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City of San Diego
Public Utilities Department

March 2022

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APPENDIX D

PLUME BEHAVIOR AND TRACKING

City of San Diego
Public Utilities Department

March 2022

APPENDIX D

Plume Tracking and Behavior

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Plume Tracking and Behavior

SECTION D-1 | SUMMARY OF FINDINGS

The City of San Diego (City) utilized specialized monitoring techniques to assist in the collection of oceanographic data surrounding the Point Loma Ocean Outfall (PLOO) to better understand the dispersion of wastewater discharged to the Pacific Ocean. Through a combination of fixed grid sampling, real time monitoring and adaptive surveys, the City collected a range of data between 2014 and 2020, both spatially and temporally, via various instruments, to track the trajectory of the wastewater plume. In isolation, none of the instruments used were sufficient to fully assess the plume's behavior, but in combination the data gathered were significantly more insightful. As a result of this comprehensive data collection effort, observations have confirmed that the Point Loma wastewater effluent plume generally remains in offshore waters and does not rise to the surface. These observations support previous studies showing that there is no evidence that wastewater discharged from the Point Loma Ocean Outfall has ever reached the shoreline or had any significant impact on state recreational waters.

SECTION D-2 | INTRODUCTION

The City collects a comprehensive suite of oceanographic data utilizing a range of methods and instrumentation, including, but not limited to, Conductivity, Temperature, Depth (CTD), Acoustic Doppler Current Profilers (ADCP), Real-Time Oceanographic Mooring Systems (RTOMS), and Remotely Operated Towed Vehicles (ROTVs). These instruments are used to assess water quality and hydrography surrounding the PLOO to inform whether treated wastewater discharged to the Pacific Ocean has a negative impact on the local environment and to better understand the behavior of the wastewater plume.

Historically, the City has assessed the fate and transport of the wastewater plume via a fixed grid of water quality stations utilizing CTD and bacteriological data (for example, see City of San Diego 2020b). Following an independent review of the City's Ocean Monitoring Program (SIO 2004), the City collaborated with Scripps Institution of Oceanography (SIO) to develop and conduct enhanced monitoring intended to provide an improved understanding of the density structure, physical circulation, and current movement patterns in local coastal waters surrounding the PLOO. Initially, non-telemetered moored temperature loggers (thermistor strings) and ADCPs were utilized to characterize the thermocline structure and current regime in the area surrounding the PLOO (Storms et al. 2006).

Subsequent studies of the fate and behavior of wastewater discharged to the ocean via the PLOO included recommendations to use RTOMS and advanced sampling technologies (e.g., autonomous underwater vehicles or ROTVs) to better understand near-shore coastal water quality and the impacts of local ocean currents and tidal fluxes on effluent plume dynamics (Rogowski et al. 2012a, 2012b, 2013). Based on these recommendations, the City, U.S. Section of the International Boundary and Water Commission (USIBWC), San Diego Regional Water Quality Control Board (SDRWQCB), and US Environmental Protection Agency (USEPA) reached an agreement that initial plume tracking and real-time monitoring requirements for the PLOO region should include, but not be limited to, the following main elements:

> (1) design and installation of a permanent RTOMS located near the north diffuser leg of the PLOO;
>
> (2) development of a schedule and monitoring work plan for implementation and testing of the RTOMS, including data acquisition and processing (City of San Diego 2018b);
>
> (3) networking the RTOMS to be fully compatible with an additional system, which is operated by SIO in the coastal waters approximately 100 meters (m) depth off the City of Del Mar as well as a similar City-owned platform near the terminus of the South Bay ocean outfall;
>
> (4) development of a schedule and work plan for using advanced oceanographic sampling instrumentation and technologies, such as an ROTV, in conjunction with the RTOMS to enhance the collection of water quality data and provide high-resolution maps of plume dispersion and location (City of San Diego 2020a).

This appendix presents a review of four primary methods by which the City has endeavored to monitor the discharge from the PLOO and track the subsequent behavior of the resultant plume. The four primary methods that the City has utilized to track the plume are as follows: 1) CTD surveys; 2) non-telemetered ("static") ADCP deployments; 3) RTOMS deployments; 4) ROTV surveys. This review aims to evaluate the efficacy of using each of these instrument systems to enhance the interpretation of plume dynamics around the PLOO.

SECTION D-3 | METHODS

CTD

Data Collection

A total of 36 offshore water quality monitoring stations were sampled quarterly to assess coastal oceanographic conditions in the PLOO region (Figure D-1). These stations are designated F1–

F36 and are located along, or adjacent to, the 18, 60, 80, and 98-m depth contours. All 36 stations were monitored during winter (February or March), spring (May), summer (August), and fall (November), and were typically sampled over a three to four-day period during each survey. Sampling at an additional eight kelp bed stations off Point Loma (stations A1, A6, A7, C4–C8) was conducted four to five times per month, to meet bacterial monitoring requirements. However, only data collected during years when sampling methods at the kelp stations were compatible with methods at the offshore stations (i.e., 2018-2020) are included in the analyses presented, and data were limited to those collected within one week of the quarterly offshore station surveys. Oceanographic data were collected at each station using a CTD fitted with a rosette water sampler. The City's CTD collects continuous measurements of water temperature, conductivity (used to calculate salinity), pressure (used to calculate depth), dissolved oxygen (DO), pH, transmissivity (a proxy for water clarity), chlorophyll *a* fluorescence (a proxy for phytoplankton), and colored dissolved organic matter (CDOM) fluorescence.

Data Analysis

Presence or absence of the wastewater plume at the PLOO stations from 2014 through 2020 was estimated by evaluating a combination of oceanographic parameters (i.e., detection criteria). Previous monitoring results have consistently shown that the PLOO plume remains trapped below the pycnocline with no evidence of surfacing throughout the year (City of San Diego 2015, 2016, 2018a, 2020b, Hess 2021, Rogowski et al. 2012a, b, 2013). Water column stratification and pycnocline depth were quantified using buoyancy frequency (BF, cycles/min) calculations for each quarterly survey. This measure of the water column's static stability was used to quantify the magnitude of stratification for each survey and was calculated as follows:

$$\mathrm{BF} = \sqrt{}g/\rho * (d\rho/dz)$$

where g is the acceleration due to gravity, ρ is seawater density, and dρ/dz is the density gradient (Mann and Lazier 1991). The depth of maximum BF was used as a proxy for the depth at which stratification was the greatest. If the water column was determined to be stratified (i.e., maximum BF > 5.5 cycles/min), subsequent analyses were limited to depths below the pycnocline.

Identification of potential plume signals were determined for each quarterly survey at each monitoring station based on a combination of CDOM, chlorophyll *a*, and salinity levels, as well as a visual review of the overall water column profile. Detection thresholds for the PLOO stations were set adaptively for each quarter according to the criteria described in the City's annual report (City of San Diego, 2016). These thresholds are based on observations of ocean properties specific to the distinct PLOO monitoring region, and thus constrained to only this region. Finally, water column profiles were visually interpreted to remove stations with spurious signals (e.g., CDOM signals near the seafloor that were likely caused by sediment resuspension).

ADCP

Data Collection and Analyses

Non-telemetered (static) upward-facing bottom-mounted ADCPs (Teledyne RD Instruments 300 kHz Workhorse Monitor) were deployed at the terminal end of the PLOO (Figure D-1). Data were collected every five minutes in 4-m depth bins, ranging from 9 to 93 m. Data from the top eight meters were eliminated due to backscattering of the acoustic signal from the air-ocean interface. Ocean current data collected by static ADCP instruments were checked for quality by eliminating measurements that did not meet percent good criteria (i.e., minimum PG4 reading of 80) or exceeded the velocity threshold of 1 m/s. Following this initial screening, tidal frequency data were removed using the PL33 filter (Alessi et al. 1984), compass direction was corrected to true north (+12.8 degrees), and data were hourly averaged. For this appendix, all reportable static mooring deployment data from 2014 to 2020 were summarized by season and depth bin. Summaries of seasonal periods aligned with quarterly water quality sampling: winter (January–March); spring (April–June); summer (July–September); fall (October–December).

RTOMS

Deployment and Configuration

The RTOMS are anchored buoys suspended in the water column collecting physical and biogeochemical observations, with a primary role to measure temporal variability through the collection of continuous data and to provide near-real time information on changing conditions. The Point Loma RTOMS was initially anchored at a depth of approximately 100 m, just to the west of the northern diffuser leg of the PLOO from March 2018 to March 2019. For the second deployment, from October 2019 through September 2020, the anchor location was adjusted slightly to just east of the northern leg (Figure D-1, see City of San Diego 2020b for additional details). The RTOMS was outfitted with a series of instruments at various depths throughout the water column (see City of San Diego 2020b Appendix B for details on configuration). Critical parameters that were measured on a real-time basis included temperature, conductivity (salinity), total pH, DO, dissolved carbon dioxide (xCO_2), nitrogen as nitrate + nitrite, chlorophyll *a*, CDOM, backscatter (turbidity), biological oxygen demand (BOD), and current direction and velocity. All parameters were recorded at 10-minute intervals, with the exception of nitrogen, which was recorded at 1-hour intervals, and xCO_2, which was recorded at 10-hour intervals.

Data Collection

Real-time data management and integration support was provided by SIO. This included, but was not limited to:

(1) maintaining the data management system (i.e., servers and modems);

(2) conducting preliminary data processing and verification;

(3) hosting real-time data and posting data to an accessible website (see: http://mooring-dev.ucsd.edu/dev/ploo/ploo_03/); and

(4) providing ongoing technical support and training for real-time mooring technology to City staff.

SIO was also responsible for networking the PLOO real-time mooring with the City's other ROTMS located near the terminus of the South Bay ocean outfall (SBOO) as well as the SIO Del Mar mooring to form a comprehensive state-of-the-art ocean observing system for the San Diego region.

Data Processing and Analysis

Prior to any data analysis, all data were subject to a comprehensive suite of quality assurance/quality control (QA/QC) procedures following Quality Assurance of Real-Time Oceanographic Data (QARTOD) methodologies (US IOOS 2020). Methodology for ADCP data differed slightly and is described separately. For all other sensor data, QARTOD tests were applied to all data prior to analysis (City of San Diego 2020b). In addition to these automated tests, all data were reviewed manually and flagged to identify questionable data, which may result from biofouling, interference from bubbles, sensor drift, or other malfunctions. A detailed log of data flagged manually by parameter, site, depth, and date range is available upon request. After review, all data that were flagged as suspect or erroneous, either manually or from automated QARTOD tests, were excluded from further analyses and are not presented. In addition, equipment problems and sensor failures resulted in some data gaps during deployments. Note that pH is reported in total scale from moored instruments with a more accurate calibration and measurement method for seawater, while pH has been reported in National Bureau of Standards (NBS) scale from CTD casts, and it is not recommended to convert between these scales (Marion et al. 2011).

As with the static ADCPs, ocean current data collected by downward-facing surface-mounted RTOMS ADCP instruments (Teledyne RD Instruments 300 kHz Workhorse Broadband) were checked for quality by eliminating those measurements that did not meet specific criteria. Only those data meeting the echo intensity variability criteria (i.e., coefficient of variation among the four beams of < 25%) were processed further. Following this initial screening, tidal frequency data were removed using the PL33 filter (Alessi et al. 1984), compass direction was corrected to true north (+12.8 degrees), and hourly averaged. These instruments also differed from the static ADCP in having either 1-m (deployment 1) or 2-m resolution (deployment 2).

ROTV

The ScanFish III is a wing-shaped ROTV programmed to track a fixed depth span in the water column, moving in an undulating pattern from surface to seabed, or moving in a terrain-following mode. Its large payload enables a variety of modular sensors to be outfitted to the vehicle frame. The City's current package includes a Sea-Bird SBE25Plus CTD with a Sea-Bird pump, temperature, conductivity and dissolved oxygen sensors, a Wetlabs Wetstar CDOM sensor, three Turner Designs fluorometers tuned for CDOM, Tryptophan and Optical Brightener (OB) measurements and a Chelsea BOD sensor.

City staff have been evaluating the use of a ROTV for plume tracking as part of an ongoing project (City of San Diego 2020a, c). The initial goal of the project was to compare towed CTD measurements from the ROTV to traditional fixed grid vertical-profile CTD measurements during each quarterly water quality sampling period in 2020 including winter (February 18-19), spring (May 19-21), summer (August 18-20), and fall (November 10-13). ROTV efforts in the first three quarters of 2020 were focused on cross-validation of ROTV data against CTD data. As such, the ROTV tows were conducted in parallel with regular quarterly water quality sampling (see City of San Diego 2021). The ROTV was towed through water quality stations along the 98, 80, and 60-m transects each quarter over three consecutive days (Figure D-2), except for the month of May, during which the 60-m transect and portions of the 80-m transect were not captured due to instrument failure after the first day of sampling. In November, ROTV surveys were conducted adaptively, so survey efforts were focused on areas and depths where there was evidence of the PLOO plume (typically where elevated CDOM and/or OB values were observed in real-time). ROTV surveys did not, therefore, follow the same spatial pattern as surveys conducted in other quarters. During all surveys, vessel speed while towing was kept below 11 knots. The tow rope length varied from 200 to 600 m depending on the depth of the transect and vessel speed. Data from the ROTV were continuously monitored in real-time to ensure instrument function. Fathometer readings from both the ROTV and the shipboard instruments were also closely monitored to ensure capture of the largest possible portion of the water column. To prevent altimeter errors, the ROTV was typically flown no less than 10-15 m below the surface, especially after May, when shallow depths were determined to be a cause of altimeter failure. To prevent collision with the seafloor, the ROTV was kept 5-15 m from the bottom. ROTV data QC is ongoing. For analyses presented herein, data outside of climatological ranges established for RTOMS QC have been flagged as suspect and removed from analysis, as well as data that appeared suspect upon first-pass manual QC.

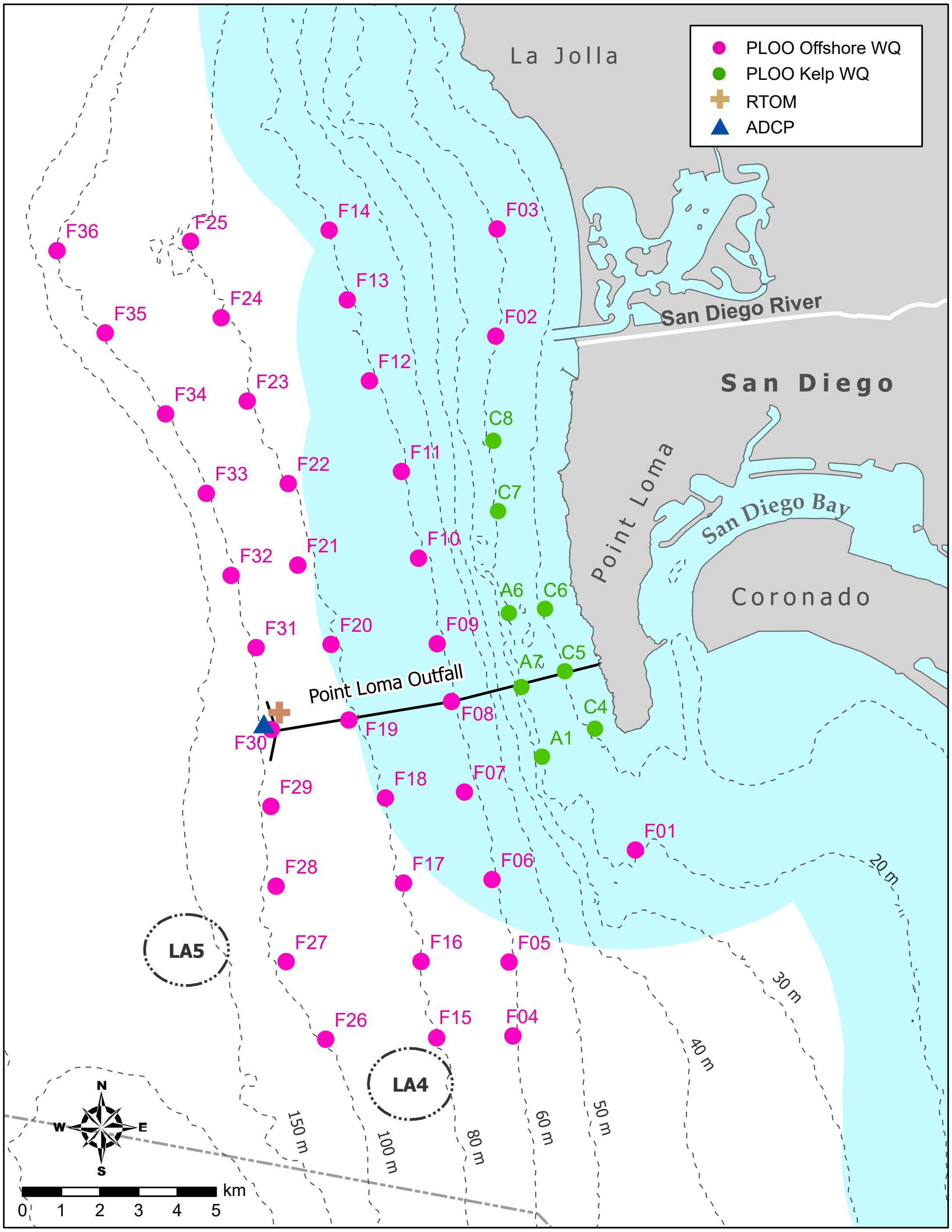


FIGURE D-1
Water quality (WQ) monitoring stations, non-telemetered ADCP and RTOMS locations sampled around the PLOO as part of the City of San Diego's Ocean Monitoring Program. Light blue shading represents State of California jurisdictional waters.

