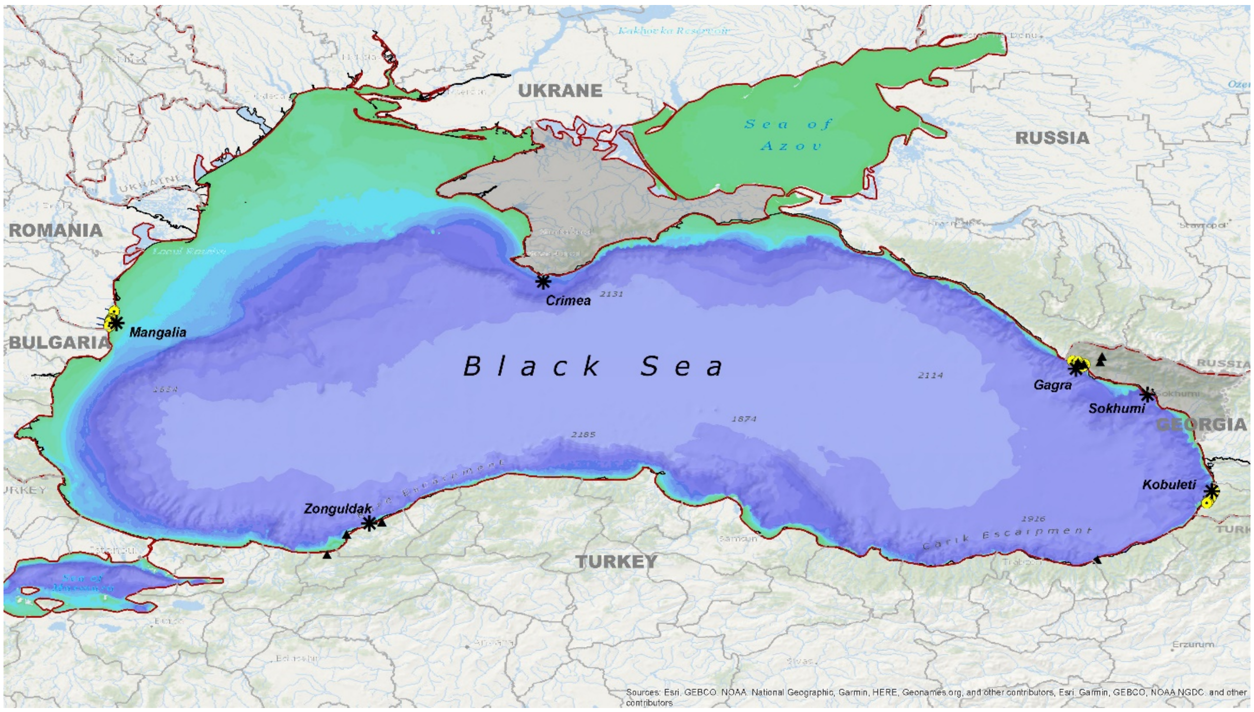
Search for Submarine Springs & Caves in the Black Sea - 2020



Prepared for:

The Wren Group

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November 4, 2020

Executive Summary

GeoHydros, LLC was contracted by the Wren Group LLC to continue a reconnaissance of the coastal Black Sea that was initiated in 2019 (GeoHydros, 2020) and that aimed to locate and characterize submarine springs and caves that may exist in the upper 100 meters of water depth. The purpose of the 2020 study was three-fold:

1. conduct more detailed surveys of the locations surveyed in 2019 focusing on locations of previously reported SGD in Mangalia and areas of steep bathymetric relief in Georgia;
2. establish contact with one or more professionals in Romania who may be able to assist in the identification of offshore springs and caves; and
3. formalize a collaboration with Dr. George Melikadze, Director of the Institute of Geophysics at the Tbilisi State University in Georgia that had been initiated during the 2019 survey.

GeoHydros assisted the Wren Group in the design and organization of a 3-week survey expedition aboard a 50-foot sailing catamaran to investigate the target areas in Romania and Georgia. Dr. Todd Kincaid of GeoHydros joined three members of the Wren Group (*the Team*) aboard the survey vessel to lead a series of surveys in the Mangalia and Kobuleti target areas and along the transits across the Black Sea spanning an approximately 30-day period. The surveys were to include a series of vertical CTD (conductivity, temperature, depth) casts, multi-parameter, video, and photographic surveys conducted by divers, and vertical casts performed during the transits to identify background CTD profiles not likely to be affected by the presence of freshwater discharge.

Due to complications which stemmed almost entirely from Covid-19 restrictions, the Team was only able to conduct survey work on 11 days of the anticipated 30-day mission. Those included three days conducting CTD casts in the Mangalia target area, one day conducting diving surveys with the multi-parameter sonde and cameras in the Mangalia target area (overlapping with the three days of CTD castings), and the eight transit days across the Black Sea.

Two dives were conducted on October 1, 2020 within approximately 200m of shore off the coast of Mangalia adjacent to Saturn Beach. Eight spring vents in the Mangalia survey area were observed, recorded and characterized. Prolific growth of white bacteria was observed at all spring vents and smaller quantities of bacteria were observed to be covering the substrate in several other areas between the obvious vents. The data collected during this study supports the hypothesis that spring discharge is associated with lower salinities than the values typical of the coastal Black Sea though the deviations may only be obvious when evaluated locally. Temperatures recorded in the spring group areas showed a significantly stronger deviation (colder) than the values recorded in the shallow waters along the transits across the Black Sea. Locally, however, temperature values did not differ significantly between the spring vents and the surrounding ambient waters. Values for pH and dissolved oxygen did not differ greatly from the values measured in the surrounding ambient waters though both parameters consistently fell at or below the low end of the observed range in the surrounding ambient water.

The data and observations collected in the Mangalia area thus far indicate the following.

1. SGD is occurring in the form of discrete small magnitude spring vents as well as disperse flows emanating from rubbelized sections of the substrate.
2. SGD is likely dispersed across a broad section of the coast proximal to Mangalia but is likely limited to water depths less than 10m.

3. Where it occurs, SGD is distinguishable from the surrounding ambient water by lower salinities though the deviations may only be identifiable when evaluated locally.
4. Extensions of the diving and casting surveys to the north and south of the two dive sites surveyed in October 2020 will likely reveal a substantial number of additional spring vents and areas of disperse SGD.

The following recommendations stem from the observations and results obtained from the 2020 survey.

1. Complete and submit the permit application to the Romanian Hydrographic Directorate at least 3 months prior to the next intended survey period.
2. Secure a collaboration agreement with the Speleological Institute Emil Racovita citing Dr. Virgil Dragusin and Mr. Mihai Baciu as primary collaborators for future work in Romaina.
3. Target future diving surveys in Romania to water depths of less than 10m and leverage diver propulsion vehicles (DPVs) to cover substantially larger portions of the coast line.
4. Use surface marker buoys to mark the locations of each spring vent observed.
5. Continue to measure CTD, pH, and DO at the spring vents and the ambient waters such that better correlations can be drawn between those parameter values and SGD in coastal Romanian waters.
6. Perform surface casts using the EXO multi-parameter data sonde such that better correlations can be drawn between pH and DO values in the spring vents and values associated with coastal and offshore waters in the Black Sea.
7. Develop and secure a collaboration agreement with the Georgian Geothermal Association citing Dr. George Melikadze as the primary collaborator for future work in Georgia.
8. Obtain and invitation letter from Dr. Melikadze prior to arriving in the Black Sea.
9. Work with Dr. Melikadze to refine survey targets in Georgia and strategies to capitalize on local knowledge.
10. In the absence of local knowledge, continue to target the steep bathymetric contours between water depths of 30-80 meters as dive target areas in Georgia with the primary goal being to find caves and potentially locations of present or historical SGD in the rocky slopes.
11. Add surveys in water depths of less than 10m in Georgia to determine if SGD is similar to that occurring in Romania.

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Appendix V: High-resolution Photos of Spring Vents
provided electronically at:
https://www.dropbox.com/sh/6ohci42n7l81648/AABlmmhYZ1dirQse93Z5BqUda?dl=0

Appendix VI: Videos of Spring Vents
provided electronically at:
https://www.dropbox.com/sh/6ohci42n7l81648/AABlmmhYZ1dirQse93Z5BqUda?dl=0

1. Overview

GeoHydros, LLC was contracted by the Wren Group LLC to continue a reconnaissance of the coastal Black Sea that was initiated in 2019 (GeoHydros, 2020) and that aimed to locate and characterize submarine springs and caves that may exist in the upper 100 meters of water depth. Six regions were identified in the 2019 study as potential locations for submarine springs and caves (Figure 1) based one or more of the following criteria in the respective areas.

1. Published descriptions of submarine groundwater discharge (SGD) and/or springs or caves within the upper 100 meters of water depth.
2. Karstic or fractured carbonate or fractured volcanic or plutonic bedrock exposed at or near the surface offshore and/or nearshore.
3. Substantial onshore catchment area.
4. Evidence of spring discharge onshore within the target or adjacent catchments.
5. Apparent or probable imbalance between recharge and river outflow to the Black Sea within the target catchment.

Two of the six areas: Mangalia, Romania and Kobuleti, Georgia were surveyed at a preliminary level during the 2019 study.

1.1. Objectives

The purpose of the 2020 study was three-fold:

4. conduct more detailed surveys of the locations surveyed in 2019 focusing on locations of previously reported SGD in Mangalia and areas of steep bathymetric relief in Georgia;
5. establish contact with one or more professionals in Romania who may be able to assist in the identification of offshore springs and caves; and
6. formalize a collaboration with Dr. George Melikadze, Director of the Institute of Geophysics at the Tbilisi State University in Georgia that had been initiated during the 2019 survey.

1.2. Benefits

Identifying and quantifying SGD in the Black Sea, particularly spring discharges, will significantly benefit three areas of societal concern and interest. First, in many areas of the world including the Black Sea nations, submarine groundwater discharge presents an untapped or largely untapped freshwater resource. Identifying spring locations and quantifying discharge will provide necessary information for the development and calibration of groundwater flow models needed to manage groundwater resources and potentially provide new local water supplies (Gilli and Cavalera, 2009).

Second, SGD is known to be a substantial vector for contaminant transport to the Black Sea. Contaminants include both point and non-point source constituents including the nutrient loading known to be contributing to the ongoing eutrophication problem (Talley and Swift, 2011). Identifying spring locations and quantifying discharge will help efforts to rank contaminant sources in terms of their contributions to pollutant discharge; and provide water resource managers with the information needed to justify political and regulatory actions aimed at contaminant reduction.

