Narragansett Bay
Research Reserve

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Water Quality and Meteorological Station Annual Report 2007: Recent and Long-term Data

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Executive Summary

The Narragansett Bay National Estuarine Research Reserve (NBNERR or Reserve) is part of the National Estuarine Research Reserve System (NERRS or Reserve System) established under Section 315 of the Coastal Zone Management Act of 1972. The Reserve System protects estuarine and coastal habitats and promotes well-informed management of these habitats through research and education. The Reserve protects an estimated 1780 hectares of land and water (out to a depth of 5.5 m), which includes four islands: Prudence, Patience, Hope and Dyer. The mission of the Reserve is to preserve and protect representative estuarine habitats within Narragansett Bay and provide opportunities for long-term research, education, and training for sound coastal stewardship.

A major component of the NERRS is the System-Wide Monitoring Program (SWMP). The SWMP was established to collect a broad suite of water quality and meteorological parameters for tracking short-term variability and long-term changes in estuarine environments. Since 1995, the Reserve has collected SWMP data providing long-term datasets that provide science-based information to decision-making agencies and the private sector to effectively address coastal resource management issues. This is accomplished by the deployment of automated data loggers at four permanent stations strategically established around Prudence Island, which represents a gradient in habitat types: from salt marsh (Nag Creek) to shallow cove (Potter Cove) to open Bay water (T-Wharf: Surface and Bottom stations).

At the Reserve, water quality parameters have been since the establishment of the first water quality monitoring station at Potter Cove in 1995. Water temperature (^{o}C), salinity (ppt), dissolved oxygen (% saturation, and mg L^{-1}), pH, turbidity (NTU), and chlorophyll (ug L^{-1}) data are collected at each station. The sondes are calibrated and deployed approximately every two weeks, collecting data every 15 minutes. Variability and trends in meteorological parameters are also monitored at the Reserve since 2001 through the SWMP. The Reserve has an automated weather station that collects data on air temperature (^{o}C), relative humidity (%), wind speed (m s^{-1}), wind direction (degrees), barometric pressure (mb), rainfall (mm), and photosynthetically active radiation (PAR, mmol m^{-2}). The data from each sensor are stored by a central data logger and downloaded on an approximate monthly basis. The water quality and meteorological data used in this report were authoritative datasets from the NERRS Centralized Data Management Office (CDMO) website. The data were revised for the analyses according to quality assurance quality control guidelines from CDMO.

In general, the results of the analysis for the water quality data for 2007 showed the seasonal variability distinctive of a temperate estuary. In a smaller temporal and spatial scale, variability was evident when the results showed significant differences among stations on temperature, salinity, dissolved oxygen, pH, turbidity, and chlorophyll ($p<0.05$, Kruskal-Wallis One-Way Anova). Theses results underline the gradient of habitats types that the four monitoring stations represent at Prudence Island: from salt marsh (Nag Creek) to shallow cove (Potter Cove) to open Bay water (T-Wharf). Moreover, the preliminary assessment of the long-term water quality data showed differences among all the stations throughout the years. Additionally, a clear stratification of the water column occurs in open Bay waters represented by T-Wharf Surface and T-Wharf Bottom stations. Interestingly, dissolved oxygen daily means showed that no anoxic events occurred at any of the water quality stations; however, two days of hypoxic conditions prevailed at Nag Creek during 2007.

The results of the analysis for the meteorological data for 2007 also showed the characteristic seasonality in atmospheric conditions of the temperate zone. The preliminary assessment of the long-term meteorological data showed that 2007 was an average year when compared to previous years.

In conclusion, the data compiled throughout the years at the four water quality stations and meteorological station at NBNERR makes it possible to analyze and study trends and patterns of physical-chemical variables at Narragansett Bay. This information increases our knowledge on the influence that environmental parameters have over estuarine processes, and promotes well-informed management decisions and regulations concerning Narragansett Bay estuary.

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GENERAL INTRODUCTION

The National Estuarine Research Reserves System (NERRS) encompasses 27 sites representing different biogeographic regions of the United States and its territories (Figure 1). These sites are being preserved and protected for long-term research, water-quality monitoring, education, and coastal stewardship. The NERRS is a partnership program between the National Oceanic and Atmospheric Administration (NOAA) and the coastal states, as established by the Coastal Zone Management Act of 1972. NOAA provides financial support, national guidance, and technical assistance.

The Narragansett Bay National Estuarine Research Reserve (NBNERR or Reserve) was the 7th site selected to become part of NERRS. NBNERR was designated in 1980 through a partnership between NOAA and the Rhode Island Department of Environmental Management (RIDEM), which is responsible for the overall management of the Reserve. The Narragansett Bay National Estuarine Research Reserve is approximately located at the geographic center of Narragansett Bay in Rhode Island. NBNERR protects an estimated 1780 hectares of land and water (out to a depth of 5.5 m) on Prudence, Patience, Hope, and Dyer islands (Figure 2). NBNERR headquarters, lab, and learning center are located on the 1416 ha (3499 acre) on Prudence Island, which is approximately 11.3 km long and 1.6 km across its widest point. About 86% of Prudence Island land area is currently protected, either as part of the Reserve (68%) or by local conservation groups (11 and 8 % acquired by Prudence Conservancy and Audubon Society, respectively). The three other islands that are also part of the Reserve, however, are much smaller than Prudence: Patience, Hope, and Dyer islands are approximately 68 ha (167 acres), 28 ha (70 acres), and 11 ha (28 acres), respectively. In relation to Prudence Island, Patience Island is approximately 0.16 km off the northwest point, Hope Island is 2.4 km to the west, and Dyer Island is 1.1 km to the southeast. Each of these three islands is uninhabited except for three lots on Patience Island, which are privately owned.

NBNERR's principal mission is to protect, enhance and learn about the Narragansett Bay estuary and its watershed, and to provide opportunities for long-term estuarine research, education, and stewardship. The long-term scientific research and collection of water quality and meteorological data at NBNERR provides information to decision-making agencies and private sectors in RI to effectively address coastal resource management issues. The Reserve also enhances public awareness and understanding of the Narragansett Bay watershed and estuarine areas in the region through K-12 and teacher education programs as well as public education and outreach. A major component of NERRS is the System Wide Monitoring Program (SWMP), the goal of which is to develop long-term water quality and meteorological datasets in a coordinated manner at all 27 NERR sites. All the Reserves within NERRS follow the same protocols for data collection, which is continuously revised for updates and improvements. The goal of this report is to analyze water quality and meteorological data collected at NBNERR during 2007. In addition, this report will also include a preliminary analysis of long-term data collected at NBNERR since 1995.

1. WATER QUALITY

1.1. Introduction

The SWMP was created and developed by NERRS in 1995 as a nationally coordinated long-term monitoring program. The primary mission of the NERR System SWMP is to:

> *Develop quantitative measurements of short-term variability and long-term changes in the water quality, biotic diversity, and land-use / land -cover characteristics of estuaries and estuarine ecosystems for the purposes of contributing to effective coastal zone management (National Estuarine Research Reserve System, 2007).*

To achieve our mission, the SWMP was established as a phased monitoring program to focus on three aspects of coastal ecosystem characteristics (National Estuarine Research Reserve System, 2005):

Phase 1 – Abiotic Factors, including: atmospheric conditions and water quality,
Phase 2 – Biological Monitoring, including: biodiversity, habitat and population characteristics,
Phase 3 – Watershed and land use classifications, including: changes in human uses and land cover types.

At NBNERR all three aforementioned phases are currently ongoing; however, this report will focus on Phase 1 - Monitoring of the Abiotic Factors. For instance, water quality over a range of spatial and temporal scales will be covered in section (1), and section (2) will focus on the atmospheric information collected at the Reserve.

1.2. Methods

1.2.1. Study Sites

Four permanent stations strategically established around Prudence Island are used to monitor water quality: Potter Cove, Nag Creek, T-Wharf Surface, and T-Wharf Bottom (Figure 1). The existing location of the SWMP stations at NBNERR (Figure 2) enables the collection of data along a gradient in habitat types: from salt marsh (Nag Creek) to shallow cove (Potter Cove) to open Bay water (T-Wharf). A brief description of the four stations follows.

Potter Cove Station

The SWMP was established at the Reserve with the first water quality monitoring station at Potter Cove (Figure 3), constructed in December 1995. It represented an impacted area, as suggested by NERRS guidelines. It is located on a piling of a small dock in Potter Cove, which is located along the northeastern shoreline of Prudence Island (41° 38.416’ N, 71° 20.450’ W). Water depth at Potter Cove ranges from 0.9 m to 3.9 m.

Nag Creek Station

The water quality monitoring station at Nag Creek (Figure 4a) was originally constructed in March 2002. It is located on the West side of Prudence Island (41° 37.483’ N, 71° 19.450’ W), and it flows into the West Passage of Narragansett Bay (Figure 4b). The depth at this station ranges from 0.1 m to 1.4 m.

T-Wharf

The original T-Wharf (or T-Wharf (old station)) water quality monitoring station was originally installed in September 1996. It represented a non-impacted area, as suggested by NERRS. This station was located close to shore secured to a large wooden pier to the south of Prudence Island (41° 34.733' N, 71° 19.266' W). The depth range at this station was from 3.5 to 4.5 m. T-Wharf station was replaced in July 2002 with two new stations: T-Wharf Surface and T-Wharf Bottom. This modification to the T-Wharf station was done to allow the study of water column stratification in open waters of Narragansett Bay.

T-Wharf Surface Station

The water quality monitoring station at T-Wharf Surface (Figure 5) was established in July 2002, as part of the relocation of the original T-Wharf station. The current station is secured to a large wooden pier on the southeast corner of Prudence Island (41° 34.700' N, 71° 19.266' W). The sonde is deployed in water depths that range from 0.2 m to 0.9 m.

T-Wharf Bottom Station

The water quality monitoring station at T-Wharf Bottom (Figure 5) was established in 2002 as a result of the relocation of the original T-Wharf station. The current station is located on a large pier located on the southeast corner of Prudence Island (41° 34.700' N, 71° 19.266' W), adjacent to the T-Wharf Surface station. The depth at this station ranges from 4.6 m to 6.9 m.

1.2.2. Data Collection

Deployment of the Sondes

To study water quality at NBNERR, physical and chemical parameters are collected using Yellow Spring Instruments (YSI) 6600 EDS and 6600 V2 multi-parameter automated data loggers also known as sondes. They are equipped with self-cleaning optical sensor design, anti-fouling wiper, optimal power management, and built-in battery compartment which improve reliability and maintain high data accuracy during extended deployments. The sondes simultaneously measure several parameters including temperature, conductivity (salinity), dissolved oxygen (percent saturation and concentration), depth, pH, turbidity, and chlorophyll. At the Reserve, calibration and deployment of the sondes occurs approximately every two weeks. Since 1995, data were collected at 30-minute sampling intervals; however, in May 2004, this was changed to a 15-minute sampling interval. At the end of the deployment period, the sondes are retrieved and replaced with recently calibrated sondes.

History and Brief Description of the Deployment Structures at each Station

Potter Cove Station

In 1995, the sonde at Potter Cove was deployed from a PVC pipe mounted vertically on a piling located approximately 2 m west of the floating dock. The sonde was deployed inside the PVC pipe extending out past the bottom of the tube into open water. The sonde was maintained approximately 0.5 m off the bottom using a float attached to the bottom of the sonde. Since September 2006, the infrastructure at Potter Cove had slightly changed. The PVC pipe is now attached to the floating dock (Figure 6), and the sonde is deployed as previously described.

Nag Creek Station

Since March 2002, the Nag Creek the deployment structure was a metal cage which was tethered to the bank. A different structure was installed in December 2002 which consisted of a 0.1 m x 0.1 m pressure-treated post with a hinged 0.5 m x 0.1 m horizontal arm. Since September 2006, the deployment infrastructure consists of an L-shape wooden structure that is held in place in the sediment by a large metal tripod sunk into the mud in the middle of the creek. The sonde is deployed from the arm into the water via a cleat, eye and line system and hangs approximately 0.5 m from the bottom of the creek (Figure 7a-c). The station at Nag Creek can only be reached by kayak.

T-Wharf (old station)

From 1996 to 2002, the T-Wharf (old station) was set up using a PVC pipe mounted on a piling attached to the pier. The sonde was deployed inside the PVC pipe, and maintained approximately 1 m off the bottom. To facilitate water circulation, holes and large slits were drilled throughout the PVC pipe. The PVC was cleaned inside with a chimney brush in a monthly basis during the summer to reduce the impact of biofouling on the data. A PVC cap with locking mechanism was used as a precaution.

T-Wharf Surface Station

In 2002, the T-Wharf Surface station was set up using a PVC pipe. The PVC pipe for T-Wharf Surface station was prepared, installed, cleaned, and secured as previously described for T-Wharf (old station). The sonde at T-Wharf Surface station is maintained just below the surface at approximately 0.5 m by means of a buoy attached by rope to the adjacent wharf.

T-Wharf Bottom Station

In 2002, the T-Wharf Bottom station was set up using a second PVC pipe mounted on a piling attached to the pier, next to the T-Wharf Surface station. The deployment setup is as described for T-Wharf Surface station, with the exception that the PVC pipe extends approximately 6.1 m into the water column, allowing the sonde to be kept approximately 0.5 m off the bottom. The PVC pipe for T-Wharf Bottom station was prepared, installed, cleaned, and secured as previously described for T-Wharf (old station).

Quality Assurance Quality Control (QAQC)

After downloading the raw data obtained from the sonde to a computer in the laboratory, the data file is submitted to CDMO where it goes through a careful process of quality assurance and quality control. After this primary QAQC process, the data are posted and available as provisional data on the CDMO online data information service (ODIS) website (http://cdmo.baruch.sc.edu). Subsequently, the data are returned to the Reserve for a second

QAQC process. After the secondary QAQC at the Reserve, the data are sent again to the CDMO, together with the corresponding metadata as a completed annual dataset. The metadata is a document with information about the events that took place during that particular year the sondes were collecting data (i.e., deployment and retrieval dates, post-calibration measures, instruments specifications, observations, etc.). This is important information that could help to explain temporal or spatial trends observed in the data. CDMO will process the data and metadata for a final QAQC process; once it is authenticated, it will become authoritative on the CDMO-ODIS website.

The water quality data used in this report are the authoritative datasets of CDMO (dataset that has gone through several layers of QAQC processes). The data can be downloaded by any interested party through the CDMO website. In a downloaded data file, each parameter contains an additional flag column. For instance, the parameter *Temperature* will have a column next to it with the header *F_Temperature*. This column contains the quality control flag for that parameter, which was applied during the automated primary QAQC process to the raw data the Reserve uploaded to the CDMO website; subsequent QAQC checks will confirm or amend these flags. There are eleven QAQC flags ranging from 5 to -5, and are used, among others, when the data is out of the sensor range, missing, or is several standard deviations (2-3) from the historical mean (Table 1). The water quality datasets used for this report were revised according to the QAQC flags in Table 1. Only data flagged as 0, 2, 3, and 4 were used for this report (datasets had no data flagged as 5=corrected data); in this report the resulting dataset will be called 'revised data' preceded by the corresponding year of the data (i.e. 2007 revised data), and was used for statistical analysis, tables, and graphs.