SECTION D-4 | RESULTS AND DISCUSSION

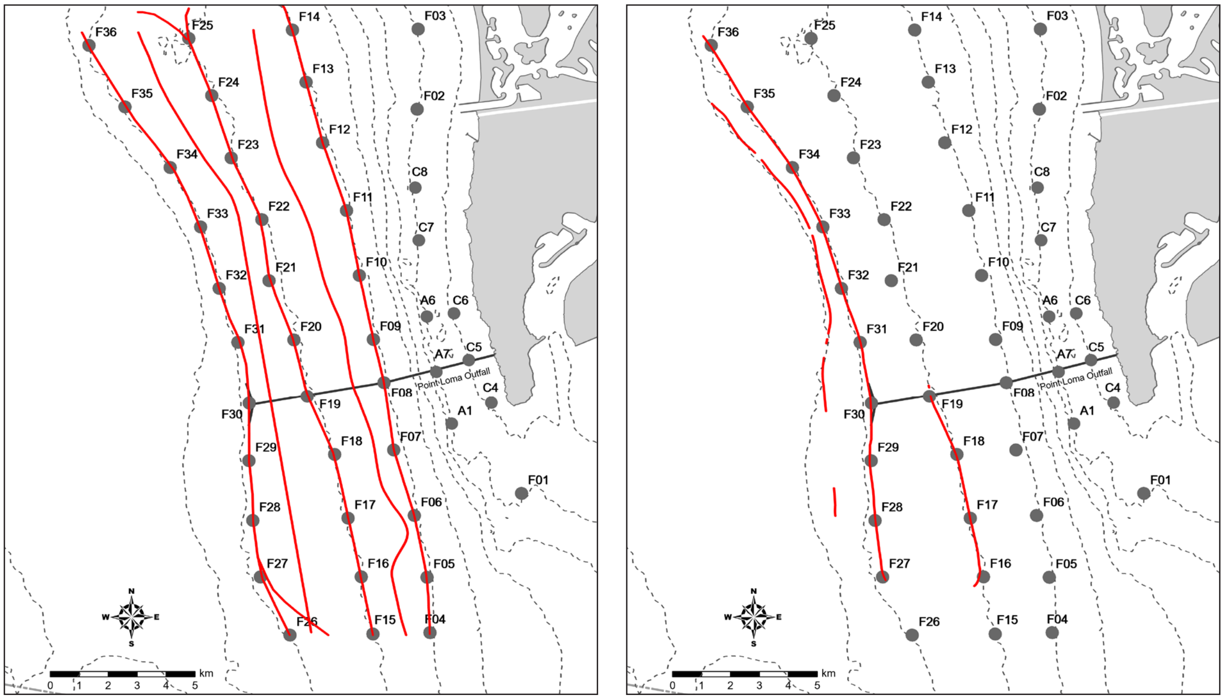
CTD

Utilizing traditional fixed grid sampling, the dispersion of the wastewater plume from the PLOO was assessed by evaluating the results of 1,068 CTD profile casts performed from 2014 through 2020. Based on the criteria described previously (City of San Diego 2016), the detection rate of a possible plume signal was just 19% (n=206 times) (Table D-1, Figure D-3). About 26% of possible plume detections (n=54) occurred at the three stations located closest to the outfall, (i.e., nearfield stations F29, F30, F31), while 31% occurred at farfield stations located along the 98-m depth contour, 26% occurred at farfield stations located along the 80-m depth contour, and 17% occurred at farfield stations along the 60-m depth contour. It is likely that not all of the possible plume detections at the farfield stations were associated with the wastewater plume, due to either their distance from the outfall or proximity to other known sources of organic matter such as Mission Bay, San Diego Bay, phytoplankton blooms or terrestrially-derived runoff plumes (see Rochelle-Newall and Fisher 2002, Romera-Castillo et al. 2010). Overall, the variation in plume dispersion observed off Point Loma from 2014 to 2020 (City of San Diego 2015, 2016, 2018a, 2020b, 2021) was similar to flow-mediated dispersal patterns reported previously for the region (Rogowski et al. 2012a, b, 2013).

Overall, 96% (n=198) of the possible plume detections occurred at depths below 40 m, and were never observed at depths above 24 m, even during periods of weak water column stratification (Table D-1, Figure D-3). These observations were further validated by ROTV data collected during 2020, which did not detect potential plume areas shallower than 25 m (see section below), and by historical satellite imagery observations that have never shown visual evidence of the plume surfacing (e.g., Svejkovsky 2011, Hess 2021; Appendix F).

ADCP

From 2014 through 2020, static mooring ADCP data have shown a consistent pattern of higher speed and more variable currents at shallow depths (i.e., less than 20 m) with more consistent, slower speeds in deeper waters near the terminus of the PLOO (Figure D-4). Although variation in speed exists on seasonal timescales (Table D-2), the overall axis of observations remains along a NW:SE trajectory (i.e., 316°:136°) (Figure D-4). Average speeds from all depths ranged from 45 to 155 millimeters per second (mm/s) in winter, 46 to 170 mm/s during spring, 48 to 150 mm/s in summer, and 56 to 132 mm/s in fall. Maximum speeds of over 700 mm/s were observed during May of 2014 in the 9-m depth bin while all depth bins had minimum speeds of less than 1 mm/s. These results are consistent with previous studies conducted in the region that demonstrate that local ocean currents tend to travel along-coast (Winant and Bratkovich 1981, Rogowski et al. 2012a).


Winter
Spring

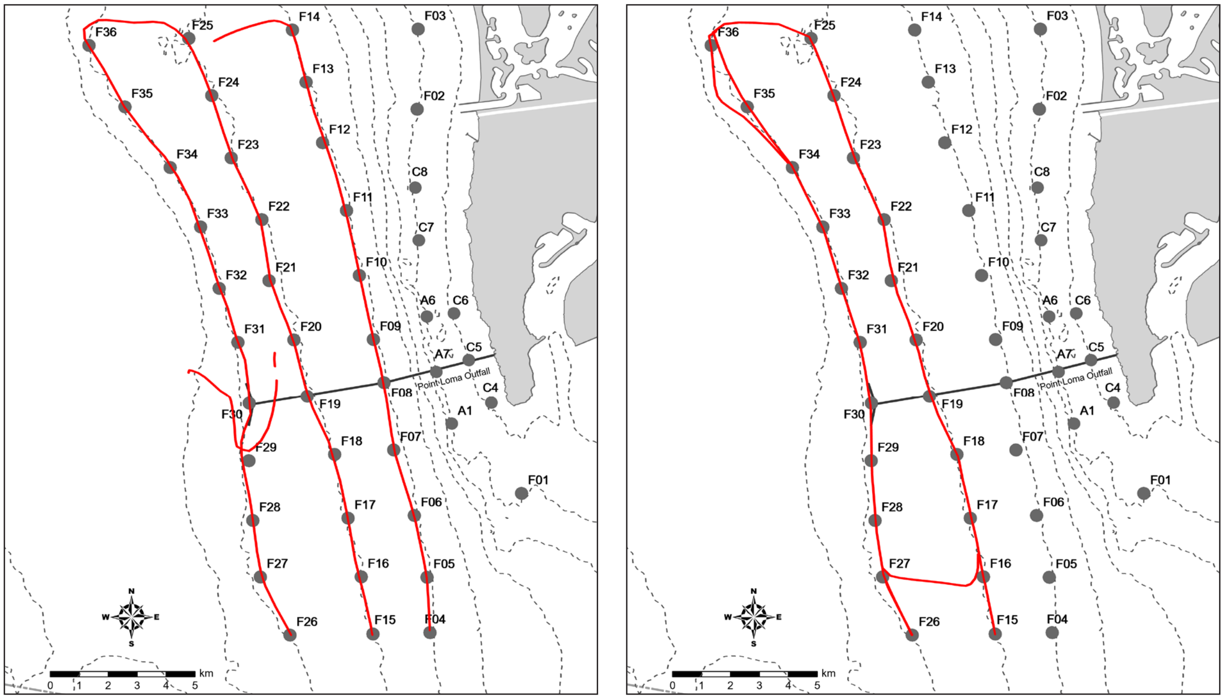

Summer
Fall

FIGURE D-2
ScanFish tow paths (in red) for each survey during 2020. Surveys were conducted over 1-3 days during each quarter. Water quality stations are shown as labeled grey circles.

TABLE D-1

Counts of possible plume detections at PLOO WQ stations sampled from 2014 through 2020.

	Season				
	Winter	**Spring**	**Summer**	**Fall**	**Total**
By Location (Depth Contour)					
60 m	13	14	2	6	35
80 m	21	20	9	3	53
100-m Farfield	11	10	26	17	64
100-m Nearfield	15	13	14	12	54
By Depth Range (m)					
21-30	2	0	0	1	3
31-40	1	1	0	3	5
41-50	8	13	1	3	25
51-60	14	19	6	4	43
61-70	9	14	19	14	56
71-80	19	7	10	10	46
81-90	5	1	10	3	19
91-100	2	2	5	0	9
Total Plume Detections	60	57	51	38	206
Total CTD Casts	267	267	267	267	1068

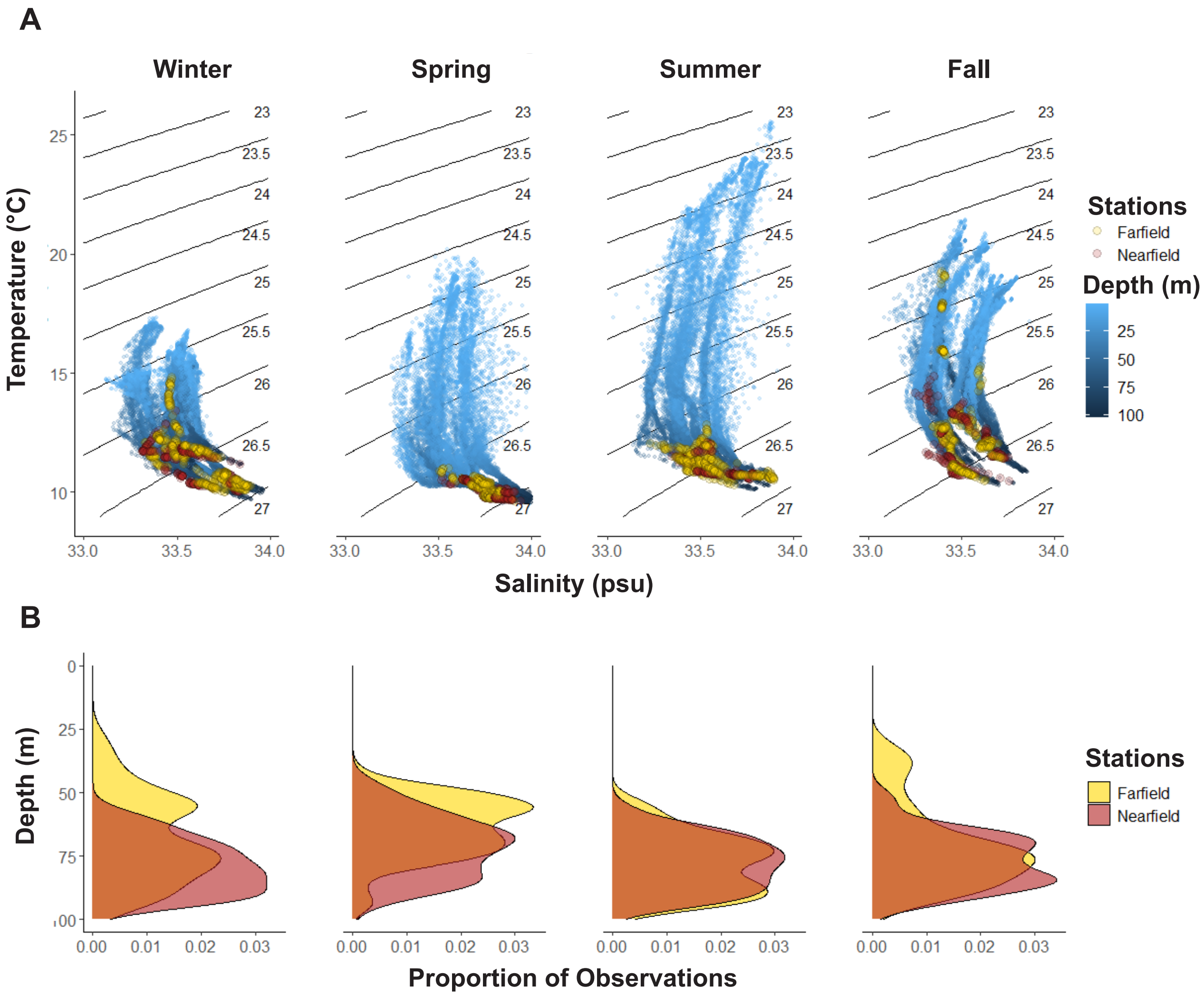


FIGURE D-3
(A) Temperature-Salinity (T-S) plots of CTD casts by season from 2014 to 2020 shaded by depth. Diagonal curving lines are isopycnals. Colored circles indicate depths with elevated CDOM for farfield (yellow) or nearfield (pink) stations. (B) Depth profiles of CDOM observations by season for farfield (yellow) and nearfield (pink) stations.

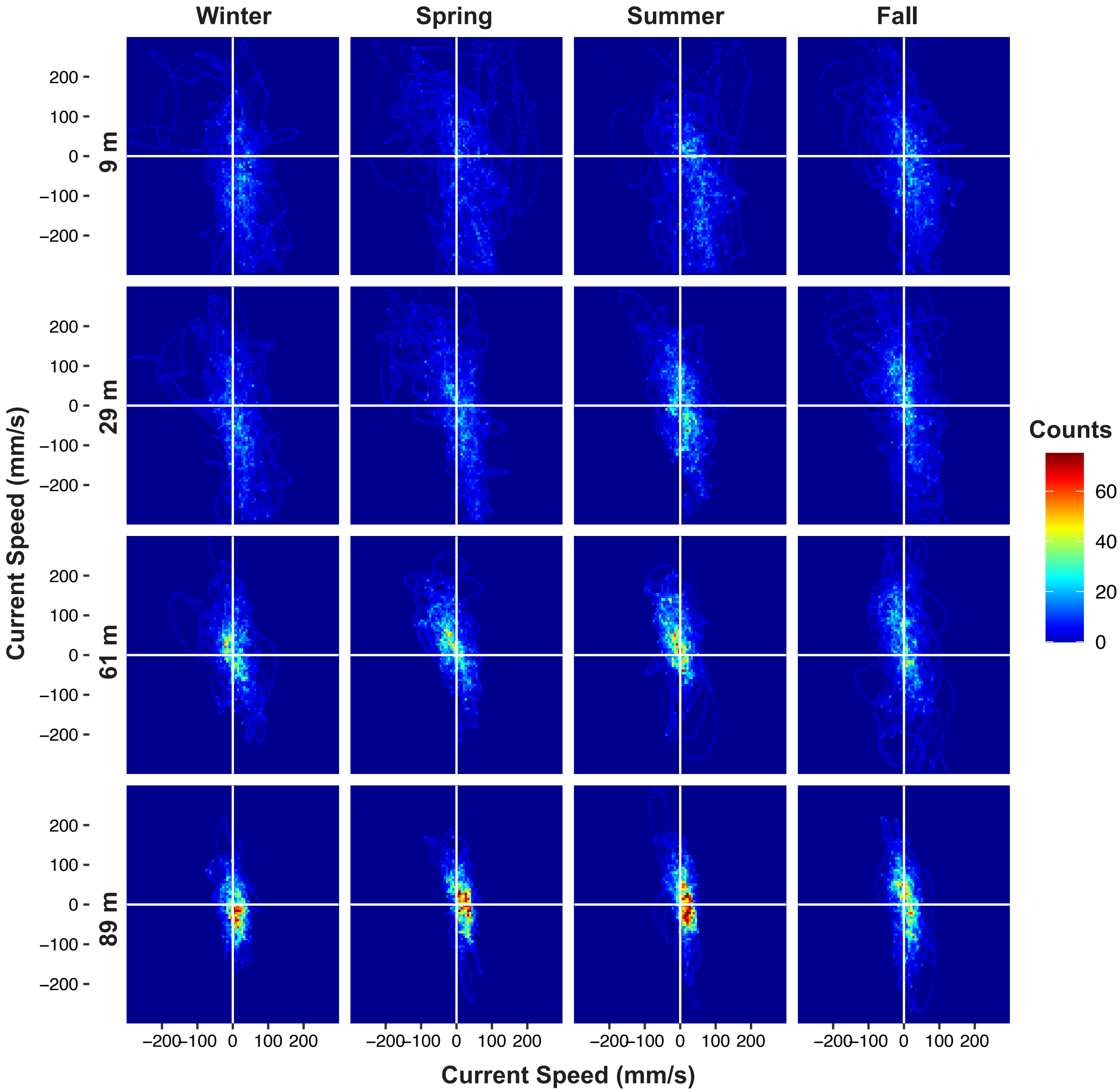


FIGURE D-4

Frequency distribution by season and select depth bins of low-pass filtered (tides removed) hourly averaged current speed (mm/s) and direction from the PLOO static ADCP deployments from 2014 through 2020. On the x-axis, positive values indicate an eastward direction and negative values indicate westward. On the y-axis, positive values indicate a northward direction and negative values indicate southward.

TABLE D-2
Summary of current velocity magnitude and direction from the bottom-mounted 100-m ADCP at the PLOO from 2014 to 2020. Data are presented as seasonal means with 95% confidence intervals (CI). Minimum and maximum angles of velocity are not shown due to the circular nature of the measurement.