Finally, springs have and continue to be locations around which communities develop and are sustained. The identification of springs in the upper 100 meters of water in the Black Sea will provide targets for future archeological and anthropological investigations of ancient civilizations in the Black Sea area.

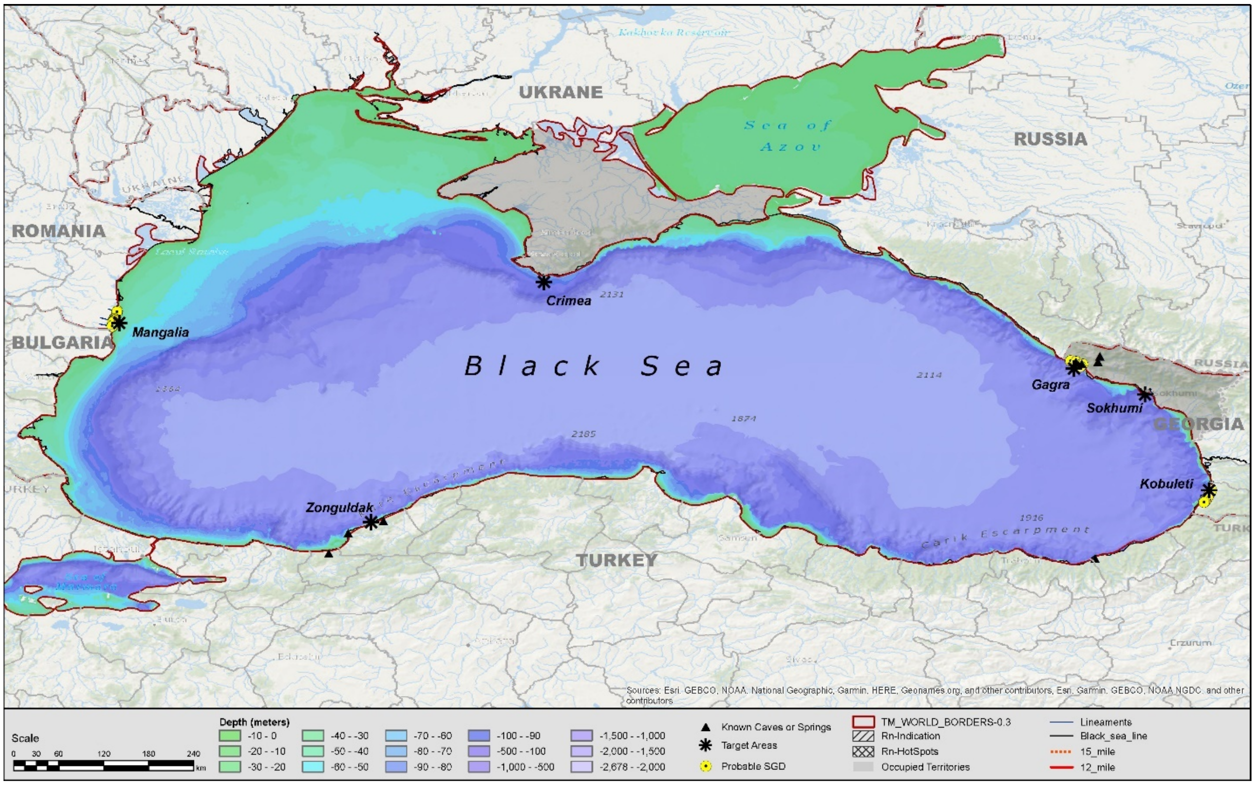


Figure 1. Map of the Black Sea showing bathymetric contours (EMODnet, 2019) emphasizing the upper 50 and 100 meters of water depth, and the locations of target areas that meet two or more criteria for the likely presence of submarine springs and/or caves as determined through a review of published literature.

2. Previous Investigations

The motivation and purpose of our Black Sea surveys are, in part, based on the results and hypotheses described in three publications:

- Buachidze (2007) who described the occurrence of SGD as a function of riverine discharge to the Black Sea in the coastal waters off of northwestern and southwestern Georgia as well as the probable existence of SGD in the coastal waters on northern Turkey;
- Klimchouk (2012) who described cave and karst development in the Arabika region of northwestern Georgia and the connection between deep dry cave systems in the mountains to coastal and submarine springs in the vicinity of the Arabika Submarine Depression; and
- Schubert and others (2017) who conducted a series of geochemical investigations that identified the approximate locations and magnitudes of SGD in the Mangalia region of eastern Romania, and the Adjara region of southwestern Georgia.

In addition to these works, our continued efforts are based on our own previous findings including:

- GeoHydros (2020) which describes apparent deviations between salinities measured at depths between 30 and 80 meters along a bathymetric scarp approximately 1.5 km offshore of Kobuleti Georgia.

3. Target Areas

Of the six initially identified areas of interest in which hydrogeologic conditions favor the existence of submarine springs, two were selected for the initial survey in 2019 and for continued study in 2020. The selection of specific survey locations within the study areas were based, in part, on bathymetric analyses performed using GIS data obtained from the European Marine Observation and Data Network (EMODnet, 2019). Appendix I provides bathymetric maps of the Black Sea identifying the six initially targeted areas relative to surrounding topographic and political features. Only the two areas targeted for the 2020 study are described here. The others are described in GeoHydros (2020).

3.1. Adjara Region (southwestern Georgia)

The Adjara region of southwestern Georgia was studied by Schubert and others (2017). The Schubert team identified three areas of probable SGD in this region between the town of Batumi in the south and the Natanebi River at the border between the Ajara and Guria provinces in the north on the basis of Radon-222, sea surface temperatures (SST), and physical hydrogeological characteristics. Six specific locations were identified as probable locations of SGD, which they describe as potential springs associated with fissures/faults in volcanic rocks. They report that previous investigations have estimated SGD in this area as being as high as 30% of river discharge to the sea. The area specified as highest probability of large-magnitude SGD is near the town of Kobuleti continuing along the town beach and south of it for about 7 km (Figure 2-A).

Buachidze (2007) classifies the Black Sea shelf is this region as *Volcanic*. The EMODnet bathymetric data (EMODnet, 2019) show steep contours from close to the Black Sea shore to depths in excess of 100 meters as well as canyons that descend substantially deeper. We interpret these contours as evidence of steep rocky walls in the region. These probable rocky walls were selected as the primary target areas for the 2019 and 2020 surveys.

3.2. Southeastern Romania

The southeastern region of Romania was studied by Schubert and others (2017) in their investigations of SGD in the Black Sea. The Schubert team identified three areas of probable SGD in this region between the Bulgaria/Romania border in the south and Techirghiol Bay, south of Constanta in the north on the basis of Radon-222, sea surface temperatures (SST), and physical hydrogeological characteristics. Fourteen specific locations were identified as probable locations of SGD. Ten of the locations were associated with regions of very high Radon-222 (Figure 2-B).

The EMODnet (2019) bathymetric data show broad contours from the Black Sea shore to depths in excess of 100 meters. Buachidze (2007) classifies the Black Sea shelf is this region as Stable-Wide. Both of these conditions indicate that SGD, if it occurs, is likely shallow and disperse rather than associated with large spring vents. The area is included because of the SGD indications and because similar characteristics would be ascribed to the Spring Creek region of South Florida USA, which research has verified as containing numerous discrete, large magnitude springs (Kincaid and Werner, 2008).

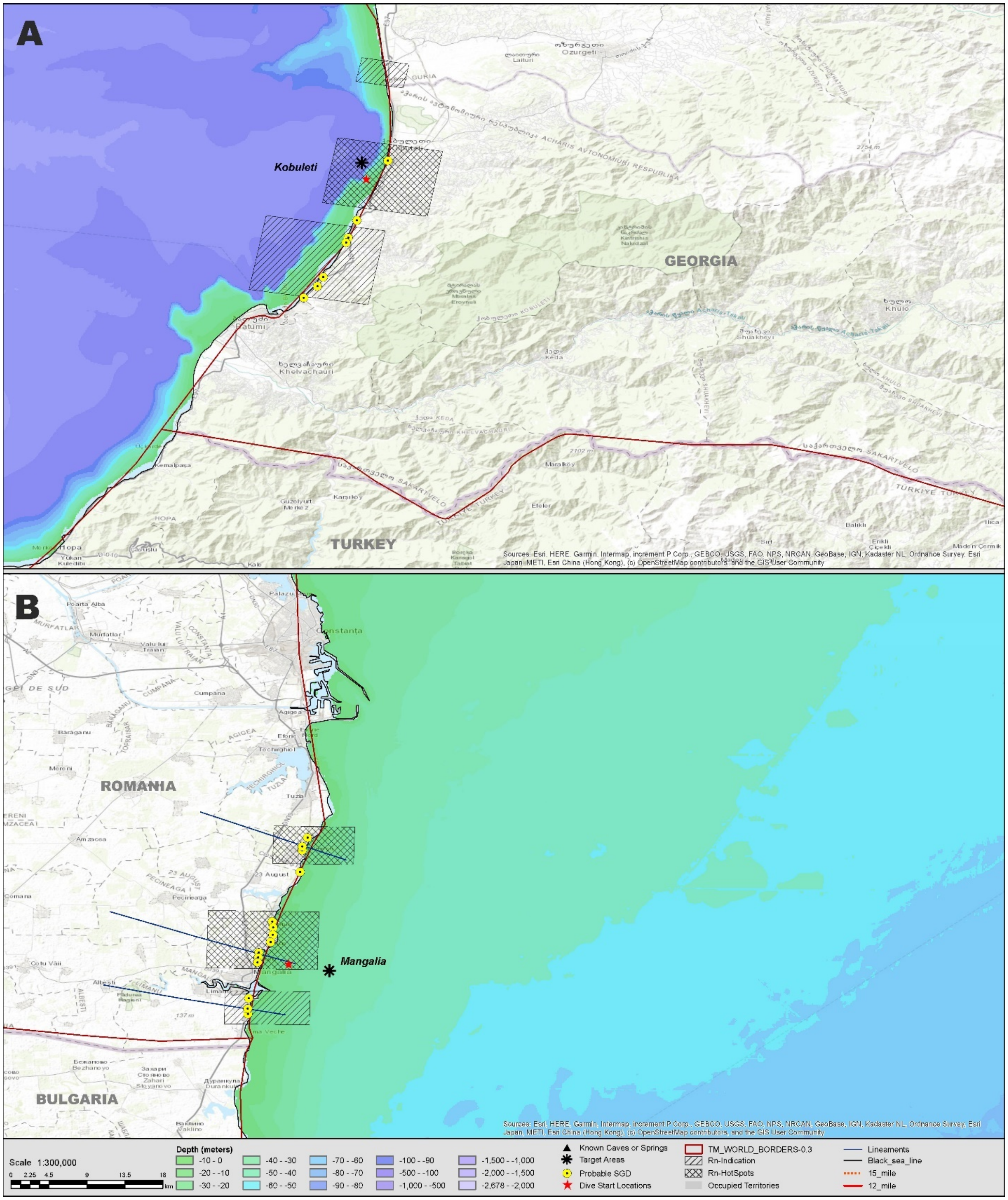


Figure 2. Maps showing (A) the location of the Kobuleti target area relative to the Adjara region of southwest Georgia and (B) the location of the Mangalia target area relative to eastern Romania and Bulgaria relative to bathymetric contours (EMODnet, 2019) highlighting water depths in 10-meter increments, and the locations of probable SGD as reported by Schubert and others (2017).

