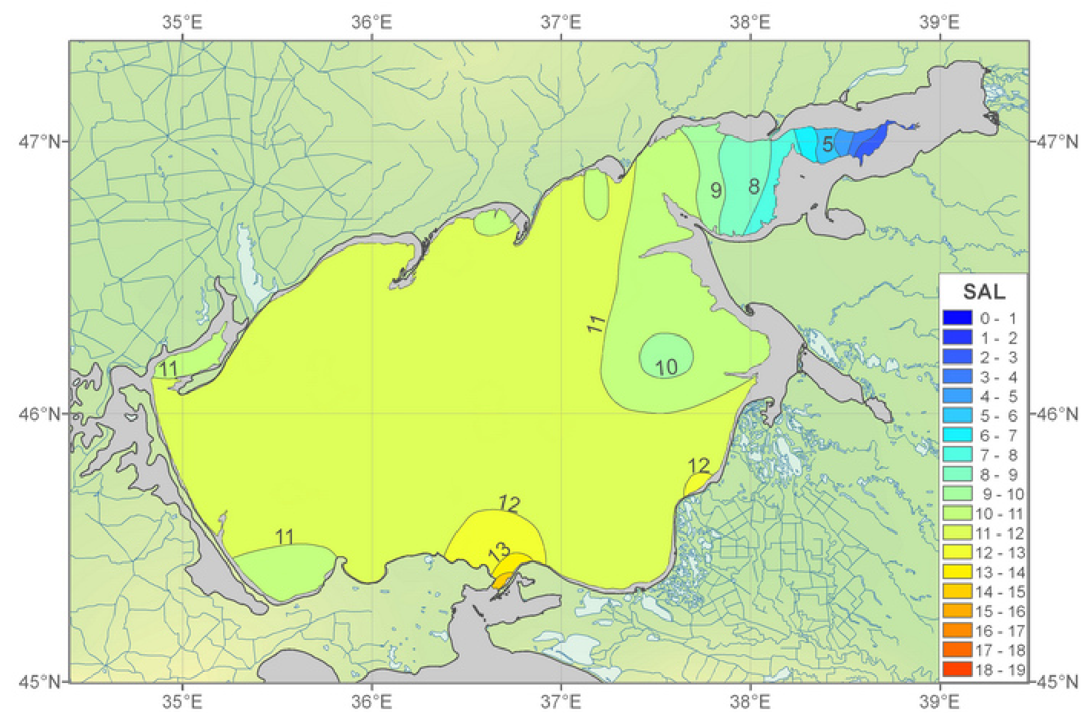
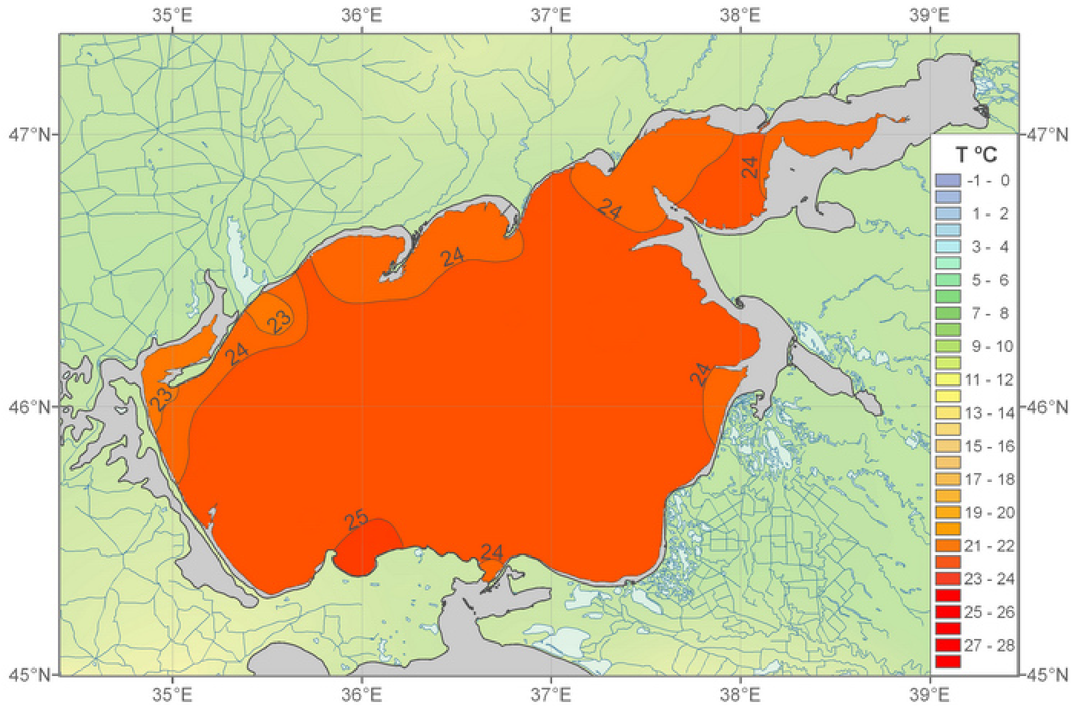




Fig. C19. Temperature ($^{o}$C) and Salinity (below). July. Depth 5 m.



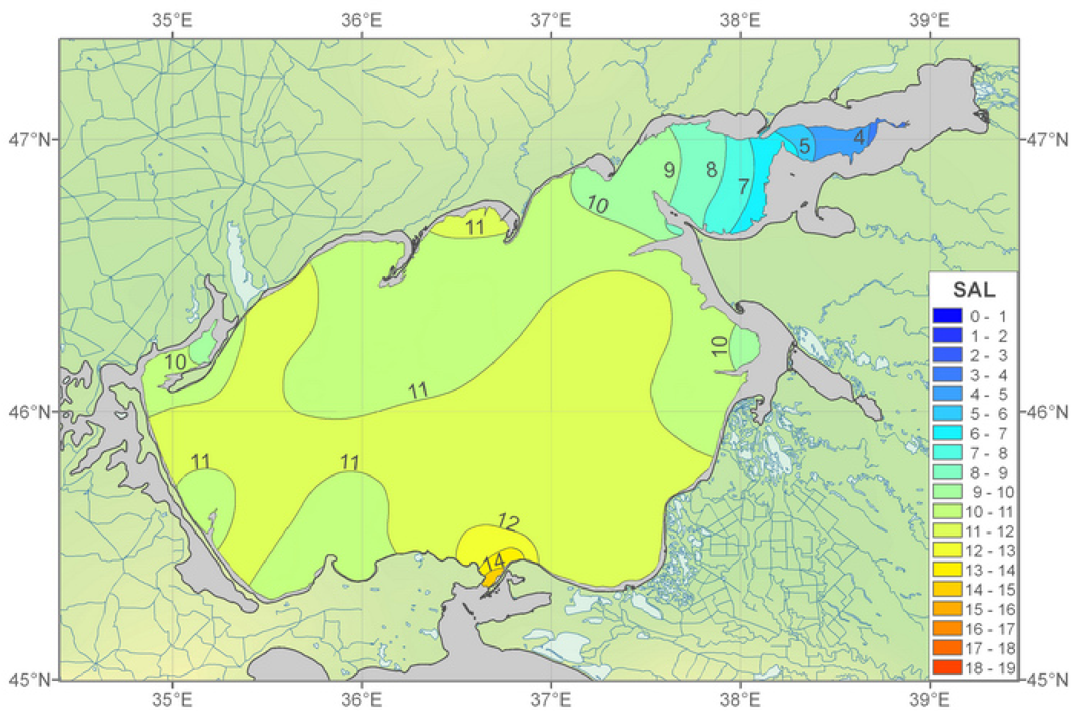
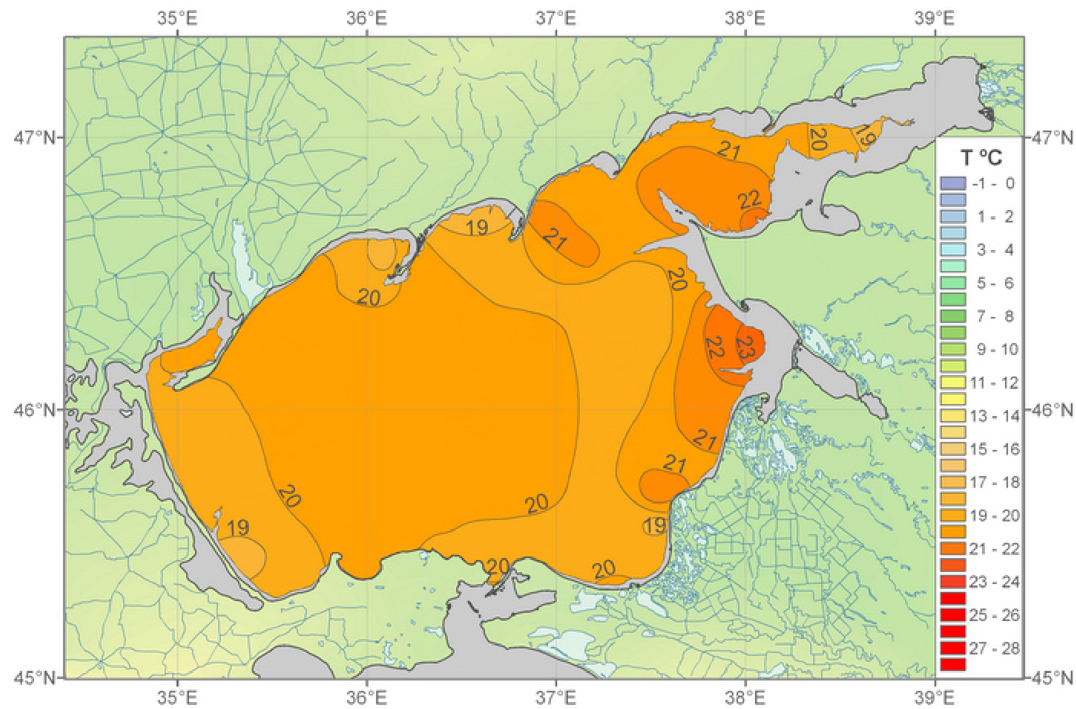




Fig. C20. Temperature ($^{o}$C) and Salinity (below). August. Depth 5 m.



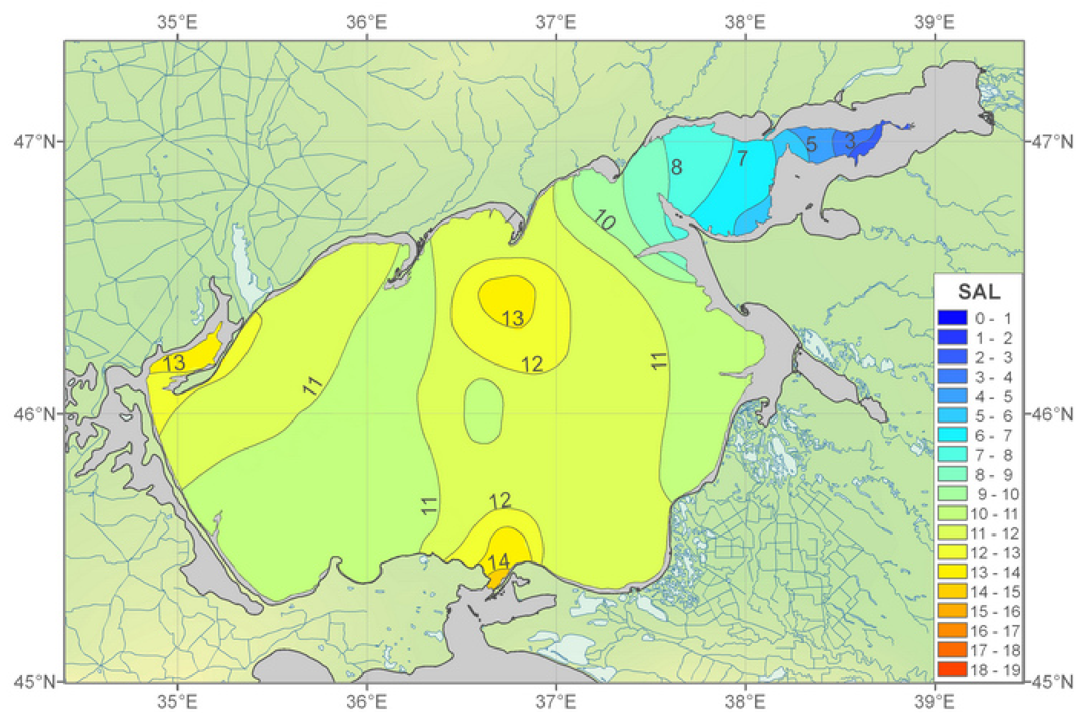




Fig. C21. Temperature ($^{o}$C) and Salinity (below). September. Depth 5 m.

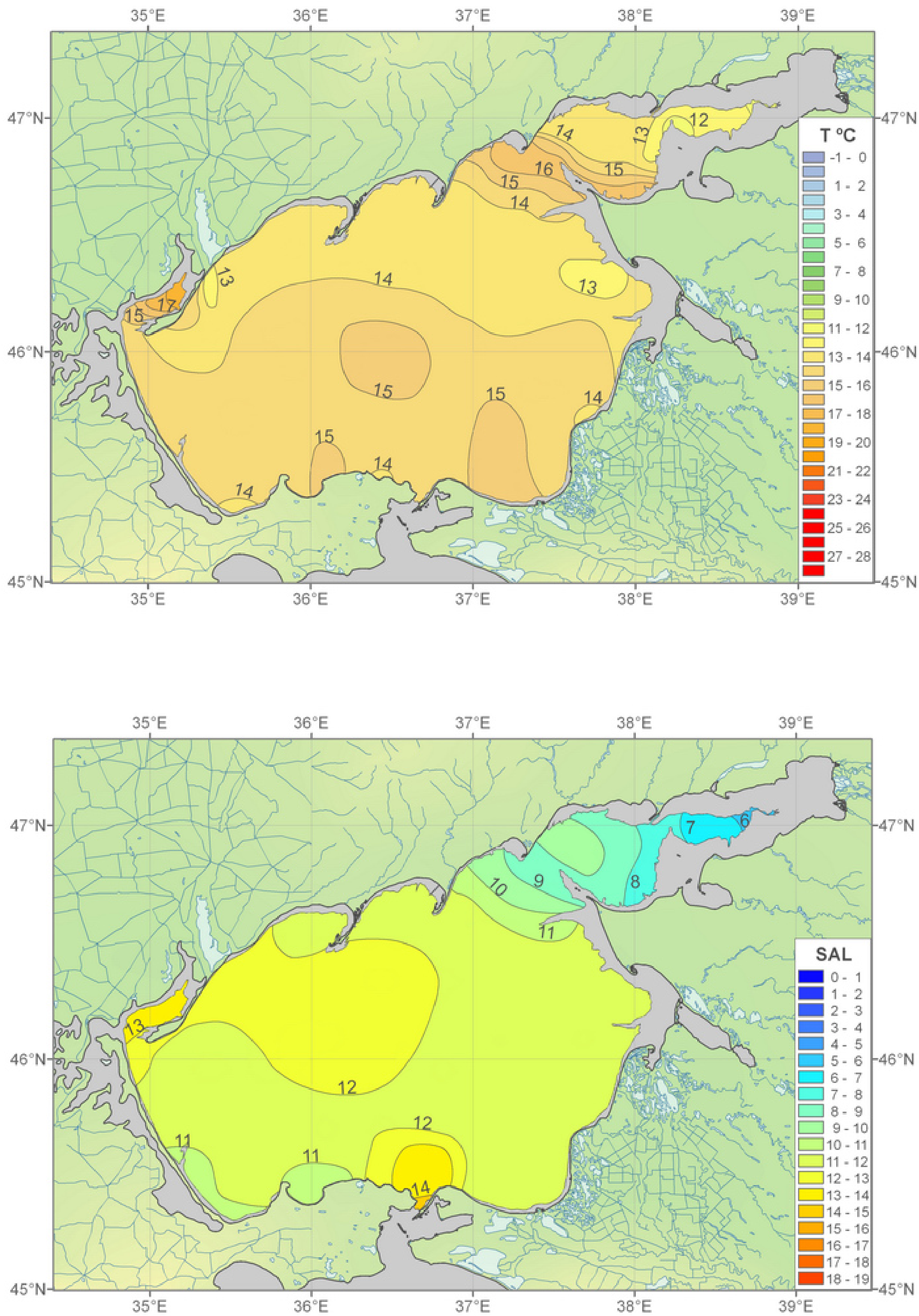



Fig. C22. Temperature ($^{o}$C) and Salinity (below). October. Depth 5 m.