		Magnitude (mm/s)				Angle	
Quarter	**Depth (m)**	**Min**	**Max**	**Mean**	**95% CI**	**Mean**	**95% CI**
Winter	9	2	664	139	2	167	71
	13	1	654	155	2	175	71
	17	1	560	148	2	172	71
	21	1	524	140	2	171	71
	25	1	491	132	2	170	71
	29	0	467	124	2	168	70
	33	0	451	117	2	167	70
	37	0	430	109	2	166	69
	41	0	403	101	2	163	69
	45	1	404	93	1	157	68
	49	0	406	85	1	143	68
	53	0	398	77	1	101	67
	57	0	376	72	1	45	67
	61	1	342	68	1	24	67
	65	0	311	65	1	17	66
	69	1	286	62	1	18	66
	73	1	266	60	1	25	66
	77	0	258	58	1	36	66
	81	1	243	55	1	57	68
	85	0	230	52	1	96	70
	89	1	212	49	1	148	68
	93	0	179	45	1	184	63
Spring	9	1	707	170	2	151	70
	13	1	526	160	2	169	67
	17	2	471	148	2	172	67
	21	1	440	134	2	173	67
	25	1	430	122	2	173	67
	29	1	404	111	2	174	66
	33	2	372	103	1	163	66
	37	0	339	96	1	12	65
	41	0	305	89	1	359	65
	45	1	274	84	1	354	64
	49	0	269	80	1	350	63
	53	1	274	77	1	347	63
	57	1	270	75	1	342	63

TABLE D-2 *continued*

		Magnitude (mm/s)				Angle	
Quarter	**Depth (m)**	**Min**	**Max**	**Mean**	**95% CI**	**Mean**	**95% CI**
	61	0	254	73	1	338	63
	65	1	243	70	1	336	63
	69	1	239	67	1	337	64
	73	0	254	64	1	341	66
	77	1	266	60	1	351	68
	81	0	266	58	1	7	70
	85	0	260	56	1	33	70
	89	0	247	53	1	64	70
	93	0	215	46	1	97	68
Summer	9	2	693	149	2	151	71
	13	1	512	138	2	160	66
	17	0	652	126	1	163	67
	21	0	657	110	1	161	68
	25	1	643	97	1	152	69
	29	1	620	86	1	111	69
	33	1	599	79	1	34	69
	37	1	579	75	1	15	69
	41	0	552	73	1	10	69
	45	0	516	72	1	7	69
	49	1	485	72	1	4	68
	53	0	466	72	1	359	68
	57	0	452	71	1	354	68
	61	1	433	70	1	348	68
	65	0	418	69	1	342	68
	69	1	410	68	1	340	69
	73	2	399	65	1	342	70
	77	0	387	62	1	348	72
	81	1	365	59	1	0	74
	85	0	336	57	1	21	74
	89	0	301	55	1	54	72
	93	1	263	48	1	93	69
Fall	9	0	452	110	1	157	68
	13	0	489	132	2	177	70
	17	1	438	126	2	173	70
	21	1	425	119	2	164	69
	25	0	428	114	1	16	70
	29	1	410	110	1	8	70

TABLE D-2 *continued*

		Magnitude (mm/s)				Angle	
Quarter	**Depth (m)**	**Min**	**Max**	**Mean**	**95% CI**	**Mean**	**95% CI**
	33	1	394	107	1	7	70
	37	1	391	104	1	10	70
	41	1	384	101	1	13	70
	45	0	379	100	1	15	70
	49	0	372	99	1	15	70
	53	1	367	97	1	12	71
	57	1	361	95	1	9	71
	61	1	343	92	1	4	71
	65	0	316	90	1	359	71
	69	0	305	86	1	357	71
	73	1	308	83	1	357	71
	77	0	316	80	1	0	72
	81	1	319	76	1	8	73
	85	0	307	72	1	26	74
	89	0	273	67	1	75	73
	93	0	238	56	1	164	70

RTOMS

Ocean conditions surrounding the PLOO RTOMS that could potentially affect the dispersion of the wastewater plume were generally within historical ranges for the Point Loma monitoring region (e.g., City of San Diego 2020b, 2021). Ocean temperature, temperature gradients, salinity, density, and ocean currents showed typical seasonal patterns over both RTOMS deployments (Figures D-5, D-6), and align with the seasonality of the region (Terrill et al. 2009). Strong and persistent thermal stratification (at depths from near surface to 30 m) was observed from April through September, with some moderate stratification occurring in March and October through November. The weakest stratification was observed in the winter months (December through February). Density patterns closely followed temperature observations and align with the finding that density is primarily influenced by temperature differences in the region (Bowden 1975, Jackson 1986, Pickard and Emery 1990). In addition, other parameters, such as dissolved oxygen (DO), show a strong seasonal signal, with lower DO occurring during the spring at deeper depths along with high salinities and low temperatures (Figure D-7), likely corresponding to upwelling conditions bringing oxygen-poor water masses inshore (Jackson 1986).

Subsurface, relatively low salinities (<33.5 Practical Salinity Unit [PSU]) are frequently observed in the Point Loma region (City of San Diego 2020b), likely influenced by seasonal evaporation at the surface and the incursion of the low salinity and low temperature Pacific Subarctic water mass within the California Current System (Jones et al. 2002, Lynn and Simpson 1987). At the PLOO RTOMS, the lowest salinity excursions (<33.2 PSU) were typically observed from 60 to 89 m and occurred throughout the year regardless of season, as well as at a range of temperatures (Figure D-8). Salinity measurements from the RTOMS at these depths are lower than what has historically been reported from CTD data (City of San Diego 2018a, 2020b) or the more recent ROTV surveys (City of San Diego 2021) and are likely due to the presence of the PLOO effluent plume at depths greater than 45 m. Given the proximity of the mooring to the PLOO, its high frequency of sampling, and the reduced potential mixing of water masses by the suspended mooring instruments compared to large profiling or towed packages such as the CTD rosette (Paver et al. 2020) or ROTV, it is expected that the potential presence of the plume can be better discerned using salinity at the RTOMS. Although previous studies in the region also used salinity signatures to estimate effluent dilution near the outfall (e.g., Washburn et al. 1992), more recent work found it impractical to discern the effluent plume using weak salinity signatures alone and relied on additional identifying plume characteristics such as elevated CDOM (Rogowski et al. 2012a). For future deployments, auxiliary measurements (such as CDOM) will be relocated to the depth of lowest observed salinities (i.e. 75 m) to assist with plume detection.

Along with density structure, ocean currents play an important role in plume dispersion and

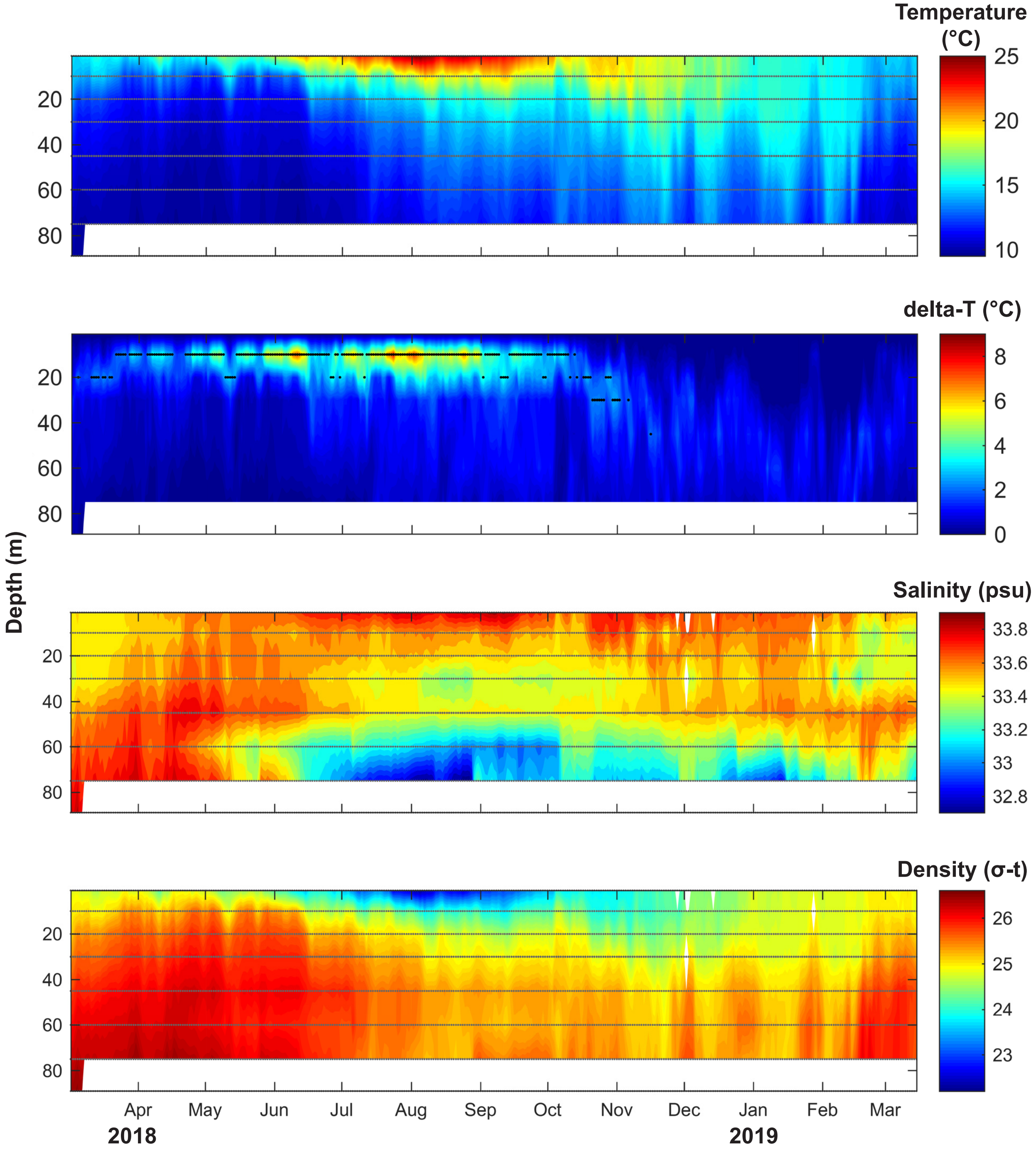


FIGURE D-5
Daily averaged ocean temperature, temperature differences (delta-T), salinity, density, north-south and east-west current speeds during the first deployment of the PLOO RTOMS (March 2, 2018 to March 15, 2019). White areas indicate loss of data due to instrumentation issues or failure to meet data quality criteria (see text). Grey lines on temperature, salinity, and density plots indicate positions of sensors. Black lines on delta-T plot indicate presence and depth of strong thermal stratification (≥2°C change over 10 m).

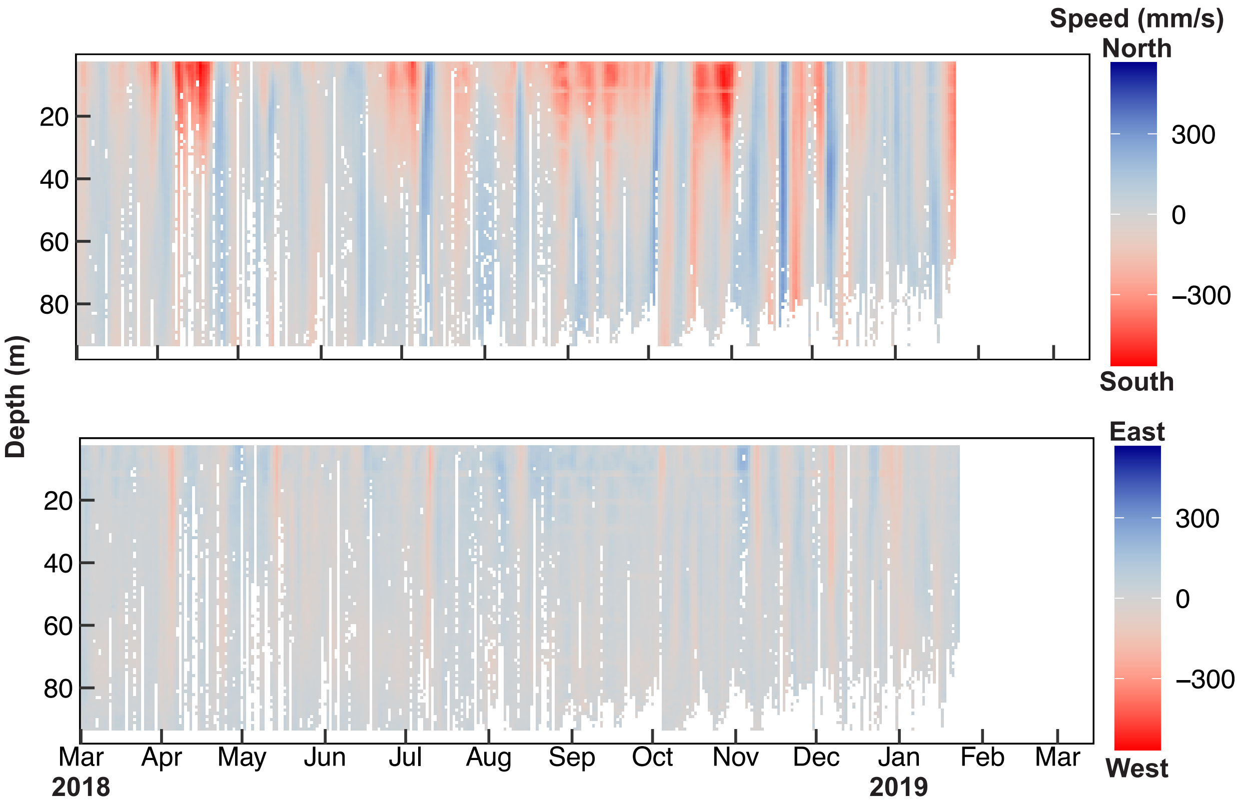


FIGURE D-5 *continued*

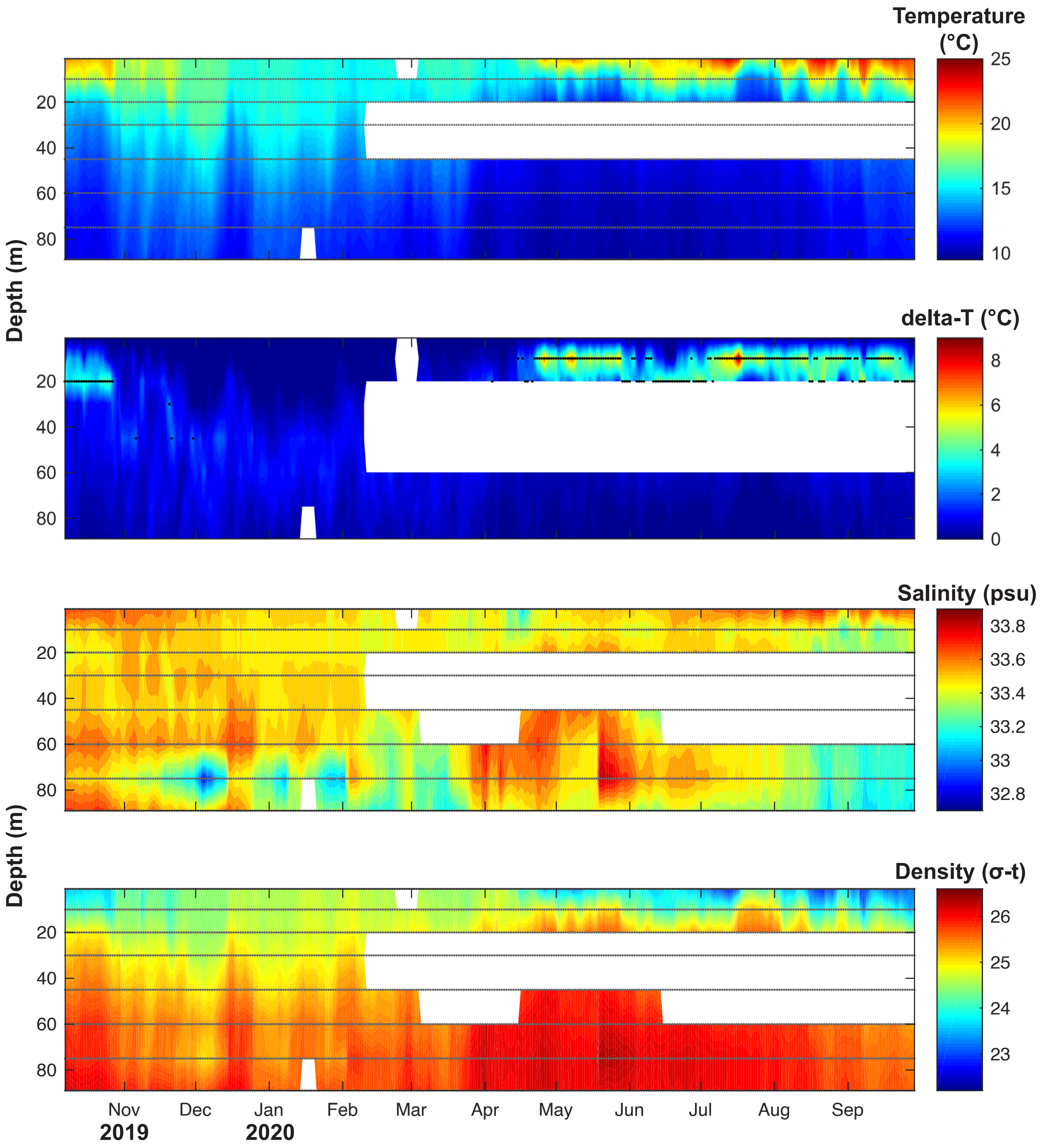


FIGURE D-6
Daily averaged ocean temperature, temperature differences (delta-T), salinity, density, north-south and east-west current speeds during the second deployment of the PLOO RTOMS (October 7, 2019 to September 29, 2020). White areas indicate loss of data due to instrumentation issues or failure to meet data quality criteria (see text). Grey lines on temperature, salinity, and density plots indicate positions of sensors. Black lines on delta-T plot indicate presence and depth of strong thermal stratification (≥2°C change over 10 m).

