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Estuarine Water Quality in Parks of the Northeast Coastal and Barrier Network

Vital Signs Estuarine Nutrient-Enrichment Monitoring, 2006–11

Natural Resource Technical Report NPS/NCBN/NRR—2015/902



ON THE COVER
Top left: Little Pleasant Bay, Cape Cod National Seashore; photograph by Hilary Neckles.
Top right: Jamaica Bay, Gateway National Recreation Area; photograph by Blaine Kopp.
Bottom right: Back Creek, Colonial National Historic Park; courtesy of Colonial National Historic Park.
Bottom left: Great South Bay, Fire Island National Seashore; photograph by Blaine Kopp

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Abstract

This report summarizes results of water-quality monitoring within estuaries of the National Park Service Northeast Coastal and Barrier Network (NCBN) from 2006 through 2011. Data collection formed part of the NCBN Vital Signs Monitoring Program implemented to detect threats of estuarine nutrient enrichment. Data included here were collected from six parks at predetermined intervals: Cape Cod National Seashore, Massachusetts (2007, 2008, 2009, 2010, 2011); Fire Island National Seashore, New York (2009, 2011); Gateway National Recreation Area, New York and New Jersey (2010); Assateague Island National Seashore, Maryland and Virginia (2006, 2008, 2010); George Washington Birthplace National Monument, Virginia (2009, 2011); and Colonial National Historic Park, Virginia (2008, 2010). Monitoring variables consisted of dissolved-oxygen concentration, chlorophyll a concentration, attenuation of downwelling photosynthetically available radiation (PAR), turbidity, water temperature, and salinity. All monitoring was conducted during four-week summer index periods. The monitoring design incorporated data collection at multiple, complementary spatial and temporal scales. Within each park, a spatial survey was conducted once during the index period following a probability design using a grid of tessellated hexagons as the basis for sample site selection. The spatial survey was supplemented with weekly measurements at a subset of sites and continuous monitoring at a single reference site. Within parks, data were reported as area-weighted water-quality conditions during each index period, the location and extent of estuarine area within condition categories, and spatial and temporal trends. In addition, we used a repeated measures analysis of variance to determine the extent to which variability in three water quality metrics (chlorophyll a in surface water, dissolved oxygen in bottom water, and water clarity expressed by PAR attenuation) was explained by year to year changes in each park's respective estuary.

Acknowledgments

This report is the culmination of efforts by many people who contributed to estuarine Vital Signs monitoring in the National Park Service Northeast Coastal and Barrier Network (NCBN) from 2006 through 2011. First and foremost, we are grateful to the scientists and field technicians who collected the field data summarized here; their attention to quality assurance during data collection and data entry is paramount and provides the foundation for this report. For work at Cape Cod National Seashore we thank Kate Allison, Holly Bayley, Allison Bodine, Melanie Congretel, Sophia Fox, Michelle Galvin, Emily Greer, Megan Holcomb, Krista Lee, Alana Marcinko, Kelly Medeiros, Kelly Peebles, Megan Tyrrell, and Jessie Wilson; for Fire Island National Seashore and Gateway National Recreation Area we thank Sterling Brisbin, Salvetore Caldarello, John Carroll, Kyle Chadderton, Liam Dolgin, Bradley Furman, Lisa Jackson, Rebecca Kulp, Kale Liantonio, Paul Ligorski, Peter Miller, Bradley Peterson, Brooke Rodgers, Joanne Siskidis, and Amber Stubler; and for Assateague Island National Seashore, George Washington Birthplace National Monument, and Colonial National Historic Park we thank Jim Goins, Voight Hogge, Ken Moore, Betty Neikirk, Eric Sherry, Erin Shields, Brian Sturgis, and Steve Snyder. We are particularly grateful to Dennis Skidds for his assistance in accumulating park data in a central database and his cheerful and prompt responses to innumerable requests for data corrections and data export. We also greatly appreciate the extensive work by John Kiddon in developing a data-reduction and integration tool. Tom Huntington prepared the graphs of the continuous water-quality data and Robin Baranowski formatted the report for publication; we thank them both for their expertise and thoroughness. We greatly appreciate the support and leadership provided by Sara Stevens, NCBN Program Manager, throughout this project. This report was improved substantially by the thoughtful reviews provided by Megan Tyrrell and Charles Culbertson. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Conversion Factors

SI to Inch/Pound

Multiply	By	To Obtain
Length		
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.54	mile, nautical (nmi)
Area		
hectare (ha)	2.471	acre
sqaure kilometer (km^2)	247.1	acre
Volume		
liter (L)	33.82	ounce, fluid (fl.oz)
liter (L)	0.2642	gallon (gal)
Mass		
gram (g)	0.0.527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Horizontal coordinate information is referenced to the “North American Datum of 1983 (NAD83).

Units

Concentrations of dissolved oxygen in water are given in milligrams per liter (mg/L) and as a percentage of the saturation concentration (% saturation).

Concentrations of phytoplankton chlorophyll *a* are given in micrograms per liter (µg/L).

Turbidity is reported in nephelometric turbidity units (NTU).

Photosynthetically available radiation (PAR) is measured in micromoles of photons per square meter per second (µmol photons/m_2/s) and as the instantaneous ratio of underwater PAR to in-air

PAR. Attenuation through the water column (K_d) is given as the $\log_{10}$ attenuation coefficient per meter of water depth (m^{-1}).

Salinity is reported in practical salinity units (PSU).

Acronyms

ASIS..... Assateague Island National Seashore

CACO..... Cape Cod National Seashore

COLO..... Colonial National Historical Park

ENE..... Estuarine Nutrient Enrichment

FIIS..... Fire Island National Seashore

GATE..... Gateway National Recreation Area

GEWA..... George Washington Birthplace National Monument

GIS..... Geographic Information System

NCBN..... NPS Northeast Coastal and Barrier Network

NER..... NPS Northeast Region

NOAA..... National Oceanic and Atmospheric Association

NPS..... National Park Service

NTU..... Nephelometric turbidity units

PAR..... Photosynthetically available radiation

RTS……...…. Random tessellation stratified

SAHI..... Sagamore Hill National Historic Site

SAV……. Submerged aquatic vegetation

THST..... Thomas Stone National Historic Site

USEPA..... United States Environmental Protection Agency

Introduction

This report summarizes estuarine water-quality data collected by the Vital Signs Monitoring Program of the National Park Service (NPS) Northeast Coastal and Barrier Network (NCBN) between 2006 and 2011. The NCBN includes eight coastal parks from Massachusetts to Virginia (Figure 1), six of which protect extensive estuarine, bay, and lagoon habitats. Water-quality monitoring is implemented in these parks following the NCBN Protocol for Monitoring Estuarine Nutrient Enrichment (ENE; Kopp and Neckles 2009). Data collected during development and testing of the ENE protocol from 2003 to 2006 were summarized by Kopp et al. (2009). The present report includes all estuarine water-quality data collected in NCBN parks since the ENE protocol became fully operational in 2007, as well as data collected prior to 2007 that were not included in the earlier report (Table 1).

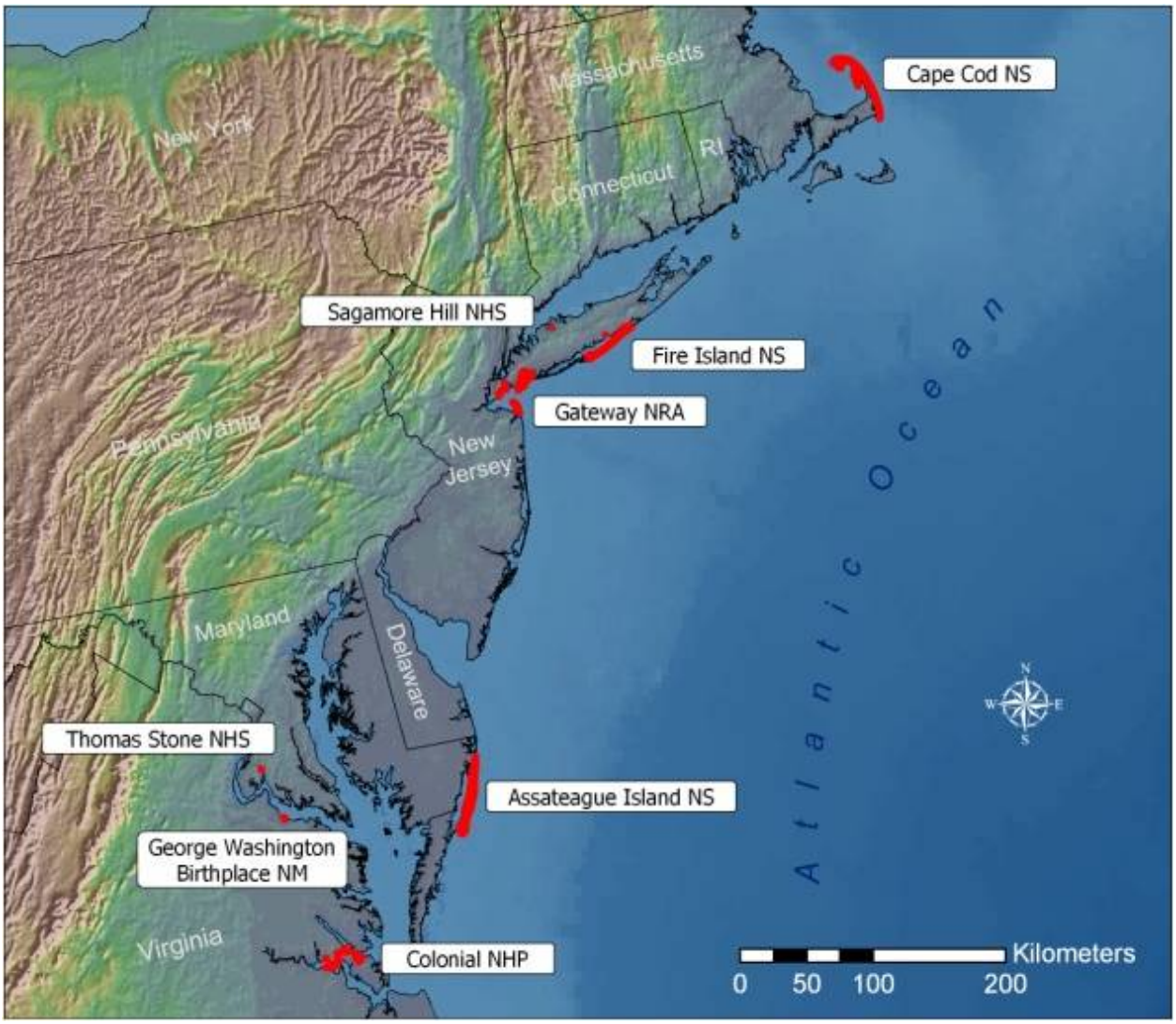


Figure 1. Map of National Parks in the Northeast Coastal and Barrier Network.

Table 1. NCBN water-quality monitoring data sets (years of monitoring) summarized in this report.

Park Code	Park Name	Location	Years of Water- Quality Monitoring Included in Report
CACO	Cape Cod National Seashore	Massachusetts	2007, 2008, 2009, 2010, 2011
FIIS	Fire Island National Seashore	New York	2009, 2011
GATE	Gateway National Recreation Area	New York and New Jersey	2010
ASIS	Assateague Island National Seashore	Maryland and Virginia	2006, 2008, 2010
GEWA	George Washington Birthplace National Monument	Virginia	2009, 2011
COLO	Colonial National Historic Park	Virginia	2008, 2010

Vital Signs Monitoring

The Organic Act of 1916 established the National Park Service and mandated that it manage park resources "unimpaired for the enjoyment of future generations." More recently, the National Parks Omnibus Management Act of 1998 established the framework for fully integrating natural resource monitoring and other science activities into NPS management processes. The following year, NPS released an action plan, The Natural Resource Challenge, addressing the major challenges facing NPS in preserving natural resources and outlining strategic approaches to resolving them. These were the origins of the present NPS Vital Signs Monitoring Program.

The Vital Signs Monitoring Program organized 270 parks into 32 biogeographic networks that share funding and a core professional staff. Each network links parks that share similar geographic and natural resource characteristics to improve efficiency and reduce costs while still using customized and relevant monitoring approaches. The five goals for all networks are as follows:

- Determine the status of and trends in selected indicators of the condition of park ecosystems to allow managers to make better informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

Goals of NCBN Monitoring

The NCBN coastal parks are dependent on high-quality aquatic resources to sustain the complex estuarine and nearshore ecosystems they represent. Collectively, parks in the NCBN represent a wide range of sizes (33 ha to almost 20,000 ha), latitudes (37°11.3'N. to 42°05.3'N., or more than 540 km of latitude), watershed geology (shallow soils overlying granite bedrock to thick sandy glacial deposits), tidal range (microtidal to more than 3 m), and freshwater sources (surface water versus ground water) (Roman et al. 2000). Estuaries within these parks share fundamental characteristics, however, including temperate zone flora and fauna and the threat of nutrient enrichment as a primary management concern (Roman et al. 2000). Their broad similarities are the basis for development of a uniform estuarine Vital Signs monitoring protocol.

Park Vital Signs are selected physical, chemical, and biological elements and processes of park ecosystems that represent the overall health or condition of the park, known or hypothesized effects of stressors, or elements that have important human values. For the NCBN, estuarine Vital Signs relate to the stressor with the greatest potential impact: nutrient enrichment (Kopp and Neckles 2009).

The specific goals of estuarine monitoring in coastal parks of the NCBN are (1) to determine whether nutrient loads to park estuaries are increasing over time, and (2) to assess how estuarine natural resources are affected by changing nutrient inputs. Two distinct monitoring protocols have been developed to achieve these monitoring goals, and the utility of the protocols and interpretability of the monitoring data from each are tightly linked. Goal 1 is addressed by an Estuarine Nitrogen Loading monitoring protocol that prescribes direct monitoring and modeling of nutrient loading to the estuaries (Stevens et al. 2005). Goal 2 is addressed by the ENE monitoring protocol, which tracks indicators of estuarine response to nutrient enrichment (Kopp and Neckles 2009). The data presented in this report result from water-column metrics of the ENE protocol.

The ENE protocol includes monitoring variables associated with six Vital Signs: water chemistry, water quality, water clarity, sediment organic carbon, seagrass distribution, and seagrass condition (Kopp and Neckles 2009). Monitoring data for the following measures related to water-column Vital Signs are reported here: dissolved-oxygen concentration, chlorophyll *a* concentration, water temperature, salinity, attenuation of downwelling photosynthetically available radiation (PAR), and turbidity.

Conceptual Monitoring Approach

The ENE monitoring protocol incorporates several spatial and temporal designs to address questions at a hierarchy of scales. Characteristics that address the Vital Signs of water quality, water clarity, water chemistry, and sediment organic carbon are all sampled using a probability design within park estuaries during a late-summer index period. This statistical approach allows the condition of unsampled locations to be inferred from the distribution of data from a set of randomly positioned "probability" stations. A subset of sampling stations is sampled repeatedly during the index period, and is not re-randomized in subsequent years. These "trend stations" allow us to examine temporal variability within the index period, and to improve the sensitivity of the monitoring protocol to detecting change through time. Additionally, one index site within each park is equipped for

continuous monitoring throughout the index period. Thus, the protocol includes elements of probabilistic and targeted spatial sampling, and the temporal intensity ranges from snapshot assessments to continuous monitoring. This mixture of sampling approaches and intensities was adopted to allow for overall condition assessment while enhancing the ability to detect change in response to nutrient enrichment. The result is a geographically broad program that tracks condition in almost 500 km^2 of estuarine habitat. It is statistically rigorous and is designed to integrate with marine monitoring programs of the USEPA and NOAA.

Study Areas and Target Sampling Populations

The ENE protocol is implemented in all NCBN parks with estuarine resources. The four largest parks within the NCBN contain extensive estuarine habitat (Assateague Island National Seashore, Maryland/Virginia; Cape Cod National Seashore, Massachusetts; Gateway National Recreation Area, New York/New Jersey; Fire Island National Seashore, New York). Colonial National Historic Park, Virginia, is a park with a moderate amount of estuarine shoreline, and two small parks (Sagamore Hill National Historic Site, New York; George Washington Birthplace National Monument, Virginia) also include short stretches of estuarine shoreline. The eighth of the network parks, Thomas Stone National Historic Site, neither contains nor directly abuts any estuarine resources.

Probability surveys use a cost-effective, statistically based, and scientifically defensible method to determine the overall condition of estuarine waters within and among the NCBN parks. Key to the probability survey design is the site-selection process. This process requires a delineation of the estuarine area of interest within each park and a method for site selection that includes randomization. The probability sampling approach adopted for the ENE protocol includes spatial balance, and, for some parks, a stratification of effort among different estuarine components.

The ENE protocol adopts Pritchard's (1967) widely accepted definition of an estuary as a basis for identifying the target sampling populations:

> *"An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which seawater is measurably diluted with fresh water derived from land drainage."*

In no instance is an estuary wholly contained within the boundary of an NCBN park. Estuaries fall either partially within a park (sometimes predominantly within), or outside but abutting a park. NPS resource and program managers agreed that park boundaries alone were not an adequate tool for delineating target populations as resource management objectives could not be achieved by universally ignoring estuarine resources outside park boundaries. In some cases, doing so would artificially divide an estuary, and in all cases it risked ignoring resources with significant importance to, or influence upon, the parks. On the other hand, monitoring the entirety of an estuary simply because it abuts a network park may, in some instances, severely dilute the monitoring effort while not providing information most important to the monitoring objectives. To assist in selecting target populations as consistently and objectively as possible, the following selection rules were applied:

1. include all estuarine water falling within a park boundary;
2. expand the area to include non-NPS estuarine waters--both the remainder of those partially contained within park boundaries and those abutting parks when the adjacent resources are integrally connected to park estuarine waters and (or) significantly influence other natural or cultural resources of the parks;

3. retreat from the spatial domain identified in 1 and 2 above if necessary due to logistical constraints, feasibility, or excessive dilution of effort (particularly when considering non-NPS estuarine waters).

The application of these three selection rules is described in detail for all parks of the NCBN in the ENE protocol (Kopp and Neckles 2009).

Methods

Spatial Sampling Design

The probability survey design adopted for NCBN estuaries uses a grid of tessellated hexagons as the basis for sample site selection. This design was developed by the USEPA Environmental Monitoring and Assessment Program in the early 1990s, and first applied to estuaries in the Louisianan (Summers et al. 1993) and Virginian (Strobel et al. 1995) provinces. It was subsequently adopted by the USEPA National Coastal Assessment (USEPA 2001a). The hexagonal sampling grid results in a set of samples that is balanced spatially over the entire estuary of interest, but specific sampling locations are selected randomly within each hexagon. This approach combines the benefits of a systematic design with the statistical advantages of random sampling. Because this sampling protocol is consistent with that used by the USEPA National Coastal Assessment Program during the same period, the condition of NCBN estuaries can be evaluated within the context of other estuaries in the region, and data from NCBN estuaries can also contribute toward overall regional condition assessments.

The ENE spatial sampling design treats each park estuary as a continuous resource. The spatial domain was overlaid with a grid of tessellated hexagons, and one random site was selected for monitoring within each hexagon; each point in the estuary has a known probability of being sampled. This approach is known as a random tessellation stratified (RTS) design, and was developed to permit control of the spatial dispersion of the samples with explicit recognition of the continuous nature of ecological resources (Stevens 1997, Stevens and Olsen 2003). For each assessment, these “probability” stations are each sampled once during a 4-week summer index period.

Trend Stations

Designs that are optimal for status estimation are generally not optimal for trend estimation (Urquhart et al. 1998). Monitoring for trends is best accomplished by revisiting one set of sites through time, whereas monitoring for status is best accomplished by obtaining the greatest overall number of random (never-revisit) sites. For the water-column measures reported here, 20 percent of the hexagons in each park were selected as “trend” stations. For parks without existing individual monitoring programs, trend stations were positioned randomly within these identified hexagons, and were resampled each week of the index period and for every subsequent year of monitoring. To the extent possible, hexagons identified for trend stations were distributed systematically throughout the spatial domain. At two NCBN parks with existing monitoring programs (GATE and ASIS) existing permanent monitoring stations could be used as Vital Signs trend stations, thereby anchoring the ENE protocol to long-standing data sources and avoiding unnecessary redundancy. Several conditions must be met in order for these substitutions to be made. First, the sampling location must have been selected to be representative of the area from which it was selected, and must be considered representative of the hexagon within which it falls. Therefore, its location should not have been selected to target a specific area of concern (such as a waste- or stormwater discharge pipe or particular basin) unless that concern is representative of the entire hexagon. Also, trend stations must be distributed around the estuarine spatial domain. At both GATE and ASIS, more than 20 percent of

the hexagons already contained suitable trend-monitoring stations so that pre-existing permanent monitoring stations could be incorporated into the ENE design.

Continuous Monitoring Stations

Continuous monitoring stations were established in areas expected to represent typical conditions for the estuarine environment at each park, or that at least avoid obvious sources of bias to water quality. Continuous data are used to identify temporal variability in estuarine Vital Signs that is not captured by weekly trend monitoring. Although continuous stations do not contribute statistically to assessments of average estuarine condition, these high-resolution trend stations provide information that assists in interpreting spatial data. At all but one of the NCBN continuous monitoring stations, the data are collected by a multi-parameter water-quality data logger that is mounted to a pier, piling, or other structure a fixed distance from the estuary bottom, so that the water depth of the data logger is tidally varying. As noted below, one data logger at CACO is suspended from a floating buoy, thus the water depth of the logger remains relatively stable throughout the tidal cycle.

NCBN Parks

Cape Cod National Seashore

Cape Cod is a large glacial moraine peninsula that extends 96.5 km into the Atlantic Ocean from the coast of Massachusetts, and Cape Cod National Seashore (CACO) is located on the outer portion of the Cape. Almost all the estuarine habitat at CACO is associated with two large coastal lagoon systems, Pleasant Bay (PB) and Nauset Harbor/Marsh (NH) (Figure 2). Because of restricted flushing with the ocean and severe residential development pressures outside the seashore boundary, NPS interest in estuarine condition extends throughout these coastal embayments, not just in the areas within the seashore boundary. PB and NH are each fringed by small, deep, glacially-formed kettle-hole salt ponds that flush with seawater from the lagoons.

Because deep water replacement may be restricted through density stratification and the presence of shallow sills at their mouths, these estuarine kettle holes are particularly susceptible to nutrient over enrichment. Estuarine condition within these systems may serve as early indicators of broader trends, and so all of the estuarine kettle holes connected to PB and NH are identified for monitoring regardless of whether they fall within or outside the Seashore boundary. Salt Pond is one of these estuarine kettle holes of particular concern. It falls within the National Seashore boundary, is very deep (12 m), has restricted flushing with NH, and already shows signs of degradation. For these reasons, Salt Pond is identified to receive a continuous monitoring station during the summer index period. Because of the great depth of this system, the continuous data-logger in Salt Pond is suspended from a floating buoy, so that the water depth measured at this station does not exhibit regular tidal variation.

Fire Island National Seashore

FIIS is a 7,810-ha park on the south shore of Long Island, New York. Approximately 46 percent of this area is submerged estuarine land (Figure 3). Although FIIS owns only a minority portion of the submerged land in these bays, the area in park ownership is, nonetheless, extensive.

According to the selection rules adopted for identifying ENE target populations, all of the estuarine area within the FIIS boundary is included in the monitoring design. The spatial design for FIIS includes approximately 4,532 ha of estuarine area, which is 100 percent of the NPS estuarine resources at this park.

Gateway National Recreation Area

GATE consists of 10,783 ha of coastal uplands, freshwater ponds, marshes, bays, beaches, and mudflats (Figure 4). It is divided into three geographically separate units: Jamaica Bay, Staten Island, and Sandy Hook. Estuarine resources identified for ENE monitoring at GATE are fully contained within Jamaica Bay. Pilot testing at GATE was conducted in 2003, 2005, and 2006; the sampling design was revised following the 2003 and 2005 implementations. In all years, the target population included 100 percent of park estuarine holdings in Jamaica Bay, but in 2003, several tributary branches outside the park boundary were excluded, whereas others were included Criteria for including or excluding non-park areas were not fully objective, so the target population was adjusted to its current extent beginning with the 2005 monitoring effort (Figure 4). In addition to the approximately 4,615 ha of estuary within the park boundary, an additional 1,257 ha within Jamaica Bay but outside the park boundary are now included in the spatial sampling design.

Assateague Island National Seashore

The boundary of ASIS encompasses more than 19,400 ha, with more than 60 percent of the area submerged as oceanic and estuarine habitat (Figure 5). The management and monitoring of estuarine natural resources at the park is a joint effort among many federal and state partners. The boundary of ASIS encircles NPS land holdings, as well as those of the U.S. Fish and Wildlife Service and Maryland's Assateague State Park; the Maryland portion of the system is managed under the Maryland Coastal Bays Program. Consequently, ASIS has natural-resource and monitoring interests that are not confined to areas within the park boundary. The spatial target population for ENE monitoring is consistent with these interests, and encompasses approximately 37,319 ha of estuary, of which approximately 6,867 ha fall inside park boundaries.

George Washington Birthplace National Monument

George Washington Birthplace National Monument (GEWA) is a small, 223-ha unit of the NPS located along the tidal reaches of the Potomac River in Westmoreland County, Virginia. The Potomac shoreline delineates the northern boundary of the monument, and three small sub-basins drain into the Potomac at this location. The largest of these sub-basins, and the most significant estuarine resource at GEWA, is Popes Creek (Figure 6). Since the park boundary is largely defined by the shoreline, GEWA contains only a very small amount of estuarine habitat. Indeed, estuarine resources that are mapped inside the park boundary are associated only with temporally dynamic drainage patterns at the mouth of Popes Creek and with discrepancies between the park boundary map and the shoreline maps used here.

Colonial National Historic Park

COLO consists of two significant land holdings, the Yorktown and Jamestown units, connected by a narrow traffic corridor, the Colonial Parkway. Although the Yorktown unit and the Parkway both abut the lower York River and cross a number of tidal creek systems, park interests in estuarine

condition are dominated by the area surrounding the Jamestown unit. Jamestown Island is bordered by the lower James River on one side. Whereas Jamestown Island itself is undeveloped, the Powhatan Creek watershed on the mainland is under tremendous development pressure. The spatial target population for estuarine monitoring at COLO includes all estuarine resources falling inside park boundaries. This includes small tidal creeks that drain off park wetlands, the small regions of park ownership where the Colonial Parkway overpasses tidal creeks, and a few additional areas where the park boundary does not precisely coincided with a tidal creek shoreline. The sampling frame also includes non NPS estuarine resources in Sandy Bay, Back River and The Thoroughfare. The COLO sampling frame is divided into two strata. The Tidal Creek stratum includes the area of NPS ownership at each location where Colonial Parkway overpasses a tidal creek or where tidal creeks drain NPS lands (Figure 7A). Exhaustive sampling of these discrete small areas is prescribed for this stratum. Any sampling point within each location can reasonably be considered representative, so constraints related to accessibility and water depth for sampling instruments are allowed to dictate specific locations. As a general approach for locations where estuaries cross beneath Colonial Parkway, sampling is done from the bridge at mid channel. For estuarine tidal creeks draining NPS lands, the single sampling station is located at the creek mouth. The Thoroughfare stratum is monitored using a spatial sampling design (Figure 7B). Between both strata, approximately 293 ha of estuary are monitored, including 100% of the estuarine resources that fall within the park boundary.

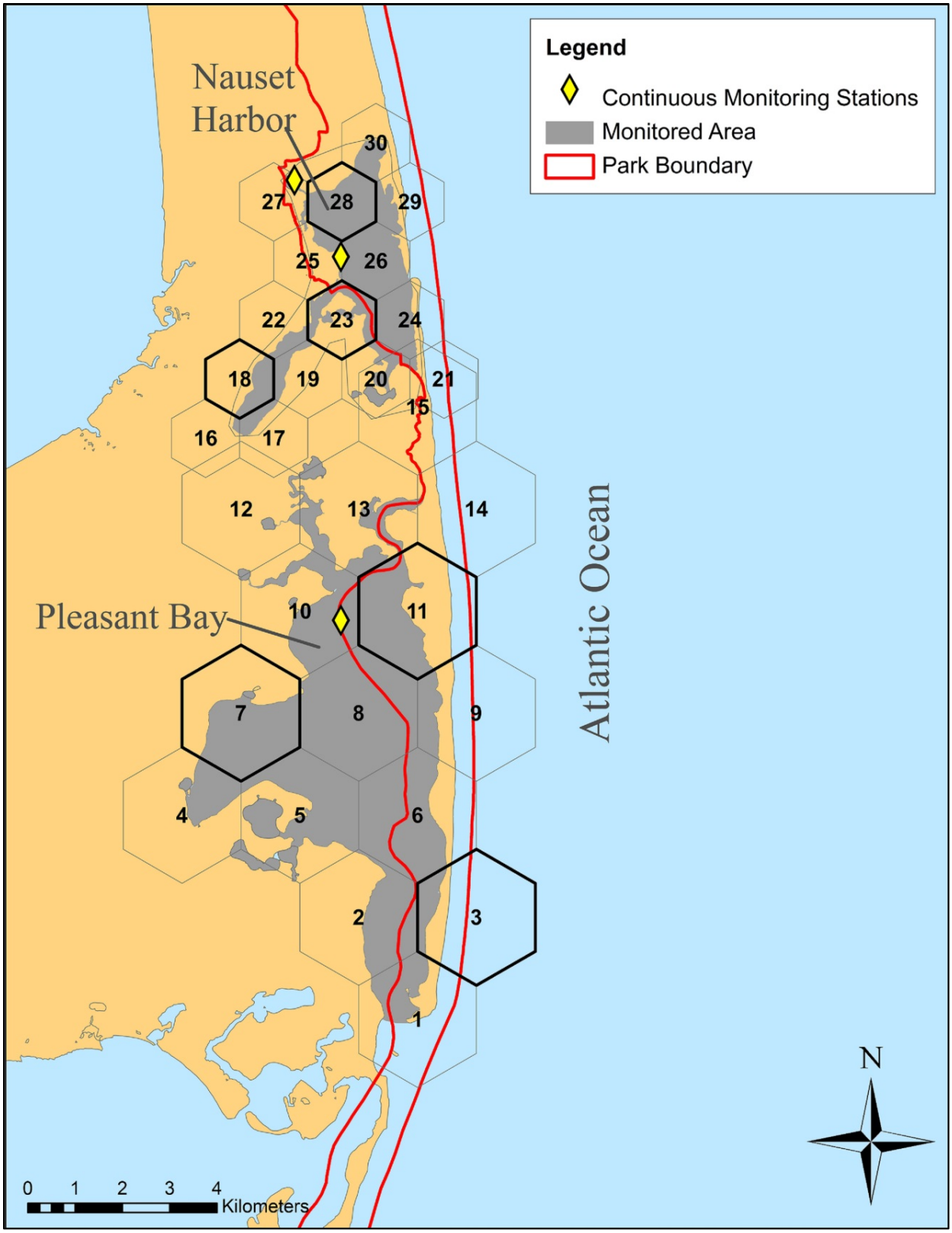


Figure 2. Spatial domain and sampling design for estuarine monitoring at Cape Cod National Seashore, Massachusetts. Sampling hexagons with a bold outline represent those assigned with trend stations.

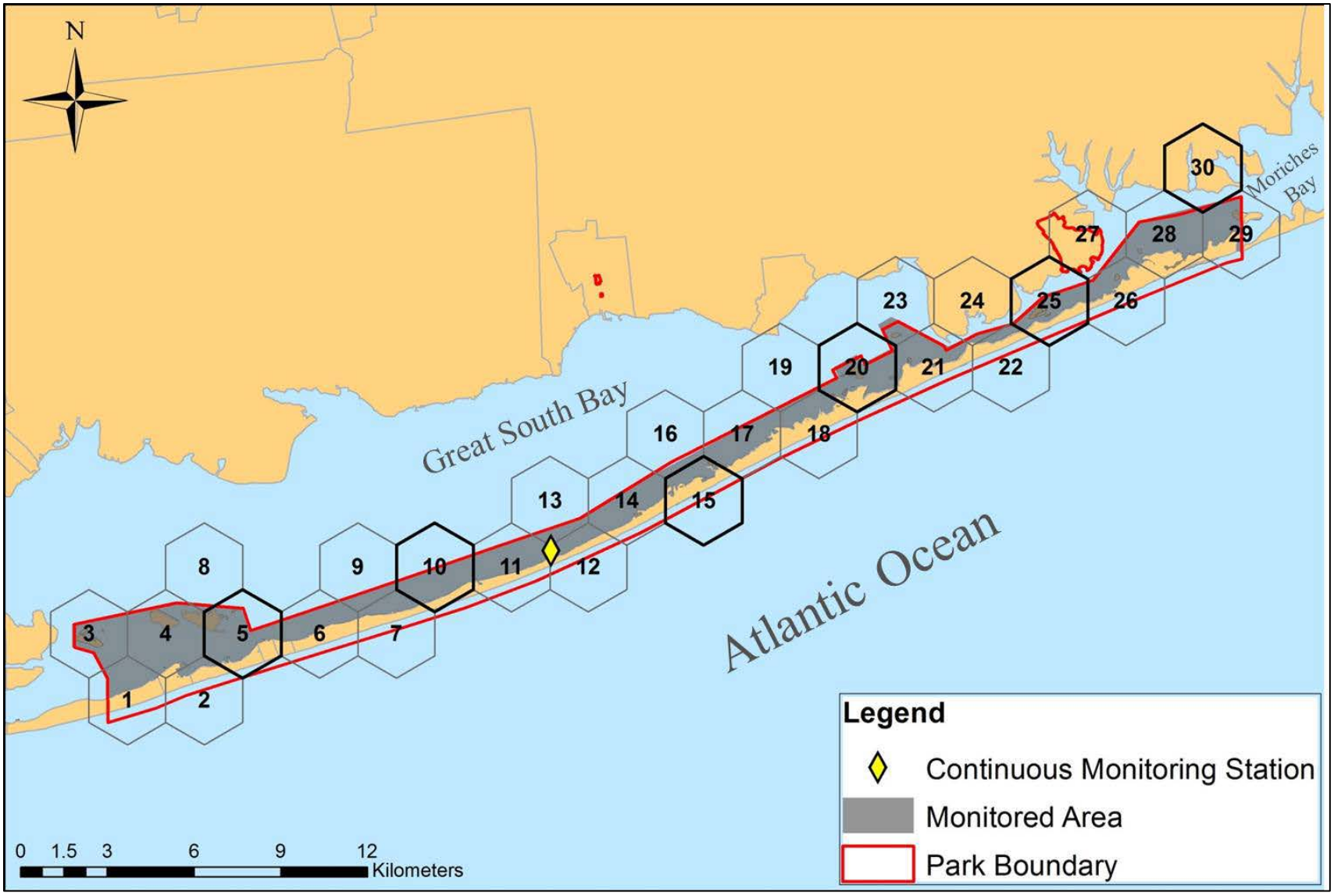


Figure 3. Spatial domain and sampling design for estuarine monitoring at Fire Island National Seashore, New York. Sampling hexagons with a bold outline represent those assigned with trend stations.

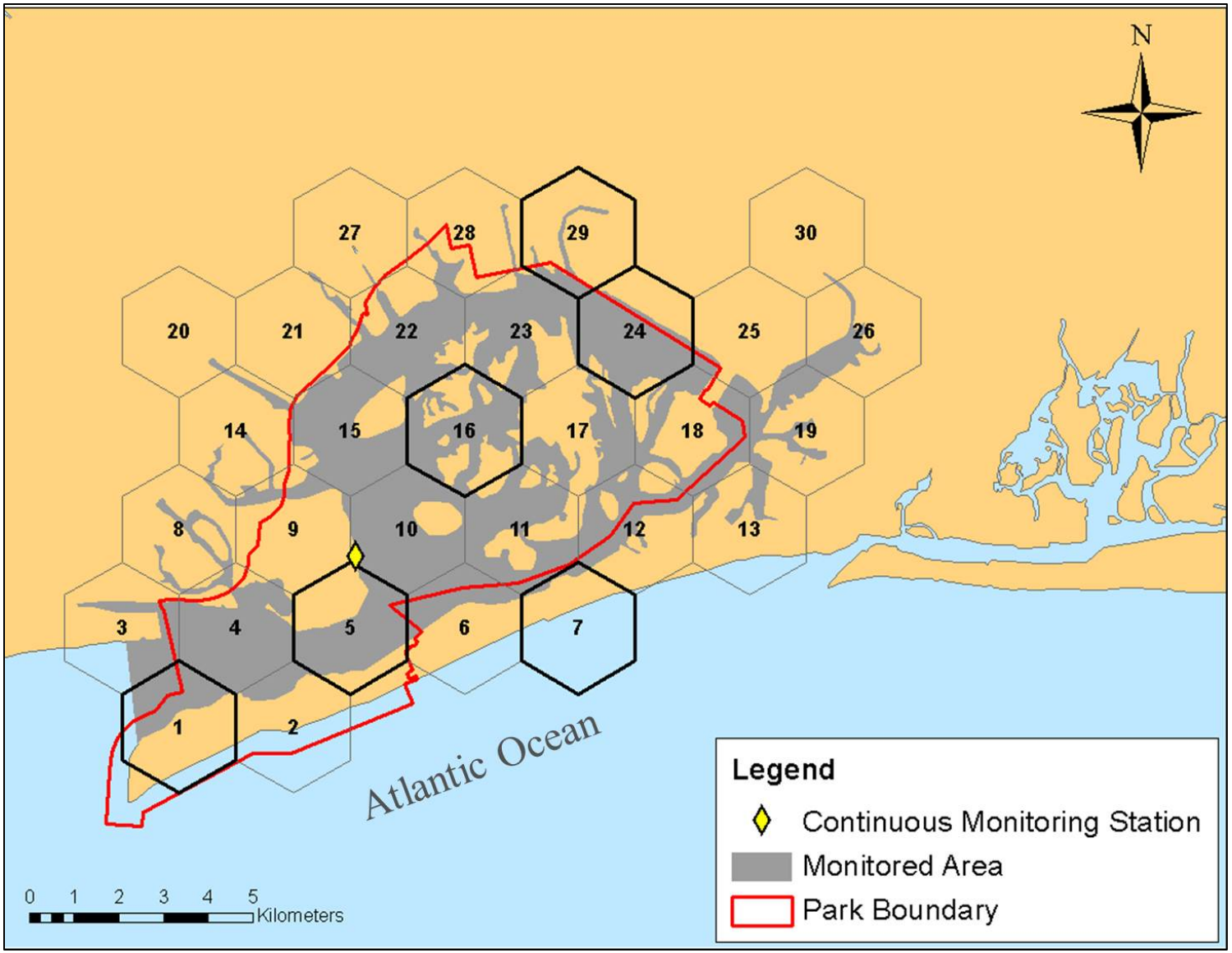


Figure 4. Spatial domain and sampling design for estuarine monitoring at Gateway National Recreation Area, Jamaica Bay unit, New York and New Jersey. Sampling hexagons with a bold outline represent those assigned with trend stations.

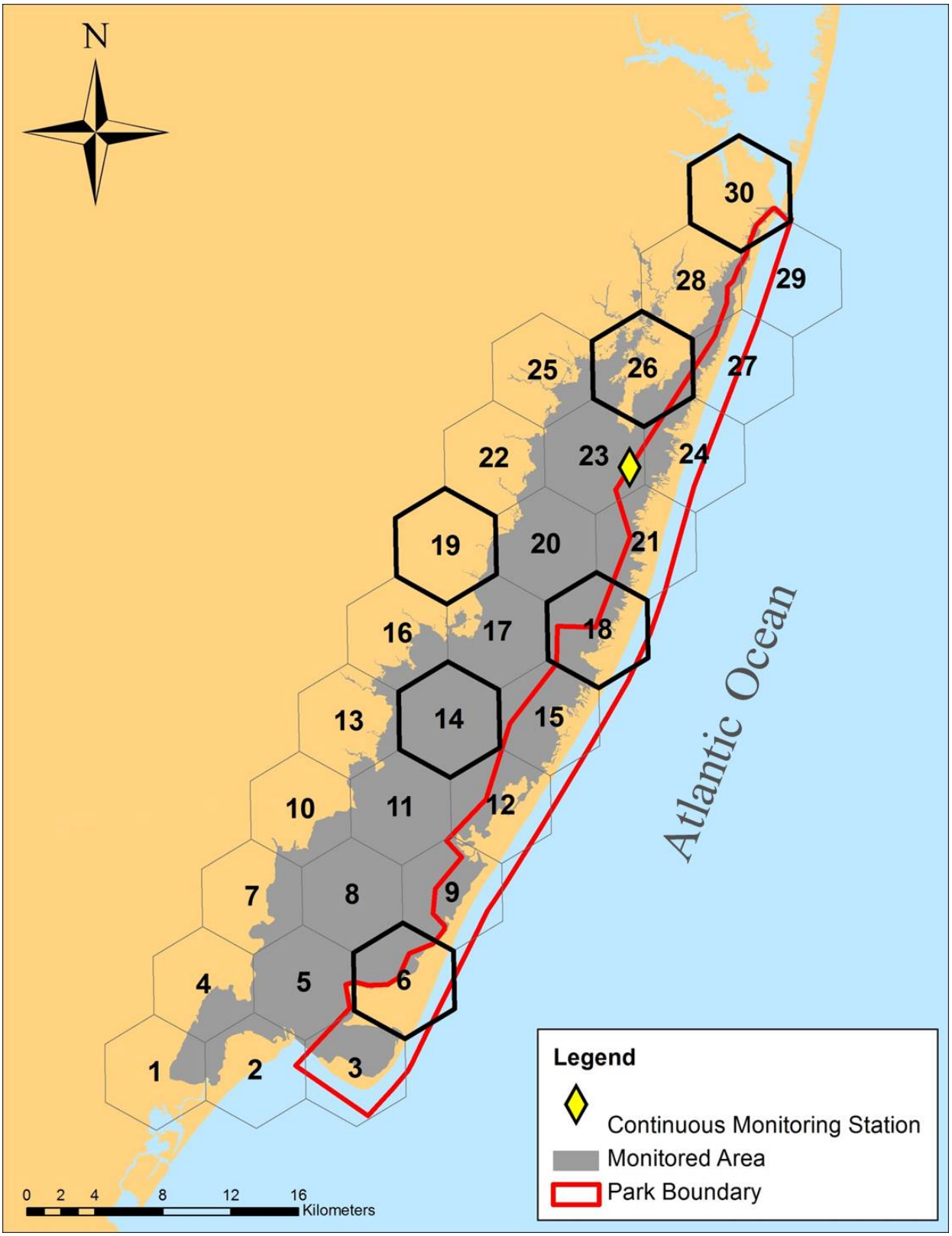


Figure 5. Spatial domain and sampling design for estuarine monitoring at Assateague Island National Seashore, Maryland and Virginia. Sampling hexagons with a bold outline represent those assigned with trend stations.

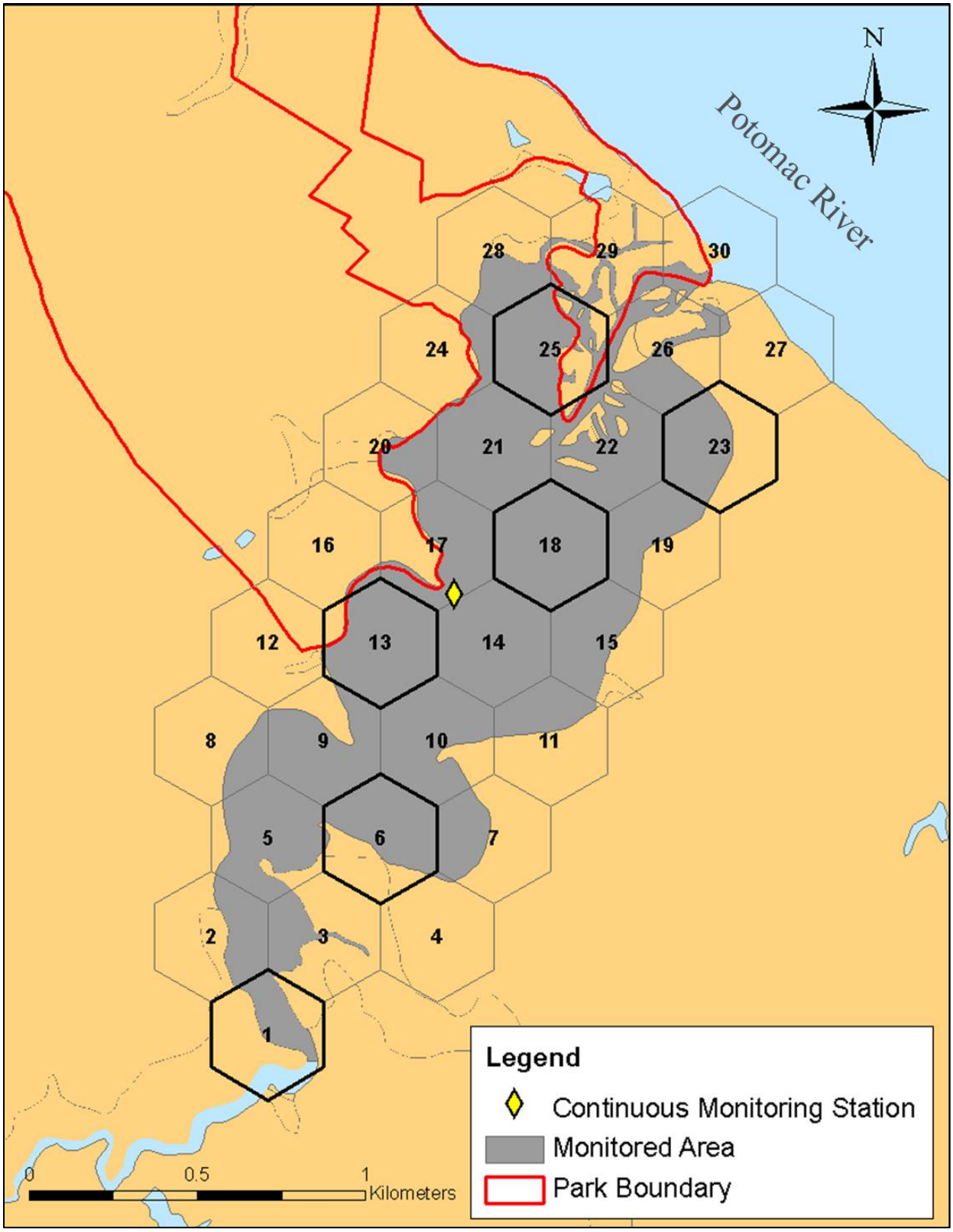


Figure 6. Spatial domain and sampling design for estuarine monitoring at George Washington Birthplace National Monument. Sampling hexagons with a bold outline represent those assigned with trend stations.

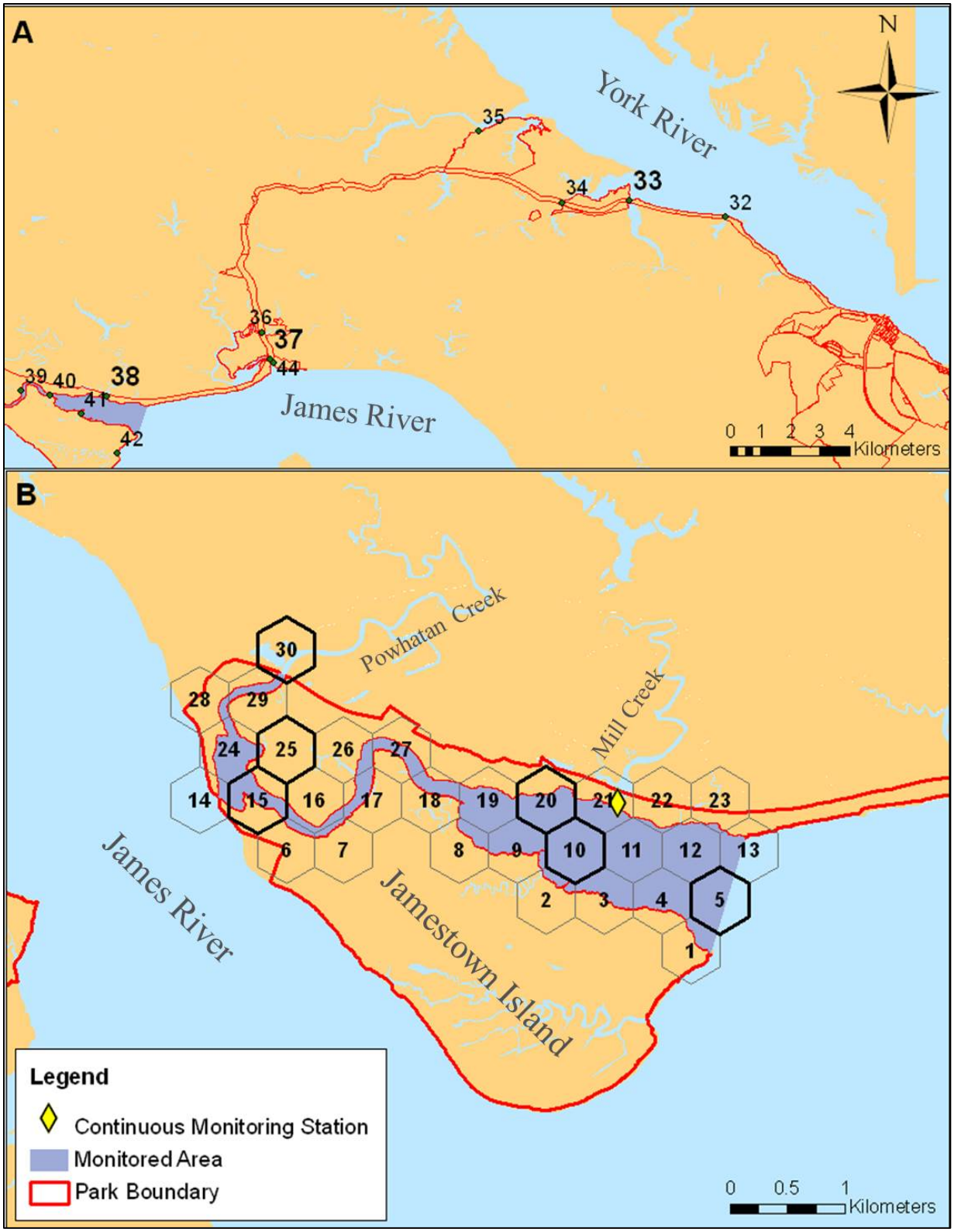


Figure 7. Spatial domain and sampling design for estuarine monitoring at Colonial National Historic Park, Virginia, Tidal Creeks stratum (A) and Thoroughfare stratum (B). Trend stations in the Tidal Creeks stratum (A) are represented by larger station numbers; trend stations in the Thoroughfare stratum (B) are established within sampling hexagons with a bold outline.

Monitoring Variables and Sampling Methods

Methods and procedures used in this study are documented fully in the NCBN ENE monitoring protocol (Kopp and Neckles 2009). We provide here a brief overview of the monitoring approach and refer readers to the protocol for further detail.

For most park assessments, all of the probability, trend, and continuous monitoring of water quality Vital Signs occurred during a 4-week index period. This index period was scheduled for 4 consecutive weeks during mid to late summer (Table 2). All spatial sampling was divided evenly among four weekly survey cruises. For each cruise, all of the trend stations were sampled, as were a quarter of the remaining probability stations. Probability stations were assigned to one of the four cruises so that spatial balance was achieved for each week of sampling.

For each probability assessment, temperature, salinity, turbidity, and dissolved oxygen were measured at the surface, at mid-depth, and near bottom at each station (probability and trend) using a YSI 6600 multi-parameter water-quality instrument (sonde). Surface measurements were taken from a depth of about 15 cm beneath the water surface, and near-bottom measurements were taken within 1 m of the bottom (within 20 cm for stations with depths less than 1.5 m). Grab samples were collected from a depth of 20 – 30 cm beneath the water surface in amber polyethelene bottles for extractive analysis of chlorophyll *a* concentration. Samples were stored in the dark on ice until being filtered later the same day. Filters were stored frozen (-20°C) for less than 3.5 weeks before analysis. Chlorophyll analyses were performed by the Atlantic Research Center at Cape Cod National Seashore, North Truro, Massachusetts, using USEPA fluorometric method 445.0 (Arar and Collins 1997). The attenuation coefficient, K_d (m^{-1}), of downwelling PAR was quantified from depth profiles of PAR obtained using LiCor quantum sensors. Because of the influence of solar angle on attenuation of downwelling PAR, all monitoring was conducted during a target sampling window of within 3 hours of local apparent noon (the time when the sun crosses the local meridian).

During the weekly sampling cruises to probability stations, samples were also collected at the continuous logging stations for quality control. At these continuous stations, temperature, salinity, turbidity, dissolved oxygen, and depths were all measured by a continuously deployed sonde using the same technologies as in the spatial assessments. The continuous sondes logged data each quarter hour. Data from quality-control visits were used to check the continuous sensors and correct for electronic drift and biofouling. Chlorophyll at the continuous station was quantified by in situ fluorescence using YSI chlorophyll sensors. During quality-control visits, discrete grab samples were collected for extractive analysis of chlorophyll *a* so that fluorometer readings could be calibrated against measurements made using the same extractive methods applied to the spatial assessments. Continuous PAR attenuation was measured using two LiCor sensors installed at different depths, integrated with optical wipers on the YSI 6600EDS sonde. The attenuation coefficient, K_d (m^{-1}), of downwelling PAR was calculated from the irradiance logged by the two sensors.

Table 2. Dates of index periods for each of the NCBN monitoring assessments.

Year	Parks	Index Period
2006	ASIS	July 25 - August 16
2007	CACO	July 24 - August 22
2008	ASIS	July 23 - August 14
	CACO	July 24 - August 22
	COLO	August 7 - August 29
2009	CACO	July 13 - August 18
	FIIS	July 15 - August 11
	GEWA	July 21 - August 12
2010	ASIS	July 7 - July 30
	CACO	July 7 - August 17
	COLO	August 3 - August 26
	GATE	June 22 - July 12
2011	CACO	July 5 - August 3
	FIIS	July 5 - July 25
	GEWA	July 19 - August 9

Data Reduction and Statistics

The four components used in the analysis and reporting of water-column monitoring data are (1) the area-weighted spatial survey, (2) comparisons of spatial survey data across index periods, (3) the trend-station data, and (4) the continuous-monitoring data. Data-quality objectives and methods for calculating summary statistics are documented in the NCBN ENE protocol (Kopp and Neckles 2009) and have been applied in preparing this report.

Spatial Data Review

Quality control and reduction of the spatial monitoring data followed methods prescribed in the ENE protocol (Kopp and Neckles 2009). These methods included the steps below.

1) Site-visit review. The calibration logs and field sheets were reviewed to identify field issues that may affect data quality. Any problems noted during the spatial water-quality monitoring, such the monitor touching the bottom sediments during the hydrocast, difficult field conditions, or instrument problems, were highlighted for further evaluation.

2) Data evaluation. All data were examined to ensure that all quality-control measurements prescribed in the standard operating procedures were made and produced reasonable results, ensuring sensor accuracy. All data that were highlighted during the site-visit review were evaluated for correctness. Any missing data found in the records were reconciled, and readings that were outside instrument range or did not meet other quality objectives (Kopp and Neckles 2009) were omitted.

3) Application of data corrections. All calculations for derived parameters (i.e., chlorophyll *a* from fluorescence measurements, K_d from PAR measurements) were performed.
4) Creation of final data set. A formatted data set, certified for correctness, was created for reporting and archiving.

Continuous Data Review

Data reduction and quality control for continuous monitoring stations similarly followed methods prescribed in the ENE protocol (Kopp and Neckles 2009), in accordance with the records-computation guidance of the U.S. Geological Survey (Wagner et al. 2006). Data processing procedures included the steps below.

1) Station-visit data review. The calibration logs and field sheets associated with each data-logging period were reviewed for any indication of sensor irregularities, sensor fouling, or instrument failure.

2) Initial data evaluation. Data were evaluated to remove erroneous values. Data errors are caused most commonly by the sensor having come out of the water, improper calibration, severe fouling of the sensors, or other instrument malfunction (as noted during the site-visit). Any data that fell outside the performance specification for the sensor were also removed as erroneous.

3) Application of data corrections. During this step, recorded data were adjusted for instrument calibration-drift and sensor-fouling errors. Data were corrected using measurements made during pre- and post-deployment calibrations and during site visits for sensor servicing. Data corrections for fouling errors were prorated by time over the correction interval. In addition, corrections for instrument calibration-drift were also prorated over the range of corrected values. Calculated parameters (i.e., chlorophyll *a* from fluorescence measurements, K_d from PAR measurements) were also derived during this step.

4) Final data evaluation. Data were reviewed to verify that any necessary rejections and corrections were applied, and a summary of all changes to the original data was generated.

Data Summary

Area-weighted water quality is reported in two ways for each park assessment: the mean condition and the percent of the estuarine area exceeding threshold values for selected parameters. In both cases, parameter values are weighted by the estuarine area within the hexagon from which each sample is collected (Cochran 1977, Stevens and Olsen 2003). NCBN adopted threshold values for Vital Signs (Table 4) to be consistent with those used by the USEPA for national coastal condition reporting (USEPA 2001b, 2004). These values are also largely consistent with the thresholds used for the NOAA National Estuarine Eutrophication Assessment (Bricker et al. 1999). The only change to these thresholds is that water clarity is expressed as K_d (m^{-1}) rather than as an index. Cutoff values of K_d have been calculated from the USEPA criteria for turbidity using the thresholds for areas with significant submerged aquatic vegetation (SAV) resources. For NPS reporting on these indicators, the proportion of the resource area that falls into each of four quality categories (good, fair, poor, or missing) is calculated for each park. The fourth (“missing”) category includes spatial elements that were not sampled or data that were excluded during quality control procedures.

Table 3. Critical threshold values and ranges used to establish the portion of the estuary that falls within a given quality category.

Measure	Good	Fair	Poor
Chlorophyll *a* (surface)	< 5 µg/L	5 - 20 µg/L	> 20 µg/L
Dissolved Oxygen (near bottom)	> 5 mg/L	2 - 5 mg/L	< 2 mg/L
Water Clarity K_d (SAV standard)	< 0.92 m^{-1}	0.92 - 1.61 m^{-1}	> 1.61 m^{-1}

[These values are based on the threshold values used by both the USEPA National Coastal Assessment and the NOAA National Eutrophication Assessment (USEPA 2001b, 2002, 2004, and Bricker et al. 1999).]

Calculations of the proportion of the estuary meeting different condition classes yield snapshots of estuarine status but do not provide statistical comparisons of estuarine condition among monitoring periods. Therefore, we used general linear models to make quantitative comparisons over time. We used a repeated measures analysis of variance to evaluate to what extent variability in three water quality metrics, chlorophyll *a* in surface water, dissolved oxygen in bottom water, and water clarity as expressed by PAR attenuation, is explained by year to year changes in each park's respective estuary. We tested the null hypothesis that there were no differences between years with respect to the estuarine response of interest, treating year as a fixed effect and treating station location as a random effect (Schabenberger and Pierce 2002). For parks with multiple strata (CACO and COLO), stratum was also included as a fixed effect. In models where the year term was significant ($P < 0.05$) we examined year-to-year comparisons using Fisher's Protect Least Significant Difference criteria (FPLSD). When used appropriately (i.e., when the year term is significant), FPLSD provides the most statistical power to detect differences and is proven to be the most accurate (Carmer and Swanson 1973). All repeated measures analyses were done in SAS (version 9.2).

Data from the trend stations (individual stations sampled weekly during each index period) were used to examine variability of the metrics throughout the index period and throughout the estuary. This allows results of the weekly spatial survey to be interpreted within the context of seasonal temporal and estuary-wide spatial variability. Trend-station data were used in estimating area-weighted average condition (Area-Weighted Spatial Data) without adding unnecessary bias to those estimates because 20 percent or fewer of the total number of stations in a park estuary are trend stations.