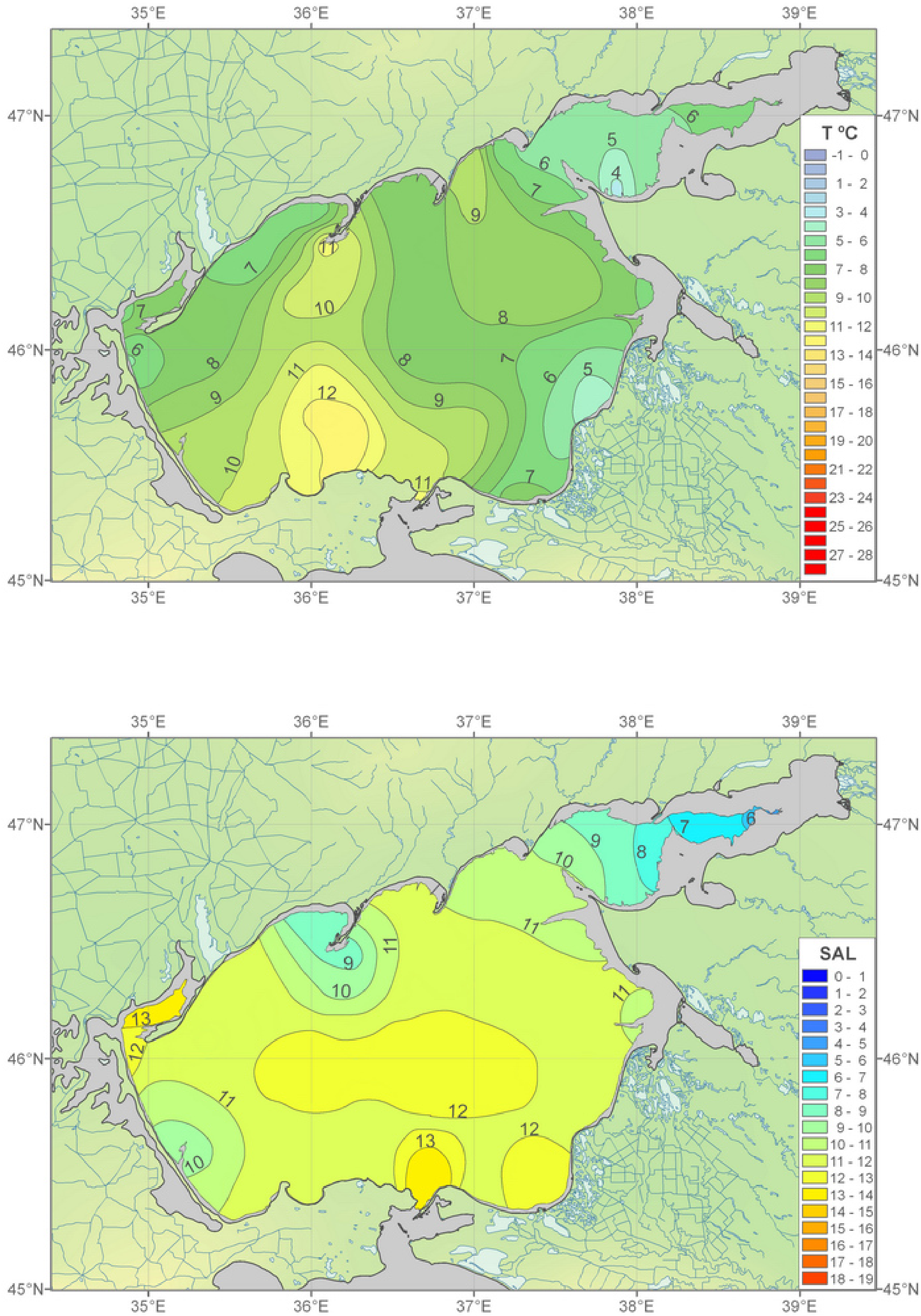



Fig. C23.. Temperature ($^{o}$C) and Salinity (below). November. Depth 5 m.

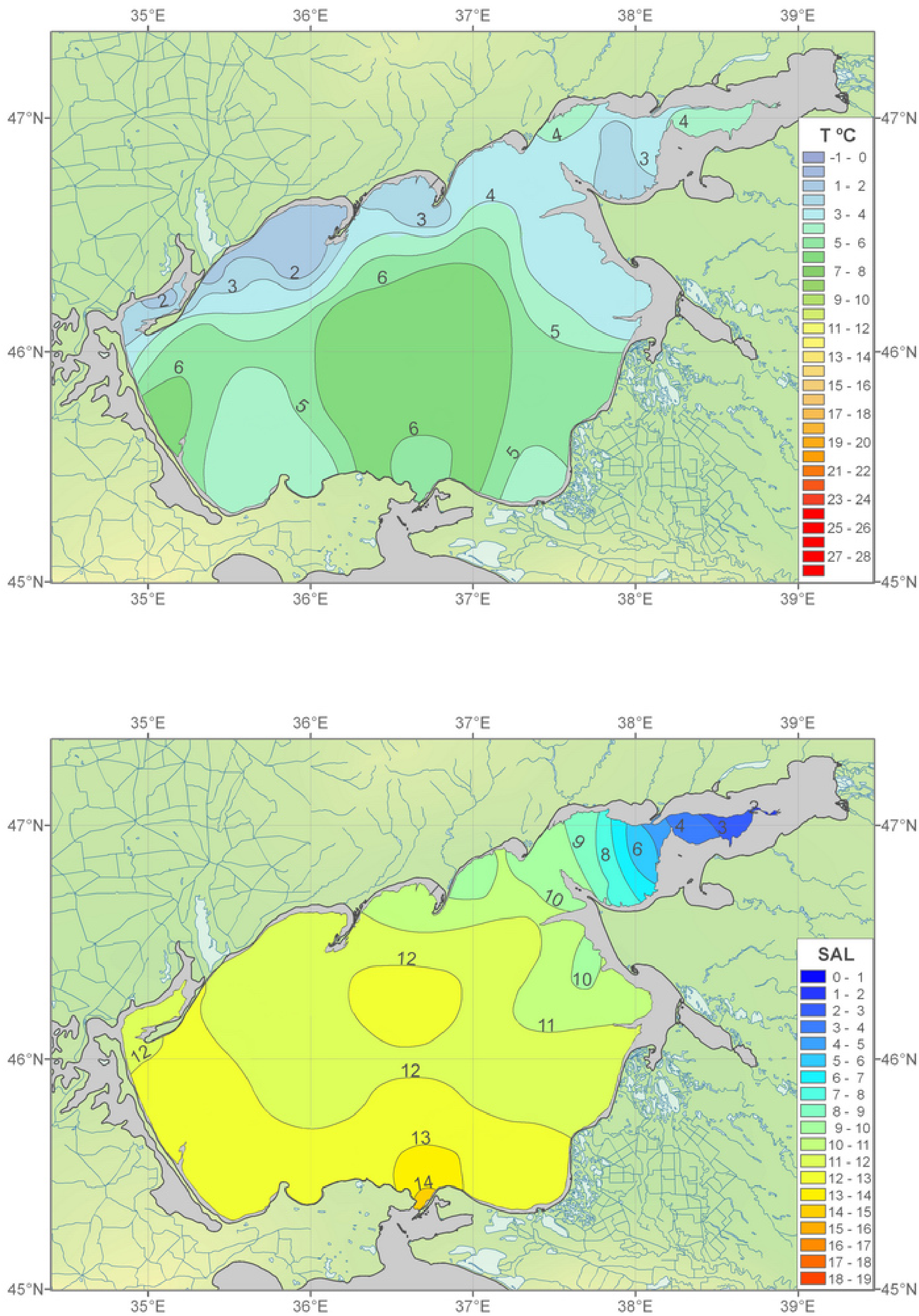
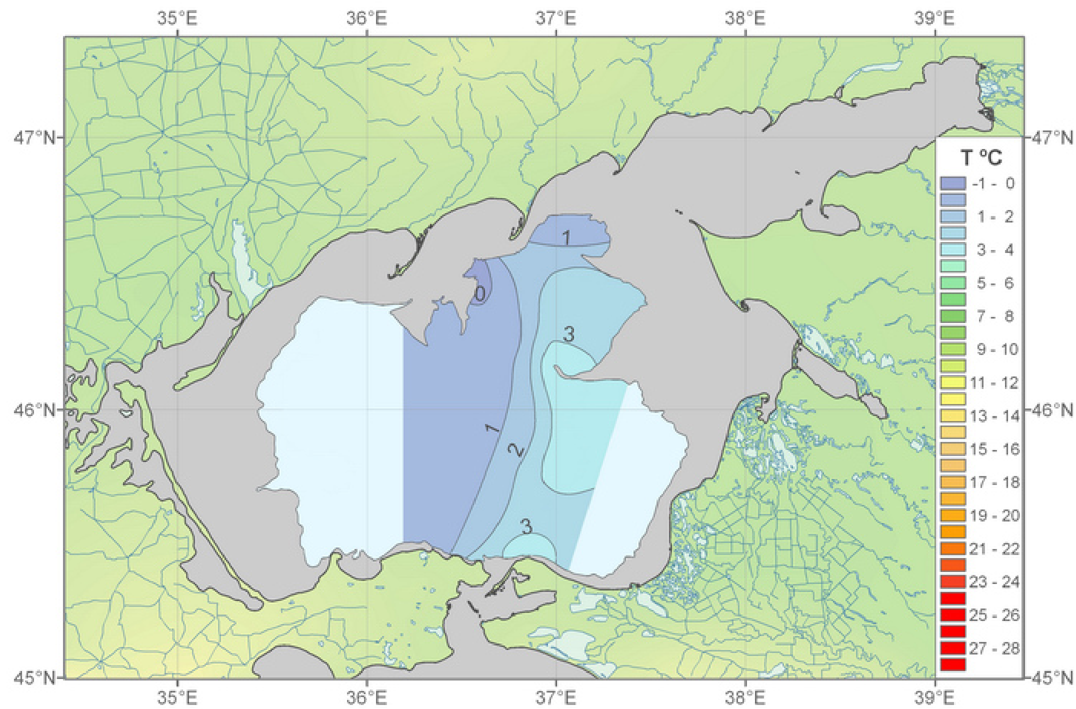



Fig. C24. Temperature ($^oC$) and Salinity (below). December. Depth 5 m.



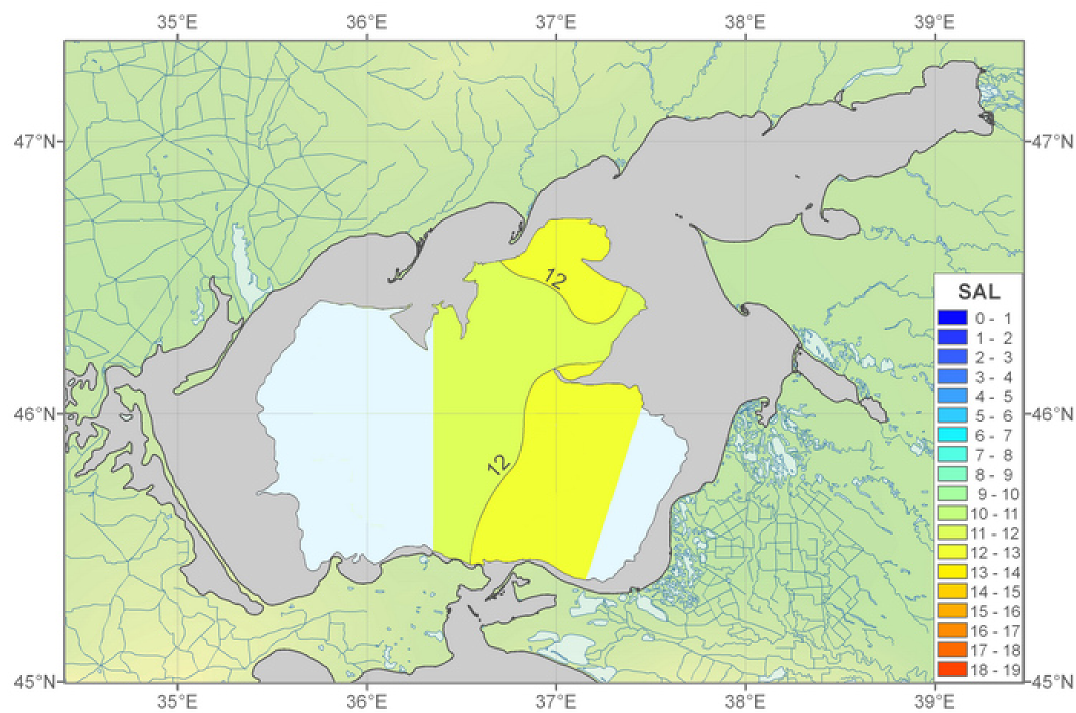
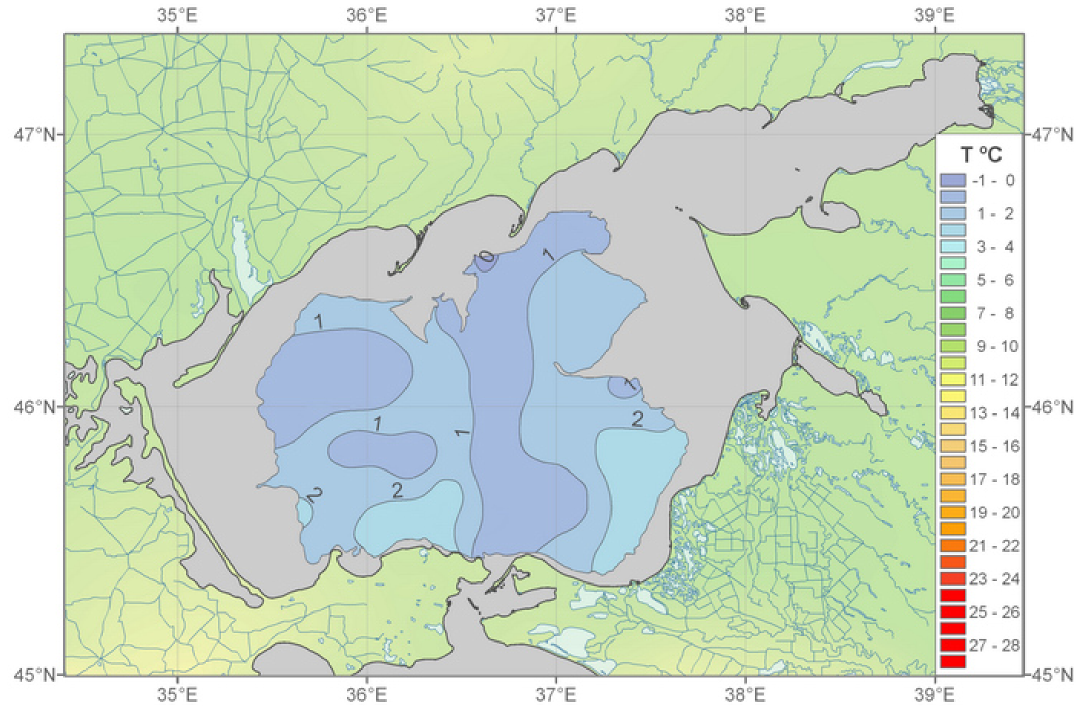




Fig. C25. Temperature ($^{o}$C) and Salinity (below). January. Depth 10 m.