Water Quality Telemetry

In July 2006, telemetry equipment was installed at the T-Wharf to allow for the near-real-time transmittal of water quality from the T-Wharf Bottom sonde to the internet. This equipment includes a Sutron Sat-Link2 transmitter, which is connected to the T-Wharf Bottom water quality sonde by a cable that transmits the collected data in an hourly basis to the NOAA GOES satellite (Figure 8). The near-real-time data are posted and available online at the CDMO website.

Water quality data collected at the T-Wharf Bottom station is also part of the Integrated Ocean Observing Systems (IOOS, http://ioos.noaa.gov), which is a coordinated effort to generate, disseminate, and make available to scientists continuous data from the Great Lakes, coastal waters, and oceans. With this information, scientists can work on developing a more complete characterization of our oceans and coasts and improve our knowledge of climate and environmental changes. All 27 Reserves within the NERRS contribute SWMP data to IOOS.

1.2.3. Data Analysis

2007 Data

The 2007 revised data comprised from 69 to 100% of the original datasets among stations (Appendix I). The revised data were used to calculate daily and monthly means for temperature (^{o}C), salinity (ppt), dissolved oxygen (% saturation, and mg L^{-1}), pH, turbidity (NTU) and chlorophyll (µg L^{-1}) for all stations. To compare the parameters among the four stations, and the different habitats they represent, monthly means from all stations were calculated and plotted.

Descriptive statistics for 2007 water quality parameters for all stations are presented in Appendix I. Graphs of daily and monthly means (± standard deviation) grouped by station can be found in Appendix II and III, respectively.

Statistical analysis was performed using 2007 revised data from April to November to test for significant differences among stations for each water quality parameter. Only data from April to November was used since the stations differ in the amount of data collected (Table 2). For instance, at Nag Creek the sonde was retrieved during the winter due to frozen conditions. In addition, the pH data analyzed in the report was from May to September and November; pH data from April and October from T-Wharf Bottom were suspect data due to calibration errors, as determined through the QAQC processes; consequently, April and October pH data were not included for any station in the analysis.

The normality and homogeneity of variance assumption was tested using the Kolmogorov-Smirnov and the Levene test, respectively, using SigmaStat statistical computer program. The normality and homogeneity test failed ($p<0.05$) even after ln (x+1) transformation of the data, therefore, a non-parametric test, Kruskal-Wallis One-Way Analysis of Variance on Ranks (K-W One-Way ANOVA) was used. An all pairwise multiple comparison test (Dunn's Method) was performed to isolate the station or stations that statistically differ from one another. All statistical tests were done at $p<0.05$ confidence level.

Long-term Trends

The long-term water quality data acquired through CDMO for yearly means calculations extends from 1995 to 2007. Data were available from January to December for all the stations (years varied per station, see Table 2) with several exceptions: 1) Potter Cove 1995 had only a month of data; this year was excluded from the calculations, 2) T-Wharf (old station) 1996, 1999, and 2002 had 4, 10, and 6 months of data, respectively; only 1996 and 2004 were excluded, 3) Nag Creek had 10 to 12 months of data available per year (Table 2) due to ice in the creek during winter. To calculate long-term yearly means, all datasets that included 10 or more months in their yearly dataset were included in the yearly mean calculations. After revising the long-term datasets as described on section 1.2.2 (Data Collection – QAQC), the percentage of data used for the yearly means calculations for all the stations and parameters is presented in Appendix I. Assessment and comparison of 2007 data with earlier long-term data were done for this report.

1.3. Results

1.3.1. Temperature

Water temperature recorded for 2007 ranged from -1.3 to 26.9°C at Potter Cove, from -1.5 to 33.4°C at Nag Creek, from -0.80 to 25.3°C at T-Wharf Surface, and from 0.70 to 24.4°C at T-Wharf Bottom (Appendix I). Daily means calculated for water temperature (Appendix II) showed higher variability throughout the year at Nag Creek than at the other stations, probably due to the shallow nature of this site. April, May, and June seem to be the months that contribute to the high variability observed in water temperature at Nag Creek (Appendix III).

Water temperature minimum monthly mean was recorded in February as 1.1 at Potter Cove, 1.7 at T-Wharf Surface, and 2.1°C at T-Wharf Bottom (Figure 9a). Water temperature maximum monthly mean was recorded in August as 22.8 at Potter Cove, 21.9 at T-Wharf Surface, and

21.0^{o}C at T-Wharf Bottom (Figure 9a). At Nag Creek the lowest was recorded as 3.5^{o}C in January (no data in February or March due to freezing of the creek) and the highest as 24.7 ^{o}C in July (Figure 9a).

Water temperature was significantly higher at Nag Creek than at the other stations ($p<0.001$, K-W One-Way ANOVA); the stations were significantly different from each other ($p<0.05$, Dunn's Method).

Long-term mean water temperature plotted for all stations (Figure 10a) showed high variation within stations from 2002 to 2005. Data from 2007 seem to be an average year when visually compared to the long-term data. In addition, it seems that a slight increase in temperature has occurred throughout the years. Future statistical analysis could determine if the increase is significant. Figure 10a also shows that for years 2003, 2006, and 2007 (data available for the entire year, see Table 2), Nag Creek had consistently higher temperatures than the other stations during the same years (except T-Wharf Surface 2006), perhaps because of the shallow water depths at this site.

1.3.2. Salinity

In 2007, salinity ranged from 20.3 to 31.9 ppt at Potter Cove, 1.2 to 31.8 ppt at Nag Creek, 21.0 to 31.9 ppt at T-Wharf Surface, and 25.1 to 32.6 ppt at T-Wharf Bottom (Appendix I). Daily means show the highest variation in salinity during the year at Nag Creek (Appendix II). January, March and April seem to be the months contributing to high variability (Appendix III) in salinity at Nag Creek.

Mean monthly salinity values (Figure 9b) were the lowest in April 2007 at Potter Cove, T-Wharf Surface, and T-Wharf Bottom (25.9, 27.2, 29.6 ppt, respectively), coinciding with the maximum precipitation recorded for 2007 at the weather station (174 mm, Figure 12f). At Nag Creek, the lowest salinity was recorded in May (19.2 ppt). The maximum monthly means were recorded in November at Potter Cove, in October at T-Wharf Surface, and in August at Nag Creek and T-Wharf Bottom (30.0, 31.2, 30.0, and 31.3, respectively; Figure 9b).

Salinity followed similar trends at Potter Cove, T-Wharf Surface and T-Wharf Bottom during 2007 (Figure 9b). Nevertheless, T-Wharf Surface had significantly higher salinity followed by Potter Cove, Nag Creek, and T-Wharf Bottom ($p<0.001$, K-W One-Way ANOVA); all stations were significantly different from one another according to Dunn's Method ($p<0.05$).

Long-term yearly mean salinity graph showed a clear separation among stations (Figure 10b). Salinity seems to be highest at T-Wharf Bottom, followed by T-Wharf (old station), T-Wharf Surface, Potter Cove, and Nag Creek. Long-term data plotted on Figure 10b shows that a halocline at T-Wharf. Data from 2007 seem to be an average year at all stations when visually compared to previous years.

1.3.3. Dissolved Oxygen (percent saturation)

Dissolved oxygen (DO) measured as percent saturation (% sat.) for 2007 ranged from 27.3 to 154% at Potter Cove, 0.0 to 227.4% at Nag Creek, 45.9 to 148% at T-Wharf Surface, and 53.5 to 134% at T-Wharf Bottom (Appendix I). Nag Creek had the highest variation in percent saturation of dissolved oxygen during the year (range = 227%, Appendix I). Daily means showed more variation in DO at Potter Cove and Nag Creek than at T-Wharf Surface and

Bottom (Appendix II). The highest variability in DO observed at Nag Creek occurred during the month of January, and from April to October; less variation was observed at the other sites (Appendix III).

Dissolved oxygen % sat. minimum monthly means observed at Potter Cove, Nag Creek, T-Wharf Surface, and T-Wharf Bottom (81.1, 57.8, 93.7, 87.3% sat., respectively) occurred during the months of April, July, November, and August, respectively (Figure 9c). Anoxic conditions (DO < 1% sat.) were recorded at Nag Creek for a short period of time during the months of July (12 days) and August (5 days), coinciding with the highest water temperature during the year. Most of the readings were sporadic during those days, except when the sonde recorded anoxic conditions continuously for 1.25 hrs (i.e., six consecutive readings on July 19). Water temperature and the shallow depth of Nag Creek might have been, among others, significant factors contributing to the anoxic conditions observed at the creek. The data showed anoxic conditions recorded several times during those 17 days. However, daily mean DO% sat. calculated for each of those days was between 38.7 to 90.1% saturation (Appendix II). Mean daily DO% sat. calculations also showed two days during 2007 (September 29, 30) where hypoxic conditions (DO = 1 to 30 % sat.) prevailed at Nag Creek. The dataset from Potter Cove shows only one reading (out of 92 daily readings made by the sonde) during August 7th to be within the hypoxic range (27.3 % DO); however, the calculated daily average for the same day was 75.78 % DO. No anoxic or hypoxic readings were found at T-Wharf Surface and Bottom; no anoxic conditions were found at Potter Cove for 2007.

Dissolved oxygen % sat. maximum monthly mean during 2007 was recorded during the month of December at Potter Cove and Nag Creek (109.0, and 102.9% sat., respectively) and during April and February at T-Wharf Surface (110.5% sat.) and Bottom (109.5% sat.), respectively (Figure 9c). Dissolved oxygen % sat. over 100 % is referred to as supersaturation of dissolved oxygen. Dissolved oxygen supersaturation (DOSS) was also recorded at Potter Cove during the months of January, February, March, and December; at Nag Creek during December; however, the sonde was out of the water during February and March, thus, no measurements of dissolved oxygen were possible during those months. At T-Wharf Surface, DOSS occurred from January to May and during December, and at T-Wharf Bottom in January, February, April, and May. These results are expected since the solubility of oxygen increases with decreasing water temperature. Hence, the supersaturation conditions at the four stations occurred during the colder months of the year (Figure 9c).

Dissolved oxygen % sat. in 2007 was significantly higher at T-Wharf Surface followed by T-Wharf Bottom, Potter Cove, and Nag Creek ($p<0.001$, K-W One-Way ANOVA). Even though they followed similar trends, all stations were significantly different from each other ($p<0.05$, Dunn's Method).

Long-term mean DO% sat. plotted over time showed a clear separation among stations (Figure 10c). Among all stations across years, DO% sat. yearly means were above 75%. T-Wharf Surface was the only station where DOSS was observed across years (2002-2007, Figure 10c), therefore, T-Wharf Surface had the highest DO% sat. across years, followed by T-Wharf (old station), Potter Cove, T-Wharf Bottom and Nag Creek. DO% sat. at Nag Creek shows higher variability across years than the other stations. When visually compared to the long-term datasets, DO% sat. from 2007 seems to be typical at T-Wharf Surface and Potter Cove, but slightly higher at T-Wharf Bottom, and lower at Nag Creek.

1.3.4. Dissolved Oxygen Concentration (mg L^{-1})

Dissolved oxygen concentration (mg L^{-1}) during 2007 ranged from 1.9 to 16.8 at Potter Cove, 0.0 to 18.4 at Nag Creek, 3.4 to 14.1 at T-Wharf Surface, and 3.9 to 14.0 at T-Wharf Bottom (Appendix I). Nag Creek seems to have the highest variability for dissolved oxygen concentration or [DO] during the year (range=18.4, Appendix I). Daily and monthly means showed higher variation at Nag Creek than at the other stations (Appendix II and III, respectively).

Minimum monthly mean [DO] at Potter Cove and Nag Creek (6.3, 3.9 mg L^{-1}, respectively), and T-Wharf Surface and T-Wharf Bottom (6.9, 6.4 mg L^{-1}, respectively) occurred during the months of July and August, respectively (Figure 9d). The maximum monthly [DO] values were recorded during the months of December at Nag Creek (12.1 mg L^{-1}) and in February at Potter Cove, T-Wharf Surface and Bottom (12.1, 12.3, 12.1 mg L^{-1}, respectively) (Figure 9d).

Dissolved oxygen concentration was significantly higher at T-Wharf Surface followed by T-Wharf Bottom, Potter Cove, and Nag Creek ($p<0.001$, K-W One-Way ANOVA); all the stations were significantly different from each another ($p<0.05$, Dunn's Method).

Long-term mean [DO] shows a well-defined separation among stations, and a slightly decrease over time at Potter Cove (Figure 10d). True long-term differences among stations can only be determined with additional statistical analyses. Nevertheless, when visually comparing the long term datasets, 2007 seems to be a typical year for all stations, except Nag Creek, where it seems much lower than previous years.

1.3.5. pH

In 2007, pH ranged from 7.2 to 8.8 at Potter Cove, 6.3 to 9.3 at Nag Creek, 7.5 to 8.5 at T-Wharf Surface, and 7.6 to 8.5 at T-Wharf Bottom (Appendix I). Nag Creek had the highest pH variability during the year (range = 3, Appendix I). Daily means seem more variable at Nag Creek that at any other site (Appendix II). Moreover, monthly variations also seem to be much higher at Nag Creek that at the other sites (Appendix III).

Minimum monthly mean values for pH in 2007 at Potter Cove and T-Wharf Surface (7.6, 7.8, respectively) were observed during the month of August; while for Nag Creek and T-Wharf Bottom (7.1, 7.9, respectively) it was in July and September, respectively (Figure 9e). Maximum monthly mean values in pH at Potter Cove and T-Wharf Bottom (8.4, 8.3, respectively) were during March. At Nag Creek and T-Wharf Surface (7.8, 8.2, respectively) maximum values were recorded during January and April, respectively (Figure 9e).

Significant differences in pH were found among stations; T-Wharf Bottom had significantly higher pH concentrations followed by T-Wharf Surface, Potter Cove, and Nag Creek ($p<0.001$, K-W One-Way ANOVA); all stations were significantly different from each ($p<0.05$, Dunn's Method).

Long-term mean pH values plotted for all stations showed a clear separation of Nag Creek from the other stations, and a drop, then increase for Potter Cove throughout the years (Figure 10e). In general, a decrease can be observed throughout the years for all stations except Nag Creek. For 2007, Potter Cove and Nag Creek have increased; while T-Wharf Surface and T-Wharf Bottom have decreased, when compared with pH values obtained from previous years.

1.3.6. Turbidity

Turbidity (NTU) during 2007 ranged from 0 to 497 at Potter Cove, 0 to 933 at Nag Creek, 0 to 969 at T-Wharf Surface, and 0 to 78 at T-Wharf Bottom (Appendix I). T-Wharf Surface had the highest variability during the year (range = 969, Appendix I). Daily means showed higher variation for Nag Creek than for the other stations (Appendix II), while monthly means showed high variation in September and October for Nag Creek, and in July for T-Wharf Surface (Appendix III).