The role of the continuous-monitoring data is similar to that of the trend data except that temporal resolution is further emphasized, displacing any ability to resolve spatial patterns. Estuaries are highly pulsed systems, and the weekly sampling at trend stations may miss ecologically important events such as phytoplankton blooms or episodes of low dissolved oxygen concentration and high turbidity. Monitoring results can even be influenced by the time of day that samples are collected; e.g., estuarine dissolved oxygen concentrations typically fluctuate in response to community metabolism (oxygen production during day-time photosynthesis and consumption during night-time respiration; Kemp and Boynton 1980), and chlorophyll *a* fluorescence (measured as a proxy for chlorophyll concentration) varies with instantaneous irradiance due to non-photochemical quenching

(Marra 1997, Roesler and Barnard 2013). Thus the continuous-monitoring data can help relate spatial data to diel cycles. Each logging station is sampled 96 times per day (as many as 3,000 times during the index period), so short-term events are more likely to be captured. Although not spatially representative, data from the logging station can also be used to track interannual changes. Because there is no spatial replication, we can only interpret results within the context of that one station.

Results and Summary Statistics

Cape Cod National Seashore

During five years of annual monitoring at CACO from 2007 through 2011, the area-weighted average chlorophyll *a* concentration ranged from 4.57 µg/L to 7.63 µg/L; the area-weighted average dissolved oxygen concentration in bottom waters ranged from 6.73 mg/L to 10.06 mg/L, or from about 92% to 104% of the saturation concentrations; and the area-weighted average water-column PAR attenuation coefficient (K_d) ranged from 0.7 m^{-1} to 1.23 m^{-1} (Table 4, Table 6, Table 8, Table 10, Table 12).

For each year of monitoring, estuarine condition-classes at CACO in terms of chlorophyll concentration, daytime dissolved-oxygen concentration in bottom waters, and water clarity were mapped throughout the entire estuarine monitoring area and the proportions of the estuarine area falling within different condition classes were summarized within the three distinct monitoring strata: Nauset Harbor, Pleasant Bay, and the salt ponds (2007:Figure 8 - Figure 10; 2008: Figure 15 - Figure 17; 2009: Figure 22 - Figure 24; 2010: Figure 29 - Figure 31; 2011: Figure 36 - Figure 38). The majority of the estuarine area each year was classified as fair to good condition. In general, during any given year, a larger proportion of the open bays than the salt ponds fell into fair and good condition classes, although comparisons of spatial patterns are hindered by missing data within many data sets (in particular, water clarity in 2007; all variables in 2008 and 2009; Pleasant Bay data in 2010). The spatial distribution of water-quality conditions within Pleasant Bay and Nauset Harbor showed that poor condition was restricted to the upper reaches of the estuaries. The continuous monitoring data from the fixed logging stations in Pleasant Bay, Nauset Harbor, and a salt pond (see Figure 2 for locations of the logging stations) showed short term increases in chlorophyll concentration that exceeded values measured during spatial sampling (2007: Figure 11 - Figure 13; 2008: Figure 18 - Figure 20; 2009: Figure 25 - Figure 27; 2010: Figure 32 - Figure 34; 2011: Figure 39 - Figure 41). In general, spikes in chlorophyll concentrations were less frequent and of lower magnitude in Pleasant Bay than in Nauset Harbor or the salt pond. Dissolved oxygen concentration generally remained above the threshold for good condition at the Pleasant Bay and Nauset Harbor logging stations, but routinely dropped below the threshold for fair or poor condition at the salt pond station. Continuous water clarity, expressed by attenuation of downwelling PAR, was measured only at the Pleasant Bay and Nauset Harbor logging stations. Continuous water clarity general remained good at the Pleasant Bay logging station throughout the index periods, whereas it routinely dropped to fair or poor condition for extended periods in Nauset Harbor. Within-season variability in water-quality parameters is displayed by the trend station data (2007: Table 5, Figure 14; 2008: Table 7, Figure 21; 20009: Table 9, Figure 28 ; 2010: Table 11, Figure 35; 2011: Table 13, Figure 42).

Inter-annual changes in water quality were analyzed system-wide and within the three distinct monitoring-strata. There were no differences among the five index periods (2007 – 2011) in the means of chlorophyll *a* concentration or dissolved oxygen concentration in bottom waters at the system-wide level ($P > 0.60$ for both parameters) or within any individual stratum ($P > 0.50$ for both parameters). However, both parameters differed among strata. The overall mean chlorophyll concentration, across years, was similar between Pleasant Bay (unweighted mean 9.03 µg/L) and

Nauset Harbor (unweighted mean 11.53 µg/L; P > 0.20), but the overall mean chlorophyll concentration in the salt ponds, across years (unweighted mean 19.98 µg/L) was considerably higher than in Pleasant Bay ($P < 0.01$) and tended towards a higher level than was measured in Nauset Harbor ($P = 0.07$). In the same way, the mean dissolved oxygen concentration was similar between Pleasant Bay (unweighted mean 7.4 mg / L) and Nauset Harbor (unweighted mean 7.08 mg / L), but the mean dissolved concentration in the salt ponds (unweighted mean 5.46 mg / L) was lower than in either of the open bays (unweighted mean 5.46 mg / L; $P < 0.001$).

In contrast to chlorophyll and dissolved oxygen concentrations, K_d did differ among the five index periods (2007 – 2011; $P < 0.05$), and these temporal differences varied across the strata ($P < 0.05$). Average values measured in Pleasant Bay, Nauset Harbor, and the salt ponds are plotted in Figure 43. Within Pleasant Bay the highest average K_d was measured in 2010 (unweighted average 1.32 m^{-1}), and this was significantly greater than the lowest average value (2008, unweighted average 0.71 m^{-1}, $P < 0.05$); there were no other temporal differences in Pleasant Bay. In Nauset Harbor, the highest average K_d was measured in 2007 (unweighted average 1.81 m^{-1}), and this was significantly greater than the average measured in 2010 (0.80 m^{-1}, $P < 0.01$) and in 2011 (0.68 m^{-1}, $P < 0.05$). Within the salt ponds there were no significant differences among years in average K_d (salt pond unweighted average, across all years, 1.13 m^{-1}, $P > 0.05$).

2007 Index Period

Table 4. Area-Weighted average water-quality condition at CACO during the 2007 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	1.23	- -	- -	- -
Dissolved oxygen (mg/L)	- -	8.26	8.19	8.21
Dissolved oxygen, % Saturation	- -	109.44	106.64	108.07
Chlorophyll *a* (µg/L)	- -	4.57	- -	- -
Turbidity (NTU)	- -	0.93	1.06	1.51
Temperature (°C)	- -	19.99	19.29	19.46
Salinity (psu)	- -	31.86	31.87	31.90

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol was used for these calculations. "- - ", not applicable.]

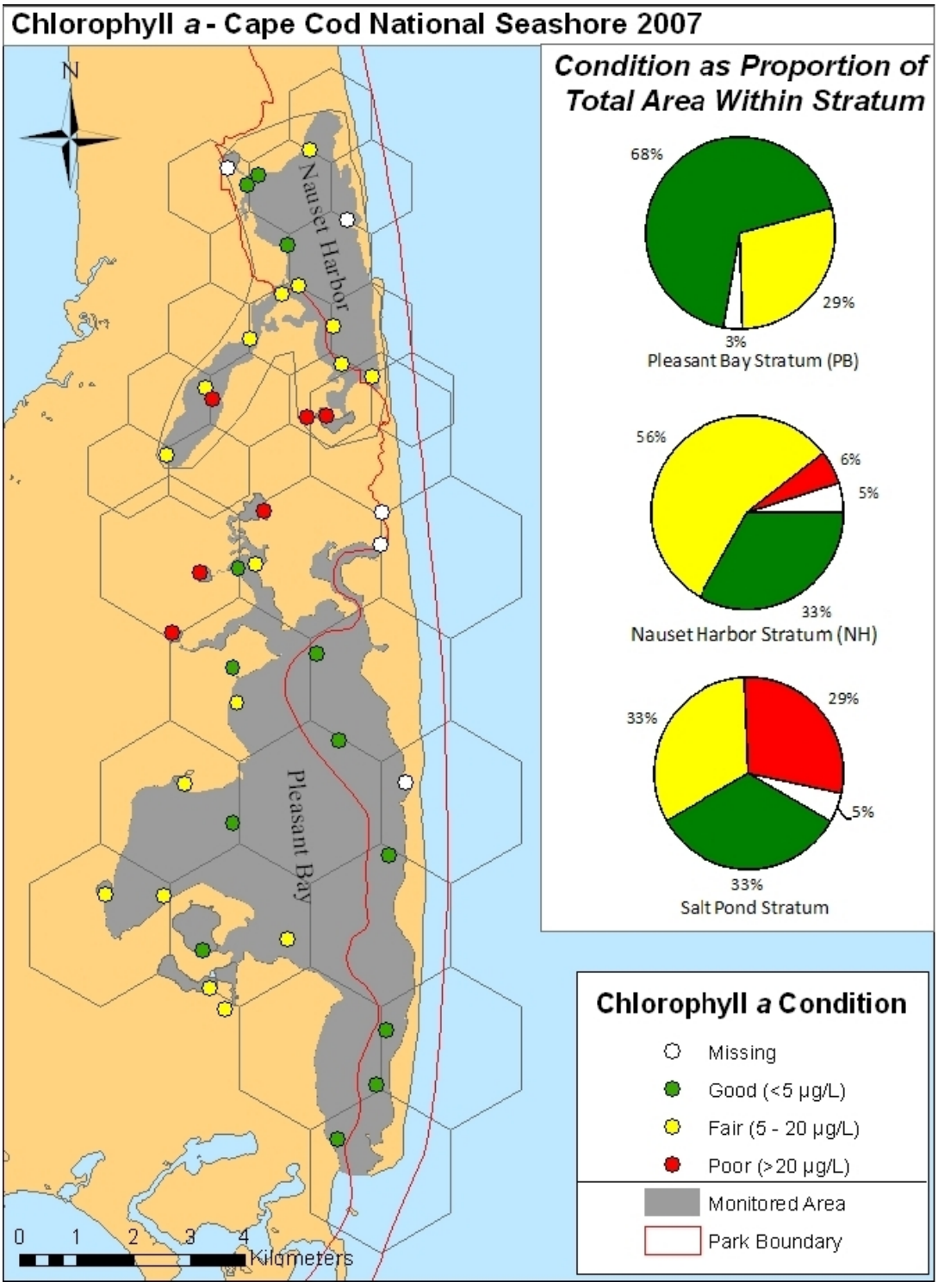


Figure 8. Chlorophyll *a* (µg/L) concentration in surface samples from the 2007 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

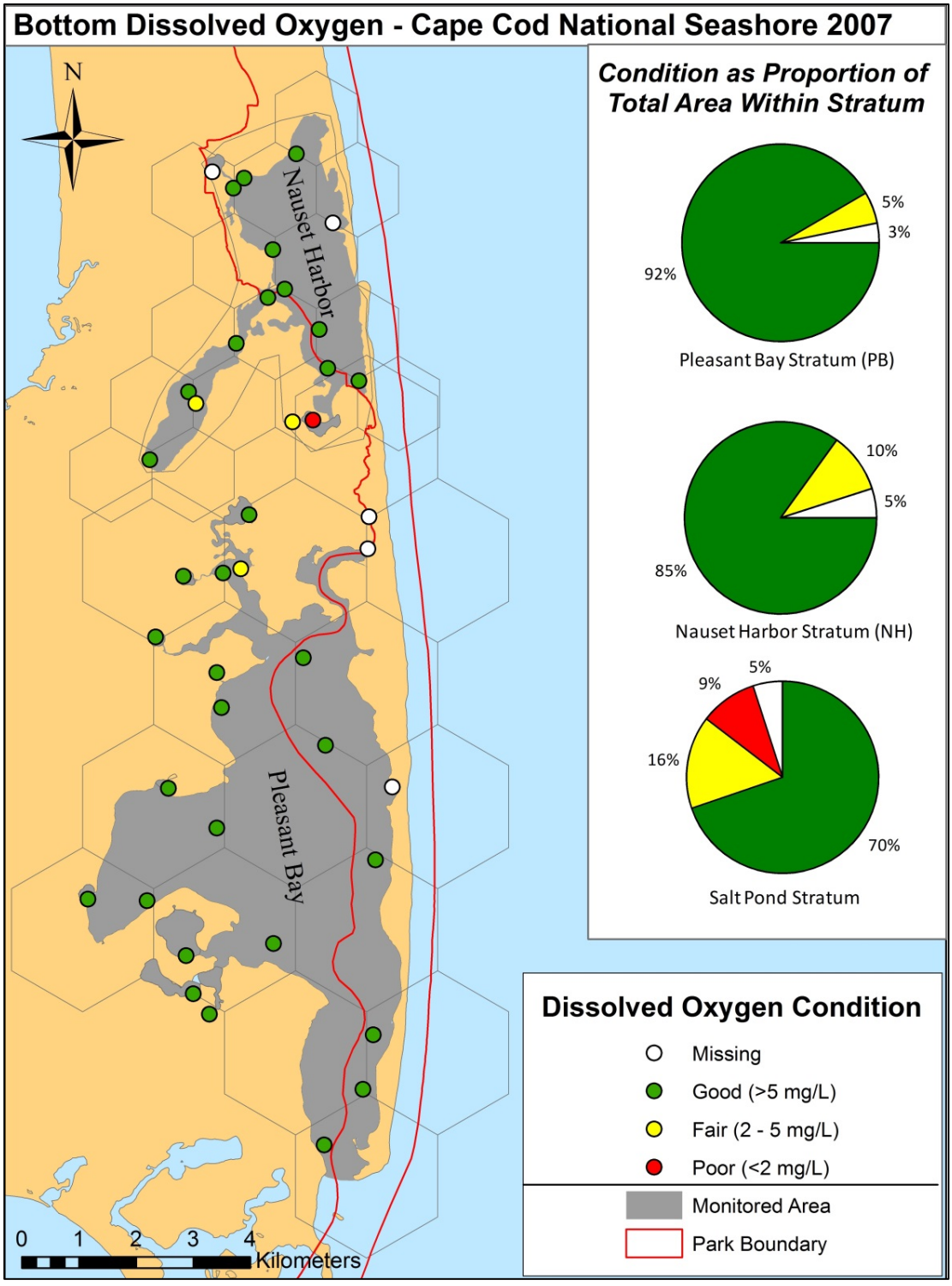


Figure 9. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2007 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

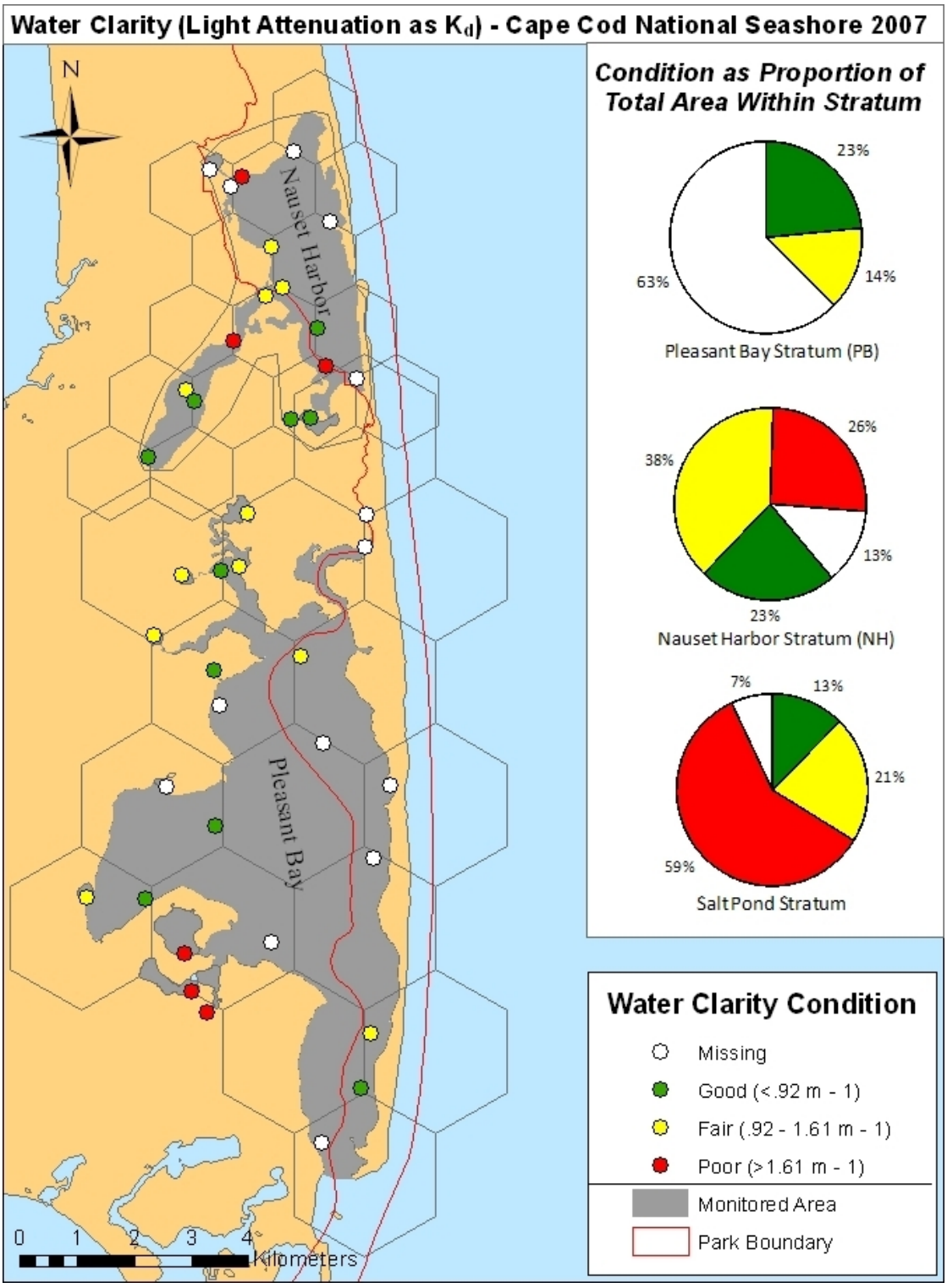


Figure 10. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2007 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

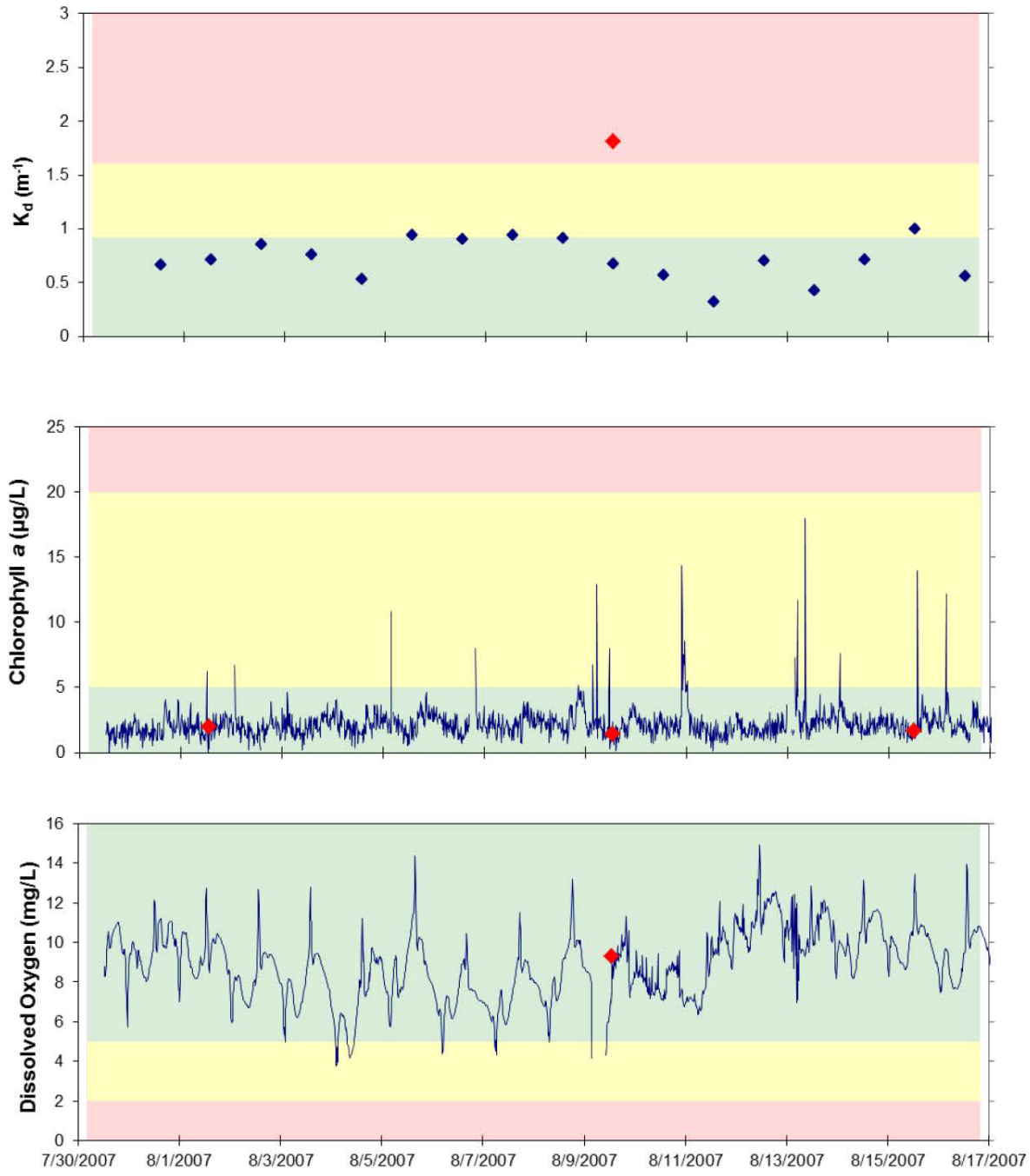


Figure 11. Continuous water-quality data from the 2007 assessment at CACO: Pleasant Bay Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Data also indicate the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN.

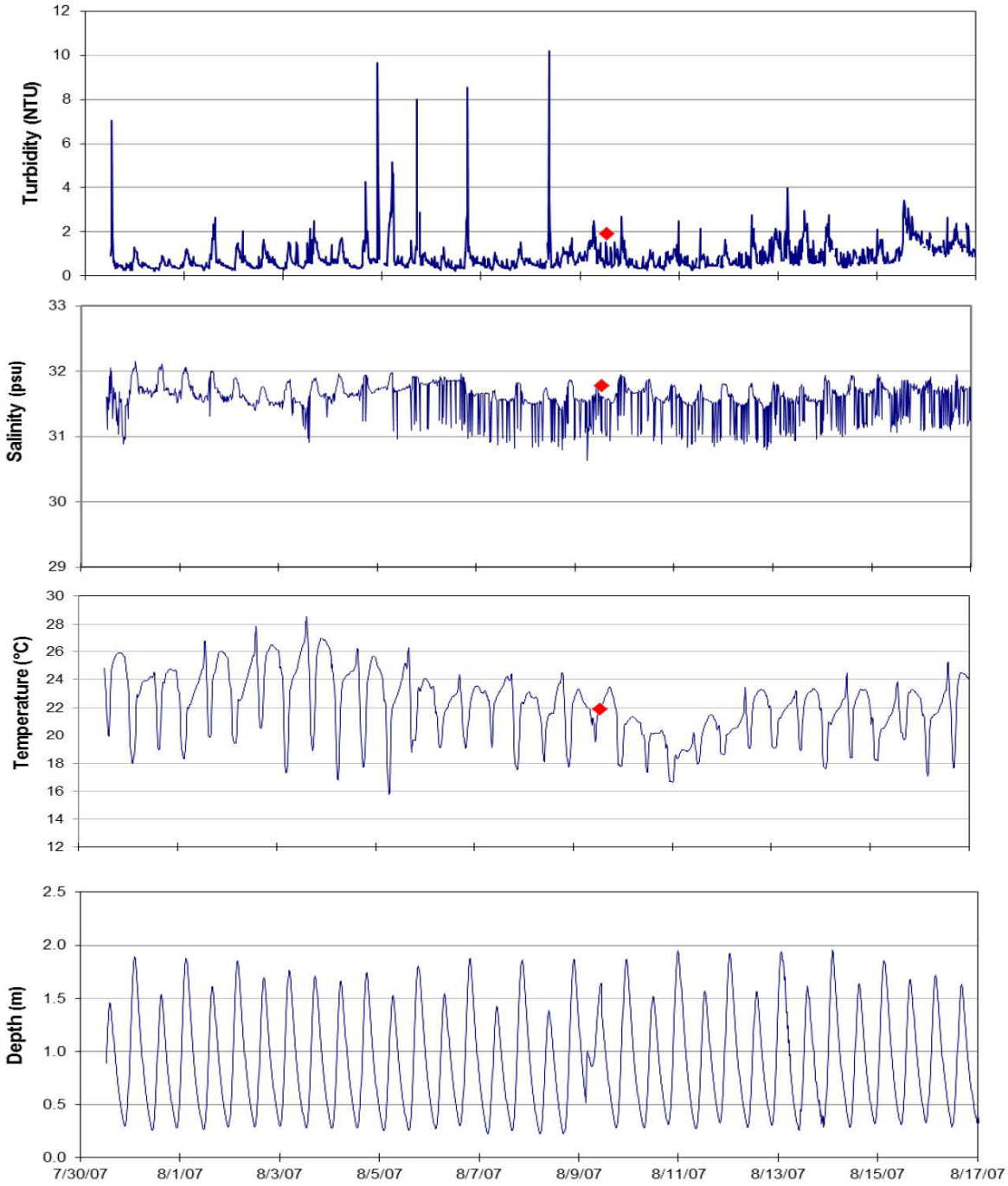


Figure 11 (cont.). Continuous water-quality data from the 2007 assessment at CACO: Pleasant Bay Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

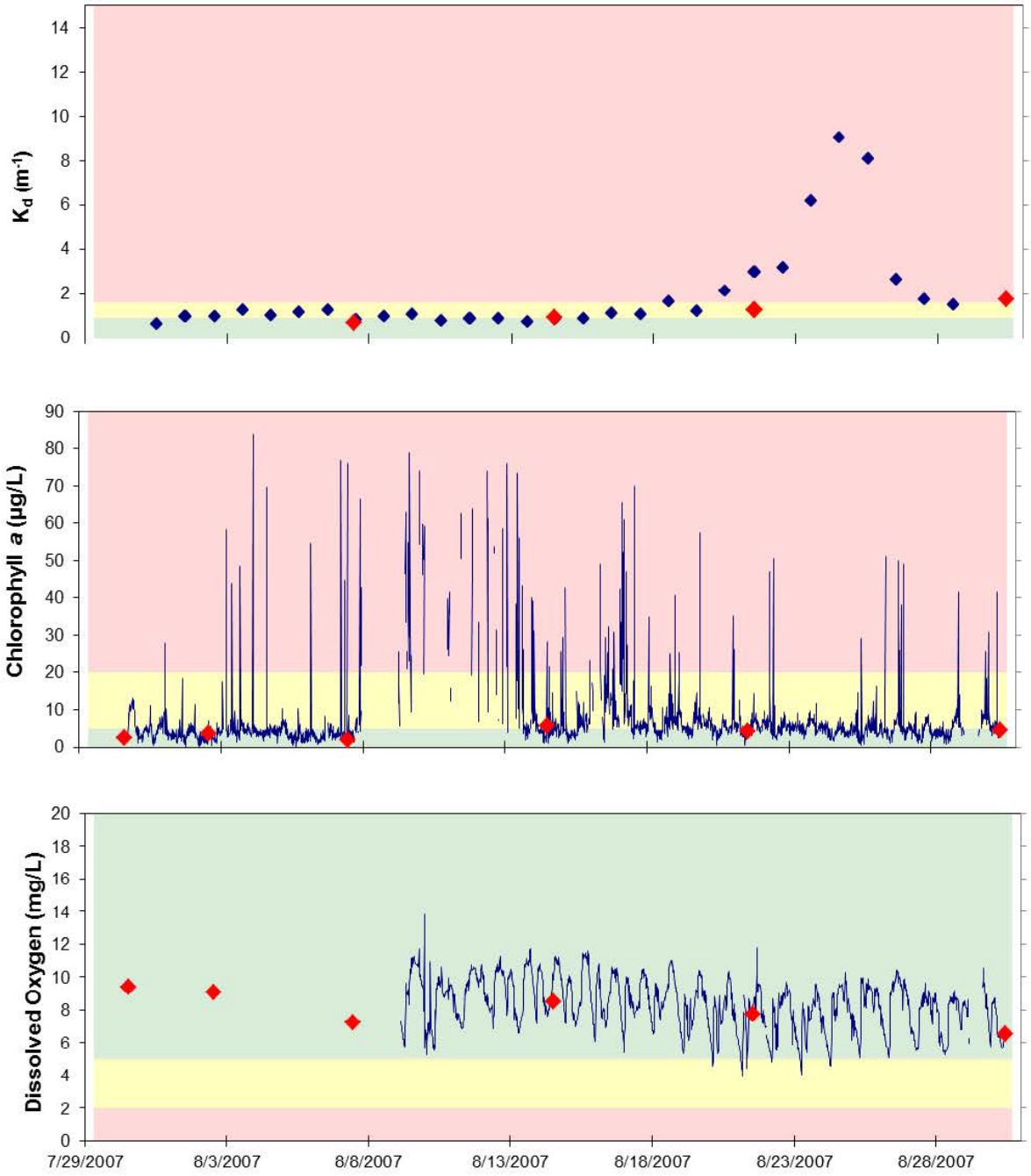


Figure 12. Continuous water-quality data from the 2007 assessment at CACO: Nauset Harbor Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Data also indicate the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN.

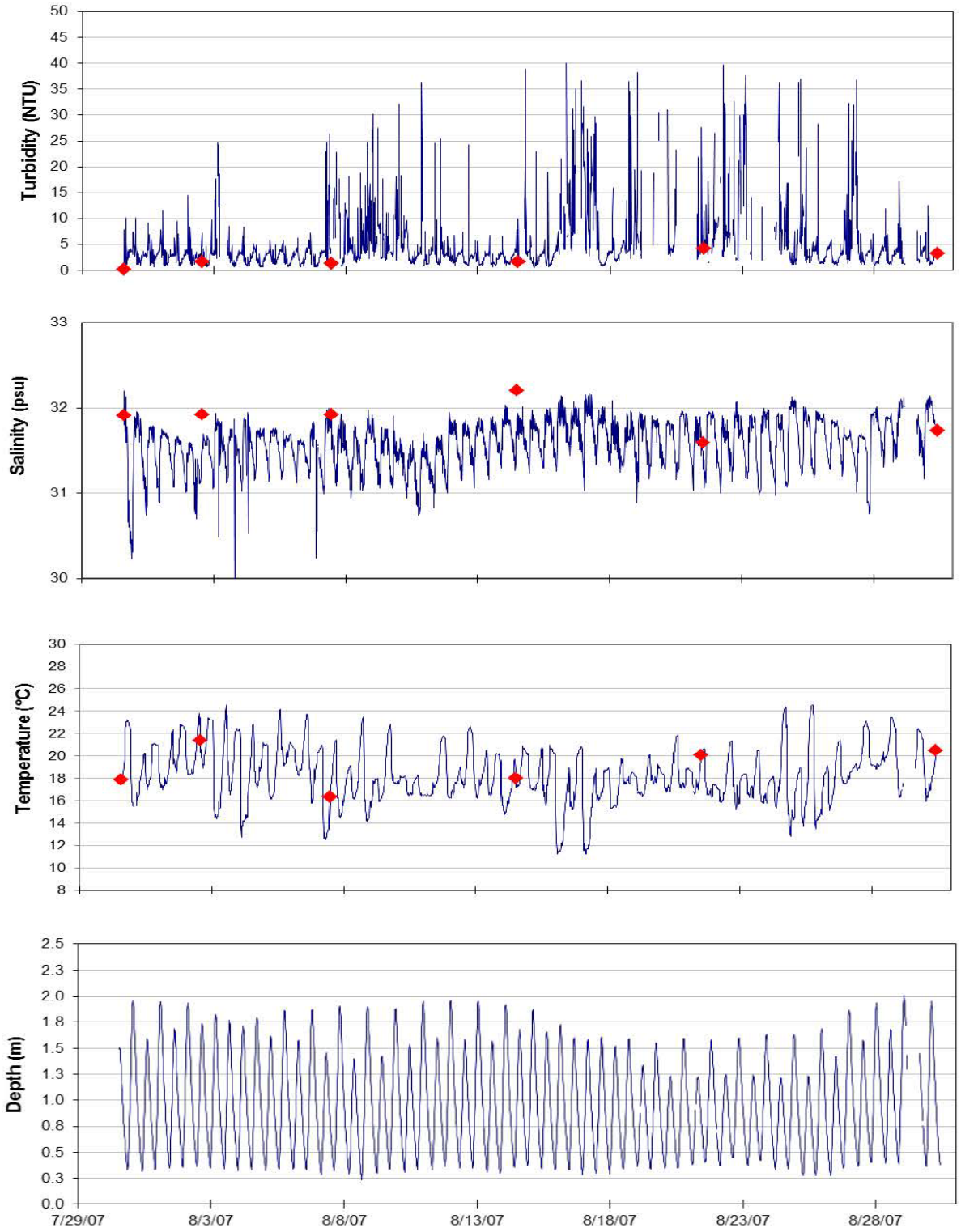


Figure 12 (cont.). Continuous water-quality data from the 2007 assessment at CACO: Nauset Harbor Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

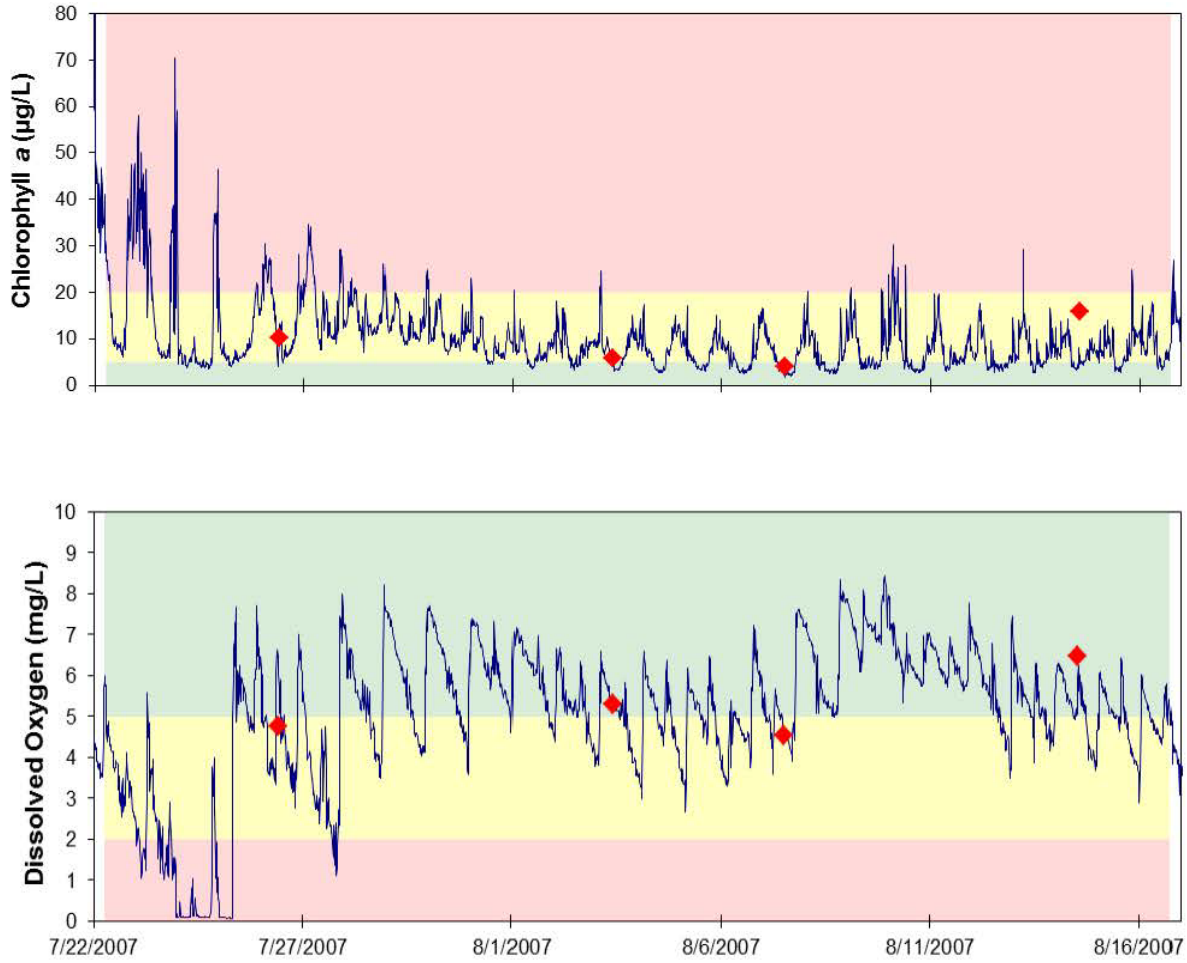


Figure 13. Continuous water-quality data from the 2007 assessment at CACO: Salt Pond Stratum. All measurements were made using a YSI6600EDS multiparameter sonde following the NCBN ENE protocol (Kopp and Neckles 2009). Continuous PAR measurements were not made at the Salt Pond logging station. Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN.

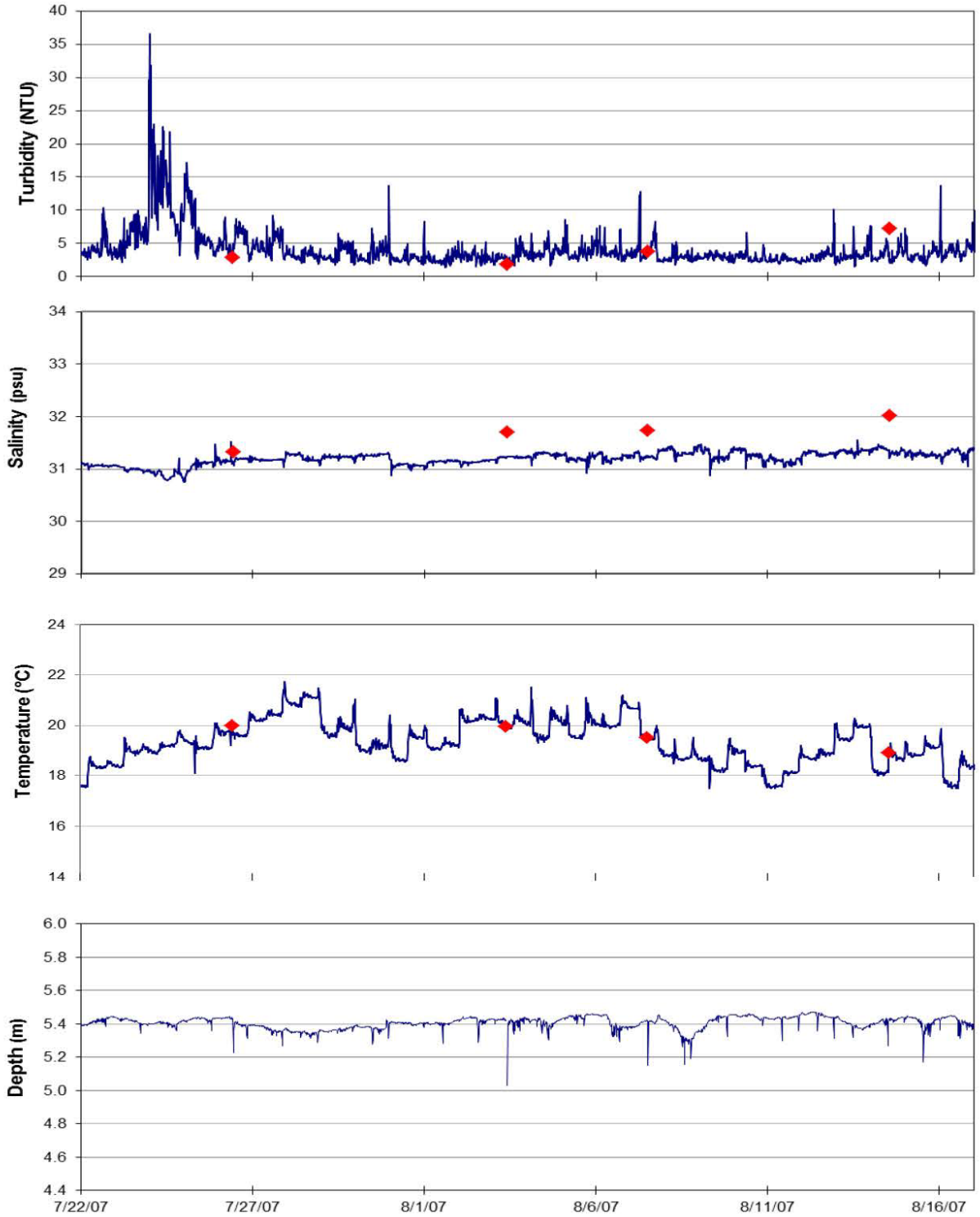


Figure 13 (cont.). Continuous water-quality data from the 2007 assessment at CACO: Salt Ponds Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 5. Trend-station water-quality data from the 2007 assessment at CACO.

		Trend Stations (Hexagon)					
Measure	**Statistic**	**3 (PB)**	**7 (PB)**	**11 (PB)**	**18 (NH)**	**23 (NH)**	**28 (NH)**
PAR attenuation	mean	0.71	0.62	2.51	2.04	1.21	1.37
(K_d (m^{-1}))	std.dev.	0.45	0.20	2.83	1.31	0.28	0.62
	n	2	3	3	4	4	4
Temperature	mean	16.25	21.95	25.18	22.68	20.34	19.26
(°C)	std.dev.	3.46	0.88	2.85	2.41	1.84	2.08
	n	4	4	3	3	4	4
Salinity	mean	32.07	31.73	31.55	31.48	31.77	31.81
(psu)	std.dev.	0.09	0.26	0.51	0.03	0.17	0.34
	n	4	4	3	3	4	4
Dissolved oxygen	mean	8.8	7.7	7.8	8.0	7.7	8.0
(mg/L)	std.dev.	0.6	0.4	1.4	1.3	0.7	0.6
	n	4	4	4	4	4	4
Turbidity	mean	0.4	1.0	0.7	2.4	2.7	1.8
(NTU)	std.dev.	0.1	0.3	0.6	0.7	0.8	0.7
	n	4	4	3	3	4	4
Chlorophyll *a*	mean	3.7	5.1	2.5	10.4	9.9	5.3
(µg/L)	std.dev.	0.8	1.9	0.9	1.5	4.7	4.9
	n	4	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Locations of hexagons with trend stations are shown in Figure 2. Stations 3, 7, and 11 are in the Pleasant Bay stratum (PB); stations 18, 23, and 28 are in the Nauset Harbor stratum (NH).]

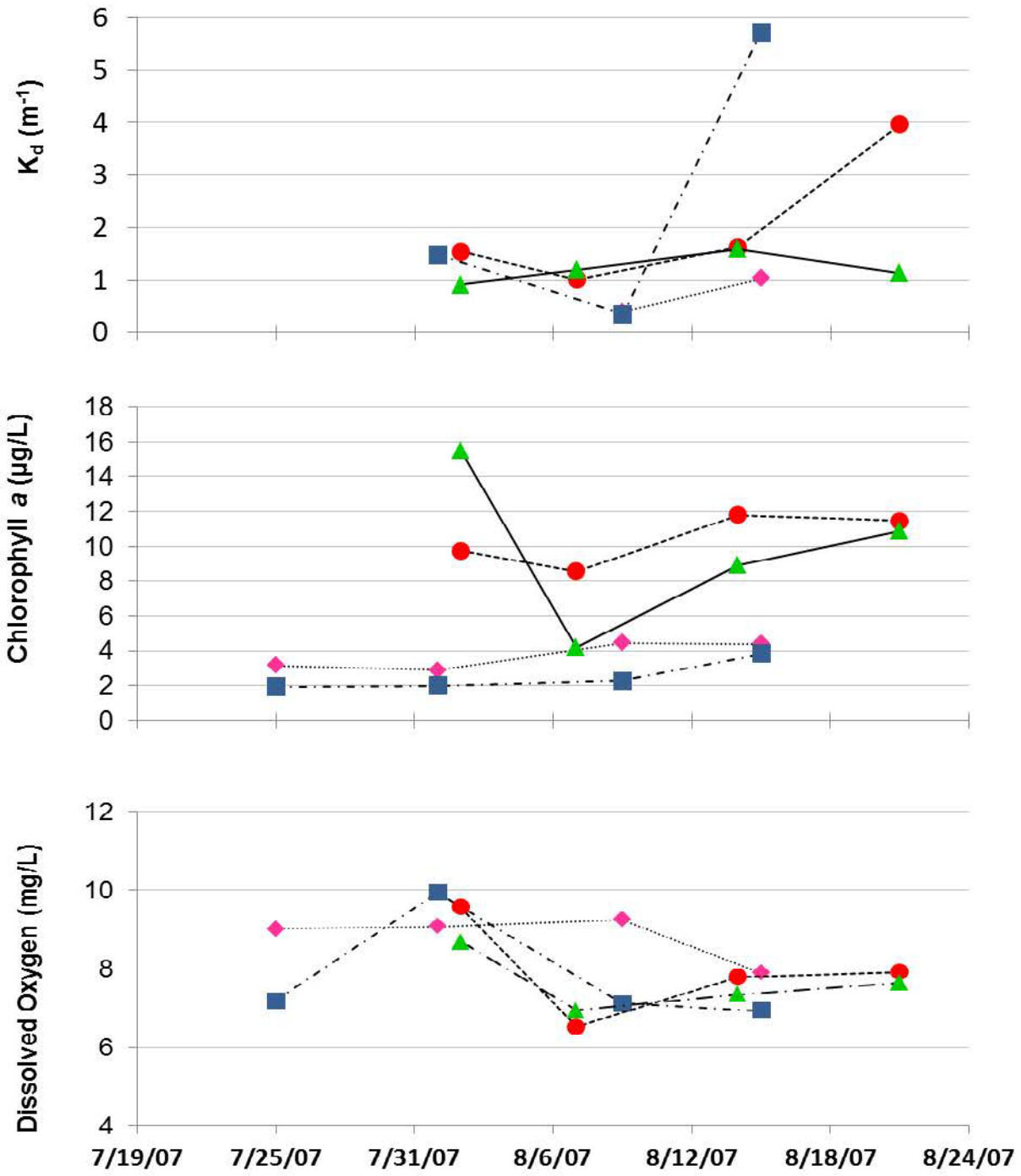


Figure 14. Trend Station water-quality data from the 2007 assessment at CACO. Trend data depicted are derived from selected trend stations representative of an upper estuary and lower estuary station located in both Pleasant Bay and Nauset Harbor Stratums. The blue square (■) and pink diamond (♦) represent hexagons 11 and 3 in the upper and lower portions of Pleasant Bay, respectively. The red circle (●) and green triangle (▲) represent hexagons 18 and 23 in the upper and lower portions of Nauset Harbor. No trend stations were assigned to the Salt Pond Stratum.

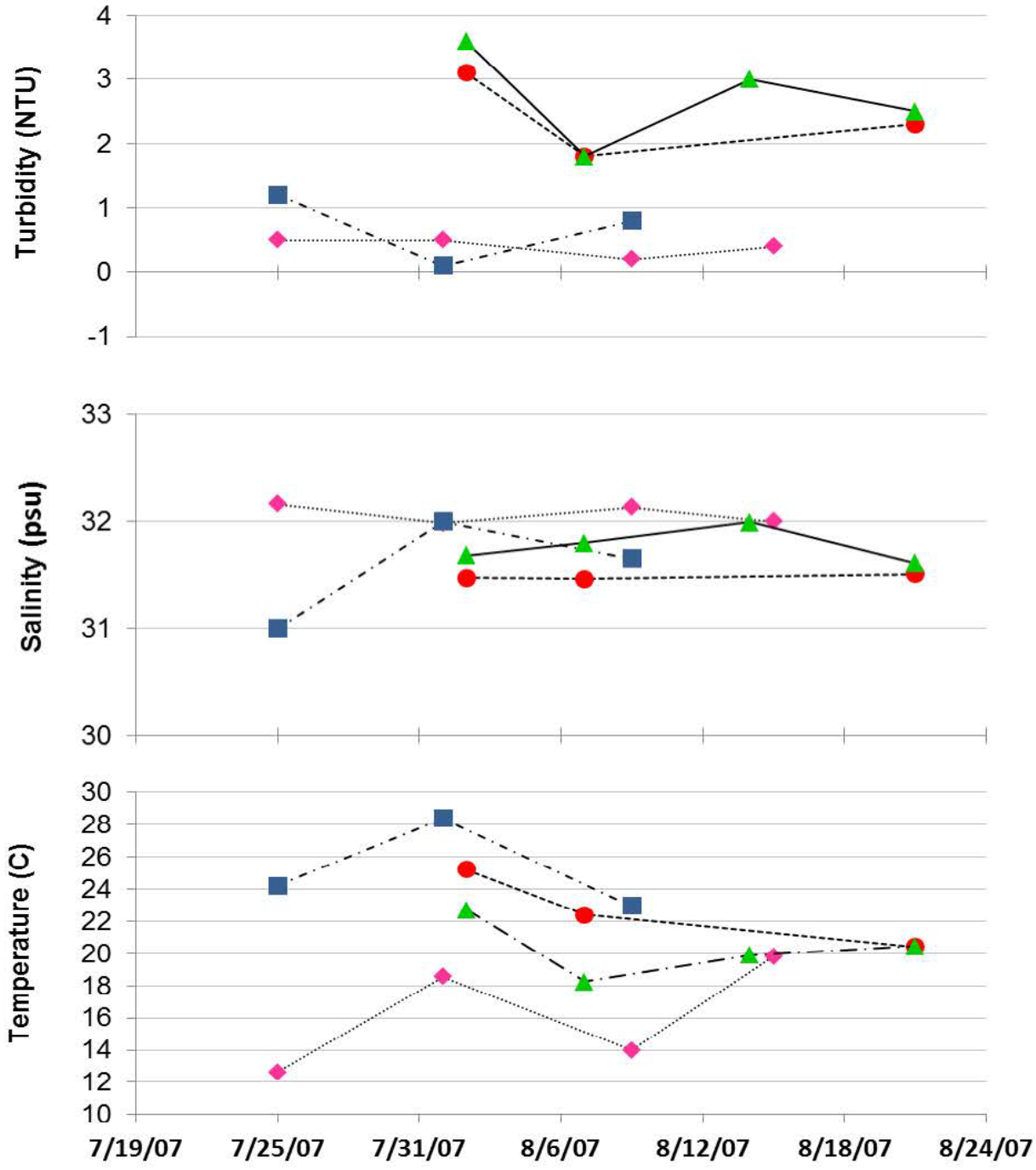


Figure 14 (cont.). Trend Station water-quality data from the 2007 assessment at CACO. Trend data depicted are derived from selected trend stations representative of an upper estuary and lower estuary station located in both Pleasant Bay and Nauset Harbor Stratums. The blue square (■) and pink diamond (♦) represent hexagons 11 and 3 in the upper and lower portions of Pleasant Bay, respectively. The red circle (●) and green triangle (▲) represent hexagons 18 and 23 in the upper and lower portions of Nauset Harbor. No trend stations were assigned to the Salt Pond Stratum.

2008 Index Period

Table 6. Area-Weighted average water-quality condition at CACO during the 2008 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	0.80	- -	- -	- -
Dissolved oxygen (mg/L)	- -	7.03	6.93	6.79
Dissolved oxygen, % Saturation	- -	95.33	94.70	92.19
Chlorophyll *a* (µg/L)	- -	6.24	- -	- -
Turbidity (NTU)	- -	1.59	1.36	5.75
Temperature (°C)	- -	21.40	21.87	21.53
Salinity (psu)	- -	32.23	32.24	32.23

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

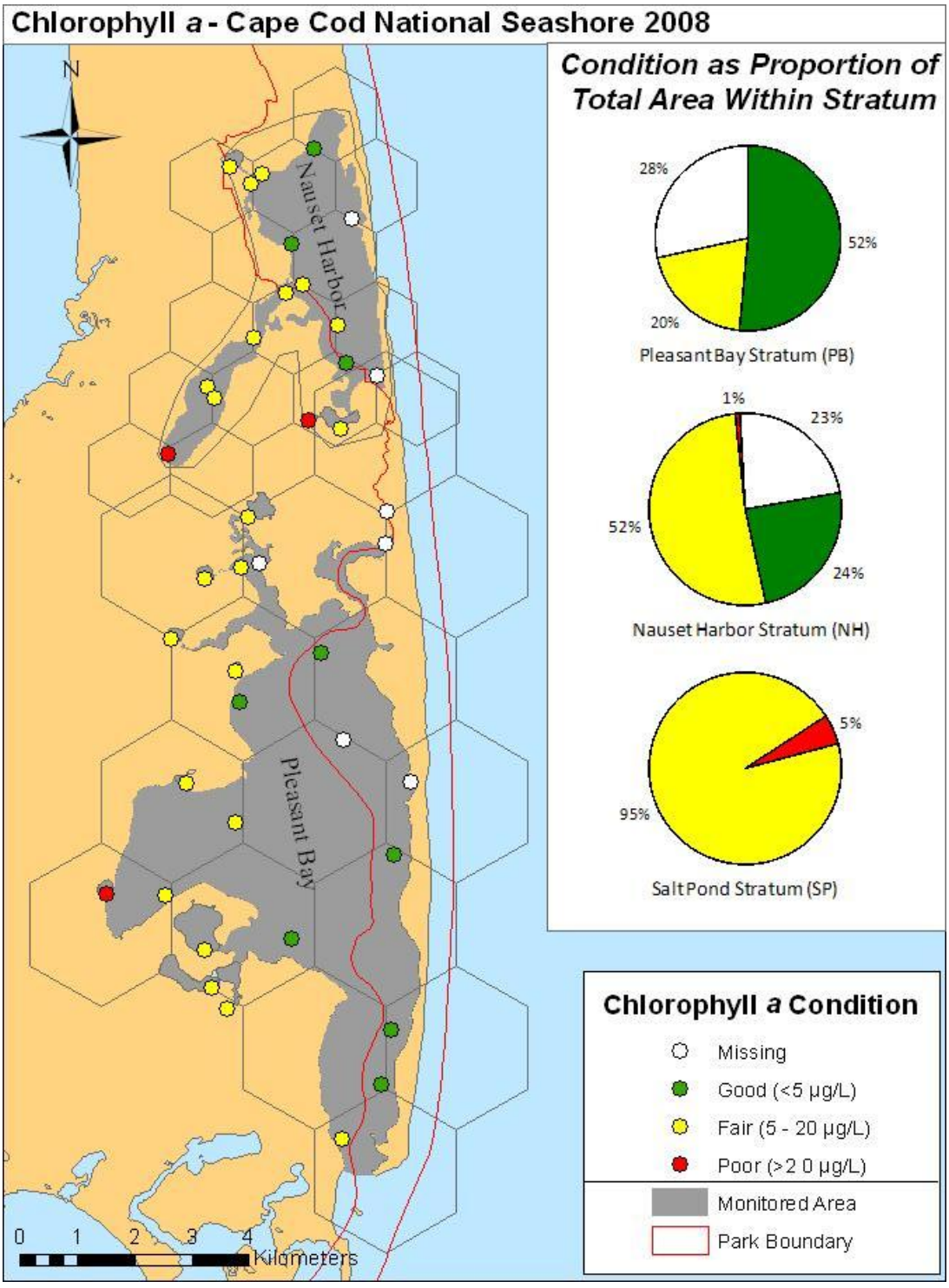


Figure 15. Chlorophyll *a* (µg/L) concentration in surface samples from the 2008 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

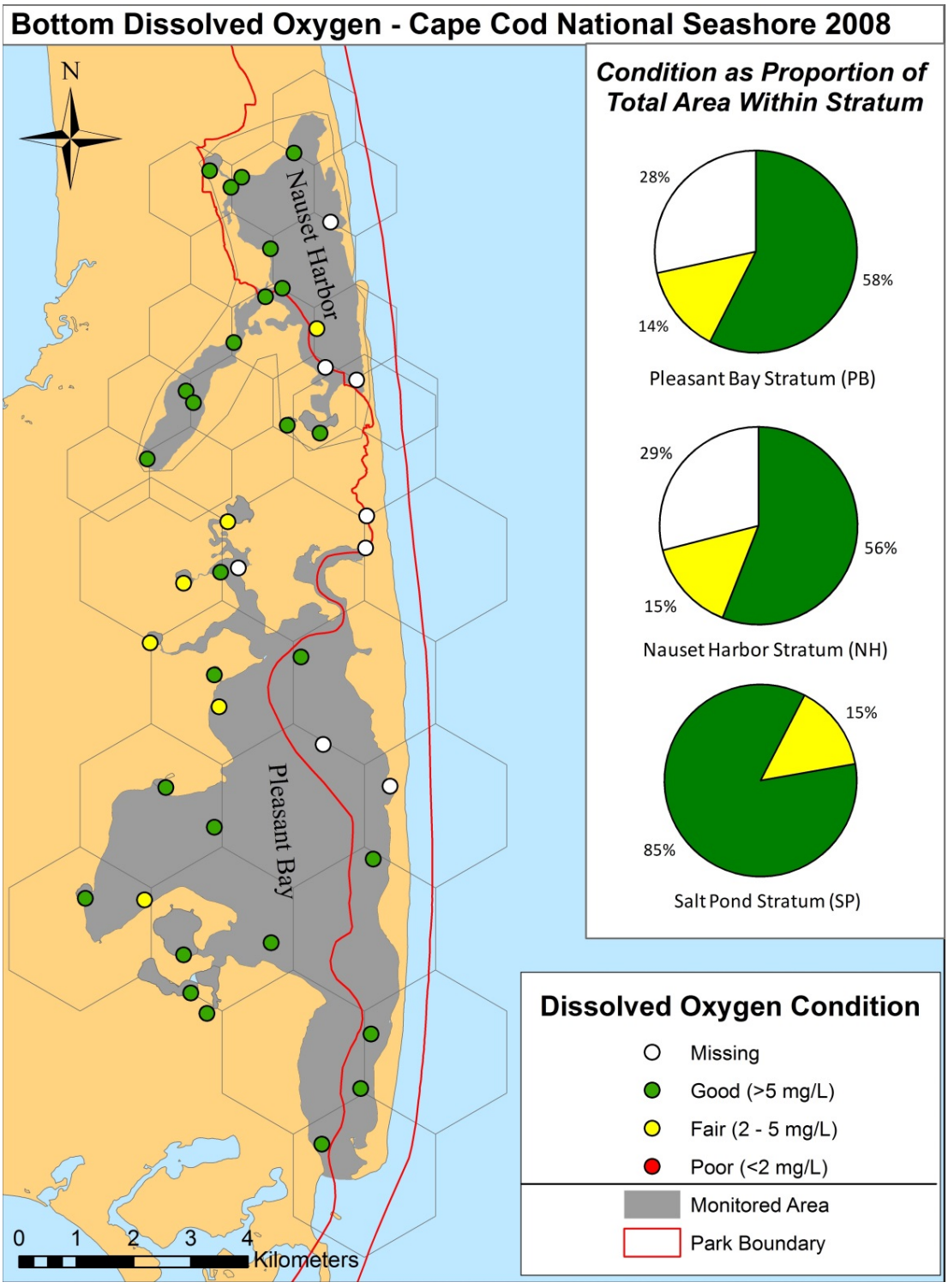


Figure 16. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2008 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

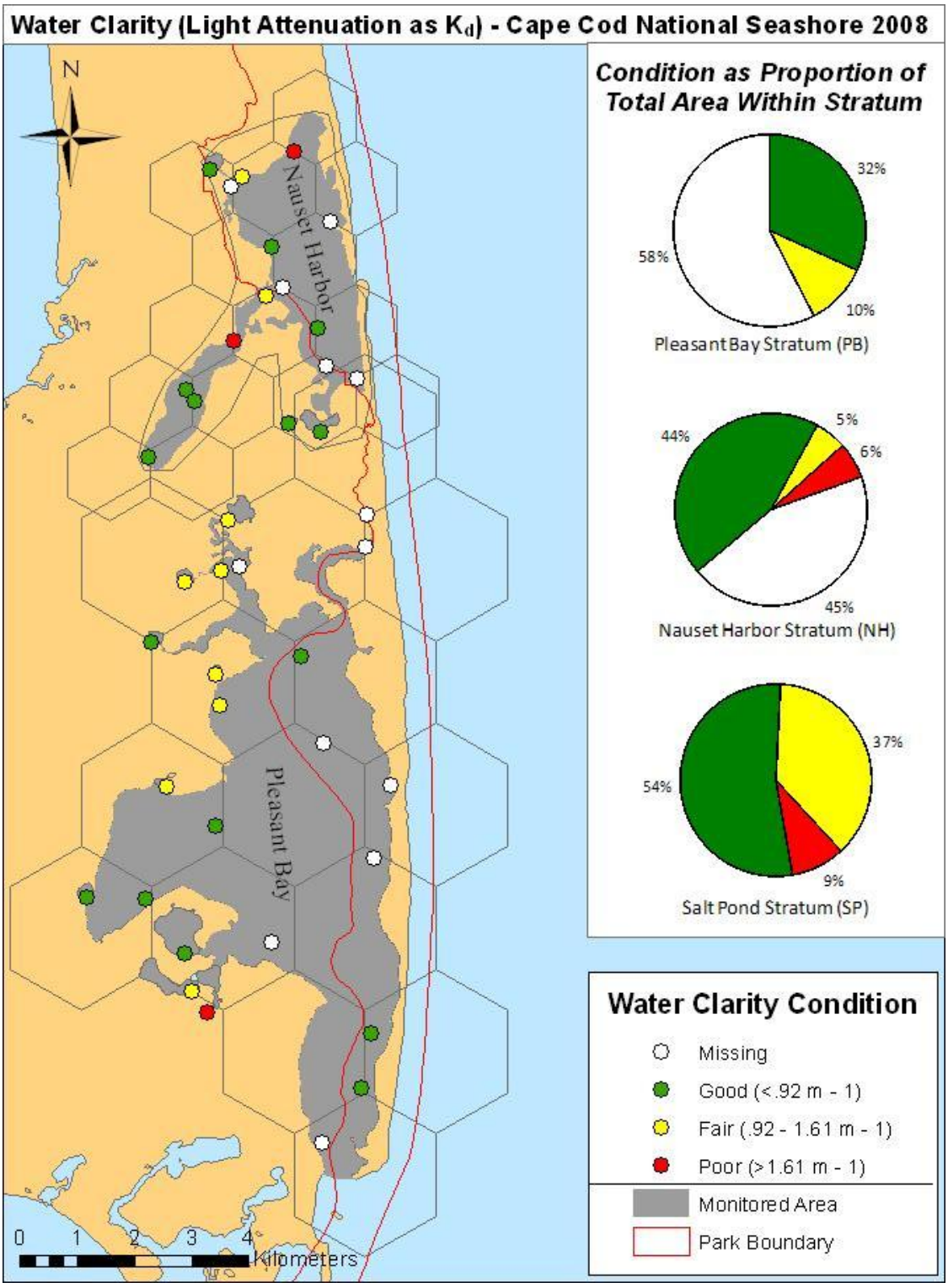


Figure 17. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2008 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

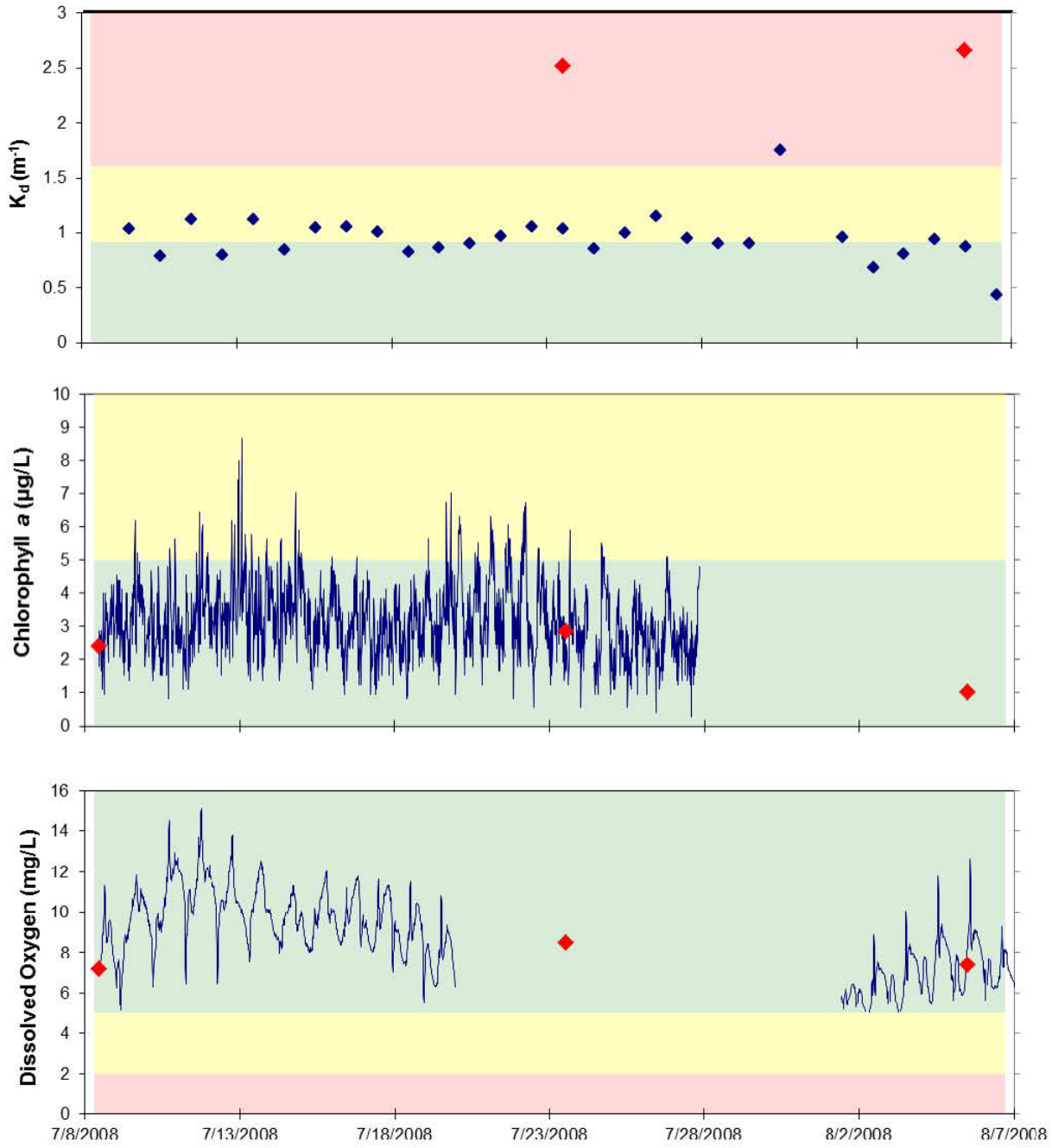


Figure 18. Continuous water-quality data from the 2008 assessment at CACO: Pleasant Bay Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN.