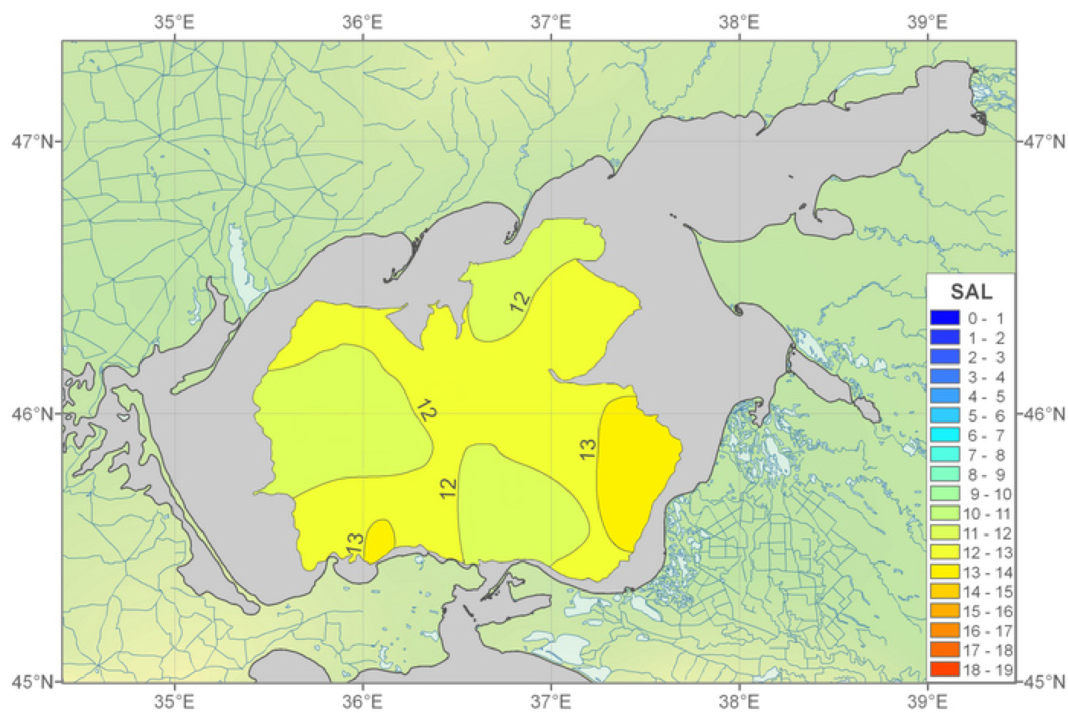




Fig. C26. Temperature ($^oC$) and Salinity (below). February. Depth 10 m.

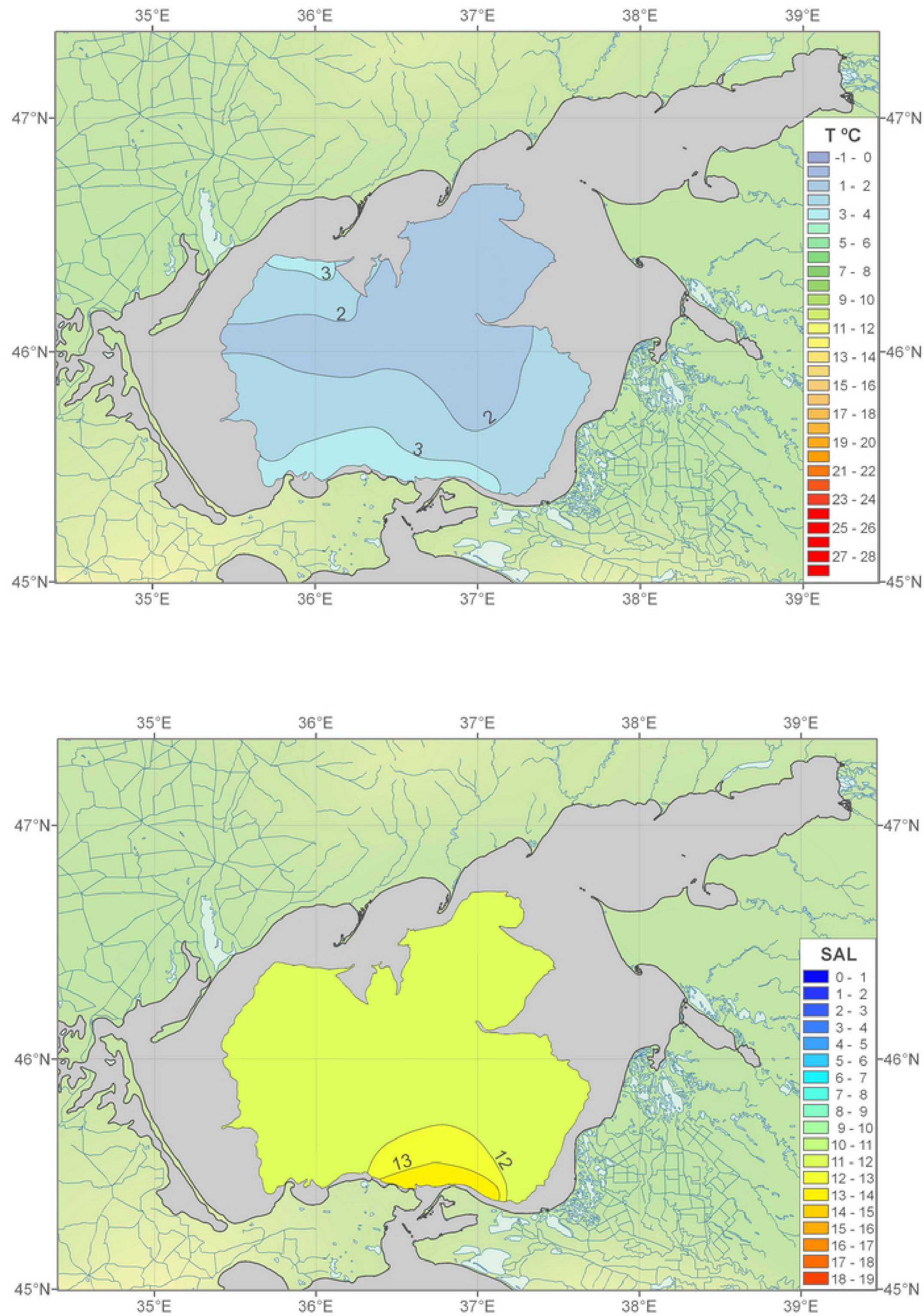



Fig. C27. Temperature ($^{o}$C) and Salinity (below). March. Depth 10 m.

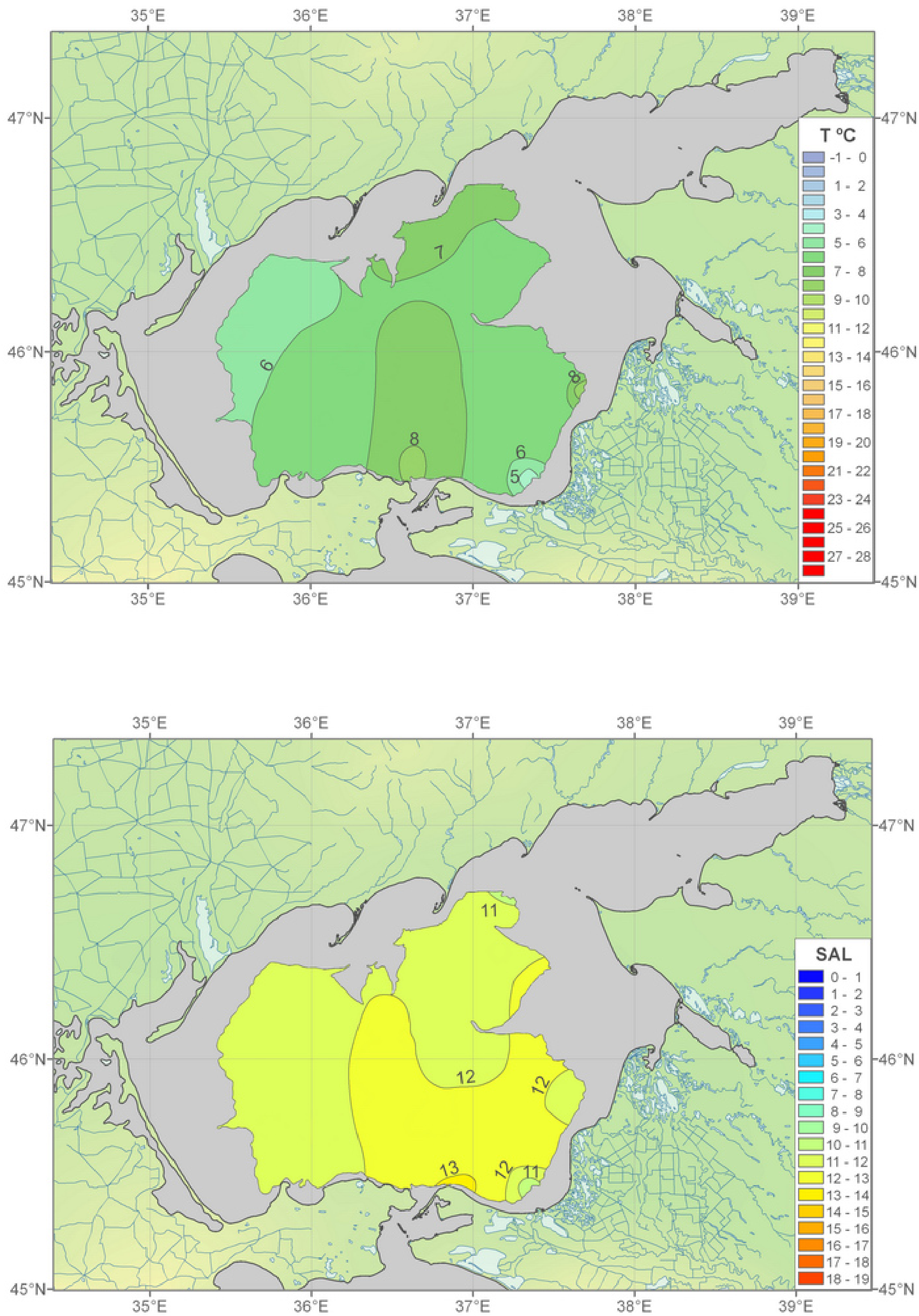



Fig. C28. Temperature ($^oC$) and Salinity (below). April. Depth 10 m.

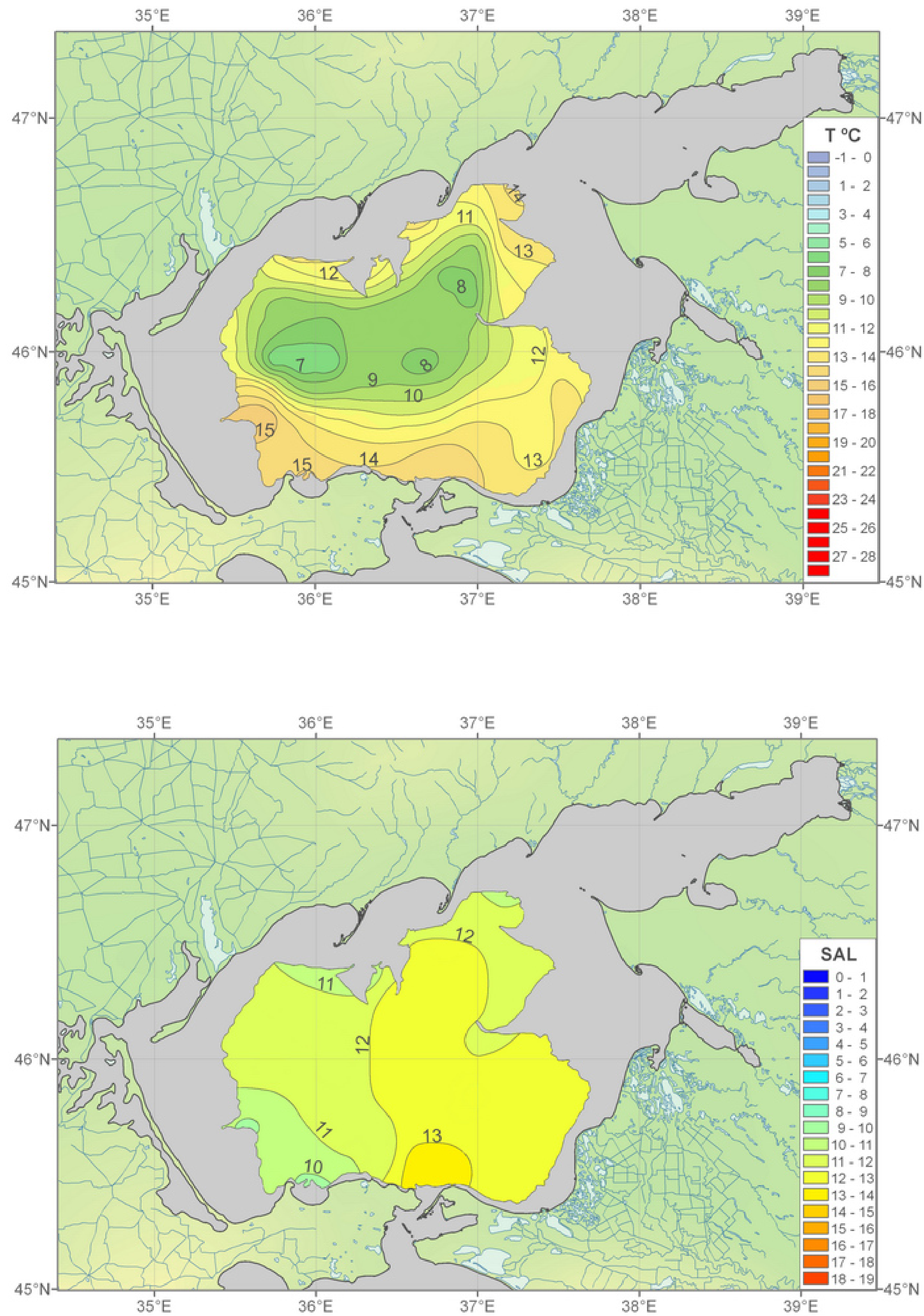
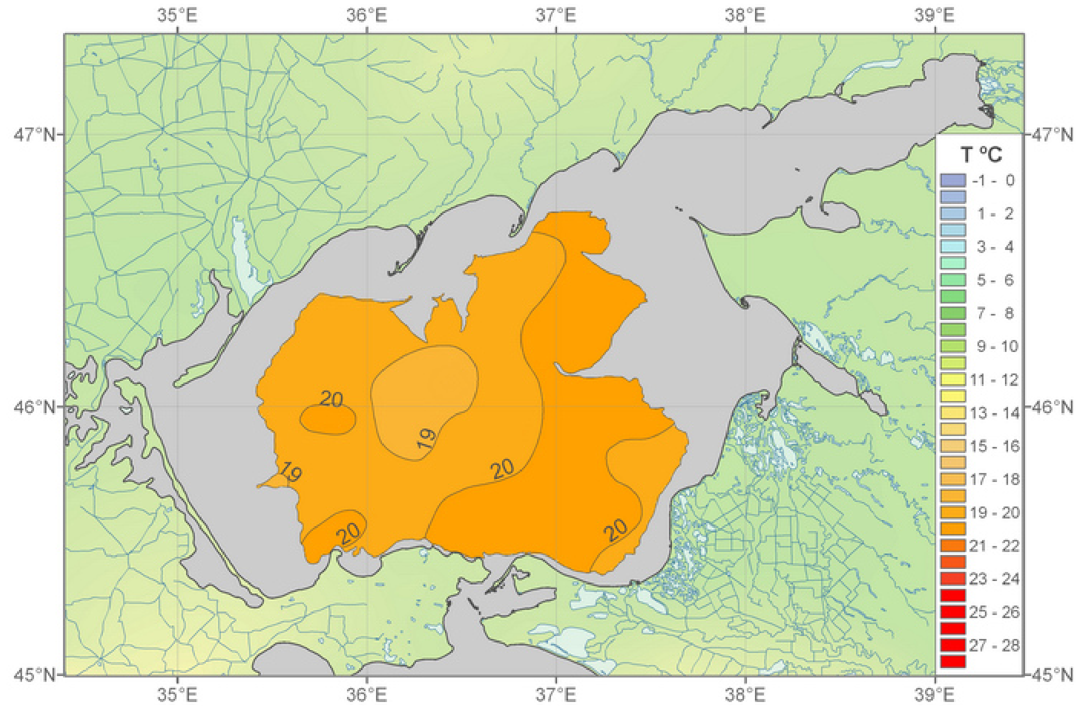



Fig. C29. Temperature ($^{o}$C) and Salinity (below). May. Depth 10 m.