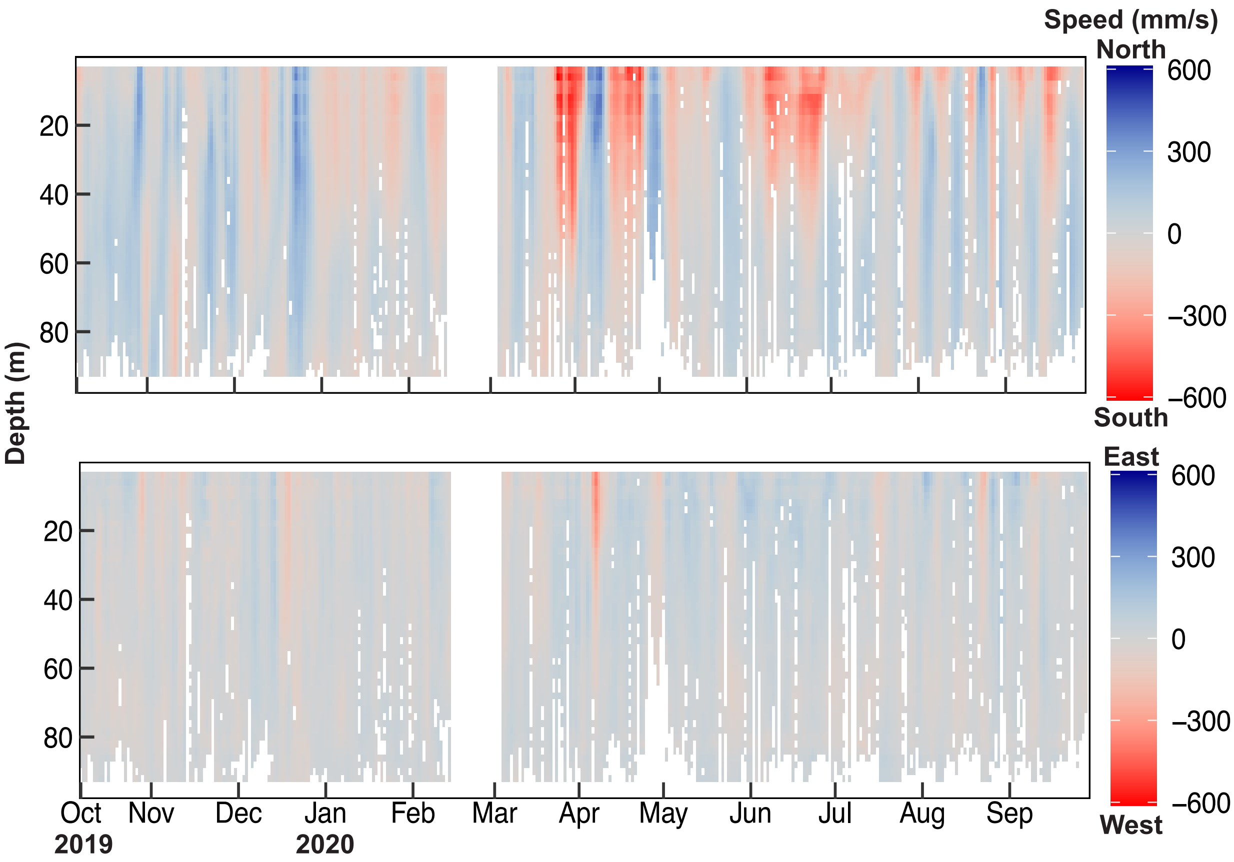


FIGURE D-6 *continued*

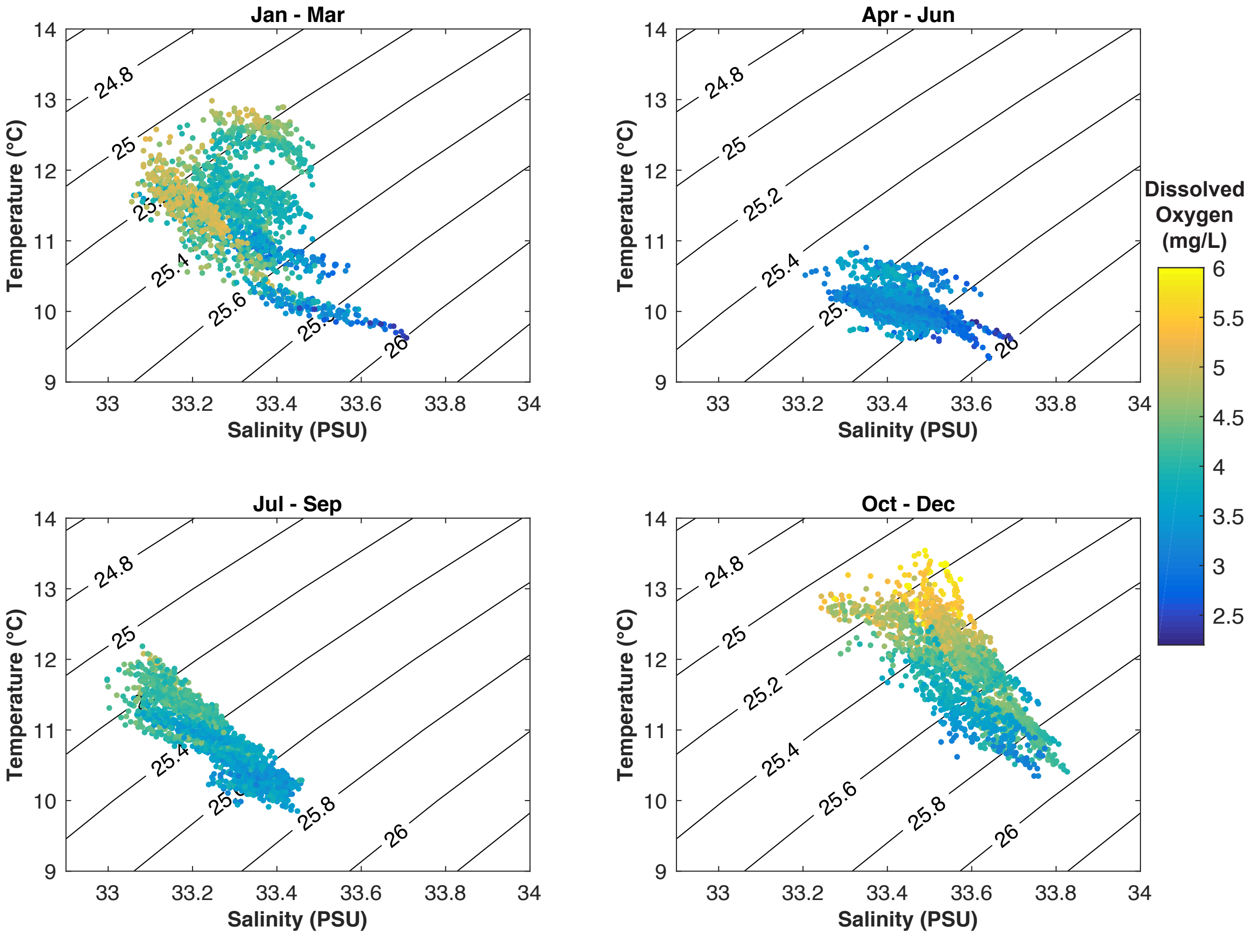


FIGURE D-7

Hourly averaged DO by season shown on temperature versus salinity plots at 89 m for both PLOO mooring deployments between 2018 to 2020. Isopycnals and corresponding σ-t values shown by black lines.

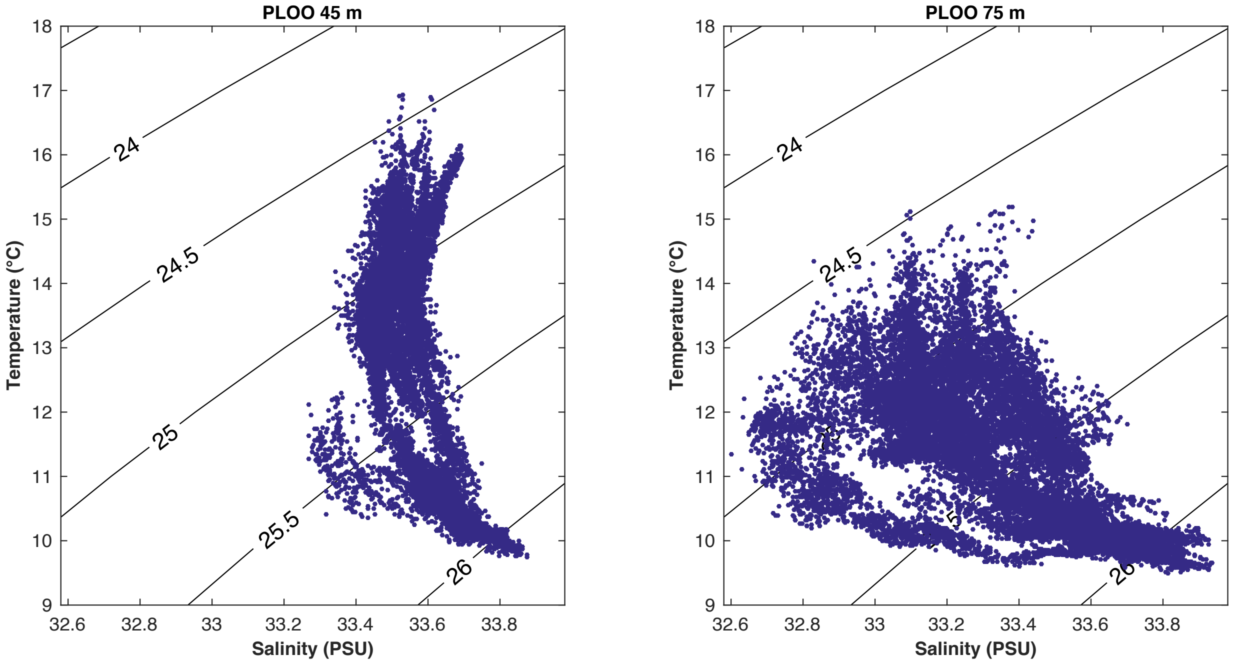


FIGURE D-8
PLOO RTOMS temperature versus salinity plots from 45 m (left) and 75 m (right), using hourly averaged data for both mooring deployments between 2018 to 2020. Isopycnals and corresponding σ-t values shown by black lines.

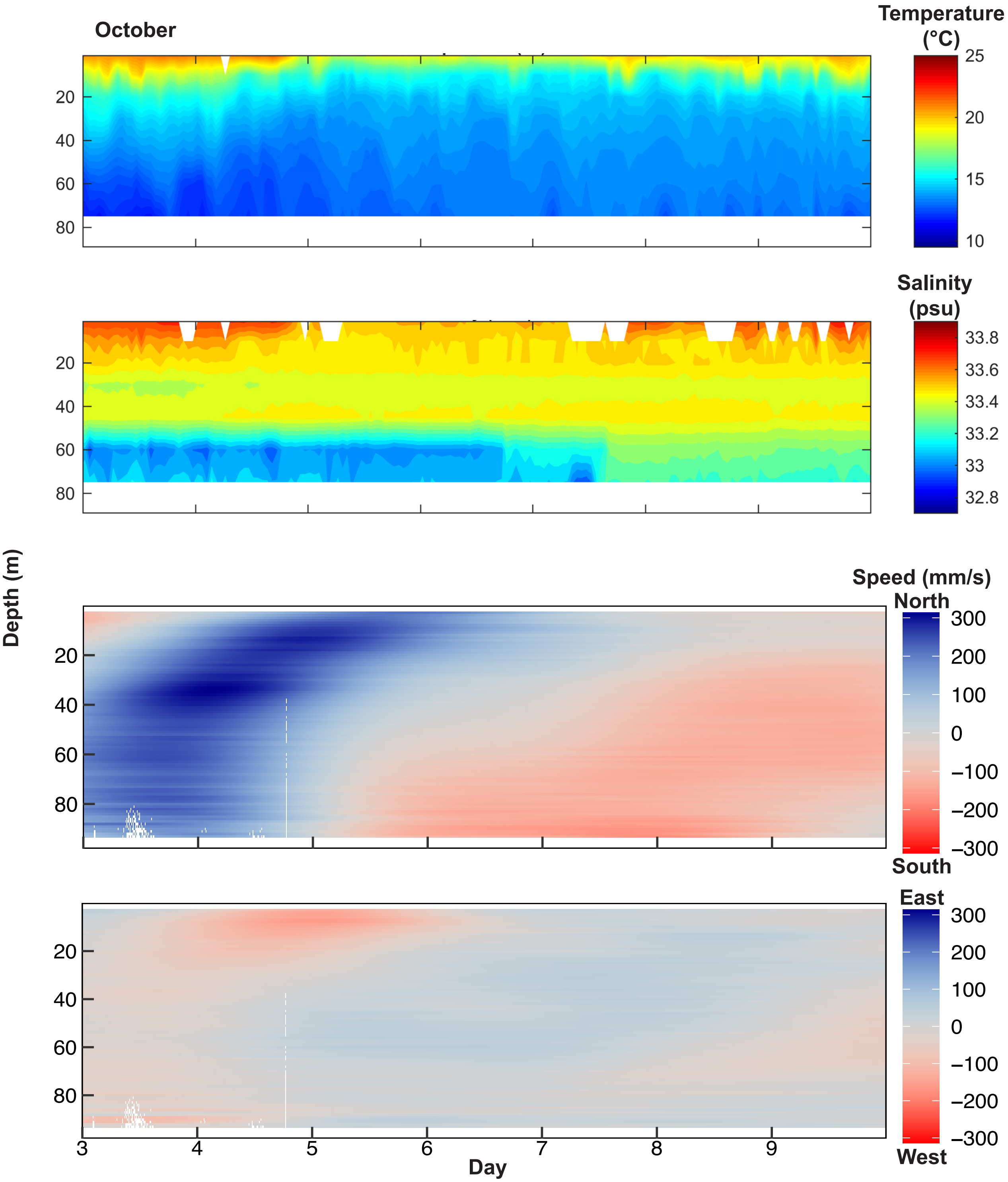


FIGURE D-9
Hourly averaged ocean temperature, salinity, north-south and east-west current speed and direction (with tides removed) during the week of October 3-9, 2018. White areas indicate loss of data due to instrumentation issues or failure to meet data quality criteria (see text).

can be used to estimate transport and orientation of the plume. Ocean currents recorded by the PLOO RTOMS showed distinct periods of predominantly N:NW and S:SE directed currents throughout the water column from days to weeks at a time (see Figures D-5, D-6). Transitions in current direction and speed can indicate a shift in local conditions that may also result in further mixing of the water column. These changes in conditions can impact whether the plume is observed at the mooring via potential plume salinity signals. For example, during October 2018, a shift from strong N:NW to moderate S currents, along with a corresponding weakening of thermal stratification, was followed by a weakening of plume salinity signal at the mooring two days later at depths from 60 to 75 m (Figure D-9).

ROTV

ROTV sampling has proven to be quite challenging for a number of reasons related to technical issues and deployment challenges, which may hinder the future usefulness of this technique for plume tracking purposes. Specifically, the occurrence of obstacles and abandoned fishing gear caused significant damage to the ROTV, which resulted in many repairs at great cost to the City. On numerous occasions, the ROTV was almost completely lost due to entanglement and obstructions in the water column. Furthermore, technical challenges related to software and access to replacement parts has delayed operations as there is no local support available. Nevertheless, preliminary results (presented here) were obtained in 2020 and further trials of this equipment are ongoing.

Despite the challenges, ROTV sampling during 2020 captured a range of ocean conditions (Table D-3). For example, during February's survey, ocean temperature and salinity conditions were weakly stratified and ocean currents remained consistent during the entire week (Figure D-10). In contrast, the August survey was conducted at a time of strong thermal stratification and a pronounced near-surface halocline (Figure D-11). Ocean currents were also much more variable, undergoing a near-complete reversal from NW to SE leading into the ROTV survey cruise days. Data collected by the ROTV were within the ranges of values observed with CTD instrumentation from the PLOO region for temperature, salinity, DO and CDOM (Table D-4, City of San Diego 2020b). The ROTV was the first instrument used by the City to collect tryptophan or OB in the ocean, so there are no established ranges for these data in this region. The most distinct plume signature of 2020 (CDOM > 1.0 parts per billion [ppb]) was observed during the February ROTV survey with higher CDOM values observed along a southerly trajectory (Figure D-12). Weaker, but still distinct CDOM values were also observed to the north of the PLOO. Elevated CDOM levels were observed between 55 and 98 m along the 98 and 80-m depth contours. The plume signature was not observed along the 60-m transect. Observations of the plume via elevated CDOM during the May survey were confounded by a strong regional phytoplankton bloom, confirmed via regular CTD sampling and satellite imagery (City of San Diego 2021, Hess 2021, Anderson and Hepner-Medina 2020). Dense blooms of phytoplankton are also sources of CDOM as they release organic material during their decay phase (see

TABLE D-3
Summary of ocean conditions from RTOMS and static instrumentation as well as observed plume ranges from quarterly CTD surveys during days that ScanFish surveys were completed during 2020. Deep currents are defined as measurements from >60 m depth; nd = not detected.

	Stratification [a]			Currents [b]			Plume Detections	
Quarter	**Qualitative**	**Max ΔT (°C) (surface-bottom)**	**Max thermocline depth (m)**	**Dominant alongshore current**	**Dominant cross-shore current**	**Mean deep current speed (mm/s)**	**Max observed plume width (m)**	**Min observed plume depth (m)**
Winter	Weak	4.4	nd	Very Weak North	Very Weak Variable	8	36	59
Spring	Strong	8.7	<10	Weak South	Weak East	26	15	61
Summer	Strong	12.8	<20	Transition: Moderate North to Weak South	Transition: Very Weak West to Very Weak East	40	24	72
Fall	Moderate	6.3	<22	Moderate South	Weak East	68	27	55

[a] RTOMS data not available in November. Thermocline calculated from static thermistor data (from 4 to 98 m depth, spaced 4 m apart). See City of San Diego 2020b.

[b] RTOMS data not available in February or November. Current measurements from static ADCP (4 m bins, upward facing). See City of San Diego 2020b.

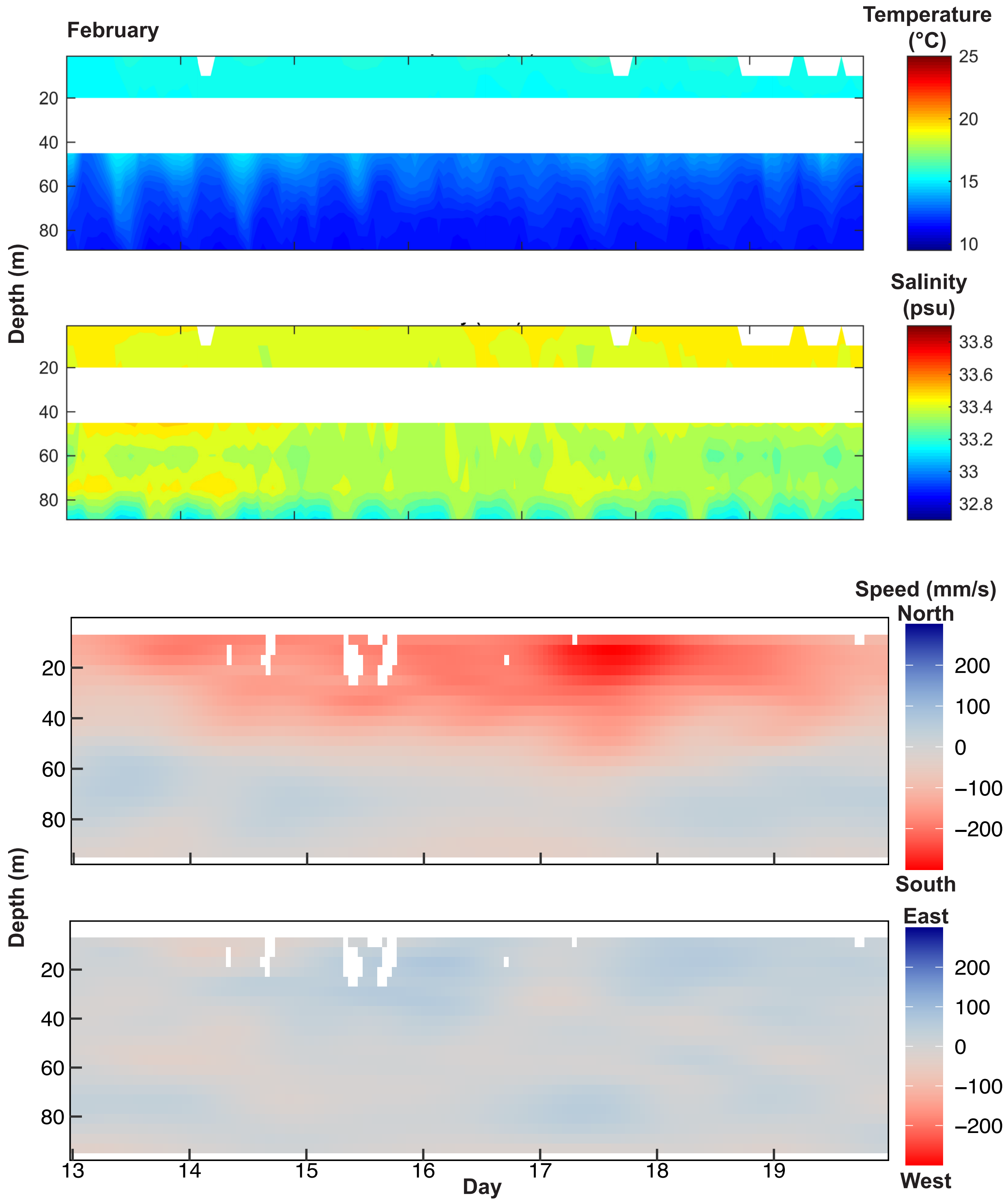


FIGURE D-10
Hourly averaged ocean temperature, salinity, north-south and east-west current speed and direction (with tides removed) during the week of February 13-19, 2020. White areas indicate loss of data due to instrumentation issues or failure to meet data quality criteria (see text).