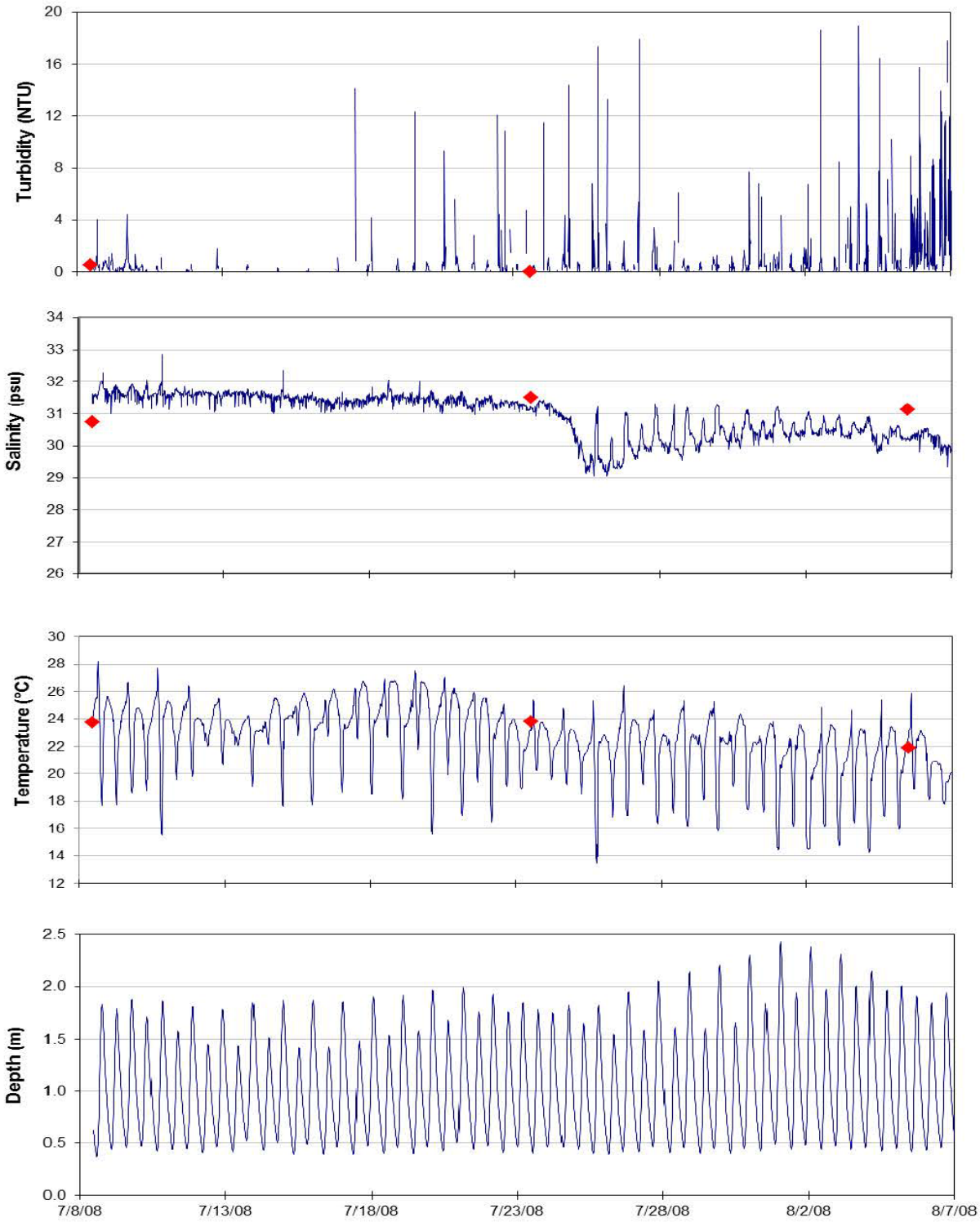


Figure 18 (cont.). Continuous water-quality data from the 2008 assessment at CACO: Pleasant Bay Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

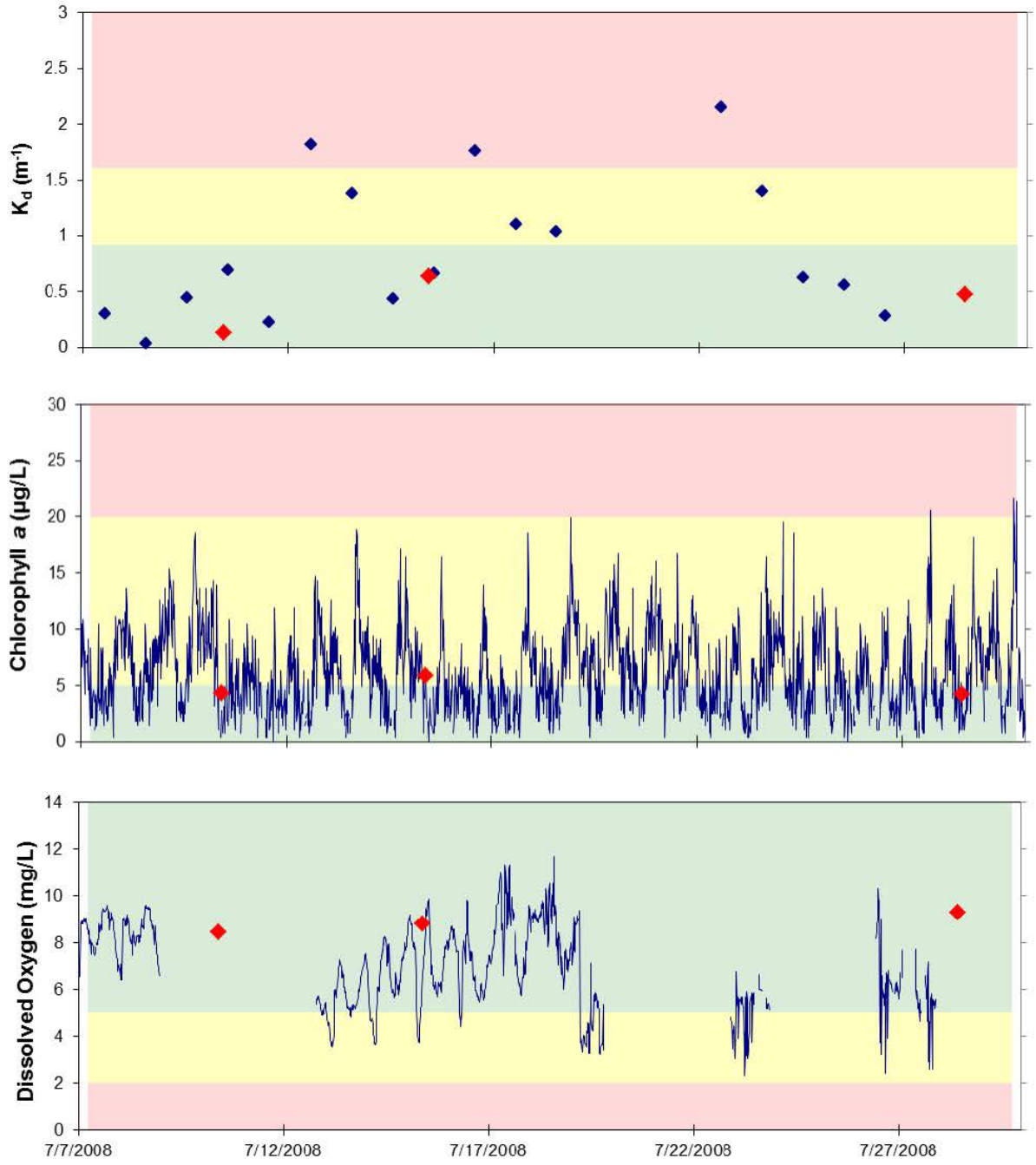


Figure 19. Continuous water-quality data from the 2008 assessment at CACO: Nauset Harbor Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

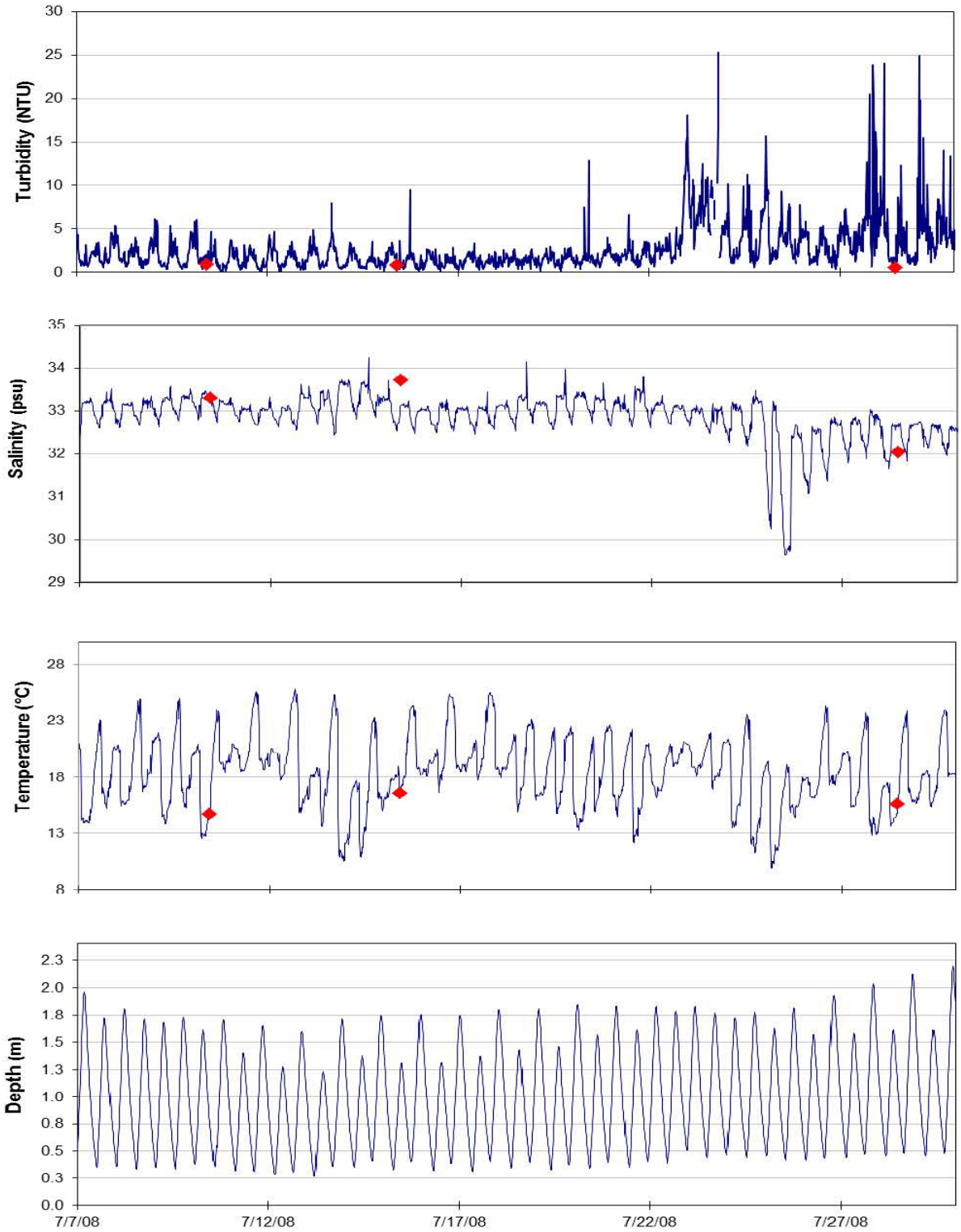


Figure 19 (cont.). Continuous water-quality data from the 2008 assessment at CACO: Nauset Harbor Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

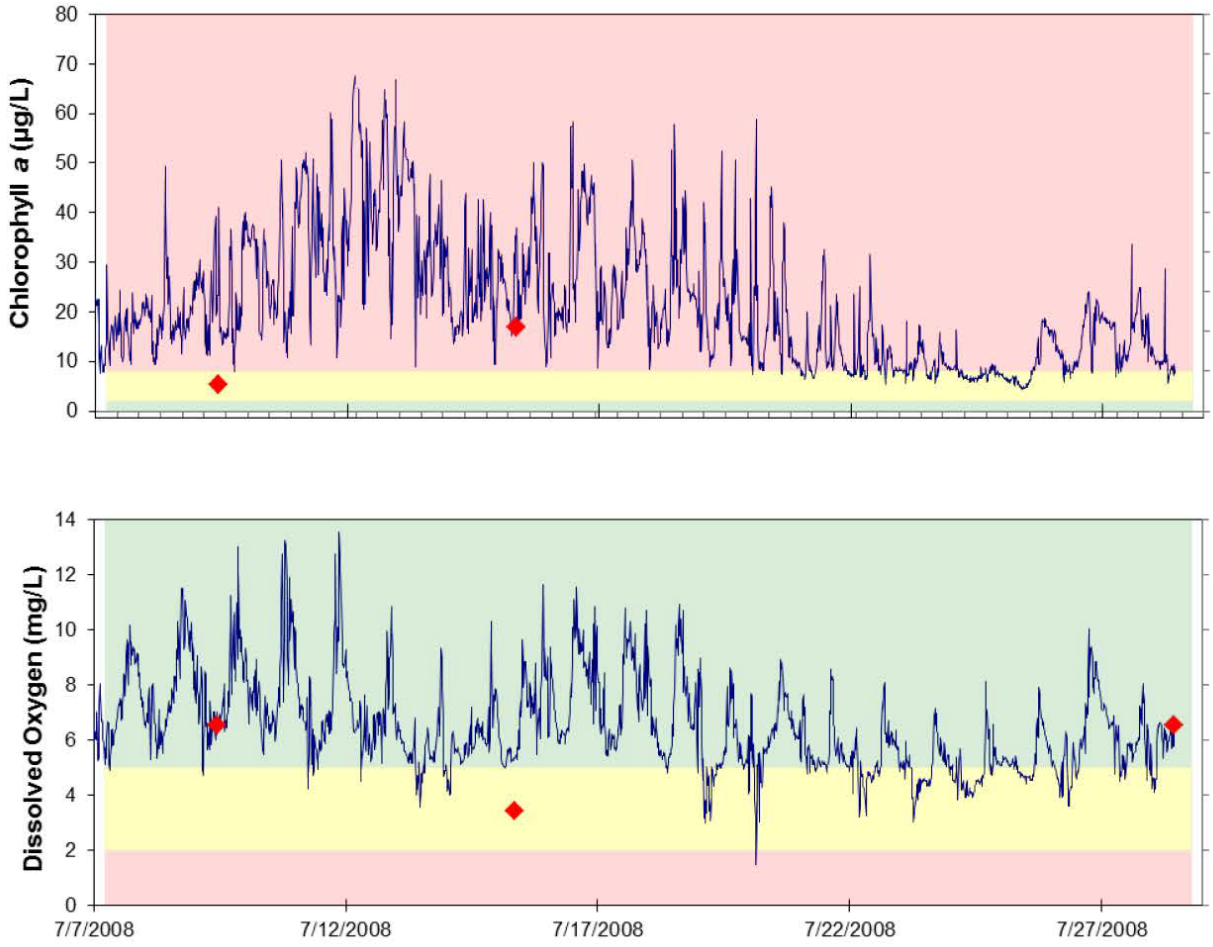


Figure 20. Continuous water-quality data from the 2008 assessment at CACO: Salt Ponds Stratum. All measurements were made using a YSI6600EDS multiparameter sonde following the NCBN ENE protocol (Kopp and Neckles 2009). Continuous PAR measurements were not made at the Salt Pond logging station. Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

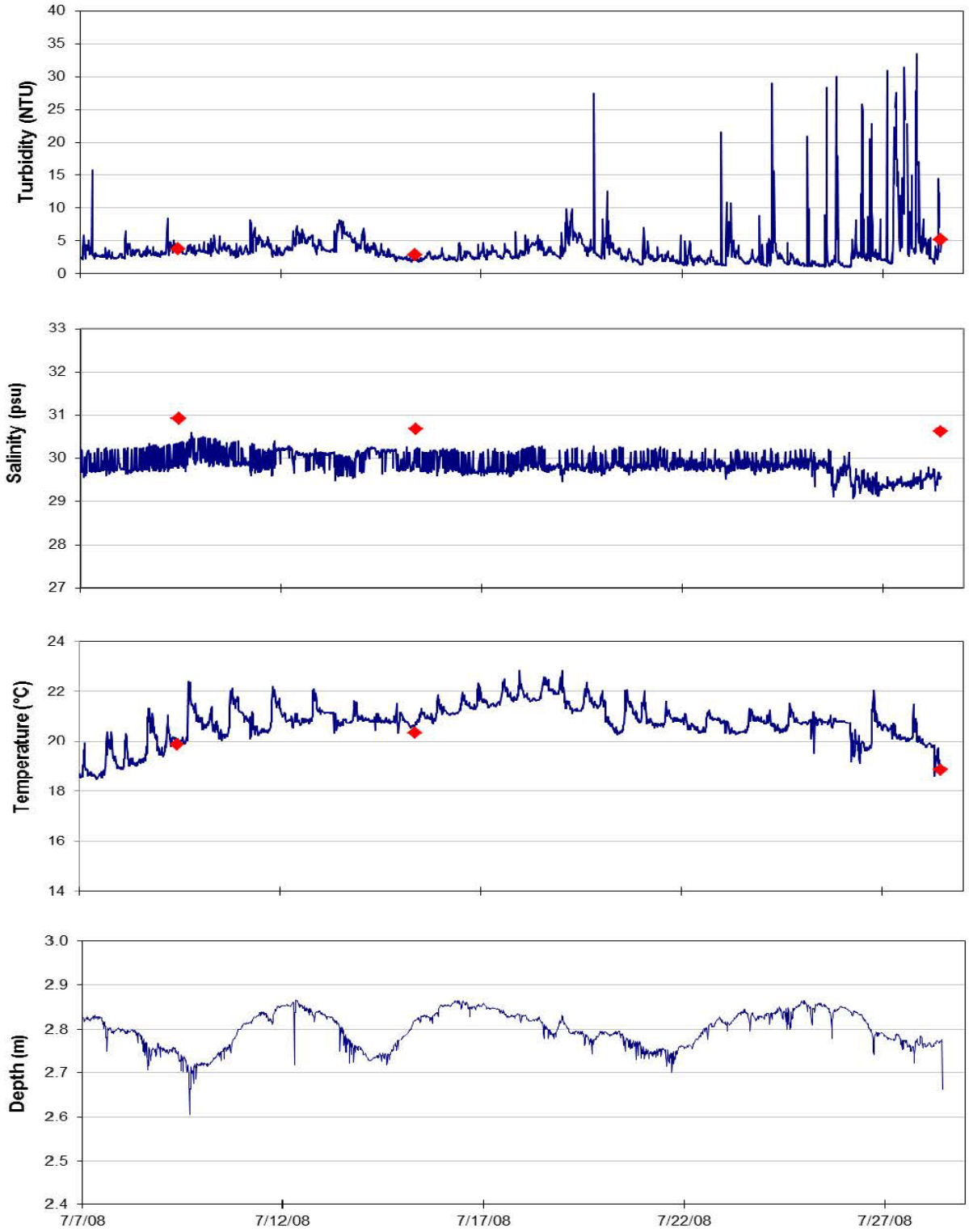


Figure 20 (cont.). Continuous water-quality data from the 2008 assessment at CACO: Salt Ponds Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 7. Trend-station water-quality data from the 2008 assessment at CACO.

		Trend Stations (Hexagons)					
Measure	**Statistic**	**3 (PB)**	**7 (PB)**	**11 (PB)**	**18 (NH)**	**23 (NH)**	**28 (NH)**
PAR attenuation	mean	0.92	1.68	1.66	1.18	1.45	1.52
(K_d (m^{-1}))	std.dev.	0.07	1.53	1.90	0.47	0.45	N/A
	n	2	3	3	3	3	1
Temperature	mean	19.74	22.03	25.01	22.03	21.17	19.04
(°C)	std.dev.	1.36	1.54	1.68	0.53	1.62	4.01
	n	3	3	4	3	3	2
Salinity	mean	32.01	32.42	32.91	30.86	32.19	31.56
(psu)	std.dev.	0.46	0.29	1.01	0.16	0.53	0.93
	n	3	3	4	3	3	2
Dissolved oxygen	mean	7.7	7.2	5.9	6.8	6.4	8.3
(mg/L)	std.dev.	0.4	1.0	0.4	0.2	1.4	0.3
	n	3	3	4	3	3	2
Turbidity	mean	1.0	1.2	1.8	4.6	1.7	6.9
(NTU)	std.dev.	0.3	0.5	1.1	5.0	0.3	7.7
	n	3	3	4	3	3	2
Chlorophyll *a*	mean	3.3	5.7	6.1	11.7	8.5	6.6
(µg/L)	std.dev.	1.1	2.2	3.2	4.1	2.0	3.5
	n	3	2	4	4	3	2

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Locations of hexagons with trend stations shown in Figure 2 Stations 3, 7, and 11 are in the Pleasant Bay stratum (PB); stations 18, 23, and 28 are in the Nauset Harbor stratum (NH).]

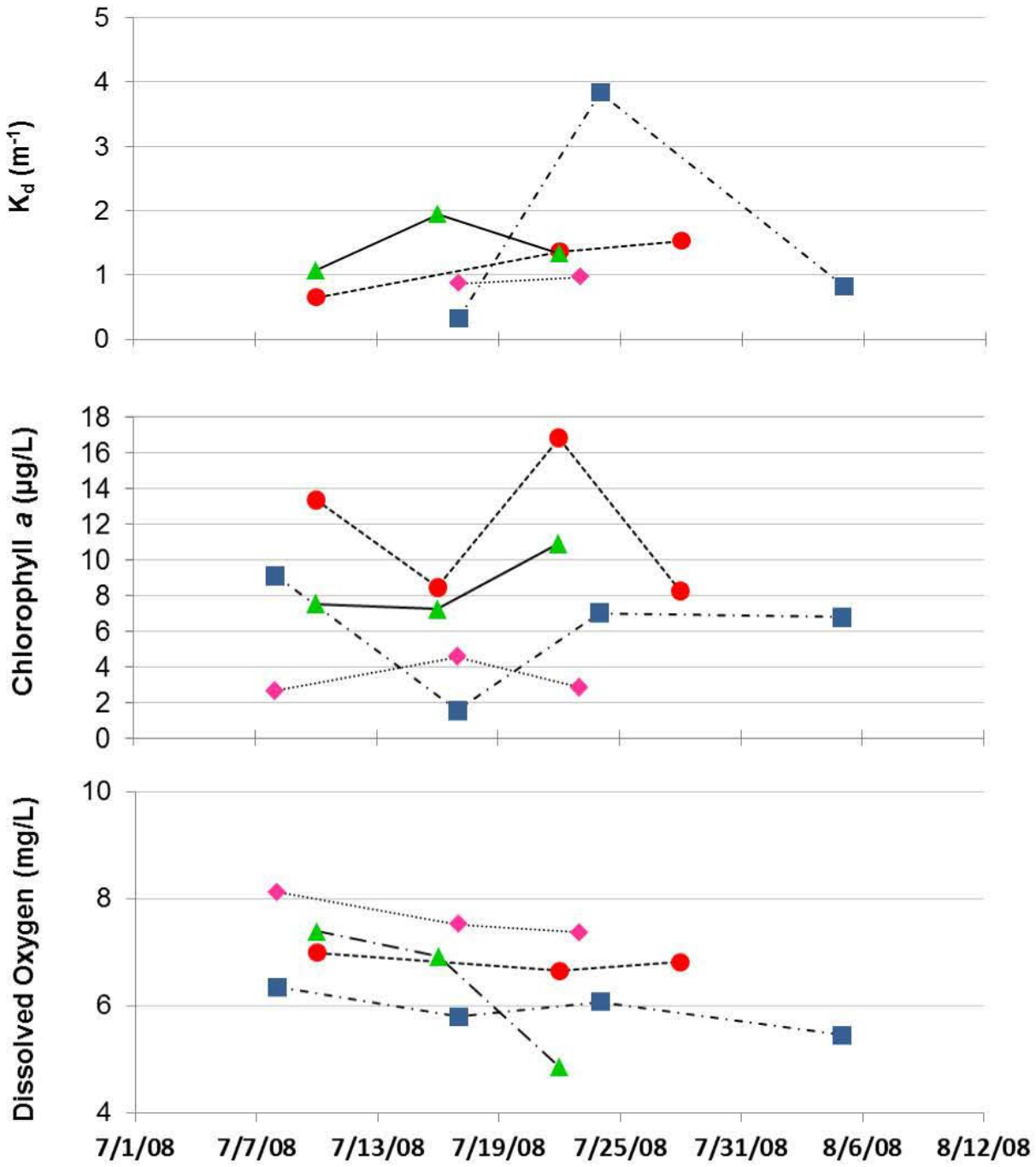


Figure 21. Trend Station water-quality data from the 2008 assessment at CACO. Trend data depicted are derived from selected trend stations representative of an upper estuary and lower estuary station located in both Pleasant Bay and Nauset Harbor Stratums. The blue square (■) and pink diamond (♦) represent hexagons 11 and 3 in the upper and lower portions of Pleasant Bay, respectively. The red circle (●) and green triangle (▲) represent hexagons 18 and 23 in the upper and lower portions of Nauset Harbor. No trend stations were assigned to the Salt Pond Stratum.

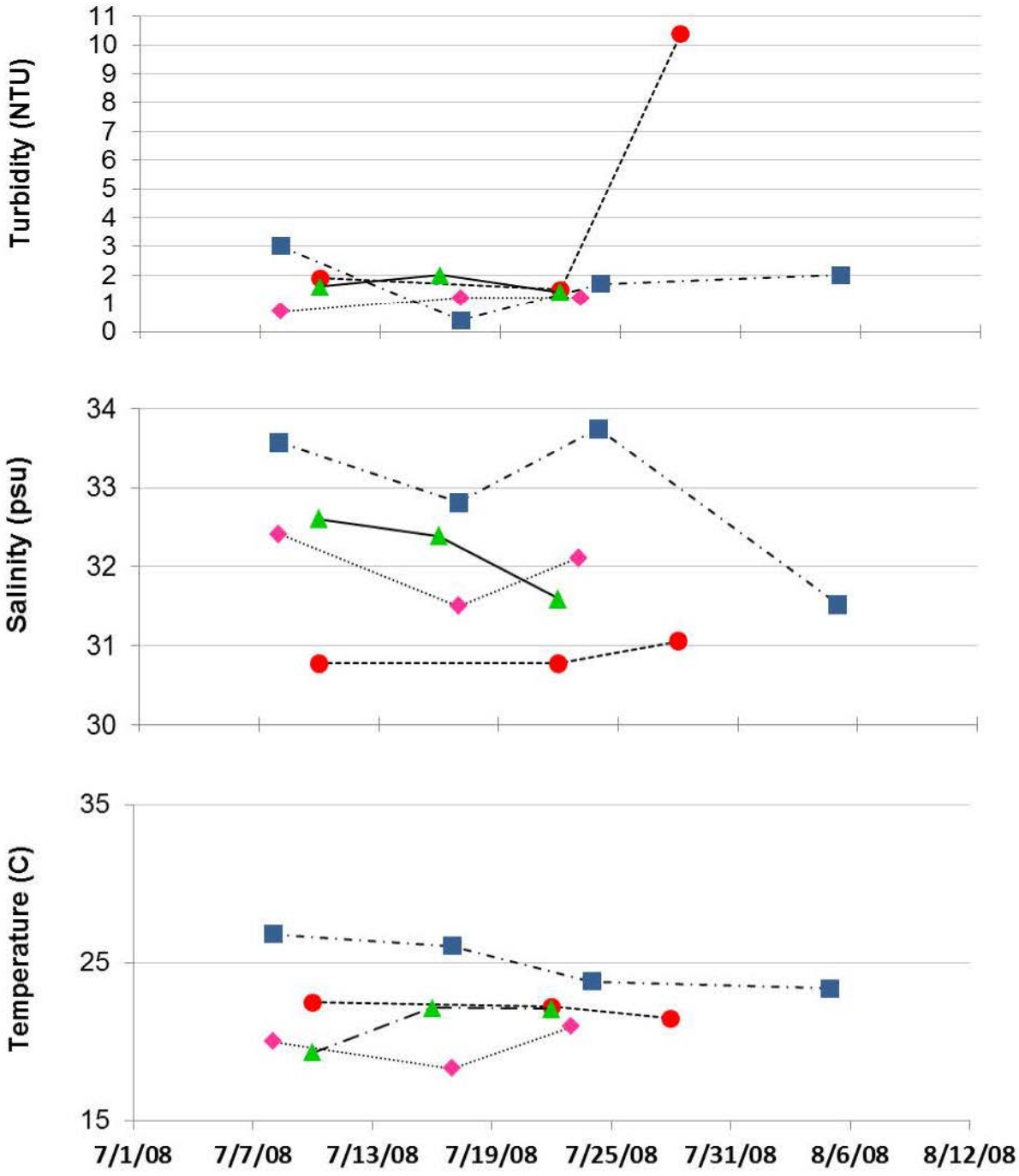


Figure 21 (cont.). Trend Station water-quality data from the 2008 assessment at CACO. Trend data depicted are derived from selected trend stations representative of an upper estuary and lower estuary station located in both Pleasant Bay and Nauset Harbor Stratums. The blue square (■) and pink diamond (♦) represent hexagons 11 and 3 in the upper and lower portions of Pleasant Bay, respectively. The red circle (●) and green triangle (▲) represent hexagons 18 and 23 in the upper and lower portions of Nauset Harbor. No trend stations were assigned to the Salt Pond Stratum.

2009 Index Period

Table 8. Area-Weighted average water-quality condition at CACO during the 2009 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	0.85	- -	- -	- -
Dissolved oxygen (mg/L)	- -	6.80	6.39	6.73
Dissolved oxygen, % Saturation	- -	93.62	88.32	91.60
Chlorophyll *a* (µg/L)	- -	7.63	- -	- -
Turbidity (NTU)	- -	1.58	1.71	2.08
Temperature (°C)	- -	21.34	21.73	20.57
Salinity (psu)	- -	31.27	31.37	31.42

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

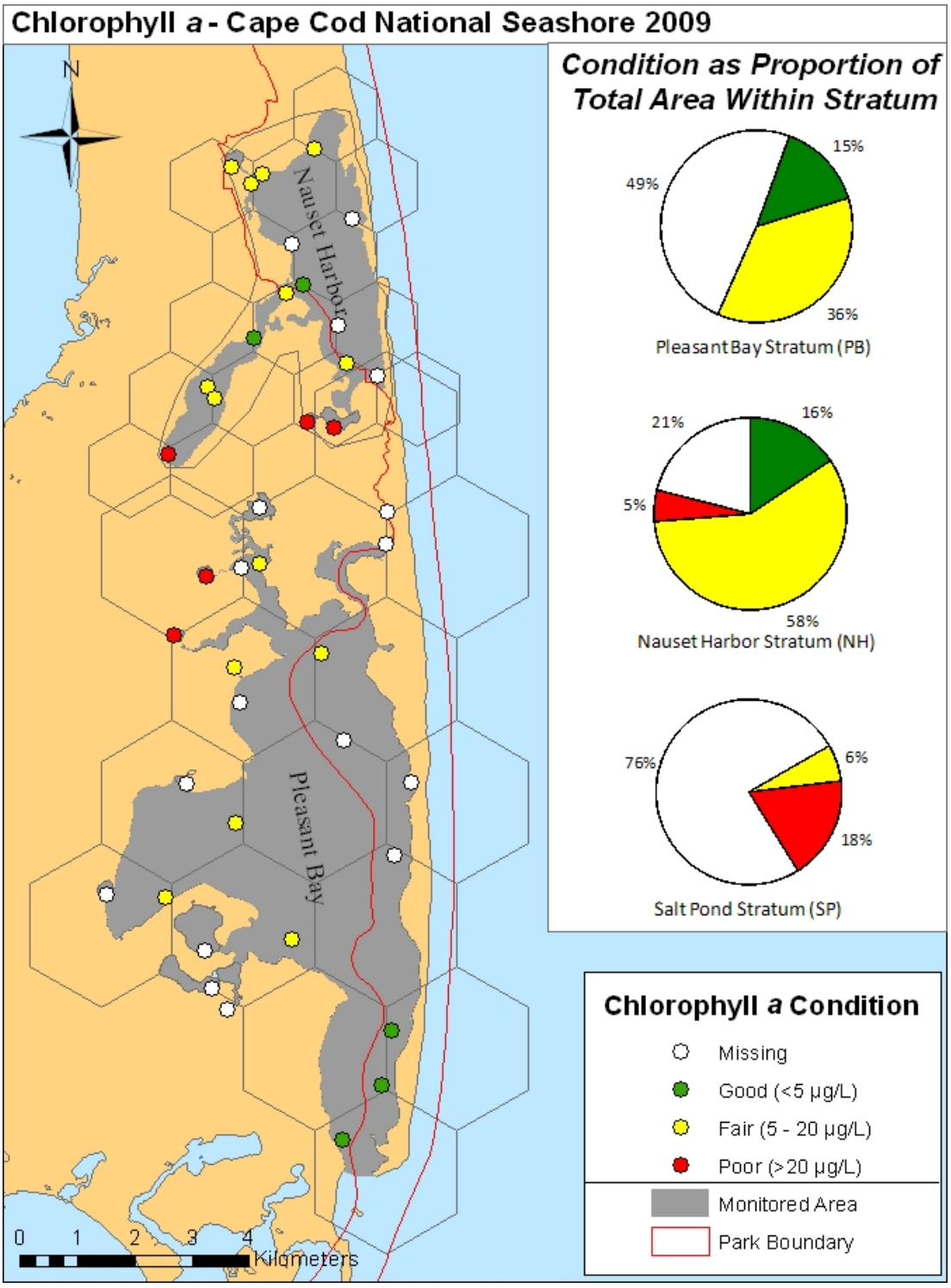


Figure 22. Chlorophyll *a* (µg/L) concentration in surface samples from the 2009 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

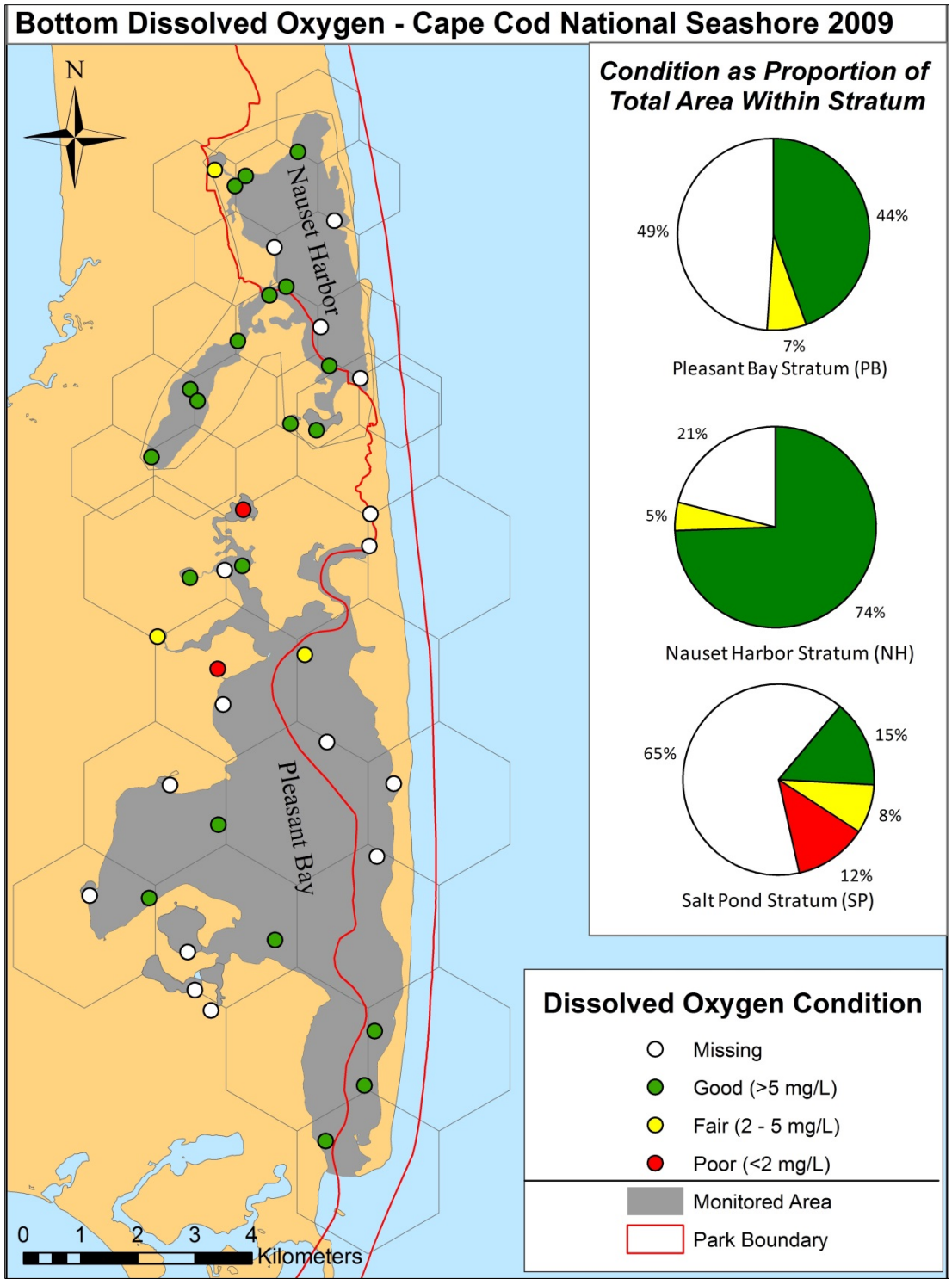


Figure 23. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2009 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

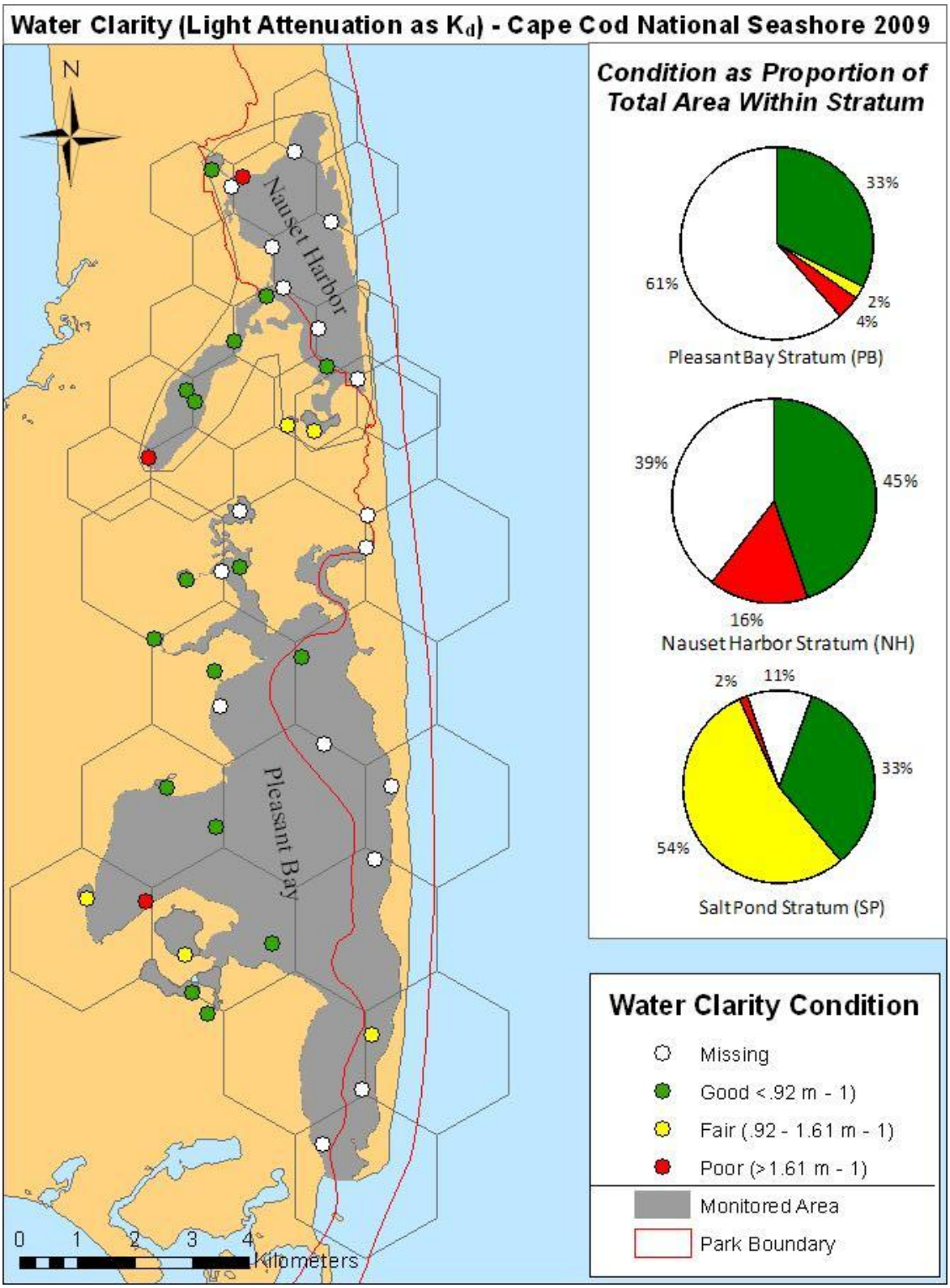


Figure 24. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2009 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

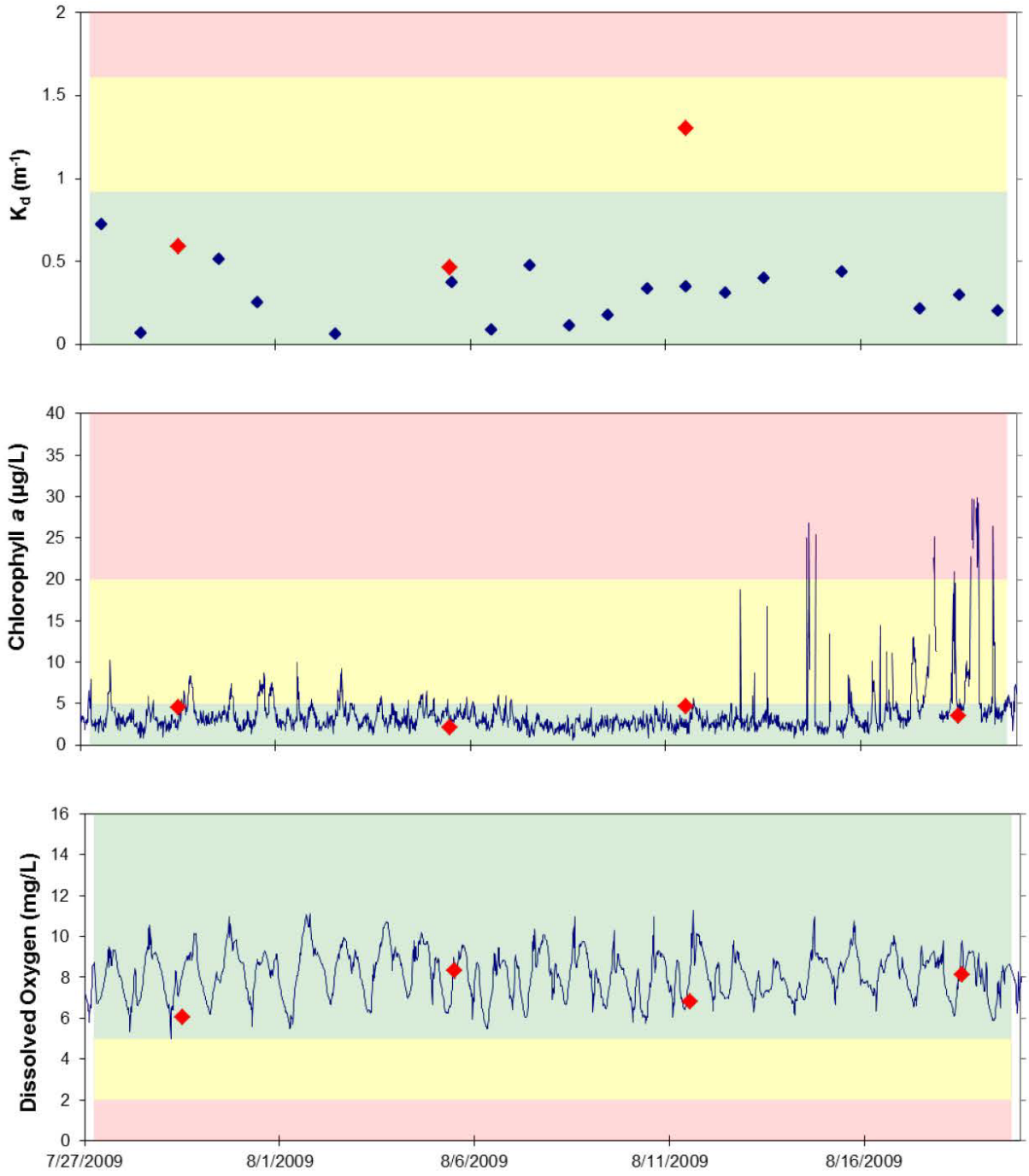


Figure 25. Continuous water-quality data from the 2009 assessment at CACO: Pleasant Bay Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN.