4. Survey Plan

GeoHydros assisted the Wren Group in the design and organization of a 3-week survey expedition aboard a 50-foot sailing catamaran to investigate the target areas in Romania and Georgia. The plan called for Dr. Todd Kincaid of GeoHydros to join three members of the Wren Group (*the Team*) aboard the survey vessel to lead a series of surveys in the Mangalia and Kobuleti target areas and along the transits across the Black Sea spanning an approximately 30-day period. One week was allocated to the surveys in the two target areas with the remaining time allowed for the Black Sea transits. The surveys were to include a series of vertical CTD (conductivity, temperature, depth) casts from the catamaran or its 13-foot tender, multi-parameter, video, and photographic surveys conducted by divers, and vertical casts performed during the transits to identify background CTD profiles not likely to be affected by the presence of freshwater discharge. The expedition was to leave from Varna, Bulgaria and follow a route to Mangalia, Romania across the northern Black Sea to Batumi, Georgia, and back to Varna along a similar route. The survey plans for the Mangalia and Kobuleti sites are depicted on maps provided as Figure 3-Figure 5 and in Appendix II.

CTD casts were to be performed using the SonTek CastAway® which is operable in water depths of less than or equal to 100m and which automatically averages measurements to produce parameter vs depth profiles. Appendix III provides documentation on the CDT sonde.

Multiparameter surveys were to be performed by divers using the YSI EXO-1® multiparameter sonde equipped with CTD, pH, dissolved oxygen (DO), and oxidation-reduction potential (ORP) sensors. The sonde was to be carried by a member of a two-person dive team using diver propulsion vehicles to cover maximum distances and rebreathers to allow for extended bottom times on each dive. Appendix III provides documentation on the CTD and multiparameter sonde.

5. Results

Due to the complications described in Section 5.1 which stemmed almost entirely from Covid-19 restrictions, the Team was only able to conduct survey work on 11 days of the anticipated 30-day mission. Those included three days conducting CTD casts in the Mangalia target area, one day conducting diving surveys with the multi-parameter sonde and cameras in the Mangalia target area (overlapping with the three days of CTD castings), and the eight transit days across the Black Sea during which time CTD casts were performed at the beginning of each 6-hour shift.

5.1. Complications

The survey plan was substantially compromised by Covid-19 restrictions imposed across Europe in early-middle 2020 that persisted and even tightened by Fall 2020 when the surveys were initiated. The most significant restriction-related problems were:

1. travel restrictions that prevented direct travel from the United States to Bulgaria where we had intended to meet the survey vessel;
2. increased scrutiny of activities conducted by foreigners along the Romania coast resulting in the implementation of permit requirements for research activities; and
3. prohibition of entry into Georgian waters by foreigners not coming directly from five specified countries, not including Bulgaria, Romania, or the United States.

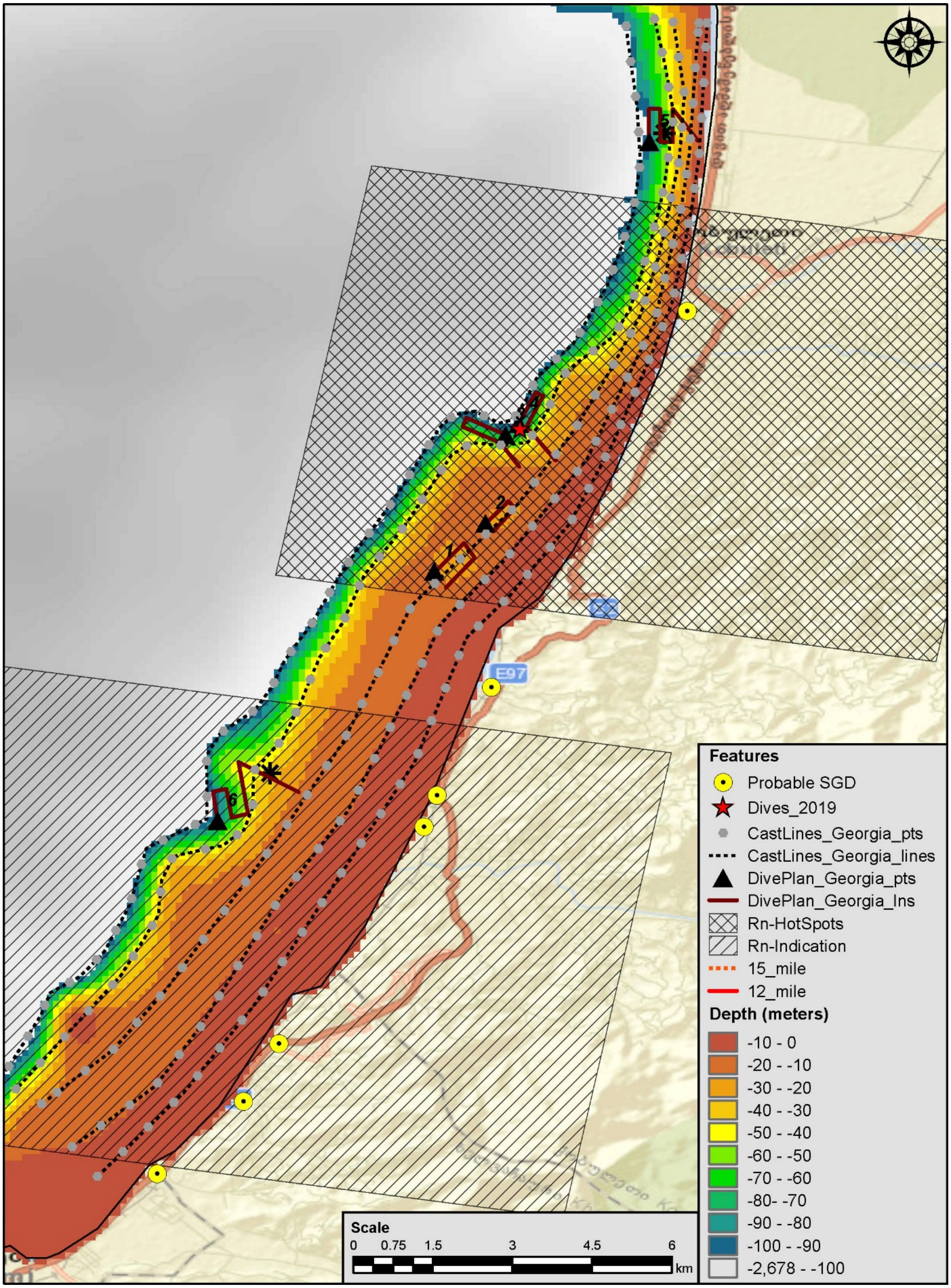


Figure 3. Map depicting the survey plan for target area off the coast of Kobuleti on the southeastern coast of the Black Sea in southwest Georgia.