Turbidity minimum monthly mean in 2007 at Potter Cove, T-Wharf Surface, and T-Wharf Bottom were observed during the month of August (1.4, 0.6, 0.9 NTU, respectively), while for Nag Creek it was observed in June (2.1 NTU) (Figure 9f). Maximum monthly mean values for turbidity at Potter Cove, T-Wharf Surface, and T-Wharf Bottom were observed during July (2.7, 21.1, 4.7, respectively), while at Nag Creek it was observed in January (9.0 NTU) (Figure 9f).

Turbidity was significantly different among stations, Nag Creek had significantly higher turbidity values, followed by T-Wharf Bottom, Potter Cove, and T-Wharf Surface($p<0.001$, K-W One-Way ANOVA); all stations were significantly different from each another ($p<0.05$, Dunn's Method).

Long-term yearly means for turbidity plotted for all stations showed that the stations seemed to be similar throughout the years, except for T-Wharf (old station) during 1997 and 1999. Turbidity during 2007 has remained very close to the turbidity values obtained from the long-term datasets for all stations (Figure 10f).

1.3.7. Chlorophyll

Chlorophyll concentration (µg L^{-1}) during 2007 ranged from 0 to 397 at Potter Cove, 0 to 384 at Nag Creek, 0 to 399 at T-Wharf Surface, and 0 to 281 at T-Wharf Bottom (Appendix I). T-Wharf Surface had the highest variability during the year (range = 399, Appendix I). Daily means seemed to be more variable at Potter Cove than at the other stations (Appendix II). Monthly mean plots showed high variation in chlorophyll for T-Wharf Surface during the months of August and September, and for T-Wharf Bottom during the month of November (Appendix III).

Chlorophyll minimum monthly means in 2007 at Potter Cove, Nag Creek, and T-Wharf Surface were observed during November (1.3, 2.2, 2.6 µg L^{-1}, respectively), while at T-Wharf Bottom the minimum was observed in December (4.3 µg L^{-1}) (Figure 9g). Maximum monthly mean values for chlorophyll at Potter Cove, Nag Creek, T-Wharf Surface, and T-Wharf Bottom (20.1, 17.4, 33.0, 112.1 µg L^{-1}, respectively) were observed during February, July, August, and November, respectively (Figure 9g).

Chlorophyll in 2007 was significantly different ($p<0.001$, K-W One-Way ANOVA) among stations; Potter Cove had significantly higher chlorophyll concentrations than the other stations. All stations were significantly different from each another ($p<0.05$, Dunn's Method).

1.4. Discussion

At the Reserve we continually monitor water quality parameters at the four SWMP stations around Prudence Island. Included among these parameters are temperature, salinity, dissolved oxygen, pH, turbidity, depth, and chlorophyll. This report summarizes the water quality data recorded during 2007. In addition, a preliminary assessment of interranual variability and trends was done.

The seasonal variability exhibited by each of the water quality parameters at all stations in 2007 was characteristic of a temperate estuary. However, spatial and temporal variability were evident at a smaller scale when significant differences were found among stations and among water quality parameters for 2007. These results are indicative of differences in habitat types that the four water quality monitoring stations represent at Prudence Island: from salt marsh (Nag Creek) to shallow cove (Potter Cove) to open Bay water (T-Wharf). Furthermore, a preliminary assessment of the long-term data showed that water column stratification occurs in the open Bay waters based on salinity data from the T-Wharf Surface and T-Wharf Bottom stations, emphasizing the differences between these two stations.

Dissolved oxygen levels are a critical coastal management issue due to the possibility of low-oxygen biological impacts such as mortality events, modified trophic webs, and localized extinction (Altieri and Witman, 2006). Reduced growth rates of aquatic organisms are typical effects of hypoxia that have been observed in situ (Altieri and Witman, 2006) and in laboratory conditions (Wu 2002). It has been suggested that recent increases in nutrient inputs in Narragansett Bay might be a significant factor triggering hypoxic conditions in the Bay (Deacutis, 2005). During 2007, no anoxic (DO < 1% sat.) readings were recorded at Potter Cove, T-Wharf Surface and T-Wharf Bottom stations; only a few sporadic readings indicating anoxic conditions were recorded during the warmest months of the year (July, August) at Nag Creek. These readings could be considered negligible since the daily mean DO saturations for the aforementioned days were all >38 %. Hypoxic conditions (DO = 1 to 30 % sat.) prevailed at Nag Creek for two days in September, and an isolated reading was observed at Potter Cove; however, no mayor effects on flora or fauna were observed at these sites (Durant personal observations). Conversely, dissolved oxygen supersaturation (DO > 100%) was observed at all stations mostly during the cold months of the year (January to May, and December), except at Nag Creek due to the ice forming in the creek during the winter. Similar to anoxia or hypoxia, oxygen supersaturation could also be a cause of concern in aquatic environments due to the formation of reactive oxygen species. However, confounding results have been found regarding the effect of oxygen supersaturation events (Dalton 1995, Foss et al. 2002) on different organisms. The Reserve does not officially monitor the impacts of anoxia, hypoxia or supersaturation of DO on aquatic life; however, no major disturbances to aquatic organisms or plants (i.e., fish kill, aquatic plant die-off) were observed during 2007 (Durant personal observations).

Turbidity was variable at the Reserve during 2007. Monthly means across all stations were between 0 and 9 NTU, with the exception of a peak in July (20 NTU) at T-Wharf Surface. High turbidity affecting water transparency can be due to several factors such as resuspension of bottom sediments, waste discharge, urban run-off, and phytoplankton concentrations, among others. However, chlorophyll concentrations (an indirect measure of phytoplankton in the water column) results were low at the four water quality stations at the Reserve; therefore, diminishing the possibility of causing major effects in water transparency. Another factor affecting turbidity measures is the presence, on a few occasions, of shrimp, fish, or other invertebrates inside the protective cup where the probes are housed. The protective cup has a plastic mesh around to prevent these events; however, occasionally these organisms get inside the cup, mostly during warm months, interfering with the readings of the probes.

At the Reserve, chlorophyll concentrations were generally low (< 33 μg L^{-1}) throughout 2007, but comparable to results from Oviatt et al. (2002) where < 30 μg L^{-1} was found at the East Passage station, near the T-Wharf. These results might be related to the decrease in intensity and duration or failure to occur of the winter–spring bloom at Narragansett Bay (Oviatt 2004) which has been found to be negatively correlated to an increase in winter water temperature (Oviatt 2004, Keller et al. 1999). At the Reserve, no clear increasing temperature trend was observed in the long-term data; however, further statistical analyses are still needed.

The SWMP long-term water quality monitoring program is successfully developing a large database over time, making it possible to assess and study environmental changes in Narragansett Bay. We are committed to the collection of continuous water quality data; however, interruptions are inevitable. These interruptions, which are not necessarily mutually exclusive, could be due to several factors including: unusual environmental conditions or events, adverse weather conditions, equipment failure, biofouling, and ice, among others. Consequently, the data collected by NBNERR should actually be considered as relatively-continuous data because of the existing gaps in the datasets. Regardless of these difficulties, our efforts are directed to obtain high quality data to study trends and patterns of physical-chemical variables that support the scientific community, enhance public awareness and understanding of the Bay's watershed and estuarine areas, and promote educated management decisions and regulations.

2. METEOROLOGICAL STATION

2.1. Introduction

Continuous monitoring of meteorological parameters increases our knowledge of the environment in Narragansett Bay and provides information on meteorological conditions that have an effect on water quality variables. For example, precipitation in RI influences salinity in Narragansett Bay, and increases runoff of sediment and organic material; this in turn could have an effect on several water quality variables such as dissolved oxygen, turbidity, pH, and temperature. Meteorological data are also used to support ongoing water quality and biological monitoring, and to assist other scientific research projects.

At the Reserve, meteorological data has been collected by an automated weather station at Potter Cove since 1992. However, it was not until 2001 when the meteorological station was updated and became part of NERR-SWMP. The principal objective of this station is to record long-term meteorological data in order to observe any environmental changes or trends over time.

2.2. Methods

2.2.1. Study Site

The weather station is located on a grassland on the east side of Prudence Island (41° 38.216' N, 71° 20.350' W) (Figure 1), approximately 388.62 m South of Potter Cove water quality monitoring station. A large wooden platform (2.4 m W x 1.8 m D x 2.1 m H) has housed some of the instruments for approximately 16 years (Figure 11). This structure was build by the U.S. Environmental Protection Agency (EPA) to house atmospheric deposition equipment, which is no longer in use. With EPA permission, the platform is being used for SWMP for the purpose of collecting meteorological data.

2.2.2. Data Collection

At the weather station a CR1000 data logger is used to collect data from sensors recording air temperature, relative humidity, wind speed, wind direction, barometric pressure, precipitation, and photosynthetically active radiation. The CR1000 is enclosed in the Campbell housing unit, situated under the aforementioned wooden platform. The housing unit also contains all associated hardware, and the barometric pressure sensor. Other associated equipment including the GPS antenna, solar panel, rain gauge, PAR meter, and beam antenna are located on top of the platform. The wind sensor and the temperature and humidity sensor are located on an aluminum tower approximately 10 m in height (Figure 11). All sensors were located in accordance with manufacturer recommendations.

Meteorological data are sampled at 5-second intervals under the control of the CDMO/Campbell Scientific Logger Net program. The data are output to memory in 15 minute intervals (an average from the sampled 5-seconds intervals). The data are downloaded from the CR1000 on an approximately monthly basis to a laptop computer via a RS-232 serial cable connection. The meteorological data are uploaded to CDMO through the website and undergoes the same rigorous and careful QAQC process as the water quality data (see section 1.2.2-Quality Assurance Quality Control).

The meteorological data used in this report were obtained from the CDMO website, and are the authoritative data that had already gone through the final QAQC process. The data can be downloaded by any interested group or individual through the CDMO website at http://cdmo.baruch.sc.edu/QueryPages/csv_export.cfm. The downloaded meteorological file is similar to the water quality file described in section 1.2.2 (see Quality Assurance Quality Control), and the same eleven QAQC flags (Table 1) described on the aforementioned section apply to the meteorological data. The meteorological datasets used for this report were checked according to the QAQC flags in Table 1. Data flagged as 0, 2, 3, and 4 were used for this report (datasets had no data flagged as 5=corrected data); the resulting dataset was called 'revised data' preceded by the corresponding year of the data (i.e. 2007 revised data), and was used for statistical analysis, tables, and graphs.

Meteorological Telemetry

In July 2006, Campbell Scientific data telemetry equipment was installed at the weather station to transmit collected data on an hourly basis to the NOAA GOES satellite. The near real-time data collected is available online as first-draft data at the CDMO website http://cdmo.baruch.sc.edu/QueryPages/googlemap.cfm,. The near real-time telemetry data from the weather station is also considered by CDMO as provisional data and not an authenticated dataset.

2.2.3. Data Analysis

2007 Data

The 2007 data were not edited since the flags applied by the QAQC process were 0, 2, and/or 3; therefore, 100% of all the data in the 2007 dataset was used (Appendix I). The data were used to calculate daily and monthly means for air temperature (^{o}C), relative humidity (%), wind speed (m s^{-1}), wind direction (degrees), barometric pressure (mb). Daily and monthly totals were determined for precipitation (mm) and photosynthetically active radiation (PAR, mmol m^{-2}). Descriptive statistics for 2007 meteorological parameters are presented in Appendix I; graphs of daily means and daily totals can be found in Appendix II.

Long-term Trends

The long-term data obtained for this report extends from 2001 to 2007. However, 2001 was not included in the long-term assessment since only data from January to July was available. For 2002 to 2007, data was available from January to December. After revising the long-term datasets as described in section 2.2.2 (Data Collection), the percentage of data used for the yearly means calculations is presented in Appendix I. Precipitation data from years 2002 and 2003 were not included due to the low availability of data (5%, 21%, respectively) due to equipment failure as described in the metadata documents of each year. Visual comparisons of 2007 data with earlier long-term data were assessed for this report.

2.3. Results

2.3.1. Air Temperature

Monthly mean air temperature (^{o}C) recorded for 2007 at Potter Cove weather station followed a well-defined seasonal cycle (Figure 12a). Air temperature during 2007 ranged from -16.1 to

32.4^{o}C (Appendix I). Daily means showed high variation during 2007 (Appendix II). January and March seemed to be contributing the most to high variability in air temperature (Figure 12a).

Air temperature minimum monthly mean was recorded during February (1.7^{o}C), while maximum monthly means were recorded during July (21.3^{o}C) and August (21.9^{o}C) (Figure 12a).

Long-term yearly means for air temperature recorded at the weather station fluctuated throughout the years from 7.6 to 11.6^{o}C (Figure 13a). There is an apparent increasing trend in air temperature throughout the years. For 2007, yearly mean air temperature was 10.4^{o}C, similar to previous years.

2.3.2. Relative Humidity

Relative humidity for 2007 at the weather station ranged from 12 to 100% (Appendix I). Daily mean graphs showed high variability of this parameter during the year (Appendix II). High variability was recorded for the months of January through May (Figure 12b).

Relative humidity minimum monthly mean was observed in February (58.9%) and the maximum in October (82.3%) (Figure 12b).

Long-term yearly means for relative humidity at the weather station varied from 72.7 to 78.9% (Figure 13b). Despite an increase in humidity in 2005, there appears to be an overall decreasing trend over time (Figure 13b). Relative humidity data from 2007 seem to be an average year when visually compared to the last couple of years of the long-term dataset.

2.3.3. Barometric Pressure

The barometric pressure recorded for 2007 at the weather station ranged from 976 to 1042 mb (Appendix I). Daily means showed low variation during 2007 (Appendix II). The months with the highest variability during 2007 were December and March (Figure 12c).

Barometric pressure minimum monthly mean was recorded in April (1010.2 mb), while the maximum was recorded in March (1018.6 mb) (Figure 12c).

Long-term yearly means for barometric pressure at the weather station ranged from 1015.1 to 1017.8 mb (Figure 13c). A decreasing trend in barometric pressure is evident in Figure 13c. Data from 2007 seem to be similar to 2006 than to the previous years.

2.3.4. Wind Speed

Wind speed measured at the weather station for 2007 ranged from 0 to 18.5 m s^{-1} (Appendix I). Daily means showed high wind speed variability throughout 2007, except from June to August, which seemed to have had more consistent wind speed (Appendix II). April had the highest variability in wind speed during 2007 (Figure 12d).

Minimum monthly mean for wind speed was observed during July and August (2.8 m s^{-1}), while maximum monthly mean was observed in March (4.7 m s^{-1}) (Figure 12d).