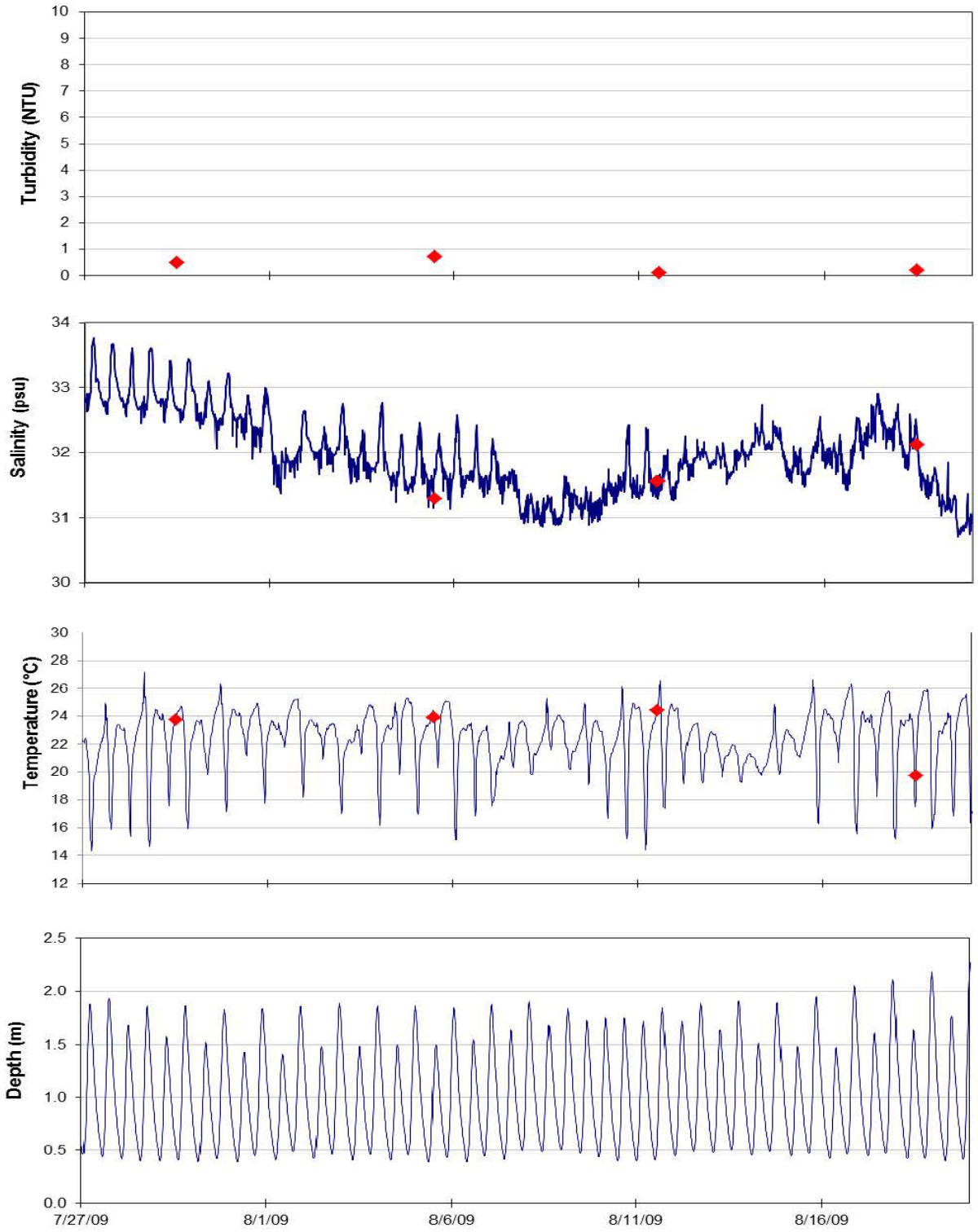


Figure 25 (cont.). Continuous water-quality data from the 2009 assessment at CACO: Pleasant Bay Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

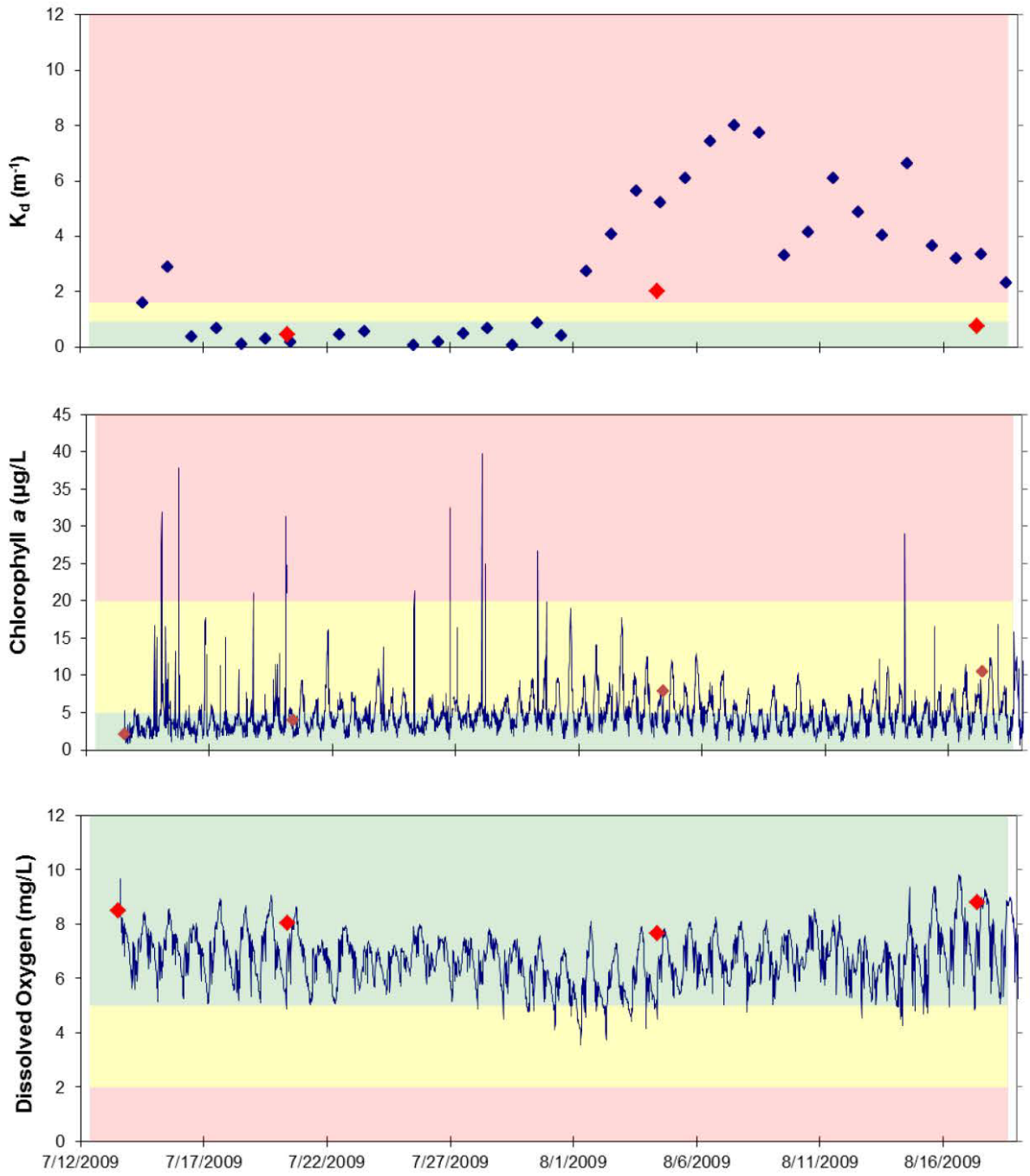


Figure 26. Continuous water-quality data from the 2009 assessment at CACO: Nauset Harbor Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

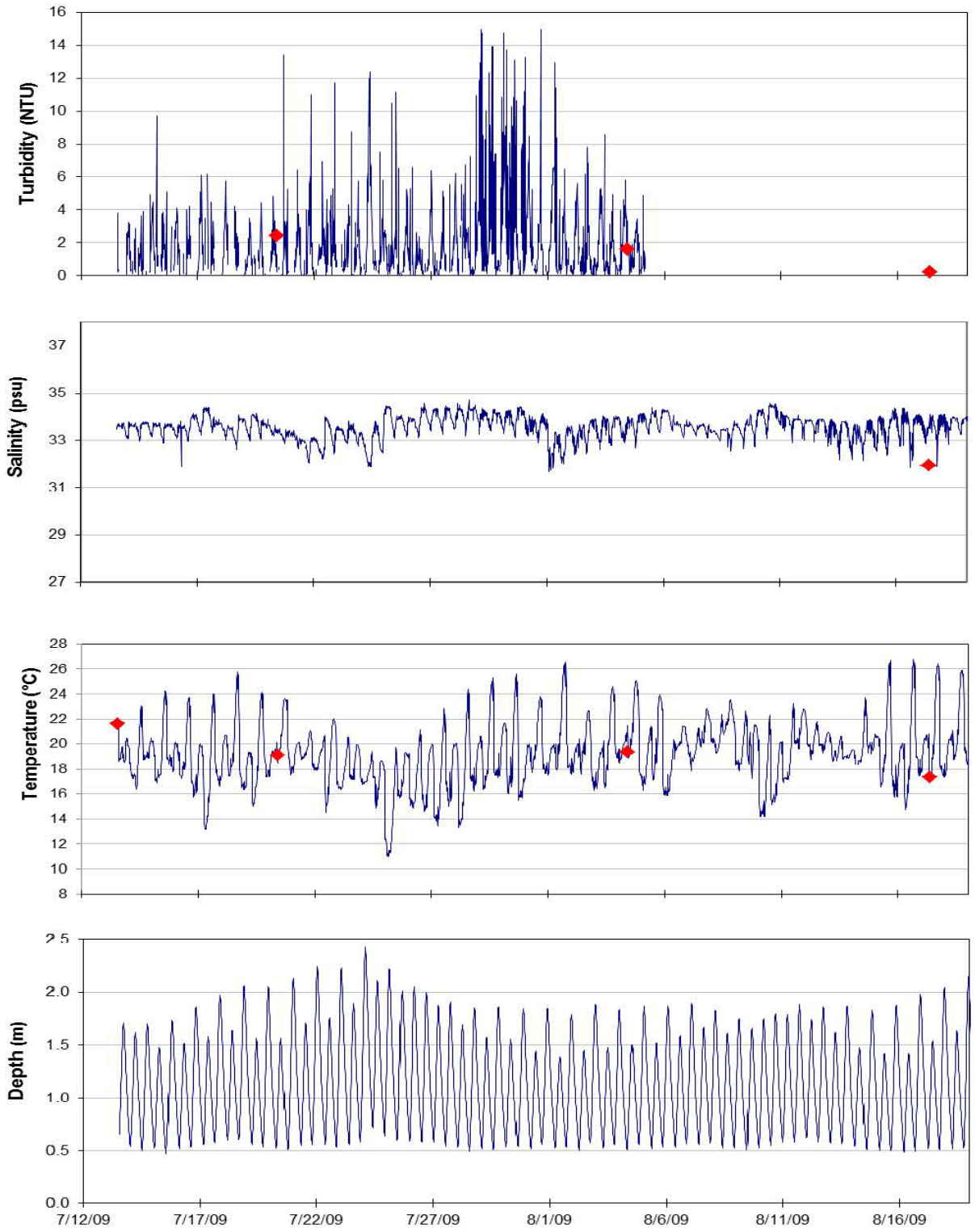


Figure 26 (cont.). Continuous water-quality data from the 2009 assessment at CACO: Nauset Harbor Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

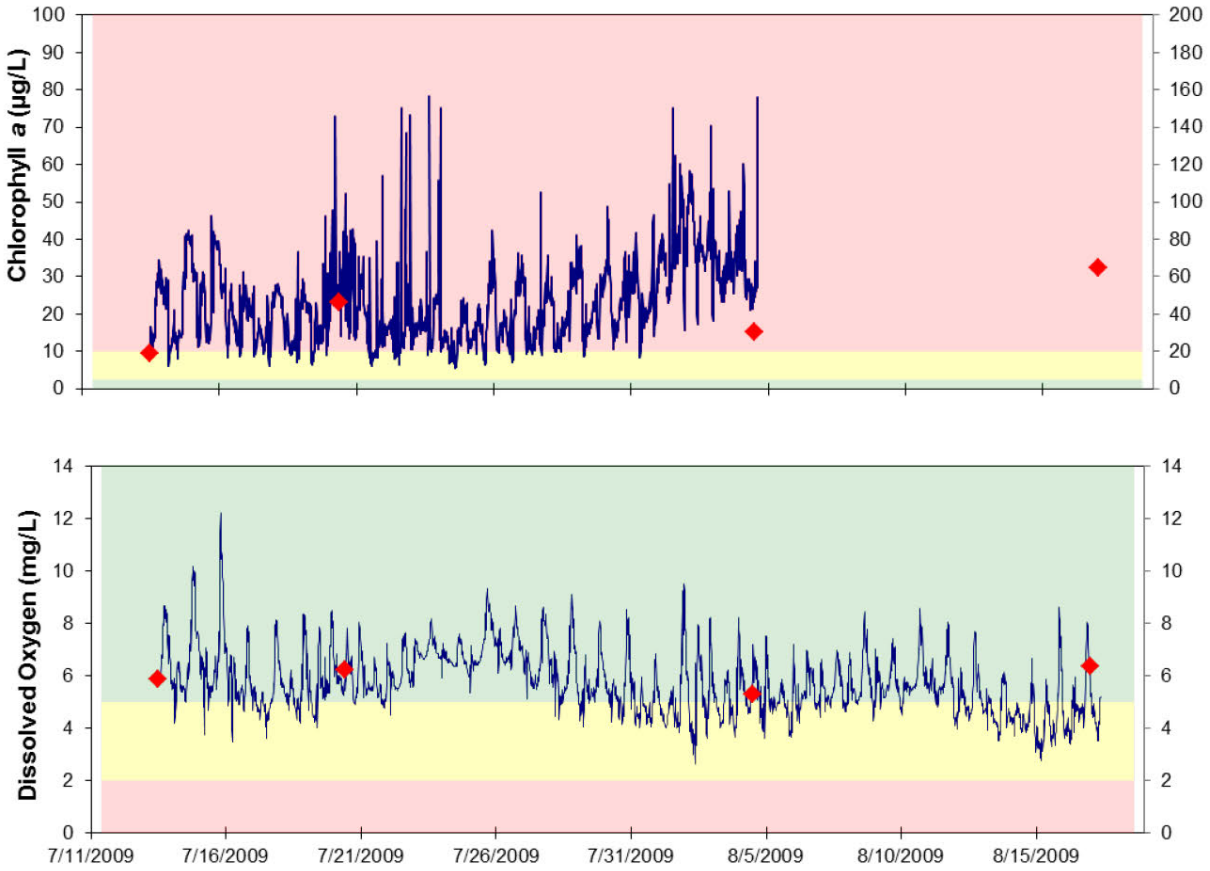


Figure 27. Continuous water-quality data from the 2009 assessment at CACO: Salt Ponds Stratum. All measurements were made using a YSI6600EDS multiparameter sonde following the NCBN ENE protocol (Kopp and Neckles 2009). Continuous PAR measurements were not made at the Salt Pond logging station. Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

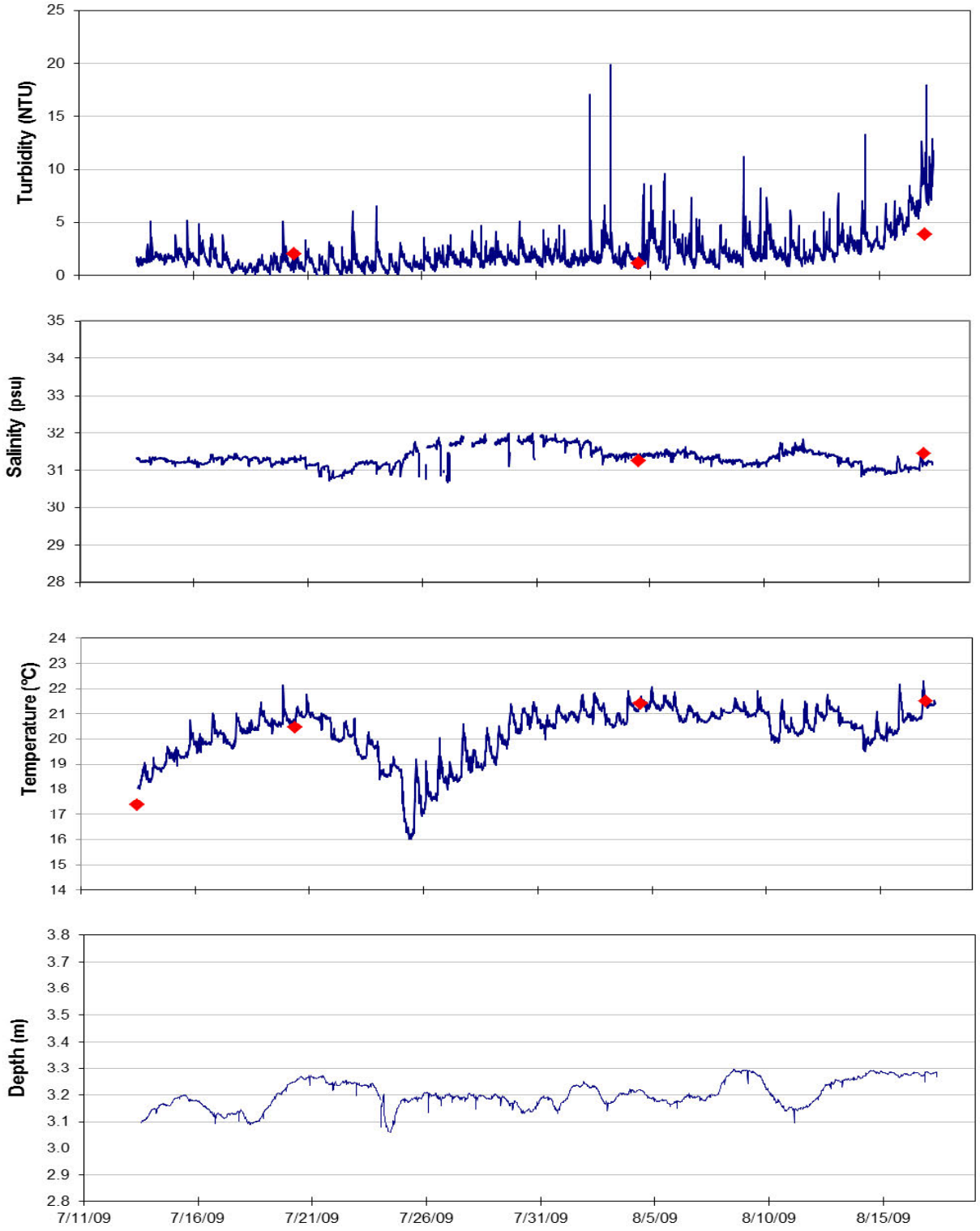


Figure 27 (cont.). Continuous water-quality data from the 2009 assessment at CACO: Salt Ponds Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 9. Trend-station water-quality data from the 2009 assessment at CACO.

		Trend Stations (Hexagons)					
Measure	**Statistic**	**3 (PB)**	**7 (PB)**	**11 (PB)**	**18 (NH)**	**23 (NH)**	**28 (NH)**
PAR attenuation	mean	0.67	0.80	0.24	0.46	1.06	4.58
(K_d (m^{-1}))	std.dev.	0.46	0.79	0.05	N/A	0.70	N/A
	n	4	3	2	1	3	1
Temperature	mean	18.61	21.91	25.12	22.45	20.08	21.60
(°C)	std.dev.	1.93	1.09	0.78	0.93	2.12	1.13
	n	4	4	4	4	4	4
Salinity	mean	31.71	31.43	31.25	31.90	31.65	31.60
(psu)	std.dev.	0.11	0.30	0.38	1.47	0.45	0.14
	n	3	3	3	3	2	2
Dissolved oxygen	mean	7.5	6.6	5.8	7.4	7.7	6.7
(mg/L)	std.dev.	0.5	0.9	1.5	0.8	1.7	1.3
	n	4	4	4	4	4	4
Turbidity	mean	0.1	0.5	2.4	3.4	1.6	5.0
(NTU)	std.dev.	0.1	0.5	2.8	1.4	1.7	1.4
	n	4	4	4	4	4	4
Chlorophyll *a*	mean	4.2	7.7	10.0	13.2	9.4	12.5
(µg/L)	std.dev.	1.6	4.5	11.4	4.1	3.7	7.7
	n	4	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Locations of hexagons with trend stations are shown in Figure 2. Stations 3, 7, and 11 are in the Pleasant Bay stratum (PB); stations 18, 23, and 28 are in the Nauset Harbor stratum (NH).]

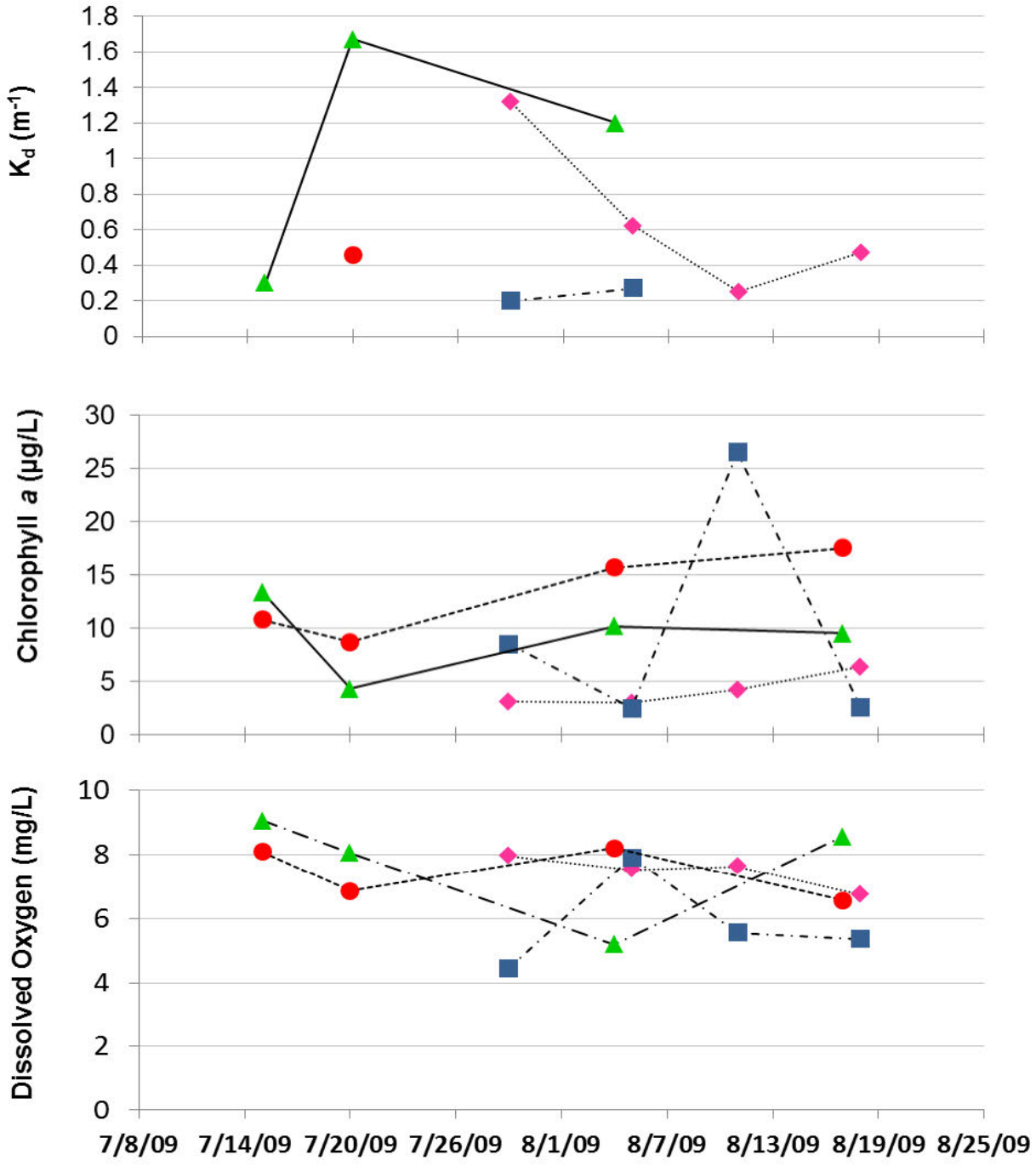


Figure 28. Trend Station water-quality data from the 2009 assessment at CACO. Trend data depicted are derived from selected trend stations representative of an upper estuary and lower estuary station located in both Pleasant Bay and Nauset Harbor Stratums. The blue square (■) and pink diamond (♦) represent hexagons 11 and 3 in the upper and lower portions of Pleasant Bay, respectively. The red circle (●) and green triangle (▲) represent hexagons 18 and 23 in the upper and lower portions of Nauset Harbor. No trend stations were assigned to the Salt Pond Stratum.

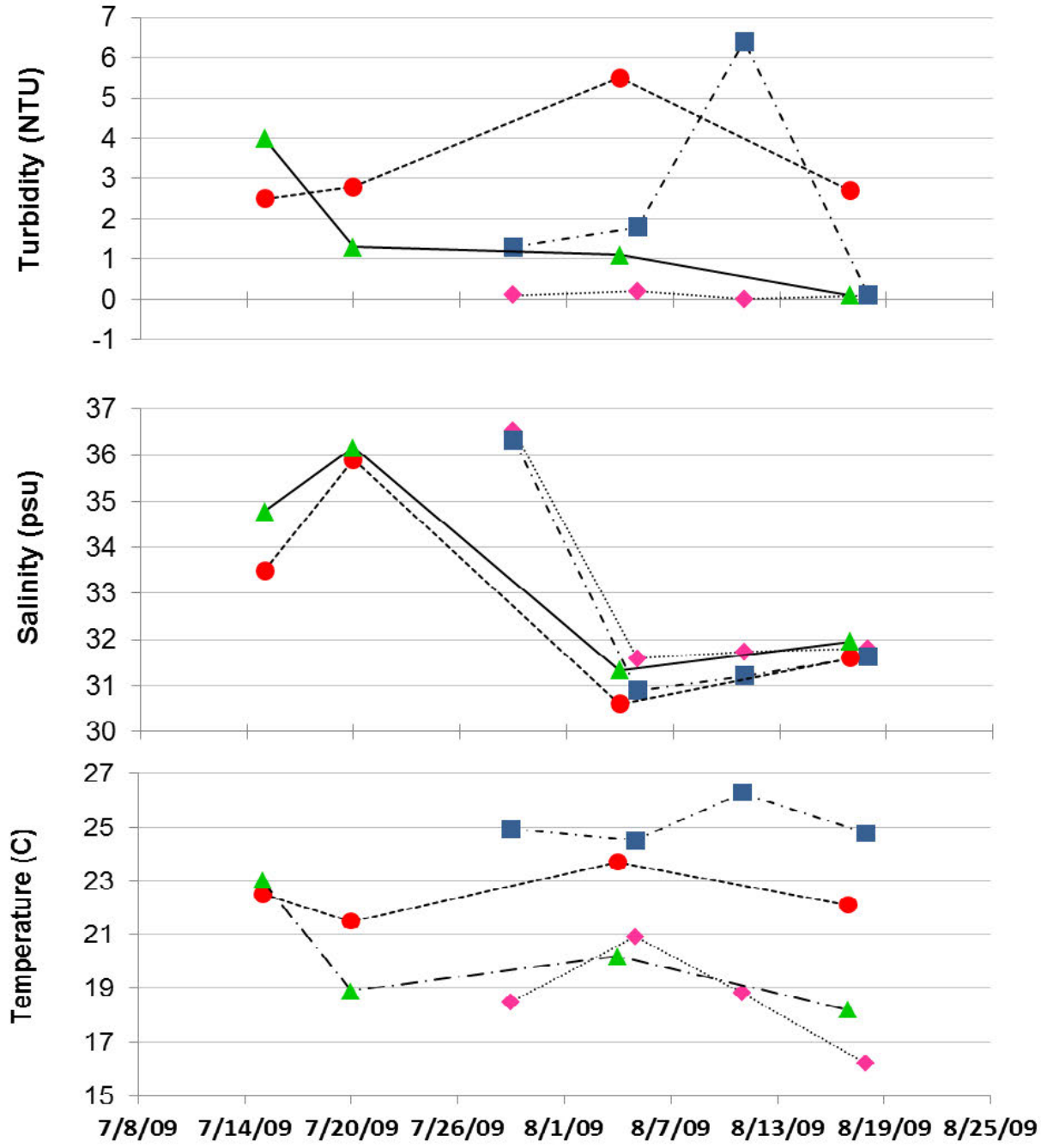


Figure 28 (cont.). Trend Station water-quality data from the 2009 assessment at CACO. Trend data depicted are derived from selected trend stations representative of an upper estuary and lower estuary station located in both Pleasant Bay and Nauset Harbor Stratums. The blue square (■) and pink diamond (♦) represent hexagons 11 and 3 in the upper and lower portions of Pleasant Bay, respectively. The red circle (●) and green triangle (▲) represent hexagons 18 and 23 in the upper and lower portions of Nauset Harbor. No trend stations were assigned to the Salt Pond Stratum.

2010 Index Period

Table 10. Area-Weighted average water-quality condition at CACO during the 2010 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	0.80	- -	- -	- -
Dissolved oxygen (mg/L)	- -	7.03	6.93	6.79
Dissolved oxygen, % Saturation	- -	95.33	94.70	92.19
Chlorophyll *a* (µg/L)	- -	6.24	- -	- -
Turbidity (NTU)	- -	1.59	1.36	5.75
Temperature (°C)	- -	21.40	21.87	21.53
Salinity (psu)	- -	32.23	32.24	32.23

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

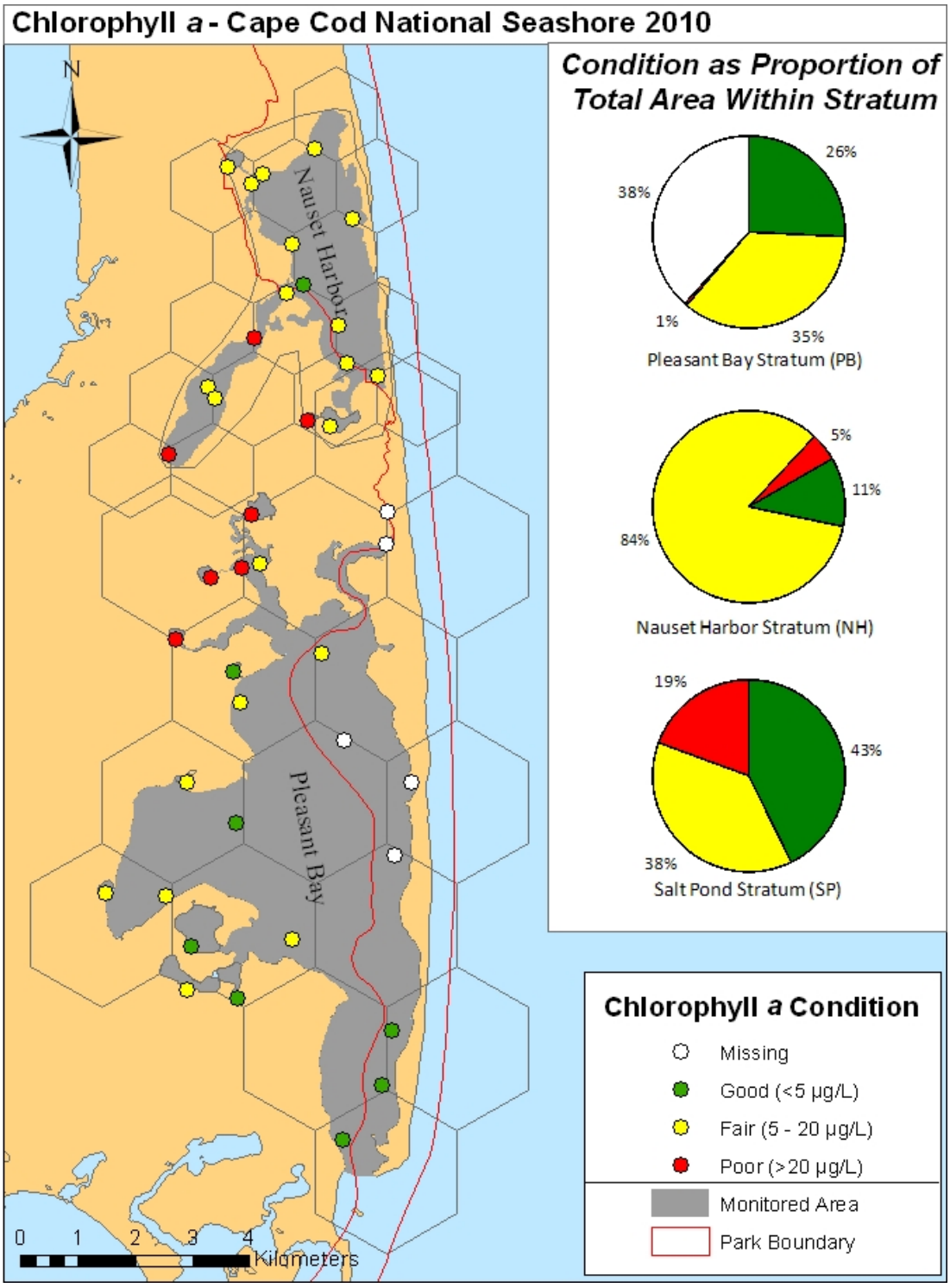


Figure 29. Chlorophyll *a* (µg/L) concentration in surface samples from the 2010 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

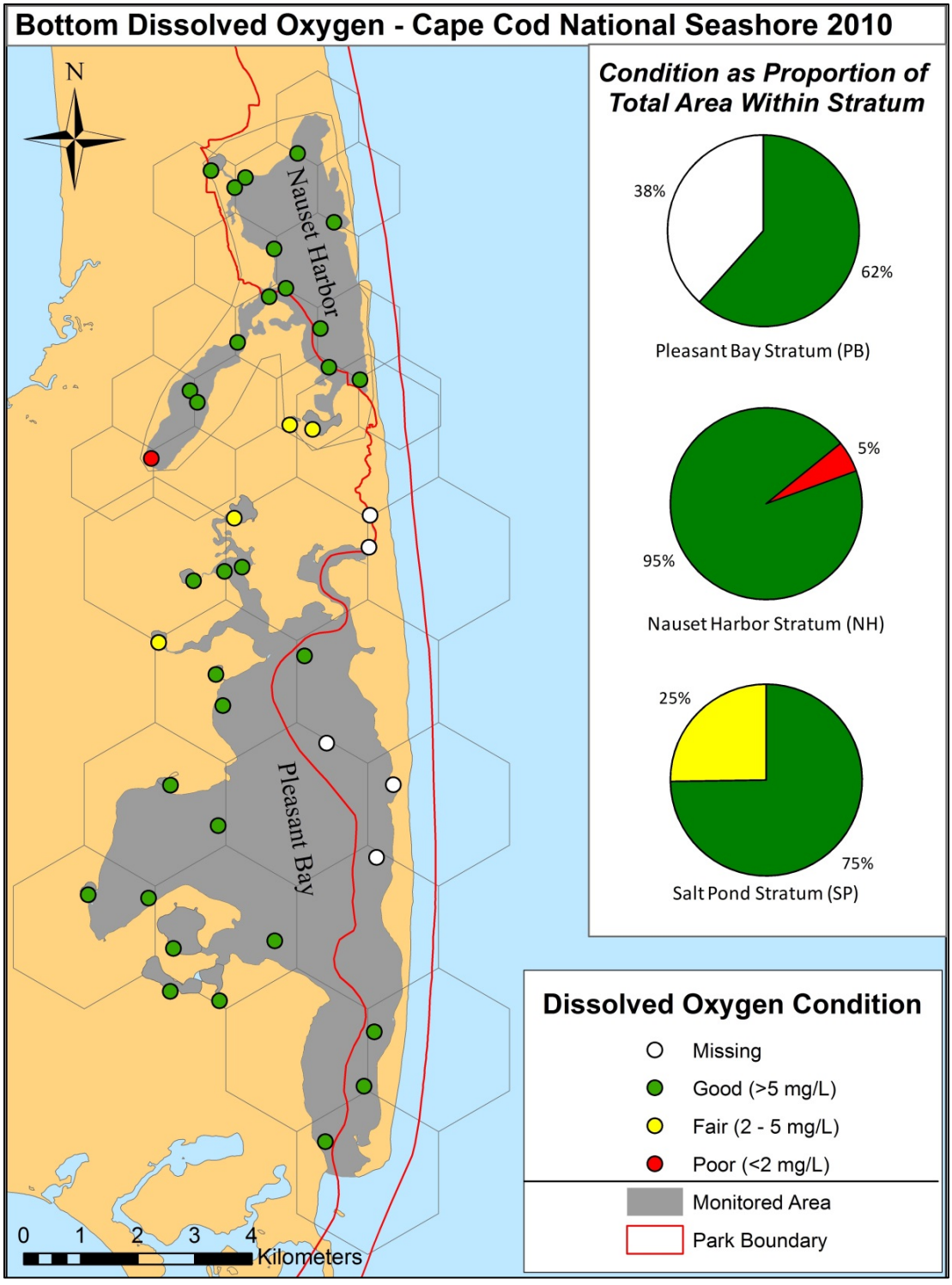


Figure 30. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2010 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

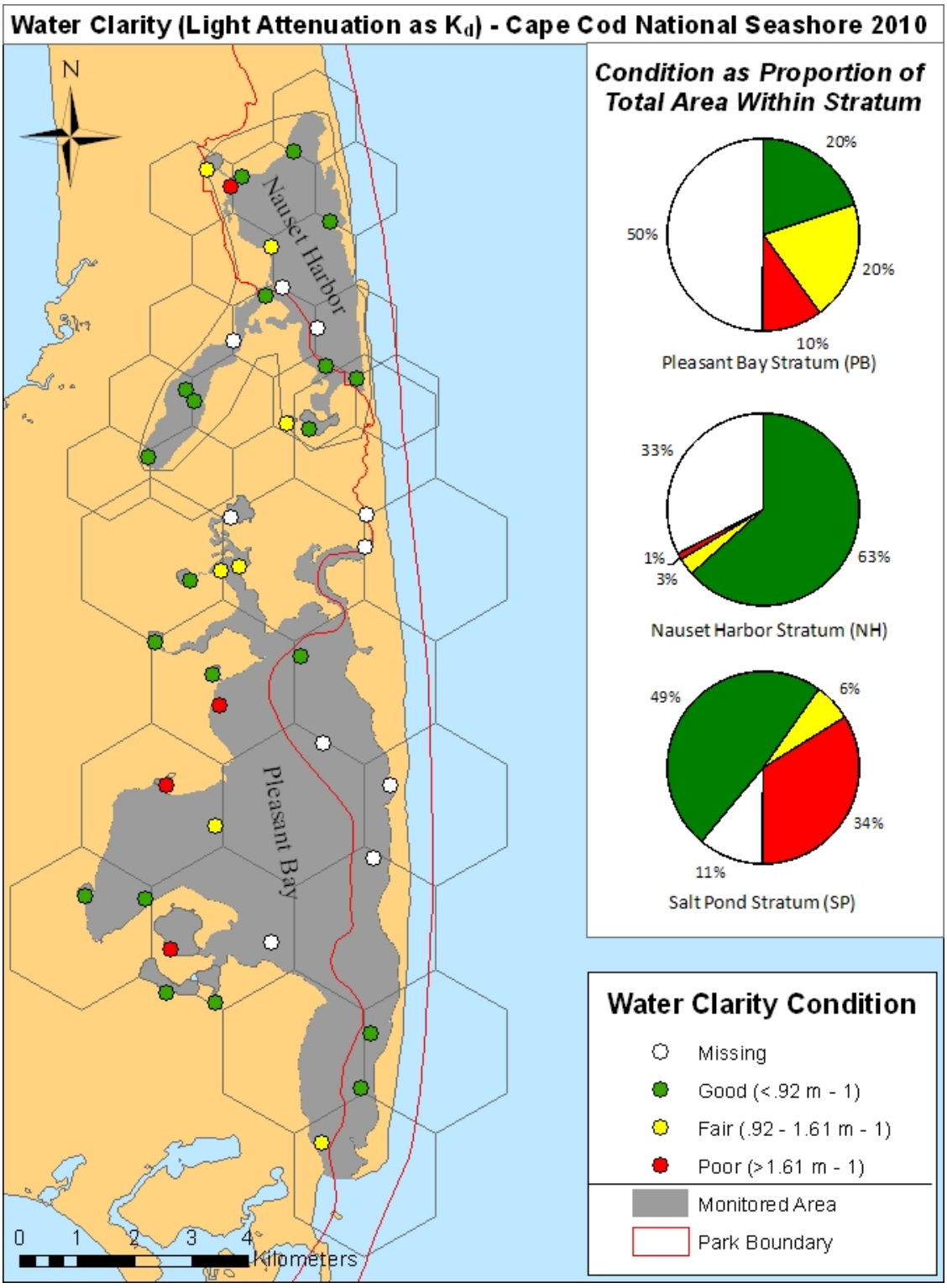


Figure 31. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2010 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

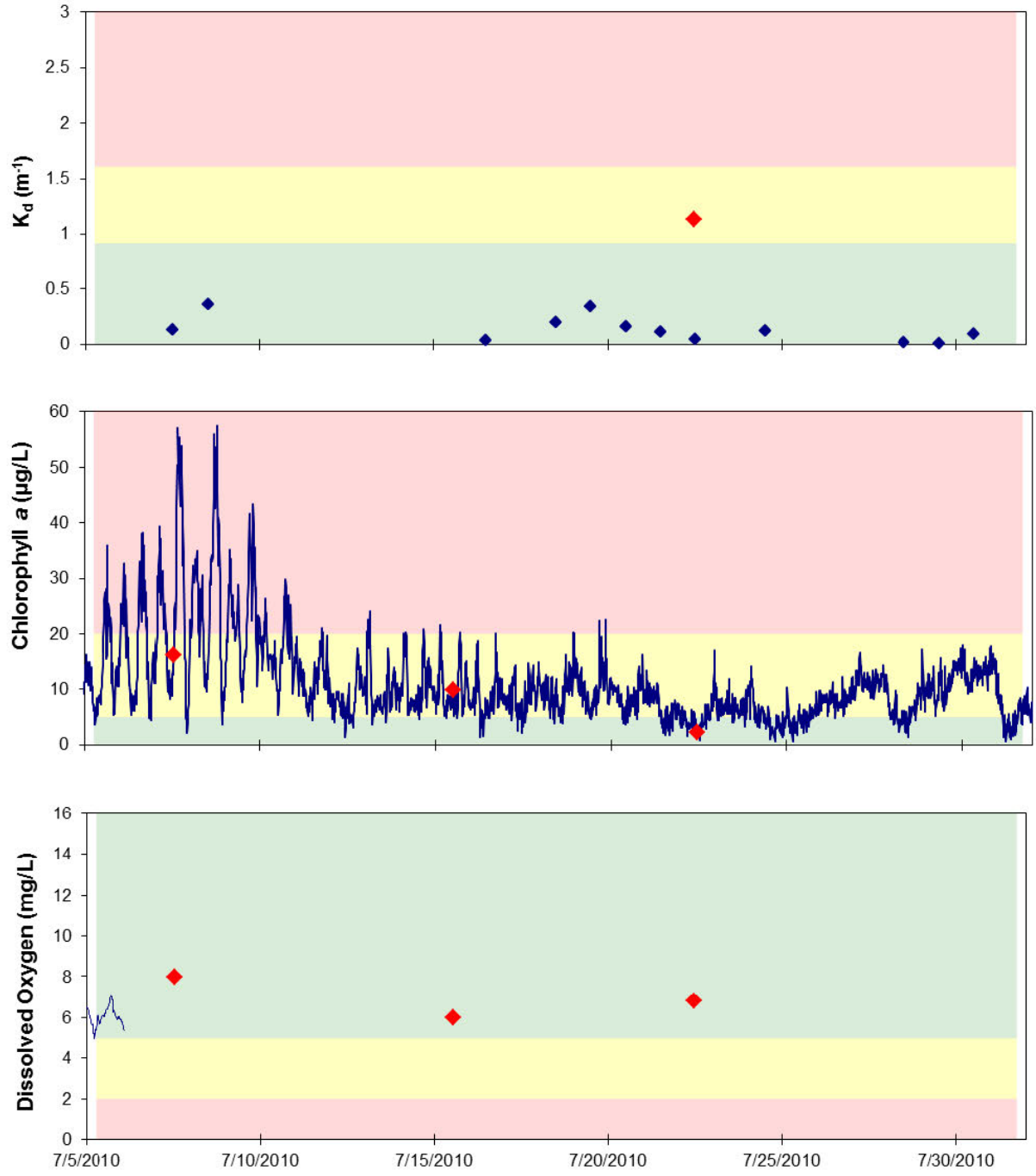


Figure 32. Continuous water-quality data from the 2010 assessment at CACO: Pleasant Bay Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

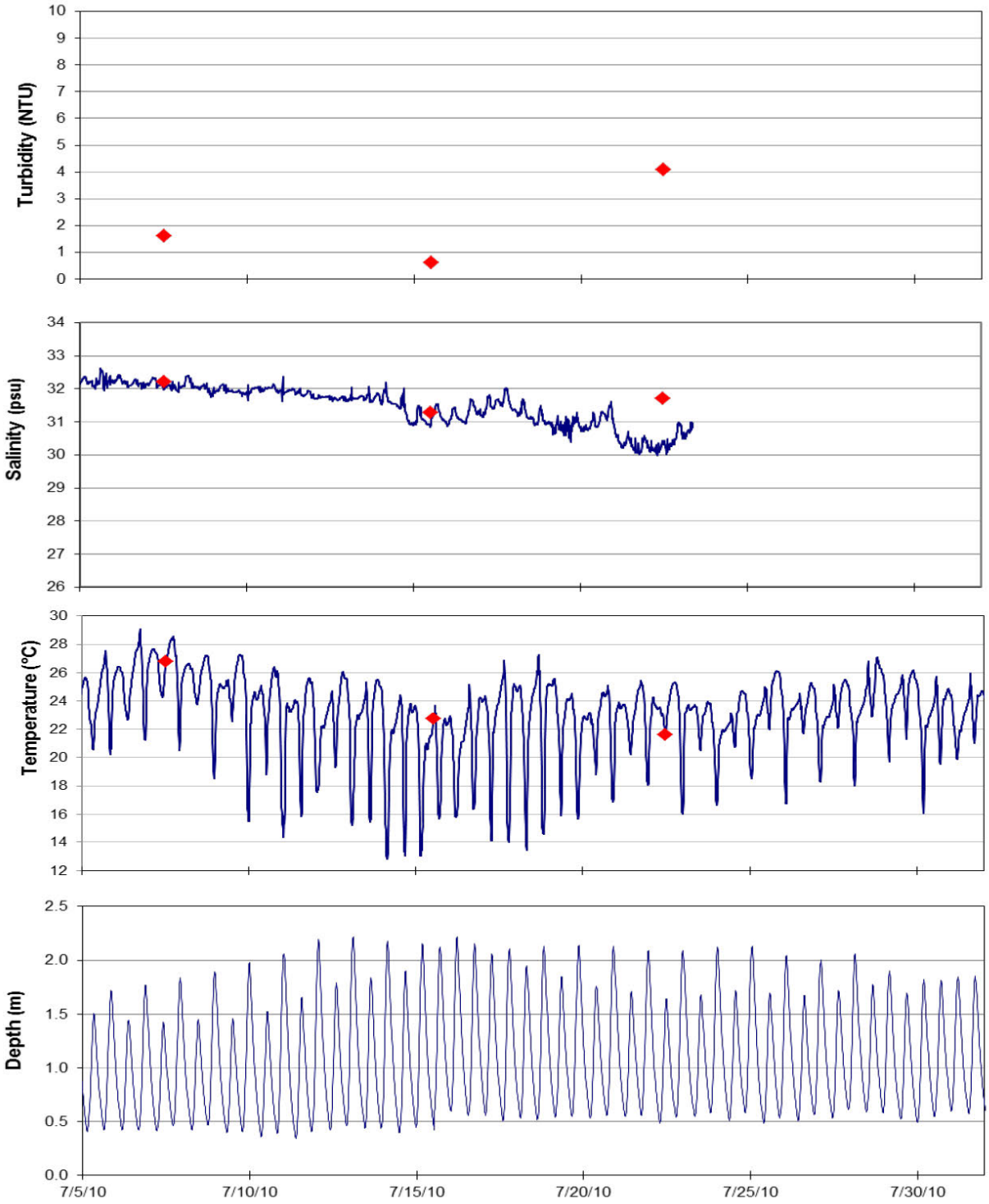


Figure 32 (cont.). Continuous water-quality data from the 2010 assessment at CACO: Pleasant Bay Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

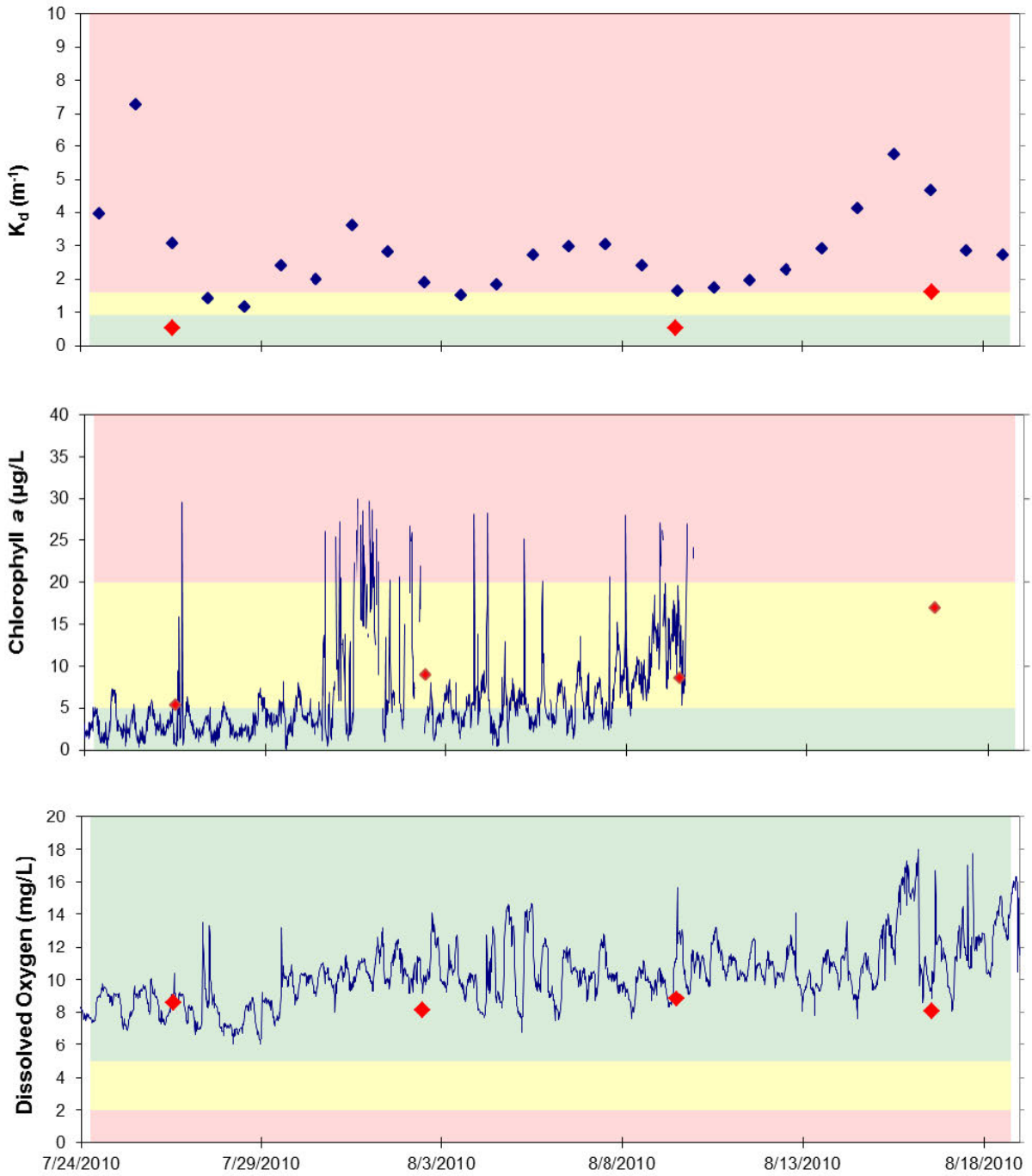


Figure 33. Continuous water-quality data from the 2010 assessment at CACO: Nauset Harbor Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

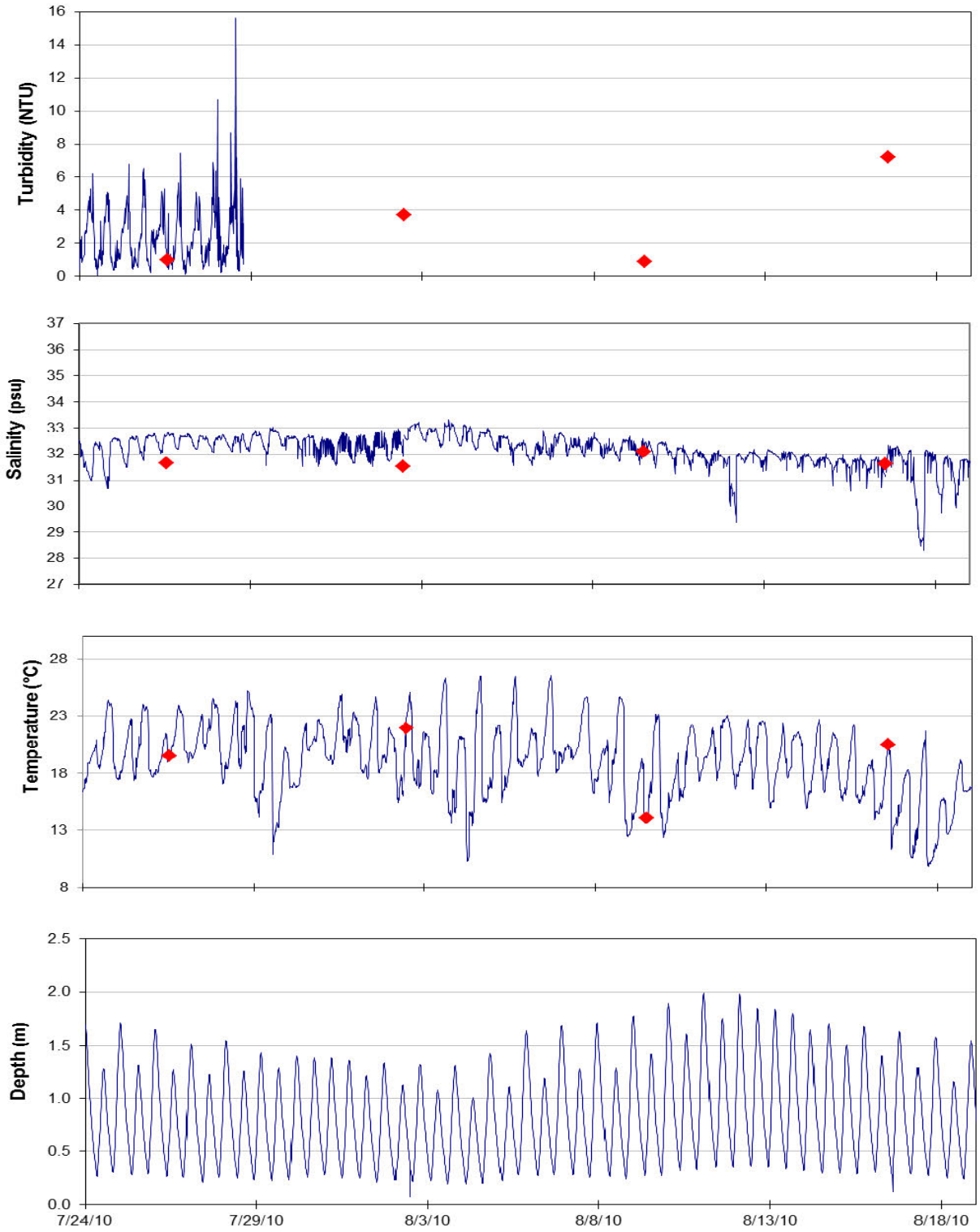


Figure 33 (cont.). Continuous water-quality data from the 2010 assessment at CACO: Nauset Harbor Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

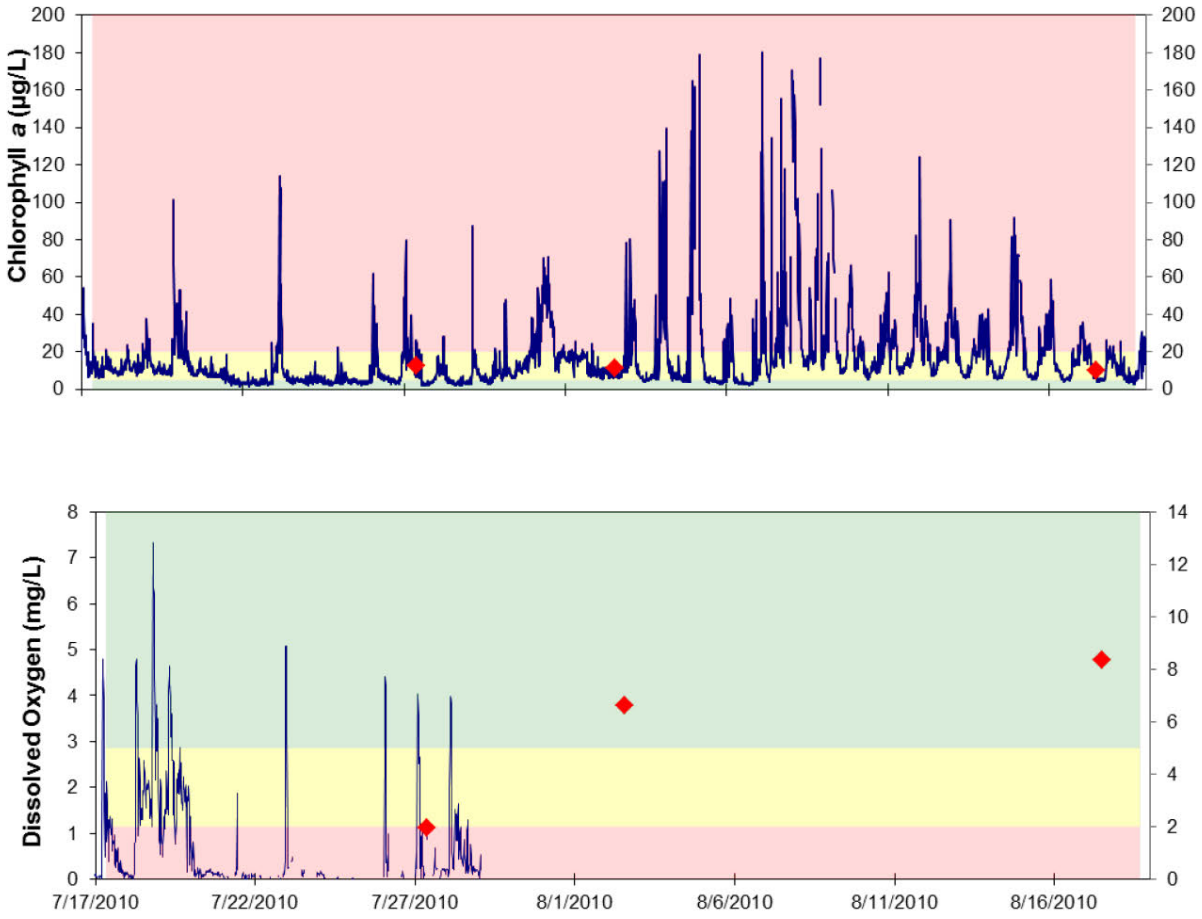


Figure 34. Continuous water-quality data from the 2010 assessment at CACO: Salt Ponds Stratum. All measurements were made using a YSI6600EDS multiparameter sonde following the NCBN ENE protocol (Kopp and Neckles 2009). Continuous PAR measurements were not made at the Salt Pond logging station. Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

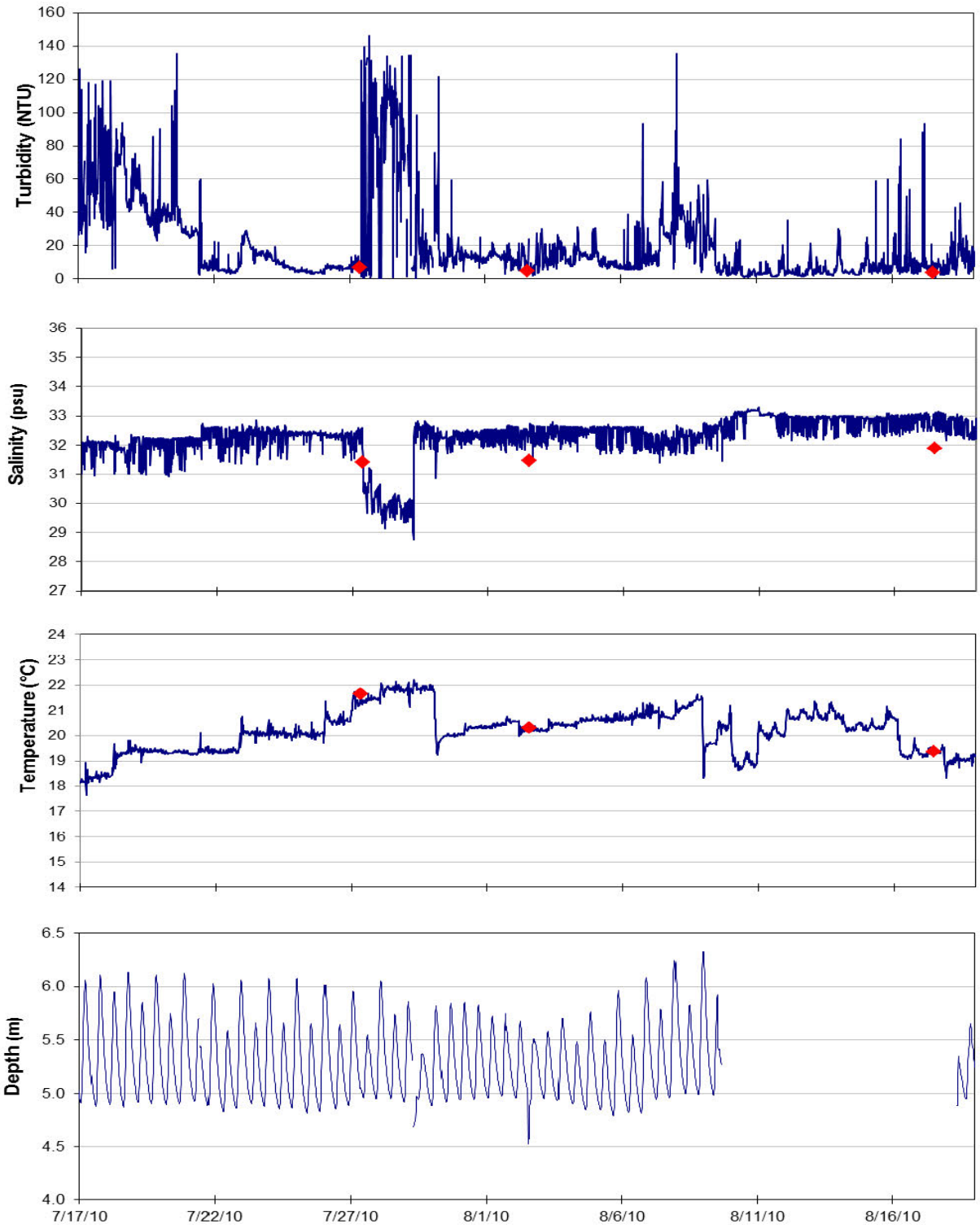


Figure 34 (cont.). Continuous water-quality data from the 2010 assessment at CACO: Salt Ponds Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 11. Trend-station water-quality data from the 2010 assessment at CACO.

Measure	Statistic	Trend Stations (Hexagons)					
		3 (PB)	**7 (PB)**	**11 (PB)**	**18 (NH)**	**23 (NH)**	**28 (NH)**
PAR attenuation	mean	1.30	0.85	0.71	1.28	0.69	0.37
(K_d (m^{-1}))	std.dev.	1.10	0.39	N/A	0.50	0.15	0.01
	n	4	3	1	4	2	2
Temperature	mean	18.48	20.78	24.07	22.92	21.29	20.72
(°C)	std.dev.	1.35	1.76	0.51	1.54	1.80	1.63
	n	4	4	3	4	4	4
Salinity	mean	31.80	31.78	30.90	31.33	31.50	30.65
(psu)	std.dev.	0.20	0.29	0.52	0.39	0.35	2.12
	n	4	4	3	4	4	4
Dissolved oxygen	mean	7.2	6.9	6.2	7.7	7.3	7.7
(mg/L)	std.dev.	0.8	0.3	1.0	0.9	0.7	1.0
	n	4	4	3	4	4	4
Turbidity	mean	0.5	1.7	1.9	13.1	4.2	3.1
(NTU)	std.dev.	0.2	2.0	0.2	20.8	3.2	1.3
	n	3	4	3	4	4	4
Chlorophyll *a*	mean	2.1	3.7	10.1	16.7	12.6	6.3
(µg/L)	std.dev.	0.9	1.3	3.7	6.9	3.8	0.6
	n	4	4	3	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Locations of hexagons with trend stations are shown in Figure 2. Stations 3, 7, and 11 are in the Pleasant Bay stratum (PB); stations 18, 23, and 28 are in the Nauset Harbor stratum (NH).]

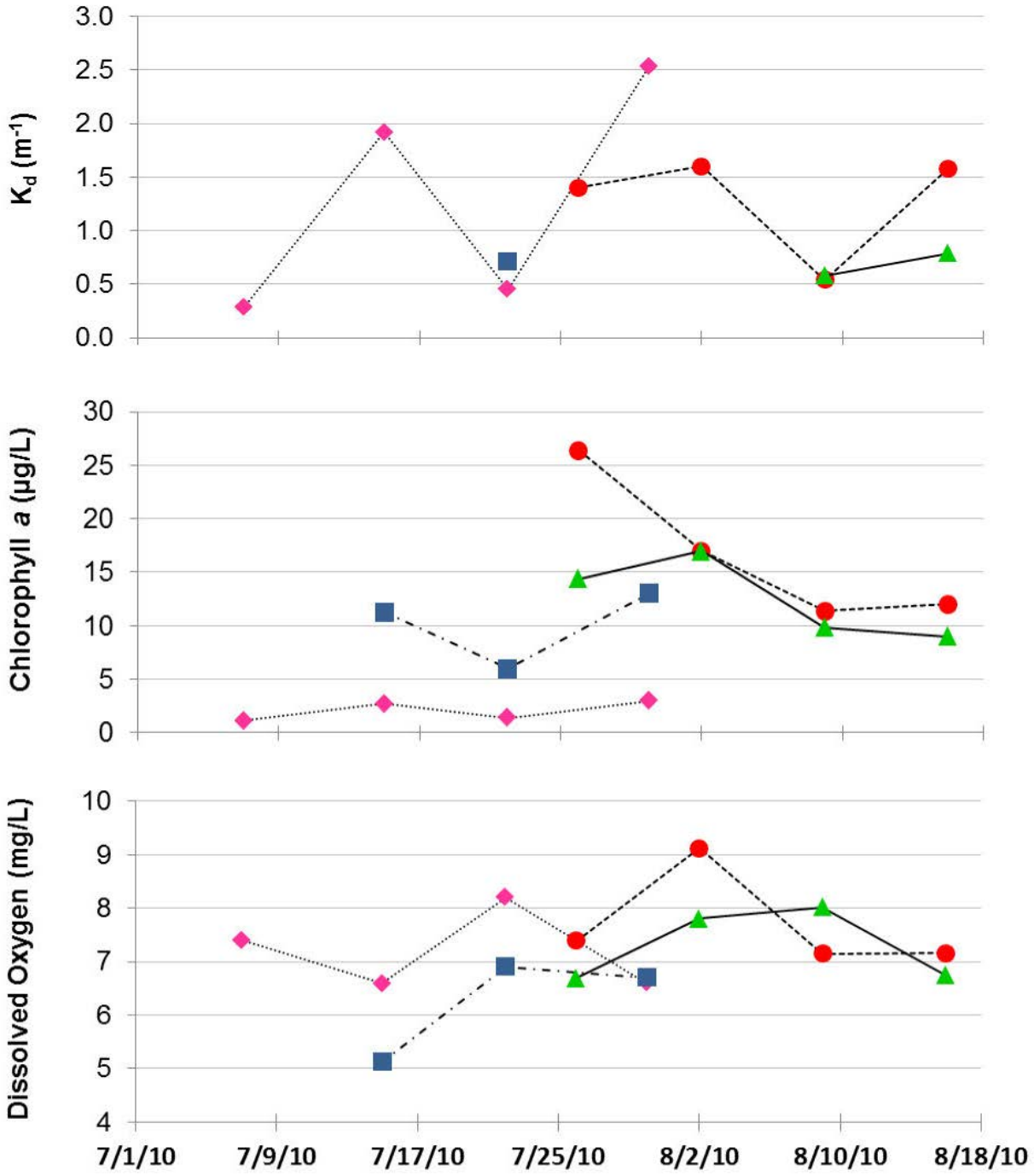


Figure 35. Trend Station water-quality data from the 2010 assessment at CACO. Trend data depicted are derived from selected trend stations representative of an upper estuary and lower estuary station located in both Pleasant Bay and Nauset Harbor Stratums. The blue square (■) and pink diamond (♦) represent hexagons 11 and 3 in the upper and lower portions of Pleasant Bay, respectively. The red circle (●) and green triangle (▲) represent hexagons 18 and 23 in the upper and lower portions of Nauset Harbor. No trend stations were assigned to the Salt Pond Stratum.