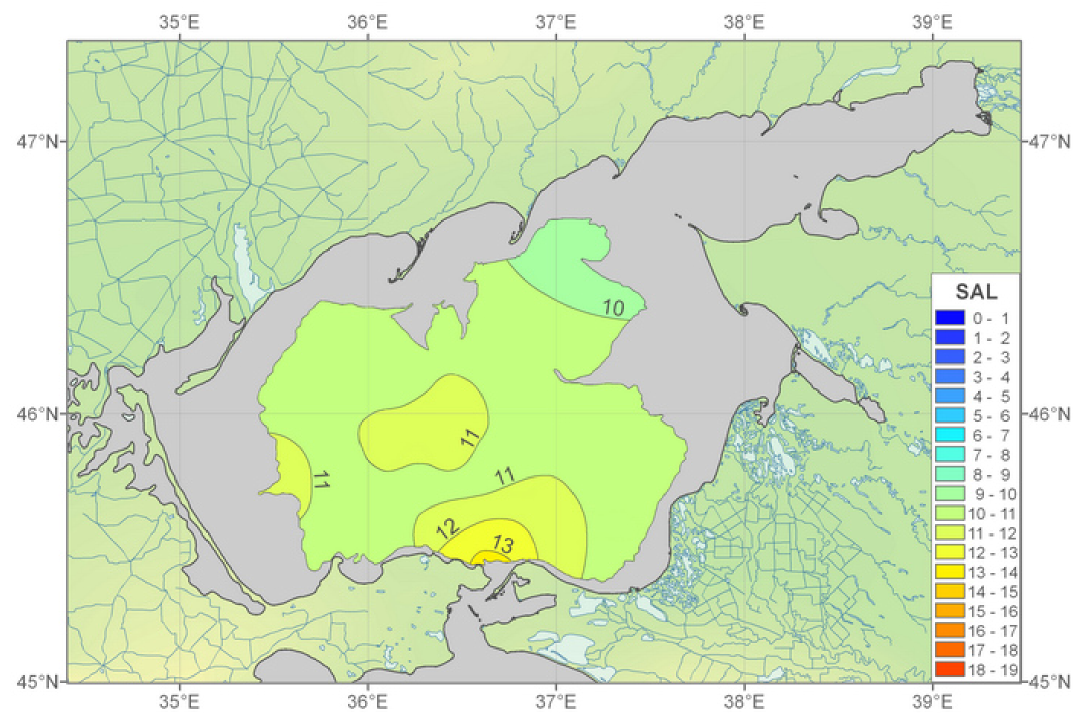
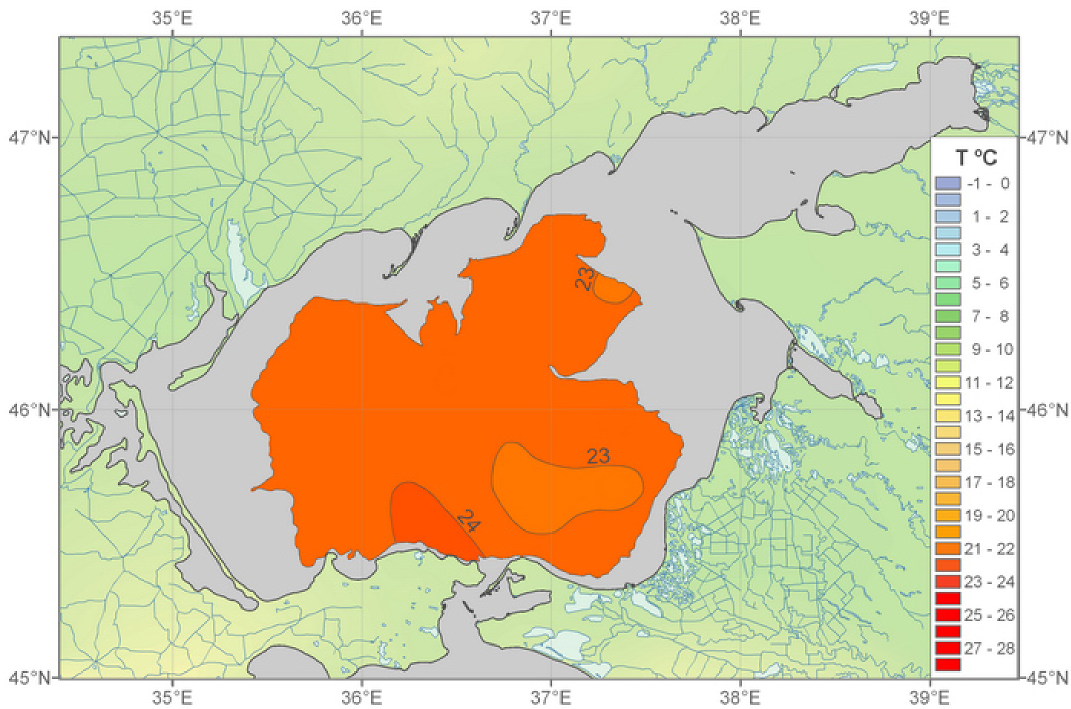




Fig. C30. Temperature ($^{o}$C) and Salinity (below). June. Depth 10 m.



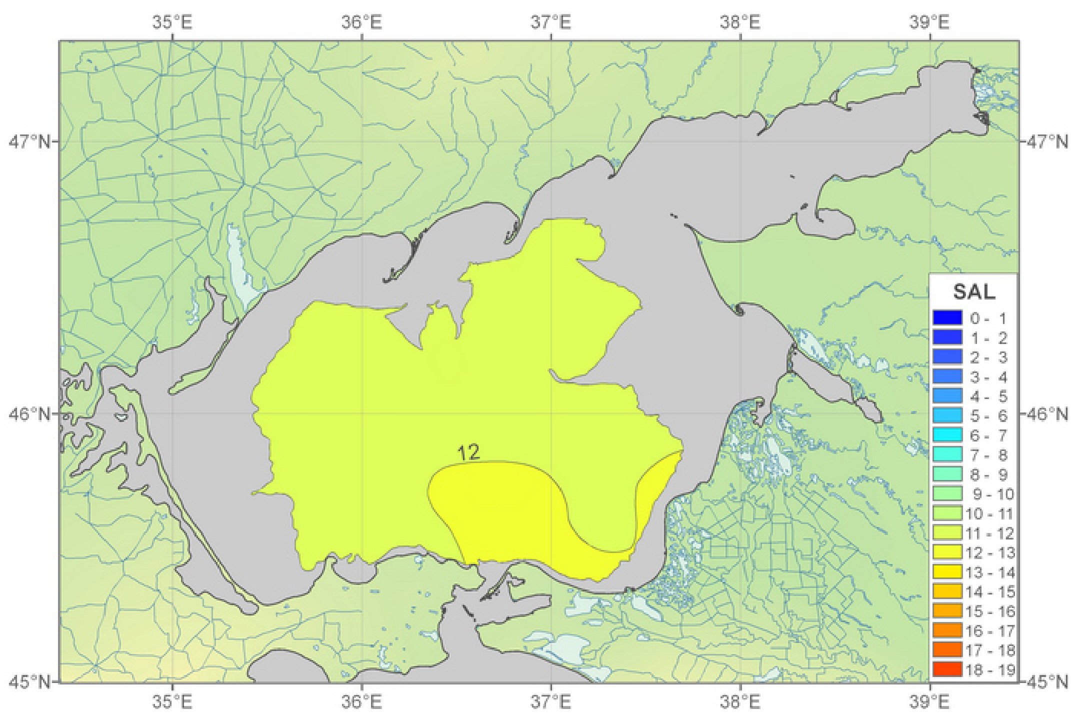
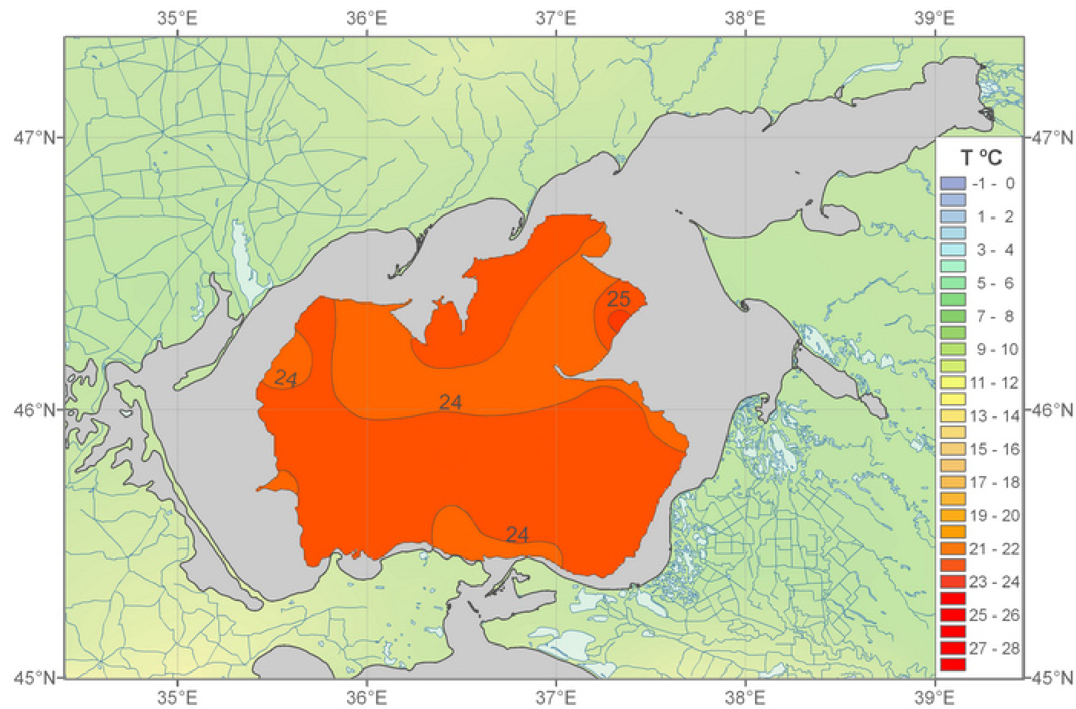




Fig. C31. Temperature ($^{o}$C) and Salinity (below). July. Depth 10 m.



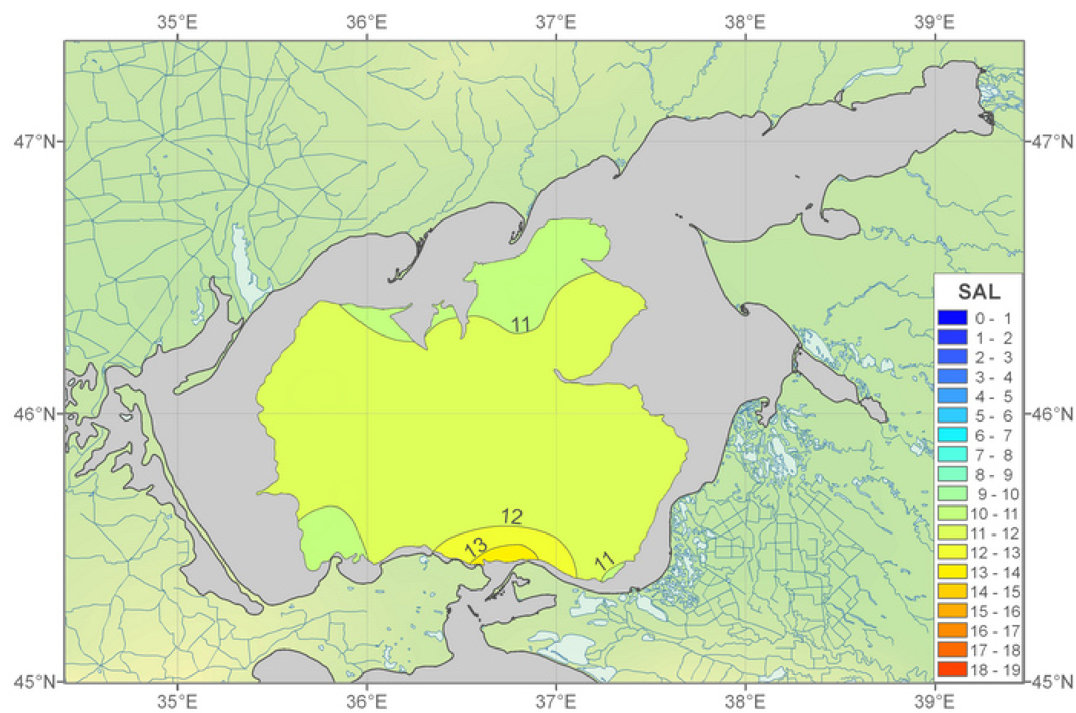
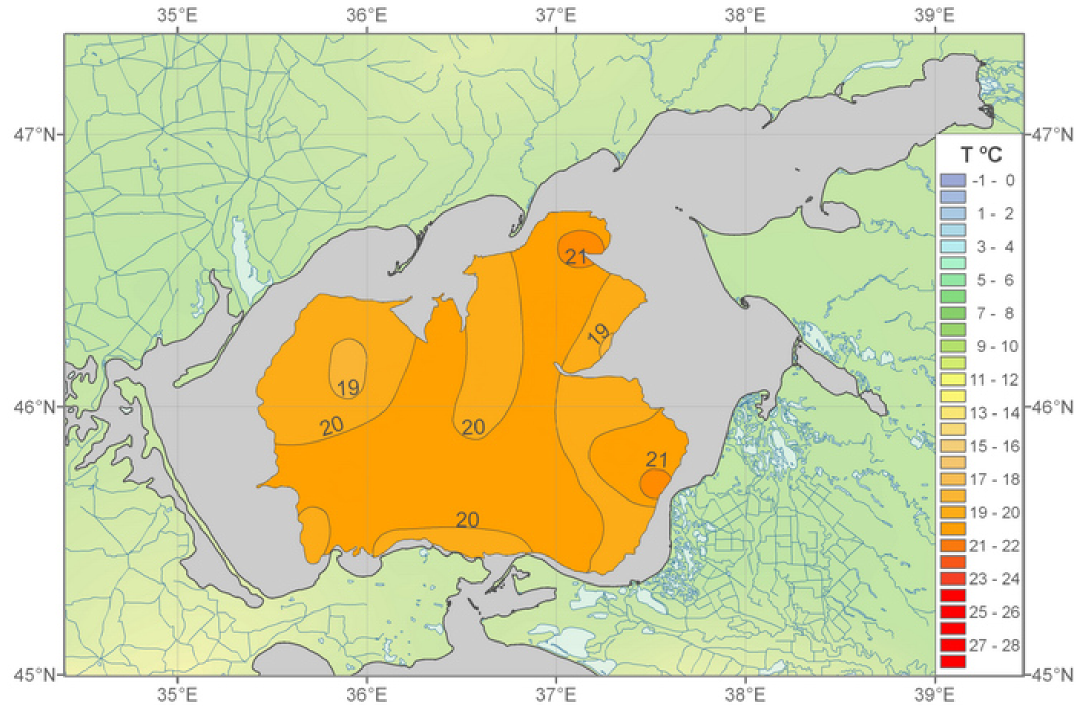




Fig. C32. Temperature ($^{o}$C) and Salinity (below). August. Depth 10 m.