Long-term yearly means for wind speed at the weather station ranged from 3.6 to 4.4 m s^{-1} (Figure 13d). A peak in yearly mean wind speed was recorded for 2006. This might be due to a wind sensor failure as recorded on the metadata document of 2006. After the revising process for this report only 36% of the data was left to calculate a yearly mean (Appendix I). Most of the data from 2006 was from the first quarter of the year, which historically is the windiest part of the year in Narragansett Bay. For 2007, wind speed (3.7 m s^{-1}) seemed to be an average year when compared to previous years.

2.3.5. Wind Direction

Wind direction measurements at the weather station showed winds blowing from all directions (0-360^o, Appendix I) in 2007. Daily and monthly means showed high variation occurring throughout the year (Appendix II, Figure 12e, respectively).

Wind direction for 2007 showed winds coming mostly from the southeast (90-180^o) in April, August and September, and from the southwest (181-270^o) the rest of the year (Figure 12e).

Long-term yearly means for wind direction recorded at Potter Cove over time showed winds coming mostly from the southwest throughout the years (Figure 13e), which is similar to the conditions observed in 2007 (Figure 12e).

2.3.6. Precipitation

Precipitation measured at the Potter Cove weather station for 2007 ranged from 0 to 16 mm (Appendix I) when examining records from the 15 minute interval data. Precipitation at the Reserve could be in the form of rain, snow, or both. Daily totals showed total precipitation to range from 0 to 56.4 mm (Appendix II).

Monthly total precipitation for 2007 showed August and September to be the months with the least amount of total precipitation (34.4, 47.8 mm, respectively), but showed March and April to be the months with the highest amount of total precipitation during the year (144.6, 173.9 mm, respectively) (Figure 12f).

Long-term total precipitation at the weather station from 2004 to 2007 varied from 796.3 to 1088.3 mm (Figure 13f). Precipitation was very similar among years. For 2004, 2005 and 2006, there were 106 (29%), 118 (32%), and 135 (37%) days of precipitation, respectively. Meanwhile, no precipitation occurred during 260 (71%) days of 2004, 247 (68%) days of 2005, and 230 (63%) days of 2006. For 2007, precipitation was similar to previous years: 115 days (32%) of precipitation, and 250 (68%) days of no precipitation.

2.3.7. Photosynthetically Active Radiation

Photosynthetically active radiation measured at the Potter Cove weather station for 2007 ranged from 0 to 1612 mmol m^{-2} (Appendix I) when examining records from the 15 minute interval data. Daily totals showed a well-defined seasonal curve where total PAR peaked during June and July (Appendix II).

Monthly total PAR calculated for 2007 (Figure 12g) was the lowest during December (2 x 10^5 mmol m^{-2}) and highest during May (11 x 10^5 mmol m^{-2}).

Long-term PAR totals varied from 69 to 125 mmol m-^{2} (Figure 13g). Yearly total PAR for 2007 was 90 x 10^5 mmol m^{-2}. In general, Figure 13g shows an increasing trend in total PAR, after a decrease in 2005.

2.4. Discussion

The NBNERR continues to monitor all meteorological parameters at the Potter Cove Weather Station. The parameters monitored are air temperature, relative humidity, wind speed, wind direction, barometric pressure, precipitation, and photosynthetically active radiation. This second section of the report provides a summary of data recorded by the Reserve from the weather station on Prudence Island during 2007. A preliminary review of the long-term meteorological data is presented in this report. The long-term weather monitoring program has successfully accrued a large database over eight years making possible the assessment and study of environmental changes in Narragansett Bay.

In summary, meteorological parameters for 2007 followed the seasonal variations characteristic of temperate zone. At the Reserve, air temperature followed a distinctive seasonal cycle during the year, and monthly mean relative humidity varied from ~60 to 80%. Wind direction was mostly from the southwest, and moderate wind speeds (3-5 m s^{-1}) prevailed during 2007. Precipitation was low during 2007 but comparable to earlier years. As expected, photosynthetic active radiation in 2007 was higher during summer months.

3. Future Work

Future work with the water quality and meteorological data could include (1) examining possible seasonal trends, (2) conducting statistical analysis (i.e. multivariate analysis of variance or multidimensional scaling analysis) to determine separation among habitats using all water quality parameters, (3) determining which parameter(s) contributes the most in the differences or similarities between them (i.e. discriminant function analysis or principal components analysis), (4) keeping the report up-to-date incorporating new datasets every year, and (5) incorporating other studies conducted in Narragansett Bay.

4. Acknowledgements

I would like to thank the NBNERR staff for their help and support during the production of this report. Special thanks to Robin Weber for creating the map, on land-related information about NBNERR, and historical background.

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6. TABLES

Table 1. QAQC flags used by CDMO during the automated primary QAQC process.

QAQC Flag	Flag description
-5	Outside High Sensor Range
-4	Outside Low Sensor Range
-3	Data Rejected due to QAQC
-2	Missing Data
-1	Open – reserved for later flag
0	Good Data
1	Suspect Data
2	Data Outside 2 Standard Deviations from the historical seasonal mean
3	Data Outside 3 Standard Deviations from the historical seasonal mean
4	Historical Data: Pre-Auto QAQC
5	Corrected Data

Table 2. Datasets available for the historical data analysis of the water quality data collected at five different stations on Prudence Island.

Year	Potter Cove	T-Wharf (old station)	Nag Creek	T-Wharf Surface	T-Wharf Bottom
1995	Dec 4-7, 20-31				
1996	Jan-Dec	Sep 20-30, Oct-Dec			
1997	Jan-Dec	Jan-Dec			
1998	Jan-Dec				
1999	Jan-Dec	Mar-Dec			
2000	Jan-Dec	Jan-Dec			
2001	Jan-Dec	Jan-Dec			
2002	Jan-Dec	Jan-Jul	Mar-Dec	Jul-Dec	Jul-Dec
2003	Jan-Dec		Jan-Dec	Jan-Dec	Jan-Dec
2004	Jan-Dec		Jan, Apr-Dec	Jan-Dec	Jan-Dec
2005	Jan-Dec		Mar-Dec	Jan-Dec	Jan-Dec
2006	Jan-Dec		Jan-Dec	Jan-Dec	Jan-Dec
2007	Jan-Dec		Jan, Apr-Dec	Jan-Dec	Jan-Dec

Note:
Empty cells = no data available.
Italics = datasets not included when calculating yearly means.

7. Figures

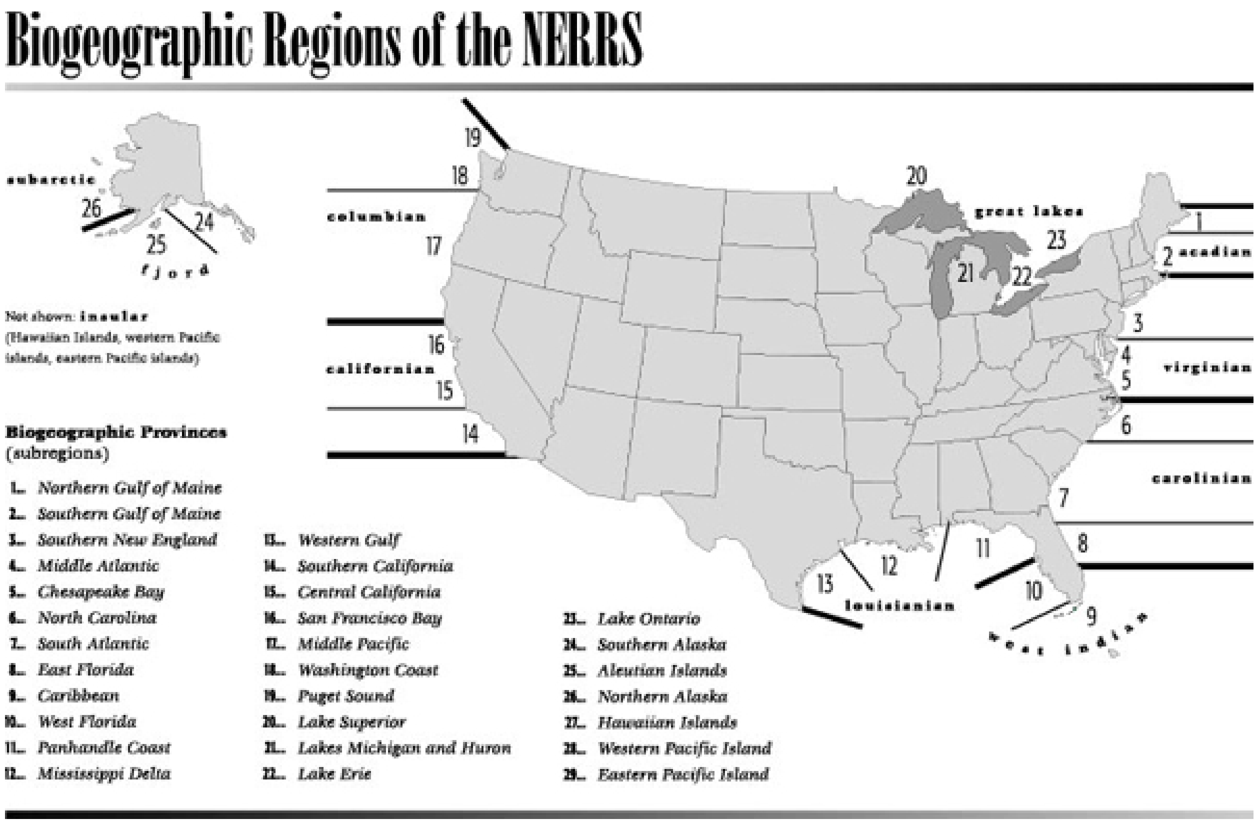


Figure 1. Biogeographic regions of the NERRS. A biogeographic region is a geographic area with similar dominated plants, animals and prevailing climate. Map obtained from http://www.nerrs.noaa.gov/Bioregions/regions.html.

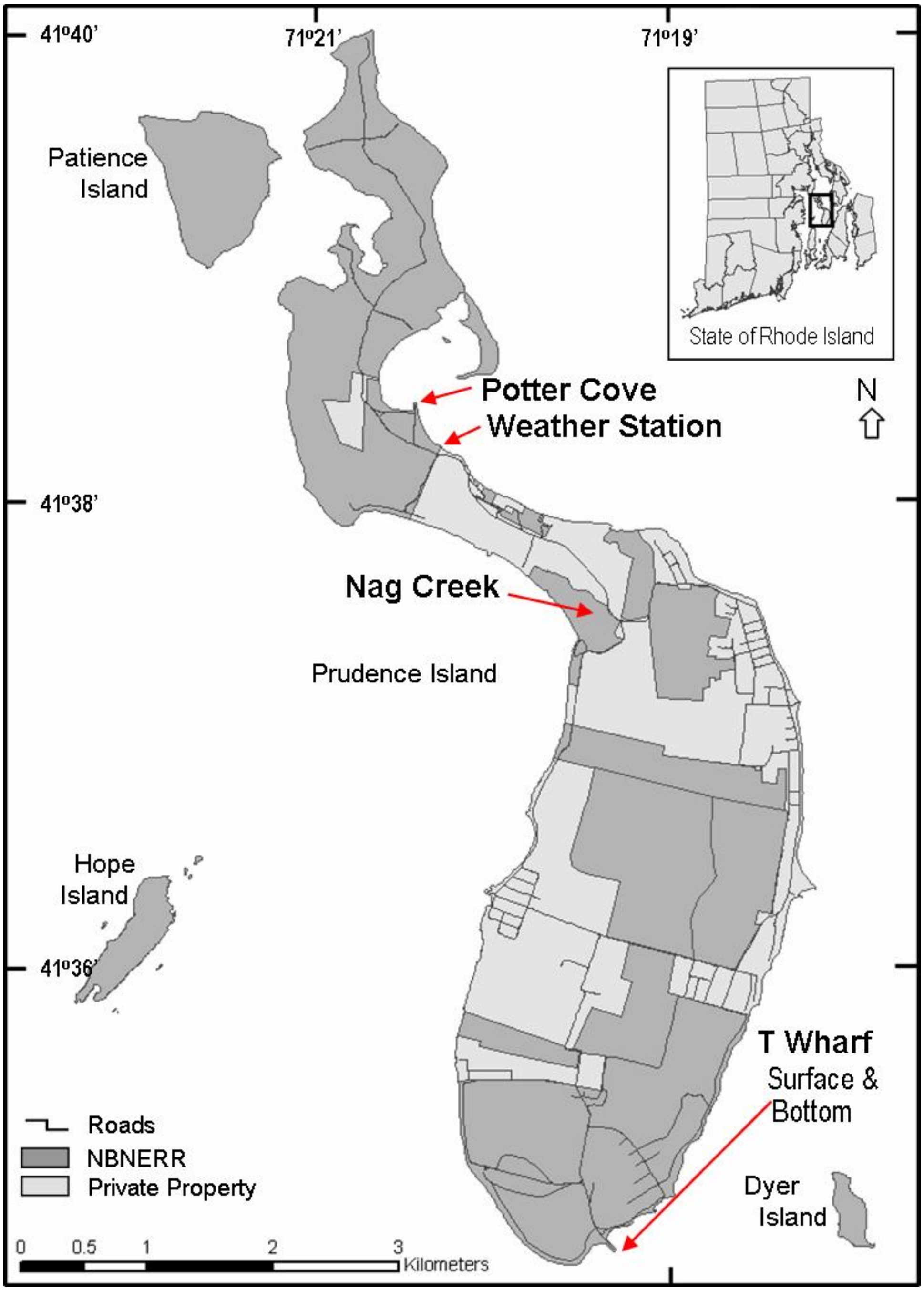


Figure 2. Map showing the location of the four islands included in the Narragansett Bay National Estuarine Research Reserve (Prudence, Patience, Hope, and Dyer), the four water quality stations (Potter Cove, Nag Creek, T-Wharf Surface, T-Wharf Bottom), and the weather station at Prudence Island.

Figure 3. Potter Cove water quality monitoring station - the first SWMP station established on Prudence Island.

a)

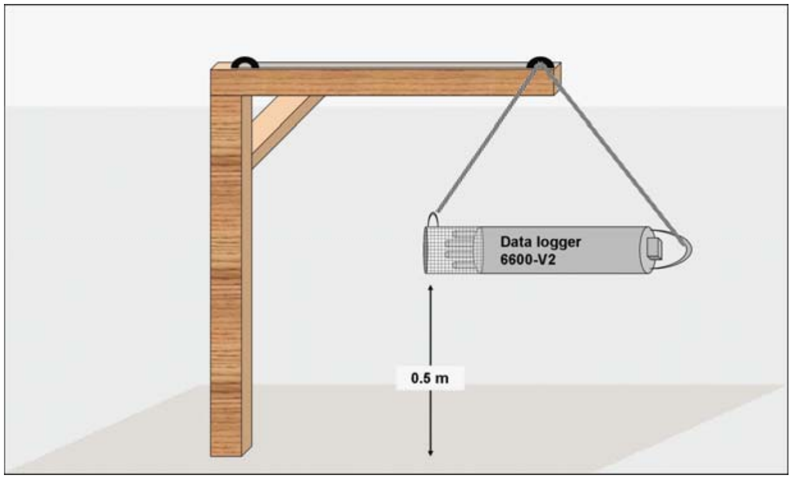
b)

Figure 4. Nag Creek water quality monitoring station at Prudence Island (a), and the approximate location (red arrow) of the deployment site (b).