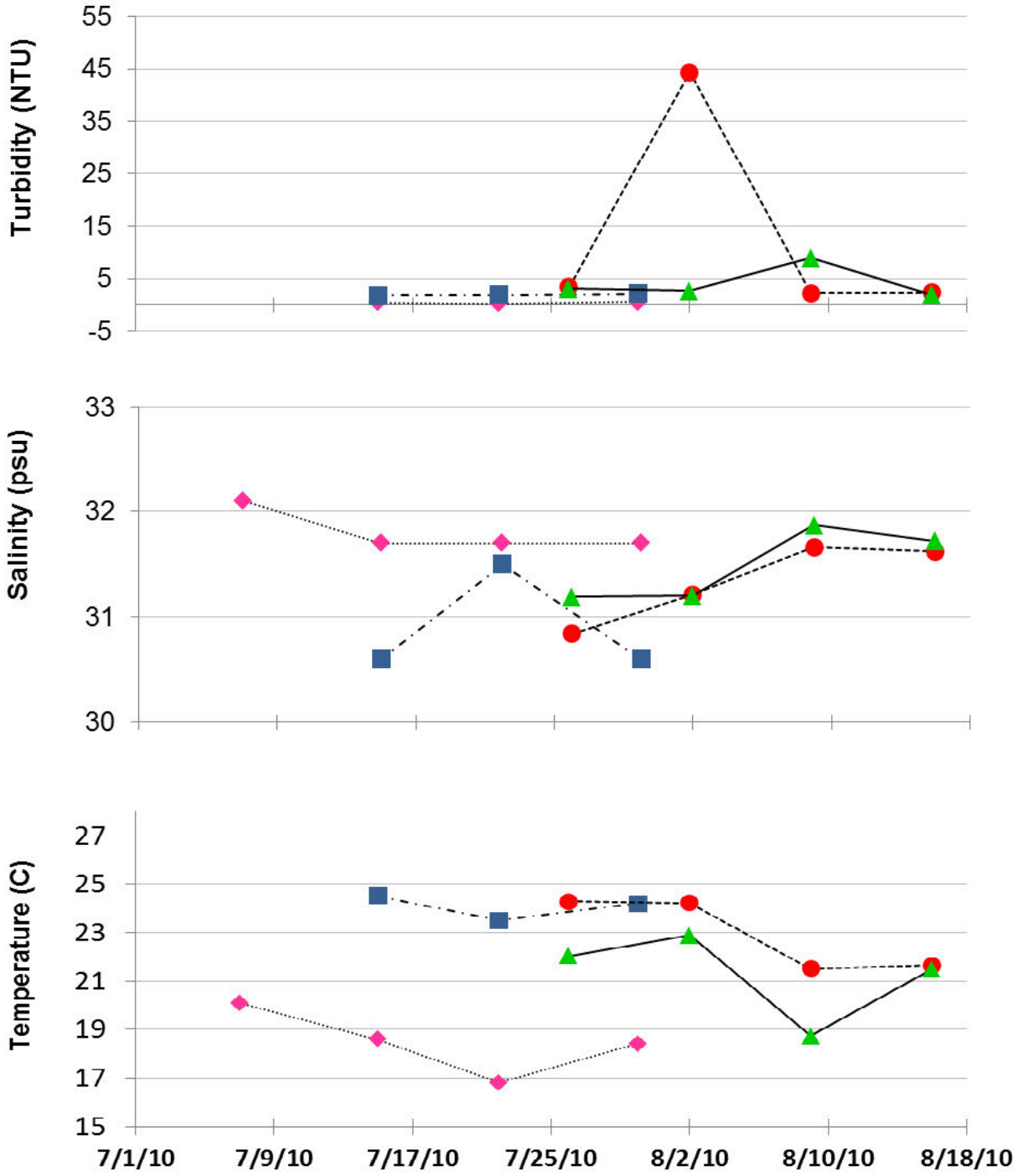


Figure 35 (cont.). Trend Station water-quality data from the 2010 assessment at CACO. Trend data depicted are derived from selected trend stations representative of an upper estuary and lower estuary station located in both Pleasant Bay and Nauset Harbor Stratums. The blue square (■) and pink diamond (♦) represent hexagons 11 and 3 in the upper and lower portions of Pleasant Bay, respectively. The red circle (●) and green triangle (▲) represent hexagons 18 and 23 in the upper and lower portions of Nauset Harbor. No trend stations were assigned to the Salt Pond Stratum.

2011 Index Period

Table 12. Area-Weighted average water-quality condition at CACO during the 2011 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	0.70	- -	- -	- -
Dissolved oxygen (mg/L)	- -	9.96	7.71	10.06
Dissolved oxygen, % Saturation	- -	102.24	102.16	103.87
Chlorophyll *a* (µg/L)	- -	6.38		
Turbidity (NTU)	- -	1.24	1.22	1.93
Temperature (°C)	- -	20.99	20.48	21.07
Salinity (psu)	- -	30.09	30.35	30.10

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

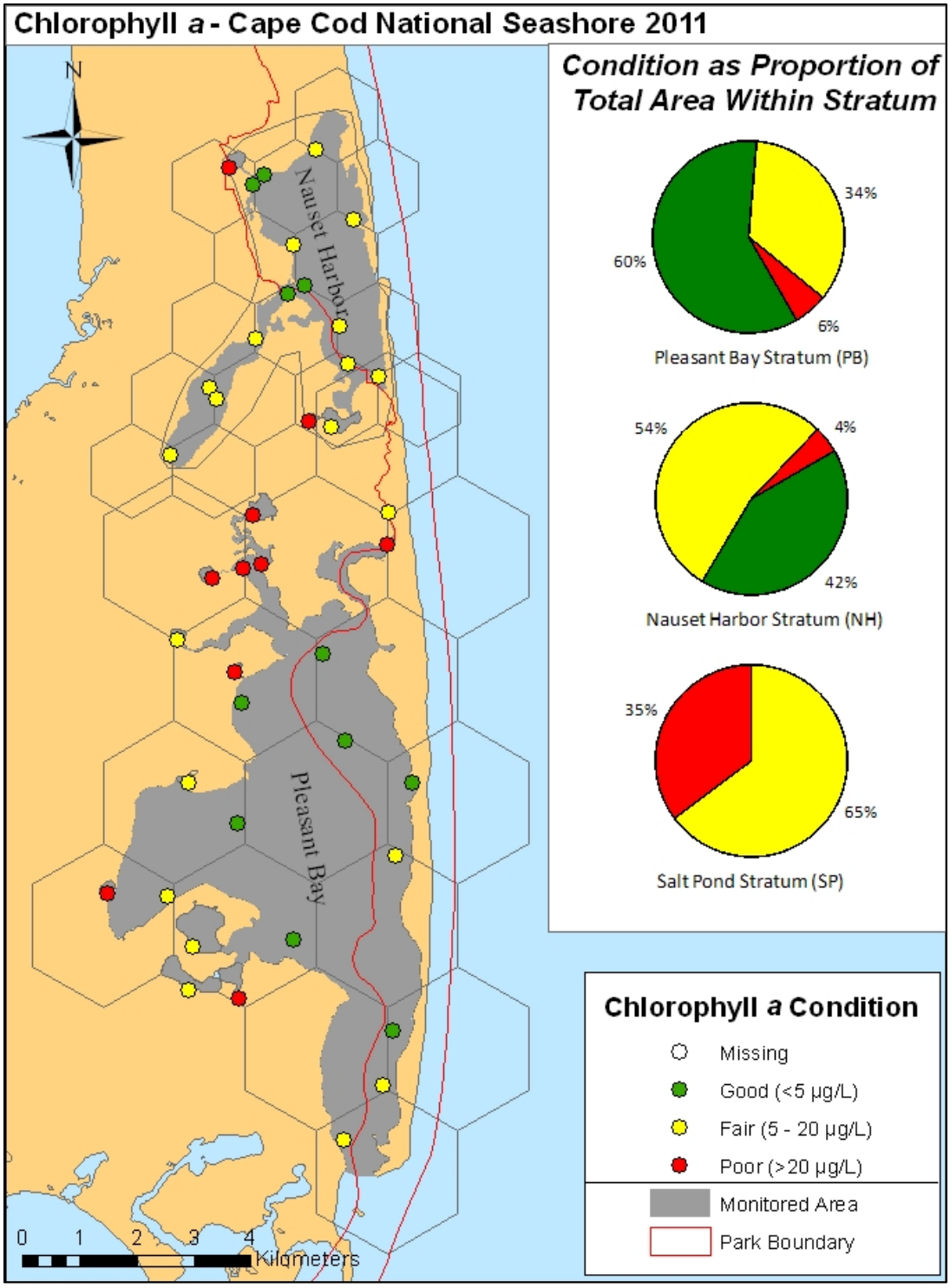


Figure 36. Chlorophyll *a* (µg/L) concentration in surface samples from the 2011 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

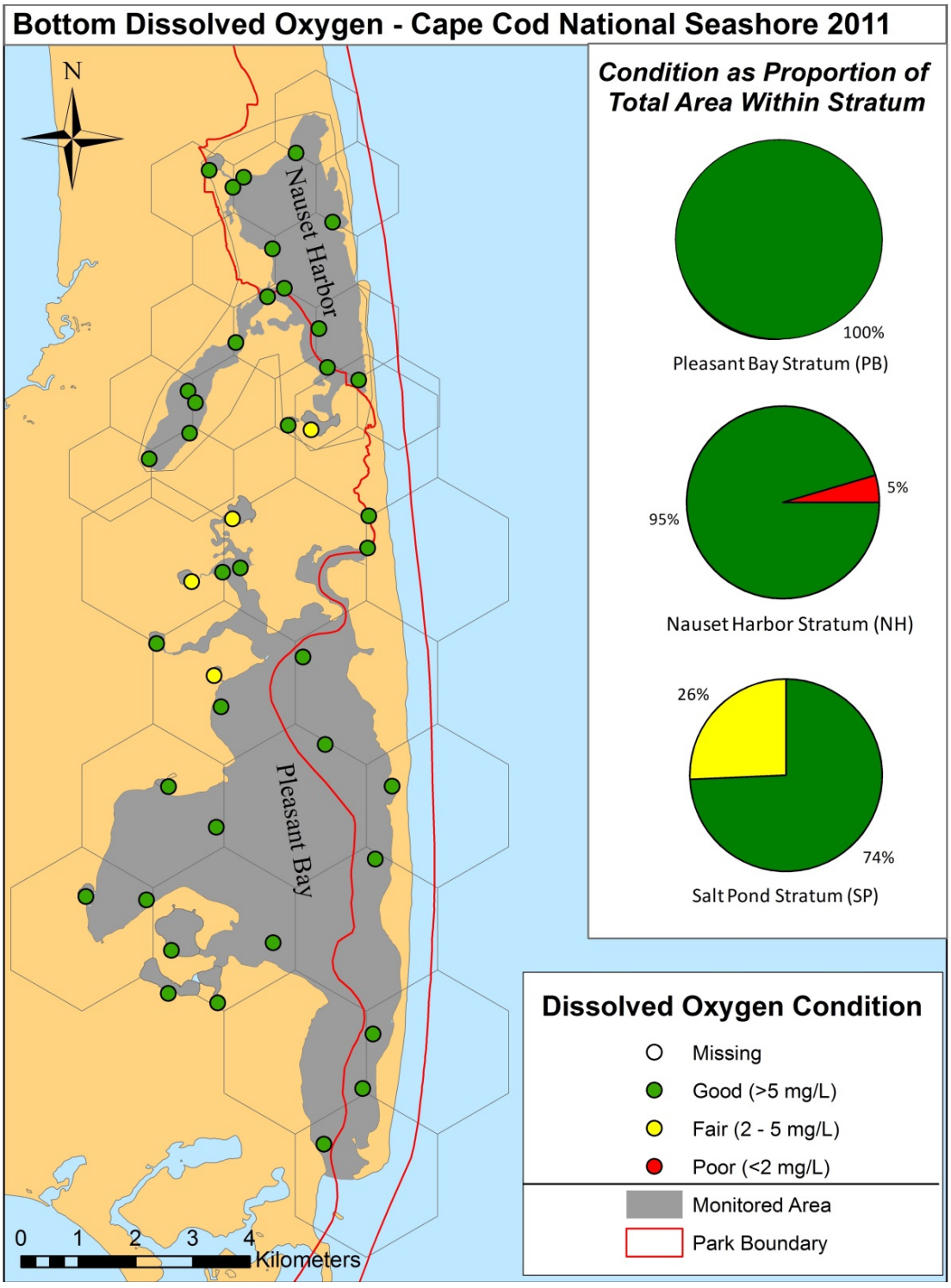


Figure 37. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2011 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

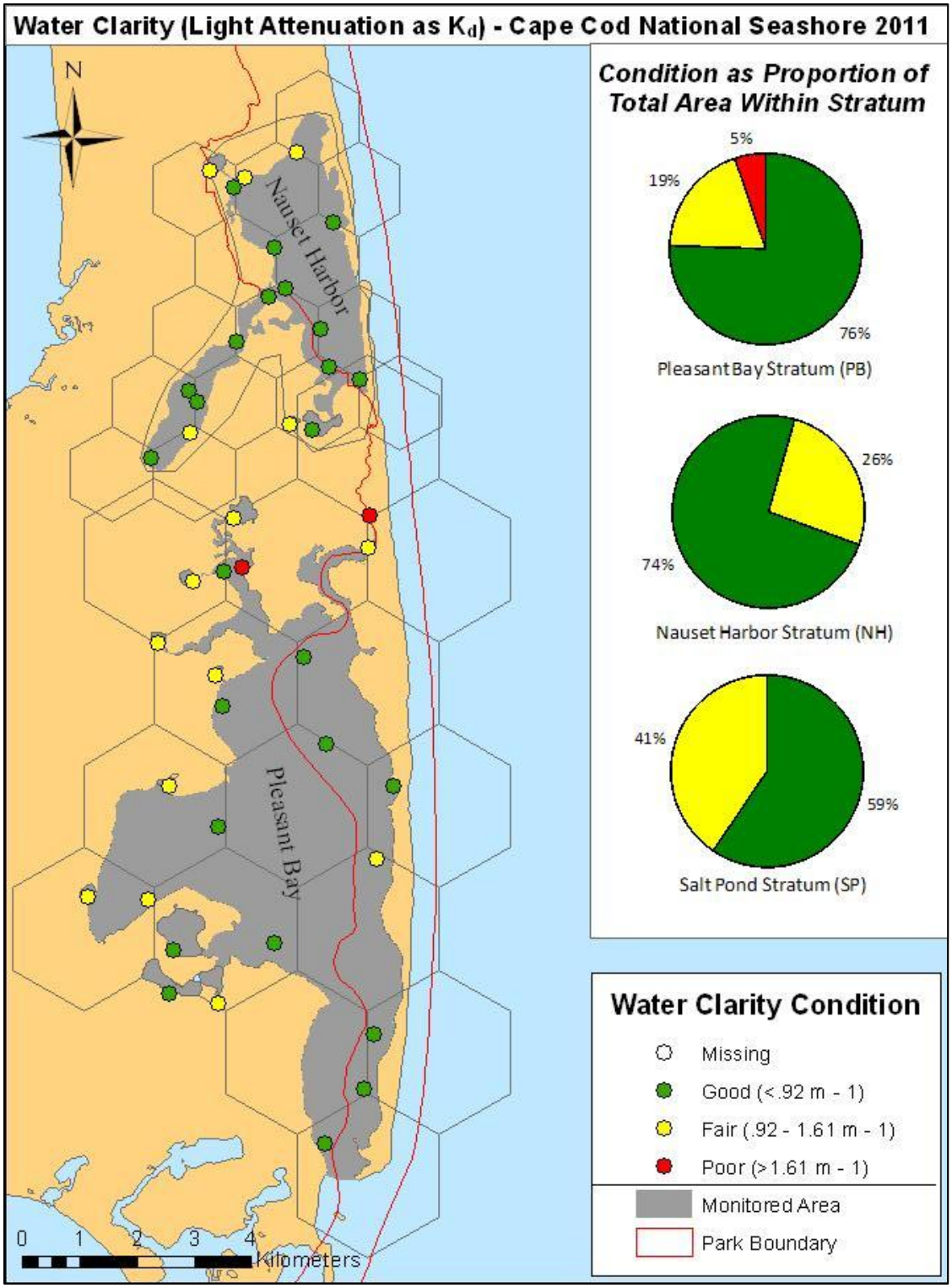


Figure 38. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2011 assessment at CACO. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

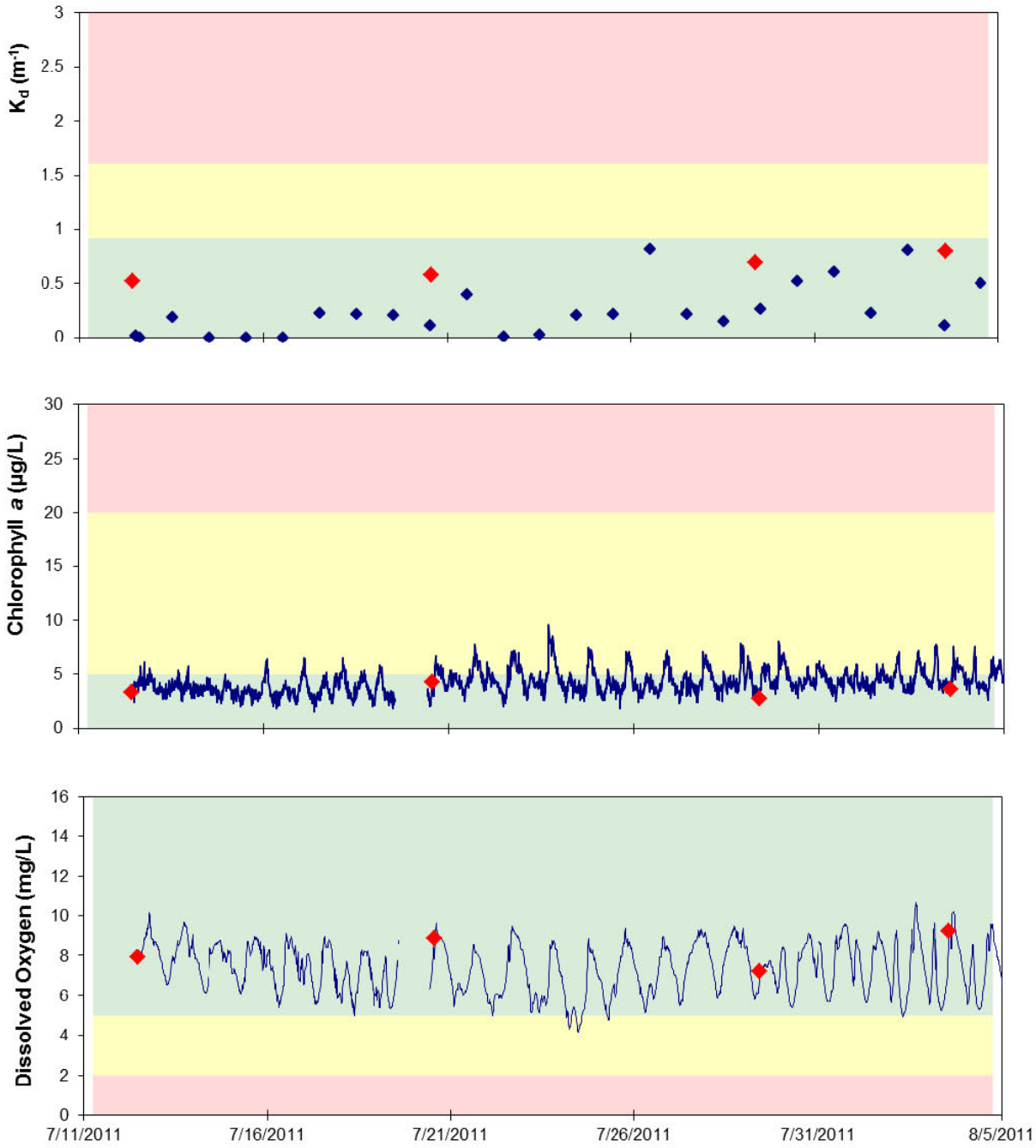


Figure 39. Continuous water-quality data from the 2011 assessment at CACO: Pleasant Bay Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

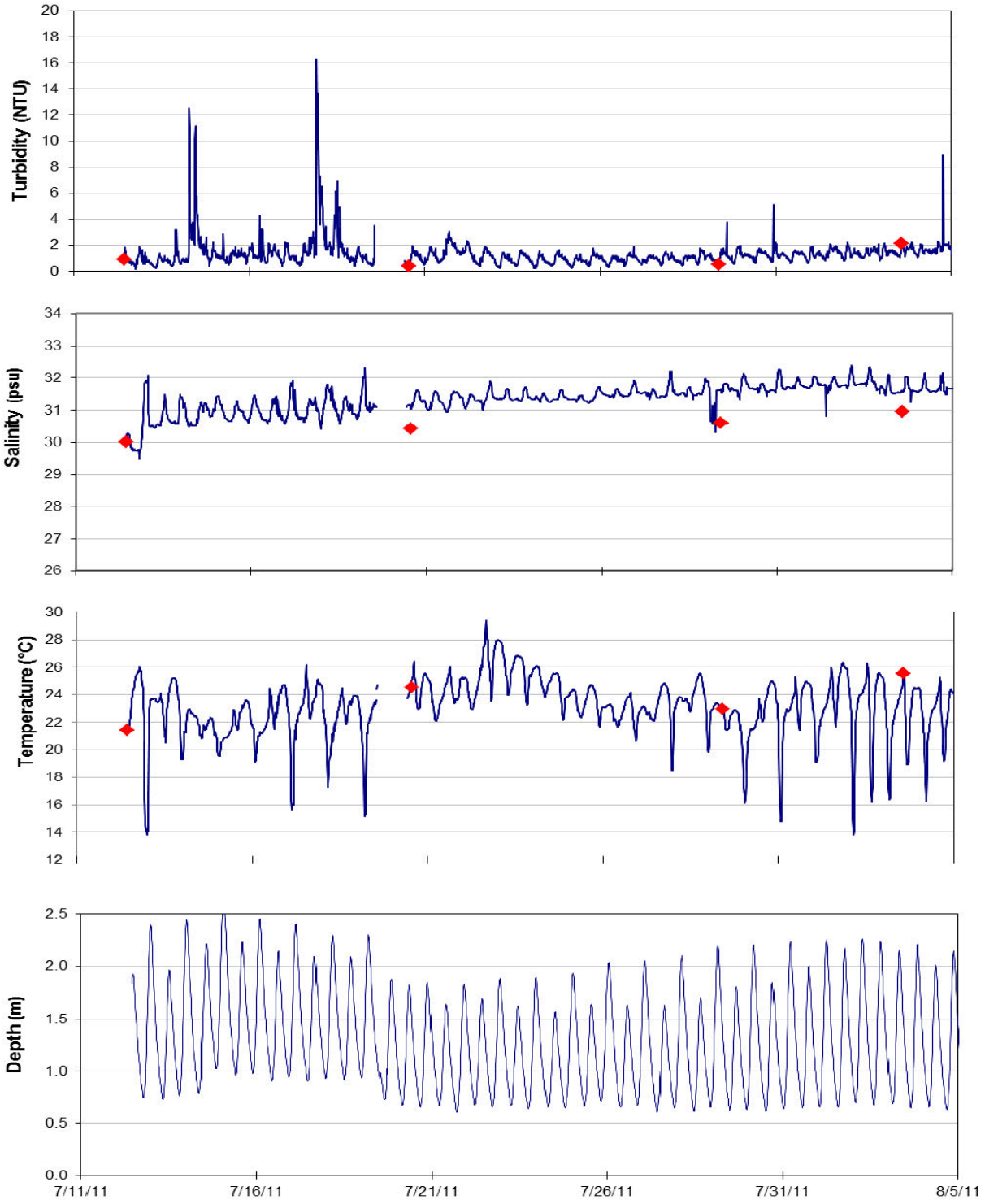


Figure 39 (cont.). Continuous water-quality data from the 2011 assessment at CACO: Pleasant Bay Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

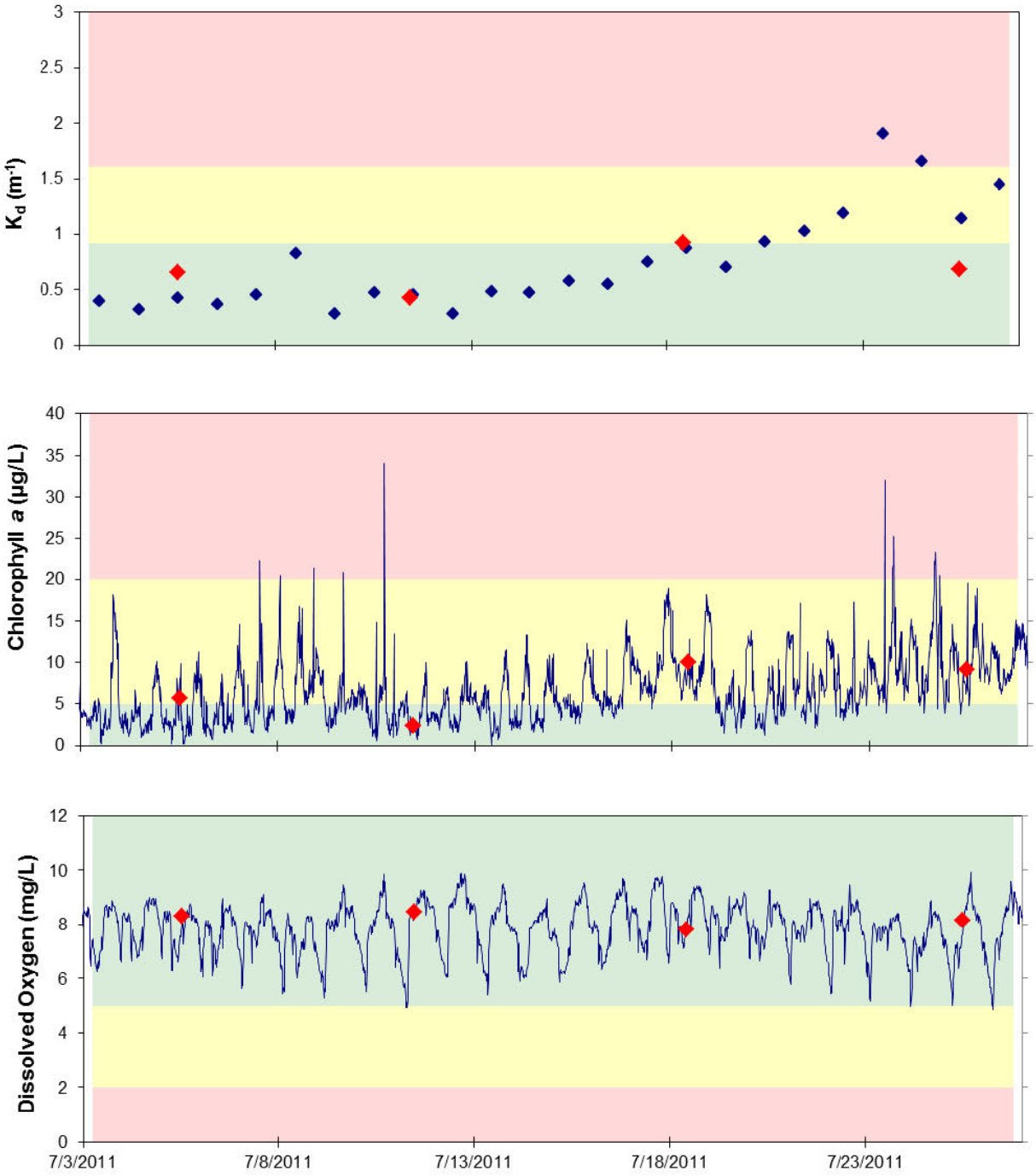


Figure 40. Continuous water-quality data from the 2011 assessment at CACO: Nauset Harbor Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

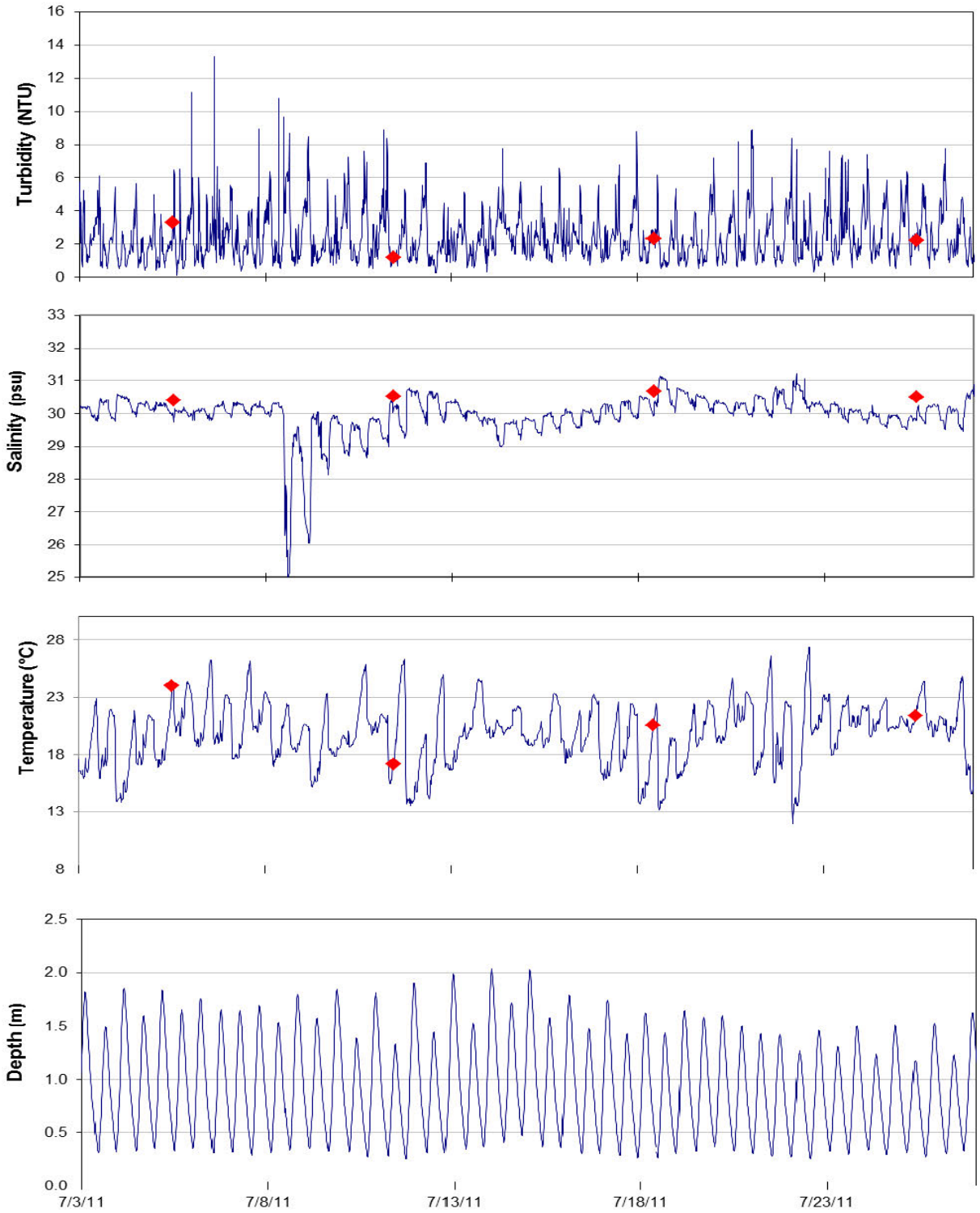


Figure 40 (cont.). Continuous water-quality data from the 2011 assessment at CACO: Nauset Harbor Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

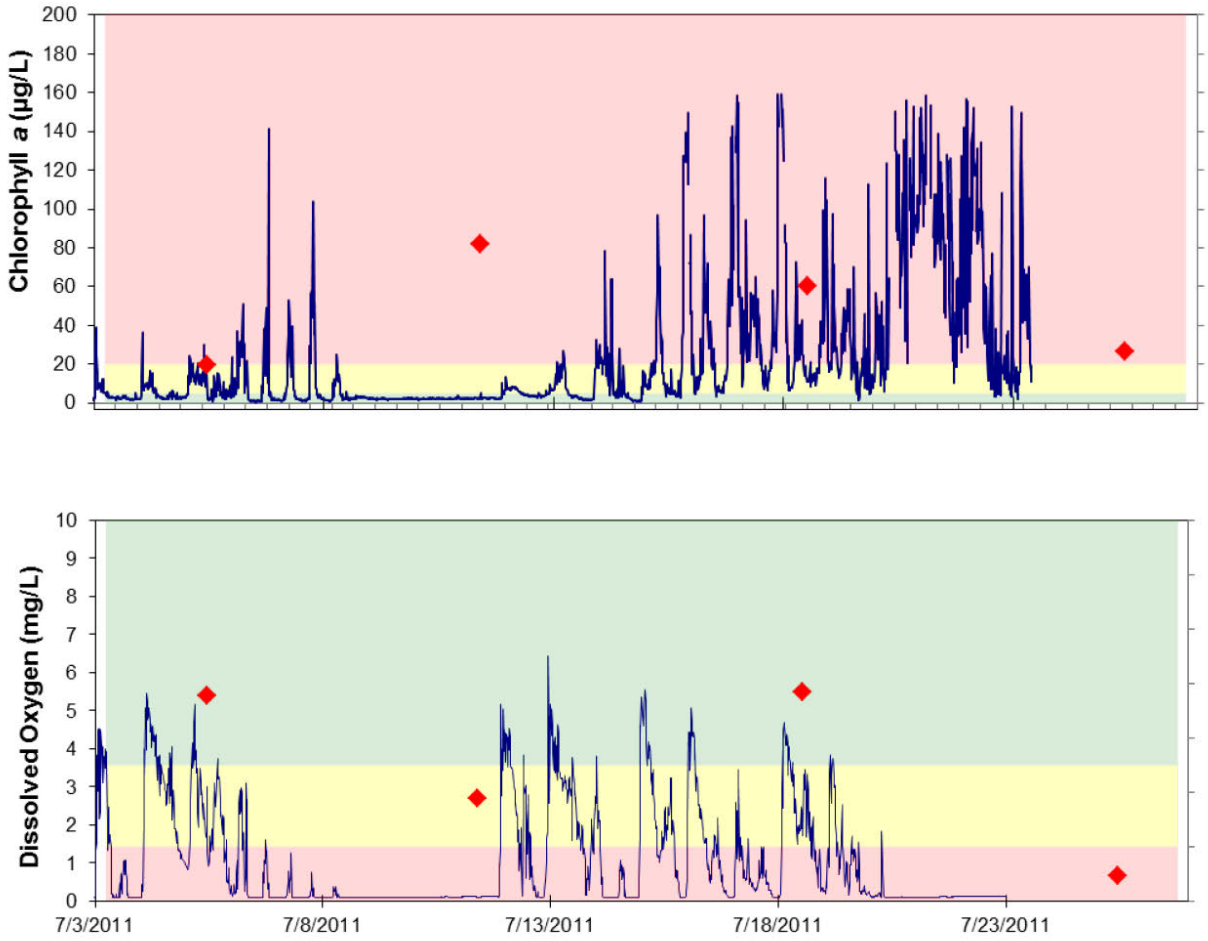


Figure 41. Continuous water-quality data from the 2011 assessment at CACO: Salt Ponds Stratum. All measurements were made using a YSI6600EDS multiparameter sonde following the NCBN ENE protocol (Kopp and Neckles 2009). Continuous PAR measurements were not made at the Salt Pond logging station. Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

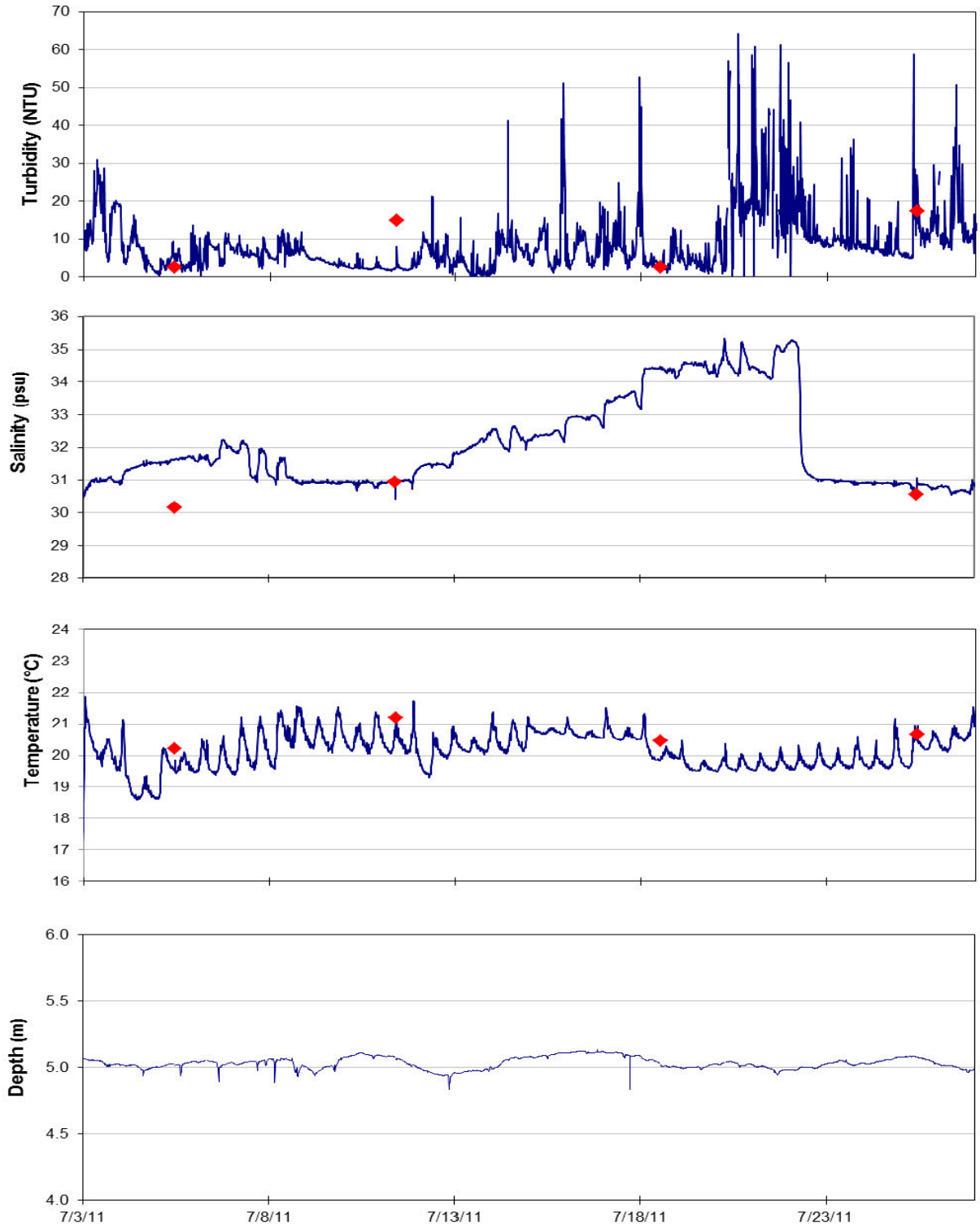


Figure 41 (cont.). Continuous water-quality data from the 2011 assessment at CACO: Salt Ponds Stratum. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 13. Trend-station water-quality data from the 2011 assessment at CACO.

Measure	Statistic	Trend Stations (Hexagons)					
		3 (PB)	**7 (PB)**	**11 (PB)**	**18 (NH)**	**23 (NH)**	**28 (NH)**
PAR attenuation	mean	0.36	0.52	0.53	0.31	0.77	1.01
(K_d (m^{-1}))	std.dev.	0.02	0.09	0.13	N/A	0.73	0.13
	n	2	4	2	1	3	2
Temperature	mean	19.13	22.13	24.28	23.79	22.75	22.16
(°C)	std.dev.	1.89	0.53	1.14	0.48	1.82	1.01
	n	4	4	4	4	4	4
Salinity	mean	31.00	30.54	30.21	29.76	30.10	30.04
(psu)	std.dev.	0.08	0.43	0.60	0.70	0.19	0.70
	n	4	4	4	4	4	4
Dissolved oxygen	mean	8.2	7.4	6.2	7.9	7.7	7.7
(mg/L)	std.dev.	0.3	0.4	1.4	0.2	0.4	1.3
	n	4	4	4	4	4	4
Turbidity	mean	0.8	1.0	1.0	3.5	2.5	4.4
(NTU)	std.dev.	0.6	0.5	0.4	1.9	1.4	3.3
	n	4	4	2	4	4	4
Chlorophyll *a*	mean	4.1	6.9	5.4	18.0	14.4	5.7
(µg/L)	std.dev.	1.1	5.1	3.1	13.0	12.7	2.6
	n	4	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Locations of hexagons with trend stations are shown in Figure 2. Stations 3, 7, and 11 are in the Pleasant Bay stratum (PB); stations 18, 23, and 28 are in the Nauset Harbor stratum (NH).]

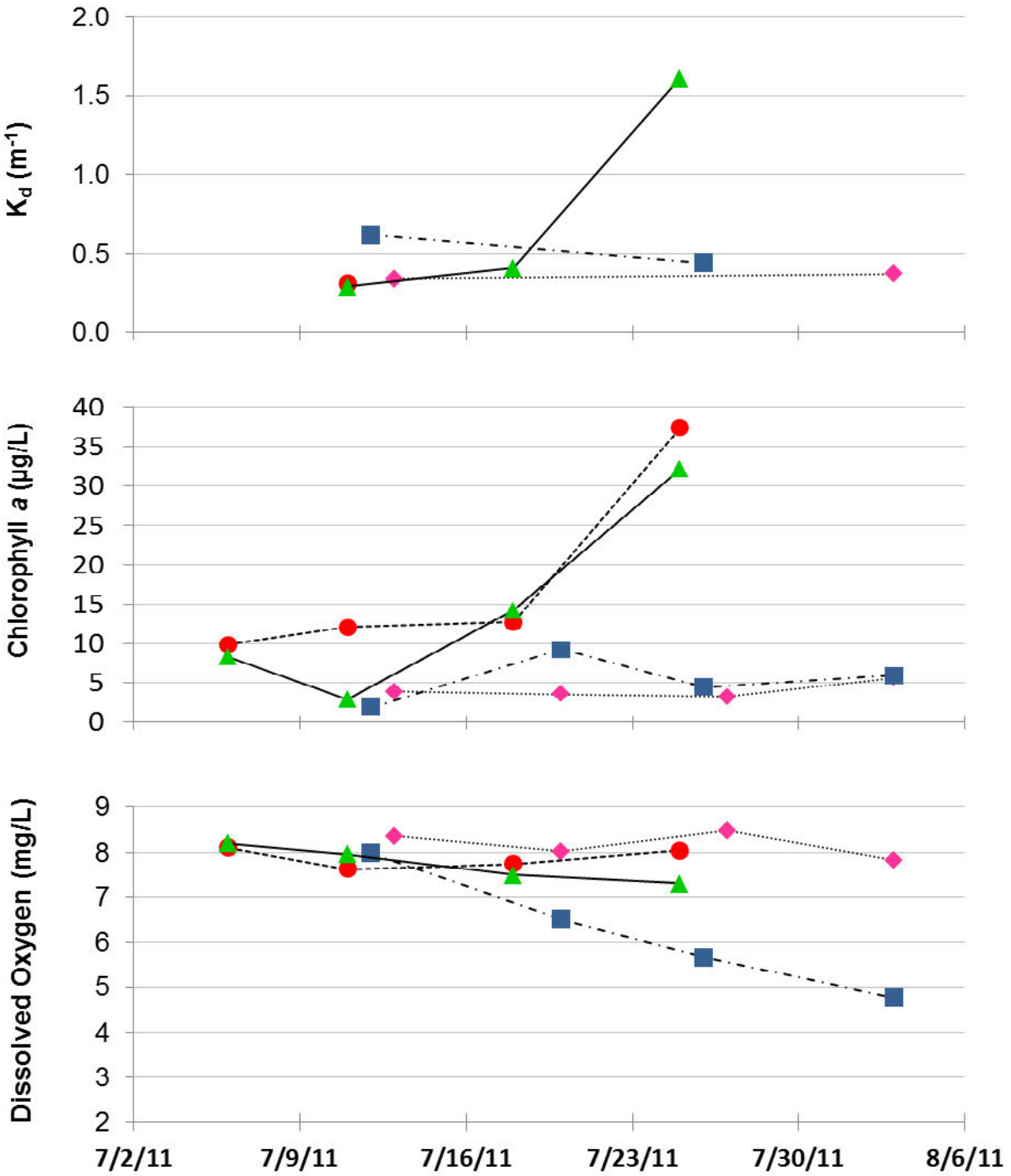


Figure 42. Trend Station water-quality data from the 2011 assessment at CACO. Trend data depicted are derived from selected trend stations representative of an upper estuary and lower estuary station located in both Pleasant Bay and Nauset Harbor Stratums. The blue square (■) and pink diamond (♦) represent hexagons 11 and 3 in the upper and lower portions of Pleasant Bay, respectively. The red circle (●) and green triangle (▲) represent hexagons 18 and 23 in the upper and lower portions of Nauset Harbor. No trend stations were assigned to the Salt Pond Stratum.

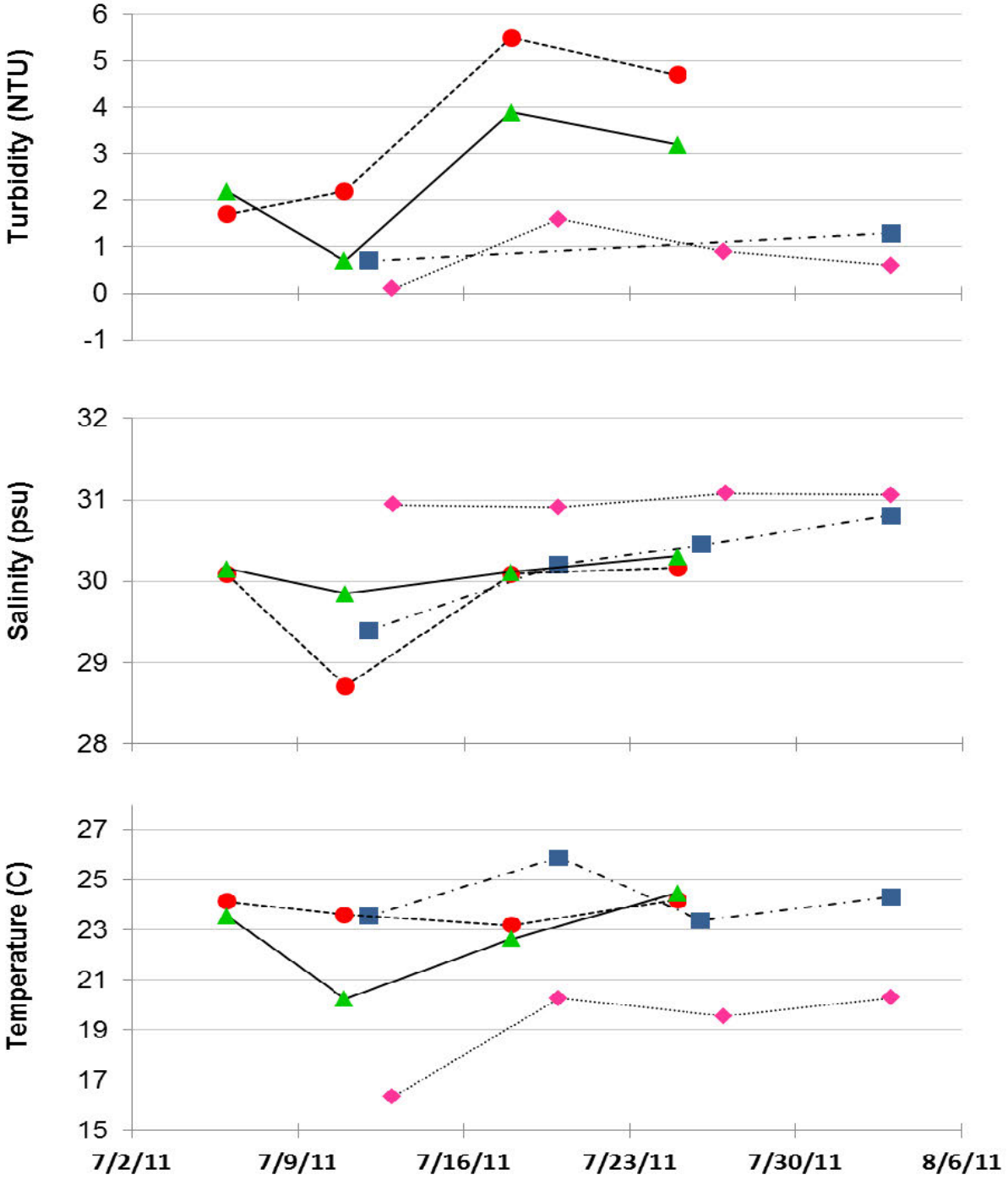


Figure 42 (cont.). Trend Station water-quality data from the 2011 assessment at CACO. Trend data depicted are derived from selected trend stations representative of an upper estuary and lower estuary station located in both Pleasant Bay and Nauset Harbor Stratums. The blue square (■) and pink diamond (♦) represent hexagons 11 and 3 in the upper and lower portions of Pleasant Bay, respectively. The red circle (●) and green triangle (▲) represent hexagons 18 and 23 in the upper and lower portions of Nauset Harbor. No trend stations were assigned to the Salt Pond Stratum.

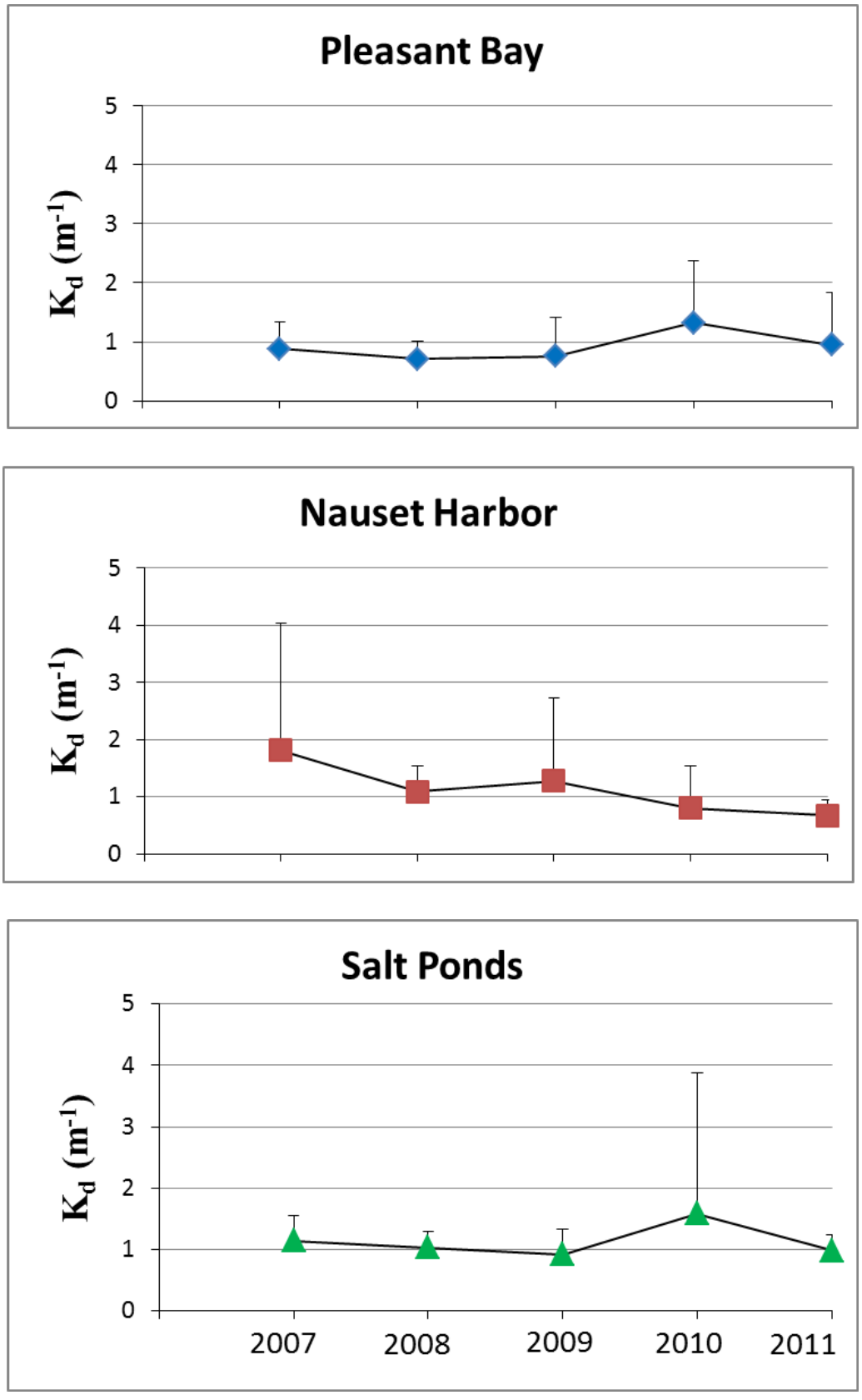


Figure 43. Unweighted means of K_d (+ SD) within strata at CACO.

Fire Island National Seashore

During the 2009 index period at FIIS the area-weighted average of chlorophyll *a* concentration was 24.30 µg/L and of PAR attenuation was 1.70 m^{-1} (Table 14), and during the 2011 index period these area-weighted averages dropped to 7.69 µg/L and 1.28 m^{-1}, respectively (Table 16). Repeated measures analysis of system-wide means showed significant differences for these two parameters between years ($P < 0.001$ for chlorophyll *a*; $P < 0.05$ for K_d). Area-weighted averages of dissolved oxygen concentration in bottom waters ranged from 8.37 mg/L in 2009 (Table 14) to 7.61 mg/L in 2011 (Table 16), or about 115% to 108% of the saturation concentrations, with no significant difference between years in the system-wide means ($P = 0.36$).

In 2009 the majority of the estuary area at FIIS rated poor condition for chlorophyll *a* concentration (72%, Figure 44) and fair to poor for water clarity (68% combined, Figure 46). The spatial distribution of water-clarity measurements showed that condition was best near the inlets at the western and eastern ends of the estuary, near the inlet sources of oceanic flushing (Figure 46). Daytime dissolved-oxygen concentrations were high throughout the estuary, however (Figure 45). The weekly variability in chlorophyll *a* concentrations was greatest near the eastern inlet (Table 15, trend stations 25 and 30), where levels declined dramatically following the first week of sampling, coincident with a decline in turbidity and an increase in salinity (Figure 48). The continuous records for K_d, chlorophyll concentration, and dissolved oxygen concentration in 2009 failed to meet data-quality objectives and were thus omitted from the data set. In 2011 all of the estuary rated fair to good for chlorophyll *a* concentration (Figure 49) and most rated fair to good for water clarity (83% combined, Figure 51). Weekly trends varied substantially among water quality parameters and the eastern end, middle, and western ends of the estuary (Figure 53).