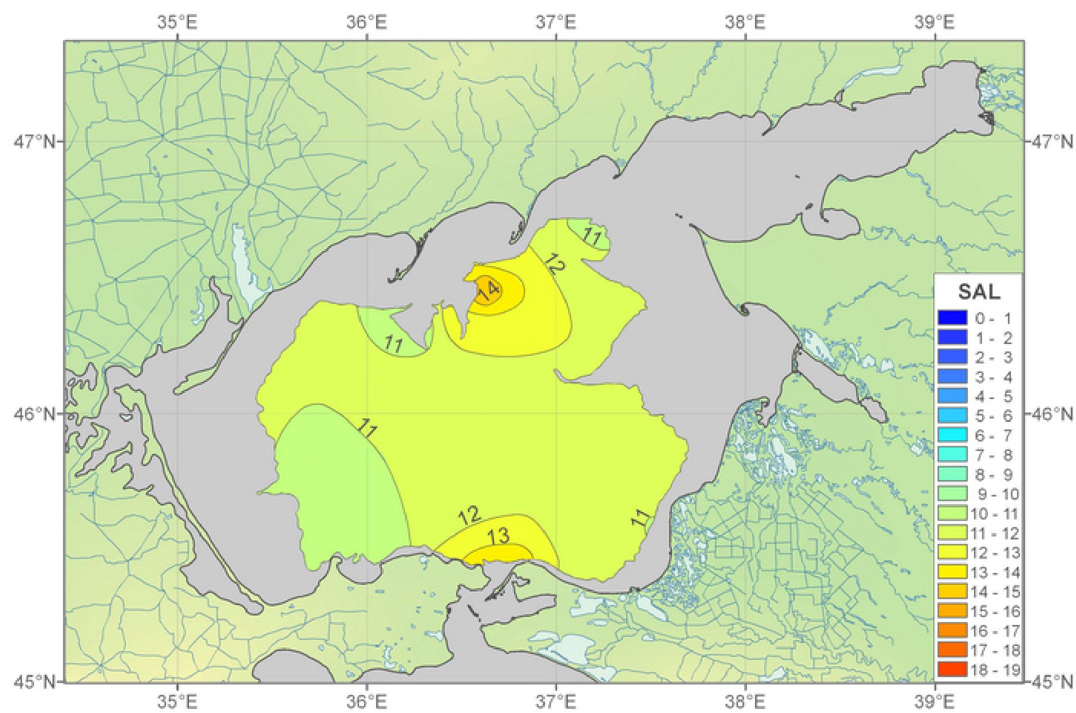
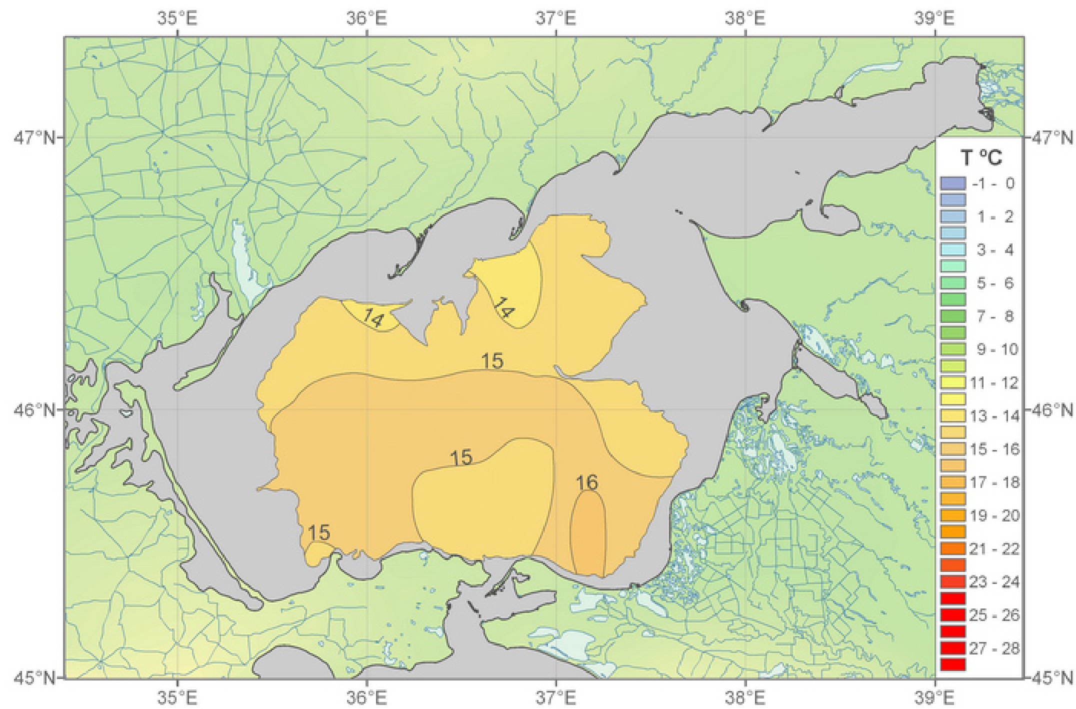




Fig. C33. Temperature ($^{o}$C) and Salinity (below). September. Depth 10 m.



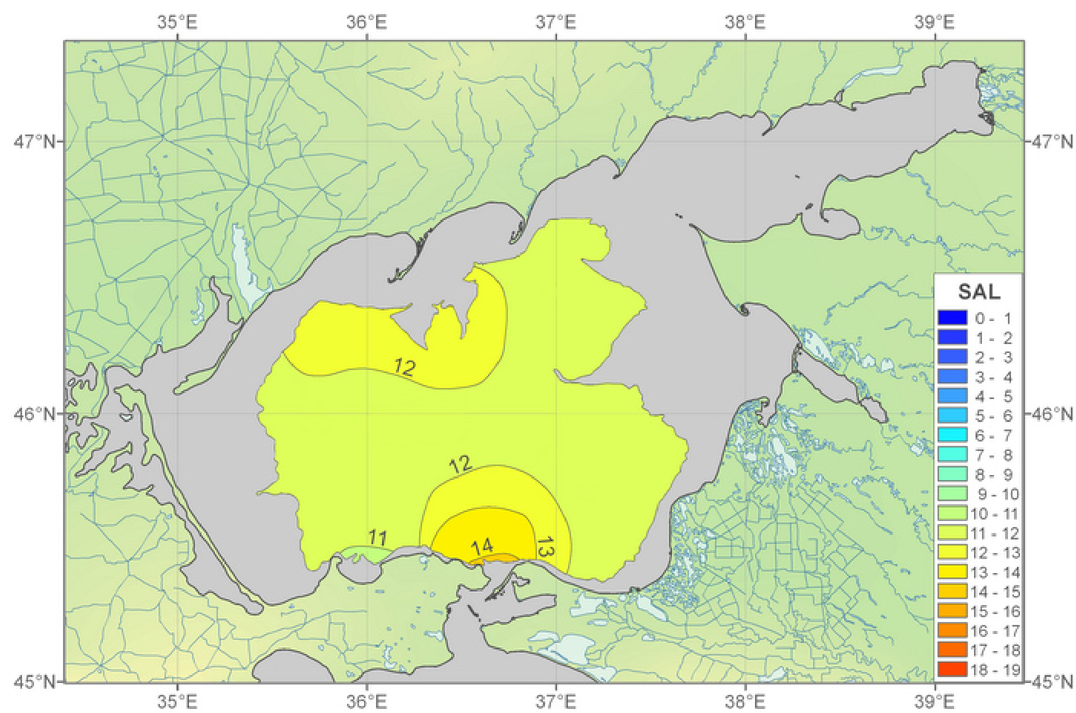
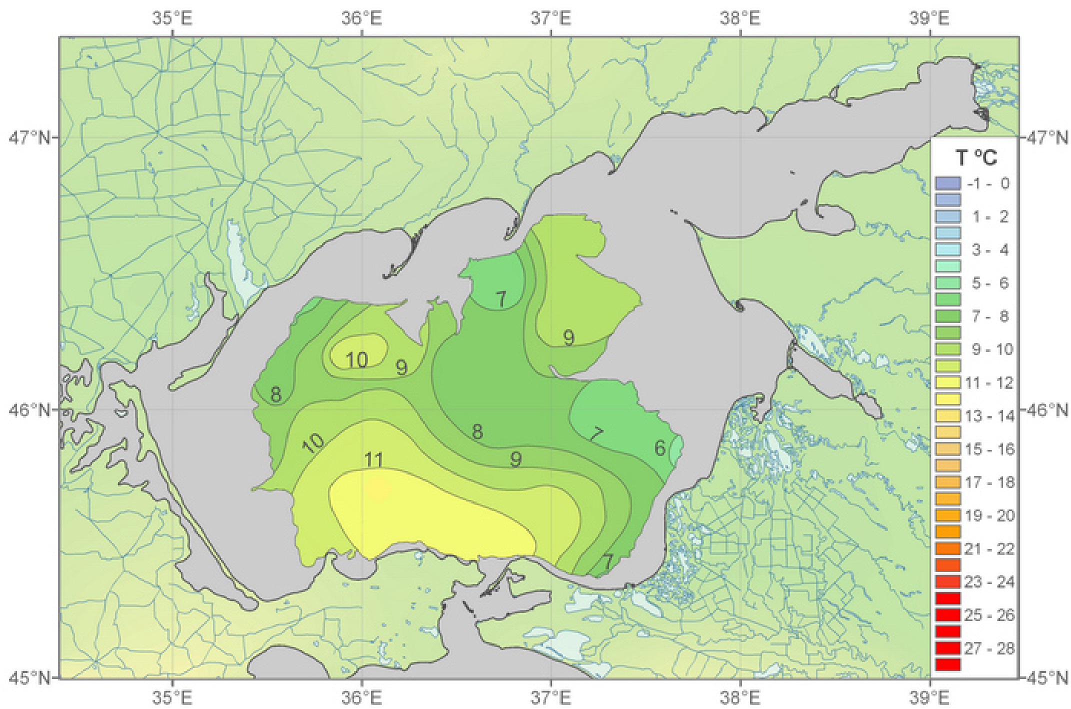




Fig. C34. Temperature ($^{o}$C) and Salinity (below). October. Depth 10 m.



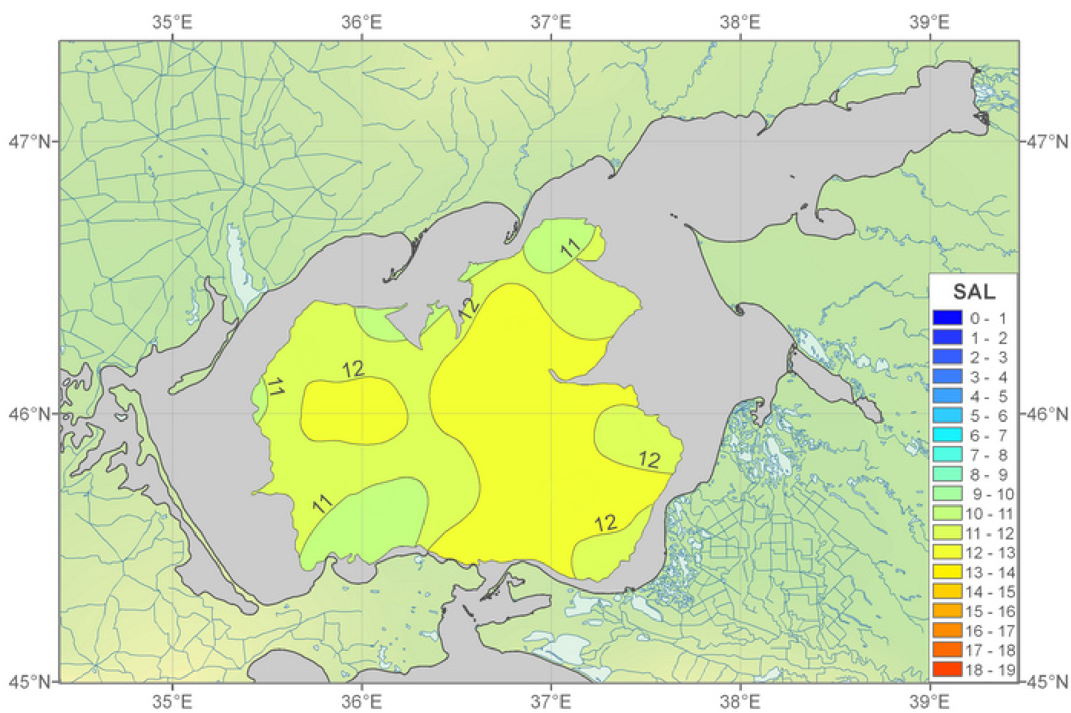




Fig. C35. Temperature ($^{o}$C) and Salinity (below). November. Depth 10 m.

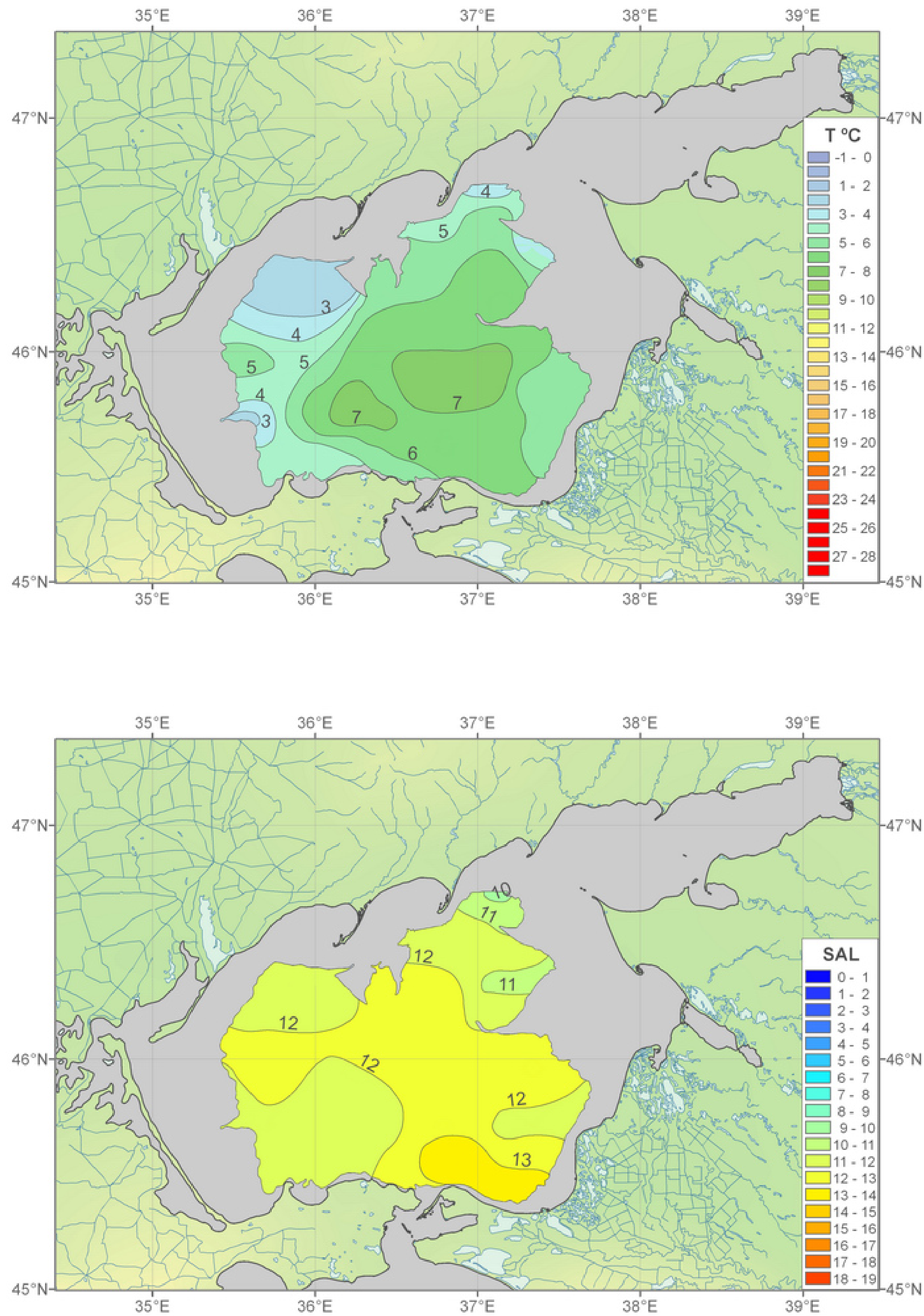



Fig. C36. Temperature (°C) and Salinity (below). December. Depth 10 m.