Figure 5. Two water quality monitoring stations are located at T-Wharf: Surface and Bottom (left and right PVC pipes, respectively).

Figure 6. Picture of the current deployment structure at Potter Cove; a PVC pipe attached to a floating dock.

a)



b)

c)

Figure 7. Deployment structure at Nag Creek: diagram of the deployment structure (a), structure in the field (b), the sonde in the water (c).

Figure 8. Telemetry station at T-Wharf transmits water quality data from the T-Wharf Bottom station via satellite. The near-real time data can be accessed online at http://cdmo.baruch.sc.edu/QueryPages/googlemap.cfm.

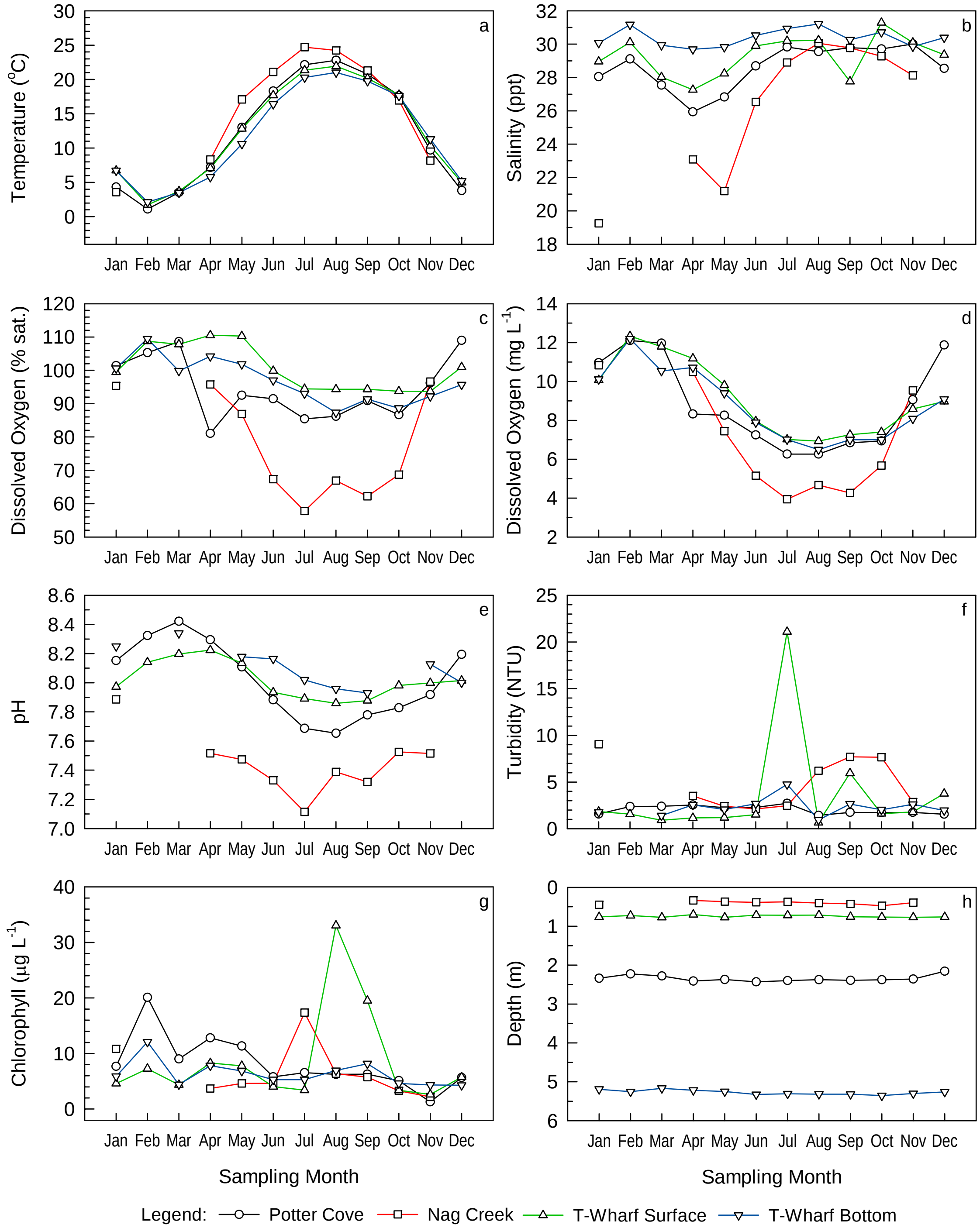


Figure 9. Monthly means calculated for water quality parameters for 2007, all stations included.

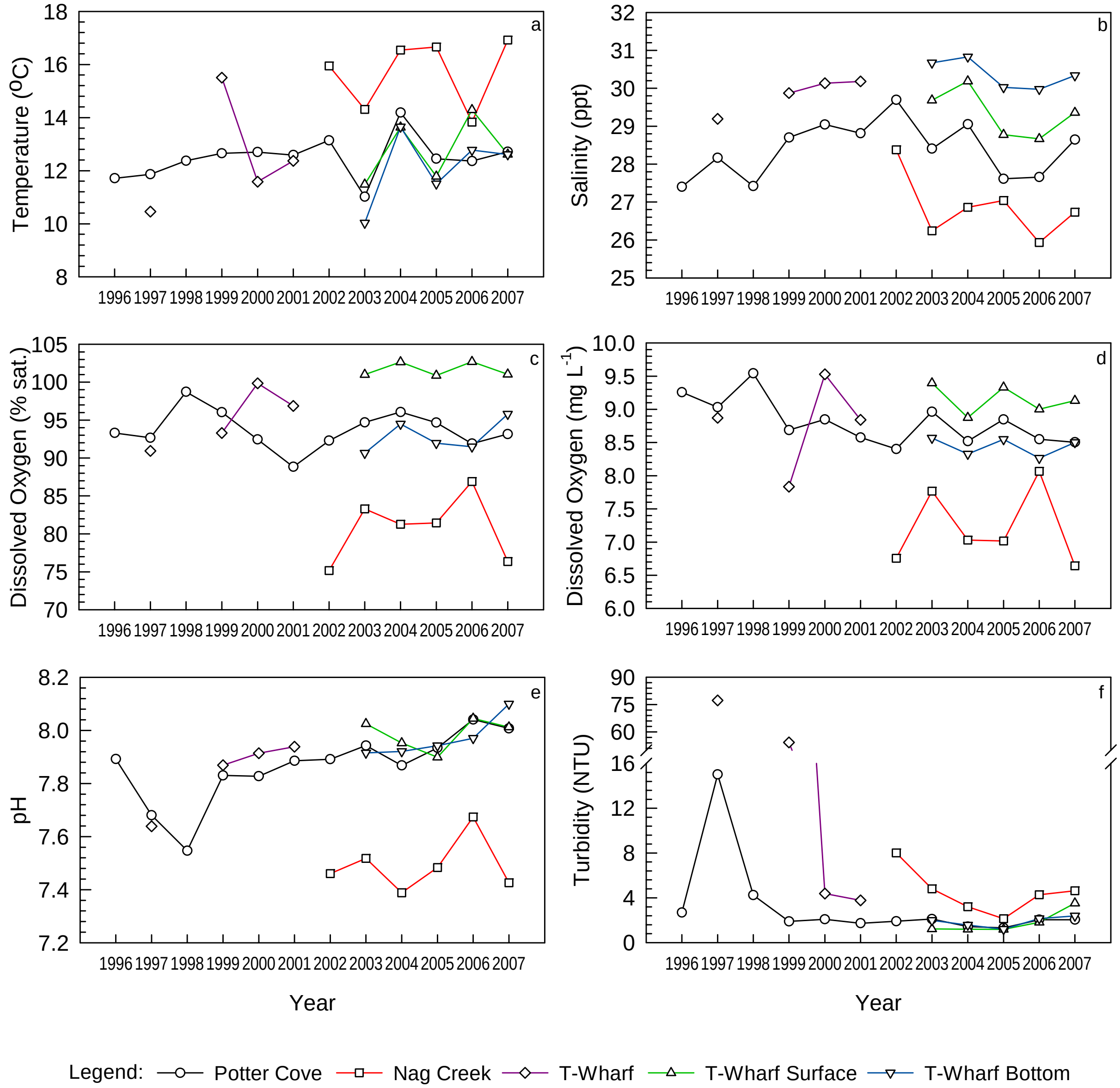


Figure 10. Long-term yearly means for Potter Cove, Nag Creek, T-Wharf, T-Wharf Surface, and T-Wharf Bottom calculated for water quality parameters from 1996 to 2007. Yearly mean calculations for T-Wharf 1999, and Nag Creek 2002, 2004, 2005, and 2006 were based on 10 months of data.

Figure 11. Picture of the meteorological station at Potter Cove showing the wooden platform and aluminum tower where the sensors are located for the collection of atmospheric data.

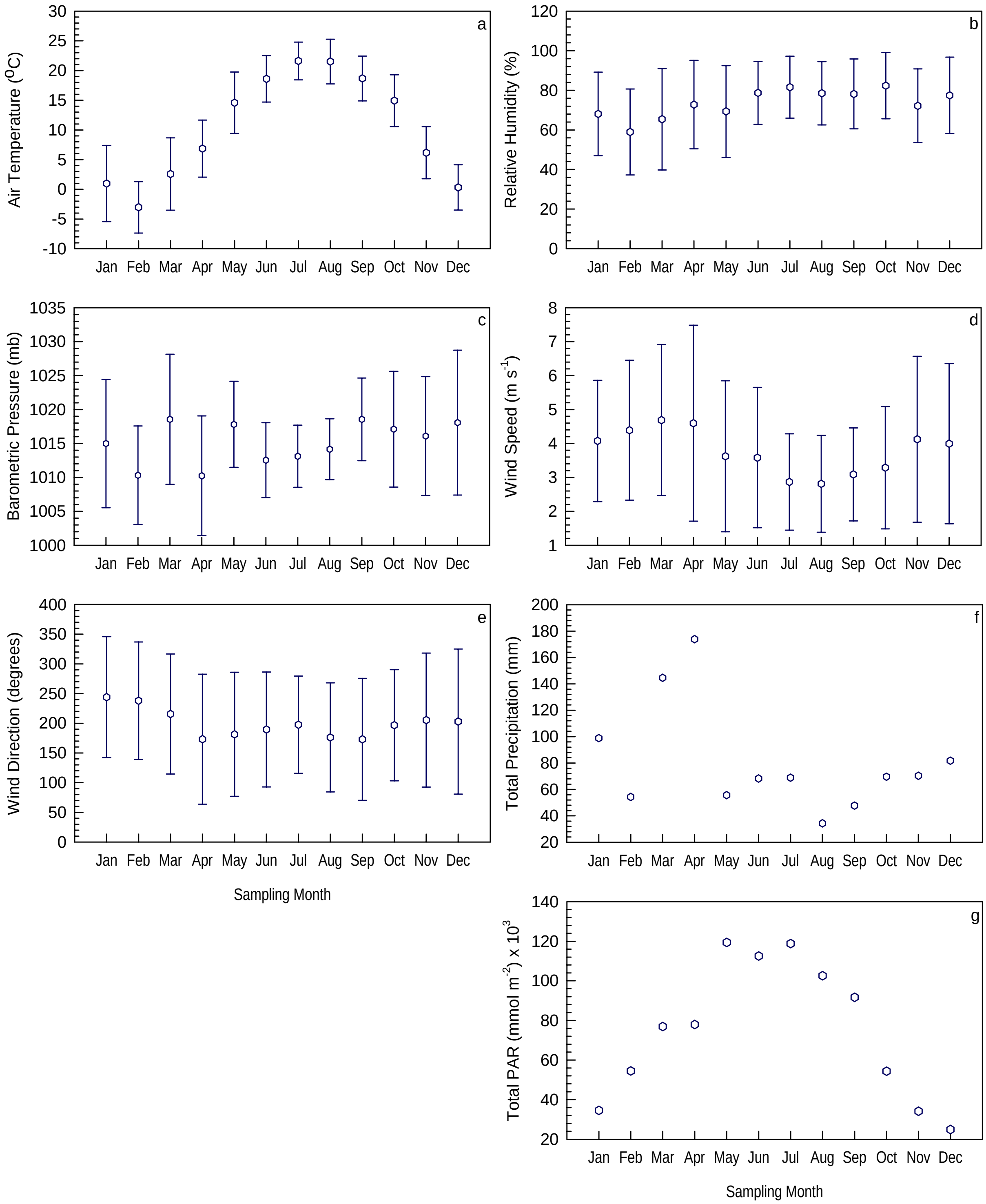


Figure 12. Monthly means (± 1 standard deviation) calculated for meteorological parameters recorded by the weather station for 2007. Precipitation and PAR are monthly totals.