2009 Index Period

Table 14. Area-weighted average water-quality condition at FIIS during the 2009 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	1.70	- -	- -	- -
Dissolved oxygen (mg/L)	- -	8.35	8.33	8.37
Dissolved oxygen, % Saturation	- -	114.89	113.39	114.65
Chlorophyll *a* (µg/L)	- -	24.30	- -	- -
Turbidity (NTU)	- -	3.67	3.85	4.03
Temperature (°C)	- -	24.12	23.49	23.85
Salinity (psu)	- -	25.16	25.48	25.36

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

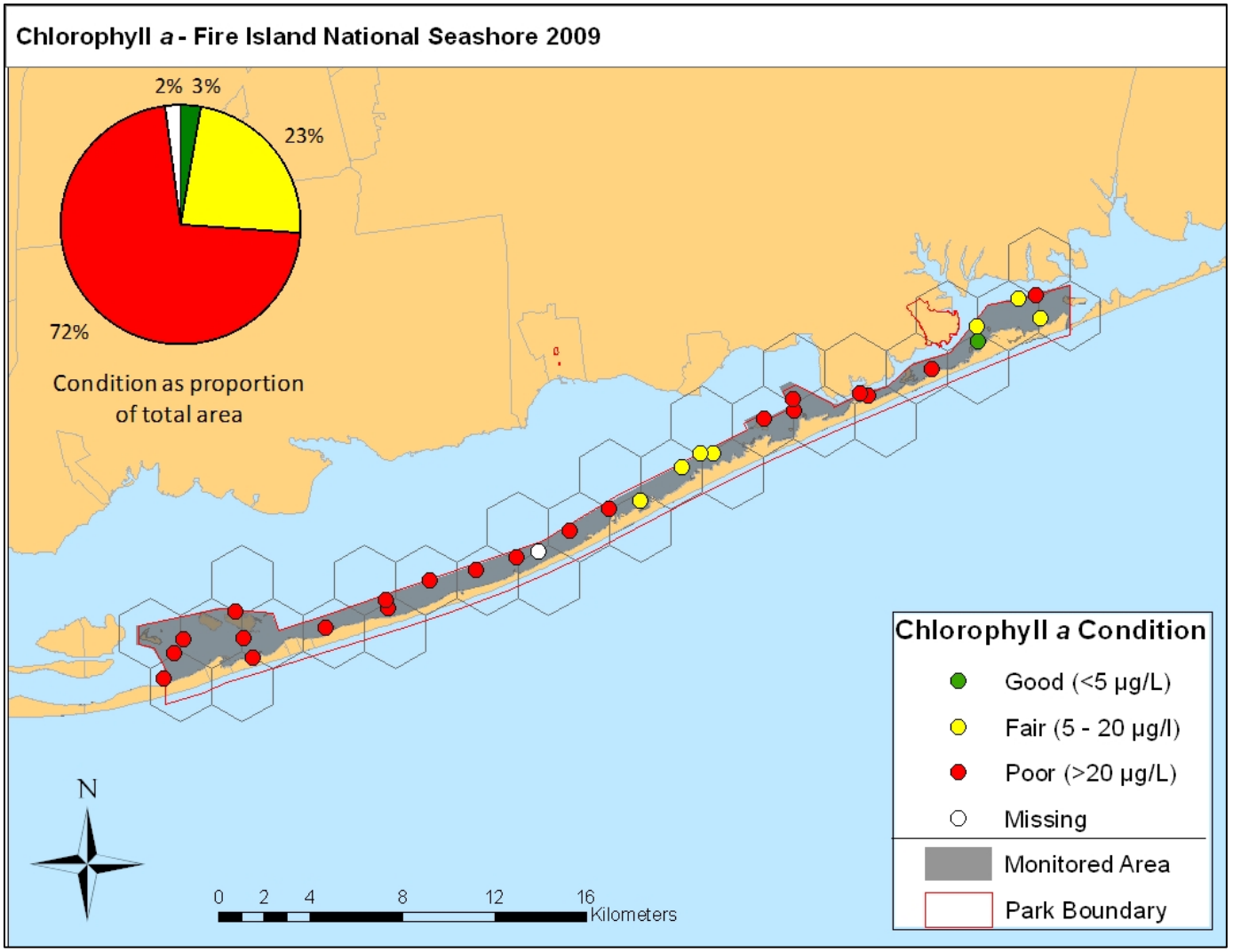


Figure 44. Chlorophyll *a* (µg/L) concentration in surface samples from the 2009 assessment at FIIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

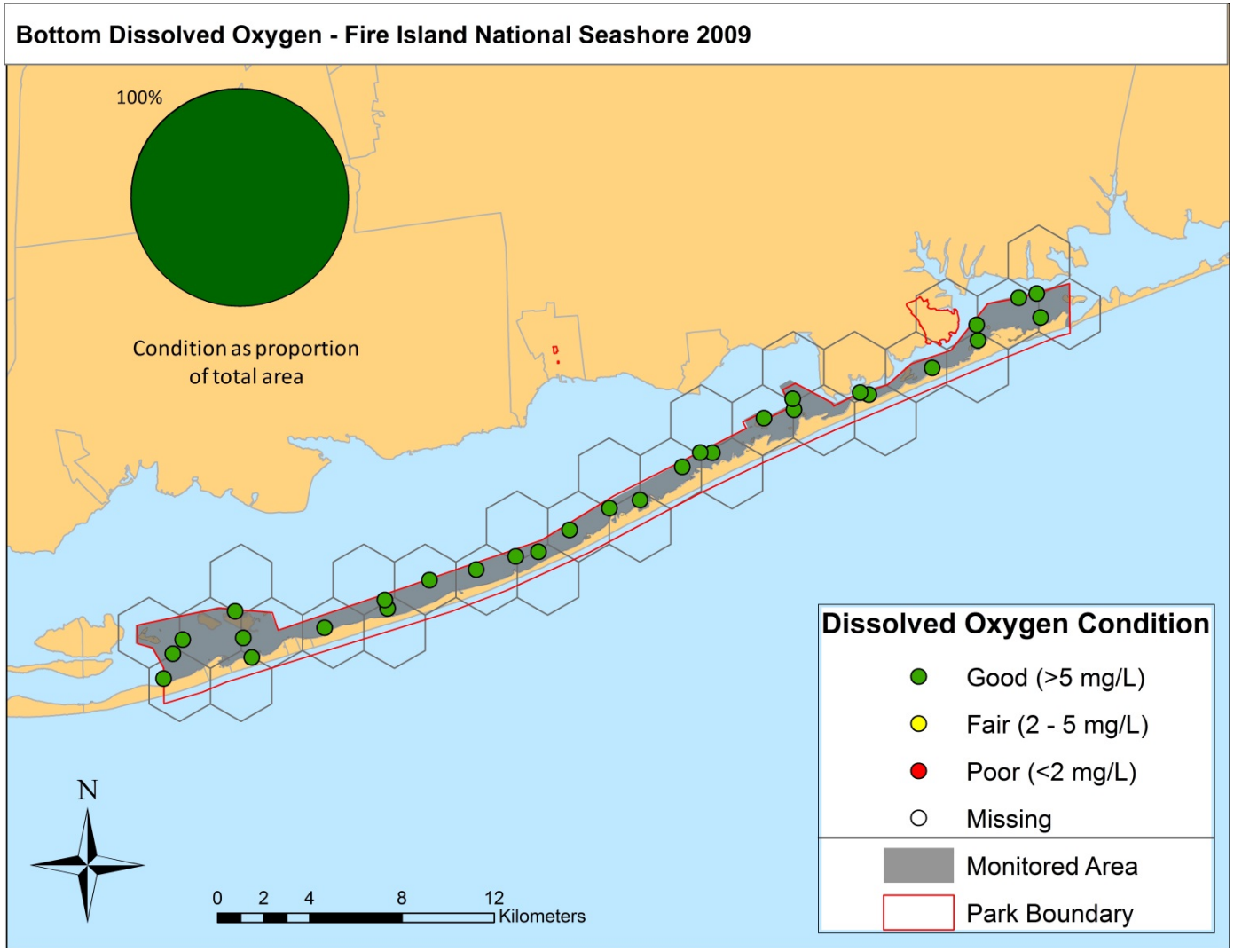


Figure 45. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2009 assessment at FIIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

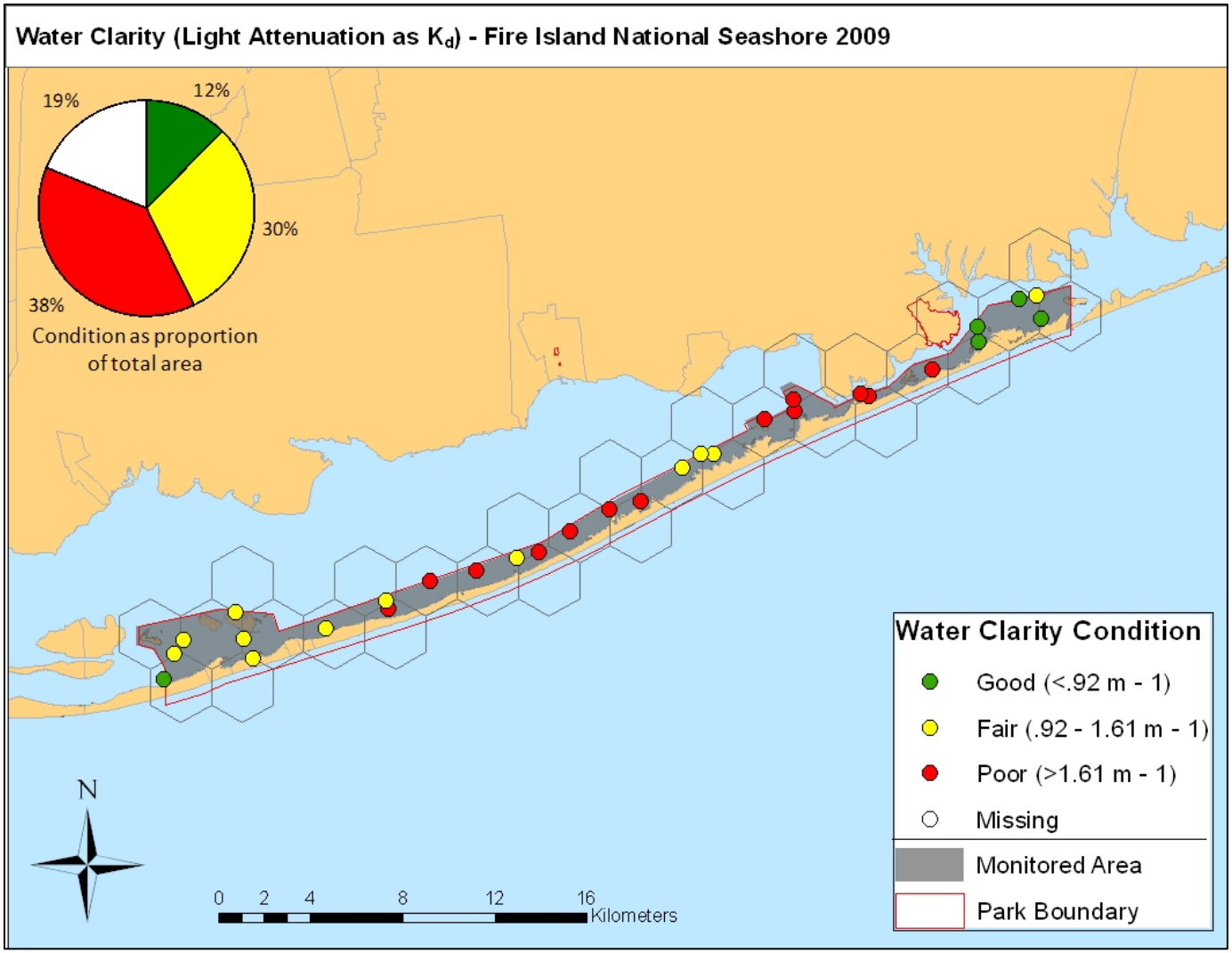


Figure 46. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2009 assessment at FIIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

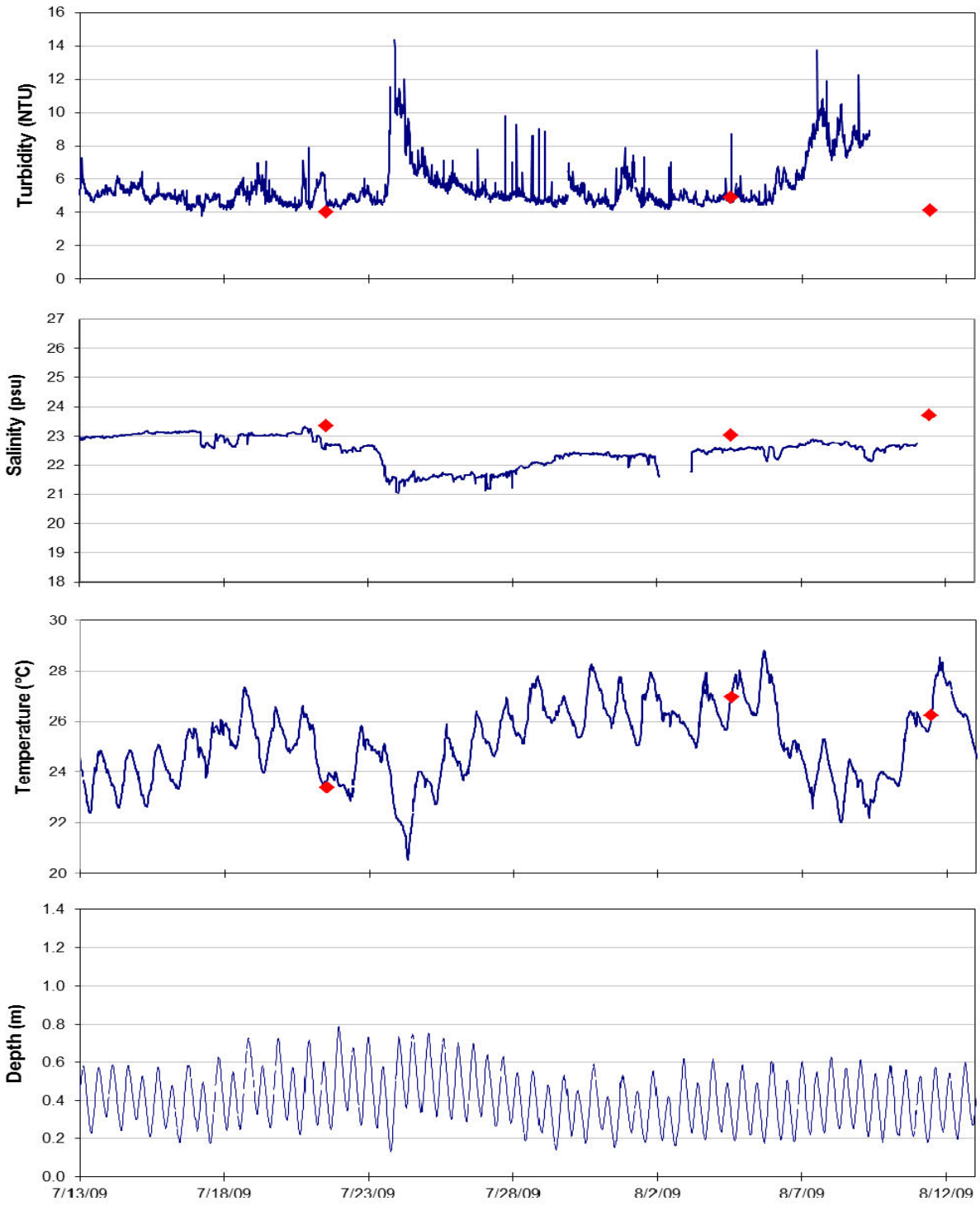


Figure 47. Continuous water-quality data from the 2009 assessment at FIIS. (The $K_{d,}$ Chlorophyll *a*, and Dissolved Oxygen data did not meet quality objectives in 2009 so are not presented.) All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 15. Trend-station water-quality data from the 2009 assessment at FIIS.

		Trend Stations (Hexagons)					
Measure	**Statistic**	**5**	**10**	**15**	**20**	**25**	**30**
PAR attenuation	mean	1.51	1.88	1.69	2.17	1.82	0.77
(K_d (m^{-1}))	std.dev.	0.05	0.19	0.84	1.58	1.02	0.55
	n	4	4	3	3	4	4
Temperature	mean	24.19	24.69	25.88	25.81	24.82	21.03
(°C)	std.dev.	1.08	1.42	2.31	2.06	2.14	1.22
	n	4	4	4	4	4	4
Salinity	mean	26.83	23.51	22.99	21.45	24.18	29.04
(psu)	std.dev.	0.91	0.31	0.37	1.60	2.74	3.53
	n	4	4	4	4	4	4
Dissolved oxygen	mean	8.5	8.0	8.8	7.7	7.7	8.8
(mg/L)	std.dev.	1.6	0.5	0.7	0.6	0.6	1.2
	n	4	4	4	4	4	4
Turbidity	mean	4.0	5.1	3.3	4.7	3.0	1.8
(NTU)	std.dev.	0.4	1.5	0.4	0.8	1.7	2.2
	n	4	4	4	4	4	4
Chlorophyll *a*	mean	26.4	32.2	22.4	31.1	33.4	13.4
(µg/L)	std.dev.	2.3	2.0	5.2	2.4	19.0	15.7
	n	4	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Location of hexagons with trend stations is shown in Figure 3. - -, no data.]

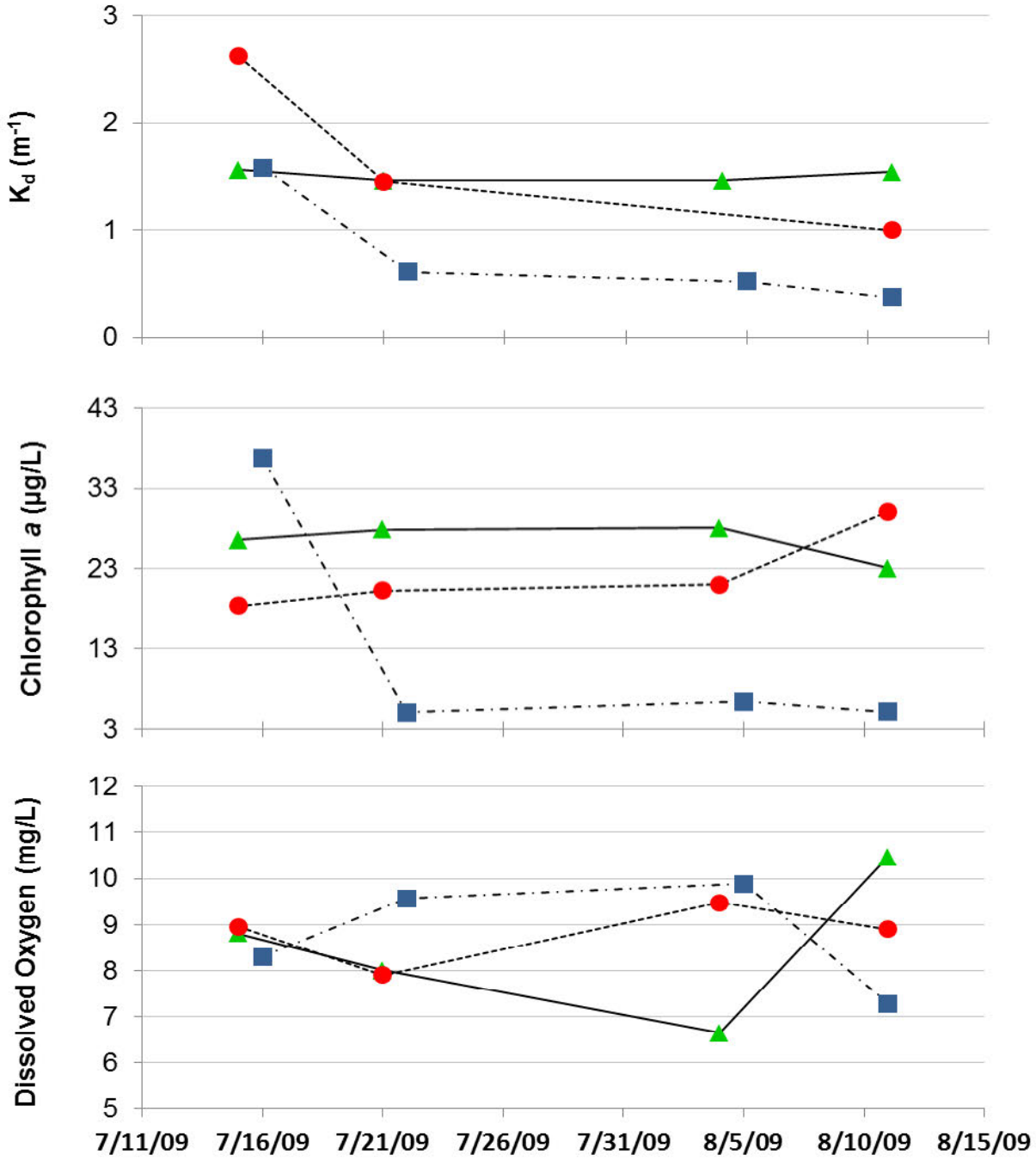


Figure 48. Trend Station water-quality data from the 2009 assessment at FIIS. Trend data depicted are derived from selected trend stations representative of an upper, middle and lower estuary station. The blue square (■) represents hexagon 30 in the upper portion of the FIIS estuary, the red circle (●) represents hexagon 15, mid estuary, while the green triangle (▲) represents hexagon 5 in the lower portion of the estuary.

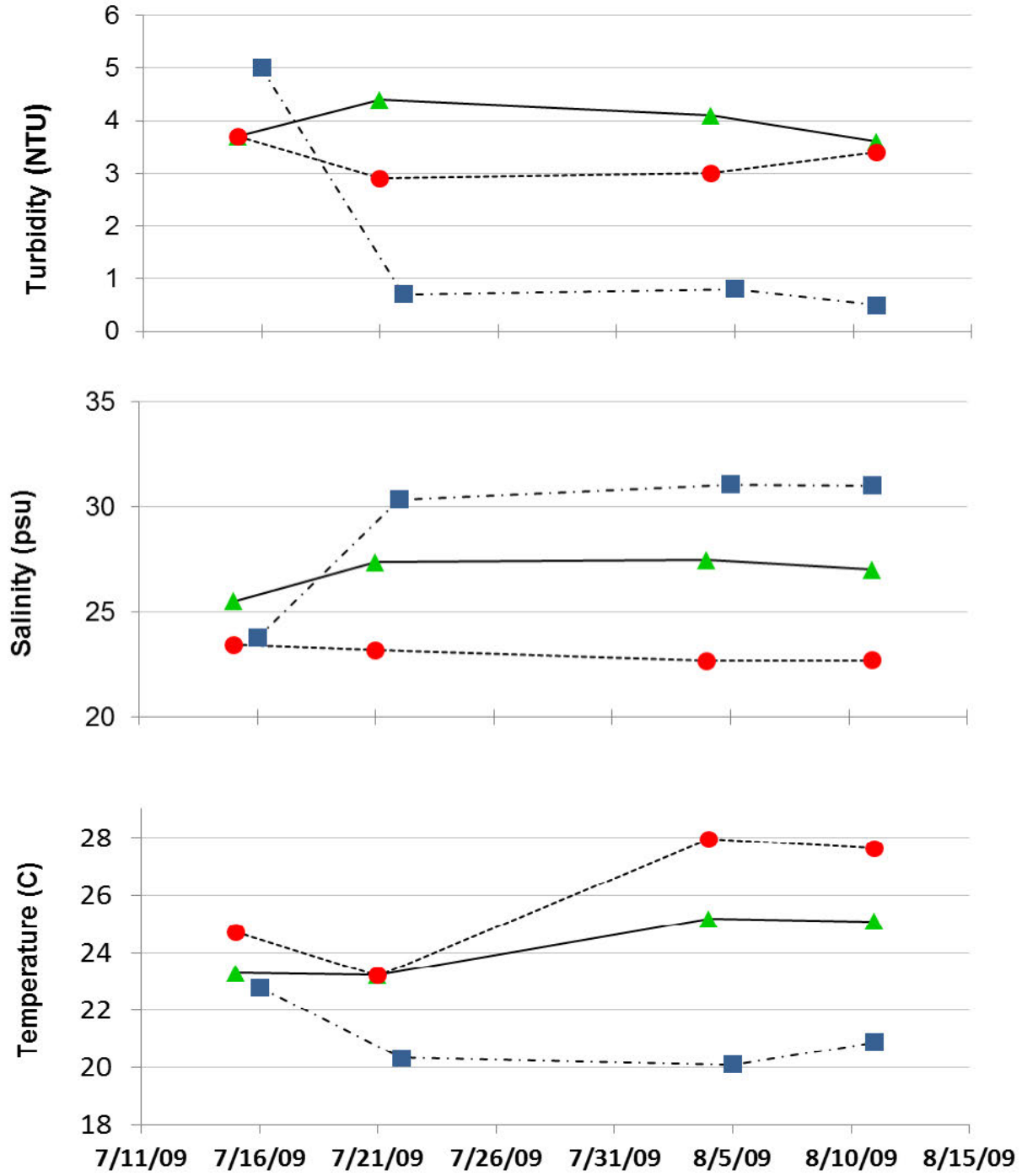


Figure 48 (cont.). Trend Station water-quality data from the 2009 assessment at FIIS. Trend data depicted are derived from selected trend stations representative of an upper, middle and lower estuary station. The blue square (■) represents hexagon 30 in the upper portion of the FIIS estuary, the red circle (●) represents hexagon 15, mid estuary, while the green triangle (▲) represents hexagon 5 in the lower portion of the estuary.

2011 Index Period

Table 16. Weighted average water-quality condition at FIIS during the 2011 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	1.28	- -	- -	- -
Dissolved oxygen (mg/L)	- -	7.70	7.34	7.61
Dissolved oxygen, % Saturation	- -	109.10	103.96	107.88
Chlorophyll *a* (µg/L)	- -	7.69	- -	- -
Turbidity (NTU)	- -	2.42	2.89	2.43
Temperature (°C)	- -	25.28	24.98	25.27
Salinity (psu)	- -	26.99	27.60	26.99

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

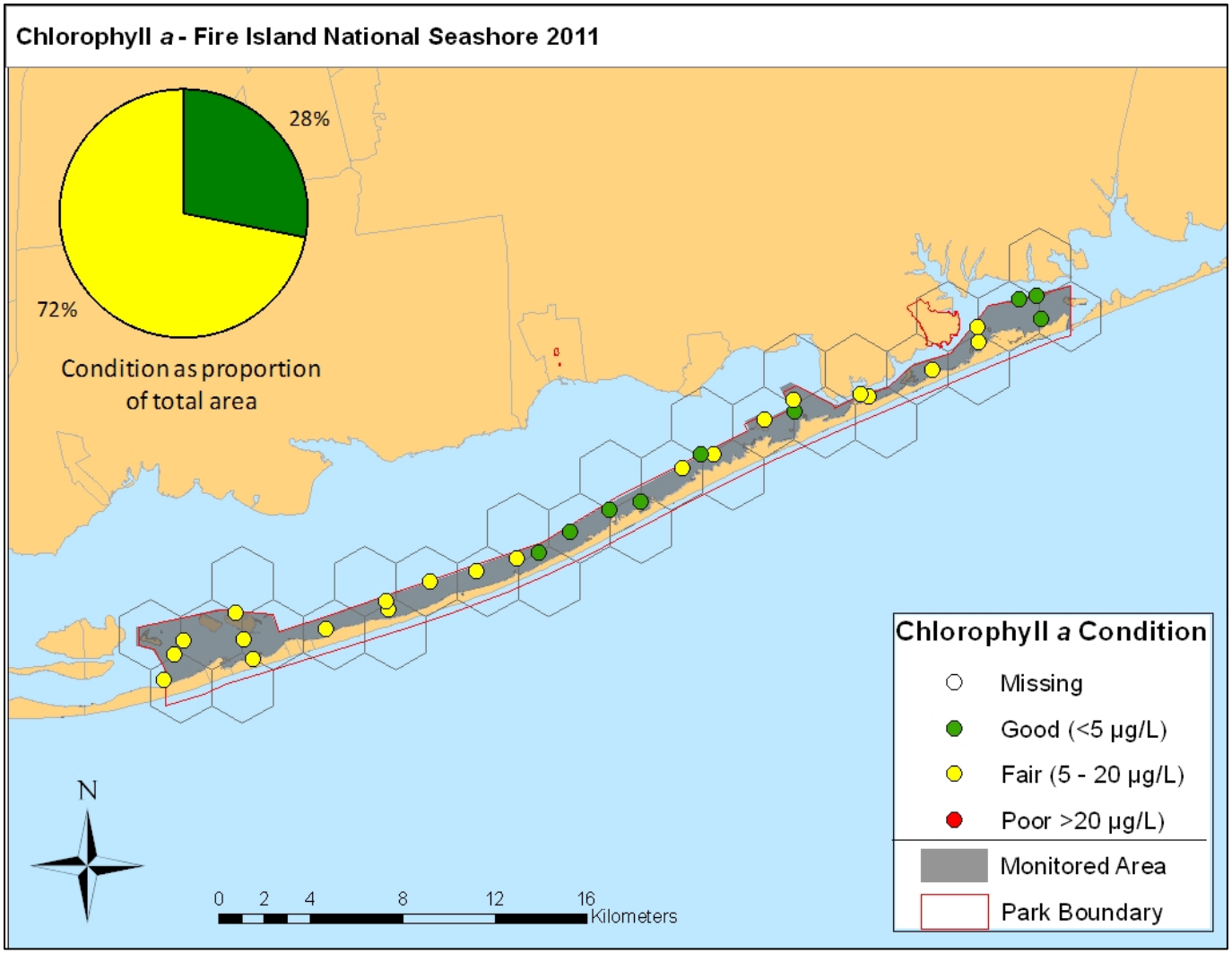


Figure 49. Chlorophyll *a* (µg/L) concentration in surface samples from the 2011 assessment at FIIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

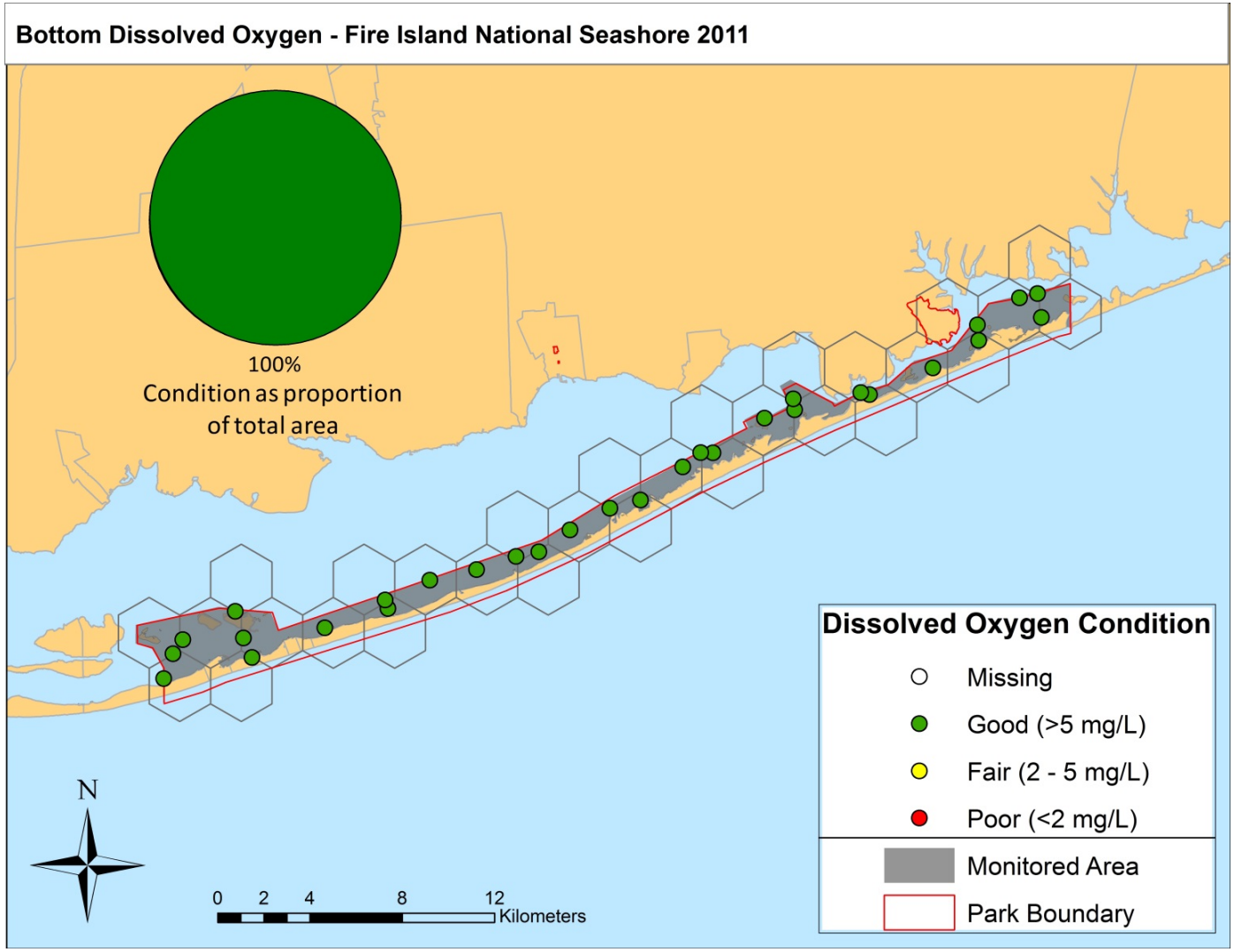


Figure 50. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2011 assessment at FIIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

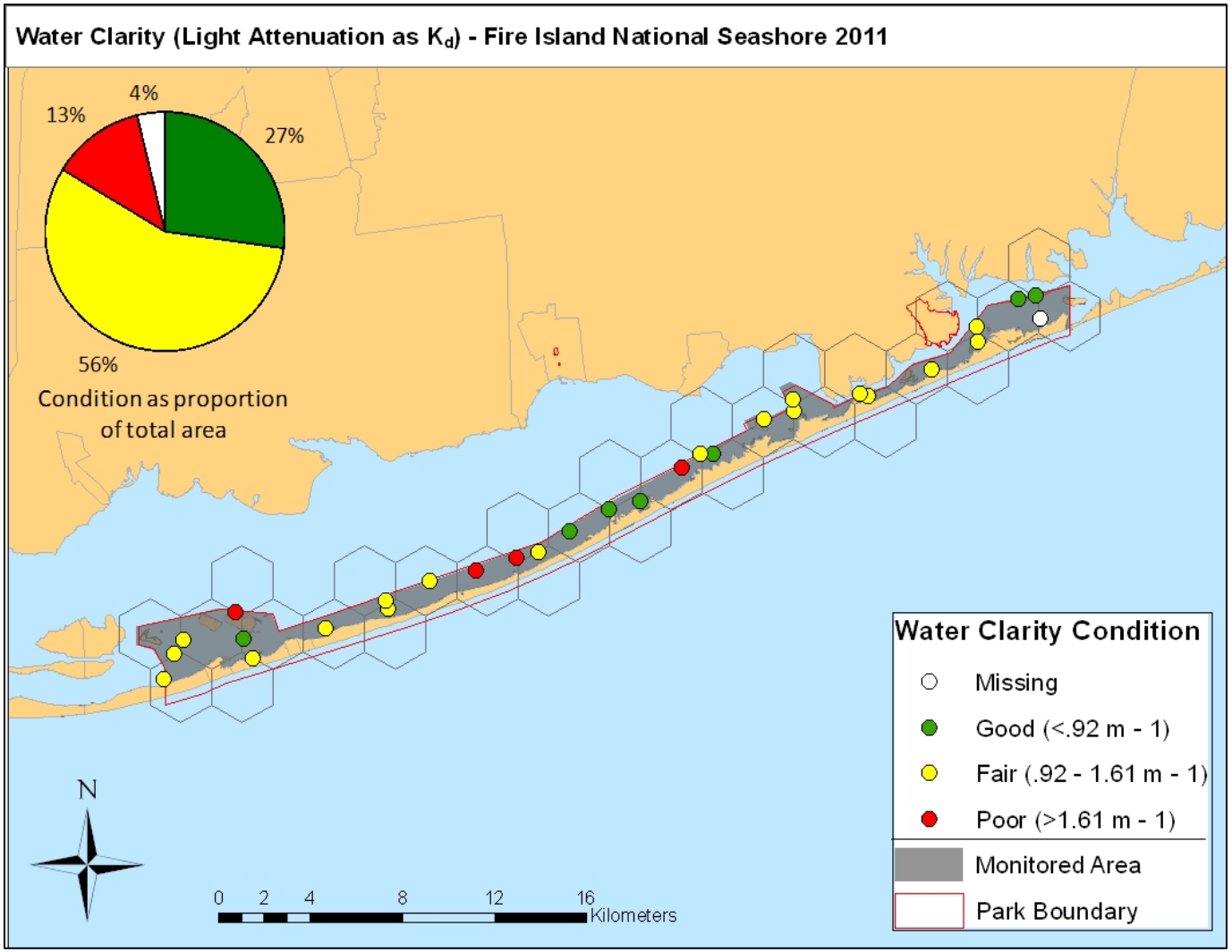


Figure 51. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2011 assessment at FIIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

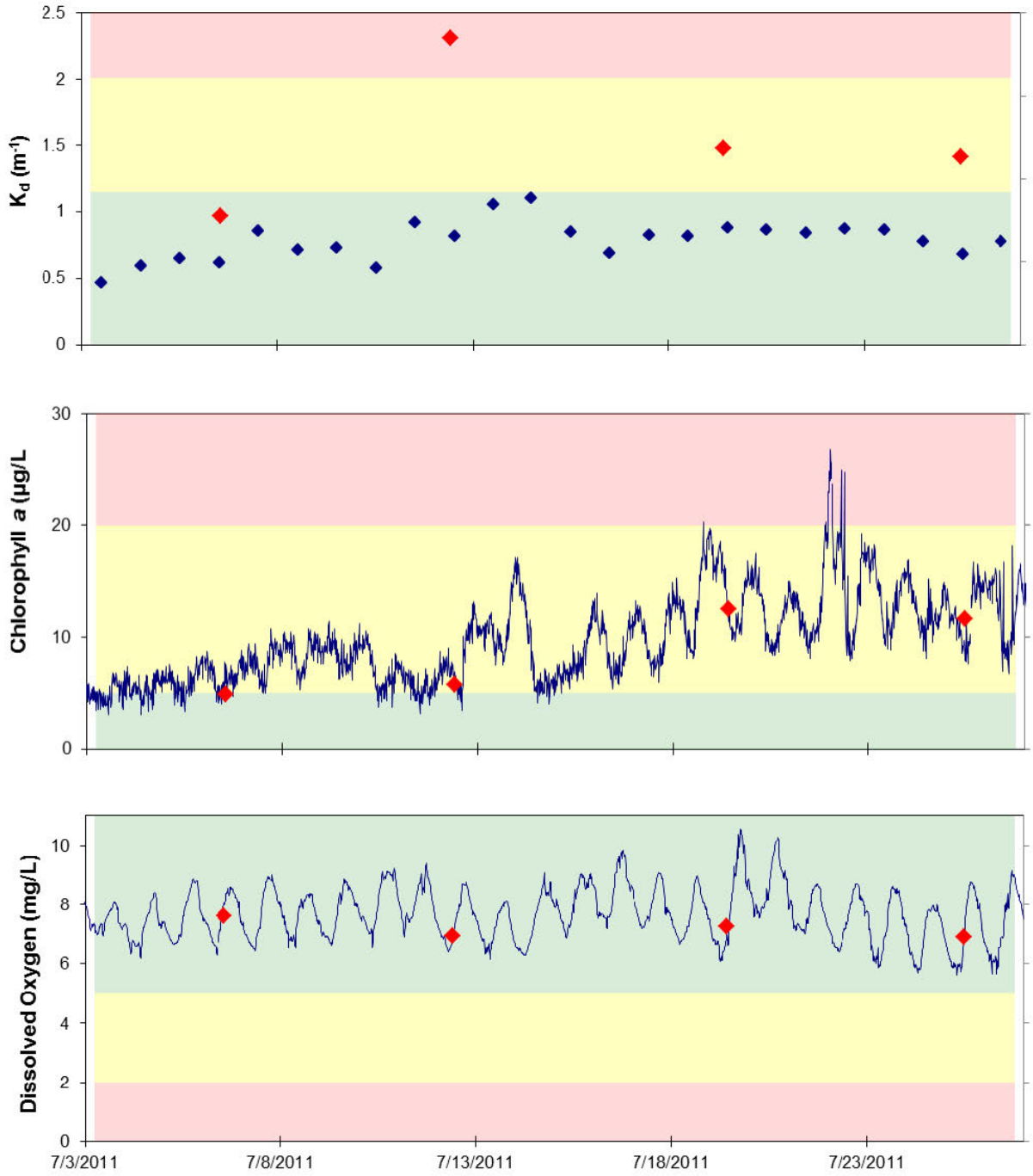


Figure 52. Continuous water-quality data from the 2011 assessment at FIIS. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN.

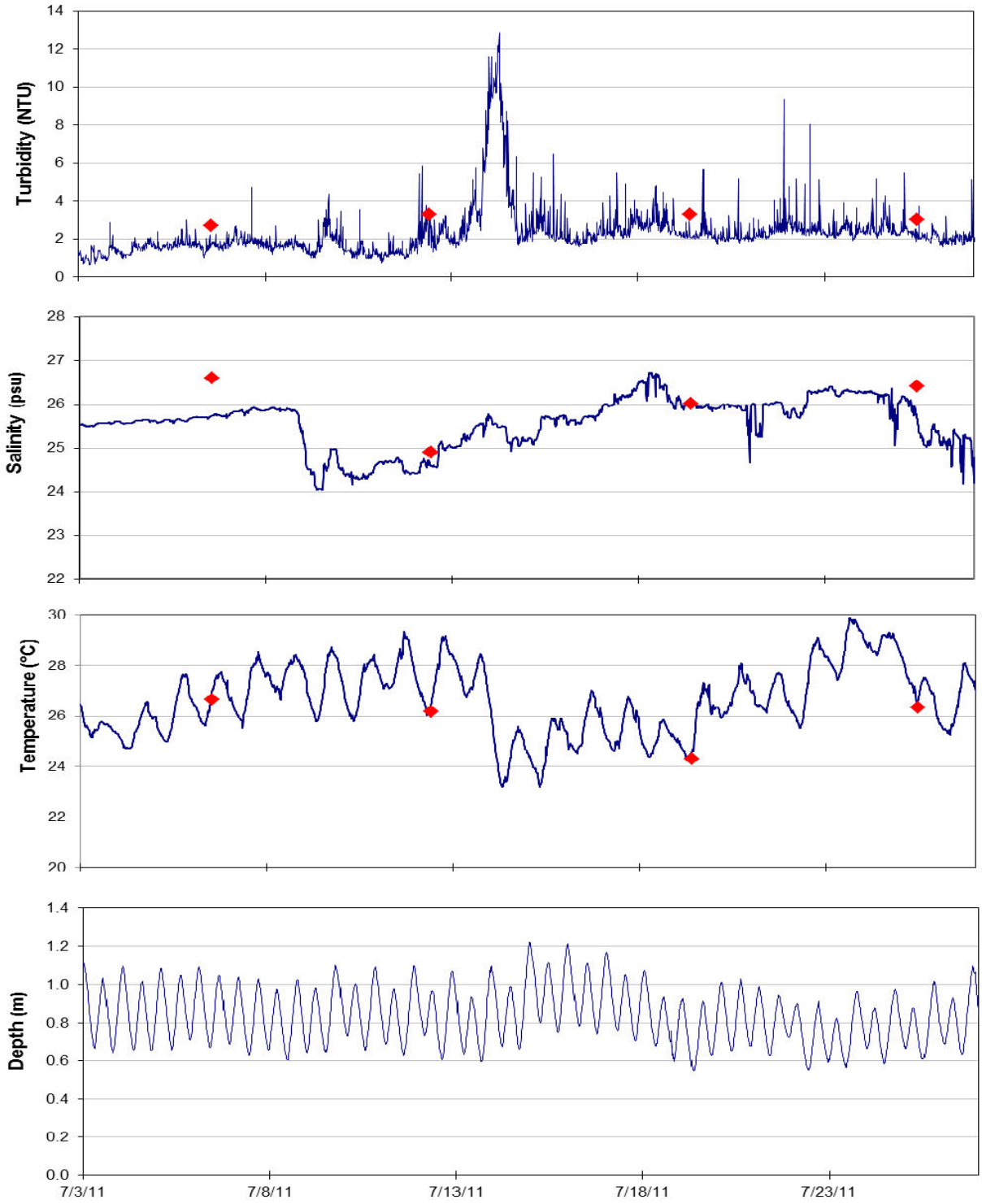


Figure 52 (cont.). Continuous water-quality data from the 2011 assessment at FIIS. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 17. Trend-station water-quality data from the 2011 assessment at FIIS.

		Trend Stations (Hexagons)					
Measure	**Statistic**	**5**	**10**	**15**	**20**	**25**	**30**
PAR attenuation	mean	1.13.	1.14	1.98	1.29	1.01	0.72
(K_d (m^{-1}))	std.dev.	0.29	0.16	1.26	0.36	0.68	0.59
	n	4	4	4	4	4	4
Temperature	mean	25.54	26.03	26.27	27.19	26.33	20.61
(°C)	std.dev.	1.32	0.97	1.37	0.59	0.70	4.74
	n	4	4	4	4	4	4
Salinity	mean	28.65	26.69	26.12	24.75	25.53	29.32
(psu)	std.dev.	0.74	0.69	0.50	0.91	1.81	3.17
	n	4	4	4	4	4	4
Dissolved oxygen	mean	6.9	7.3	7.2	8.6	8.0	7.9
(mg/L)	std.dev.	0.5	0.9	0.3	1.4	1.0	0.9
	n	4	4	4	4	4	4
Turbidity	mean	3.4	3.8	2.0	2.6	2.2	1.8
(NTU)	std.dev.	1.7	1.9	0.3	1.0	0.4	2.0
	n	4	4	4	4	4	4
Chlorophyll *a*	mean	14.4	10.0	9.3	7.8	8.1	7.0
(µg/L)	std.dev.	6.8	3.9	5.8	6.2	3.8	8.9
	n	4	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Location of hexagons with trend stations is shown in Figure 3. - -, no data.]

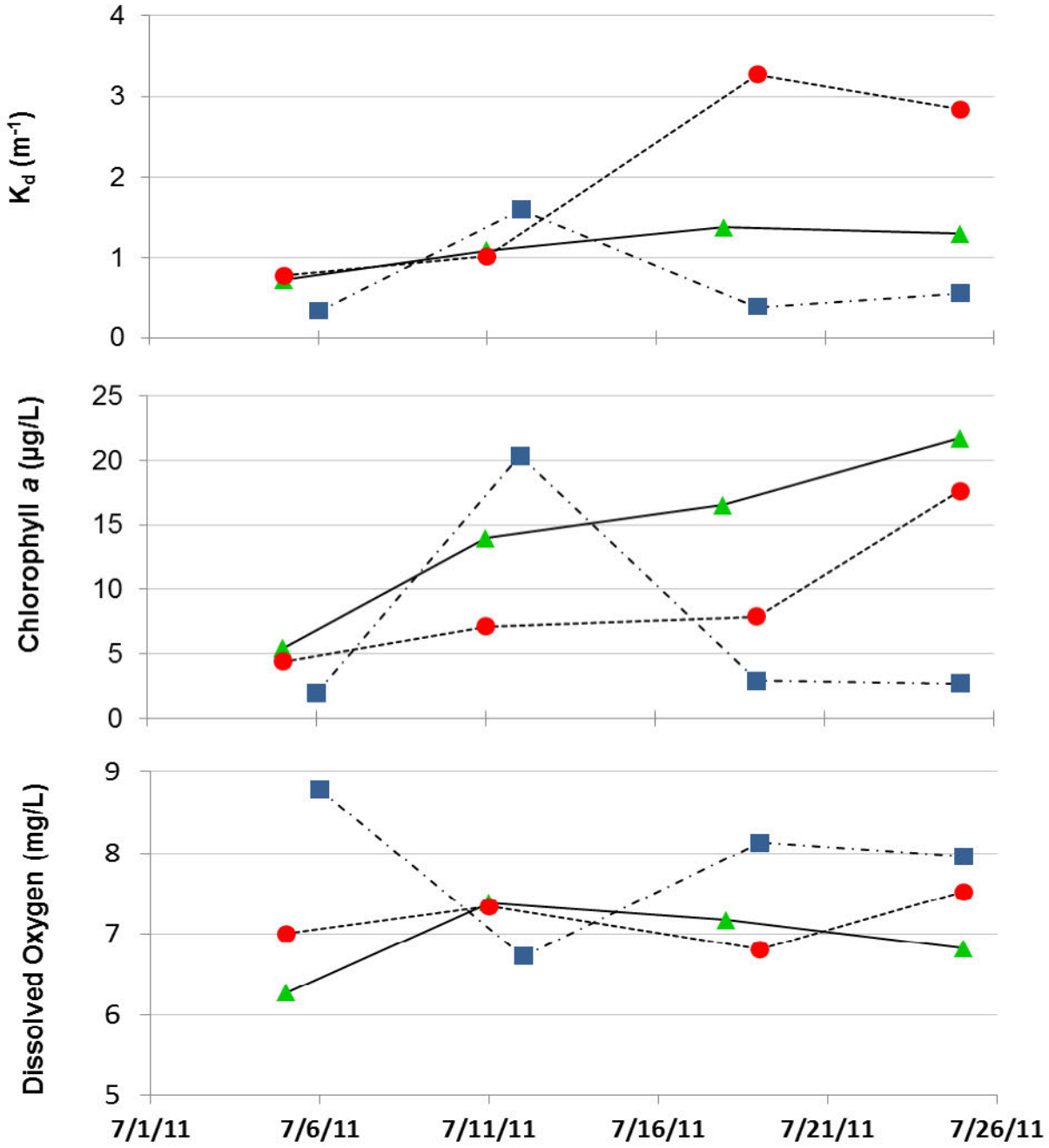


Figure 53. Trend Station water-quality data from the 2011 assessment at FIIS. Trend data depicted are derived from selected trend stations representative of an upper, middle and lower estuary station. The blue square (■) represents hexagon 30 in the upper portion of the FIIS estuary, the red circle (●) represents hexagon 15, mid estuary, while the green triangle (▲) represents hexagon 5 in the lower portion of the estuary.

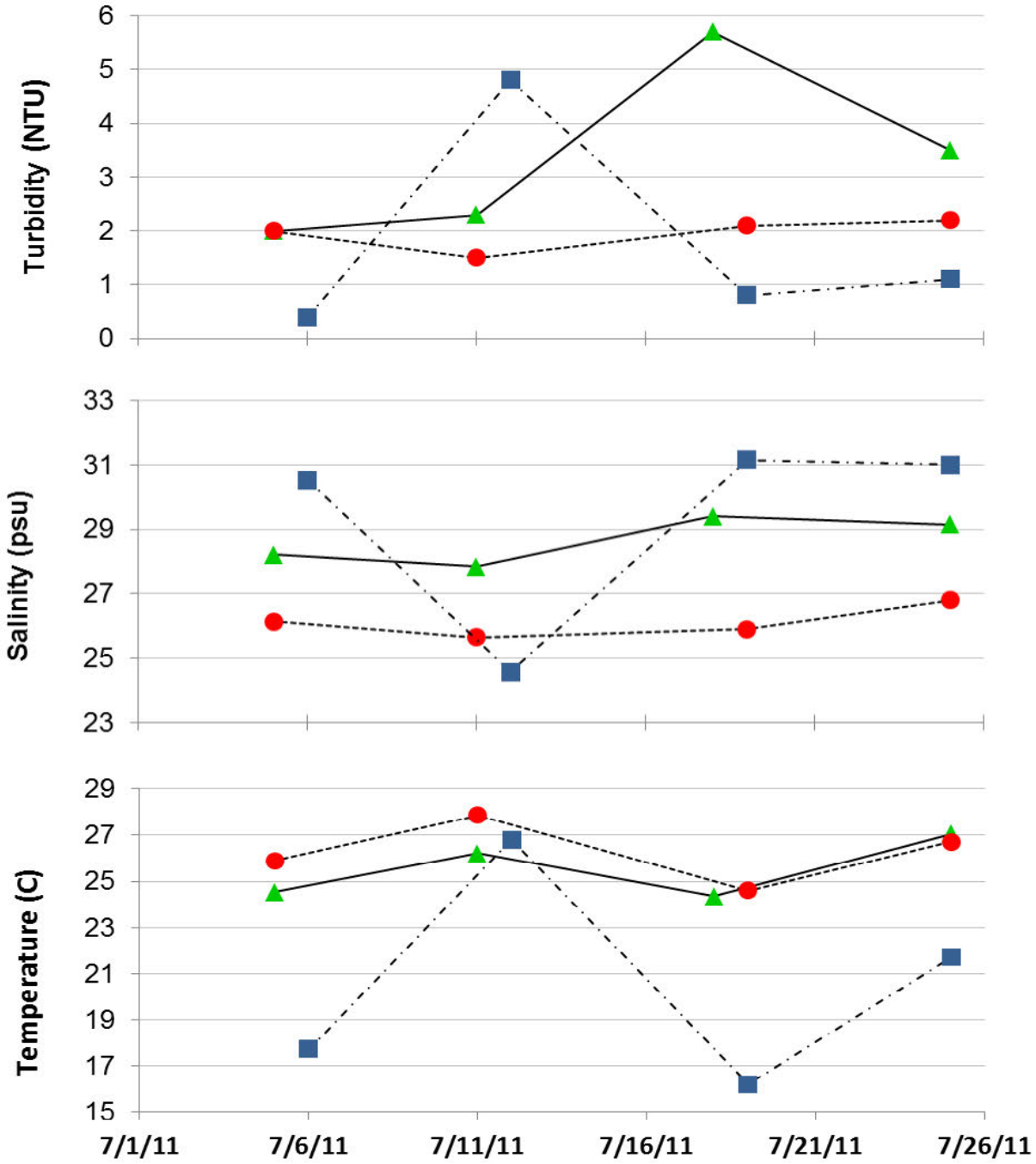


Figure 53 (cont.). Trend Station water-quality data from the 2011 assessment at FIIS. Trend data depicted are derived from selected trend stations representative of an upper, middle and lower estuary station. The blue square (■) represents hexagon 30 in the upper portion of the FIIS estuary, the red circle (●) represents hexagon 15, mid estuary, while the green triangle (▲) represents hexagon 5 in the lower portion of the estuary.

Gateway National Recreation Area

2010 Index Period

During the 2010 index period the area weighted average chlorophyll *a* concentration at GATE was 48.54 µg/L, the area-weighted average daytime dissolved oxygen concentration in bottom waters was 6.54 mg/L, or about 92% of the saturation concentration, and the area-weighted average water-column PAR attenuation coefficient (K_d) was 1.62 m^{-1} (Table 18). The baywide mean chlorophyll concentration was significantly greater in 2010 than it was during the last NCBN survey in 2006 (Kopp et al. 2009; $P < 0.05$), but there was no change detected in mean PAR attenuation coefficient (K_d) or bottom dissolved oxygen concentration since 2006 ($P > 0.05$).

In general, the water quality conditions improved with proximity to the mouth of Jamaica Bay. Most of the estuary fell in the poor condition class in terms of chlorophyll *a* concentration (Figure 54) and water clarity (Figure 56), with only stations closest to the source of oceanic flushing classified as fair (chlorophyll *a*, Figure 54) to good (water clarity, Figure 56). However, the majority of the estuary was classified as good in terms of daytime dissolved oxygen concentration (Figure 55), and the continuous monitoring data showed that the bottom dissolved oxygen concentrations generally remained above the threshold for good condition even at night (Figure 57). The continuous logging data showed short term peaks of chlorophyll *a* concentration that occurred outside of the sampling windows of the spatial survey (Figure 57). These short term phytoplankton blooms likely contributed to the increased light attenuation recorded by continuous logging during the same time period (Figure 57). Within-season variability in water-quality parameters is displayed by the trend-station data (Table 19, Figure 58).