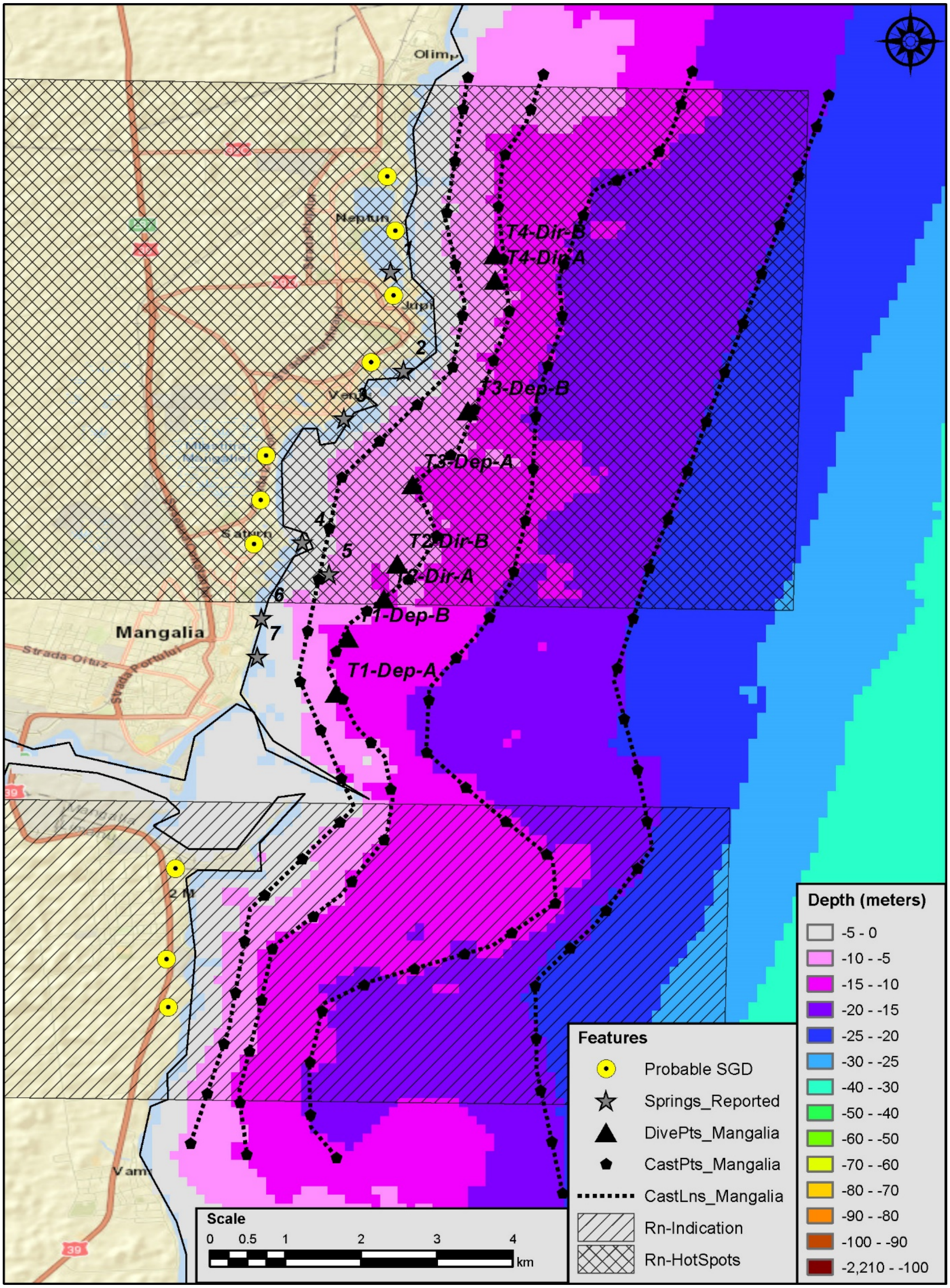


Figure 4. Map depicting the survey plan for CTD casts in the target area off the coast of Mangalia on the west coast of the Black Sea in southeast Romania.

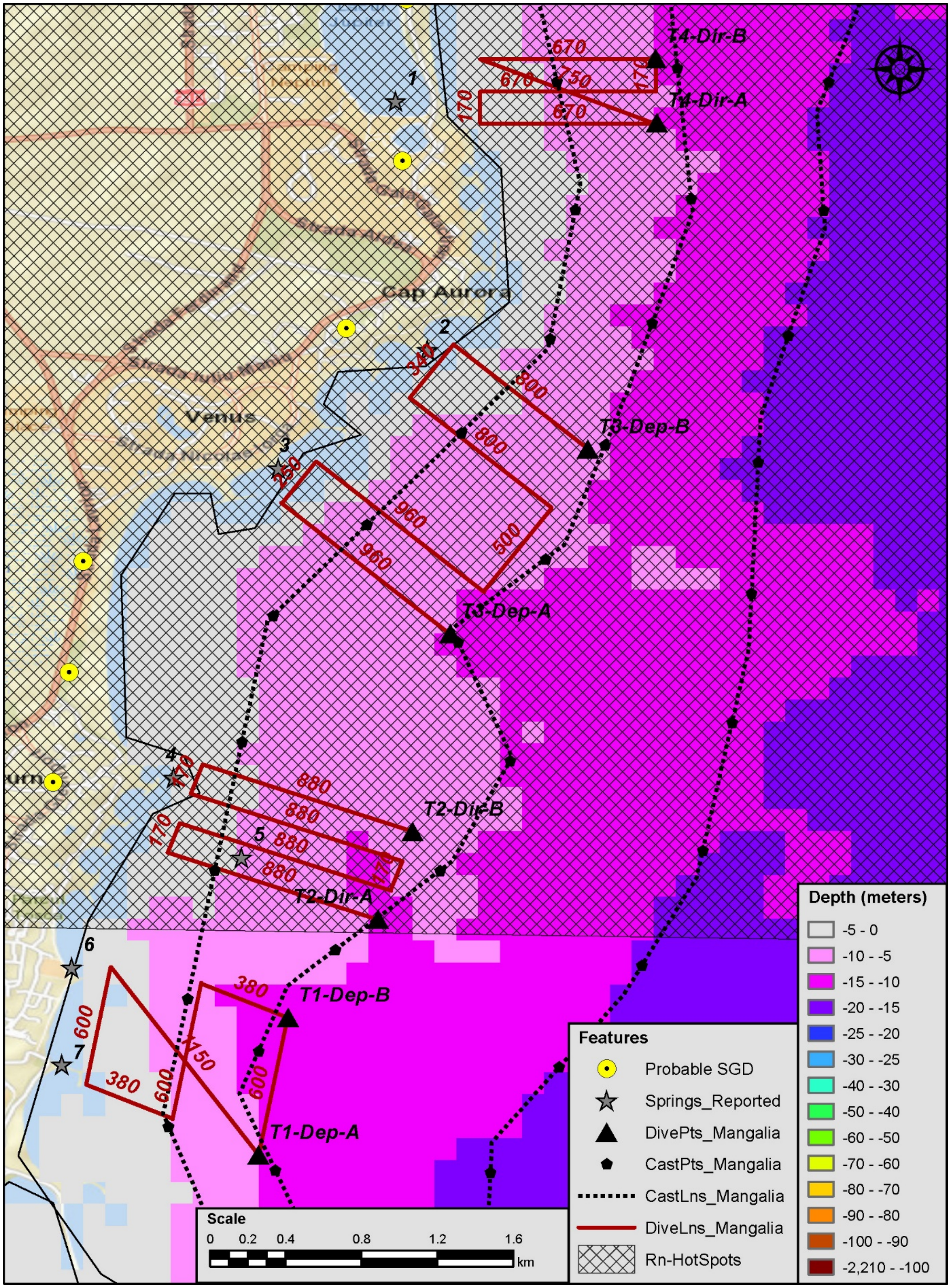


Figure 5. Map depicting the survey plan for dives and CTD casts in a portion of the target area off the coast of Mangalia on the west coast of the Black Sea in southeast Romania.

Efforts to overcome these problems included:

1. meeting the survey vessel in Dubrovnik Croatia and sailing the vessel around the Greek peninsula through the Dardanelles and the Bosporus in northern Turkey to Varna on the west coast of Bulgaria;
2. traveling to Constanta Romania to meet in person with representatives of the Romanian Maritime Hydrographic Directorate (https://www.dhmfn.ro/index_en.shtml) to request assistance with securing an expedited permit; and
3. contacting Dr. Melikadze to seek an invitation from the Tbilisi State University in Georgia, which would have exempted our team from the Covid-19 entrance restrictions.

5.2. Timeline

The Team departed Dubrovnik Croatia on September 6, spent one day in Milos Greece effecting minor repairs to the vessel and waiting out 30+ knot winds, and arrived in Varna Bulgaria on September 15. We remained in Varna for four days to effect additional repairs and resupply. We departed Varna on September 19 and arrived in Mangalia Romania later that same day. We initiated CTD casts on September 20 but, in order to capitalize on an optimal weather window in the central Black Sea, we departed for Batumi Georgia on the 21st.

Shortly before departing from Mangalia, we learned of the entrance restrictions on foreign entries to Georgian ports and immediately began seeking an invitation from Tiblisi State University to conduct our surveys. After reaching the international boundary line offshore of Batumi, we made contact with Dr. Melikadze and learned that though he had opened a path for collaboration with and an invitation from the university, it would take at least 10 days to secure the invitation needed to enter the country. At that point, we decided to return to Mangalia and focus the remainder of our trip on the Mangalia area surveys. During both transits across the Black Sea, we conducted CTD casts down to approximately 100 meters water depth at the beginning of each six-hour shift.

We arrived back in Mangalia on September 29 whereupon we learned that we would need to secure a permit from the Romanian Maritime Hydrographic Directorate in order to conduct our diving surveys. We arranged for a translator to accompany us to Constanta and also consulted Dr. Adrian Iurkiewicz to see if he could assist us with the permit and/or introduce us to potential collaborators. We met with two representatives of the Romanian Maritime Hydrographic Directorate on October 1. They were verbally supportive of our survey plan and introduced us to the permit application and the online application process, but dismissed the possibility of receiving an expedited permit for our work plans in 2020. We were told to expect the permit process to take between one and three months, two weeks minimum and that a new permit will be required for each survey period that we plan to execute.

Also on October 1, we initiated contact with Dr. Virgil Dragusin and Mr. Mihai Baciu, researchers at the Speleological Institute Emil Racovita (https://iser.ro/cluj-napoca.php?lang=en) in Bucharest, who coincidently were planning a survey of his own for the Mangalia area to begin on October 3rd. We met with him and a colleague in Mangalia on October 2nd and accepted an invitation to join them to surveys known and potential springs immediately offshore of Mangalia.

After exhausting our ability to legally work in Romania, we departed for Dubrovnik on October 4 but encountered significant engine and transmission problems shortly after our departure which necessitated a return to Varna to effect repairs. We departed Varna again for Dubrovnik on October 10 and arrived in Dubrovnik on October 16 after a relatively uneventful transit.

5.3. Mangalia

5.3.1. CTD Casts

Thirty-seven (37) CTD casts were performed along the entire length of the 5m and 6m transects (depth contours) depicted on Figure 4 and Figure 5 north of the port of Mangalia. Distance between the casts was approximately 400-500 meters (Figure 8). An additional 41 CTD casts were performed in two areas in which diving surveys of known and suspected springs were performed (Figure 8). Locations and distance between the casts within the spring group areas was arbitrary and random.

Temperature vs. depth and salinity vs. depth plots derived from each of the 37 CTD casts performed along the 5m and 6m depth contours are depicted on Figure 6. Temperature vs. depth and salinity vs. depth plots derived from each of the 41 CTD casts performed within the two areas surrounding the springs surveyed by diving are depicted on Figure 7. Statistics computed for approximately 1m depth intervals from all 78 CTD casts are listed in Table 1 and Table 2. The raw and processed data are available online (see Appendix IV).