# Appendix D. Monthly climatic section of temperature and salinity

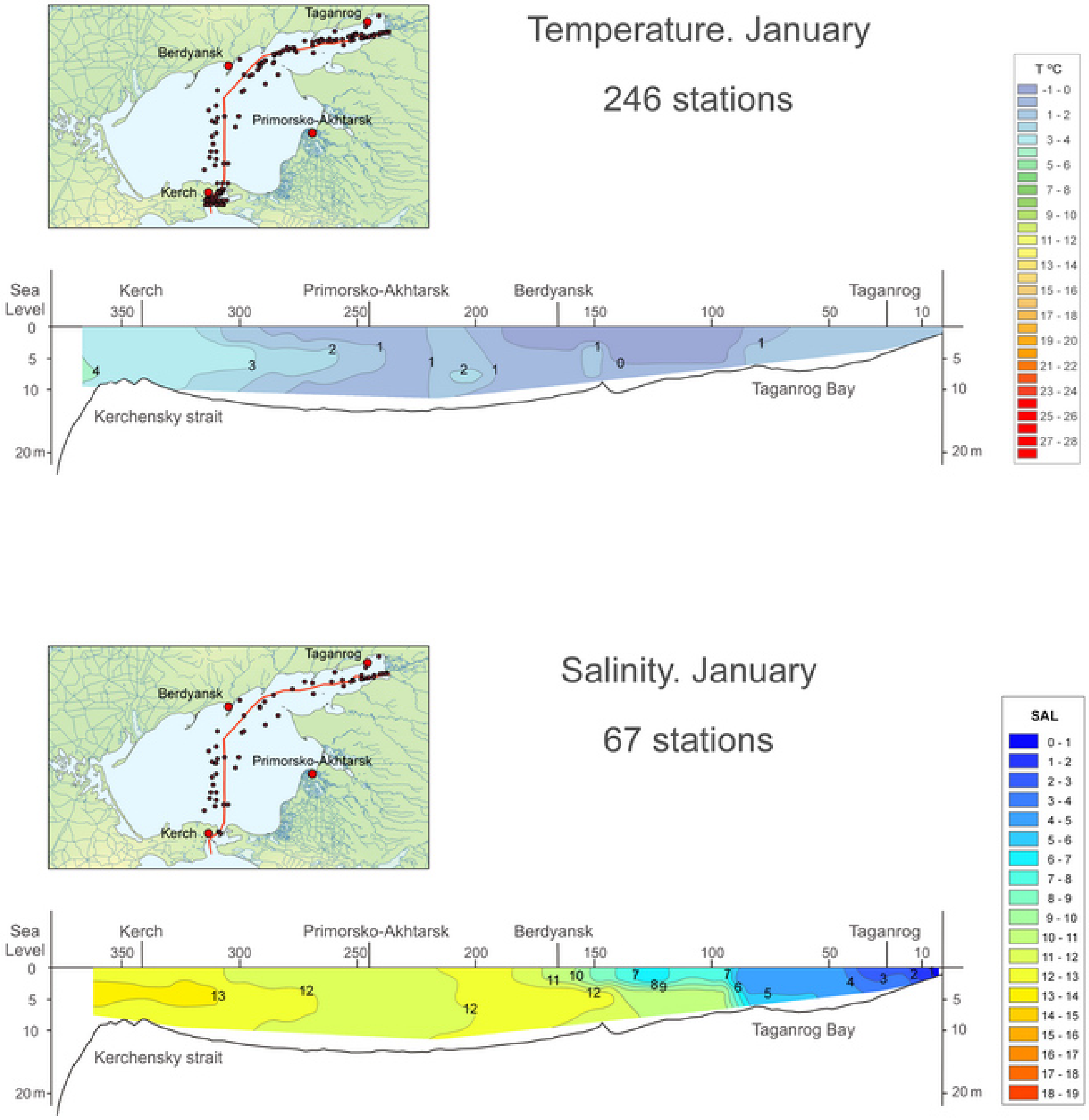



Fig. D1. Temperature and salinity. Vertical sections. January

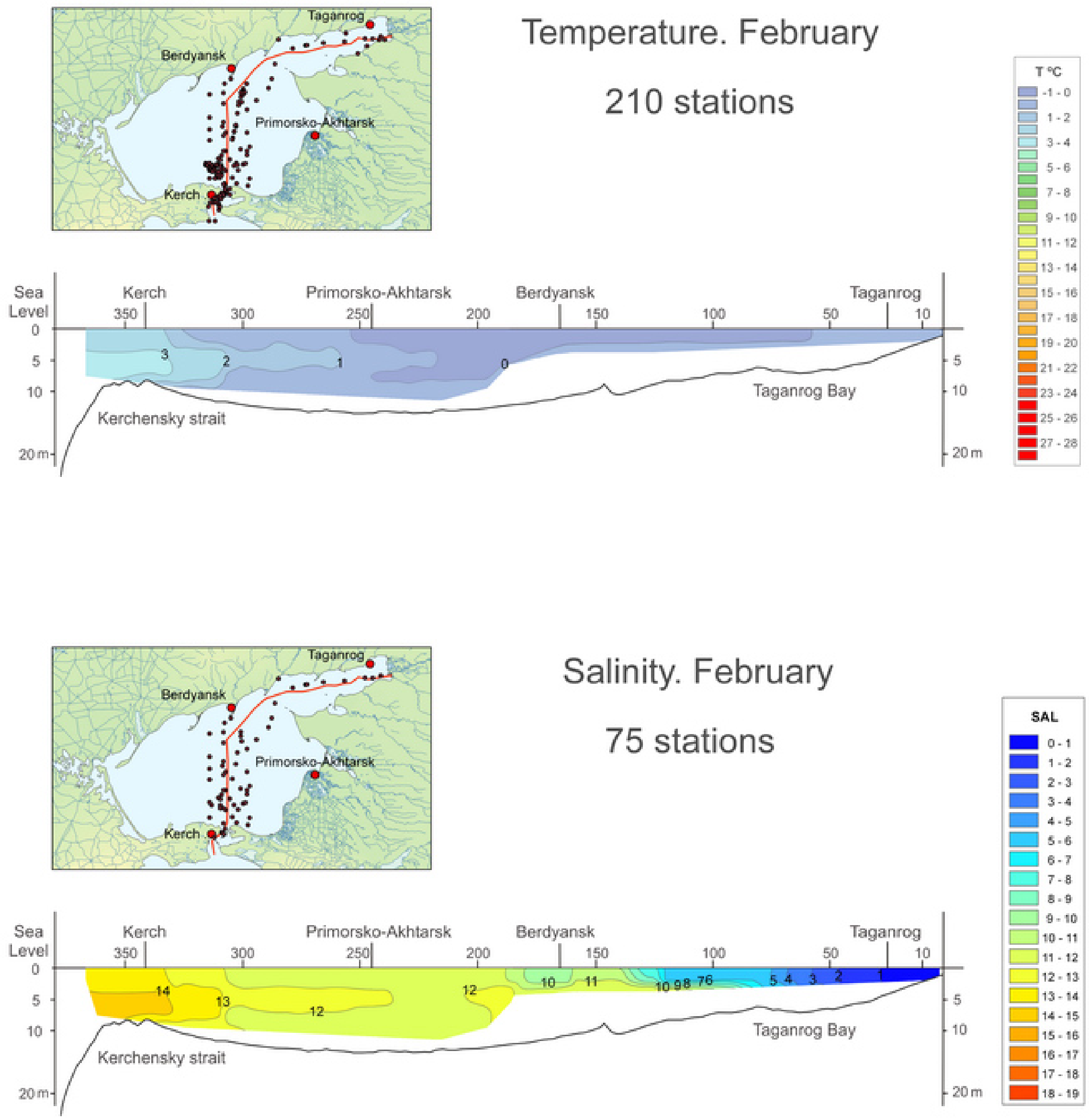



Fig. D2. Temperature and salinity. Vertical sections. February

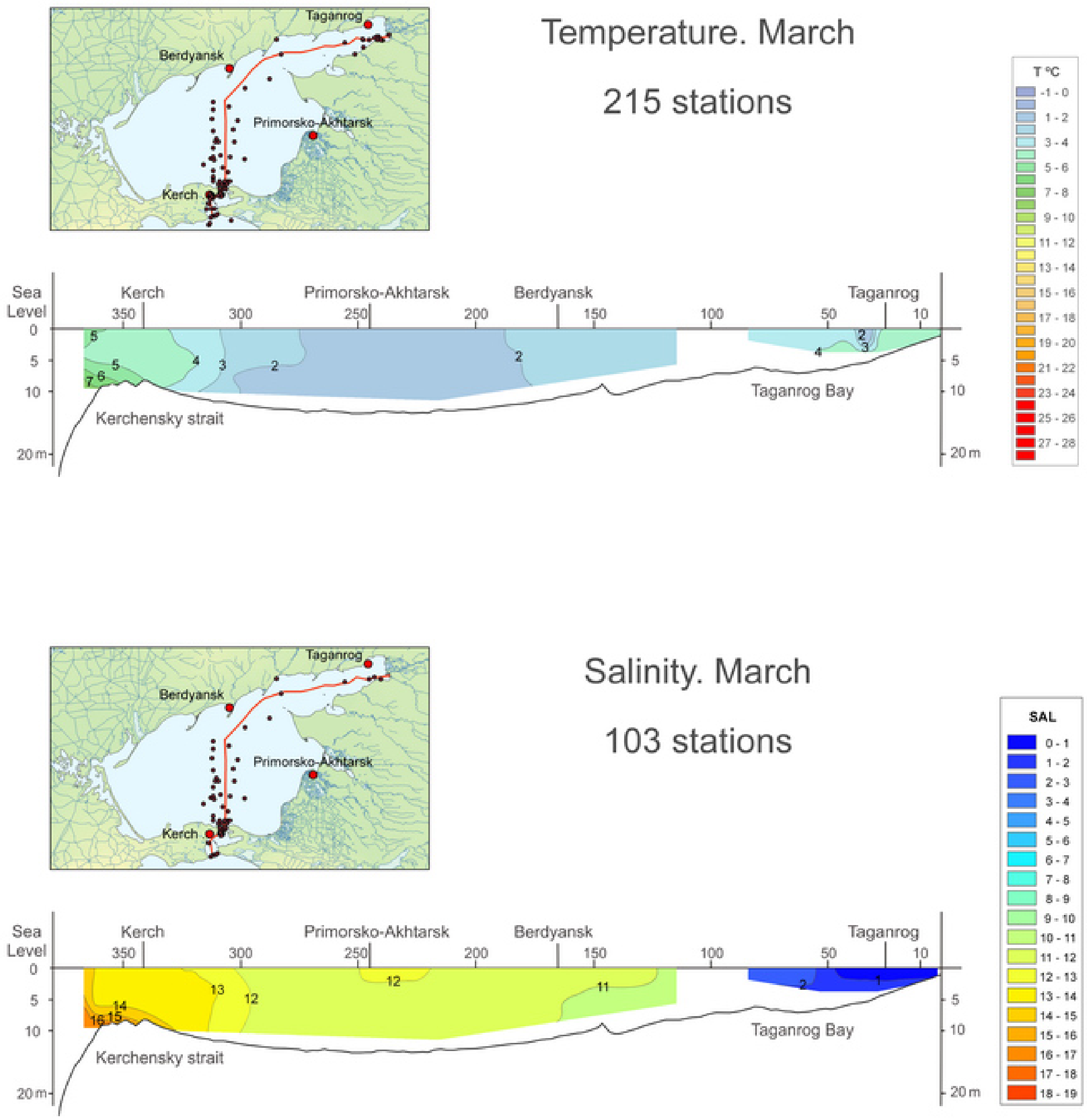



Fig. D3. Temperature and salinity. Vertical sections. March