Table 18. Area-Weighted average water-quality condition at GATE during the 2010 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	1.62	- -	- -	- -
Dissolved oxygen (mg/L)	- -	8.44	7.31	6.54
Dissolved oxygen, % Saturation	- -	119.82	103.40	92.09
Chlorophyll *a* (µg/L)	- -	48.54		
Turbidity (NTU)	- -	3.02	2.77	2.92
Temperature (°C)	- -	24.97	24.63	24.34
Salinity (psu)	- -	27.96	28.29	28.36

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable]

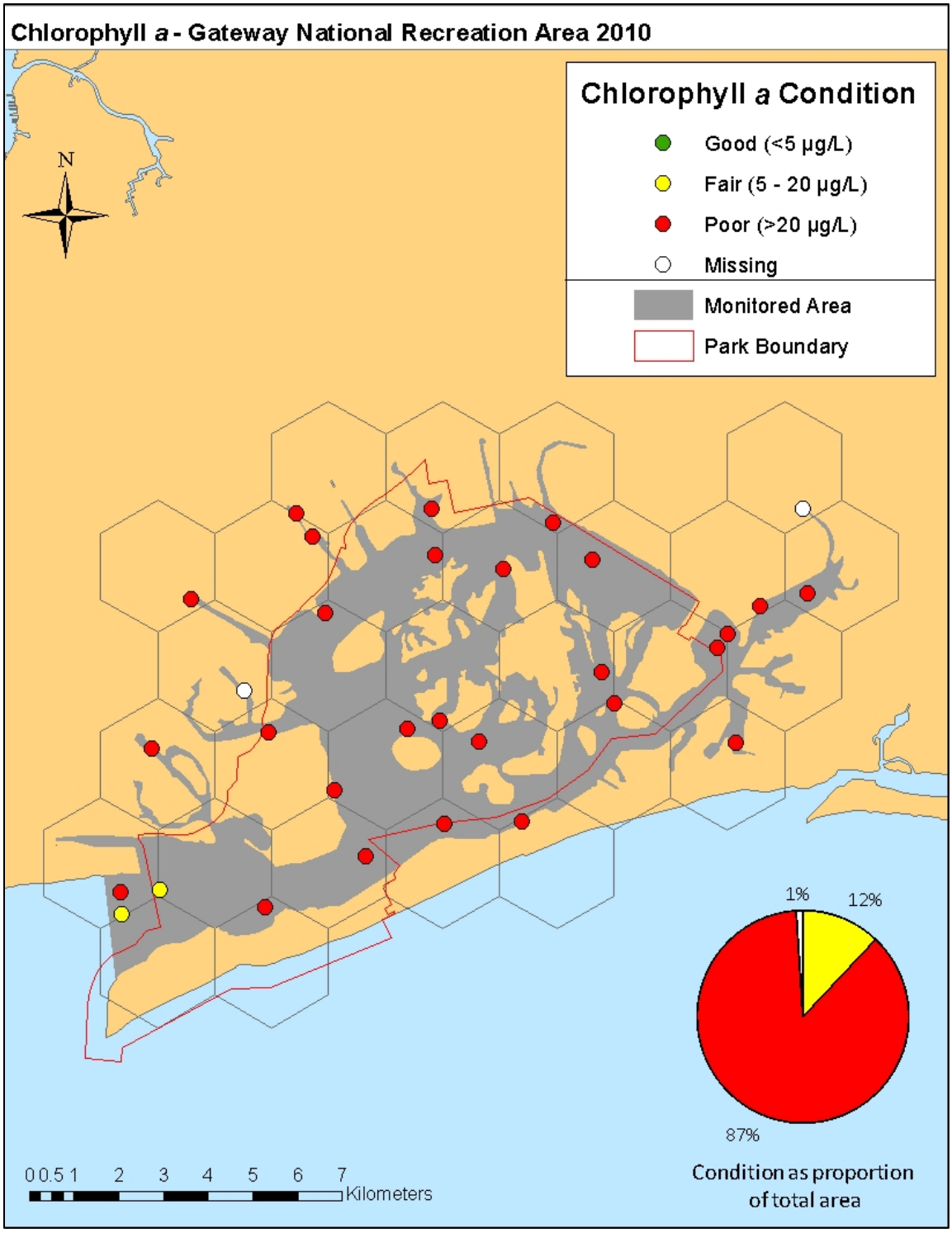


Figure 54. Chlorophyll *a* (µg/L) concentration in surface samples from the 2010 assessment at GATE. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

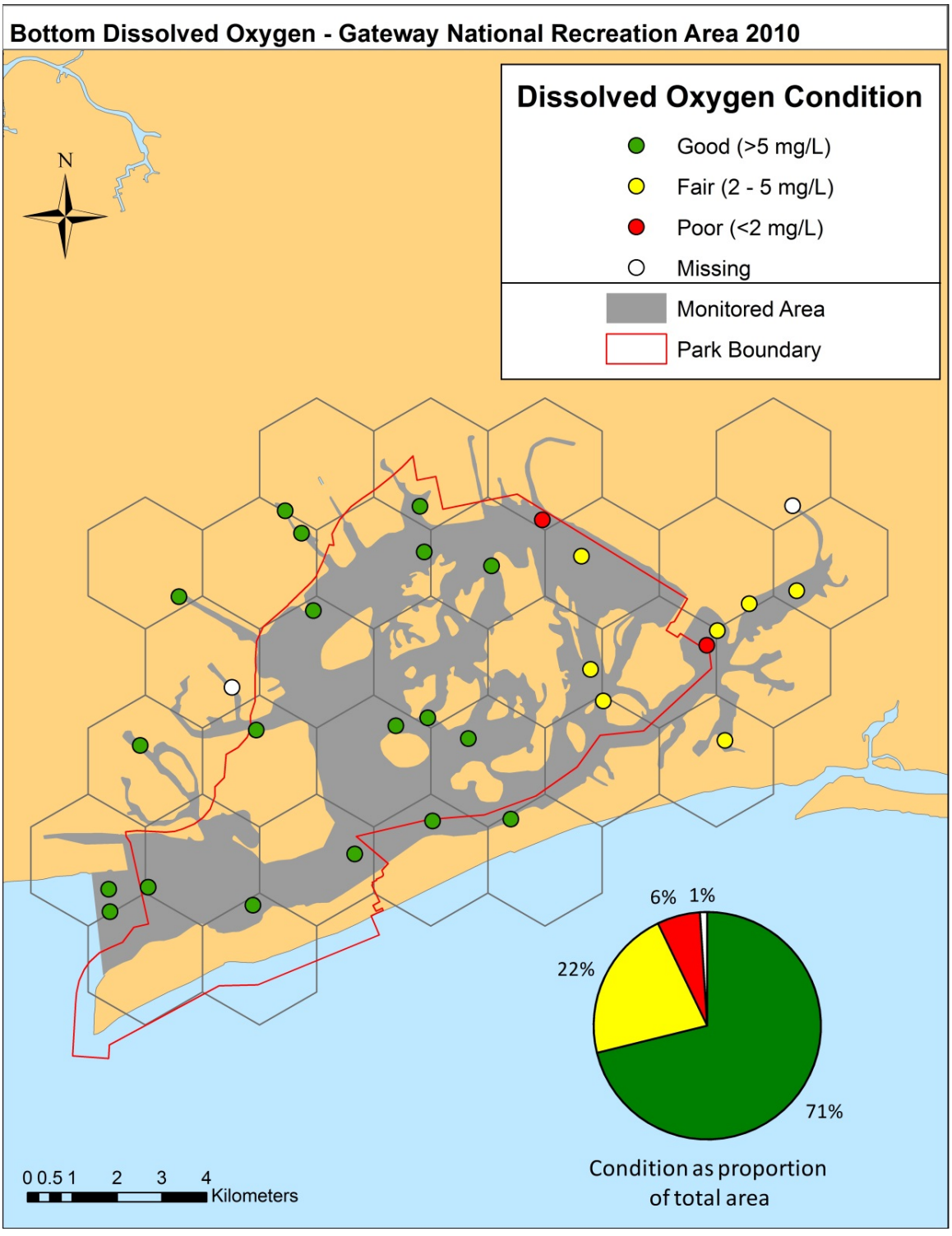


Figure 55. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2010 assessment at GATE. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

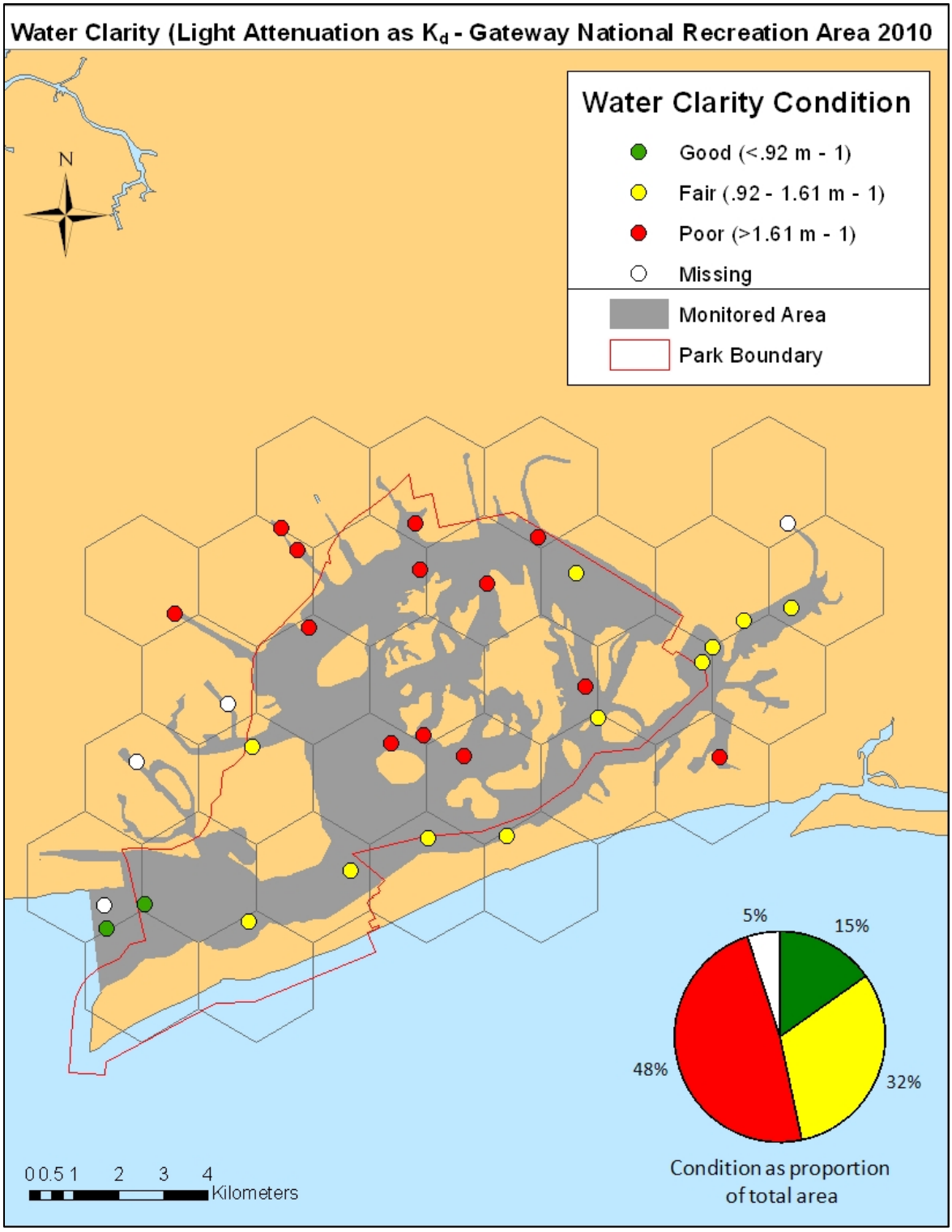


Figure 56. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2010 assessment at GATE. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

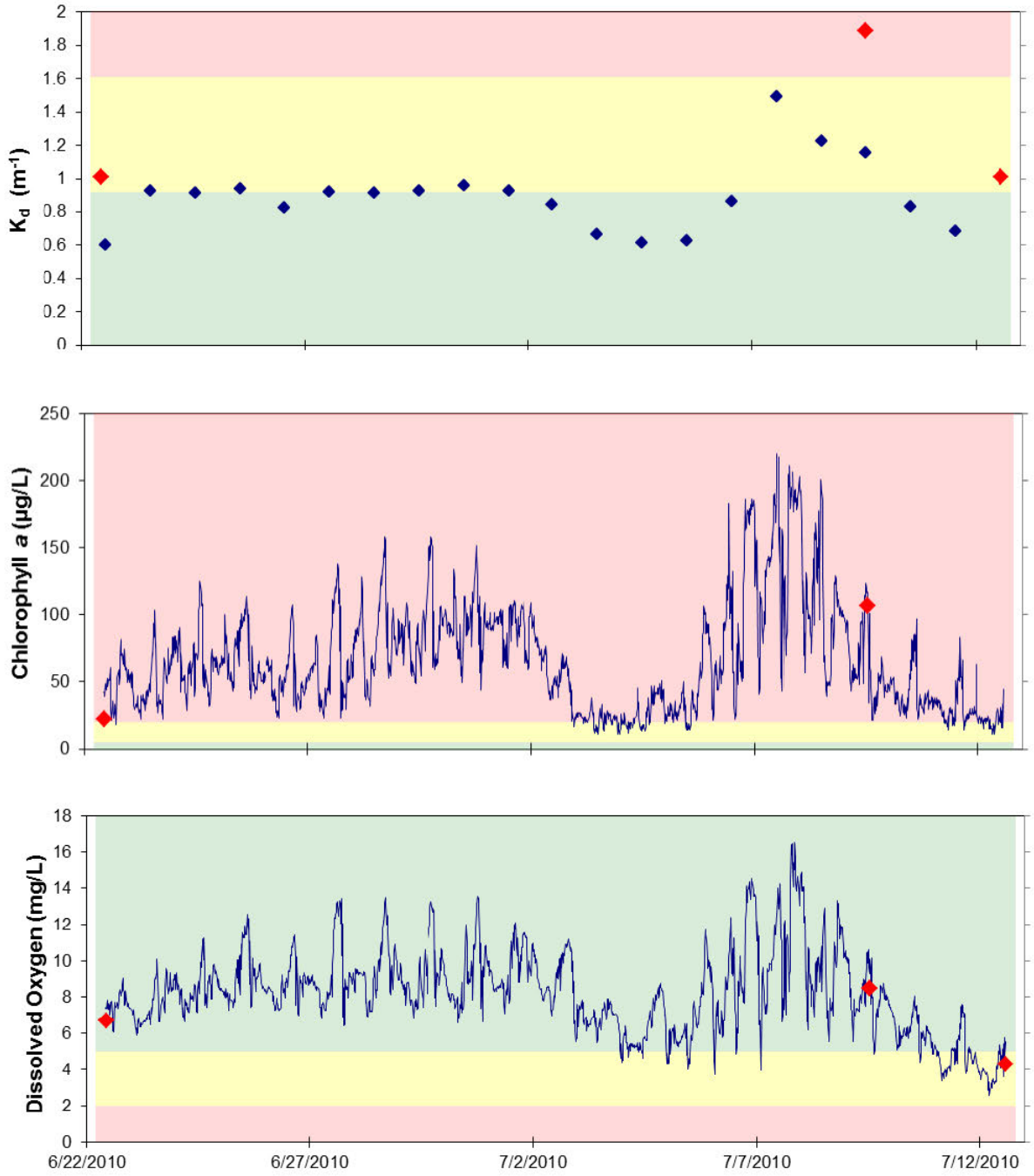


Figure 57. Continuous water-quality data from the 2010 assessment at GATE. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Figure indicates the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

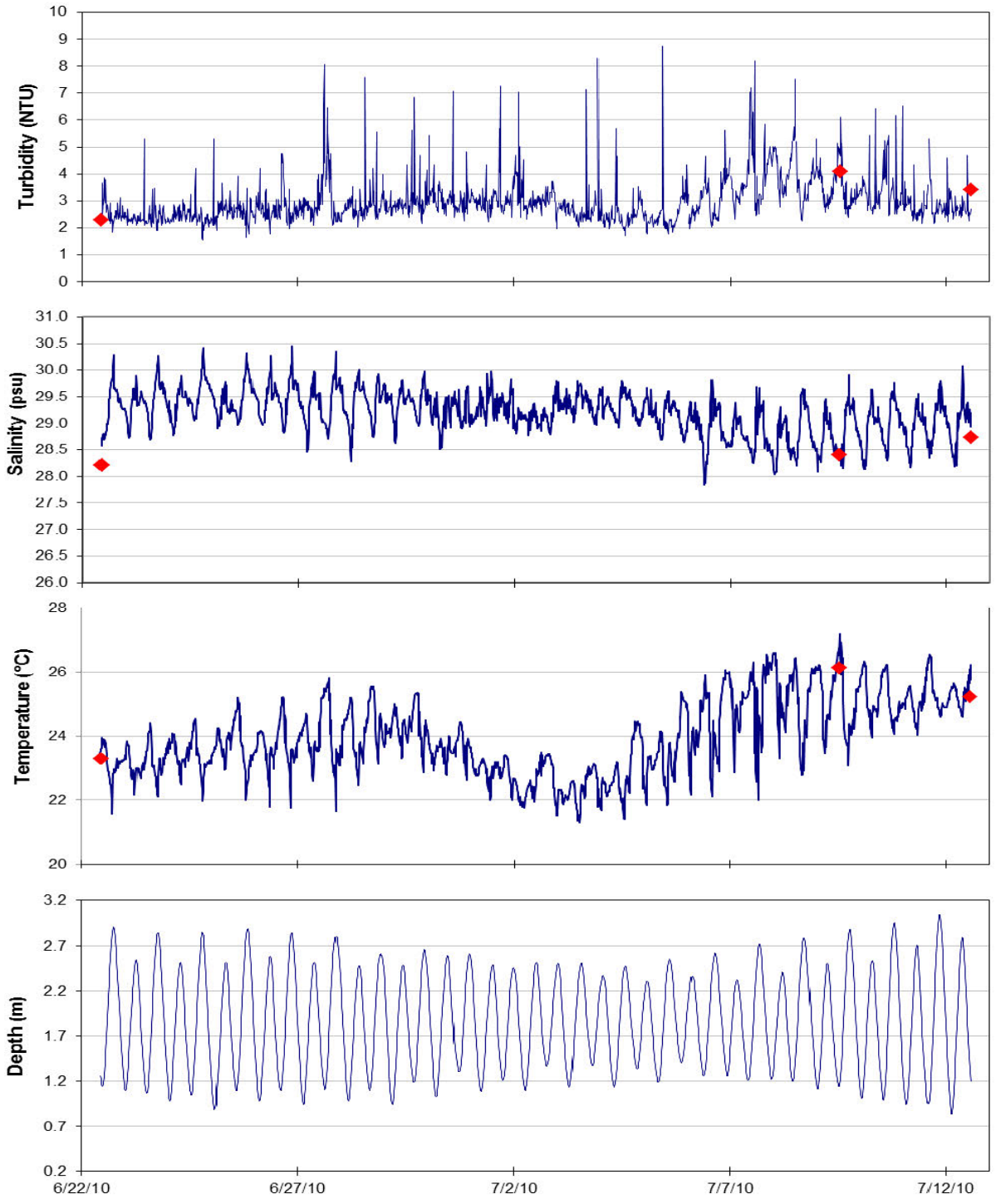


Figure 57 (cont.). Continuous water-quality data from the 2010 assessment at GATE. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 19. Trend-station water-quality data from the 2010 assessment at GATE.

		Trend Stations (Hexagons)					
Measure	**Statistic**	**1**	**5**	**7**	**16**	**24**	**29**
PAR attenuation	mean	0.81	1.09	1.15	2.14	1.68	2.01
(K_d (m^{-1}))	std.dev.	0.23	0.26	0.11	0.47	0.57	0.57
	n	3	4	4	4	5	2
Temperature	mean	22.04	23.10	24.44	26.13	25.16	25.50
(°C)	std.dev.	2.28	1.89	1.51	1.22	1.22	1.52
	n	4	4	4	4	4	3
Salinity	mean	29.71	29.29	28.62	28.50	27.16	27.11
(psu)	std.dev.	1.60	1.13	1.18	0.83	0.78	0.88
	n	4	4	4	4	4	3
Dissolved oxygen	mean	7.2	6.6	5.7	8.3	2.1	1.4
(mg/L)	std.dev.	1.3	0.8	2.1	3.1	1.3	0.9
	n	4	4	4	4	5	2
Turbidity	mean	1.7	2.0	2.5	4.9	2.4	2.6
(NTU)	std.dev.	0.9	0.6	0.4	1.0	0.9	1.1
	n	4	4	4	4	4	3
Chlorophyll *a*	mean	19.0	41.8	31.8	50.5	66.5	64.3
(µg/L)	std.dev.	10.2	23.7	8.1	17.8	27.6	31.5
	n	4	4	4	4	4	3

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Location of hexagons with trend stations is shown in Figure 4. - -, no data.]

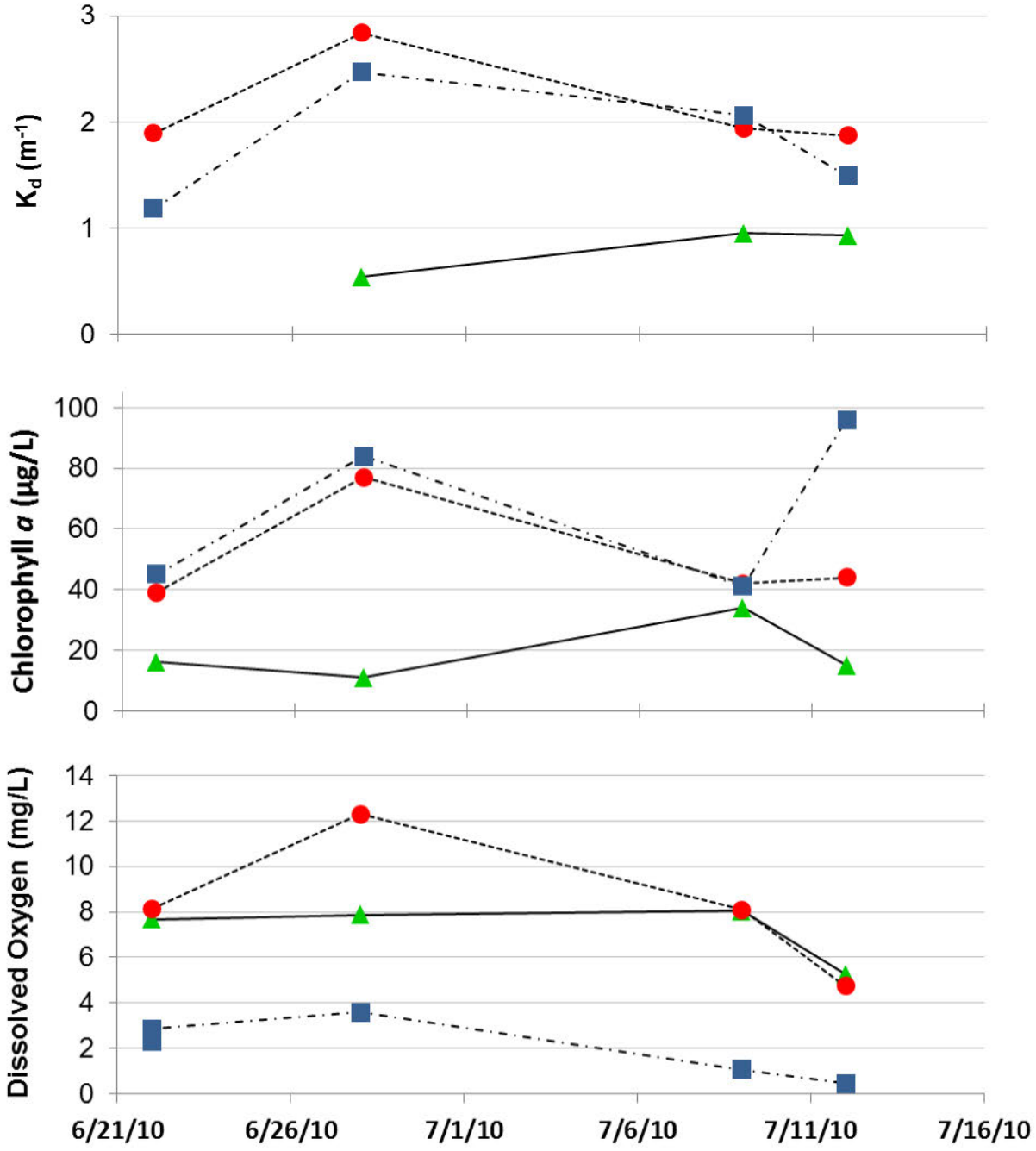


Figure 58. Trend Station water-quality data from the 2010 assessment at GATE. Trend data depicted are derived from selected trend stations representative of an upper, middle and lower estuary station. The blue square (■) represents hexagon 24 in the upper portion of the GATE estuary, the red circle (●) represents hexagon 16, mid estuary, while the green triangle (▲) represents hexagon 1 in the lower portion of the estuary.

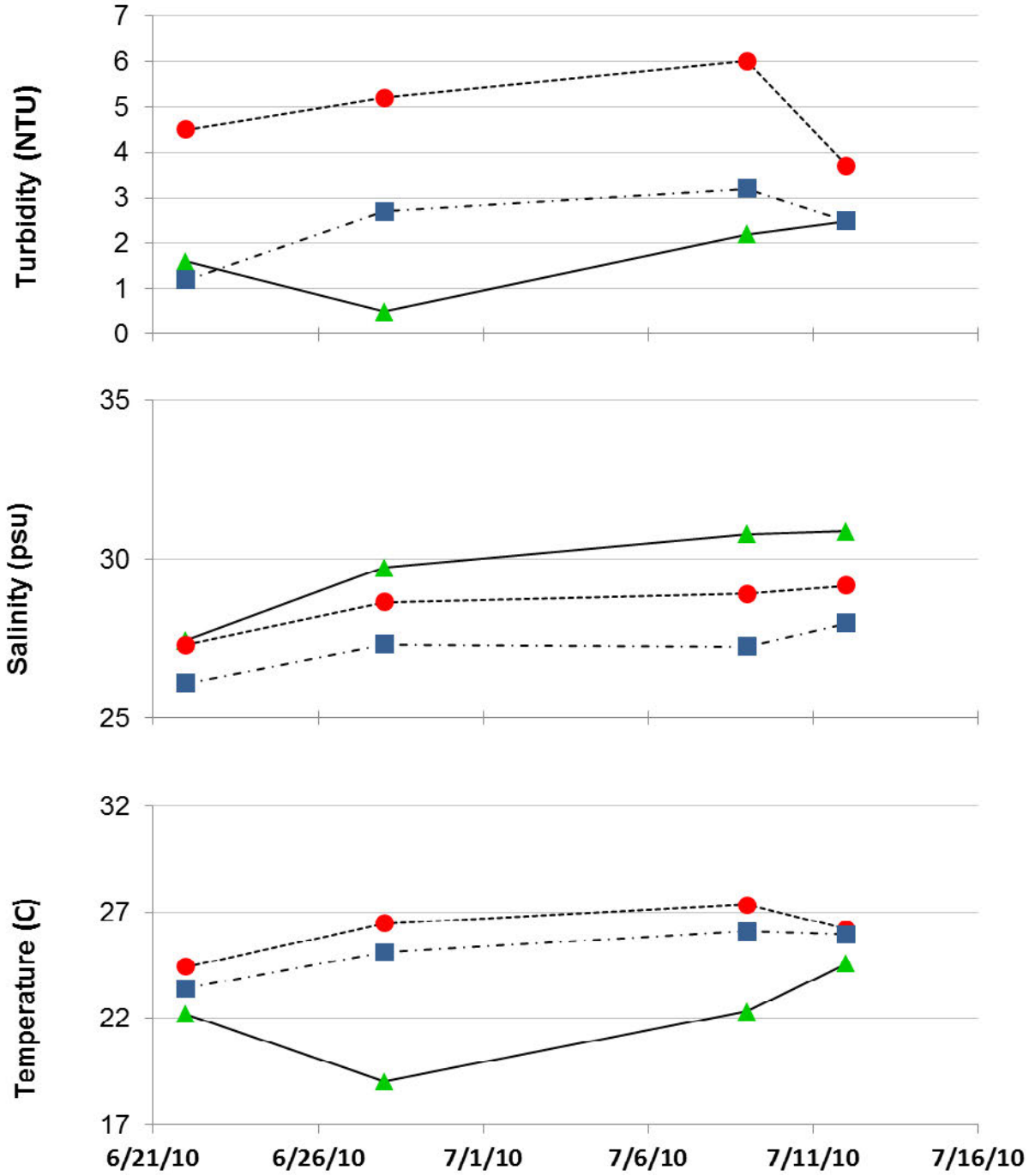


Figure 58 (cont.). Trend Station water-quality data from the 2010 assessment at GATE. Trend data depicted are derived from selected trend stations representative of an upper, middle and lower estuary station. The blue square (■) represents hexagon 24 in the upper portion of the GATE estuary, the red circle (●) represents hexagon 16, mid estuary, while the green triangle (▲) represents hexagon 1 in the lower portion of the estuary.

Assateague Island National Seashore

During the 2006, 2008, and 2010 index periods, the area-weighted average chlorophyll *a* concentration at ASIS ranged from 13.91 µg/L to 21.36 µg/L; the area-weighted average dissolved oxygen concentration in bottom waters ranged from 6.07 mg/L to 6.55 mg/L, or from about 91% to 100% of the saturation concentrations; and the area-weighted average water-column PAR attenuation coefficient (K_d) ranged from 2.21 m^{-1} to 2.83 m^{-1} (Table 20, Table 22, Table 24). There were no differences in the system-wide means of dissolved oxygen concentration or K_d among index periods ($P > 0.20$), but chlorophyll *a* concentration was higher in 2010 than in either 2006 ($P < 0.05$) or 2008 ($P < 0.01$).

In general, water quality improved from north to south with increasing proximity to the mouth of estuary. In 2006 the condition of most estuarine sampling stations was classified as fair for chlorophyll *a* concentration (Figure 59), good for daytime bottom dissolved-oxygen (Figure 60), and poor for PAR attenuation (Figure 61). The continuous monitoring data from the fixed logging station showed periodic, short-term peaks in chlorophyll *a* concentration that exceeded 40 µg/L and pre-dawn dissolved oxygen concentrations that dipped routinely into fair to poor condition classes (Figure 62). Weekly trend sampling showed the seasonal variability in water quality conditions at selected stations (Table 21, Figure 63). The spatial pattern of chlorophyll *a* and dissolved oxygen concentration were repeated in 2008 (Figure 64, Figure 65), but more stations were classified as fair for PAR attenuation (Figure 66) than occurred in 2006. At the continuous logging station, the PAR attenuation coefficient, chlorophyll *a* concentration, and dissolved oxygen concentration generally remained in good to fair categories throughout the 2008 index period (Figure 67); attenuation of PAR was associated with spikes in chlorophyll *a* concentration at the beginning of the index period and a series of high turbidity measurements at the end of the index period (Figure 67). Weekly variability from trend-station monitoring is displayed in Table 23 and Figure 68. In 2010, half of the estuary was classified as poor condition in terms of chlorophyll *a* concentration (Figure 69) and 71% was classified as poor in terms of PAR attenuation (Figure 71), but daytime dissolved oxygen concentrations remained in the good category throughout most of the estuary (Figure 70) as did the majority of pre-dawn measurements at the logging station (Figure 72). Weekly trends are displayed in Table 25 and Figure 73.

2006 Index Period

Table 20. Area-weighted average water-quality condition at ASIS during the 2006 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	2.74	- -	- -	- -
Dissolved oxygen (mg/L)	- -	6.94	6.61	6.08
Dissolved oxygen, % Saturation	- -	106.42	100.08	91.47
Chlorophyll *a* (µg/L)	- -	17.16	- -	- -
Turbidity (NTU)	- -	15.80	17.04	22.00
Temperature (°C)	- -	28.96	28.32	28.05
Salinity (psu)	- -	29.93	29.90	29.95

[Reported values are means of measurements from 24 probability, 5 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

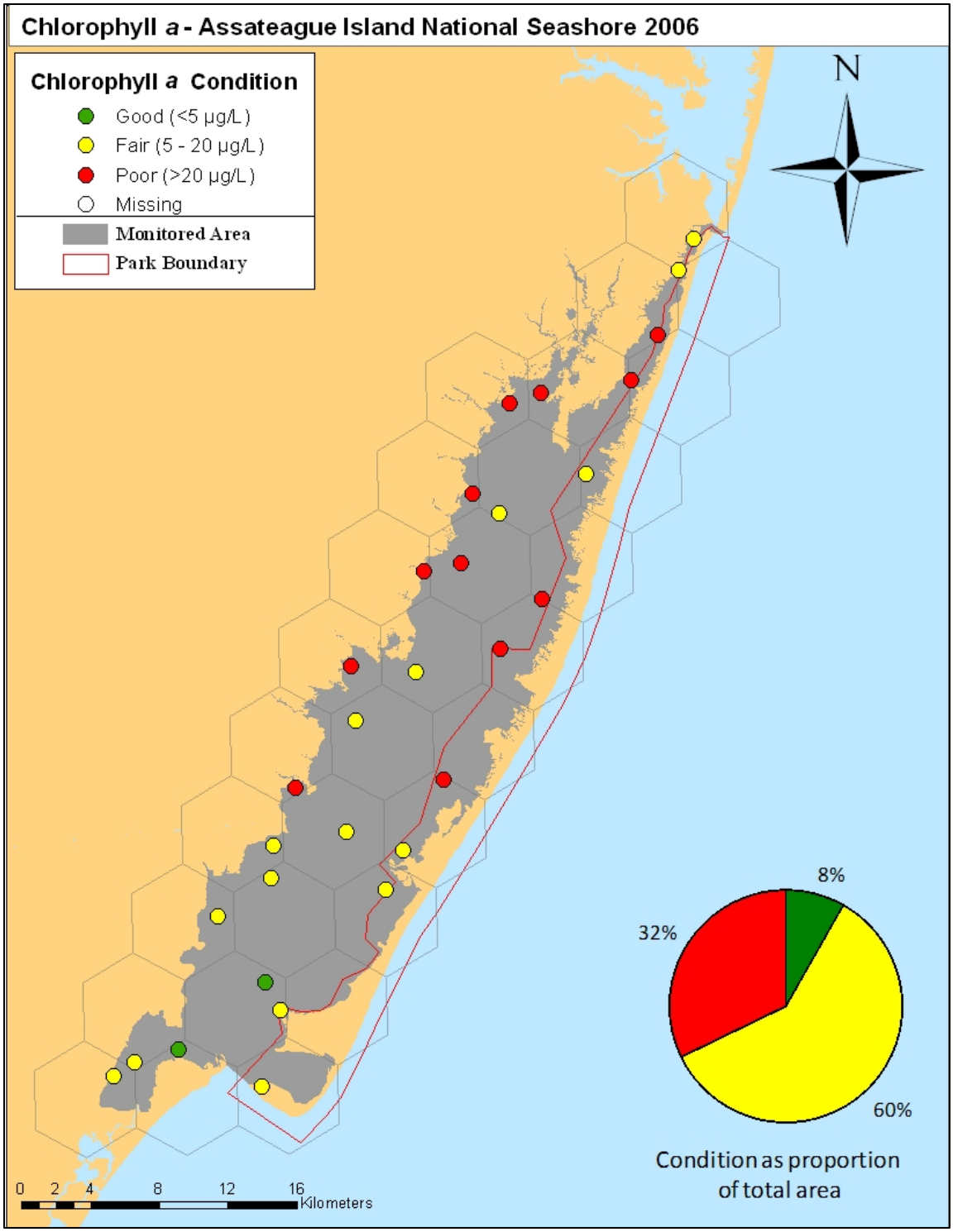


Figure 59. Chlorophyll *a* (µg/L) concentration in surface samples from the 2006 assessment at ASIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

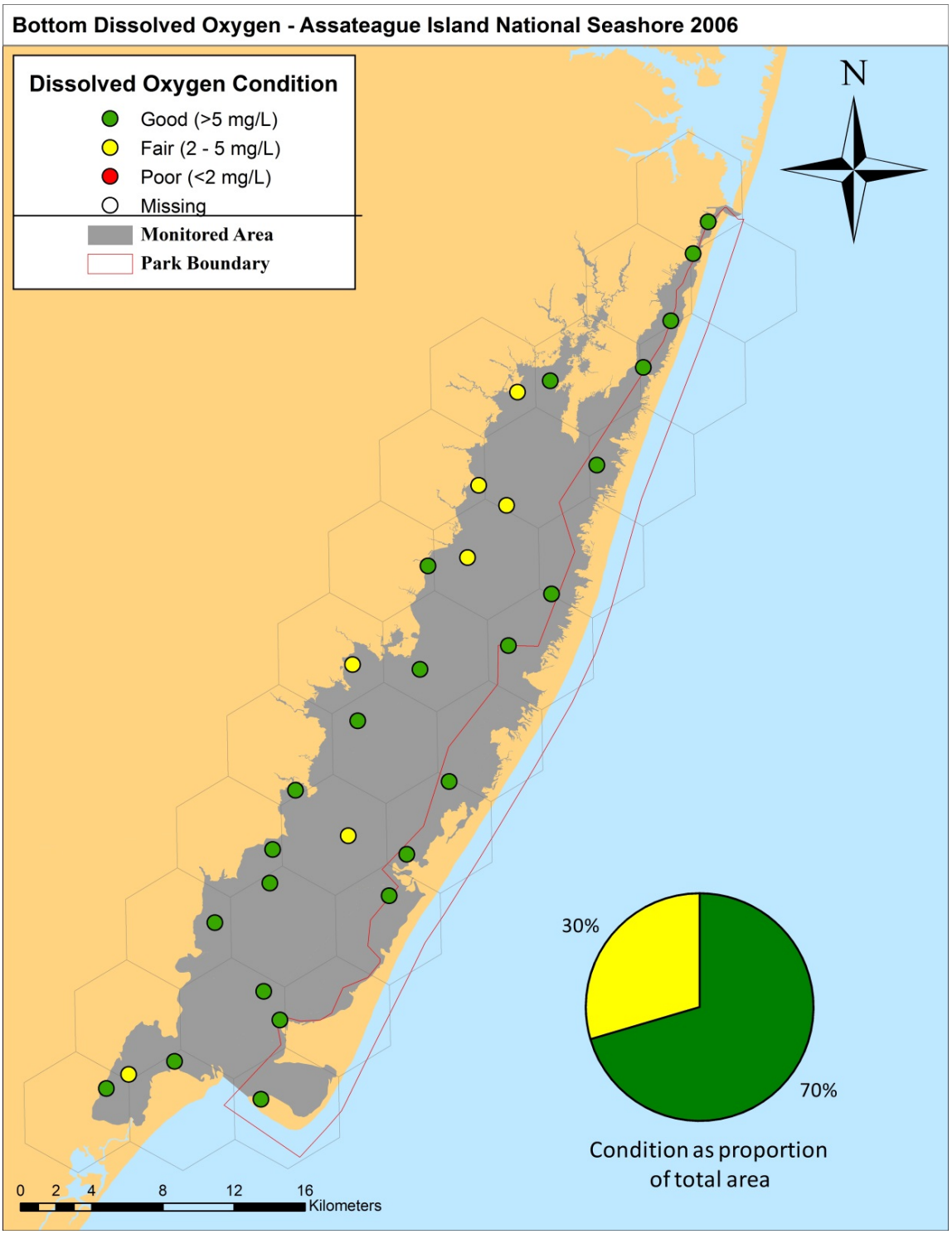


Figure 60. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2006 assessment at ASIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

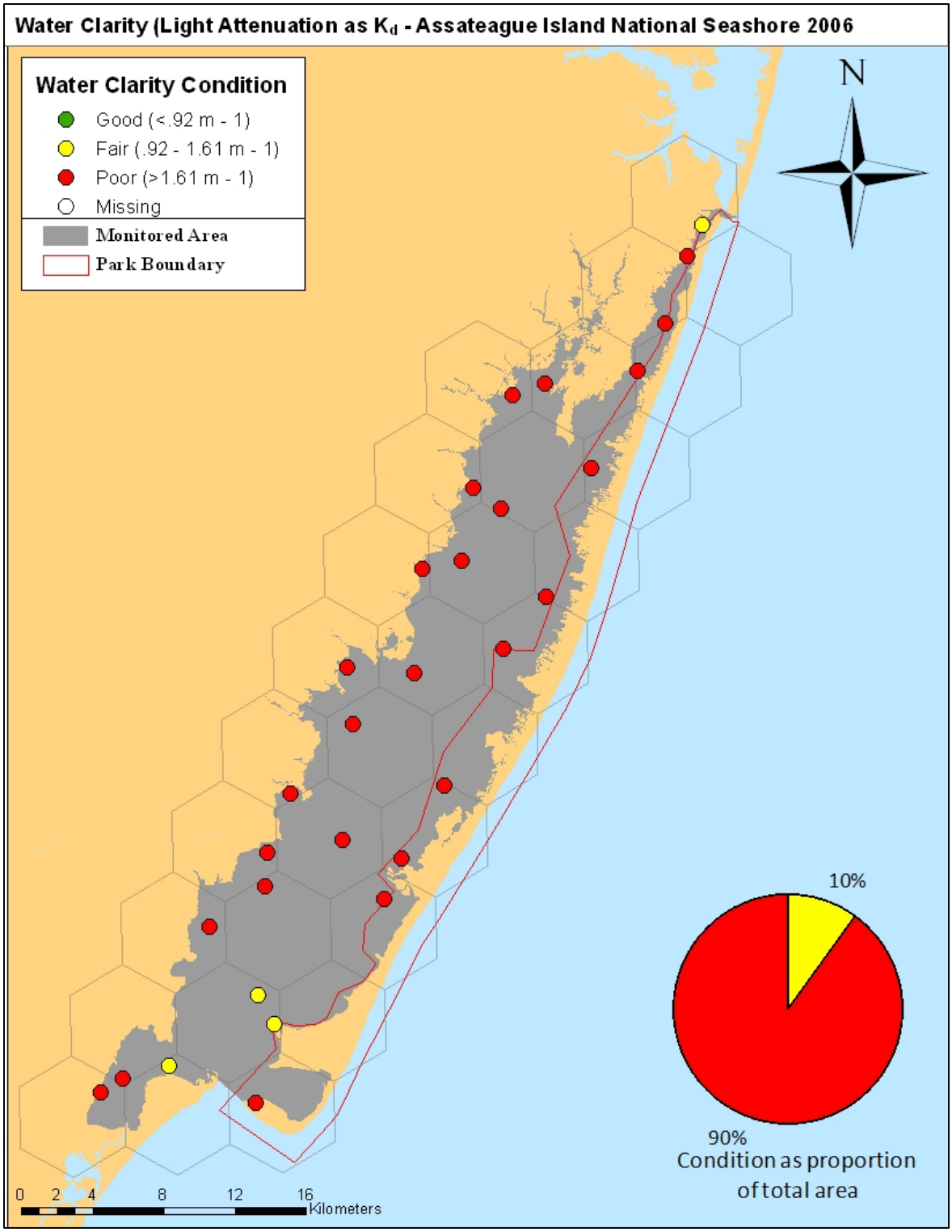


Figure 61. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2006 assessment at ASIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

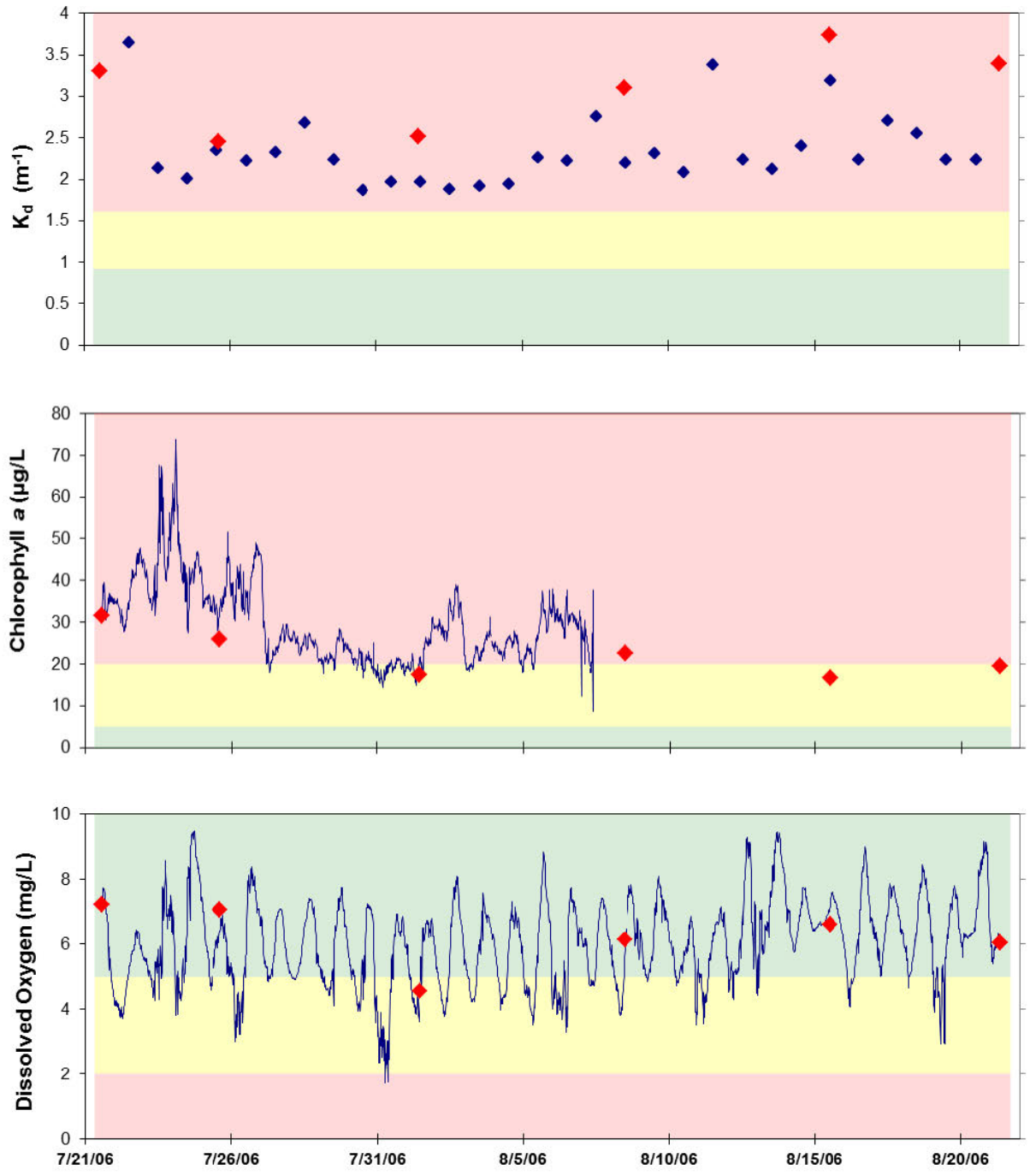


Figure 62. Continuous water-quality data from the 2006 assessment at ASIS. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Plots also indicate the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN.

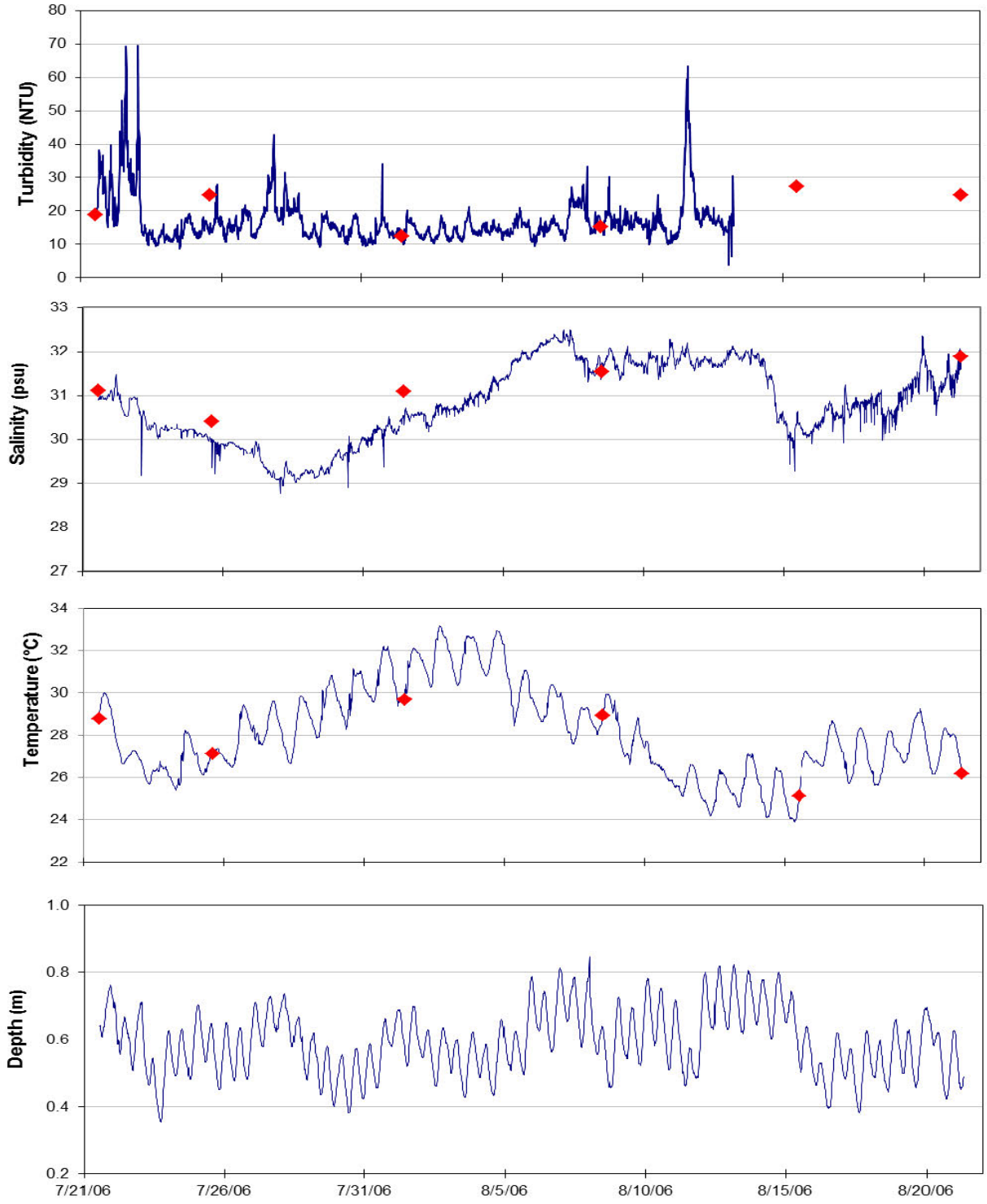


Figure 62 (cont.). Continuous water-quality data from the 2006 assessment at ASIS. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 21. Trend-station water-quality data from the 2006 assessment at ASIS.

		Trend Stations (Hexagons)				
Measure	**Statistic**	**6**	**14**	**18**	**19**	**30**
PAR attenuation	mean	2.25	4.18	3.41	5.24	1.78
(K_d (m^{-1}))	std.dev.	0.92	0.50	1.46	3.27	0.29
	n	4	4	4	4	4
Temperature	mean	26.46	28.53	28.31	28.77	24.46
(°C)	std.dev.	1.76	1.84	2.65	2.11	3.79
	n	4	4	4	4	4
Salinity	mean	30.93	29.53	30.85	30.20	30.54
(psu)	std.dev.	0.55	1.17	0.62	0.65	0.49
	n	4	4	4	4	4
Dissolved oxygen	mean	6.5	6.5	6.6	6.0	6.4
(mg/L)	std.dev.	0.8	1.4	1.0	1.6	0.6
	n	4	4	4	4	4
Turbidity	mean	18.2	28.8	23.0	25.4	16.0
(NTU)	std.dev.	10.4	9.6	17.1	4.9	8.3
	n	4	4	4	3	4
Chlorophyll *a*	mean	8.3	19.8	20.5	23.3	7.0
(µg/L)	std.dev.	2.1	1.3	7.5	0.8	2.6
	n	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Location of hexagons with trend stations is shown in Figure 5.]

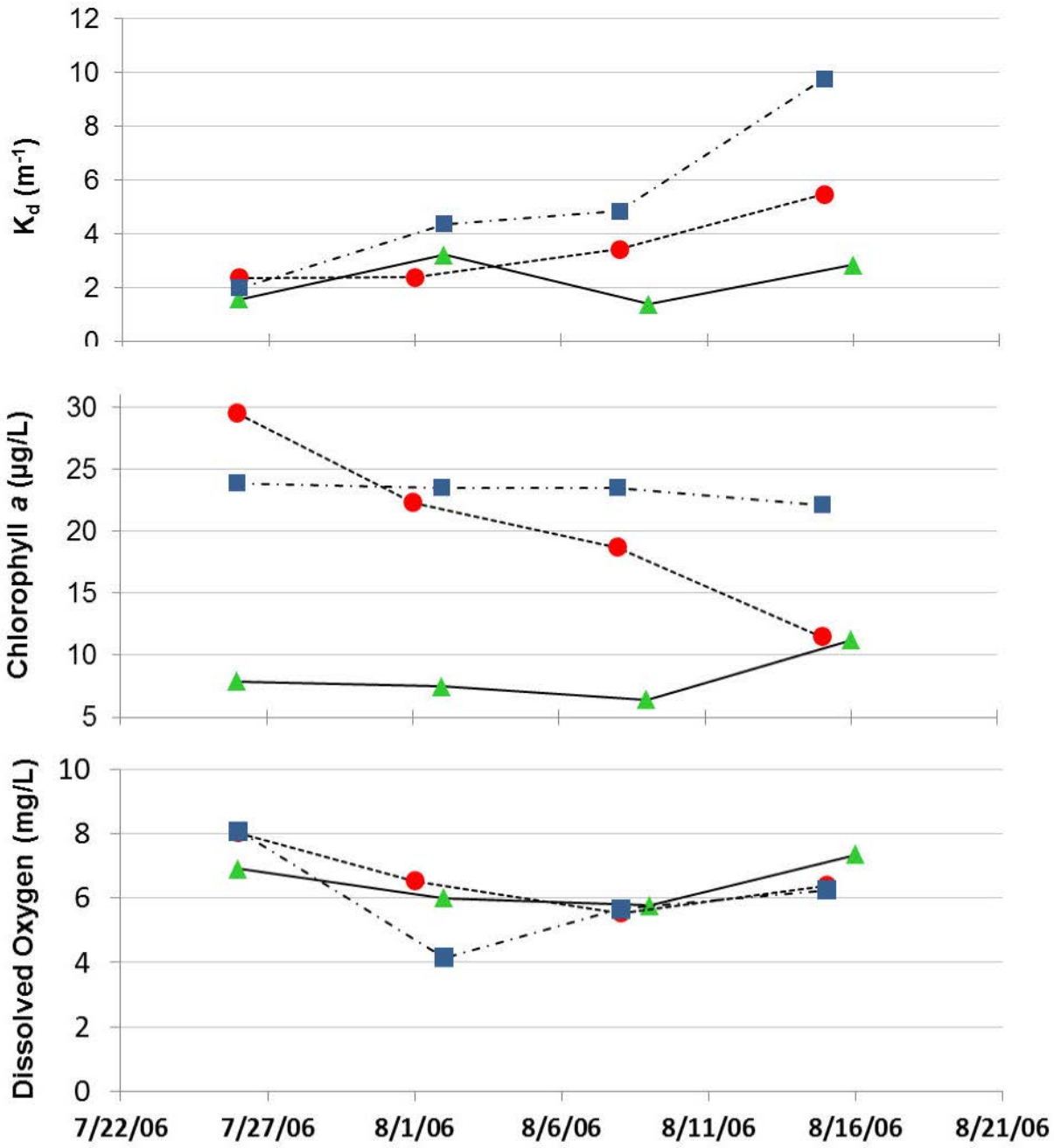


Figure 63. Trend Station water-quality data from the 2006 assessment at ASIS. Data are derived from selected trend stations within different portions of the estuary. The blue square (■) represents hexagon 19 (mid-estuary, western shore), the red circle (●) represents hexagon 18 (mid-estuary, eastern shore), and the green triangle (▲) represents hexagon 6 (lower estuary, eastern shore).

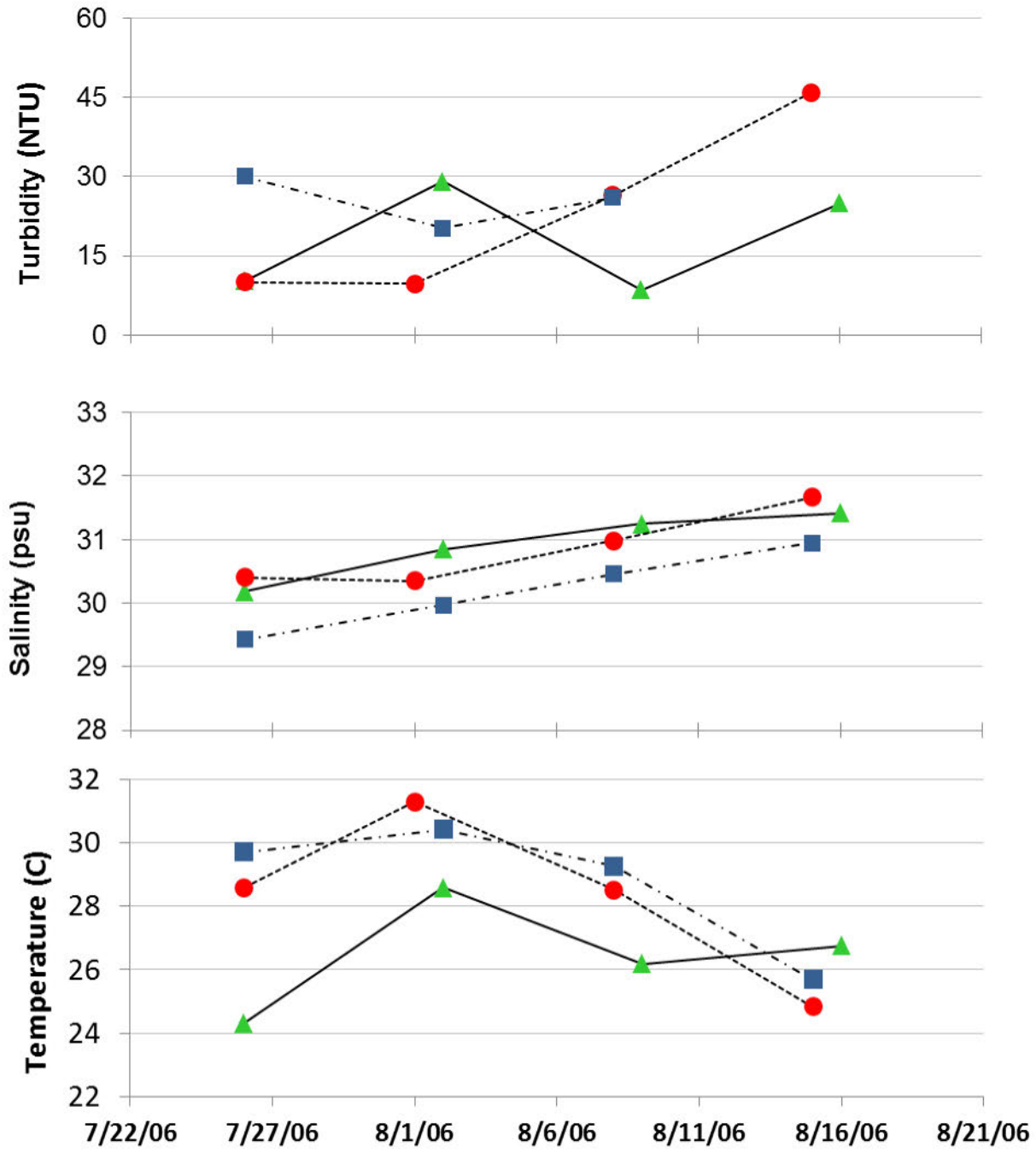


Figure 63 (cont.). Trend Station water-quality data from the 2006 assessment at ASIS. Data are derived from selected trend stations within different portions of the estuary. The blue square (■) represents hexagon 19 (mid-estuary, western shore), the red circle (●) represents hexagon 18 (mid-estuary, eastern shore), and the green triangle (▲) represents hexagon 6 (lower estuary, eastern shore).

2008 Index Period

Table 22. Area-weighted average water-quality condition at ASIS during the 2008 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	2.21	- -	- -	- -
Dissolved oxygen (mg/L)	- -	6.43	6.23	6.07
Dissolved oxygen, % Saturation	- -	96.43	93.43	90.79
Chlorophyll *a* (µg/L)	- -	13.91		
Turbidity (NTU)	- -	13.38	17.09	18.26
Temperature (°C)	- -	26.99	26.92	26.69
Salinity (psu)	- -	31.50	31.67	31.79

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

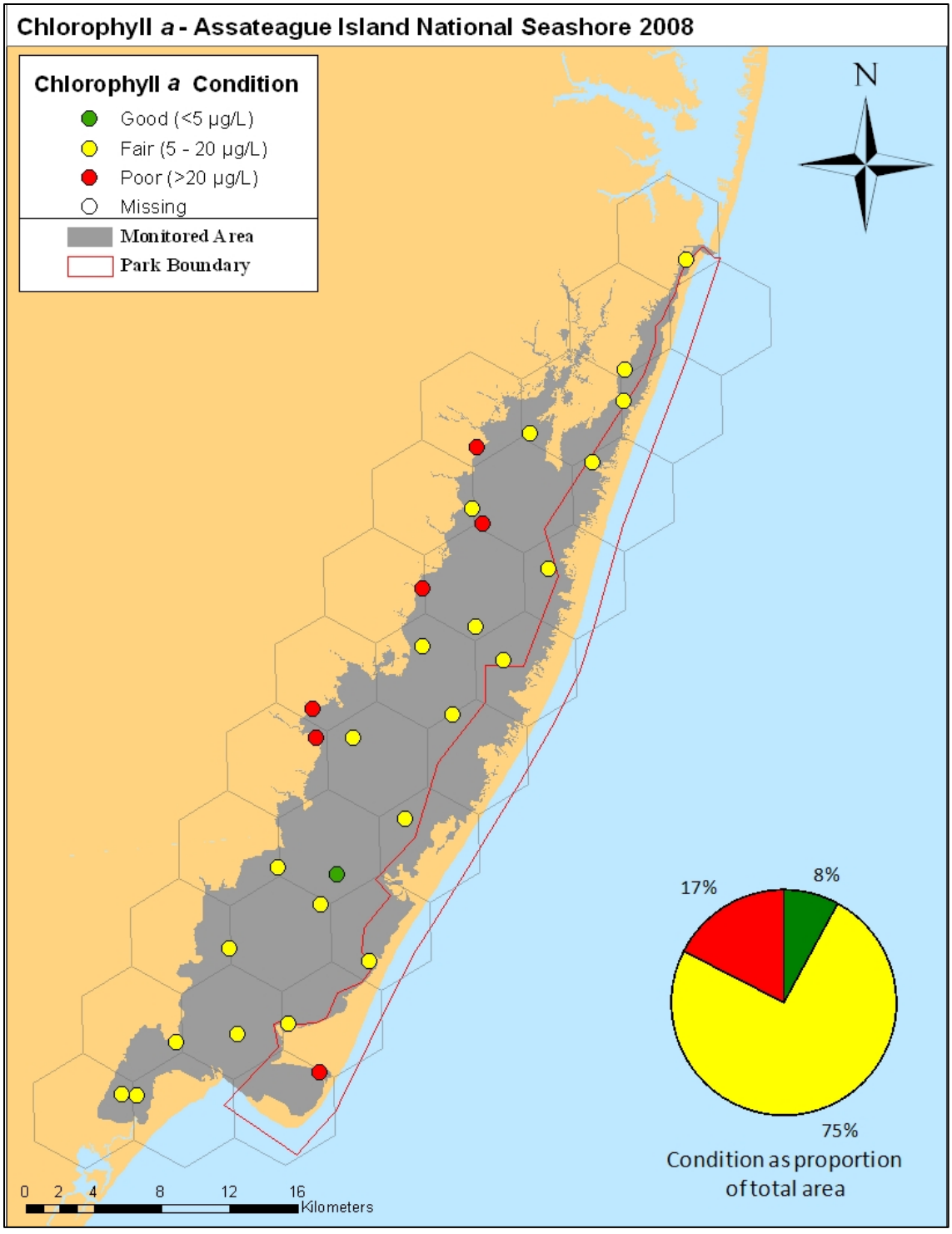


Figure 64. Chlorophyll *a* (µg/L) concentration in surface samples from the 2008 assessment at ASIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

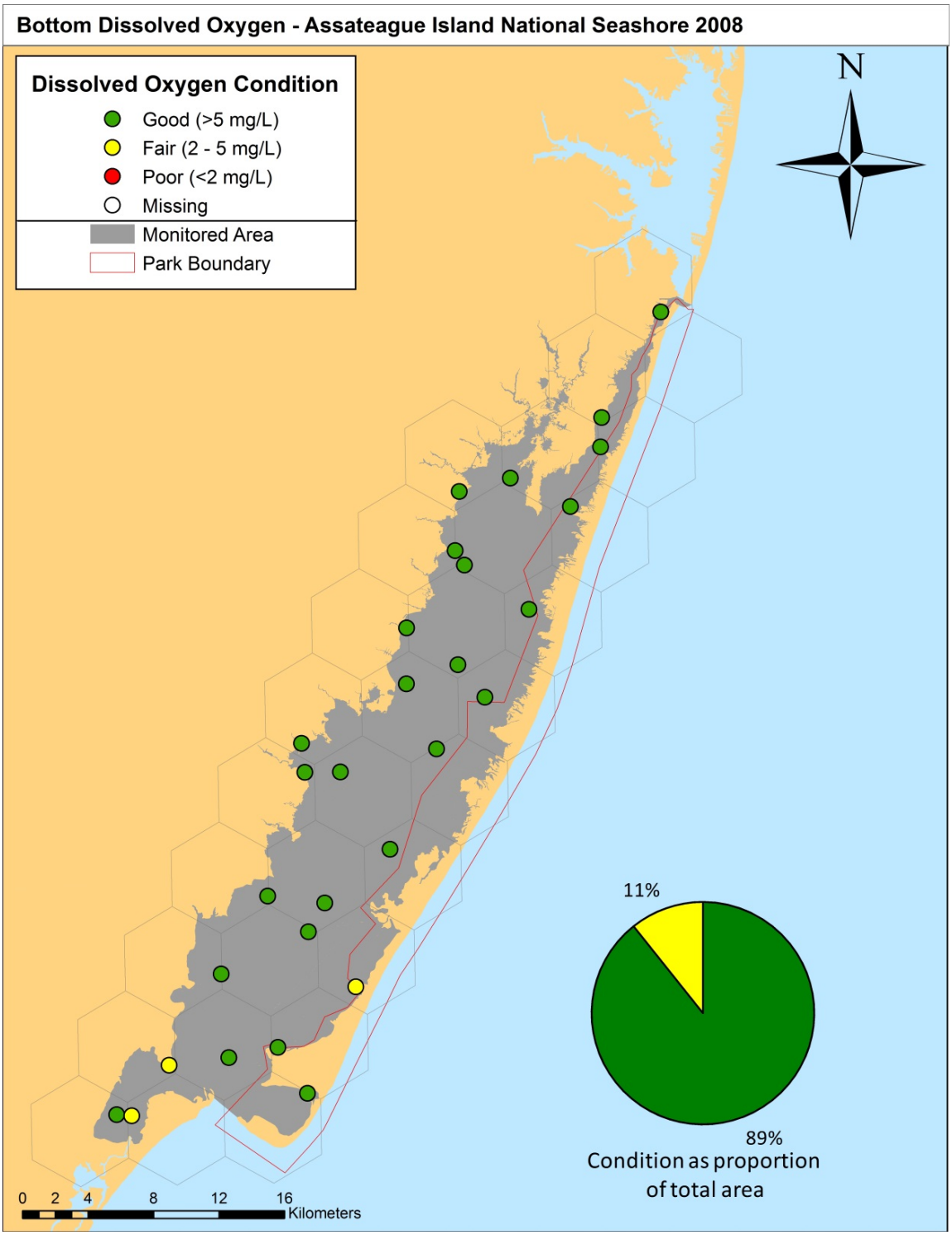


Figure 65. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2008 assessment at ASIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

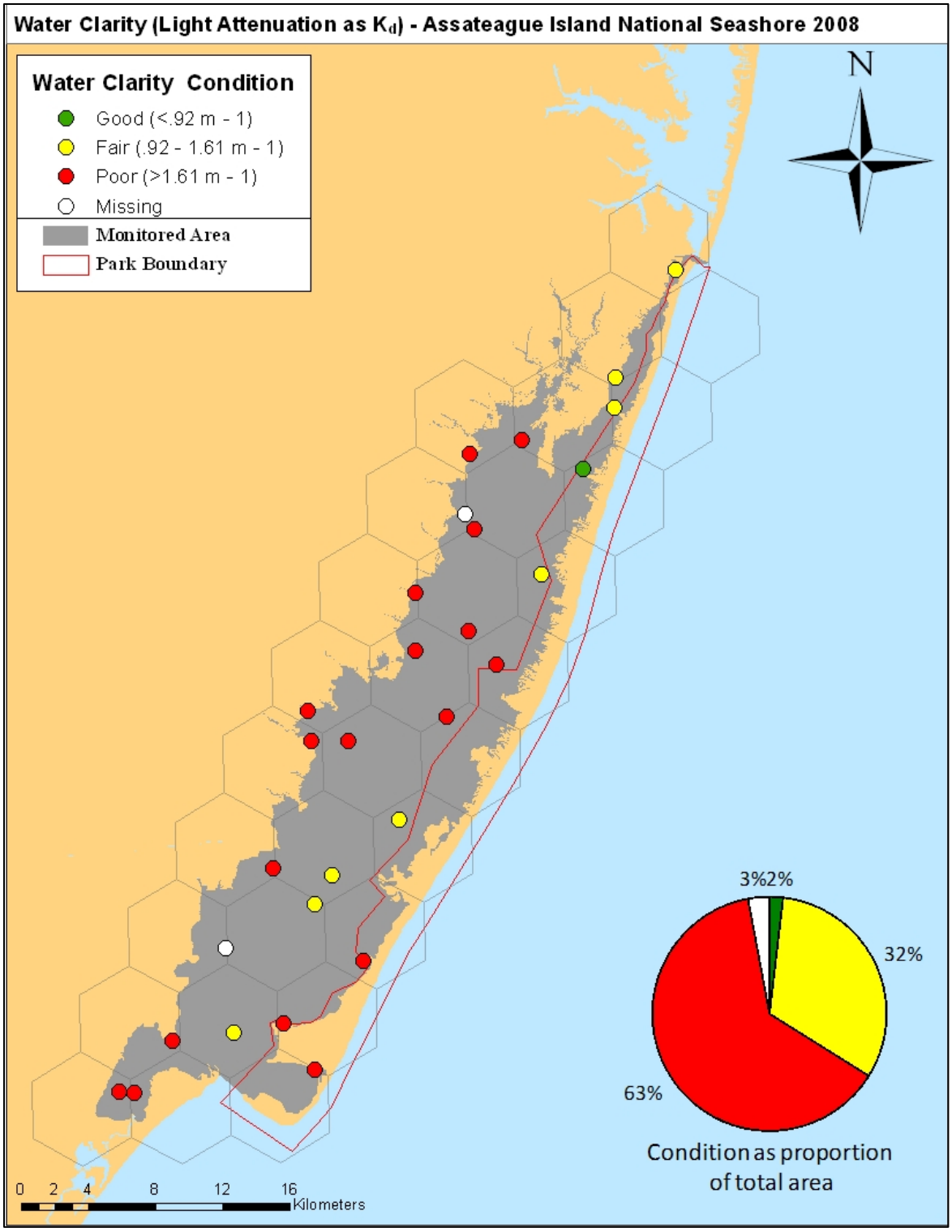


Figure 66. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2008 assessment at ASIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

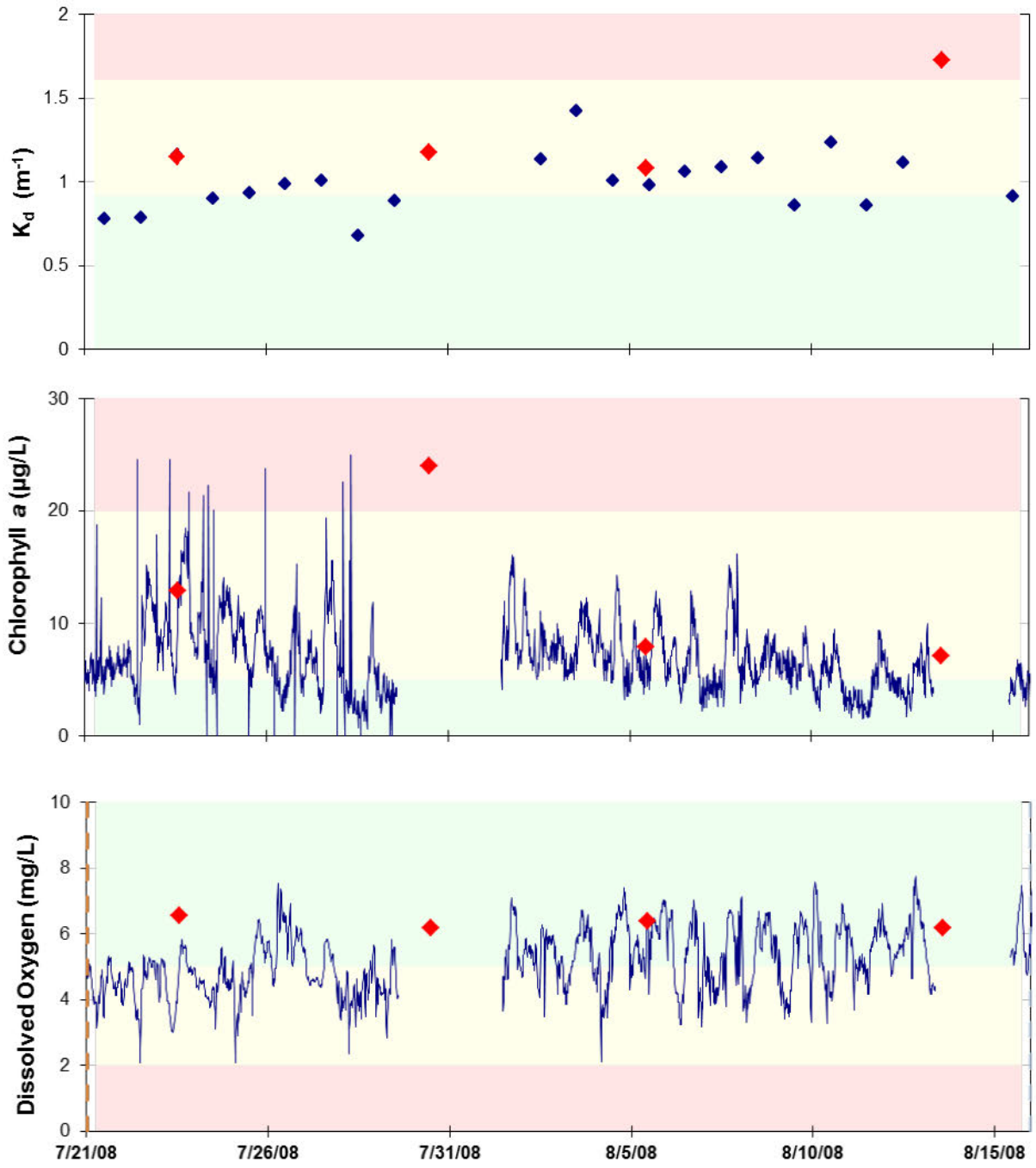


Figure 67. Continuous water-quality data from the 2008 assessment at ASIS. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Plots indicate the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN.