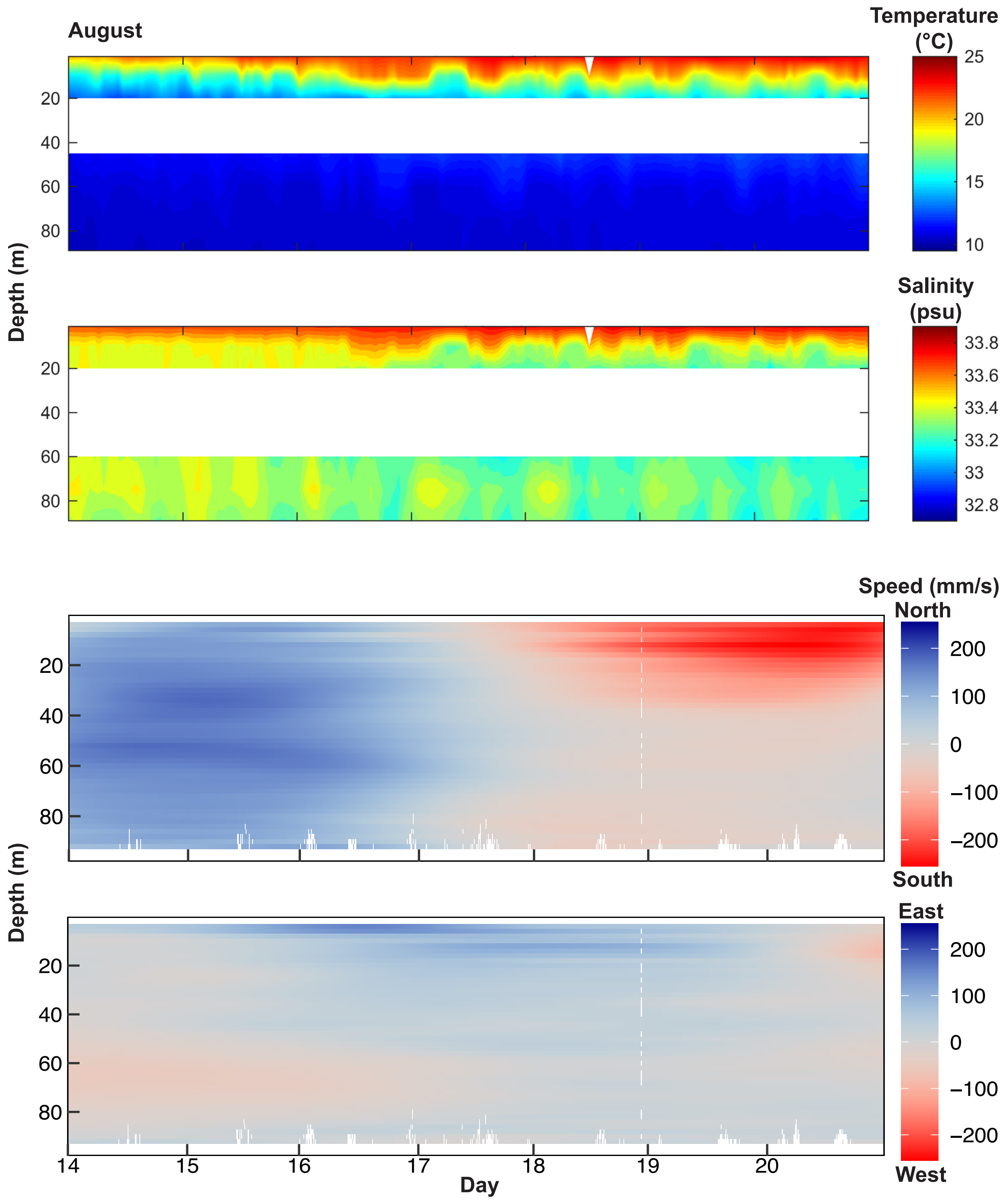


FIGURE D-11
Hourly averaged ocean temperature, salinity, north-south and east-west current speed and direction (with tides removed) during the week of August 14-20, 2020. White areas indicate loss of data due to instrumentation issues or failure to meet data quality criteria (see text).

TABLE D-4
Summary of parameters recorded by the ScanFish during 2020. Data include minimum, maximum, mean and sample size (n), separated by quarter. Sample sizes differed due to variations in sampling interval and data quality. These data have only partially been reviewed for quality. OB = optical brightener, TRYP = tryptophan.

		Parameter					
Quarter	**Statistic**	**CDOM**	**DO**	**Temp**	**Salinity**	**OB**	**TRYP**
Winter	min	0.04	4.29	11.47	33.33	9.65	1.74
	max	2.67	8.73	15.88	33.73	66.19	2.04
	mean	0.64	7.39	13.87	33.51	20.22	1.85
	n	38,390	38,462	38,483	38,483	36,248	36,220
Spring	min	0.04	3.19	9.77	33.12	1.48	1.76
	max	2.95	9.09	18.64	34.63	65.71	2.62
	mean	0.89	4.45	11.07	33.80	25.17	1.85
	n	16,614	16,614	16,614	16,614	16,609	16,614
Summer	min	0.19	3.81	10.47	32.91	2.06	1.72
	max	1.79	9.36	22.82	34.27	50.26	1.93
	mean	0.71	6.62	12.63	33.52	21.11	1.80
	n	46,927	46,927	46,927	46,927	46,927	46,927
Fall	min	0.04	4.32	11.19	33.06	5.58	1.68
	max	3.13	7.84	17.56	34.95	52.16	3.86
	mean	0.82	5.95	13.17	33.59	22.89	1.77
	n	33,311	33,311	33,311	33,311	33,310	33,311

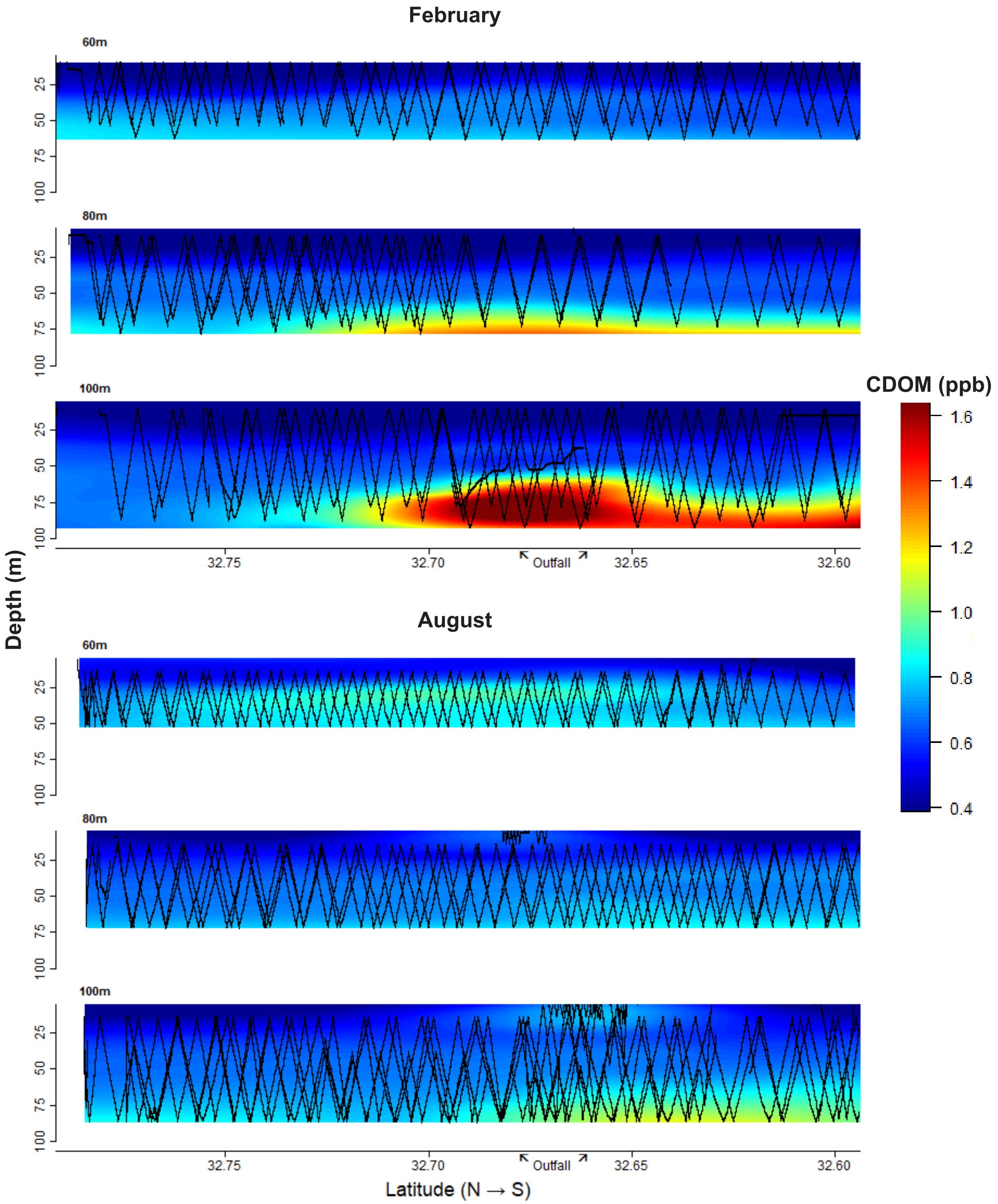


FIGURE D-12
Select oceanographic parameters recorded during February and August 2020 Scanfish tows. Transects are separated according to depth contour (determined by the nearest water quality station), and were collected over 1-3 days during each quarter in conjunction with regular quarterly water quality sampling. Data are interpolated using the LoESS (Locally Estimated Scatterplot Smoothing) method. Black marks show the location (depth and latitude) of the Scanfish. These data have only partially been reviewed for quality.