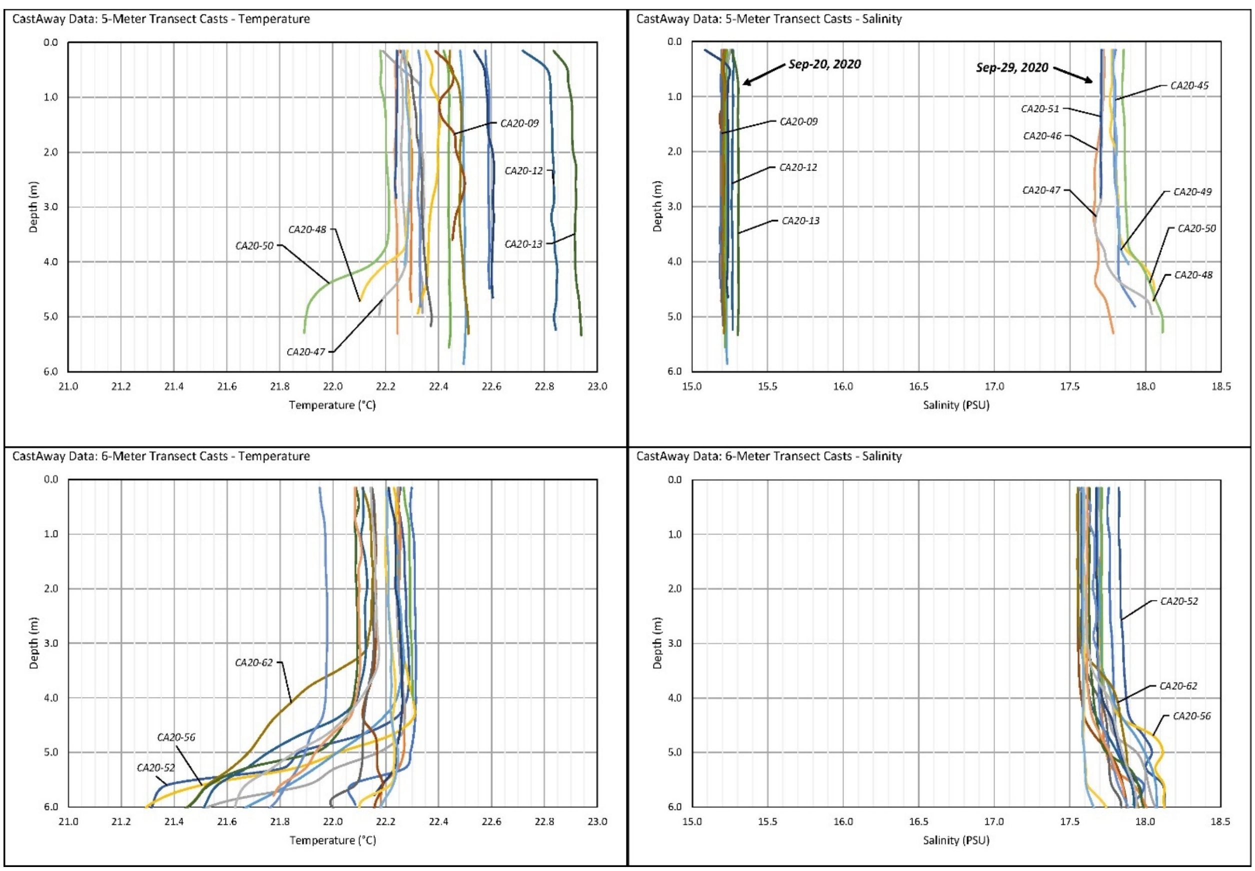


Figure 6. Temperature vs. depth and salinity vs. depth plots derived from CTD casts performed on September 20 and September 29, 2020 north of the port of Mangalia along 5m and 6m depth contours.

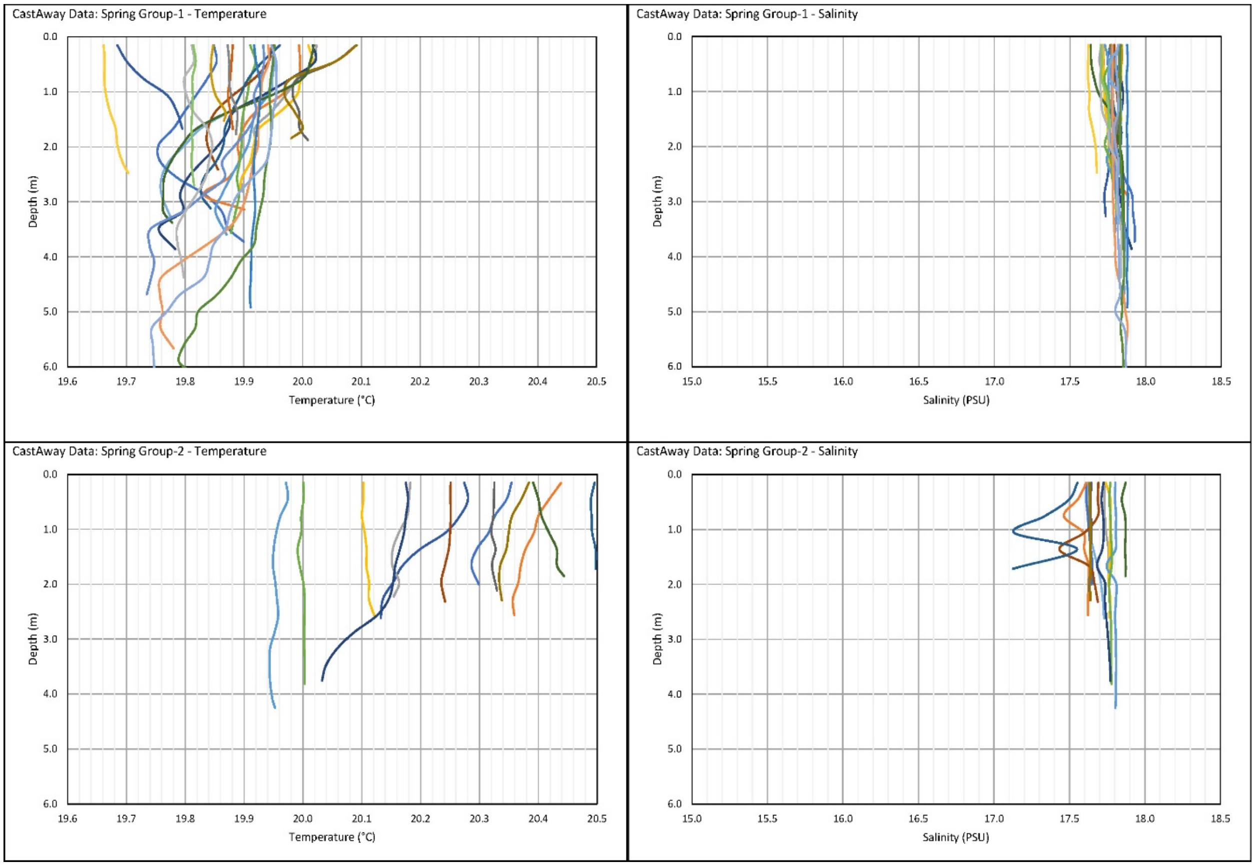


Figure 7. Temperature vs. depth and salinity vs. depth plots derived from CTD casts performed on October 1 within the two areas surrounding the springs surveyed by diving during the 2020 investigation.

Table 1. Salinity statistics computed for approximately 1m depth intervals from the 78 CTD casts performed in the Mangalia target area during the 2020 investigation.

	Depth (m)	0 - 0.5	0.5 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7
5m-20Sep	Min	15.16	15.19	15.19	15.19	15.19	15.19	15.21	Na
	Max	15.28	15.31	15.31	15.31	15.31	15.31	15.30	Na
	Range	0.11	0.12	0.11	0.12	0.12	0.12	0.10	Na
	Ave	15.22	15.25	15.25	15.25	15.25	15.25	15.26	na
5m-29Sep	Min	17.71	17.71	17.70	17.66	17.67	17.71	17.79	na
	Max	17.85	17.84	17.86	17.87	17.88	18.04	18.11	na
	Range	0.15	0.14	0.16	0.20	0.21	0.33	0.33	na
	Ave	17.78	17.78	17.78	17.76	17.78	17.88	17.95	na
6m-29Sep	Min	17.55	17.55	17.55	17.55	17.56	17.59	17.62	17.77
	Max	17.83	17.82	17.83	17.84	17.86	17.95	18.10	18.14
	Range	0.27	0.27	0.28	0.29	0.30	0.36	0.49	0.37
	Ave	17.69	17.69	17.69	17.70	17.71	17.77	17.86	17.96
SpgGrp1	Min	17.62	17.62	17.64	17.68	17.73	17.82	17.84	17.85
	Max	17.88	17.87	17.88	17.88	17.92	17.88	17.87	17.88
	Range	0.26	0.25	0.24	0.21	0.19	0.06	0.03	0.03
	Ave	17.75	17.75	17.76	17.78	17.83	17.85	17.86	17.87
SpgGrp2	Min	17.53	17.34	17.27	17.62	17.77	17.81	na	na
	Max	17.86	17.87	17.87	17.81	17.81	17.81	na	na
	Range	0.33	0.53	0.60	0.18	0.04	0.00	na	na
	Ave	17.69	17.60	17.57	17.71	17.79	17.81	na	na

Table 2. Temperature statistics computed for approximately 1m depth intervals from the 78 CTD casts performed in the Mangalia target area during the 2020 investigation.

	Depth (m)	0 - 0.5	0.5 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7
5m-20Sep	Min	22.22	22.28	22.29	22.30	22.30	22.30	22.37	na
	Max	22.86	22.89	22.91	22.92	22.92	22.92	22.94	na
	Range	0.64	0.61	0.61	0.62	0.62	0.63	0.57	na
	Ave	22.54	22.59	22.60	22.61	22.61	22.61	22.65	na
5m-29Sep	Min	22.18	22.18	22.20	22.21	22.24	22.14	22.24	na
	Max	22.33	22.33	22.33	22.32	22.33	22.33	22.24	na
	Range	0.15	0.15	0.13	0.11	0.09	0.19	0.00	na
	Ave	22.25	22.26	22.26	22.27	22.29	22.24	22.24	na
6m-29Sep	Min	21.95	21.97	21.97	21.98	21.98	21.76	21.54	21.24
	Max	22.30	22.30	22.31	22.31	22.31	22.31	22.22	22.18
	Range	0.34	0.33	0.34	0.33	0.34	0.55	0.68	0.94
	Ave	22.12	22.13	22.14	22.14	22.14	22.03	21.88	21.71
SpgGrp1	Min	19.66	19.66	19.68	19.70	19.76	19.74	19.75	19.75
	Max	20.07	20.00	20.00	19.94	19.92	19.91	19.80	19.81
	Range	0.41	0.34	0.32	0.24	0.16	0.17	0.06	0.06
	Ave	19.87	19.83	19.84	19.82	19.84	19.83	19.77	19.78
SpgGrp2	Min	19.97	19.96	19.95	19.96	19.94	19.95	na	na
	Max	20.49	20.49	20.50	20.36	20.04	19.95	na	na
	Range	0.52	0.53	0.54	0.40	0.10	0.00	na	na
	Ave	20.23	20.23	20.22	20.16	19.99	19.95	na	na

5.3.2. Diving Surveys

Two dives were conducted on October 1, 2020 within approximately 200m of shore off the coast of Mangalia adjacent to Saturn Beach. The dive locations are depicted on Figure 8 by the two clusters of CTD cast locations located north and south of the “Saturn” label and roughly adjacent to reported spring locations #4 and #6. The southern location (SpringGroup-1) was previously investigated by Dr. Dragusin and Mr. Baciu during which times they had identified several small sulfur springs discharging from small fissures and rubble in the substrate in water depths of less than 6m. Mr. Baciu led two members of our Team on an approximately 1-hour dive to six spring vents at which our divers collected photos and video, and CTD, pH, and DO readings using the EXO-1 multi-parameter sonde at each vent.