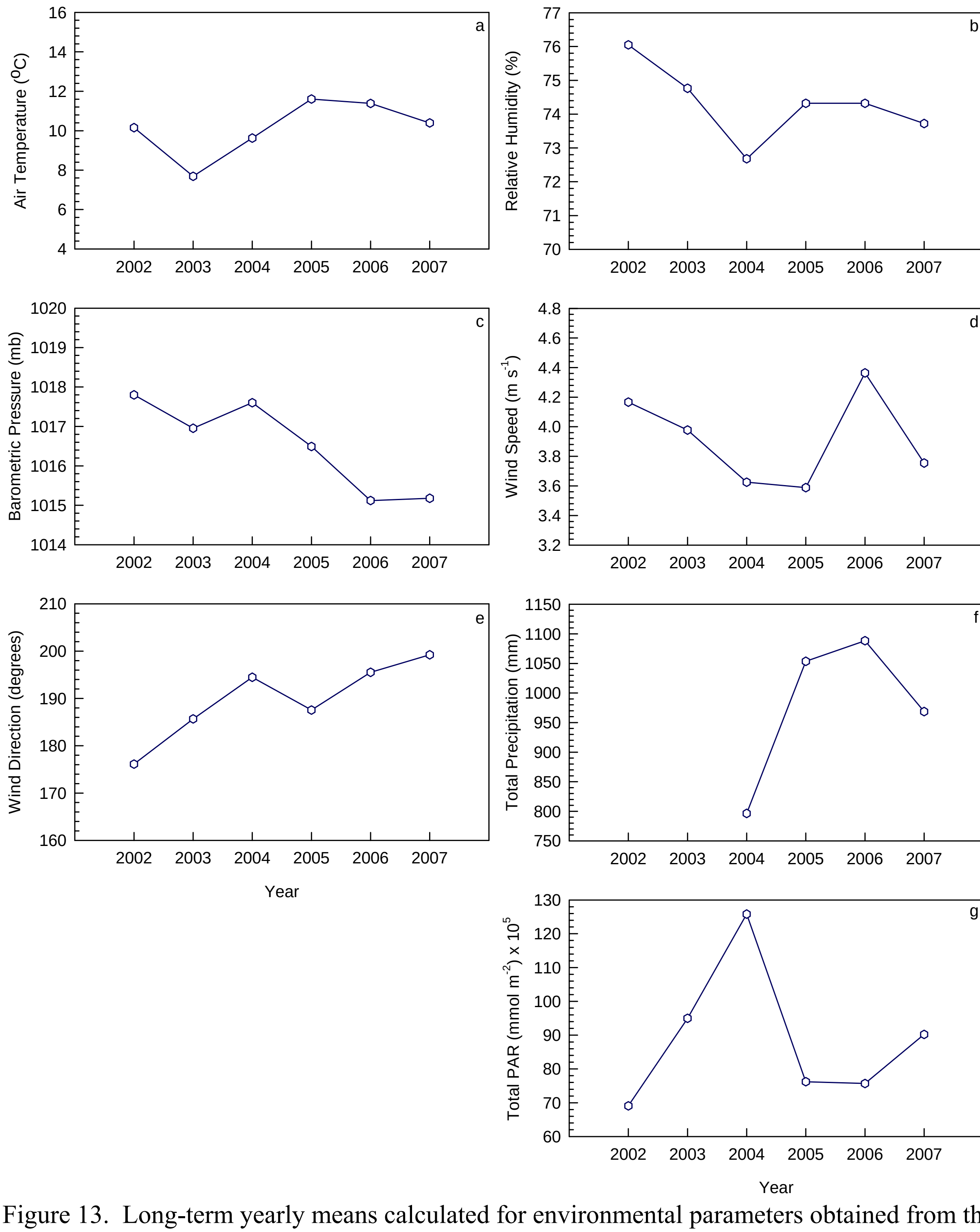


Figure 13. Long-term yearly means calculated for environmental parameters obtained from the weather station on Prudence Island from 2002-2007. Precipitation and PAR are yearly totals.

APPENDIX I. DESCRIPTIVE STATISTICS

Potter Cove

	Temp. (oC)	Sal. (ppt)	DO (% sat.)	DO (mg L-1)	pH	Turb. (NTU)	Chl. (µg L-1)
Original Dataset	32773	32773	32773	32773	32773	32773	32773
Revised Dataset	32619	32621	31427	31489	31342	31767	30231
% Data Used	100	100	96	96	96	97	92
Mean	12.713	28.646	93.13	8.5	8.004	2.047	8.239
Std Dev	7.816	1.765	18.478	2.544	0.334	3.909	10.58
Std. Error	0.0433	0.00977	0.104	0.0143	0.00188	0.0219	0.0608
C.I. of Mean	0.0848	0.0192	0.204	0.0281	0.00369	0.043	0.119
Range	28.2	11.6	147.873	15.9	8.74	497	397.9
Max	26.9	31.9	154	16.8	8.8	497	397.9
Min	-1.3	20.3	6.127	0.9	0.0603	0	0
Median	13.1	29	95	8.1	8	2	6.2
25%	5.4	27.8	81.8	6.6	7.8	1	3.4
75%	20	29.8	105.3	10.4	8.2	2	10.4

Nag Creek

	Temp. (oC)	Sal. (ppt)	DO (% sat.)	DO (mg L-1)	pH	Turb. (NTU)	Chl. (µg L-1)
Original Dataset	23848	22521	23848	23848	23848	22521	23848
Revised Dataset	22567	20054	22726	22652	23848	22498	21837
% Data Used	95	89	95	95	100	100	92
Mean	16.924	26.733	76.339	6.639	7.422	4.629	5.958
Std Dev	7.872	5.717	36.429	3.605	0.459	17.897	11.66
Std. Error	0.0524	0.0404	0.242	0.0239	0.00297	0.119	0.0788
C.I. of Mean	0.103	0.0791	0.473	0.0469	0.00582	0.234	0.155
Range	34.9	30.6	227.4	18.4	9.186	933	384.9
Max	33.4	31.8	227.4	18.4	9.3	933	384.9
Min	-1.5	1.2	0	0	0.114	0	0
Median	18.8	28.9	82.2	6.7	7.4	3	3.7
25%	10.5	25.8	49.3	3.8	7.1	2	2.6
75%	23.1	30.1	101.7	9.4	7.7	5	5.7
	Temp.	Sal.	DO	DO	pH	Turb.	Chl.

T-Wharf Surface

	Temp. (oC)	Sal. (ppt)	DO (% sat.)	DO (mg L-1)	pH	Turb. (NTU)	Chl. (µg L-1)
Original Dataset	32422	32421	32421	32421	32421	32421	32421
Revised Dataset	32422	32421	31275	32421	31275	27820	31208
% Data Used	100	100	96	100	96	86	96
Mean	12.613	29.359	101.005	9.127	8.009	3.523	8.757
Std Dev	7.323	1.831	11.506	2.078	0.234	18.447	33.516
Std. Error	0.0407	0.0102	0.065	0.0115	0.00132	0.111	0.19
C.I. of Mean	0.0797	0.0199	0.127	0.0226	0.00259	0.217	0.372
Range	26.1	10.9	145.926	13.662	8.485	969	399.8
Max	25.3	31.9	147.6	14.1	8.5	969	399.8
Min	-0.8	21	1.674	0.438	0.0151	0	0
Median	12.7	29.9	101.1	8.7	8	1	4.7
25%	5.5	28.7	93.7	7.4	7.9	1	2.9
75%	19.5	30.5	107.9	11	8.1	2	7.6

T-Wharf Bottom

	Temp. (oC)	Sal. (ppt)	DO (% sat.)	DO (mg L-1)	pH	Turb. (NTU)	Chl. (µg L-1)
Original Dataset	30319	30319	28834	28834	30319	30319	29713
Revised Dataset	30319	27347	26546	27635	21016	25465	28724
% Data Used	100	90	92	96	69	84	97
Mean	12.607	30.336	95.745	8.497	8.095	2.388	16.517
Std Dev	6.59	0.821	9.895	1.739	0.232	3.301	50.794
Std. Error	0.0378	0.00497	0.0607	0.0105	0.0016	0.0207	0.3
C.I. of Mean	0.0742	0.00974	0.119	0.0205	0.00313	0.0405	0.587
Range	23.7	7.5	131.611	13.581	8.492	78	281.5
Max	24.4	32.6	134.1	14	8.5	78	281.5
Min	0.7	25.1	2.489	0.419	0.00799	0	0
Median	12.5	30.5	96.8	8.2	8.1	2	5.3
25%	5.9	29.9	89.7	7.1	8	1	3.7
75%	19	30.8	101.6	10	8.2	3	7.9

Weather Station

	Air Temp. (°C)	Relative Humidity (%)	Barometric Pressure (mb)	Wind Speed (m s^{-1})	Wind Direction (degrees)	Total Precipitation (mm)	Total PAR (mmol s^{-1})
Original Dataset	30319	30319	28834	28834	30319	30319	29713
Revised Dataset	30319	27347	26546	27635	21016	25465	28724
% Data Used	100	90	92	96	69	84	97
Mean	10.391	73.721	1015.177	3.755	199.221	0.0276	257.5
Std Dev	9.716	20.864	8.3	2.145	104.348	0.231	395.21
Std. Error	0.0519	0.111	0.0443	0.0115	0.557	0.0012	2.111
C.I. of Mean	0.102	0.218	0.0869	0.0225	1.093	0.0024	4.138
Range	48.5	88	66	18.5	360	16	1612.5
Max	32.4	100	1042	18.5	360	16	1612.5
Min	-16.1	12	976	0	0	0	0
Median	11	77	1015	3.4	220	0	6.4
25%	2.5	58	1010	2.2	105	0	0
75%	18.6	93	1021	4.8	285	0	413.3

Percent of data used from the original datasets per station per year after revising for the long-term study.

Water Quality

Station	Year	Temperature	Salinity	DO% sat.	[DO]	Depth	pH	Turbidity
Potter Cove	1996	100	96	72	68	100	100	15
	1997	100	100	81	81	100	100	29
	1998	100	100	79	79	100	100	62
	1999	100	100	99	99	100	100	91
	2000	100	99	61	61	100	95	50
	2001	100	100	81	81	100	97	93
	2002	100	100	96	96	100	96	84
	2003	100	92	86	86	96	100	99
	2004	100	100	99	99	100	100	94
	2005	100	100	99	99	100	100	90
	2006	100	100	97	97	100	100	92
Nag Creek	2002	100	69	96	96	96	96	90
	2003	100	85	100	95	94	100	97
	2004	100	95	100	100	98	100	95
	2005	100	100	100	100	100	100	97
	2006	100	100	100	100	100	100	100
T-Wharf Surface	2003	100	100	94	94	100	100	90
	2004	100	100	94	94	100	100	87
	2005	100	100	98	98	100	100	89
	2006	100	100	100	100	100	100	98
T-Wharf Bottom	2003	100	97	94	94	100	94	99
	2004	100	100	100	100	100	99	100
	2005	100	100	99	99	100	100	96
	2006	100	100	100	100	100	100	99
T-Wharf (old station)	1997	100	100	79	79	100	100	34
	1999	100	100	71	71	100	100	81
	2000	100	93	84	84	100	97	62
	2001	100	100	100	100	100	100	65

Meteorological Data

Year	Air Temp	RH	BP	WSpd	Wdir	TotPrcp	TotPAR
2002	67	67	100	100	57	5	100
2003	86	86	100	100	100	21	100
2004	100	100	100	99	100	100	85
2005	100	100	100	53	100	100	91
2006	100	100	100	36	97	100	92
2007	100	100	100	100	100	100	100

APPENDIX II. DAILY MEANS

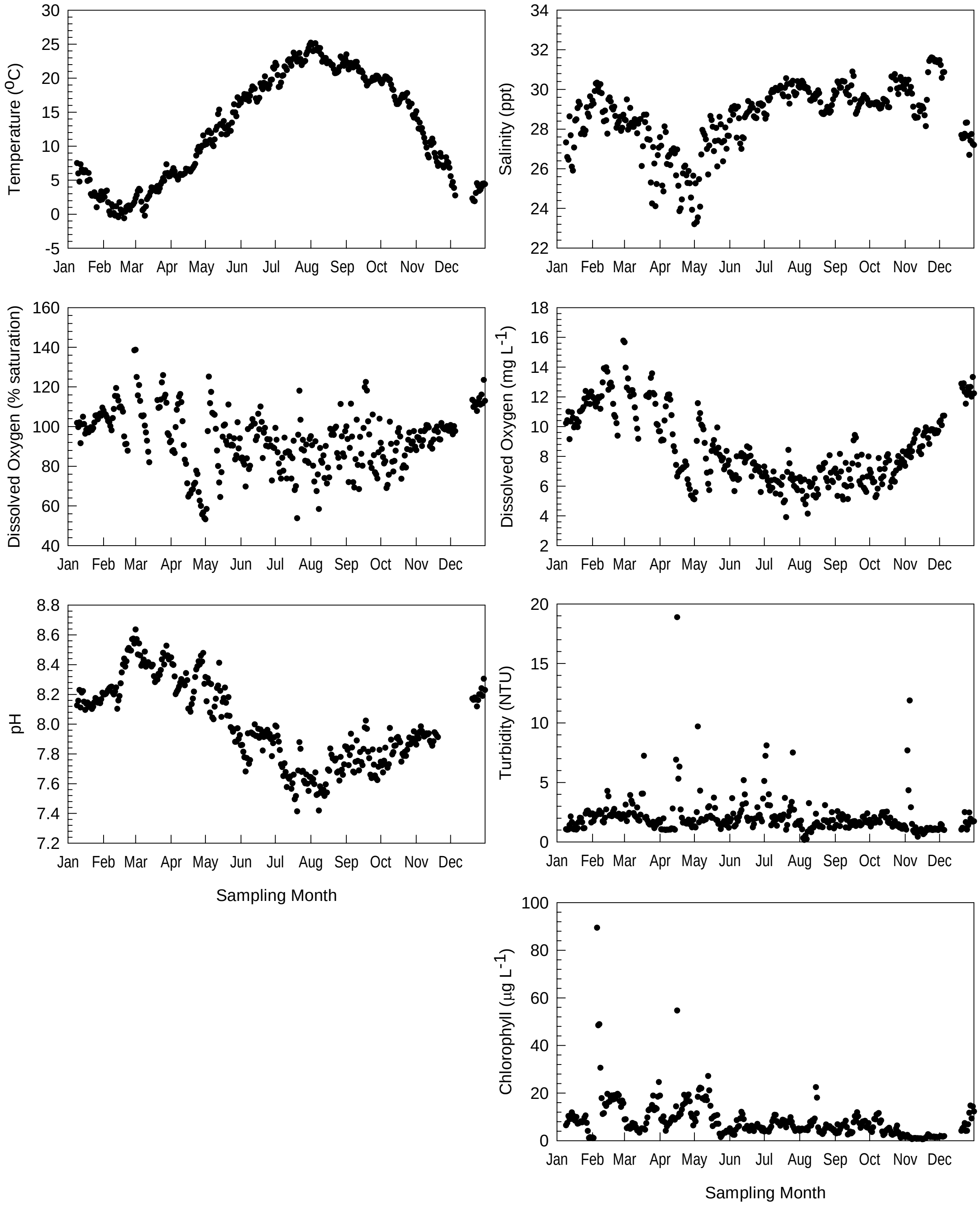


Figure 14. Daily means calculated for water quality parameters recorded at Potter Cove during 2007.