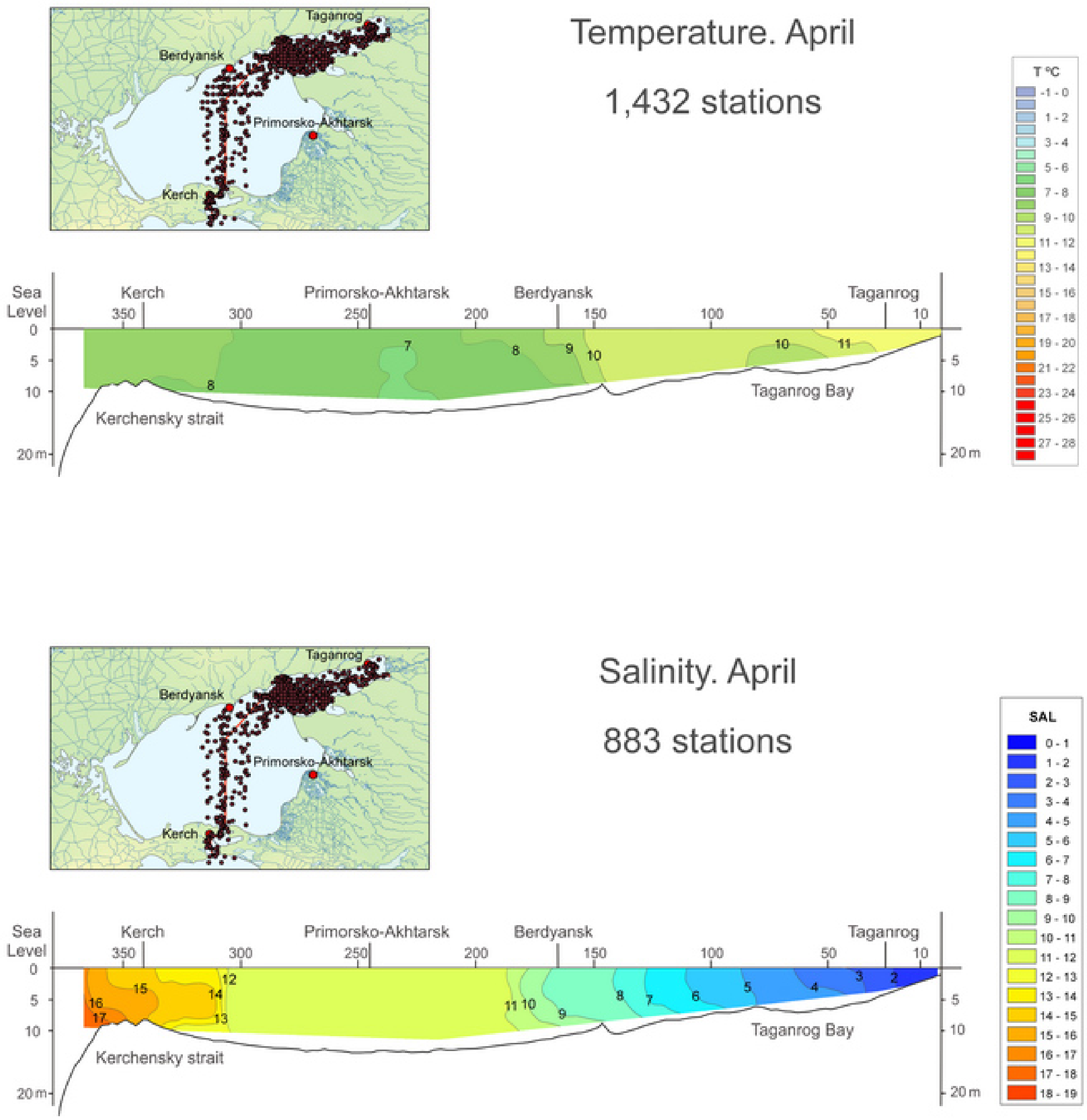



Fig. D4. Temperature and salinity. Vertical sections. April

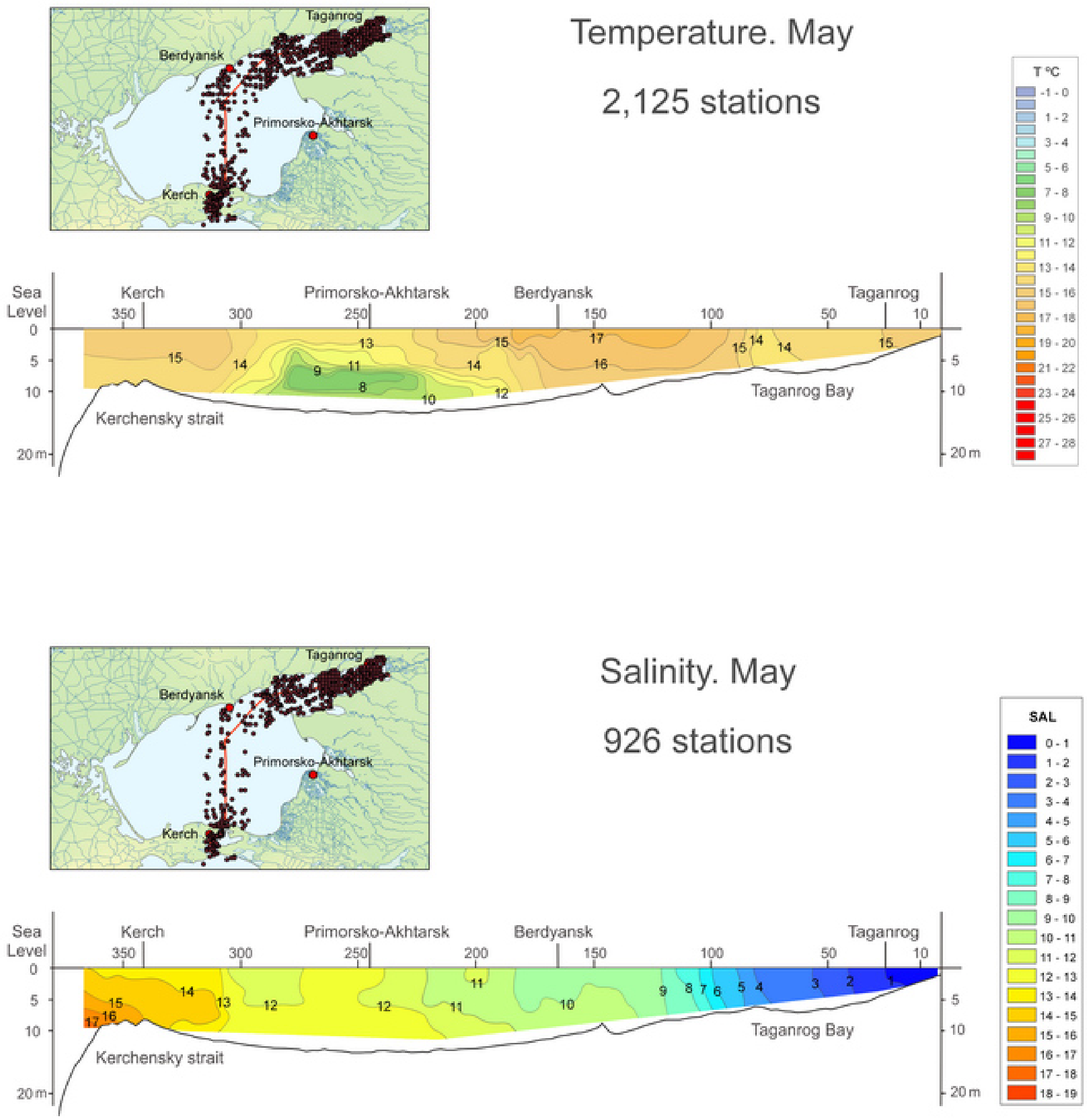



Fig. D5. Temperature and salinity. Vertical sections. May

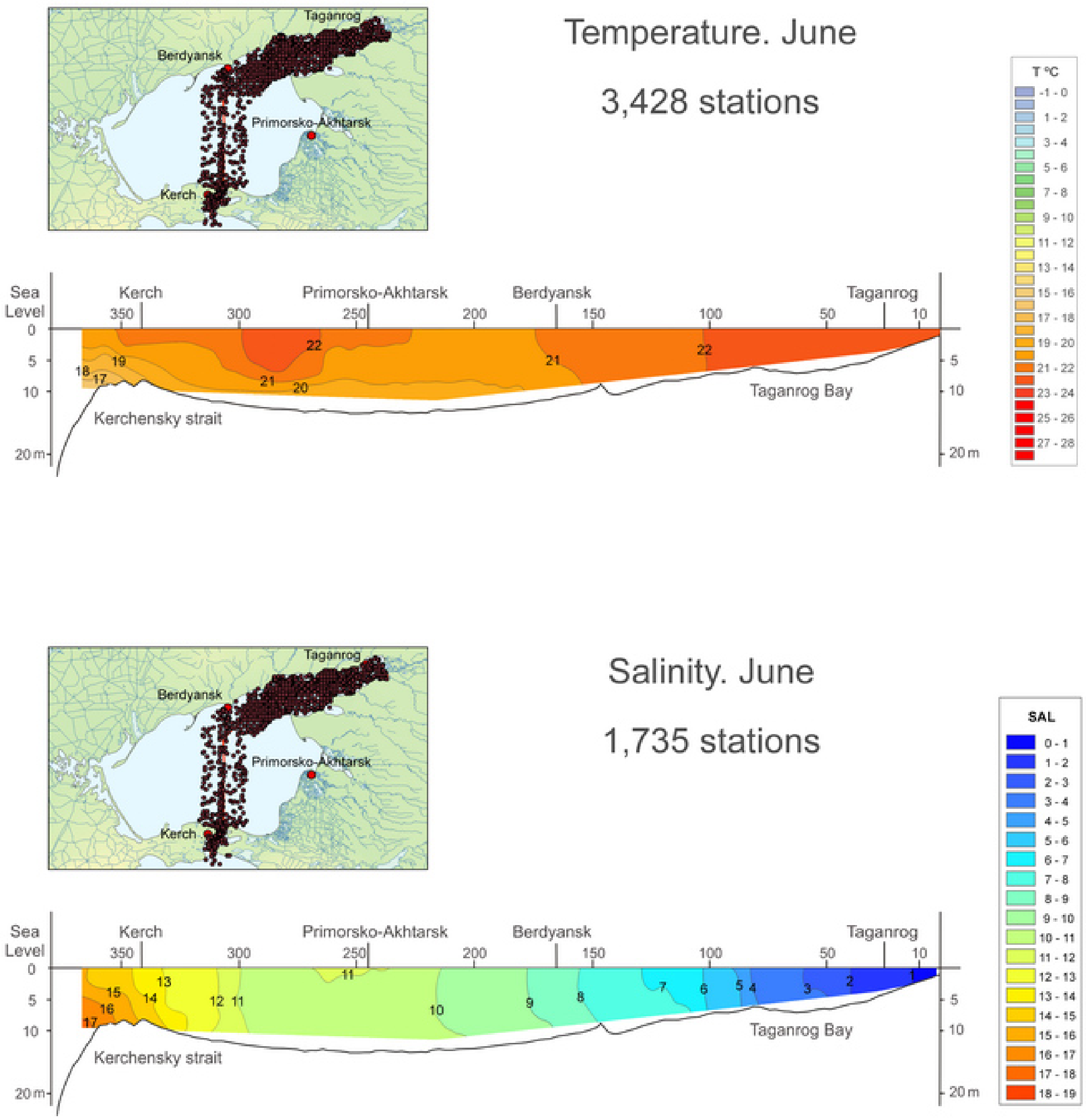



Fig. D6. Temperature and salinity. Vertical sections. June

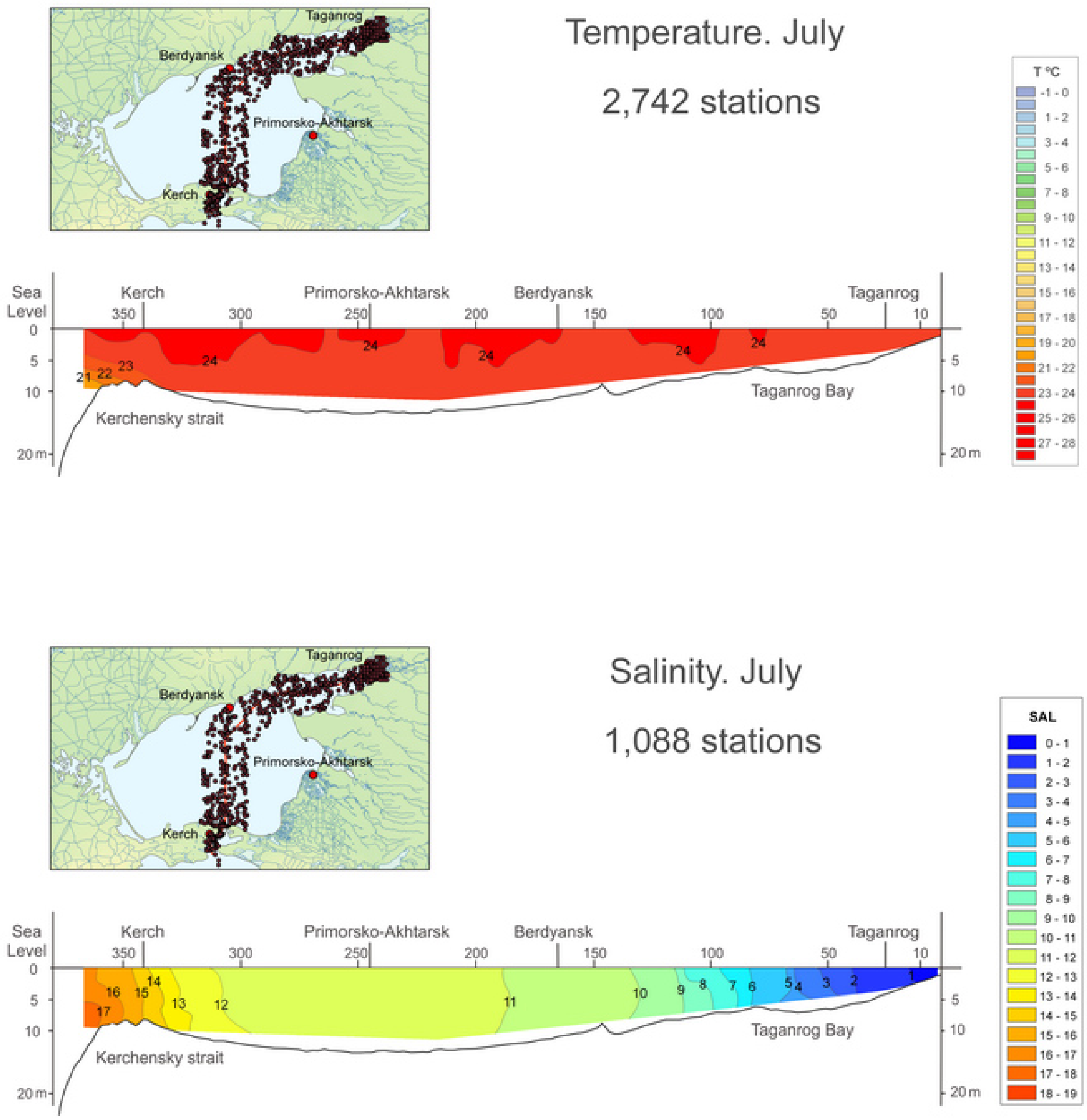
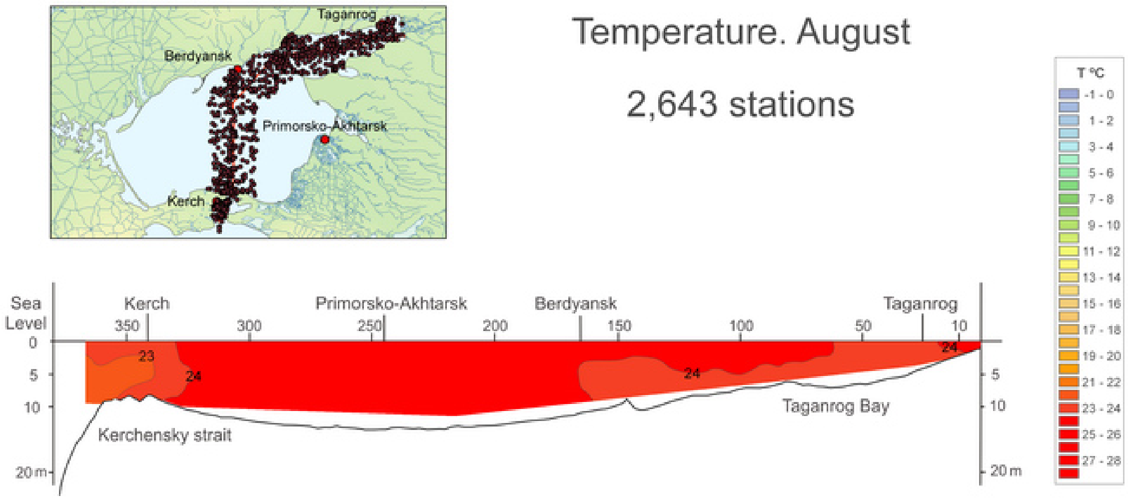