After completing the surveys at the southern location, our divers moved approximately 1.25 km north and conducted a second survey dive in an area thought by Mr. Baciu to encompass similar springs. Over the course of an approximately 1-hour dive, our divers identified two discrete spring vents and collected photos and video, and CTD, pH, and DO readings using the EXO-1 multi-parameter sonde at each vent.

All of the observed spring vents were marked by white bacteria growth and were located in less than 5 meters water depth. Some of the vents emitted visible flow as indicated by a pycnocline immediately outside of the vents. All of the observed flows were small (barely perceptible visually) but no effort was made to measure the discharge. Photos of the spring vents are provided as Figure 9 and Figure 10. Higher resolution versions of the photos and videos for each of the surveyed spring vents are available online (see Appendix V and Appendix VI respectively).

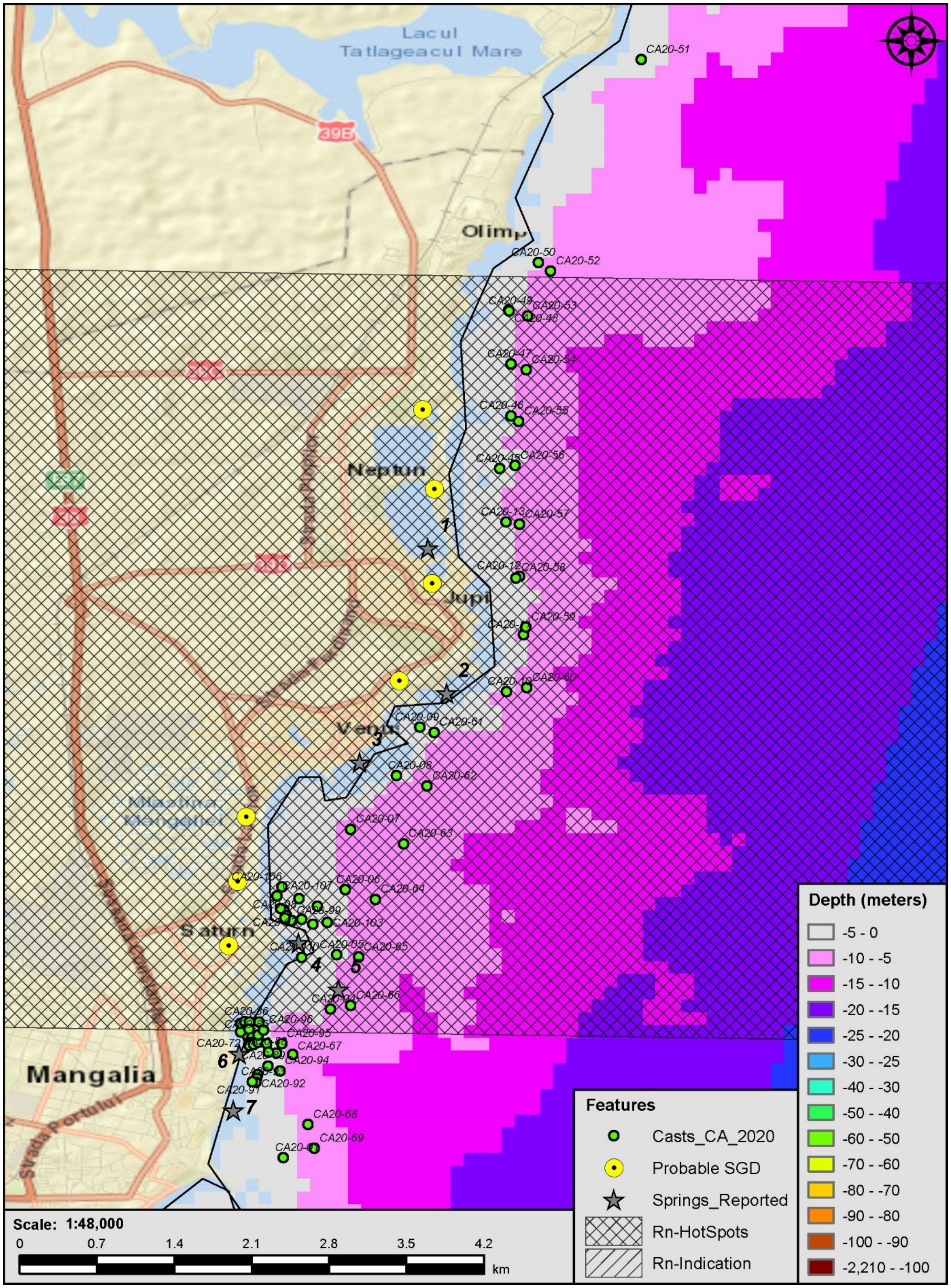
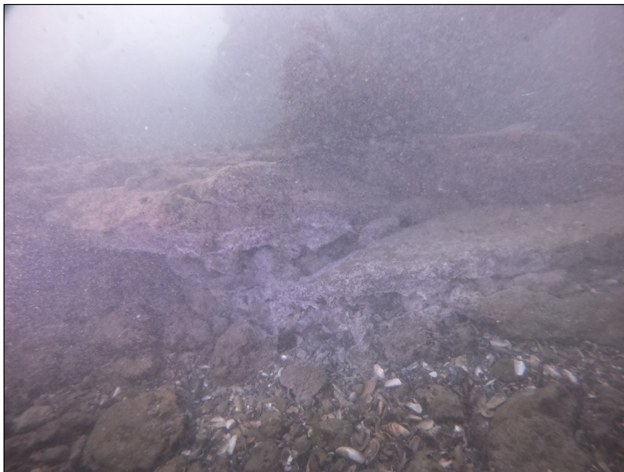
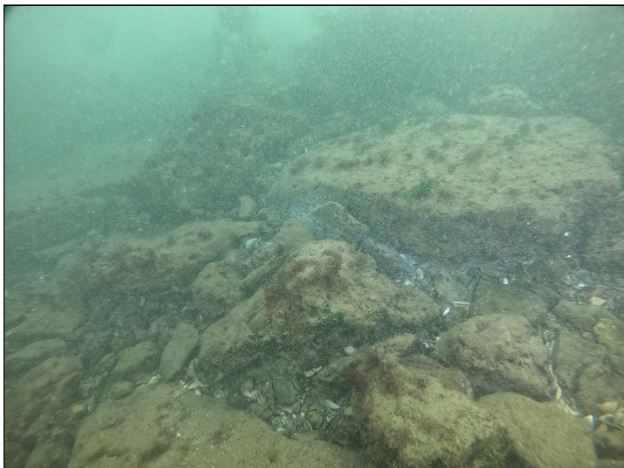


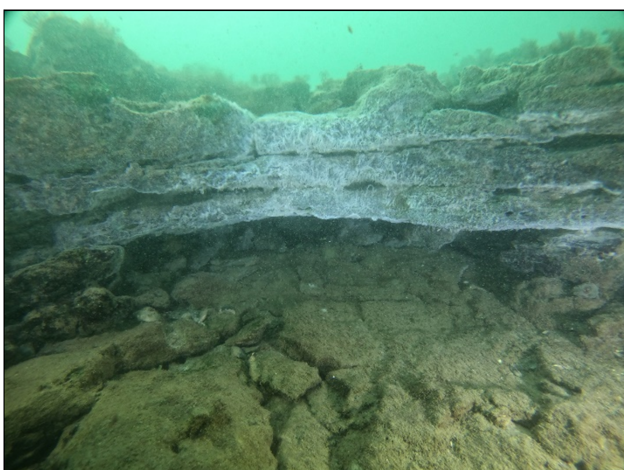
Figure 8. Map showing the locations of CTD casts performed in the Mangalia Romania target area during the 2020 survey relative to the reported locations of possible springs and locations of probable SGD identified by Schubert and others (2017).


SPG1-01


SPG1-02


SPG1-03


SPG1-04


SPG1-05


SPG1-06

Figure 9. Photos of the six spring vents observed in the southern of two dive sites (Spring Group-1) located north of the Port of Mangalia adjacent to Saturn Beach that were surveyed on October 1, 2020.

SPG2-01a

SPG2-01b

SPG2-01c

SPG2-02

Figure 10. Photos of the two spring vents observed in the northern of two dive sites (Spring Group-2) located north of the Port of Mangalia adjacent to Saturn Beach that were surveyed on October 1, 2020.

All of the spring vents were marked by lower salinity than the surrounding water to which they discharge. Most of the spring vents were also marked by lower dissolved oxygen (DO) values. Some were marked by lower pH values. No strong correlation to temperature was observed though one of the spring vents in the SpringGroup-2 area was marked by higher temperature than in the surrounding water. Parameter vs. time plots for each of the two survey dives are provided as Figure 11 and Figure 13. The values measured at the individual spring vents are compared to the range of values measured in the surrounding ambient water in Figure 12 and Figure 14. The raw and processed data are available online (see Appendix IV).

5.3.3. Transit Casts

Thirty (30) CTD casts were performed at approximately regular intervals along the entire length of both transits across the Black Sea (west-to-east from Mangalia to the Georgia coast, and east-to-west from the Georgia coast to Mangalia). Casts were performed every six hours at the beginning of each watch shift. Distance between the casts ranged between 24 and 42 nautical miles (44-78 km) due to variations in the speed of the vessel (approximately 4-7 kts).