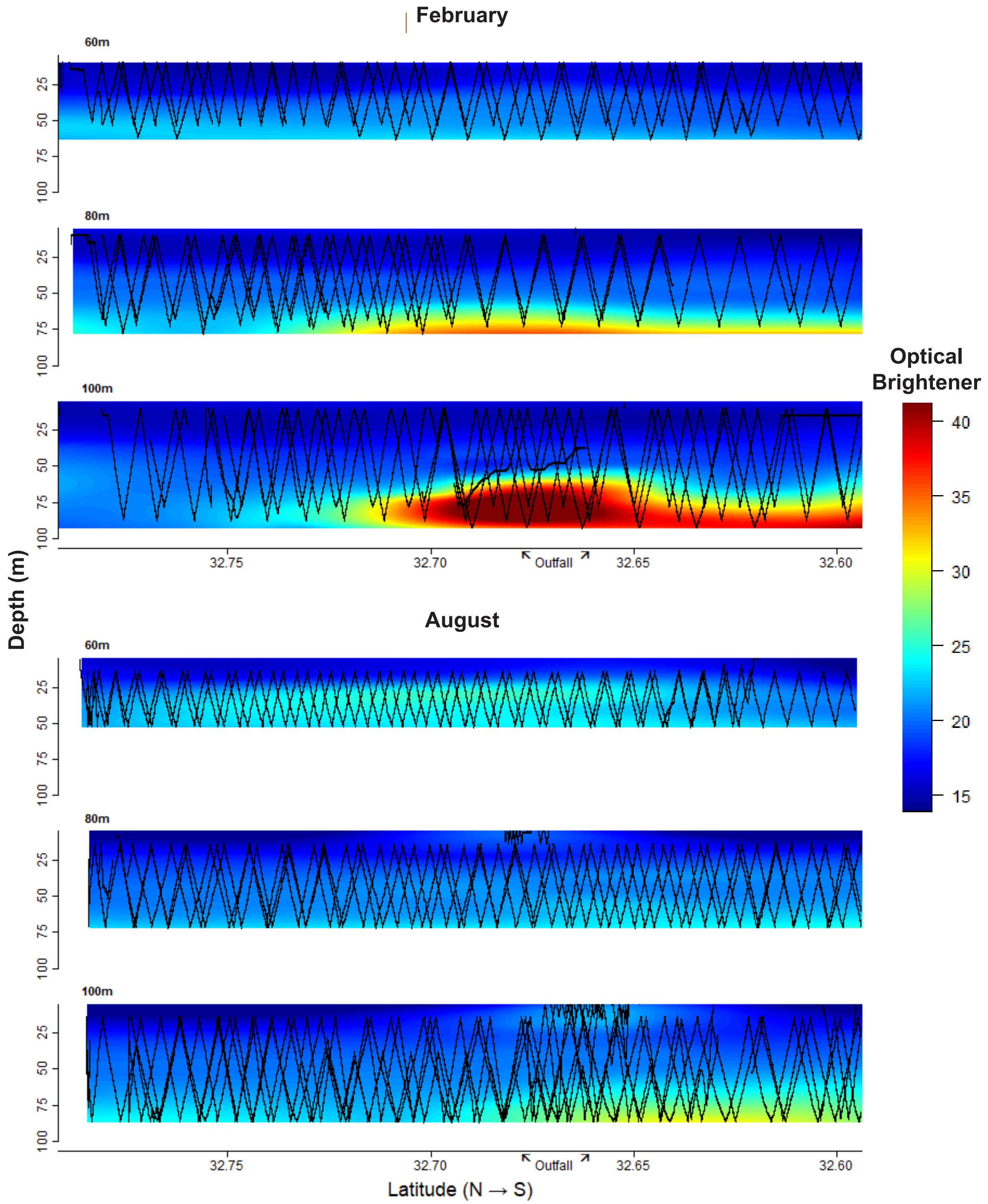


FIGURE D-12 *continued*

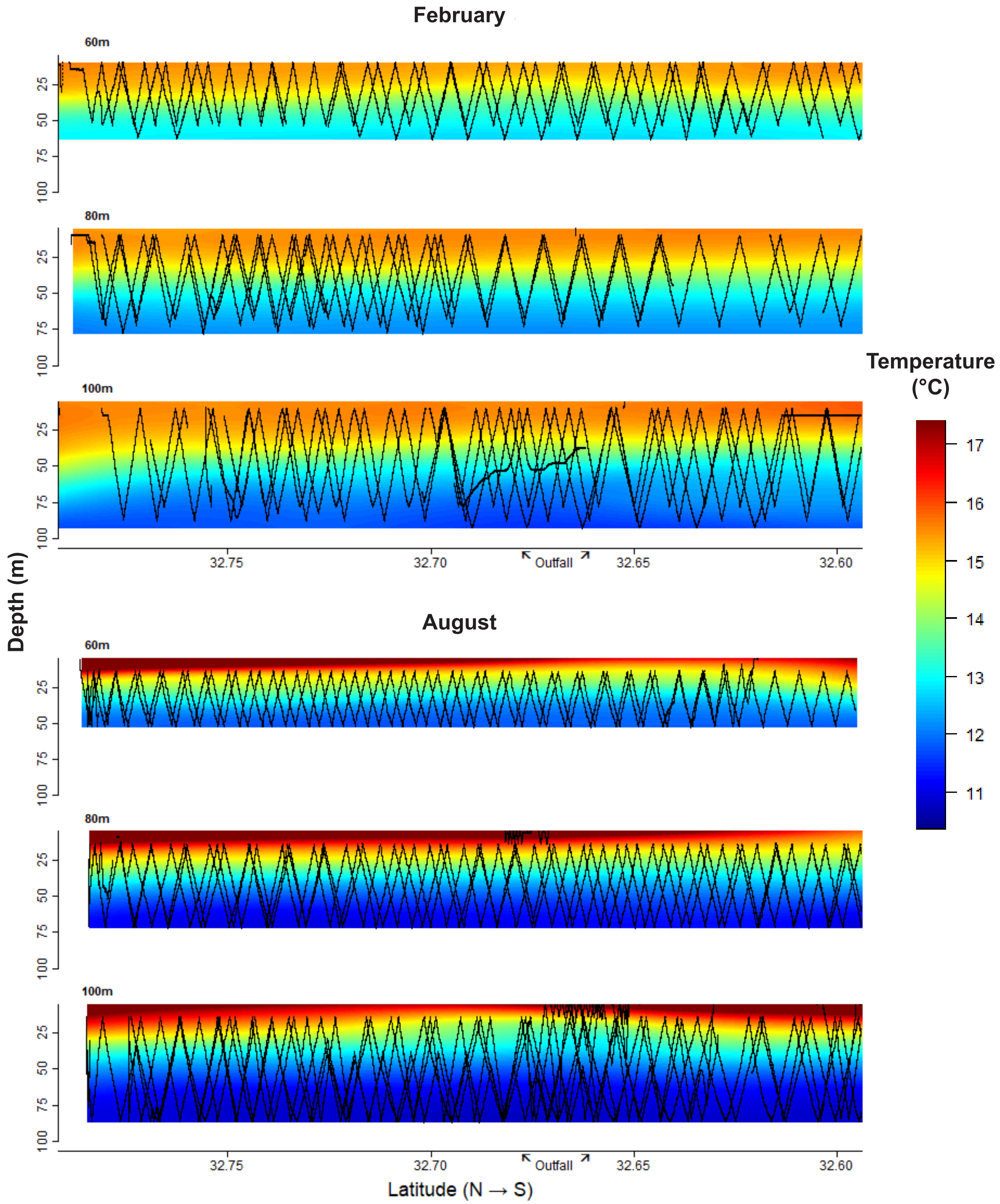


FIGURE D-12 *continued*

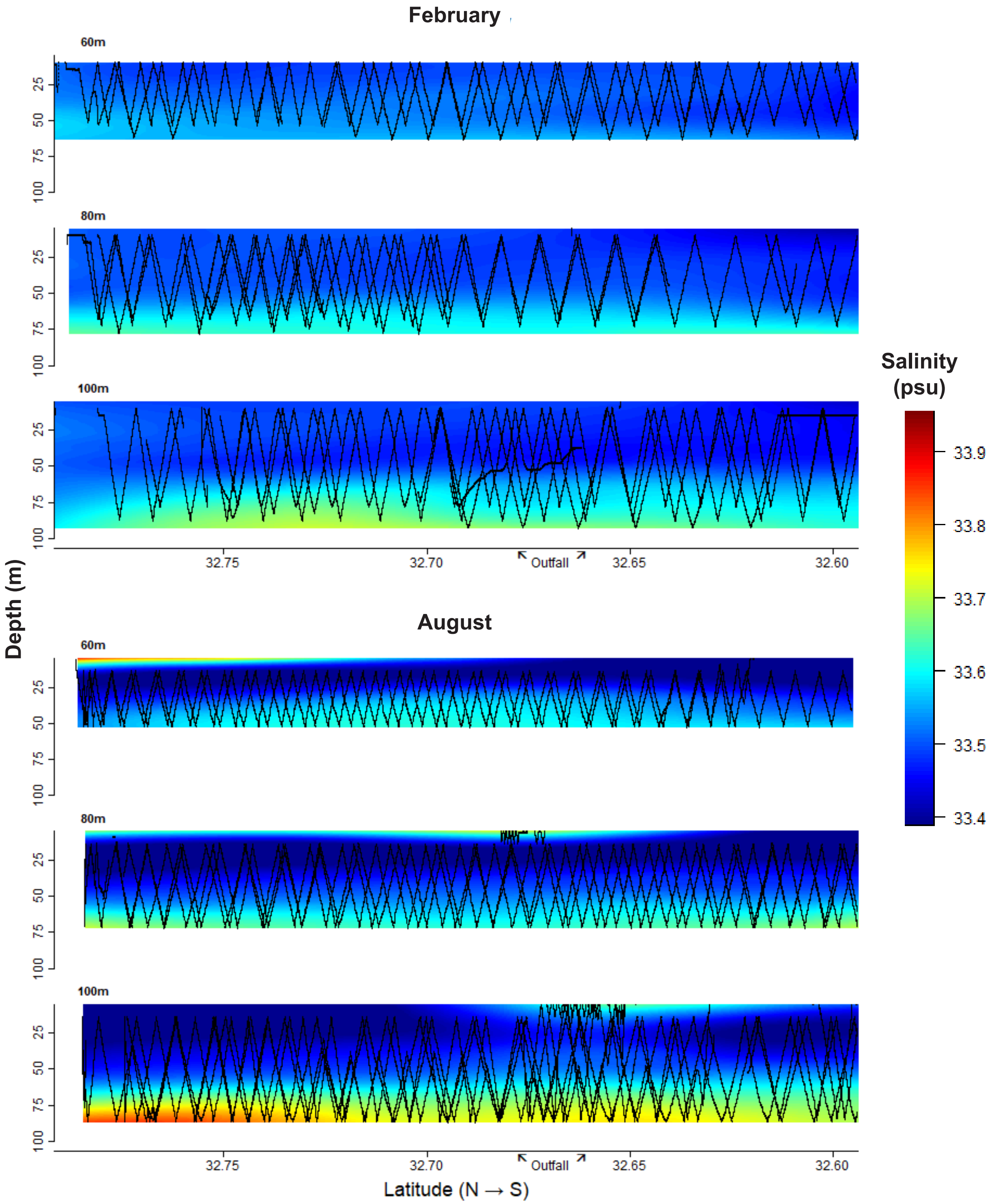


FIGURE D-12 *continued*

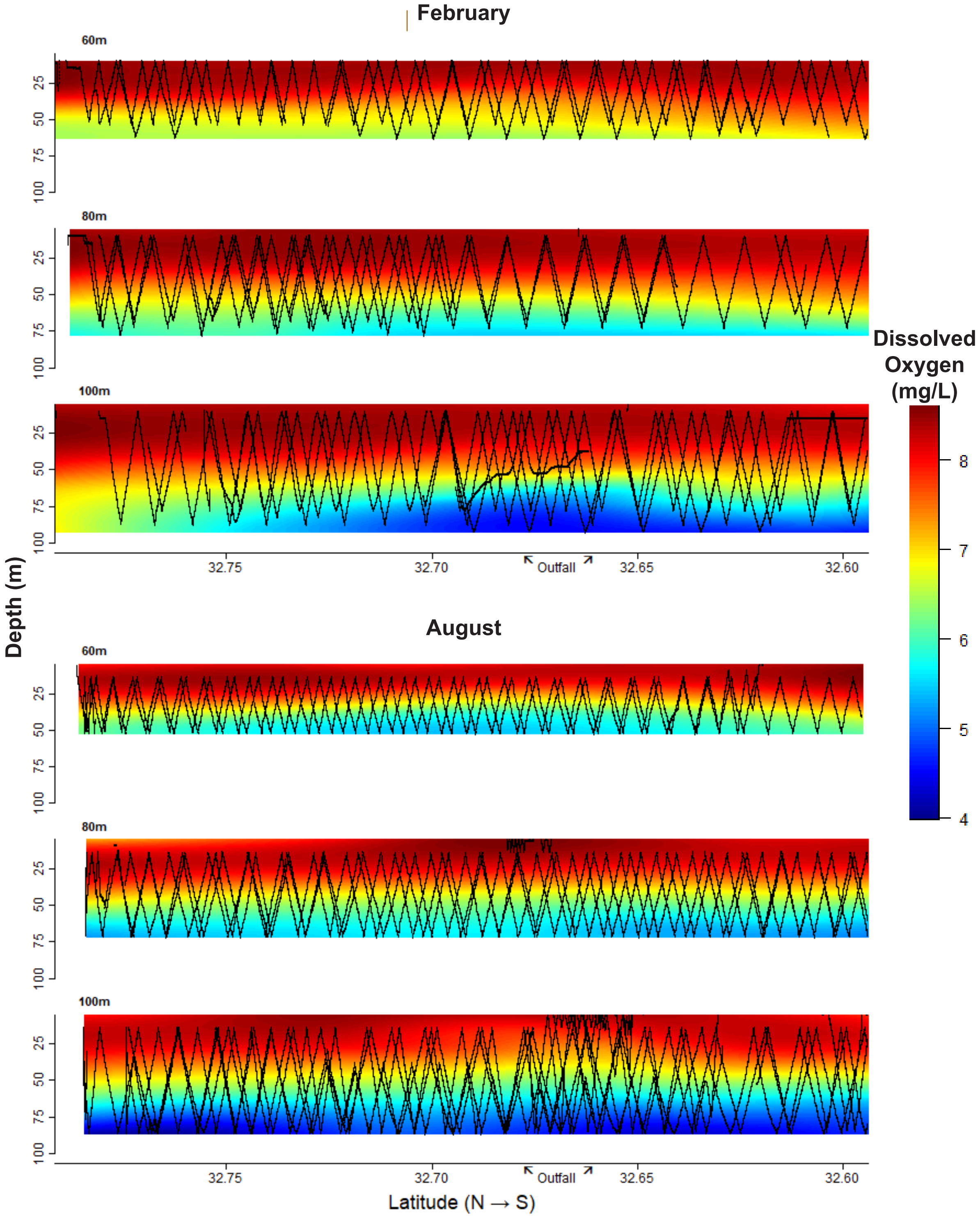


FIGURE D-12 *continued*

Rochelle-Newall and Fisher 2002, Romera-Castillo et al. 2010). Currently, the ROTV does not have a chlorophyll *a* fluorescence sensor to aid in distinguishing these confounding sources of CDOM. In August, a weak plume signature appeared along the southern end of the transect. Other, moderately elevated CDOM values observed along the 60-m transect were likely associated with a small phytoplankton bloom (City of San Diego 2021). A corresponding signal was also observed in the OB measurements (Figure D-12). However, OB fluorescence has similar confounding issues as CDOM that limits its interpretation in the absence of chlorophyll *a* fluorescence (Hagedorn and Weisberg 2009). During the November survey, the plume signature was the strongest between 60 and 25 m along the southern section of the 98-m depth contour. During all surveys, other parameters such as temperature, salinity, and DO did not show clear evidence of a plume signature (Figure D-12).

SECTION D-5 | CONCLUSIONS

Historically, the City has evaluated the fate and dispersal of the treated wastewater effluent plume through regular monitoring of a fixed grid of stations utilizing CTD instrumentation and bacteriological evidence (e.g., City of San Diego 2020b). Although this technique covers a large spatial area, the infrequent temporal sampling rate limits observations to just a few "snapshots" in time. This limited timeframe may not capture sporadic events, such as storm-driven transport or other oceanographic phenomena. To address this issue, the City installed non-telemetered ADCP instrumentation to document hydrographic conditions in the immediate vicinity of the PLOO over much finer timescales. Although variable across spatial, annual, and seasonal scales, the general axis of current velocities was consistently observed to follow a NW:SE trajectory. This indicates that as the wastewater plume is mixing with ambient seawater, it is generally travelling along the coast rather than being directed inshore toward the shoreline or kelp beds. The ADCP data have improved temporal coverage of conditions in the area, however, the data were only useful to understand events in retrospect.

More recently, real-time data have become available via the City's RTOMS, which include a variety of instrumentation at multiple depths, providing continuous information from a single platform. These observations have enabled the enhanced assessment of environmental conditions and the impact of oceanographic and anthropogenic events coastal waters. They also provided the ability to capture greater variability and extreme events, such as the intense algal bloom in spring 2020 (Anderson and Hepner-Medina 2020). In addition, these high frequency data at a single fixed location provide context on the state and variability of the receiving waters into which the PLOO discharges. For example, the rise height of the effluent plume is highly dependent on density structure and stratification of the water column, as well as ambient currents (see Appendix Q this application, Rogowski et al. 2012a). Stronger currents may result in greater initial mixing while weaker currents may result in shallower rise heights depending on stratification. Other local ocean dynamics, such as internal waves, can result in further mixing and impact observed plume rise heights (Rogowski et al. 2012a). These data can be further used to validate predictive models that seek to characterize changes, which may cause environmental degradation. The ability to monitor in near real-time is an essential component of wastewater plume tracking, as it provides the City with the ability to predict potential shoreward-based movement of wastewater plumes, which may otherwise present a hazard to people utilizing recreational waters along the shoreline. Furthermore, real-time monitoring allows the City to quickly identify issues with equipment to facilitate long-term maintenance. However, while the RTOMS provide detailed coverage over time, it is limited to a single fixed point in space, and so alone it lacks the spatial coverage to fully assess plume dispersion on a region wide scale.

To compliment the operations of the RTOMS, the ROTV may allow the City to develop a truly adaptive, dynamic sampling program that will be able to appropriately evaluate the extent of the PLOO plume dispersion. Real time information on stratification, currents, and potential plume detections at the RTOMS may be used for adaptive sampling and mapping of the plume via the ROTV as needed. Furthermore, as ROTV data appear to generally agree qualitatively with CTD data, this potentially presents a more focused method for tracking the plume over a large spatial scale. However, data are limited at this time as an assessment of the effectiveness of the ROTV is currently ongoing and due for completion in mid-2022.

Despite the different spatial and temporal coverage of the various instrumentation packages utilized by the City, all observations have confirmed that the Point Loma effluent plume generally remains offshore, below a depth of 24 m, and is transported along the coast. These observations support previous studies showing that there is no evidence that wastewater discharged to the ocean via the current configuration of the PLOO has ever reached the shoreline or had any significant impact on recreational waters.

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APPENDIX E

2014 – 2020 KELP FOREST ECOSYSTEM MONITORING SUMMARY

City of San Diego
Public Utilities Department

March 2022

APPENDIX E

2014-2020 Kelp Forest Ecosystem Monitoring Summary

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APPENDIX E

2014-2020 Kelp Forest Ecosystem Monitoring Summary

SECTION E-1 | SUMMARY OF FINDINGS

1) There was no evidence that discharge of wastewater through the Point Loma Ocean Outfall has negatively affected San Diego's kelp forests.

2) The kelp forests of Southern California, including those off San Diego, were decimated by the marine heat wave of 2014–2016. Cooler and more nutritive conditions appropriate for kelp recruitment and growth returned by the spring of 2017, when many of the kelp forests off San Diego began to recover. This recovery included the recruitment and growth of at least two giant kelp cohorts.

3) Of the kelp forests located off San Diego County, the La Jolla and Point Loma kelp forests exhibited the most significant recovery. As of 2020, the La Jolla kelp bed covered approximately 22% (1.094 km^2) of the historical all-time high of 4.9 km^2 observed in 1989, while the Point Loma kelp bed covered approximately 32% (2.545 km^2) of the historical all-time high of 7.920 km^2 observed in 2018. These kelp beds accounted for 93% of the total canopy coverage in Region Nine (south Orange County to the U.S.-Mexico Border) during 2020.

4) Sea urchins, which are major herbivores of giant kelp, were decimated by a combination of disease and lack of food during the 2014-2016 marine heat wave. Subsequently, sea urchin recruitment was observed at many of the Scripps Institution of Oceanography study sites. These new cohorts of sea urchins may pose overgrazing risks to some areas of the kelp forests off San Diego, particularly the southern portion of the Point Loma kelp forest where resilient sea urchin barrens over approximately 200 hectares in size have been observed for at least 80 years. However, there was no evidence of sea urchin overgrazing in either the La Jolla or Point Loma kelp forests.

5) Associated with, and prior to, the marine heat wave of 2014–2016, several species of sea stars in the genus *Pisaster* were nearly extirpated off San Diego due to wasting disease. Only *Pisaster giganteus* appears to be making a slow recovery.

6) Abalone densities remain low or zero at most study sites, apart from the shallowest study sites off central Point Loma where densities of the pink abalone, *Haliotis corrugata*, have been recently increasing.

SECTION E-2 | INTRODUCTION

The City of San Diego (herein ‘City’) participates in two long-standing kelp forest monitoring efforts. Since 1983, the City has been a member of the Region Nine Kelp Survey Consortium (RNKSC) that provides funding for ongoing seasonal surveys of coastal kelp beds utilizing aerial photography techniques developed by the late Dr. Wheeler J. North at the end of the 1960s to determine kelp canopy surface area. Additionally, since 1992, the City has been providing partial funding to the Scripps Institution of Oceanography (SIO) in support of a long-term diver survey program that originated in 1971. This core diver survey program was built off research conducted by SIO in the kelp forests off San Diego dating back to the 1950s.

The review presented herein is intended as a summary of findings from reports submitted in support of these kelp forest monitoring efforts between 2014 and 2020. All reports are linked below, and can also be found at www.sandiego.gov/public-utilities/sustainability/ocean-monitoring/reports:

RNKSC Annual Reports

- MBC Applied Environmental Sciences (2015). Status of the Kelp Beds, 2014, Kelp Bed Surveys: Ventura, Los Angeles, Orange, and San Diego Counties. Final Report, July 2015. MBC Applied Environmental Sciences, Costa Mesa CA.
- MBC Applied Environmental Sciences (2016). Status of the Kelp Beds, 2015, Kelp Bed Surveys: Ventura, Los Angeles, Orange, and San Diego Counties. Final Report, July 2016. MBC Applied Environmental Sciences, Costa Mesa CA.
- MBC Applied Environmental Sciences (2017). Status of the Kelp Beds, 2016, Kelp Bed Surveys: Ventura, Los Angeles, Orange, and San Diego Counties. Final Report, August 2017. MBC Applied Environmental Sciences, Costa Mesa CA.
- MBC Applied Environmental Sciences (2018). Status of the Kelp Beds, 2017, Kelp Bed Surveys: Ventura, Los Angeles, Orange, and San Diego Counties. Final Report, August 2018. MBC Applied Environmental Sciences, Costa Mesa CA.
- MBC Applied Environmental Sciences (2019). Status of the Kelp Beds, 2018, Kelp Bed Surveys: Ventura, Los Angeles, Orange, and San Diego Counties. Final Report, August 2019. MBC Applied Environmental Sciences, Costa Mesa CA.
- MBC Applied Environmental Sciences (2020). Status of the Kelp Beds, 2019, Kelp Bed Surveys: Orange and San Diego Counties. Final Report, August 2020. MBC Applied Environmental Sciences, Costa Mesa CA.
- MBC Applied Environmental Sciences (2021). Status of the Kelp Beds, 2020, Kelp Bed Surveys: Orange and San Diego Counties. Final Report, August 2021. MBC Applied Environmental Sciences, Costa Mesa CA.

SIO Kelp Forest Ecosystem Monitoring Reports

- Parnell, P.E., P. Dayton, K. Riser, and B. Bulach (2016). Evaluation of Anthropogenic Impacts on the San Diego Coastal Kelp Forest Ecosystem – Annual Project Report (2015-2016). Prepared for City of San Diego Public Utilities Department by Scripps Institution of Oceanography, University of California, San Diego, CA.
- Parnell, P.E., P. Dayton, K. Riser, and B. Bulach (2018). Status and Trends of San Diego Kelp Forests, 2016-2017. Prepared for City of San Diego Public Utilities Department by Scripps Institution of Oceanography, University of California, San Diego, CA.
- Parnell, P.E., P. Dayton, K. Riser, and B. Bulach (2019). Evaluation of Anthropogenic Impacts on the San Diego Coastal Kelp Forest Ecosystem (2014 to 2019): Final Report. Prepared for City of San Diego Public Utilities Department by Scripps Institution of Oceanography, University of California, San Diego, CA.
- Parnell, P.E., P. Dayton, K. Riser, and B. Bulach (2020). Evaluation of Anthropogenic Impacts on the San Diego Coastal Kelp Forest Ecosystem (Biennial Project Report): 2018 to 2019. Prepared for City of San Diego Public Utilities Department by Scripps Institution of Oceanography, University of California, San Diego, CA.

SECTION E-3 | REVIEWS

RNKSC Kelp Canopy Surface Coverage Monitoring 2014-2020

The following is largely excerpted from "*Status of the Kelp Beds, 2020, Kelp Bed Surveys: Orange and San Diego Counties. Final Report, August 2021.*" The lead author, Michael Lyons, has reviewed and approved of this summary.

Variation in kelp canopy size is common in areas such as La Jolla and Point Loma, where up to four-fold changes in canopy coverage occur within a single year (MBC 2015–2021). From 2014 through 2020, the La Jolla kelp bed ranged in size from 0.694 km^2 in 2017 to 2.968 km^2 in 2015. During the same seven-year period, the Point Loma kelp bed ranged in size from 1.787 km^2 in 2017 to an all-time high of 7.920 km^2 in 2018. As of 2020, the total area of kelp canopy in Region Nine covered approximately 3.9 km^2. In four of the past five years (2016, 2017, 2019, and 2020), the total kelp canopy was less than the long-term average of 7.1 km^2, after following nine years (2007 through 2015) of above average total kelp canopies. The largest kelp beds were the La Jolla and Point Loma kelp beds, which accounted for 93% of the total canopy coverage in 2020. Only three kelp beds in 2020 were greater than 20% of the maximum extent recorded since 1983: Barn Kelp at 25% of maximum, La Jolla at 23%, and Point Loma at 32%. All other kelp beds were at 11% or less than their maximum size, and all but two (North Laguna Beach and Horno Canyon) were less than 1% of maximum.