Fig. D7. Temperature and salinity. Vertical sections. July



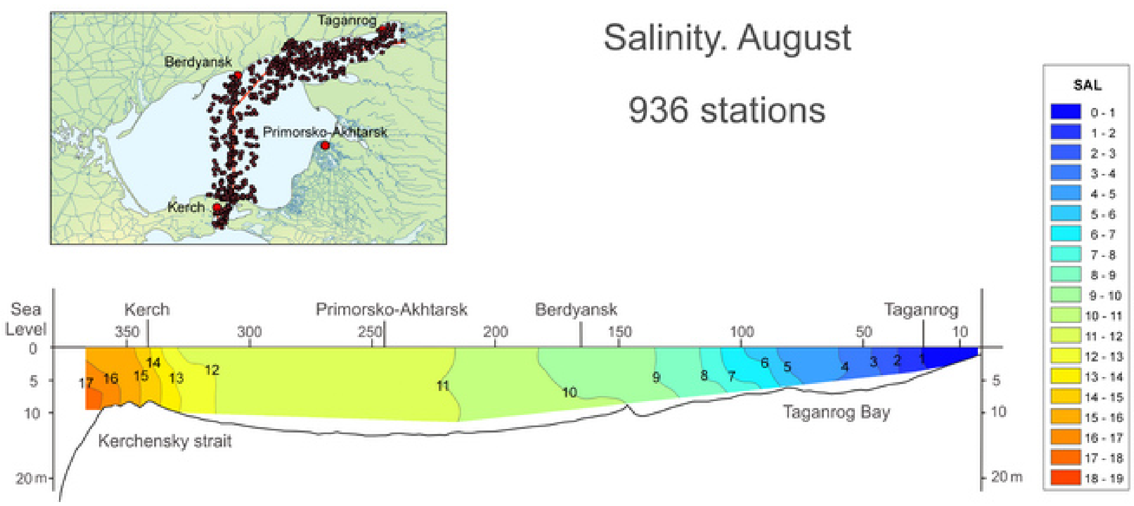
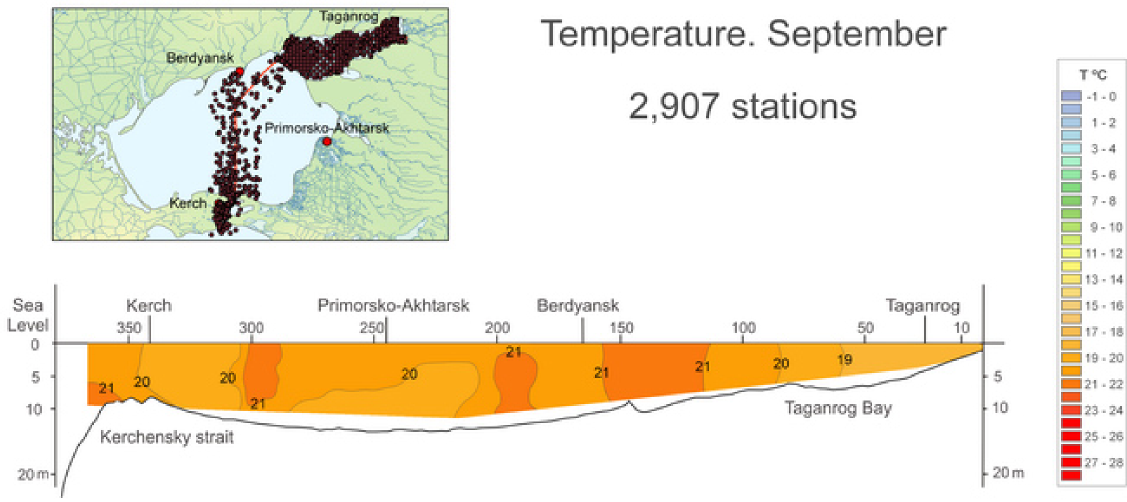




Fig. D8. Temperature and salinity. Vertical sections. August



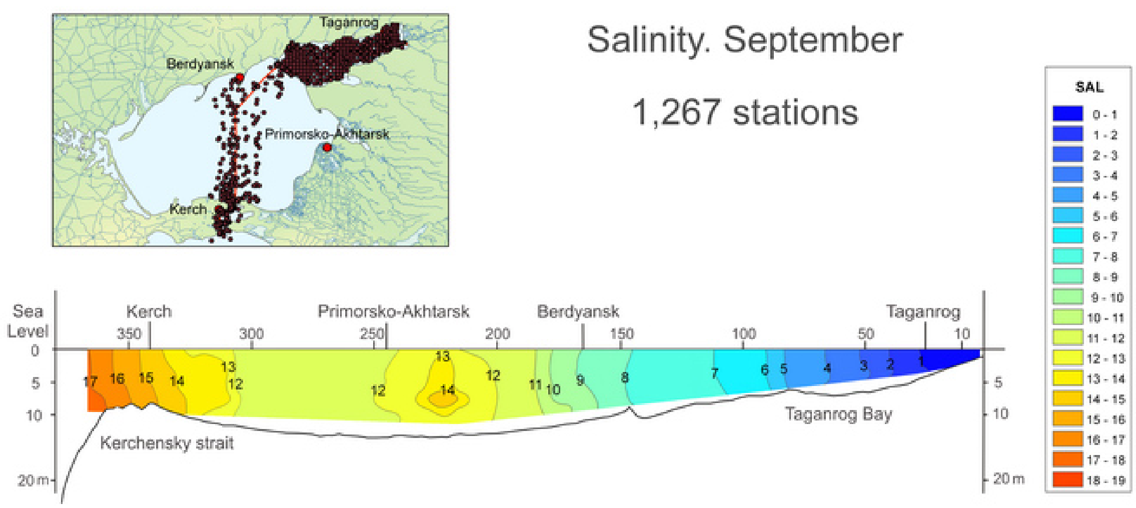




Fig. D9. Temperature and salinity. Vertical sections. September

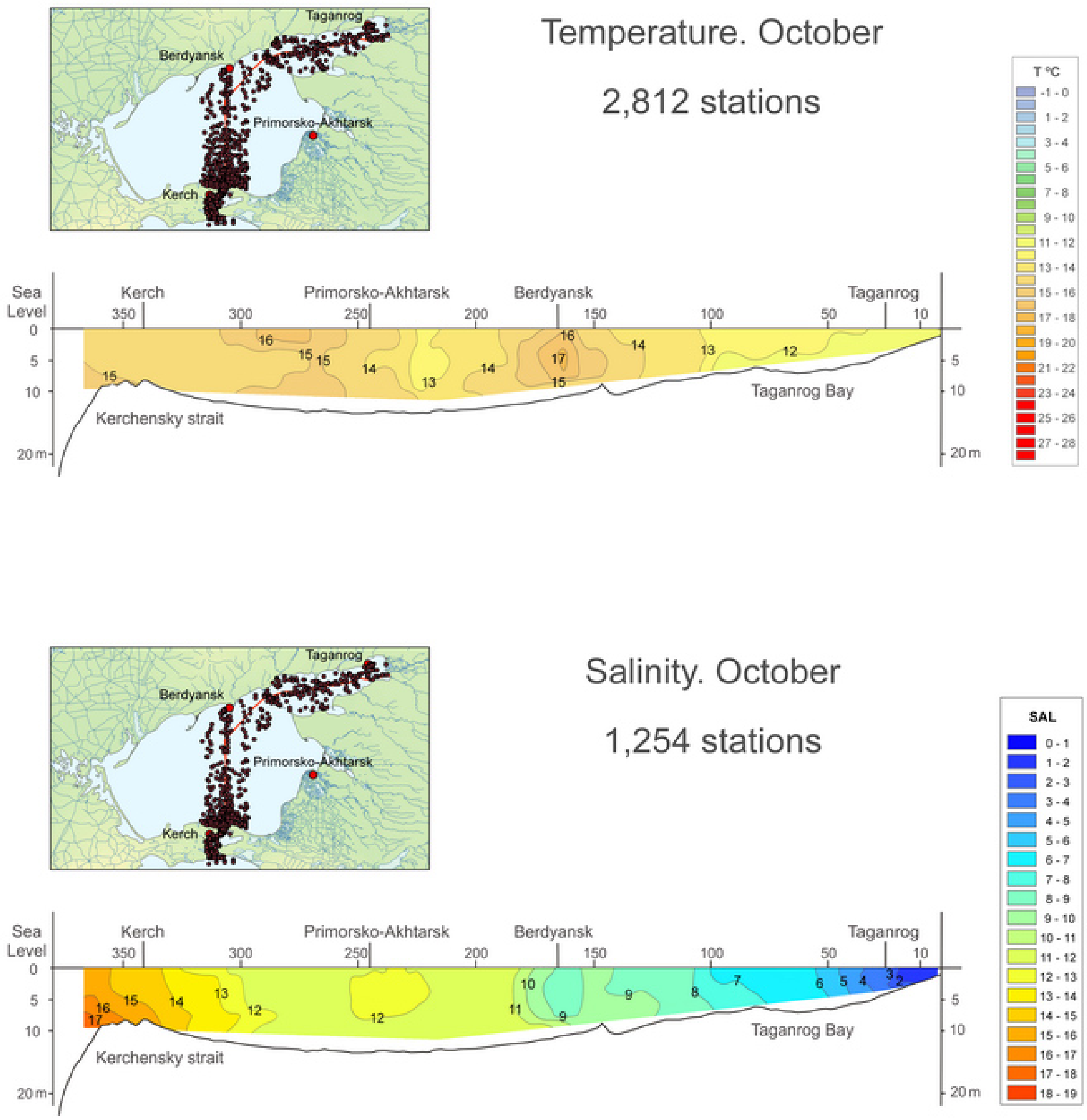
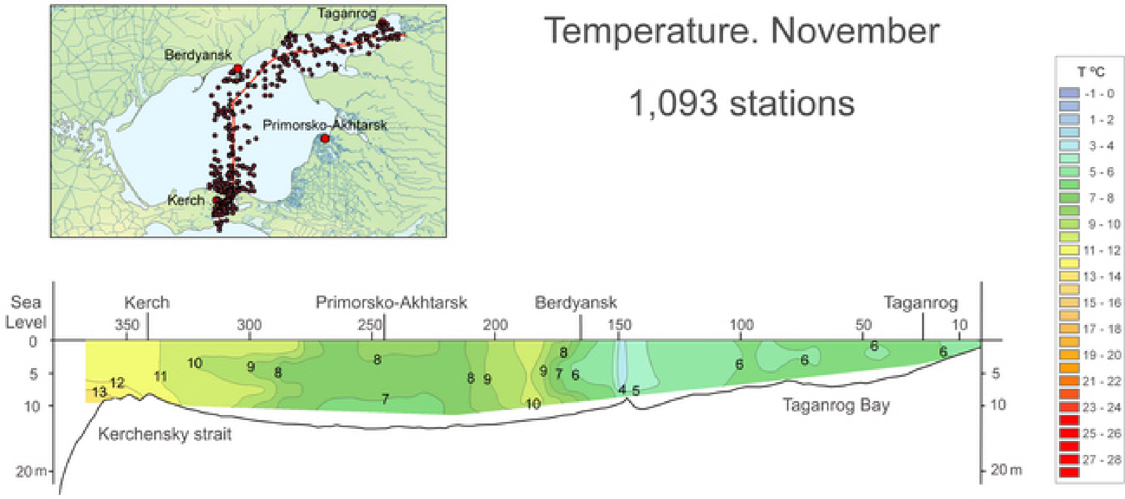



Fig. D10. Temperature and salinity. Vertical sections. October



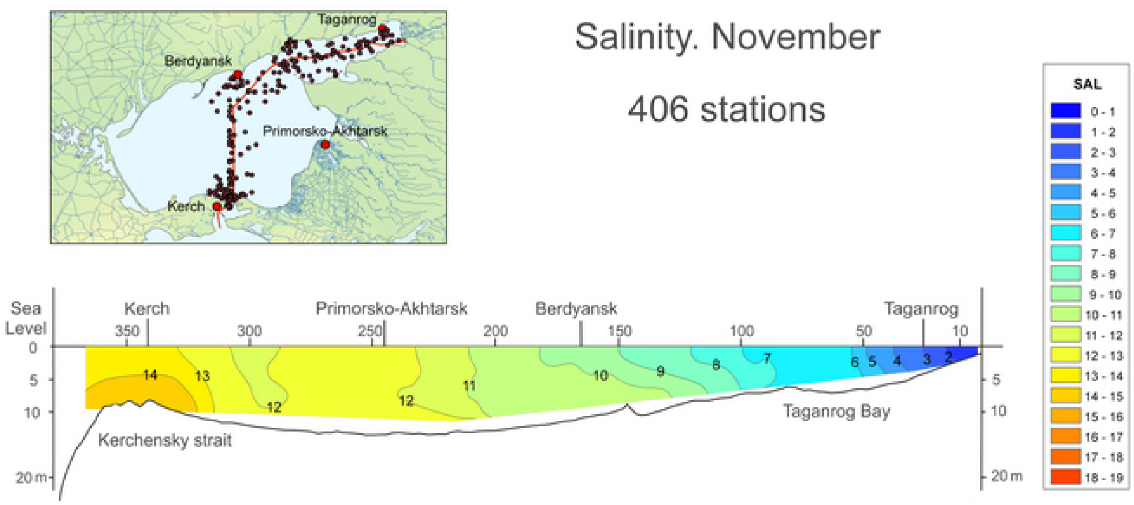
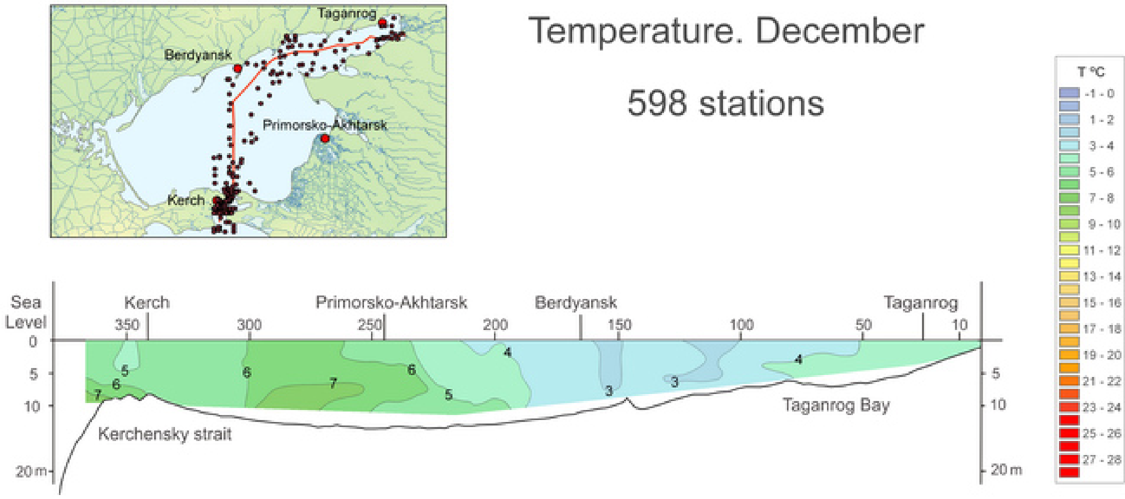




Fig. D11. Temperature and salinity Vertical sections. November



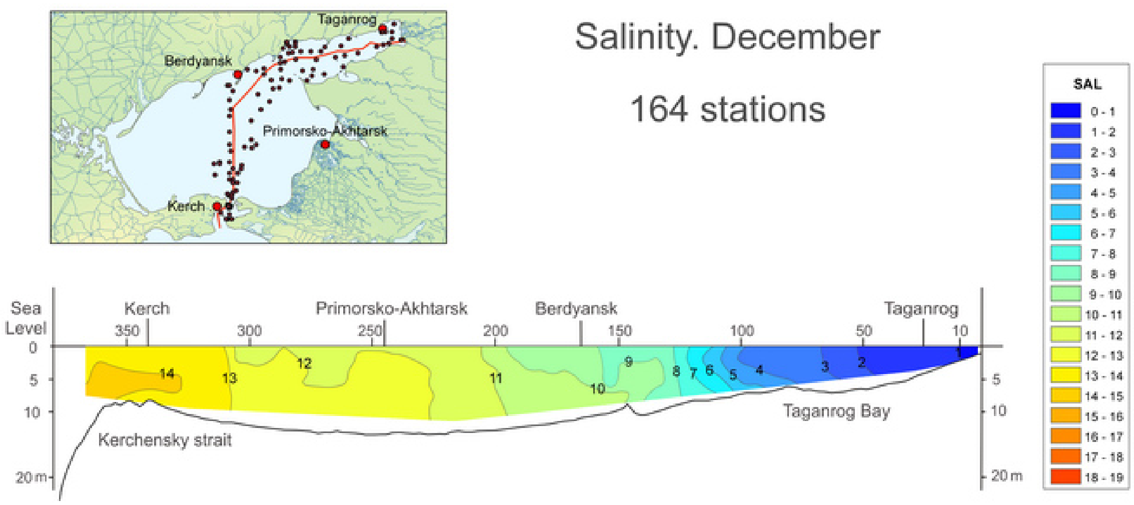




Fig. D12. Temperature and salinity. Vertical sections. December

Ocean Climate Laboratory, National Oceanographic Data Center NESDIS/NOAA
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