Temperature vs. depth and salinity vs. depth plots derived from each of the 30 CTD casts performed along the transits across the Black Sea are depicted on Figure 15. The transit values recorded in the shallow depths (<10m) demonstrate significant variability in temperature and salinity relative to the values measured within the Mangalia survey area (Figure 15). Temperatures recorded in the transit casts were however significantly warmer than those measured in the spring group areas (Figure 15).

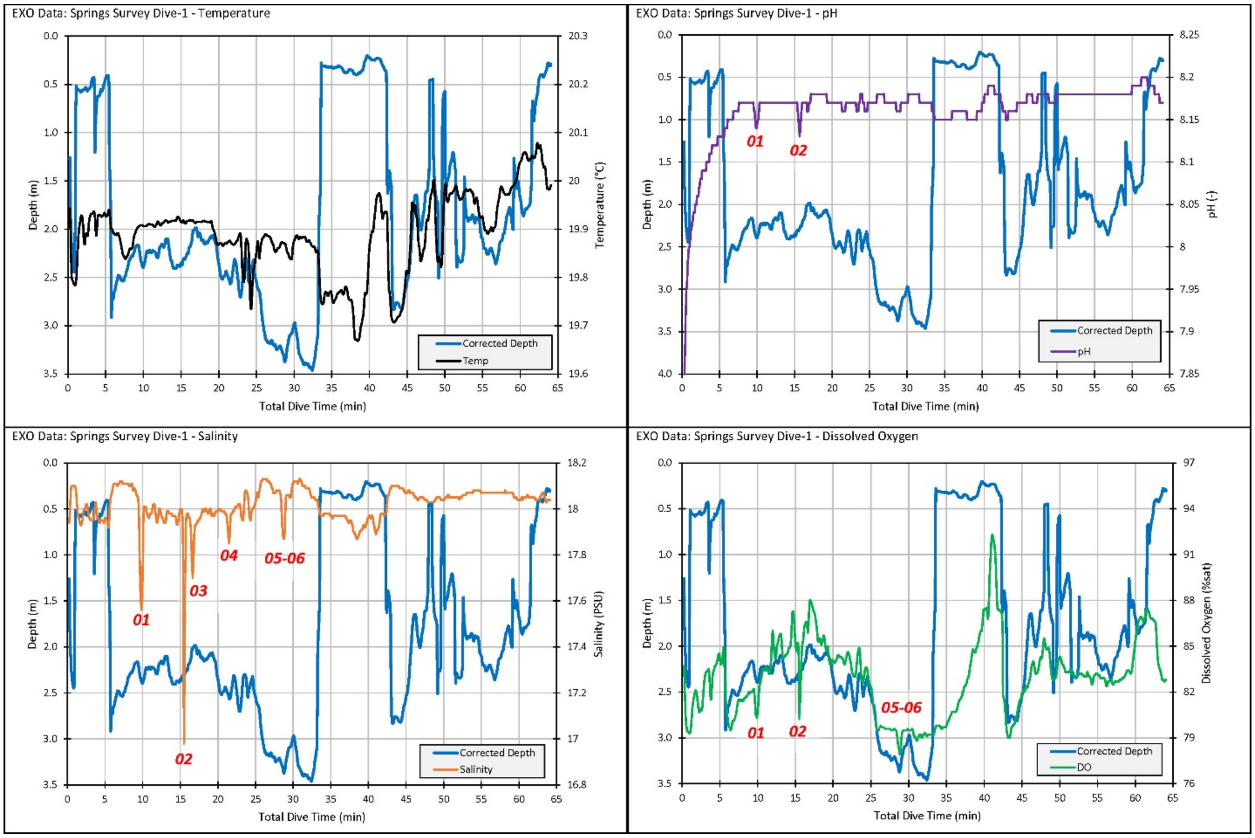


Figure 11. Parameter vs. time plots showing the variation in temperature, salinity, pH, and DO measured during the survey dive conducted on October 1, 2020 in the SpringGroup-1 area located north of the Port of Mangalia adjacent to Saturn Beach.

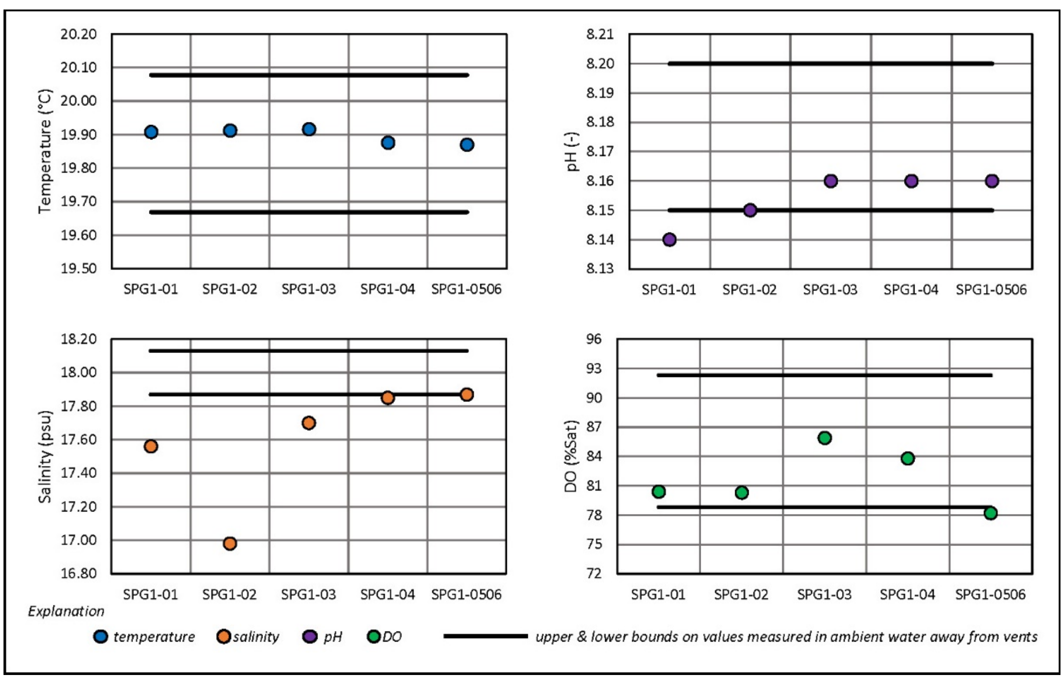


Figure 12. Comparison of parameter values measured at the spring vents in the SpringGroup1 area to the range of values measured in the ambient water away from the vents (>=30 seconds before and after the vent measurements).

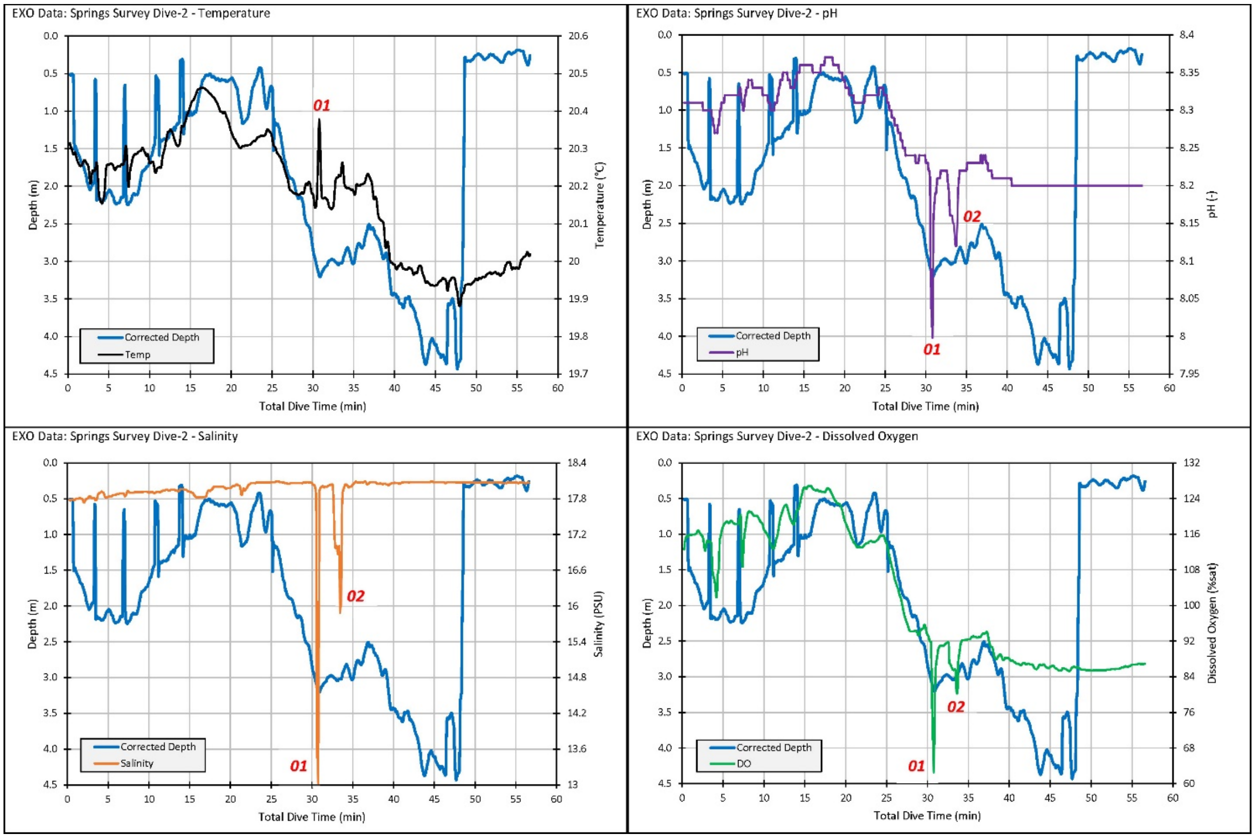


Figure 13. Parameter vs. time plots showing the variation in temperature, salinity, pH, and DO measured during the survey dive conducted on October 1, 2020 in the SpringGroup-2 area located north of the Port of Mangalia adjacent to Saturn Beach.