Kelp Forest Ecosystem Monitoring 2014-2020

The following is directly excerpted from *"Evaluation of Anthropogenic Impacts on the San Diego Coastal Kelp Forest Ecosystem (2014 to 2019)."* The lead author, Dr. Ed Parnell, has reviewed and approved of this summary, and provided an update for 2020 below.

The kelp forests off La Jolla and Point Loma are the largest contiguous kelp forests off the western coast of the U.S. They host complex marine communities supported by their eponymous species, giant kelp (*Macrocystis pyrifera*), which provides structure and food for hundreds of species of fish and invertebrates. Kelp forests off southern California are subjected to both natural and human-induced disturbance. The El Niño Southern Oscillation (ENSO) is the primary ocean climate mode that affects kelp abundance, growth, and reproduction along the west coast of the Americas. Positive ENSOs, known as El Niños, are associated with warm water, depressed concentrations of nitrate (the principal nutrient limiting giant kelp), and a more energetic storm environment off southern California. Both phenomena serve to stress giant kelp and accompanying species of algae. The opposite conditions occur during negative ENSO events (La Niñas), enhancing both the growth and reproduction of kelp species. Together, the two ocean climate modes drive the greatest amount of annual variability in surface canopy cover of *M. pyrifera* off southern and Baja California. The periodicity of El Niño is variable, typically occurring at 3 to 5-year intervals and persisting for <1 year. Kelp forests wax and wane over these cycles, experiencing high mortality during El Niños with recovery afterwards. Rates of recovery depend on growth conditions after an El Niño ebbs. The kelp forests off San Diego have been studied by researchers at the Scripps Institution of Oceanography (SIO) since the 1970s and are currently being monitored at twenty permanent study sites located among the Point Loma, La Jolla, and North County kelp forests.

During the current study (2014-2019), the kelp forests off California were subjected to severe temperature and nutrient stress beginning in late 2013 which persisted until the spring of 2017. This lengthened period of stress was due the combination of two consecutive ocean climate events. An anomalous surface warm pool extended across much of the NE Pacific from 2014-2015. This warm pool, unique in the climate record of the NE Pacific, was coined the BLOB and resulted from large scale wind patterns in the NE Pacific. This causative forcing is therefore different in nature and scale than ENSO cycles which are caused by anomalous winds along the equatorial Pacific. A strong El Niño occurred during fall of 2015 and the winter of 2016 just as the BLOB dissipated. Together these consecutive warm periods resulted in the longest and warmest period ever observed in the 103-year-old sea surface temperature time series at the Scripps Institution of Oceanography (SIO) pier. Cooler conditions returned to the equatorial eastern Pacific and the Southern California Bight by late 2016. The spring upwelling seasons of 2017 and 2018 brought cool, nutrient-laden waters up onto the inner continental shelf of southern California creating favorable conditions for giant kelp regrowth. However, it is important to note that the variability of El Niño climate cycles is superimposed onto a larger scale trend of increasing ocean temperatures within the California Current System and the world's oceans generally, and it is likely that conditions that are supportive of giant kelp growth and reproduction will decrease in frequency and duration over the next century. This will likely result in an increased susceptibility to anthropogenic stress and an overall decreased resilience to disturbances as the century progresses. Presently, there is no evidence of human stress on the marine algae of San Diego County due to wastewater discharge from the Pt. Loma Ocean Outfall.

The recent consecutive warm events and associated decreased nutrient conditions decimated *M. pyrifera* and cohabiting algal species off San Diego. Pooled across 20 kelp forest sites off San Diego, densities of adult *M. pyrifera* were reduced >90%. Unlike previous warm events attributed to El Niño, the BLOB resulted in warming and low nutrient exposure of understory kelp species for prolonged periods of time leading to dramatic reductions of those species in addition to giant kelp. The BLOB persisted longer than a typical El Niño and kelps did not recover after the warm pool dissipated because of the stress induced by the following El Niño of 2016. The two events affected kelps at the study sites differently, and the historic pattern of areal synchronized mortality and recovery was disrupted. Growth conditions returned to normal with the onset of mild La Niña conditions in the spring of 2017. Rates of giant kelp recovery since then have been variable among study sites and were initially slower than previous recovery periods and were non-existent at some study sites. Surface canopy cover in some areas was precluded by increases in understory species density. Some of these areas will likely remain devoid of giant kelp canopy for years since understory species are long-lived and competitively interfere with giant kelp recruitment. Favorable conditions for kelp growth and reproduction returned with the 2018 spring upwelling season, and another bout of kelp recruitment and recovery occurred over more areas off San Diego County. However, an anomalously warm surface layer, limited to the upper 3-5 meters of the ocean's surface, occurred during the summer of 2018. Sea surface temperature records in the SIO Pier time series were exceeded by at least 2°C when temperatures reached >27°C. By contrast, typical summer surface temperatures are ~23°C. This surface warm pool degraded the giant kelp canopy tissue which was mostly lost from the offshore forests and drifted onto nearby beaches. However, cooler temperatures persisted closer to the bottom, and most of the giant kelp plants in the initial recovery cohorts of 2017 and 2018 survived and regrew to the surface when the warm pool dissipated by the fall of 2018. The kelp forests off North County were largely lost during this surface warm period.

Presently, giant kelp densities are ~40% of their all-time historic highs when averaged across all of the study sites. Giant kelp densities are currently the greatest in the northern and central portions of the Pt. Loma kelp forest, and the southern portions of the La Jolla kelp forest. Giant kelp densities are near zero in all North County kelp forests, including areas off Del Mar, Solana Beach, and Cardiff. Giant kelp that recruited in the spring of 2017 off Solana Beach and Cardiff died during the summer 2018 surface warm pool event and there has been little recovery since due to competition with understory kelp and algal turf species that interfere with giant kelp recruitment.

Diseases in many invertebrates, including sea urchins (echinoids) and predatory seastars (asteroids), are common during warm events. Mass mortality of red (*Mesocentrotus* *franciscanus*) and purple sea urchins (*Strongylocentrotus purpuratus*) and seastars in the genus *Pisaster*, began off San Diego in 2014 and extended through 2017. This resulted in the disappearance or near-disappearance of these species from our study sites and from the kelp forests generally. Further, little to no recruitment of sea urchins was observed until the fall of 2017. Sea urchins are primary herbivores of giant kelp and can overgraze giant kelp and associated algal species given the right conditions. They are capable of precluding kelp recovery and overgrazed areas known as barrens that can persist in some areas for decades. The kelp recovery that began in 2017 and continued into 2018 is not being affected by sea urchins because of their low adult densities due to the die-off. However, rates sea urchin recruitment that began in 2017 mean that overgrazing could occur as this cohort emerges from nursery habitats and matures into adulthood. This cohort could lead to overgrazing in some areas of the kelp forests as early as 2020 especially in south Pt. Loma where a unique combination of topography and turbidity emanating from San Diego Bay contribute to resilient sea urchin barrens. Some recruitment of the seastars *Pisaster giganteus* and *Patiria miniata*, two important kelp forest predators, has been observed off Pt. Loma and La Jolla. However, adult densities are presently near zero and it is difficult to predict whether the initial bouts of post-disease recruitment will be adequate to recover their populations anytime soon.

Abalone, another important kelp forest grazer and the target of a once extensive fishery, depend primarily on giant kelp for food. Abalone once supported a large recreational and commercial fishery off southern California until all harvest was closed in 1996 due to depletion from overfishing and disease associated with warm periods. Abalone off San Diego County suffered further mortality during and after the warm event of 2014-2016 due to lack of food and disease. Abundances of all abalone species at the study sites off La Jolla and Pt. Loma have since declined to near zero with the exception of pink abalone (*Haliotis corrugata*) where there has been some recovery at the two shallowest study sites that began around 2010.

The La Niña conditions that occurred during 2017 and 2018 and resulted in kelp recovery off San Diego County have since shifted to El Niño conditions. However, the present spring upwelling of 2019 has not yet been affected, and bottom temperatures have remained conducive for kelp recruitment and growth. The present El Niño is predicted to last through summer and then shift to ENSO neutral conditions by the fall of 2019. It is not clear at this time whether unusually warm waters will again affect the kelp forests off San Diego during the summer and fall. Conditions for giant kelp recovery may therefore become less favorable during the summer of 2019. Summer is typically an important period for giant kelp growth and reproduction, and warm temperatures could potentially slow or even reverse the rate of giant kelp forest recovery off San Diego. Another source of stress is the accelerating colonization of an invasive algal species, *Sargassum horneri*, first observed in the kelp forests off San Diego in 2014. This species has now become established at 9 study sites and has been observed at 4 others. *S. horneri* can outcompete *M. pyrifera* for space and may further slow the recovery of kelp forests off San Diego, perhaps eventually precluding recovery in some areas altogether. The deeper areas off Northern La Jolla appear most at risk.

During 2020, giant kelp stipe density (the metric most related to surface canopy cover) is about 38% of the all-time high that was observed in 2012 (Parnell, pers. comm., August 31, 2021). Giant kelp densities are currently the greatest in the northern and central portions of the Point Loma kelp forest, and the southern portions of the La Jolla kelp forest, and are near or at zero in all North County kelp forests, including areas off Del Mar, Solana Beach, and Cardiff. Kelp forests in North County and deeper areas off northern La Jolla continue to appear most at risk of recovery.

APPENDIX F

2014 – 2020 COASTAL REMOTE SENSING SUMMARY

City of San Diego
Public Utilities Department

March 2022

APPENDIX F

2014-2020 Coastal Remote Sensing Summary

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APPENDIX F

2014-2020 Coastal Remote Sensing Summary

SECTION F-1 | SUMMARY OF FINDINGS

1) Remote sensing technologies have helped to visually confirm the negligible role that the Point Loma Ocean Outfall (PLOO) effluent discharge plays in local ocean waters relative to other sources, at depths up to 15 meters (m).

2) The PLOO effluent plume has not been directly observed in surface waters of the PLOO monitoring region via satellite imagery, confirming observations made with ocean monitoring data that indicate the PLOO plume does not penetrate the surface and move shoreward.

3) Satellite imagery provided observations of the frequency and distribution of algal blooms, such as red tide events, within the PLOO monitoring region. Blooms tended to originate in shallower waters off northern San Diego County and move south, or off southern San Diego and move north. No bloom was observed to originate over the PLOO discharge location. When combined with the lack of observations of effluent plume at the surface, there is no evidence to indicate that effluent discharged from the PLOO drives algal blooms off Point Loma.

4) There continues to be a lack of evidence to indicate a correlation between algal blooms in the Southern California Bight and wastewater discharges from the PLOO.

SECTION F-2 | INTRODUCTION

The City of San Diego (City) has been implementing coastal remote sensing of the San Diego coastline since 2002. The first phase of this collaboration started with a historical study utilizing satellite data acquired since the early 1980s (Svejkovsky 2000). This study established a baseline dataset for patterns of surface currents within the PLOO monitoring region, including their persistence and frequency of occurrence, along with the historical locations, size and dispersion trajectories of various land and offshore discharge sources (e.g., PLOO, Tijuana River, Punta Bandera Treatment Plant discharge in Mexico).

In October 2002, the operational monitoring phase of the remote sensing project was initiated. This work utilized 500 m resolution Moderate Resolution Imaging Spectroradiometer (MODIS) color satellite imagery, 27 and 60 m Thematic Mapper (TM5 &

TM7) color and thermal satellite imagery, and regular aerial imaging over the Point Loma and South Bay Ocean Outfall (SBOO) monitoring regions. Subsequently, the project has expanded to include a variety of satellite products (such as RapidEye, Landsat 8, SPOT 6 and SPOT 7) and satellite-derived data, including Sea Surface Temperature (SST), chlorophyll concentrations, ocean currents, and other products on a regional scale.

Below is a summary of findings from the 2014 – 2020 annual coastal remote sensing reports and includes direct excerpts from these reports as approved by the lead authors, Mark Hess and Dr. Jan Svejkovsky. All reports are linked below, and can be found at: www.sandiego.gov/public-utilities/sustainability/ocean-monitoring/reports.

- Svejkovsky, J. (2015). Satellite & Aerial Coastal Water Quality Monitoring in the San Diego / Tijuana Region - Annual Summary Report (1 January 2014 - 31 December 2014). Ocean Imaging Inc. Technical Report (18 p.).
- Svejkovsky, J. (2016). Satellite & Aerial Coastal Water Quality Monitoring in the San Diego / Tijuana Region - Annual Summary Report (1 January 2015 - 31 December 2015). Ocean Imaging Inc. Technical Report (18 p.).
- Svejkovsky, J. (2017). Satellite & Aerial Coastal Water Quality Monitoring in the San Diego / Tijuana Region - Annual Summary Report (1 January 2016 - 31 December 2016). Ocean Imaging Inc. Technical Report (28 p.).
- Hess, M. (2018). Satellite & Aerial Coastal Water Quality Monitoring in the San Diego / Tijuana Region - Annual Summary Report (1 January 2017 - 31 December 2017). Ocean Imaging Inc. Technical Report (35 p.).
- Hess, M. (2019). Satellite & Aerial Coastal Water Quality Monitoring in the San Diego / Tijuana Region - Annual Summary Report (1 January 2018 - 31 December 2018). Ocean Imaging Inc. Technical Report (43 p.).
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- Hess, M. (2021). Satellite & Aerial Coastal Water Quality Monitoring in the San Diego / Tijuana Region - Annual Summary Report (1 January 2020 - 31 December 2020). Ocean Imaging Inc. Technical Report (49 p.).

SECTION F-3 | REVIEW

The San Diego coastal region represents a relatively complex environment for water quality monitoring. Multiple sources of contamination exist in the PLOO survey area and being able to separate any impact that may be associated with PLOO wastewater discharge from other point, or non-point, sources of contamination is often challenging. Examples include outflows from the San Diego River, San Diego Bay, the Tijuana River, and Los Buenos Creek in northern Baja California (Largier et al. 2004, Nezlin et al. 2007, Gersberg et al. 2008, Terrill et al. 2009). Likewise, storm water discharges and terrestrial runoff from local watersheds during precipitation events, can also flush sediments and contaminants into nearshore coastal waters (Noble et al. 2003, Reeves et al. 2004, Sercu et al. 2009, Griffith et al. 2010).

Prior to the initiation of coastal remote sensing in the San Diego region, the only information on the potential distribution of the various plumes was derived from field measurements, by City staff, at fixed locations along the shoreline and offshore (e.g., City of San Diego 2000). Thus, accurately differentiating signals from the different inputs was extremely difficult, which made it virtually impossible to confidently monitor pollutant contributions from individual sources. By incorporating remote sensing technologies into the City's ocean monitoring program, it became possible to differentiate the dispersion of plumes from other contaminant sources and to confirm the negligible role that the PLOO discharge plays in local surface environmental conditions relative to other sources (Svejkovsky 2000, Svejkovsky et al. 2010).

Rainfall plays an important role in coastal water quality in southern California, and plumes of turbid water containing elevated concentrations of contaminants can emerge after storm events (Svejkovsky et al. 2010). Utilizing satellite imagery, almost all San Diego County beach closures can be attributed to local sewage spills, particularly via the Tijuana River, or specific rain events prior to or during the closure period (Svejkovsky 2015–2017, Hess 2018–2021). For example, during 2020, the County of San Diego posted 151 shoreline or rain advisories and 28 beach/ shoreline closures, slightly less than the number of advisories and closures in 2019 (166 and 32 respectively). All but two of the beach closures were in the South Bay, the source of which has been identified as cross-border flows from Mexico via the Tijuana River. The two other closures due to nearby sewage spills were located at Torrey Pines State Beach and Carlsbad Municipal Beach. Satellite imagery during these periods showed high turbidity and suspended solid levels along the coastline near the closed regions, as well as greater than normal Tijuana River runoff, sometimes being carried north by ocean currents. Additionally, although discharge from the San Diego River does not cause the same level of beach contamination issues as the Tijuana River discharge, runoff from the river, Mission Bay, and coastal lagoons has been shown to affect nearshore water clarity and quality throughout the year. This runoff likely contributes both directly as a source of suspended sediment and indirectly as a source of high nutrient levels to phytoplankton blooms.

Climate change, rainfall events, upwelling, and other ocean conditions are likely to be major contributing factors to the development and duration of algal blooms (Patti et al. 2008, Rykaczewski and Dunne 2010, Messie and Chavez 2015, Gobler et al. 2017, Gershunov et al. 2019). The extent of algal blooms in the Southern California Bight (SCB) region have increased significantly over the last two decades (Kahru et al. 2012, Nezlin et al. 2012). Regionally, red tides have been recorded in the SCB region for over a century, with the most recent large-scale event occurring in 2020 (Anderson and Hepner-Medina 2020).

There continues to be a lack of evidence to indicate a correlation of these blooms with wastewater discharge (Torrey 1902, Allen 1933, Horner et al. 1997, Kim et al. 2009, Svejkovsky 2003–2018, McGowan et al. 2017). This remains true for the Point Loma survey area as well. Direct visual observations of surface waters off Point Loma from 2002 through 2020 have demonstrated that no algal blooms, including red tide events, have originated in proximity to the PLOO (Svejkovsky 2003–2017, Hess 2018–2021). Despite discharging an average of 140 million gallons per day of treated wastewater to the Pacific Ocean, the PLOO effluent plume has not been directly observed at the surface via satellite imagery (Svejkovsky 2015–2017, Hess 2018–2021). This observation is consistent with data that indicates the PLOO plume remains trapped offshore at depths below the thermocline (Rogowski et al. 2012, 2013, Svejkovsky 2010, City of San Diego 2020).

Even during the winter months, when vertical stratification of the water column is weakest, stratification is typically still strong enough to prevent the plume from rising to the surface. (Svejkovsky 2015–2017, Hess 2018–2021). Consistent with this conclusion, coastal remote sensing has not detected the plume at the surface since inception of this monitoring approach. During spring and summer months, when algal blooms are most prevalent in the SCB region (Smith et al. 2018), thermal stratification is strongest and plume trapping depths are greatest (Bartlett et al. 2004). Thus, it is unlikely that PLOO discharge directly drives phytoplankton blooms on a regional scale.

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APPENDIX G

2016 – 2020 SUMMARY OF REMOTELY OPERATED VEHICLE SURVEYS FOR OUTFALL INTEGRITY

City of San Diego
Public Utilities Department

March 2022

APPENDIX G

2016-2020 Summary of Remotely Operated Vehicle Surveys for Outfall Integrity

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APPENDIX G

2016-2020 Summary of Remotely Operated Vehicle Surveys for Outfall Integrity

SECTION G-1 | SUMMARY OF FINDINGS

1) The Point Loma Ocean Outfall (PLOO) remained in good condition based on remote observations obtained using a Remotely Operated Vehicle (ROV) and evaluations made by City engineers.