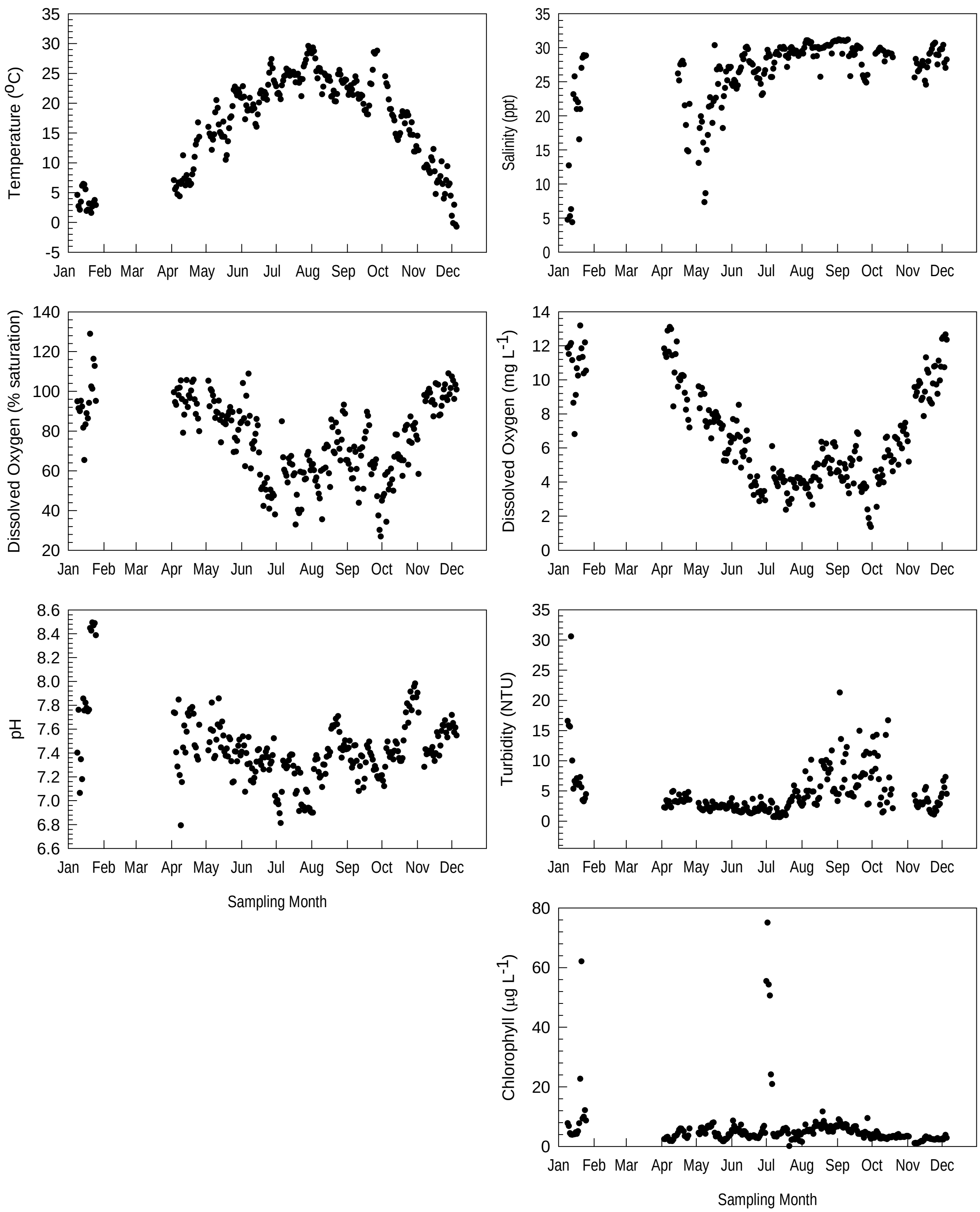


Figure 15. Daily means calculated for water quality parameters recorded at Nag Creek during 2007.

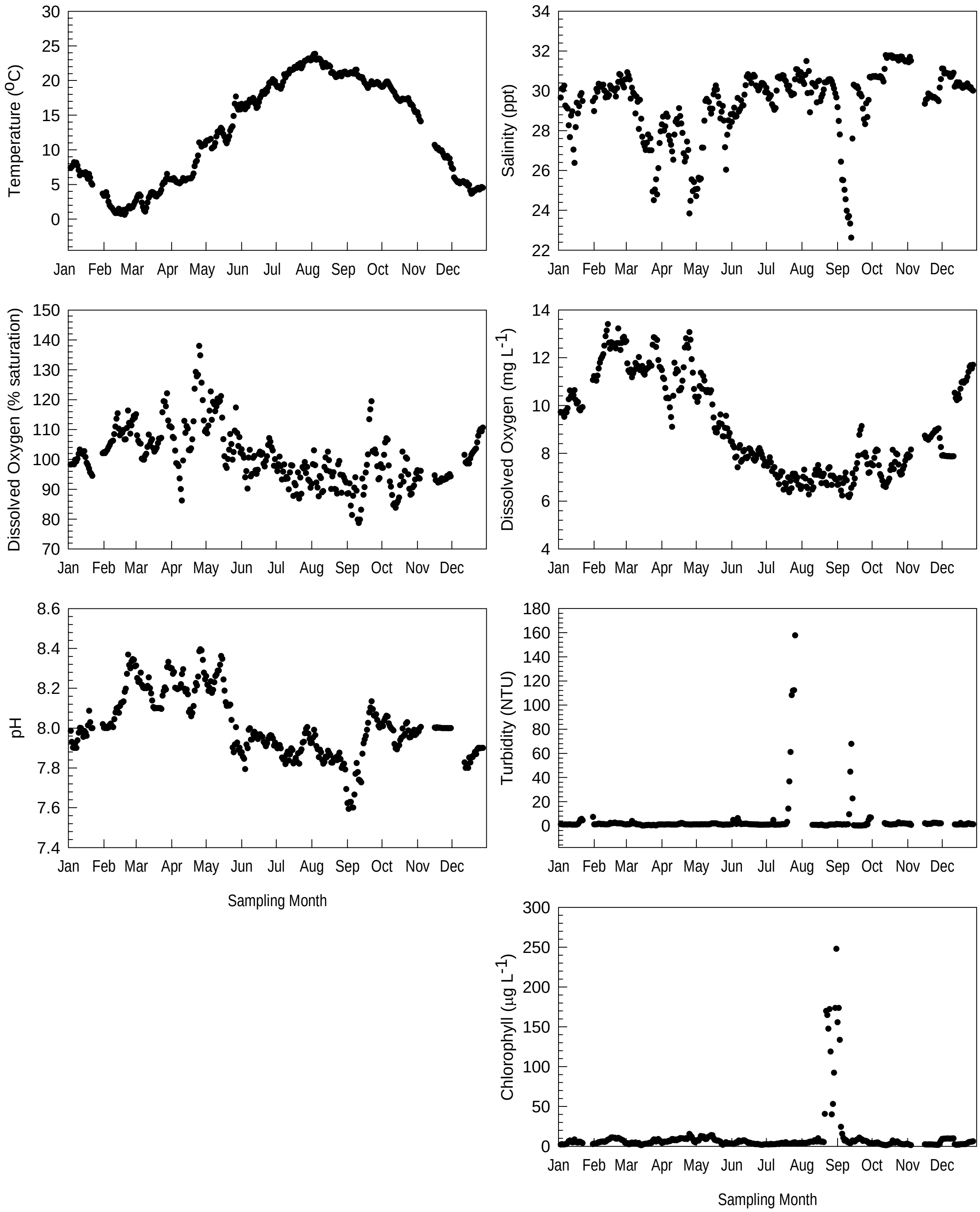


Figure 16. Daily means calculated for water quality parameters recorded at T-Wharf Surface station during 2007.

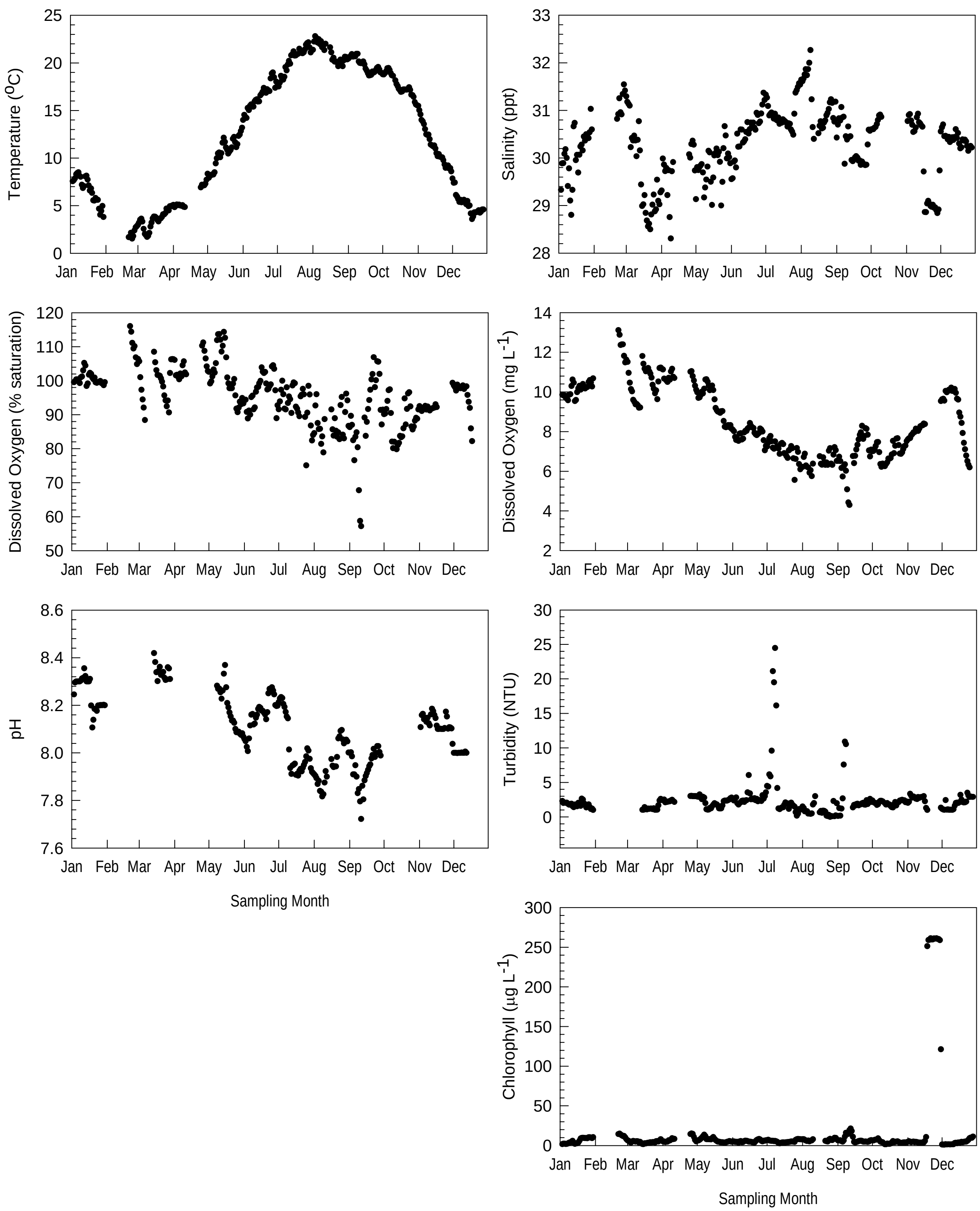


Figure 17. Daily means calculated for water quality parameters recorded at T-Wharf Bottom station during 2007.

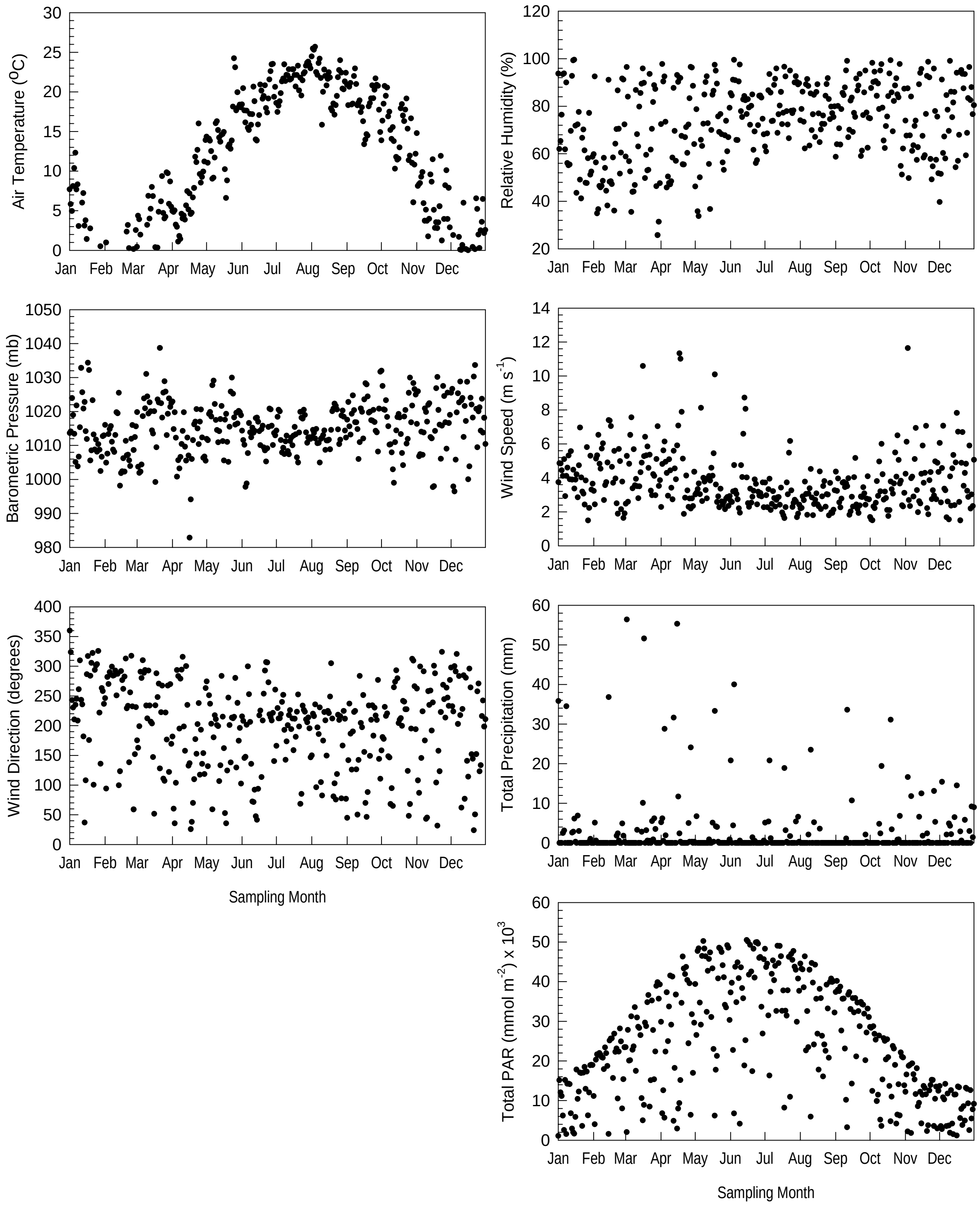


Figure 18. Daily means calculated for meteorological parameters recorded at the weather station in Prudence Island during 2007. Precipitation and PAR are daily totals.