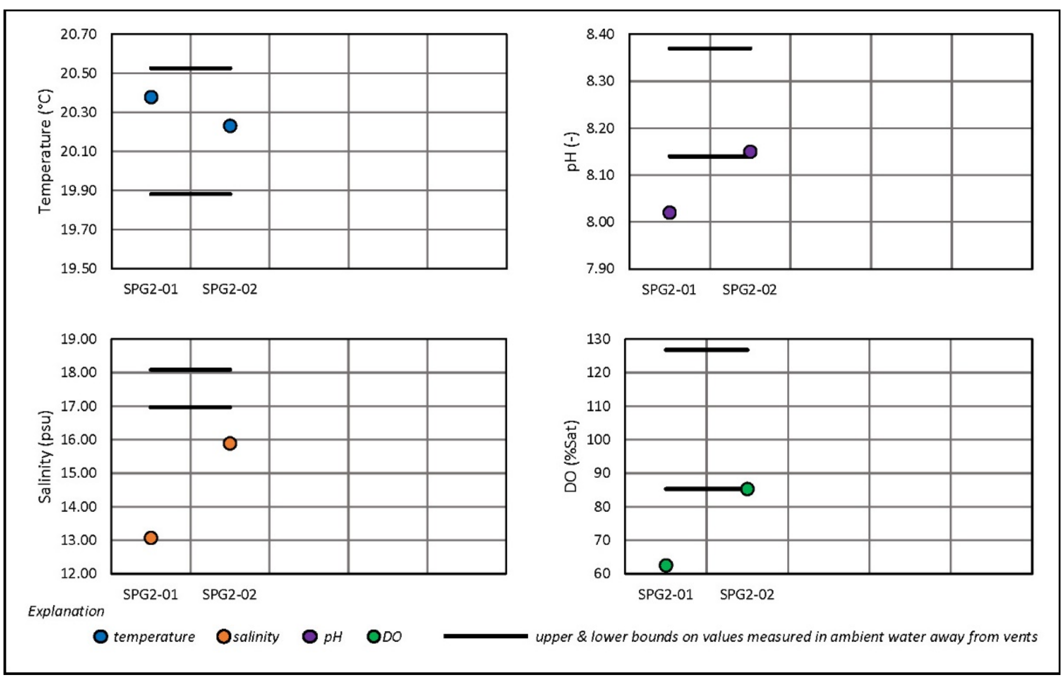


Figure 14. Comparison of parameter values measured at the spring vents in the SpringGroup2 area to the range of values measured in the ambient water away from the vents (>=30 seconds before and after the vent measurements).

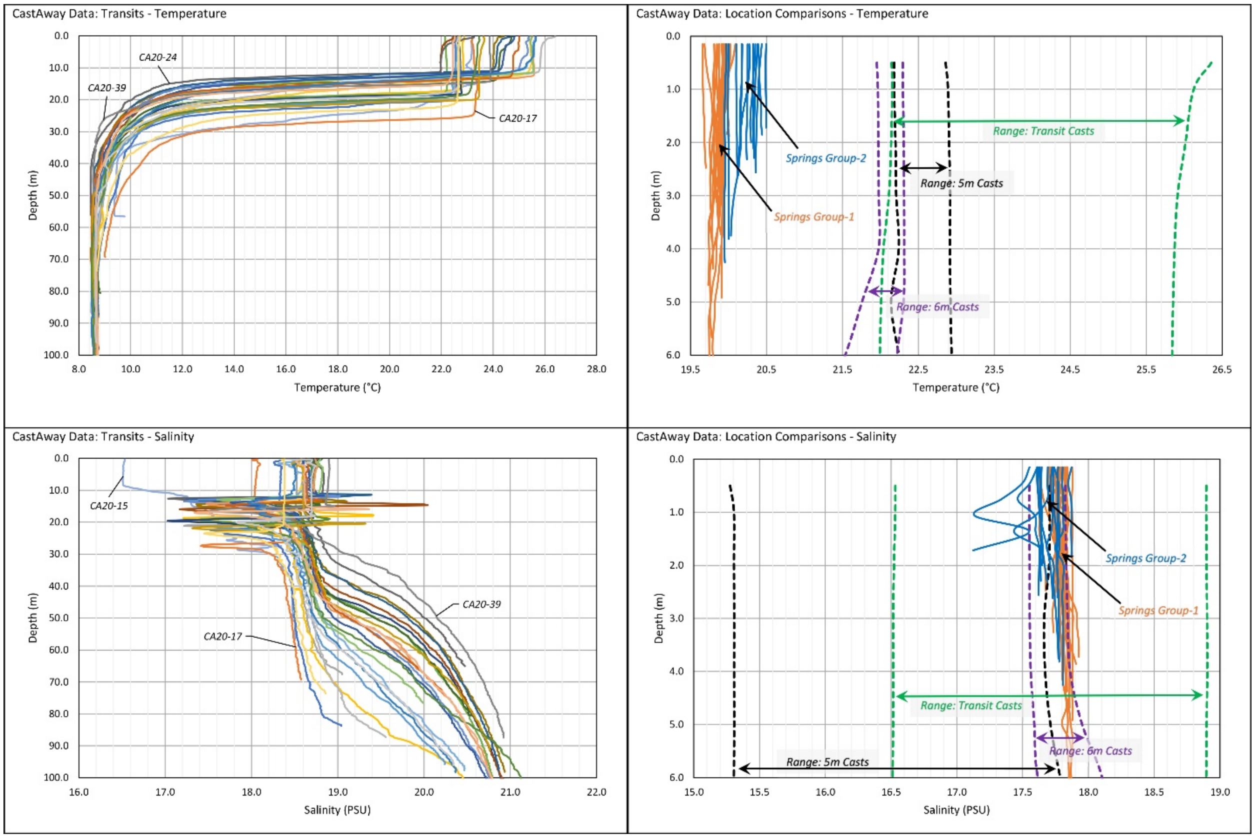


Figure 15. Temperature vs. depth and salinity vs. depth plots (left side plots) derived from CTD casts performed along the transits across the Black Sea; and comparison of the parameter vs. depth profiles measured in the Mangalia survey area to the range in values measured at the same depths along the transits (right side plots).

6. Discussion

Eight spring vents in the Mangalia survey area were observed, recorded and characterized during the 2020 Black Sea survey. Prolific growth of white bacteria was observed at all spring vents and smaller quantities of bacteria were observed to be covering the substrate in several other areas between the obvious vents. A mild sulfur smell was observed at the surface in the general vicinity of the shallowest spring vents and personal communication with Dr. Virgil Dragusin and Mr. Mihai Baciu indicates that the groundwater in this region contains significant levels of sulfur compounds. It is therefore reasonable to expect that all spring vents in the region will likely be associated with the same or similar levels of visible bacteria. Further personal communications with Dr. Virgil Dragusin and Mr. Mihai Baciu indicate that piezometric heads in the region upgradient of the sea do not exceed 1 atm. It is therefore reasonable to expect that offshore spring discharge is likely limited to water depths of less than 10m.

The data collected during this study supports the hypothesis that spring discharge is associated with lower salinities than the values typical of the coastal Black Sea though the deviations may only be obvious when evaluated locally. The lowest salinities measured at the spring vents (occurring in the SpringGroup2 area) were lower than the lowest values recorded in the shallow waters along the transits across the Black Sea.

Temperatures recorded in the spring group areas showed a significantly stronger deviation (colder) than the values recorded in the shallow waters along the transits across the Black Sea. Locally, however, temperature values did not differ significantly between the spring vents and the surrounding ambient waters. Values for pH and dissolved oxygen did not differ greatly from the values measured in the surrounding ambient waters though both parameters consistently fell at or below the low end of the observed range in the surrounding ambient water.

The data and observations collected in the Mangalia area thus far indicate the following.

5. SGD is occurring in the form of discrete small magnitude spring vents as well as disperse flows emanating from rubbelized sections of the substrate.
6. SGD is likely dispersed across a broad section of the coast proximal to Mangalia but is likely limited to water depths less than 10m.
7. Where it occurs, SGD is distinguishable from the surrounding ambient water by lower salinities though the deviations may only be identifiable when evaluated locally.
8. Extensions of the diving and casting surveys to the north and south of the two dive sites surveyed in October 2020 will likely reveal a substantial number of additional spring vents and areas of disperse SGD.

7. Recommendations

7.1. Mangalia

12. Complete and submit the permit application to the Romanian Hydrographic Directorate at least 3 months prior to the next intended survey period.
13. Develop and secure a collaboration agreement with the Speleological Institute Emil Racovita citing Dr. Virgil Dragusin and Mr. Mihai Baciu as primary collaborators.
14. Target future diving surveys to water depths of less than 10m and leverage diver propulsion vehicles (DPVs) to cover substantially larger portions of the coast line.
15. Use surface marker buoys to mark the locations of each spring vent.
16. Continue to measure CTD, pH, and DO at the spring vents and the ambient waters such that better correlations can be drawn between those parameter values and SGD in coastal Romanian waters.
17. Perform surface casts using the EXO multi-parameter data sonde such that better correlations can be drawn between pH and DO values in the spring vents and values associated with coastal and offshore waters in the Black Sea.

7.2. Georgia

1. Develop and secure a collaboration agreement with the Georgian Geothermal Association citing Dr. George Melikadze as the primary collaborator.
2. Obtain and invitation letter from Dr. Melikadze prior to arriving in the Black Sea.
3. Work with Dr. Melikadze to refine survey targets and strategies to capitalize on local knowledge.
4. In the absence of local knowledge, continue to target the steep bathymetric contours between water depths of 30-80 meters as dive target areas with the primary goal being to find caves and potentially locations of present or historical SGD in the rocky slopes.
5. Add surveys in water depths of less than 10m to determine if SGD is similar to that occurring in Romania.

8. References

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Maritime Hydrographic Directorate. Website: https://www.dhmfn.ro/index_en.shtml.

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Appendix I
Maps

Appendix II
Survey Plans

Appendix III
Documentation on the CTD and Multi-parameter Data Sondes

Appendix IV
Raw and Processed CTD and Multi-parameter Data

provided electronically at:

https://www.dropbox.com/sh/6ohci42n7l81648/AABlmmhYZ1dirQse93Z5BqUda?dl=0

Appendix V
High-resolution Photos of Spring Vents

provided electronically at:

https://www.dropbox.com/sh/6ohci42n7l81648/AABlmmhYZ1dirQse93Z5BqUda?dl=0

Appendix VI
Videos of Spring Vents

provided electronically at:

https://www.dropbox.com/sh/6ohci42n7l81648/AABlmmhYZ1dirQse93Z5BqUda?dl=0