2) The ballast level along the PLOO appeared relatively unchanged from the original construction.

3) Localized areas of less than optimal rock protection were observed towards the beginning of the outfall extension. These levels have not changed over time and are likely an artifact of rock placement during the original construction activities.

4) Minor rock surface modifications may be occurring as a result of external oceanographic forces, although this is difficult to evaluate from ROV footage alone.

5) Of the 416 ports found on the new diffuser legs all but two ports were unobstructed and flowed freely. The discharge rate, or flow, remained slightly reduced at two outfall ports due to persistent obstructions. These obstructions appeared to be pieces of the outfall PVC liner material that have eroded from the interior of the pipe. Additionally, some air vents have been persistently blocked for unknown reasons. These few obstructions and blockages did not appear to impair the operation or the integrity of the outfall.

6) The outfall’s metal structures (New Diffuser Leg Terminals Intermediate Wye Crib and New Wye Crib) remained in good condition, with the exception of the Original Diffuser Wye Crib. Corrosion of this structure is not a concern since most of the ballast rock mass surrounding the structure is grouted. Minor damage was imparted to the Original Wye by barge anchoring cables during the 1999 construction activity. Additional rock was added to this structure in 1997–1998.

7) A second engineering evaluation of the cathodic protection system of the outfall was performed in June 2012, by the Public Utilities Department Senior Corrosion Engineer,

using video from both the 2011–2012 surveys and the inspection conducted in 2006. From this review, it was concluded the anodes were being consumed and some level of cathodic protection was being provided. Although the number of visible active anodes that have been completely consumed has increased somewhat, the 2012 report noted that there was no visible corrosion of the new metal cribs or the terminal diffuser sections. This condition suggests that the remaining anode mass is likely sufficient to provide continued cathodic protection to the structures; however, City staff plan to assess whether there are any long-term concerns with the current amount of cathodic protection provided.

SECTION G-2 | INTRODUCTION

The Point Loma Ocean Outfall was completed and placed into service in October 1963. The original outfall conveyed primary treated sewage effluent from the Point Loma Wastewater Treatment Plant (PLWTP) to the ocean for dispersion at a water depth of 210 feet (ft), approximately 2.2 miles from shore (Figure G-1). The first 0.5 mile of the outfall was built as a concrete-covered trench excavated into the rock, and the remainder of the outfall was laid on the ocean bottom, over a layer of bedding, with ballast rock placed up to the pipe Spring Line (a horizontal line, running the length of the pipe, marking the widest part of the pipe). The outfall was constructed by San Diego Constructors, a joint venture formed by M.H. Golden, Trepte Construction Co., Inc., and Gunther and Shirley Company.

On November 17, 1983, the State Water Resources Control Board (SWRCB) modified the California Ocean Plan to designate the kelp beds offshore from Point Loma as a water-contact sports area. With this designation, the City was no longer in compliance with specific Ocean Plan bacteriological standards. The PLWTP effluent had been identified as the major source of the elevated bacterial levels in the kelp beds. The City was ordered to meet the bacteriological standards set forth in the Ocean Plan by August 24, 1994. After completion of an engineering study, an outfall extension was determined to be the preferred method for meeting Ocean Plan standards.The City entered into an agreement with Engineering-Science, Inc. (ESI, the former name of the Parsons Corporation), to design an outfall extension. As part of this effort, ESI investigated the condition of the existing outfall and determined the maximum length the outfall could be extended, based on the hydraulic pressure of the system. Over the course of the investigation, air entrainment was identified as a major problem with the original construction. A separate project, incorporating multiple sleeve valves, was constructed to control effluent flows, dissipate excess head, and correct the air entrainment problem in the Vortex structure.

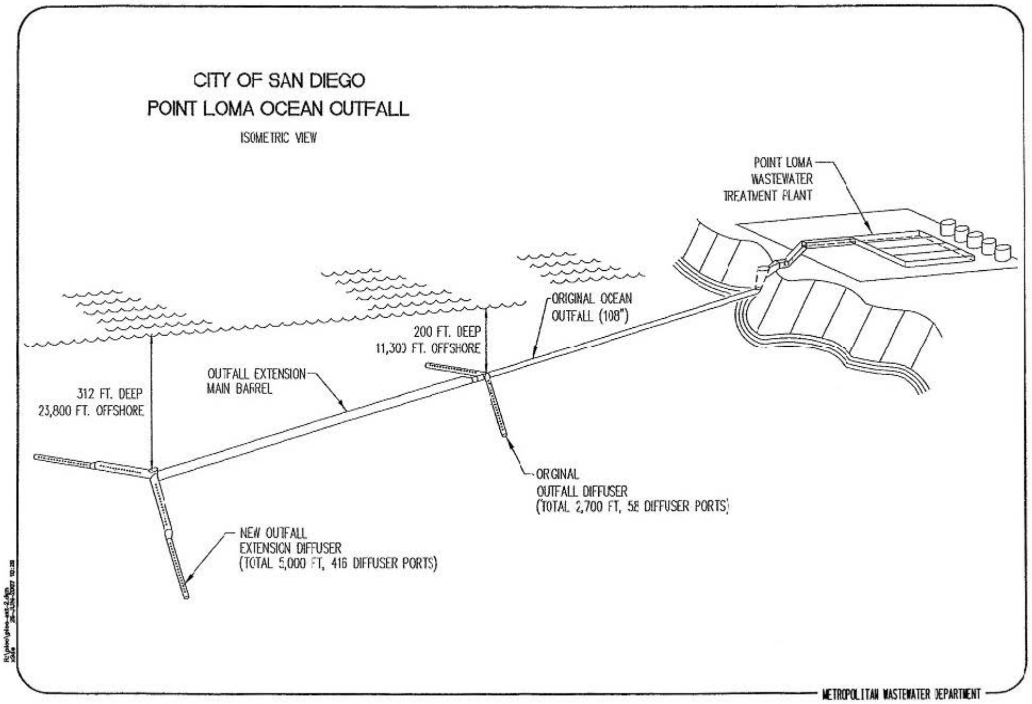

FIGURE G-1 Diagram of Point Loma Ocean Outfall showing major features: Original Outfall, New Extension, Intermediate Wye anodes and New Wye anodes.

The outfall extension was completed and commissioned on November 24, 1993. It is now one of the longest, largest, and deepest reinforced concrete bell and spigot ocean outfalls in the world, reaching 4.5 miles in length and discharging at a depth of 320 ft below sea level (Figure G-1).

Since the extension of the PLOO in 1993, the City has conducted annual external surveys of the outfall using Remotely Operated Vehicle (ROV) video observations. The City also conducted diver led surveys through 2013, until they were discontinued due to mounting costs and logistical challenges. For the past five years, the external inspection of the PLOO was carried out using the City's SAAB Seaeye Falcon ROV. The ROV was equipped with high sensitivity and resolution color and low-light black and white video cameras for recording high quality footage of the outfall.

It was also equipped with a digital sonar, and an ultra-short baseline tracking system, which used acoustic telemetry to locate the position of the ROV relative to the support vessel in real time. In addition, the ROV was equipped with a precision navigation and positioning system composed of a doppler velocity log (DVL). Due to the depth of the PLOO, the low-light black and white video camera was used for most portions of these surveys. The camera provided a good visual perspective of the outfall and its surroundings in low-light/low-visibility environments and offered greater detail and depth of field than a color camera was able to provide in the same situation.

Despite the use of high-quality cameras, highly variable water clarity in the Point Loma region made video analysis challenging. This was due in part to the substantial depth at which the outfall is located (320 ft), the dynamic environment (e.g. strong currents), and a large amount of naturally-occurring suspended organic material, which often contributes to a very turbid environment. Nevertheless, high turbidity and reduced visibility does not appear to be a factor of the outfall discharge itself, as turbidity is typically comparable along the outfall pipe regardless of distance from the active Diffusers and is common in nearshore Southern California waters.

The review presented herein is intended as a summary of findings from the City's 2016 – 2020 annual outfall inspection reports. Direct excerpts from these reports are included, as approved by the City Engineer, Stephen Cann. All reports are linked below, and can also be found at www.sandiego.gov/public-utilities/sustainability/ocean-monitoring/reports):

- City of San Diego (2017). Point Loma Ocean Outfall Inspection Report 2016. City of San Diego Technical Report.
- City of San Diego (2018). Point Loma Ocean Outfall Inspection Report 2017. City of San Diego Technical Report.
- City of San Diego (2019). Point Loma Ocean Outfall Inspection Report 2018. City of San Diego Technical Report.
- City of San Diego (2020). Point Loma Ocean Outfall Inspection Report 2019. City of San Diego Technical Report.
- City of San Diego (2021). Point Loma Ocean Outfall Inspection Report 2020. City of San Diego Technical Report.

SECTION G-3 | REVIEW

Outfall Condition

Ballast Rock

Ballast rock levels vary along the length of the outfall pipe in an oscillating pattern, but engineer consensus remains that the ballast rock has not exhibited any noticeable movement since its installation. This finding, combined with similar conclusions from 2017 reports and earlier, continues to support the premise that the observed undulations likely resulted from the original placement of the rock at the time of construction rather than having resulted from movement associated with external oceanographic forces.

Original Diffuser Legs

Although the original diffuser legs are no longer an active part of the outfall, a video inspection of the structures continues to be a standard feature of each annual inspection.

Flow into the original diffuser legs is presently blocked by bulkheads (gate covers), which were inserted when the outfall extension was brought on-line. Initially the bulkheads were too large, and they were shaved down to allow for better fitment. When the bulkheads were shaved down, too much material was removed enabling effluent to leak from the old diffuser legs. An attempt was made after the completion of the outfall extension to send divers inside the Old Wye to caulk and seal the gate covers to reduce the leaks, however this effort had little impact.

As of the 2020 report, the condition of the old diffuser legs appeared unchanged with effluent observed escaping from the first 5-10 ports closest to the main barrel on the north and south legs. The extent of the observed effluent discharged was dependent on the total volume of effluent discharged through the outfall structure with the volume decreasing with increasing distance from the wye structure. The observed variability in the rate and volume of discharge from year to year was also likely due to the differing times of day at which the surveys were conducted rather than having been the result of changes in the physical state of the diffuser legs.

Intermediate Wye

All visible sections of the intermediate wye remained in good condition. However, the 2020 report noted that eight of the original 28 anodes were buried under ballast rock making conclusions about their condition impossible (Figure G-2). Passive anode 9U was detached from its mounting bracket soon after construction, presumably due to a fouled anchor line, and passive anodes 3U and 5U are also missing. Six of the lower, active anodes still exhibit uniform levels of degradation and seem to have retained approximately 50% of their original mass. Many of the protective wrappings on the upper ring of the passive anodes have loosened over time and have become active to varying degrees, but they all appear to have retained much of their original mass.

New North Diffuser Leg

All diffuser ports continued to flow freely except for the inshore port of N98, which has been partially blocked for at least the last 5 years. Flows at this port were reduced by pieces of a white material protruding from the port openings, which were believed to be eroded sections of the PVC liner from the interior of the pipe. Additionally, the air vents at N77 and N42 have remained blocked for at least 5 years. The active anodes on the A, B, C and D anode pairs on the terminal metal diffuser section were missing and were assumed to be have been prematurely consumed. As of 2020, the passive anodes were in relatively good condition but were all unwrapped to varying degrees and exhibit evidence of degradation. The metal terminal section of the diffuser leg looked to be in very good condition and showed no sign of corrosion. Localized areas of relatively minor leaking were observed emanating from the seams of the north leg terminus structure.

New Diffuser Wye

In 2020, the new diffuser wye structure continued to be in overall good condition, however, some anodes were missing or buried and so no conclusion can be drawn regarding their

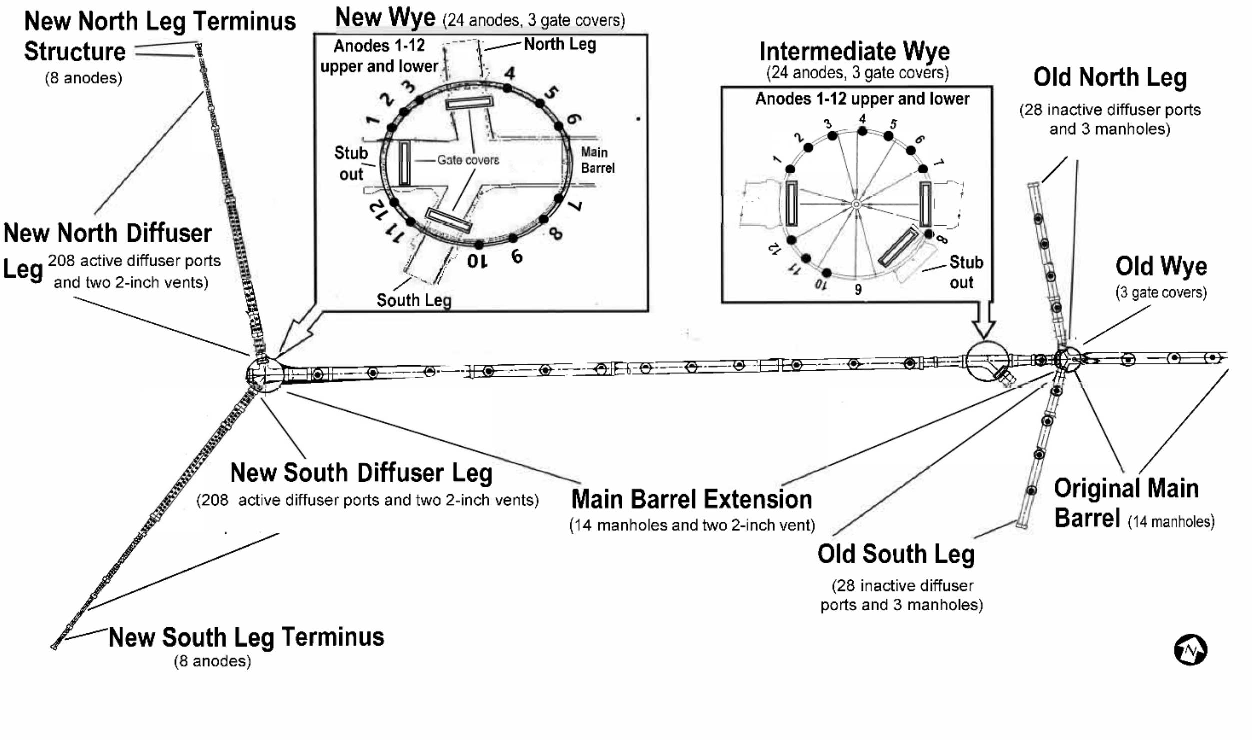

FIGURE G-2 Isometric view of Point Loma Ocean Outfall and anode schematic.

condition. The protective wrappings on the remaining anodes of the upper ring have loosened over time to varying degrees, which has caused them to become partially active. These eight anodes, however, have continued to retain much of their original mass. No corrosion of the metal crib structure has been noted and it was assumed, therefore, that the remaining anodes continue to provide adequate cathodic protection.

Across surveys, several localized areas of minor leaking have been observed emanating from the seams of the north and south leg gate covers as well as the Stubout gate cover. Minor volumes of effluent have also been observed to leak from locations on the perimeter of Stubout gate. However, all observed low-flow leaks are considered of little consequence in regard to water quality, as (1) the leaks represent an insignificant fraction of the total PLOO flow, (2) due to the slow leakage rates, this low flow is diluted to a much higher degree than that of effluent being discharged from the nearby diffuser ports, and (3) all observed minor leaks are within the designated PLOO zone of initial dilution (ZID).

New South Diffuser Leg

Similar to the new north diffuser leg, a persistent blockage, likely from the pipe PVC liner, has been observed across years at the offshore port S97. Otherwise, all the diffuser ports on this diffuser leg appeared to be flowing normally. The active anodes on the terminal metal diffuser section exhibited uniform levels of corrosion and appeared to retain at least 50% of their original mass. All the passive anodes appeared to be adequately wrapped and in good condition with a few of the anodes showing some consumption around the ends where the protective wrapping appears to have come loose. As of 2020, the level of protective rock along this structure continued to be satisfactory.

Outfall Extension Main Barrel from New Diffuser Wye to Intermediate Wye

Ballast levels do not appear to have changed noticeably over time. Rock levels along the main barrel continued to be adequate. Levels on both sides of the outfall occasionally fall below the spring line (3 and 9 o'clock positions), but rarely fell below 8 and 4 o'clock positions on the north and the south sides, respectively. There were isolated areas of low rock levels on the south side that extend in places over two sections; on the north side low spots are limited to much less than half a pipe segment. The variation in rock level is thought to be an artifact of rock placement rather than movement by external oceanographic forces. Additionally, a vent on the top of the last pipe segment (J619) persistently remains blocked and has been this way for at least 11 years.

Manholes

There are 20 manholes on the original outfall (14 on the main barrel and three each on the old diffuser legs) and 15 on the outfall extension. One manhole cover is made of concrete, the others are made of Ni-Resist alloy. Of the 14 main barrel manholes on the original outfall, five were still visible in ROV inspections. The first three manholes on the original outfall were within the area where the pipe is covered by a concrete cap. Four manholes were within the area of the pipe covered by armor rock and were not visible. Manhole 9 has a piezometer box atop of it and armor rock piled high on both sides. While there has been some concern that movement of the large armor rock might damage the piezometer box and cause a leak, the position of the rock has remained stable over time. The manholes on the main barrel all appeared to be in good condition in 2020. The visible manholes on the old diffuser legs, including a new manhole fabricated with Monel alloy near the old wye, were also in good condition. The rest of the manholes observed were also in good condition and no leaks have been detected.

SECTION G-4 | CONCLUSION

The following comments were submitted by City Engineer, Stephen Cann, as part of the 2020 outfall inspection report:

"In general, the findings of this survey agree with the conclusions of earlier inspections: the ballast, the diffusers and the exterior of the outfall system are in good condition, with the same isolated areas showing reduced rock levels. Comparisons of video from this year and former inspections suggest that while very minor rock surface modifications may be occurring because of external oceanographic forces, the ballast level along the outfall appears largely unchanged. This year's video shows that while many of the visible active anodes are consumed to some degree, or detached in some cases, there is no visible corrosion of the metal cribs or the terminal diffuser sections, suggesting that the remaining anode mass is probably enough to provide an adequate level of protection to the structures. City Staff will use the inspection videos to evaluate whether there should be any long-

term concern with the amount of cathodic protection currently being provided. Based on those findings, subsequent action may be warranted including unwrapping of passive anodes, and/or complete replacement of the currently active ingots."

FIGURE 1