APPENDIX III. MONTHLY MEANS

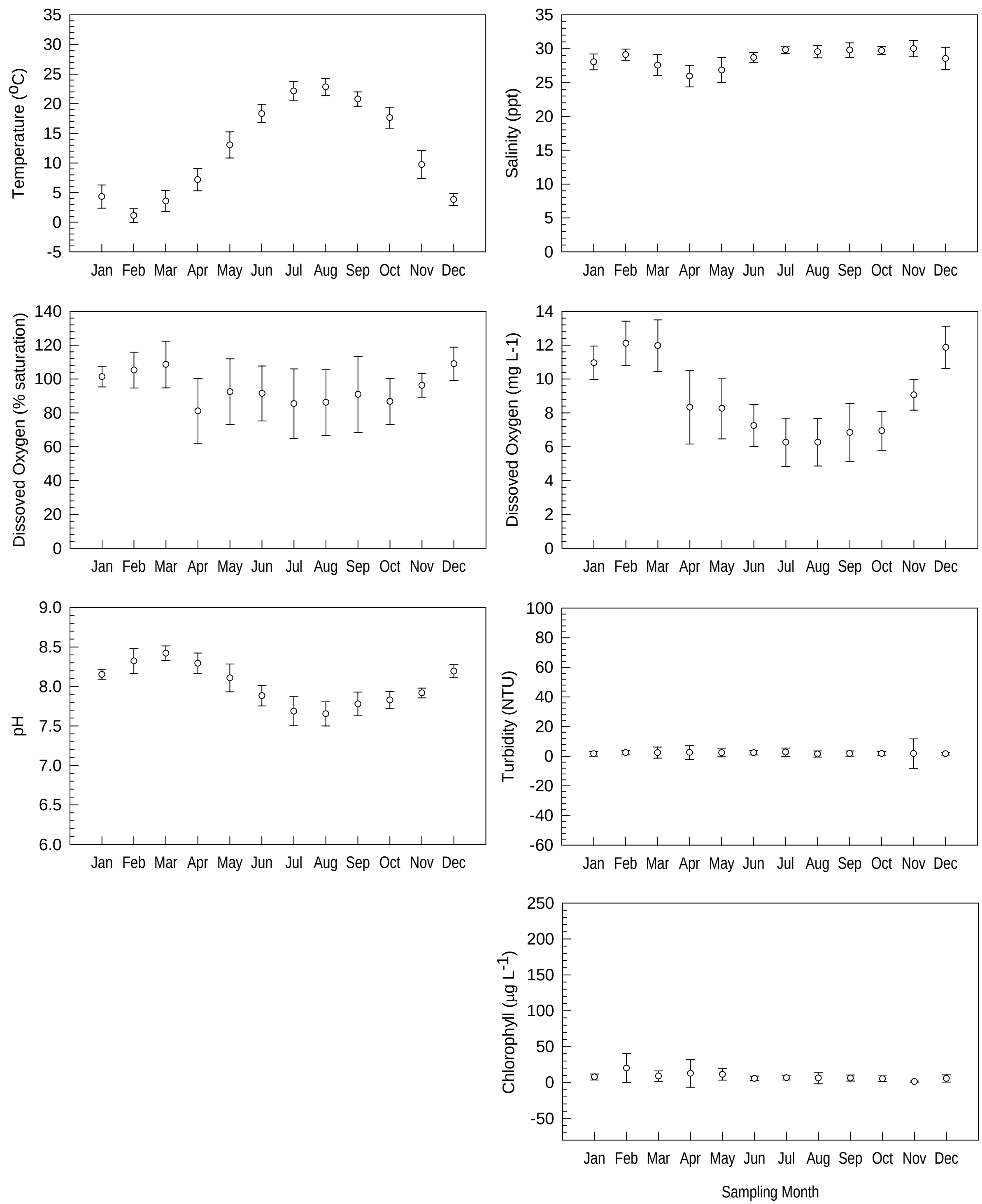


Figure 19. Potter Cove monthly means (± one standard deviation) calculated for water quality parameters for 2007.

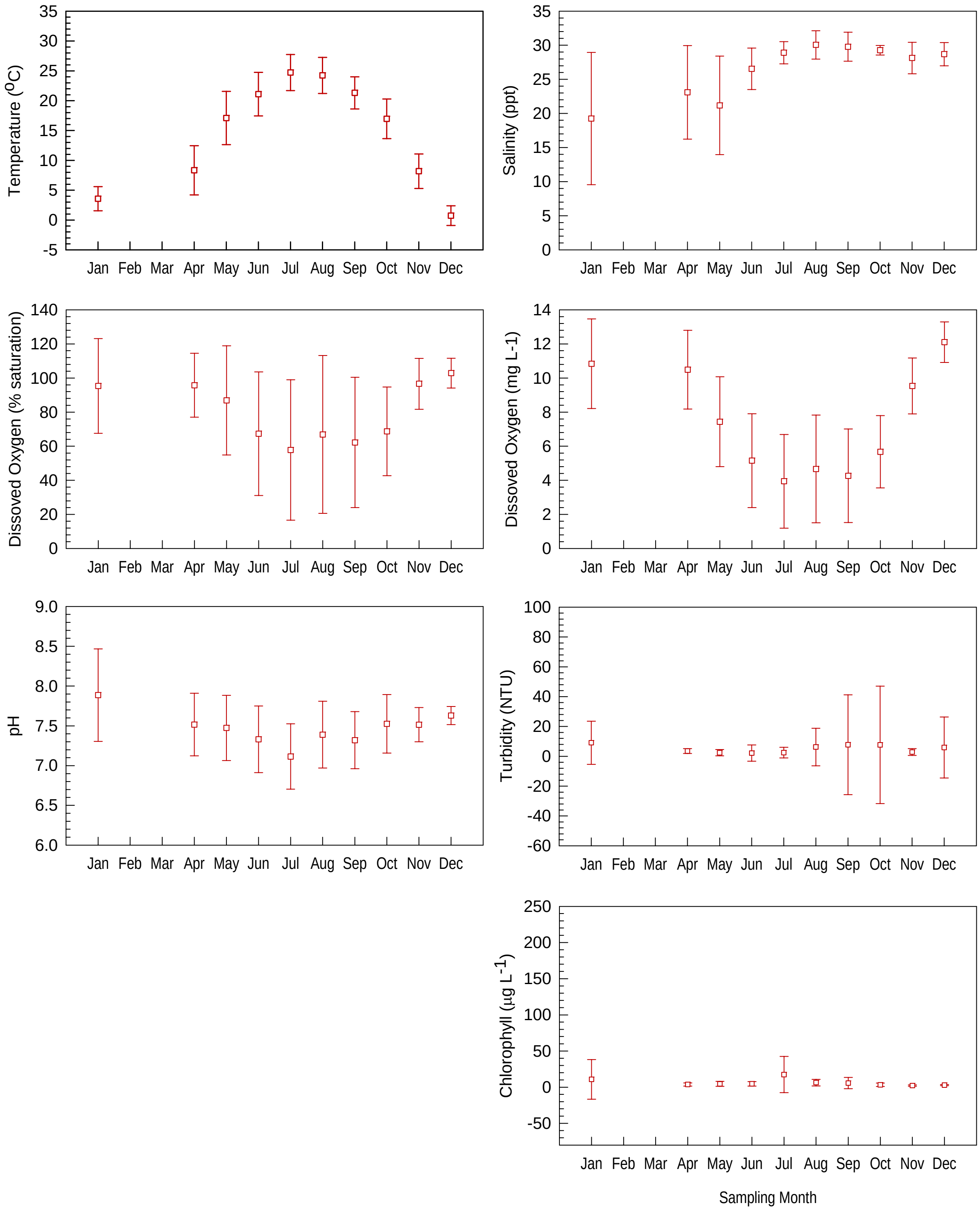


Figure 20. Nag Creek monthly means (± one standard deviation) calculated for water quality parameters for 2007.

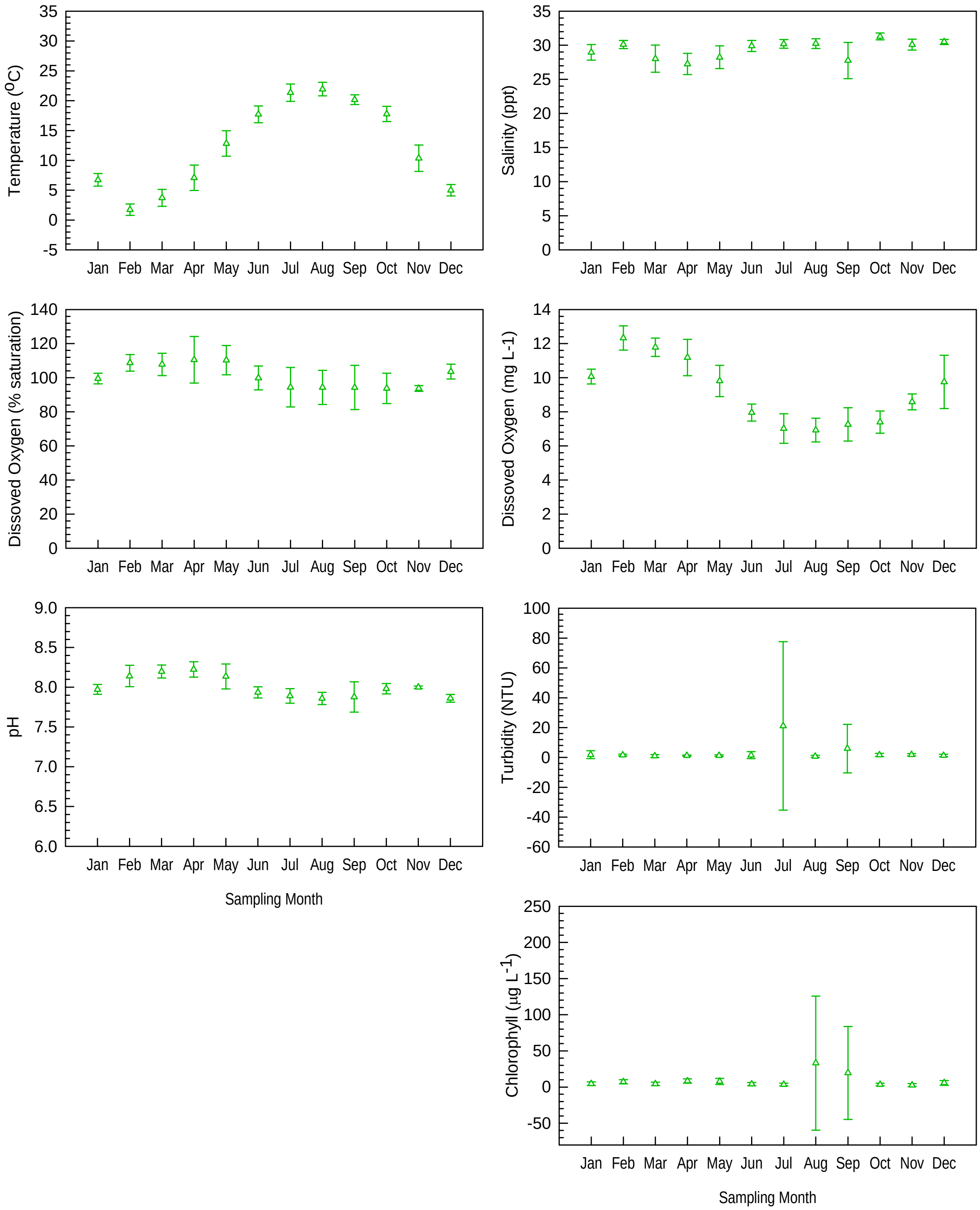


Figure 21. T-Wharf Surface monthly means (± one standard deviation) calculated for water quality parameters for 2007.

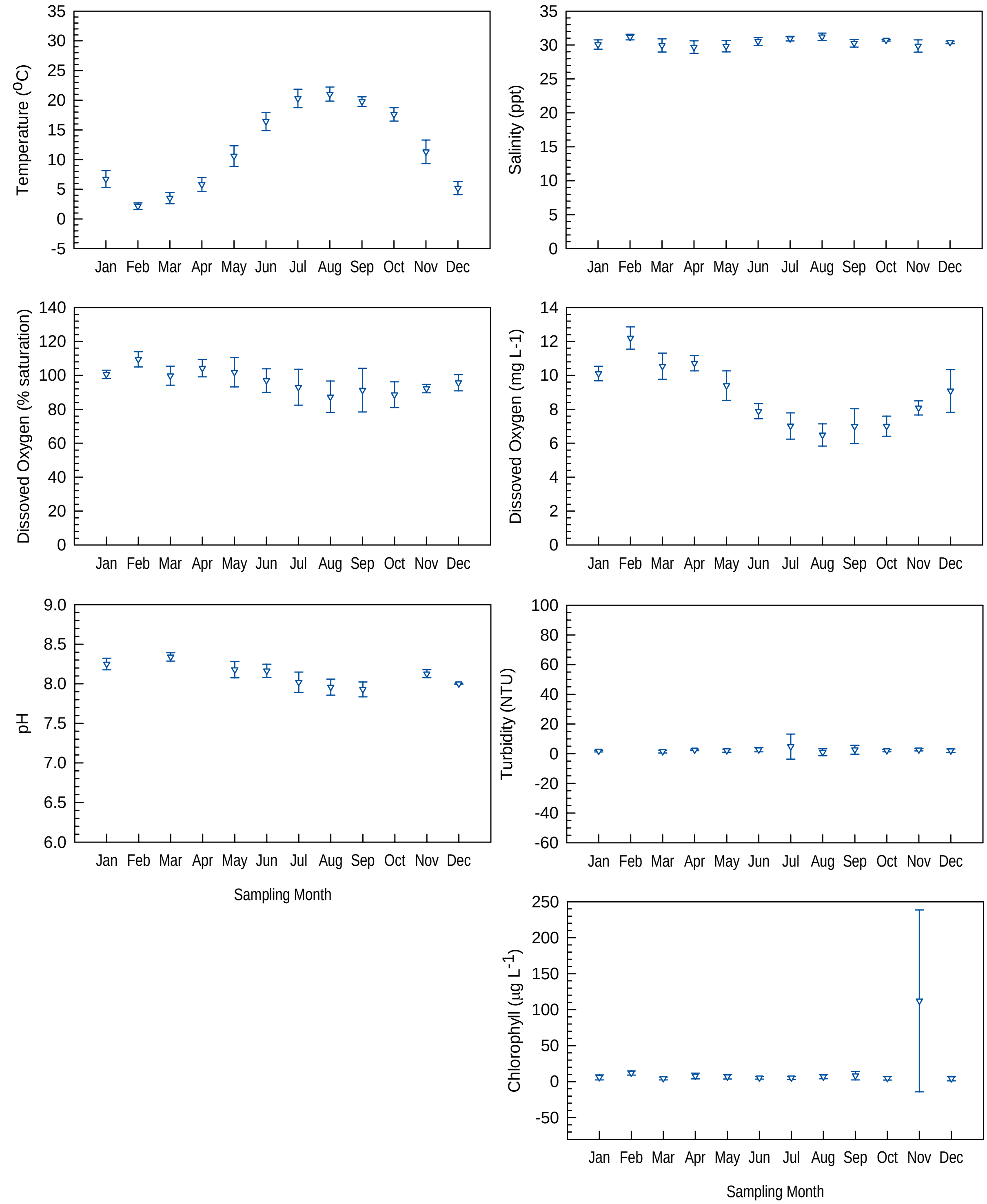


Figure 22. T-Wharf Bottom monthly means (± one standard deviation) calculated for water quality parameters for 2007.