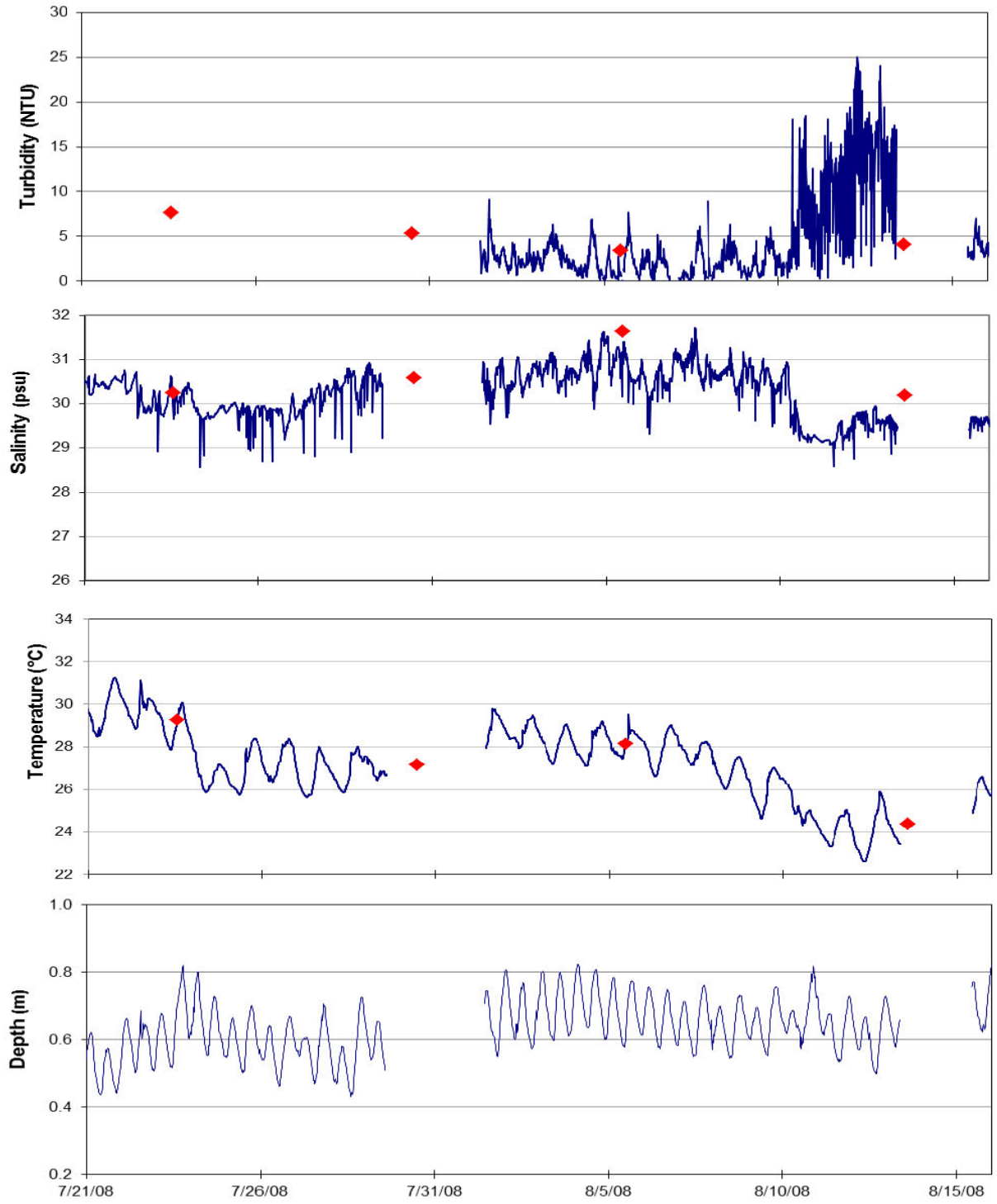


Figure 67 (cont.). Continuous water-quality data from the 2008 assessment at ASIS. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 23. Trend-station water-quality data from the 2008 assessment at ASIS.

		Trend Stations (Hexagons)					
Measure	**Statistic**	**6**	**14**	**18**	**19**	**27**	**30**
PAR attenuation	mean	1.86	2.33	1.57	3.34	1.60	1.36
(K_d (m^{-1}))	std.dev.	0.12	0.32	0.25	0.85	0.24	0.36
	n	3	4	4	3	4	4
Temperature	mean	25.44	27.44	27.03	27.78	27.55	21.62
(°C)	std.dev.	1.22	2.11	1.81	2.21	2.00	2.89
	n	3	4	4	4	4	4
Salinity	mean	31.60	32.63	32.22	30.29	30.60	31.32
(psu)	std.dev.	0.86	0.75	0.41	1.35	0.46	0.47
	n	3	4	4	4	4	4
Dissolved oxygen	mean	5.7	5.7	6.0	5.8	5.9	6.5
(mg/L)	std.dev.	0.1	0.4	0.6	0.3	0.9	0.7
	n	3	4	4	4	4	4
Turbidity	mean	14.2	18.9	6.1	17.1	8.1	7.0
(NTU)	std.dev.	3.1	10.1	2.4	5.2	1.9	3.2
	n	3	4	4	4	4	4
Chlorophyll *a*	mean	8.9	18.9	12.5	24.9	15.9	10.3
(µg/L)	std.dev.	3.6	6.2	2.1	8.5	7.6	6.1
	n	3	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Location of hexagons with trend stations is shown in Figure 5.]

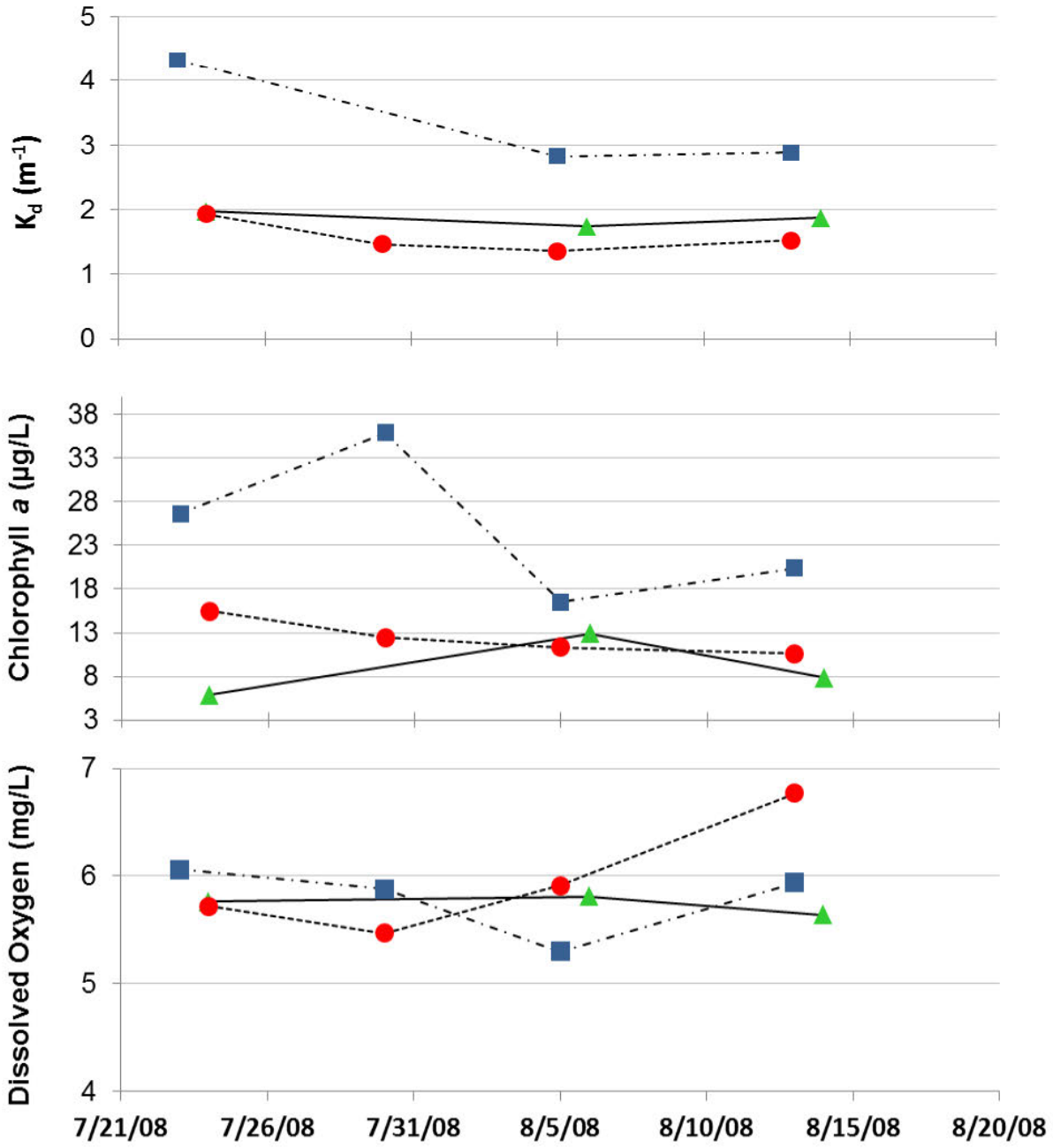


Figure 68. Trend Station water-quality data from the 2008 assessment at ASIS. Data are derived from selected trend stations within different portions of the estuary. The blue square (■) represents hexagon 19 (mid-estuary, western shore), the red circle (●) represents hexagon 18 (mid-estuary, eastern shore), and the green triangle (▲) represents hexagon 6 (lower estuary, eastern shore).

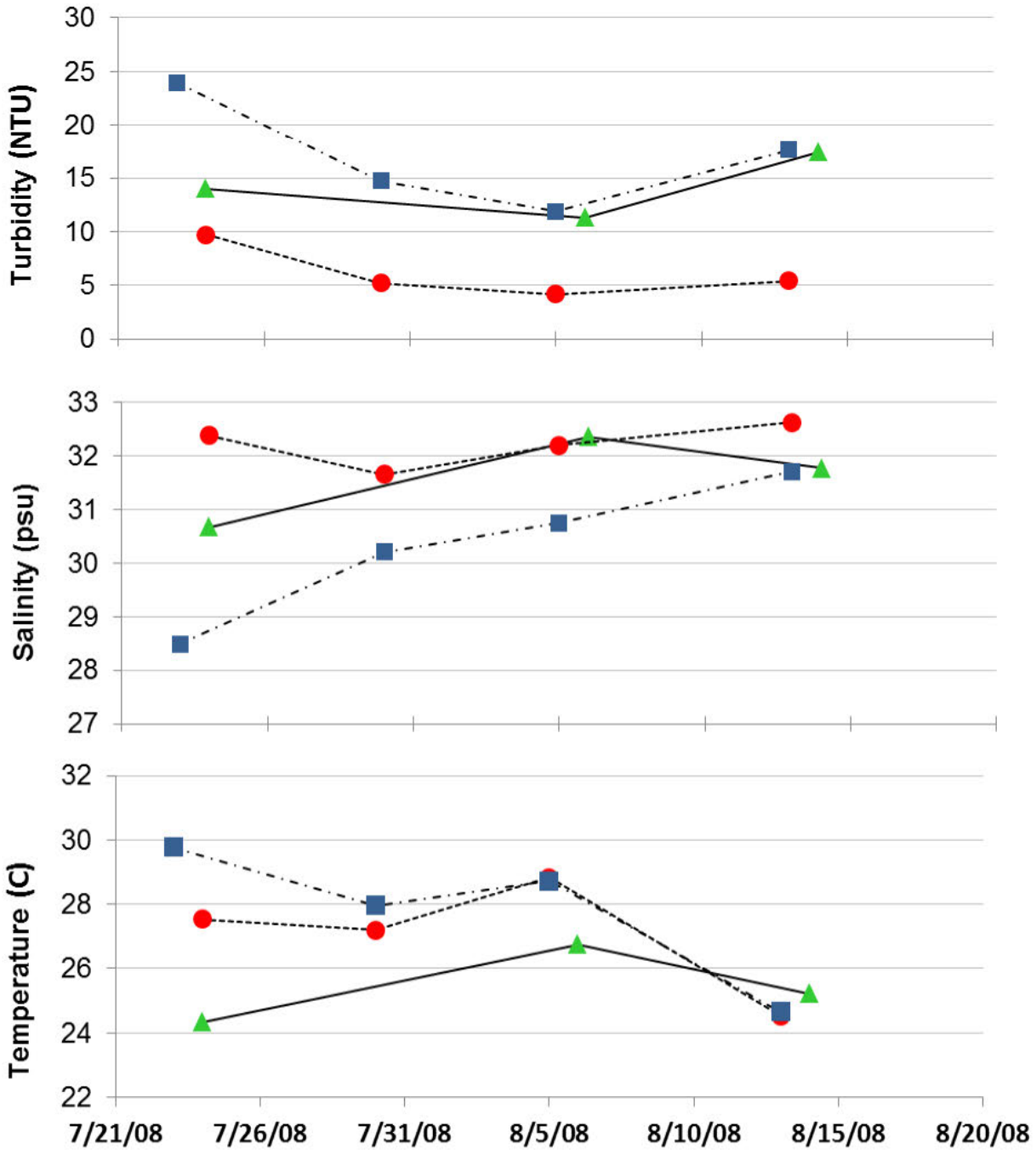


Figure 68 (cont.). Trend Station water-quality data from the 2008 assessment at ASIS. Data are derived from selected trend stations within different portions of the estuary. The blue square (■) represents hexagon 19 (mid-estuary, western shore), the red circle (●) represents hexagon 18 (mid-estuary, eastern shore), and the green triangle (▲) represents hexagon 6 (lower estuary, eastern shore).

2010 Index Period

Table 24. Area-weighted average water-quality condition at ASIS during the 2010 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	2.83	- -	- -	- -
Dissolved oxygen (mg/L)	- -	6.79	6.16	6.55
Dissolved oxygen, % Saturation	- -	104.03	93.27	100.39
Chlorophyll *a* (µg/L)	- -	21.36	- -	- -
Turbidity (NTU)	- -	18.28	25.33	41.83
Temperature (°C)	- -	28.72	28.34	28.44
Salinity (psu)	- -	30.33	29.55	30.52

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

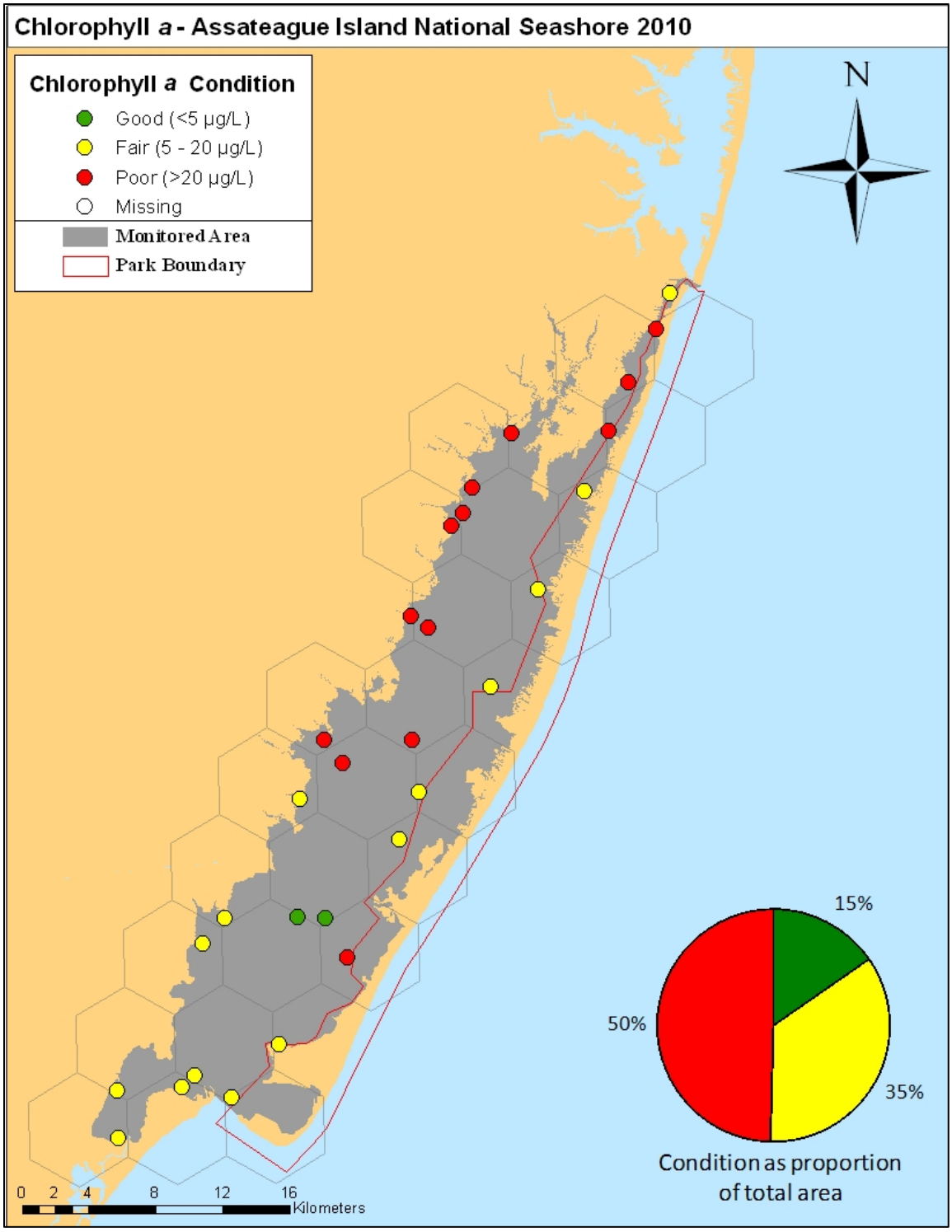


Figure 69. Chlorophyll *a* (µg/L) concentration in surface samples from the 2010 assessment at ASIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

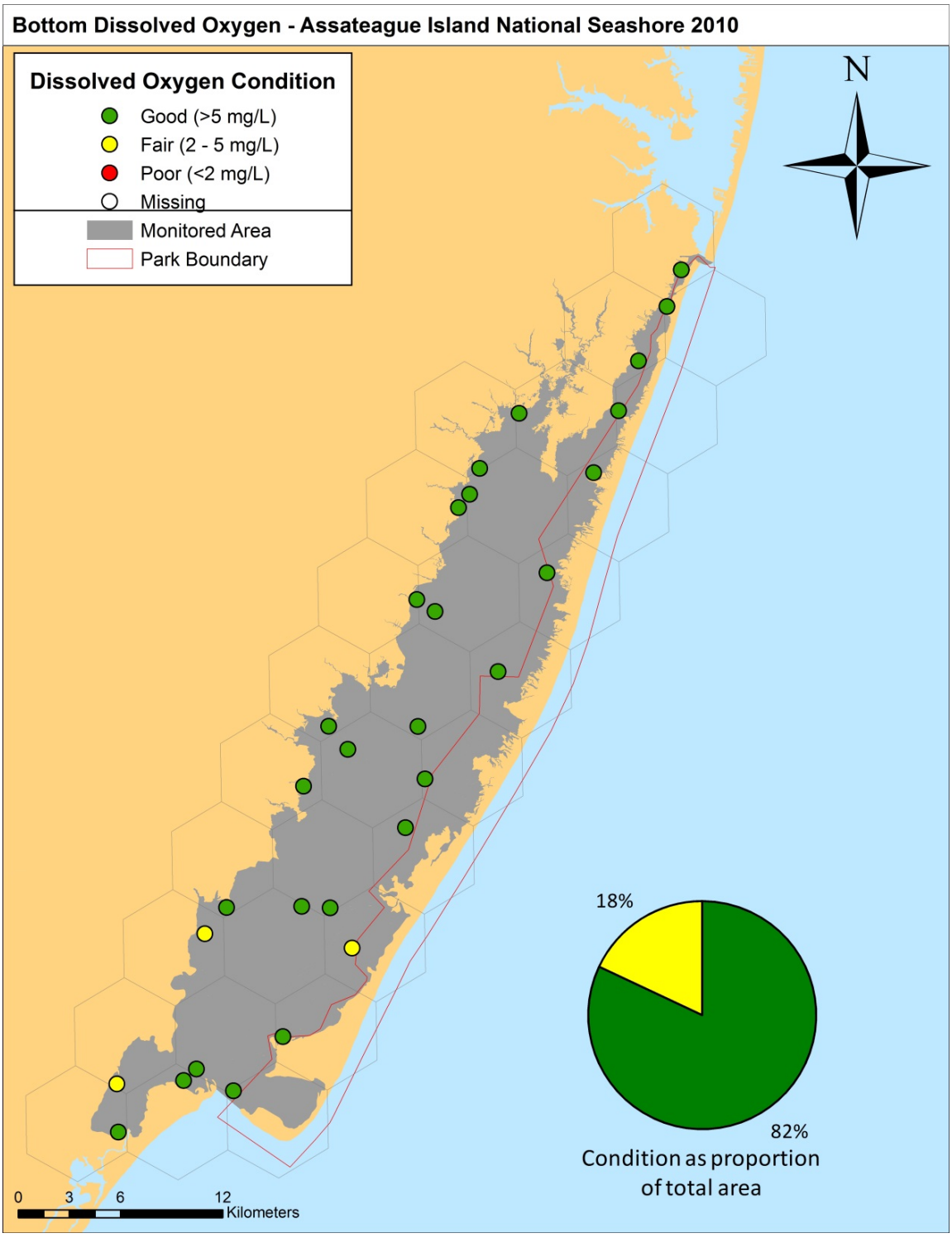


Figure 70. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2010 assessment at ASIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

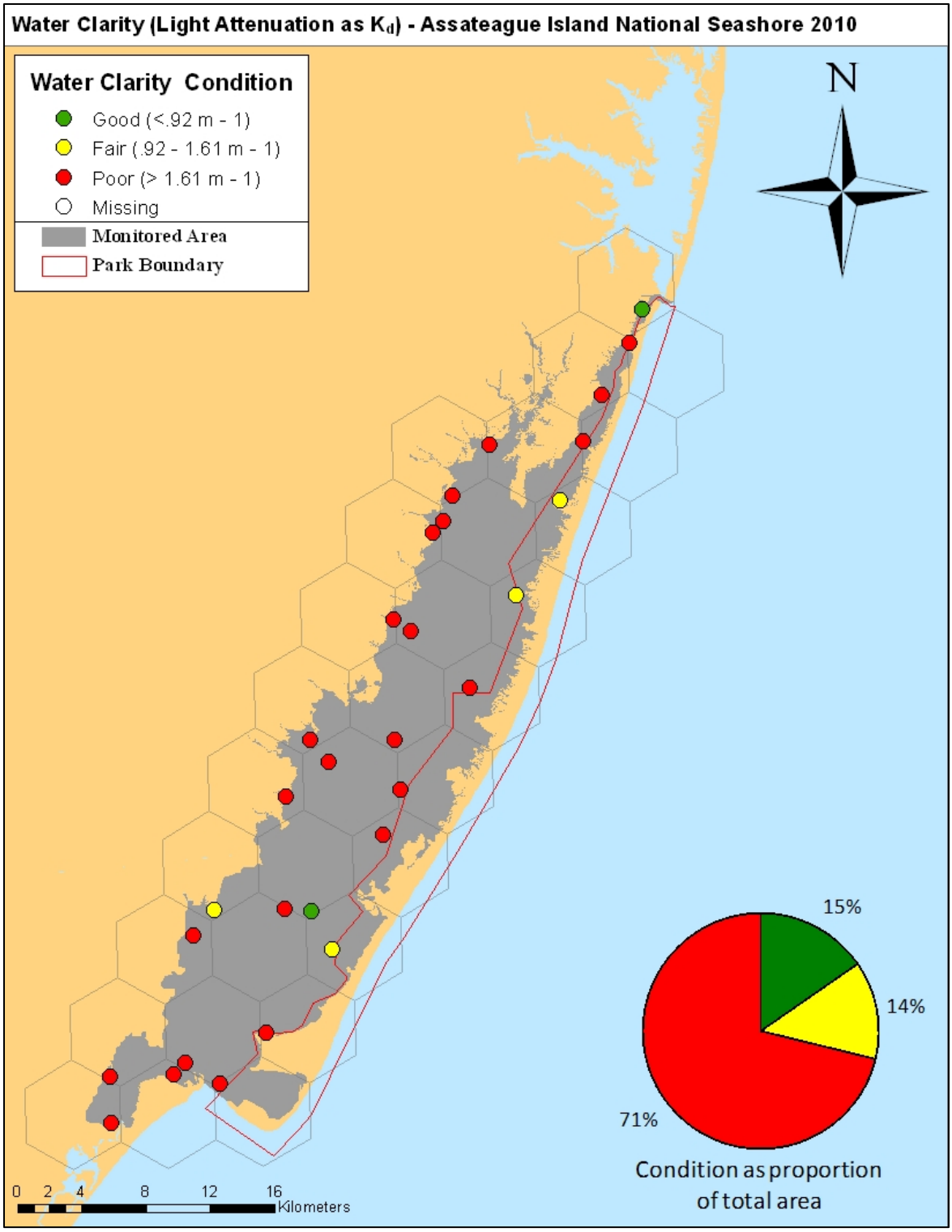


Figure 71. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2010 assessment at ASIS. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

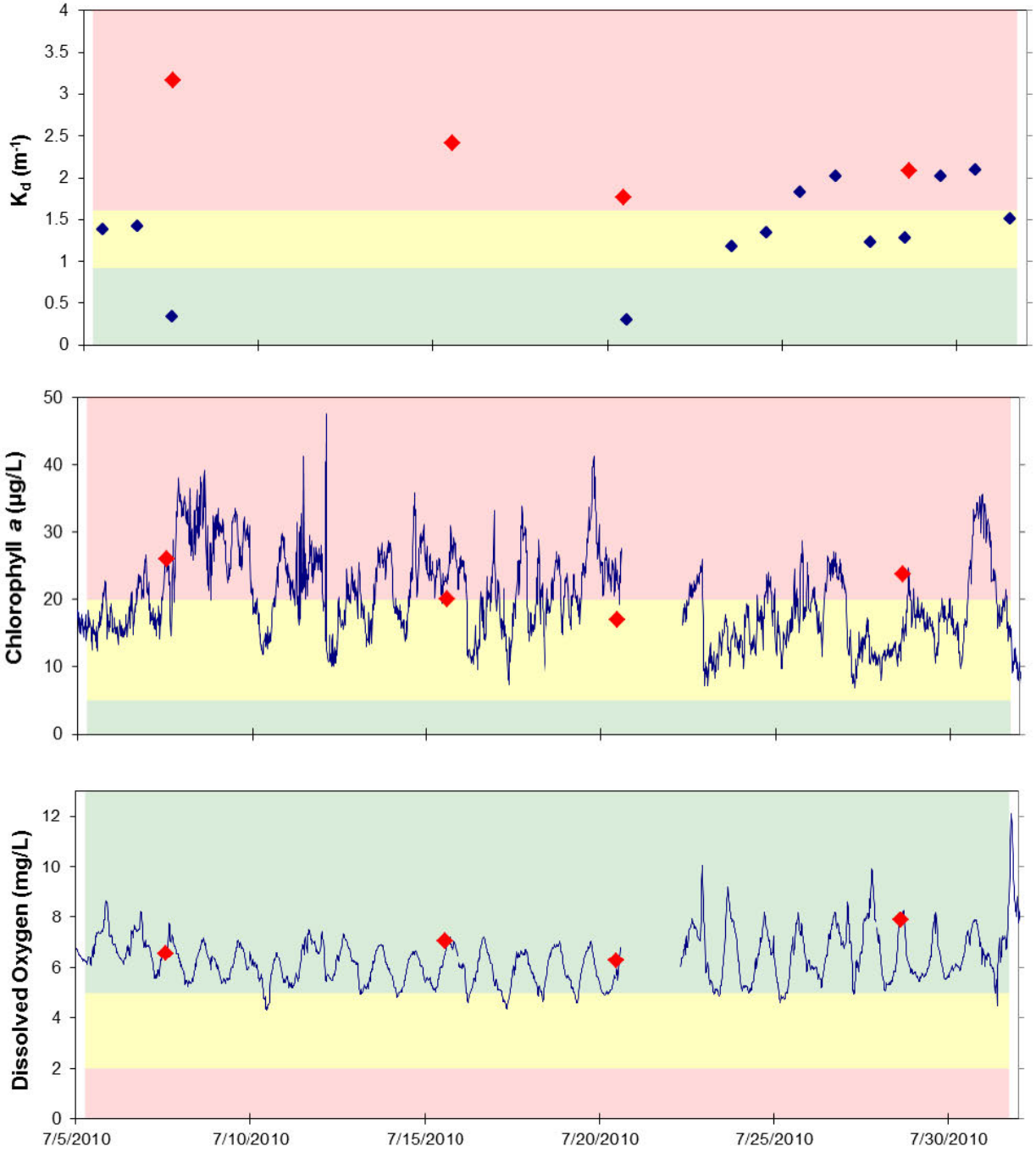


Figure 72. Continuous water-quality data from the 2010 assessment at ASIS. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Plots indicate the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

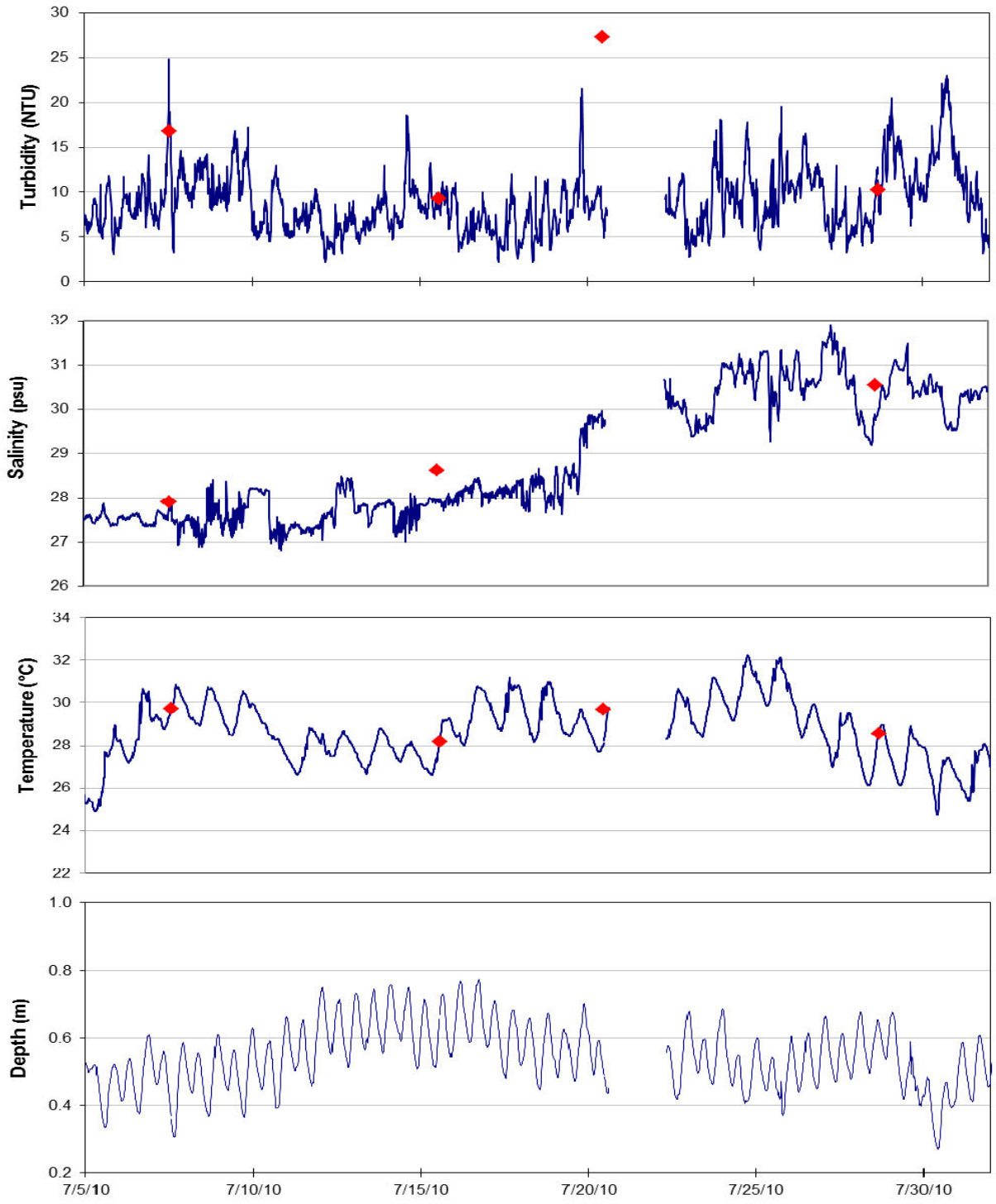


Figure 72 (cont.). Continuous water-quality data from the 2010 assessment at ASIS. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 25. Trend-station water-quality data from the 2010 assessment at ASIS.

		Trend Stations (Hexagons)					
Measure	**Statistic**	**6**	**14**	**18**	**19**	**27**	**30**
PAR attenuation	mean	3.01	3.53	2.45	4.21	2.75	2.20
(K_d (m^{-1}))	std.dev.	0.65	1.89	0.58	2.38	1.12	1.32
	n	4	4	4	4	4	4
Temperature	mean	27.21	28.89	28.45	27.96	28.98	25.62
(°C)	std.dev.	1.87	1.12	0.55	0.84	1.08	3.33
	n	4	4	4	4	4	4
Salinity	mean	31.67	32.20	31.02	28.43	24.27	30.06
(psu)	std.dev.	0.32	1.28	1.80	1.64	10.57	1.00
	n	4	4	4	4	4	4
Dissolved oxygen	mean	6.0	5.8	6.3	4.2	6.2	6.5
(mg/L)	std.dev.	0.3	0.4	1.0	1.4	0.6	0.9
	n	4	4	4	4	4	4
Turbidity	mean	24.6	26.5	13.6	30.3	23.4	14.8
(NTU)	std.dev.	6.3	16.8	5.6	27.1	11.3	10.1
	n	4	4	4	4	4	4
Chlorophyll *a*	mean	16.3	27.2	19.5	35.9	26.3	18.5
(µg/L)	std.dev.	4.7	3.7	2.6	9.0	4.6	9.6
	n	4	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Location of hexagons with trend stations is shown in Figure 5.]

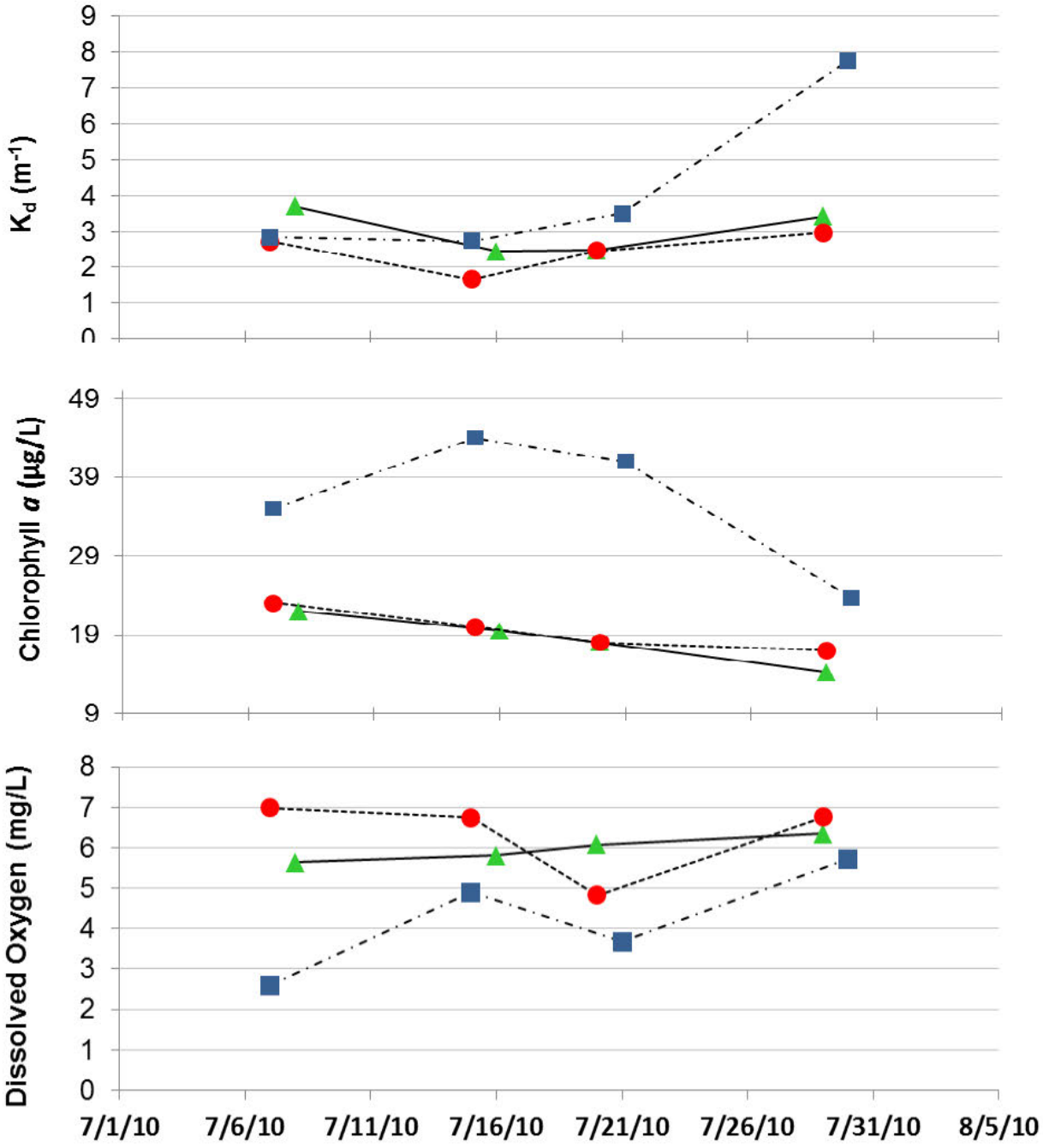


Figure 73. Trend station water-quality data from the 2010 assessment at ASIS. Data are derived from selected trend stations within different portions of the estuary. The blue square (■) represents hexagon 19 (mid-estuary, western shore), the red circle (●) represents hexagon 18 (mid-estuary, eastern shore), and the green triangle (▲) represents hexagon 6 (lower estuary, eastern shore).

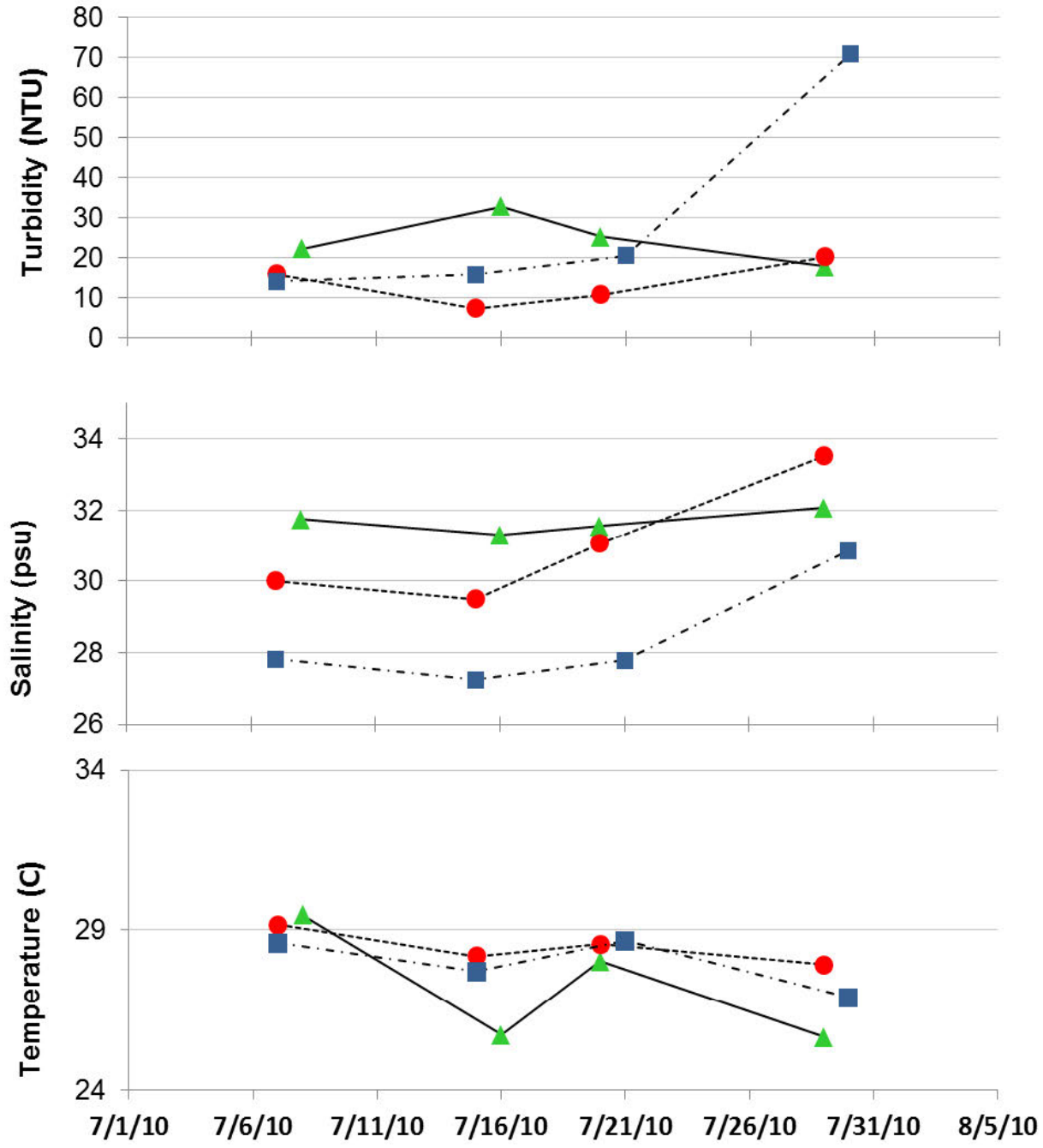


Figure 73 (cont.). Trend station water-quality data from the 2010 assessment at ASIS. Data are derived from selected trend stations within different portions of the estuary. The blue square (■) represents hexagon 19 (mid-estuary, western shore), the red circle (●) represents hexagon 18 (mid-estuary, eastern shore), and the green triangle (▲) represents hexagon 6 (lower estuary, eastern shore).

George Washington Birthplace National Monument

There were no differences in system-wide means of PAR attenuation coefficient (K_d) or chlorophyll concentration between the 2009 and 2011 index periods at GEWA ($P > 0.15$). The area-weighted average chlorophyll *a* concentration during these index periods ranged from 56.13 µg/L in 2009 to 75.55 µg/L in 2011, and the area-weighted average water-column PAR attenuation coefficient (K_d) ranged from 3.68 m^{-1} in 2009 to 3.59 m^{-1} in 2011, indicating overall poor water clarity (Table 26, Table 28). The area-weighted average of daytime dissolved oxygen in bottom waters ranged from 6.29 mg/L in 2009 to 4.69 mg/L in 2011, or about 64% to 86% of the saturation concentration (Table 26, Table 28), and comparison of system-wide means showed a significant decrease between years ($P < 0.001$).

In 2009, all sampling stations at GEWA fell in the poor condition class in terms of chlorophyll *a* concentration (Figure 74) and water clarity (Figure 76), but most of the estuary fell in the good condition class for daytime dissolved-oxygen concentration in bottom waters (Figure 75). Continuous data from the permanent logging station showed short-term peaks of chlorophyll *a* concentrations regularly exceeding 100 µg/L and diel minima of oxygen concentrations within the fair condition class (Figure 77). The magnitude of the spikes in logged chlorophyll *a* concentration declined from the beginning to the end of the 2009 index period (Figure 77), and weekly monitoring of trend stations showed a decline in chlorophyll *a* concentration from the end of July to the middle of August (Figure 78). In 2011, water clarity was again rated poor condition throughout the entire estuary (Figure 81), but in contrast to 2009, there were some stations that were classified as good in terms of chlorophyll *a* concentration (Figure 79). The continuous log (Figure 82) and the weekly trend station samples (Figure 83) showed that chlorophyll *a* concentration in the estuary dropped dramatically at the end of the index period, and this large temporal variability in chlorophyll *a* concentration was evident at each trend station (Table 29); therefore, the interspersion of “good” and “poor” conditions at spatial stations (Figure 79) reflected the intensity of the phytoplankton booms during different weeks that the stations were sampled (Figure 83). The majority of stations ranked fair for dissolved oxygen concentration in 2011 (Figure 80) and diel minima were regularly within fair or poor condition classes (Figure 82).

2009 Index Period

Table 26. Area-Weighted average water-quality condition at GEWA during the 2009 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	3.68	- -	- -	- -
Dissolved oxygen (mg/L)	- -	6.84	6.71	6.29
Dissolved oxygen, % Saturation	- -	93.94	92.31	85.89
Chlorophyll *a* (µg/L)	- -	56.13		
Turbidity (NTU)	- -	25.33	29.03	46.42
Temperature (°C)	- -	28.75	28.72	28.36
Salinity (psu)	- -	9.90	9.95	9.98

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

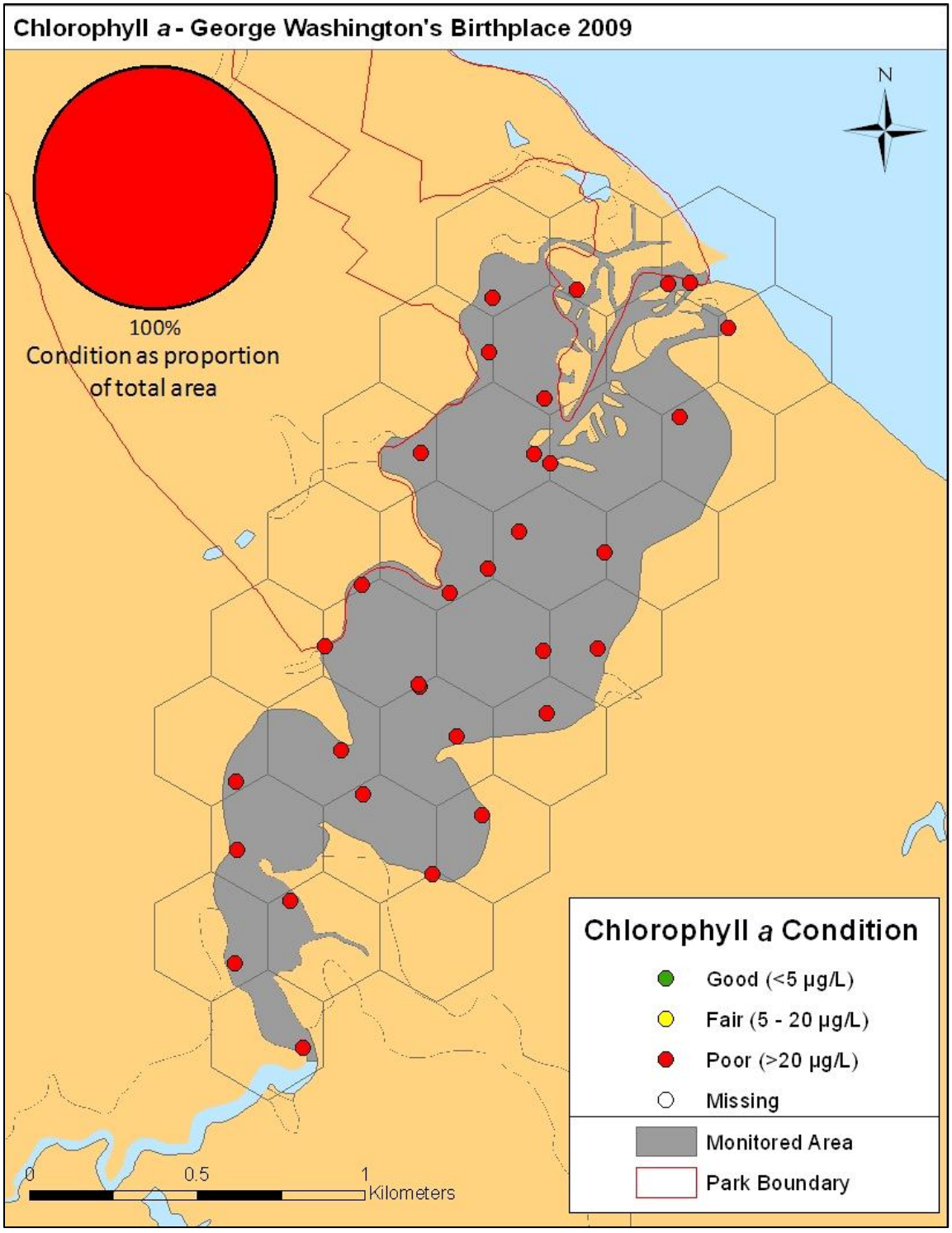


Figure 74. Chlorophyll *a* (µg/L) concentration in surface samples from the 2009 assessment at GEWA. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

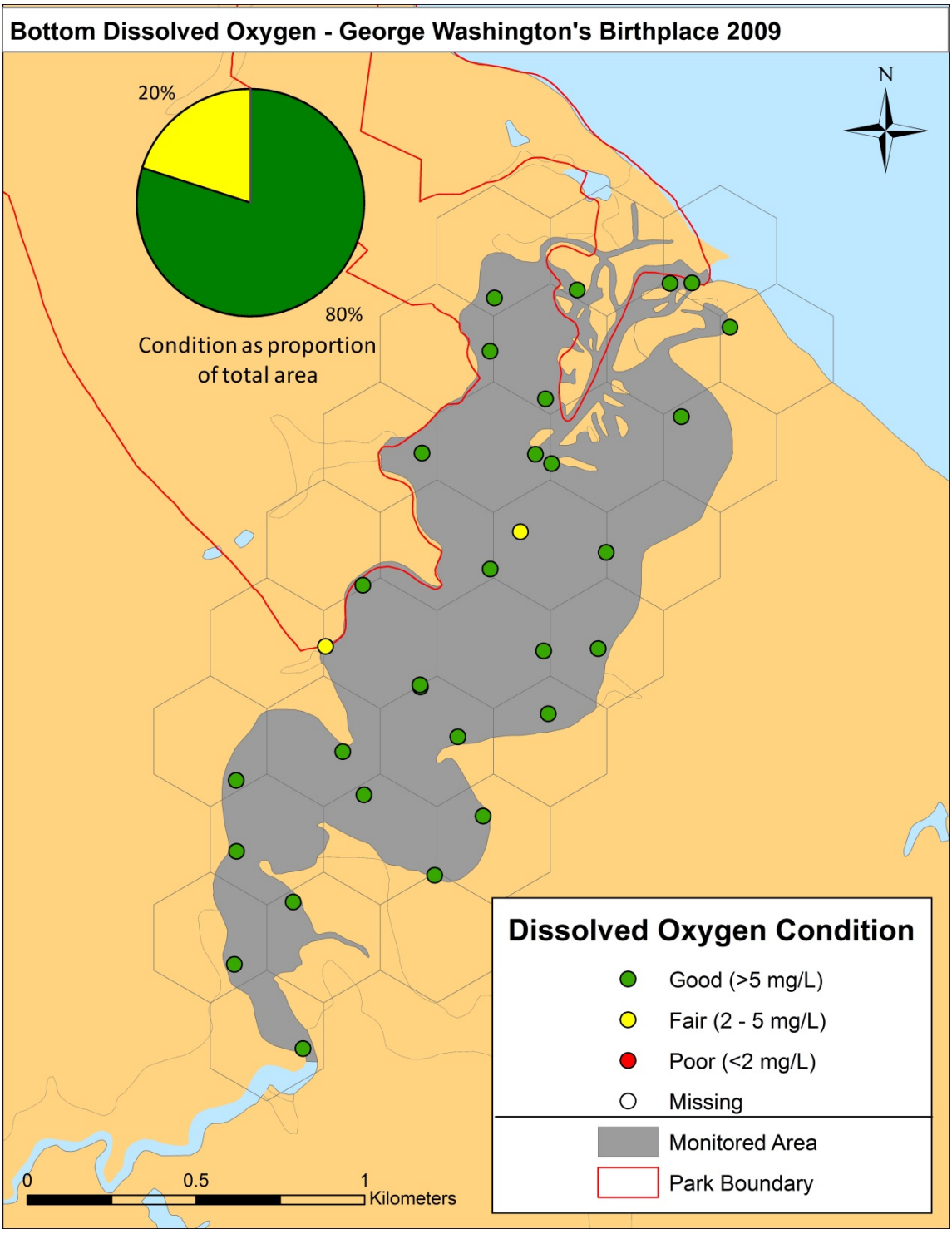


Figure 75. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2009 assessment at GEWA. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

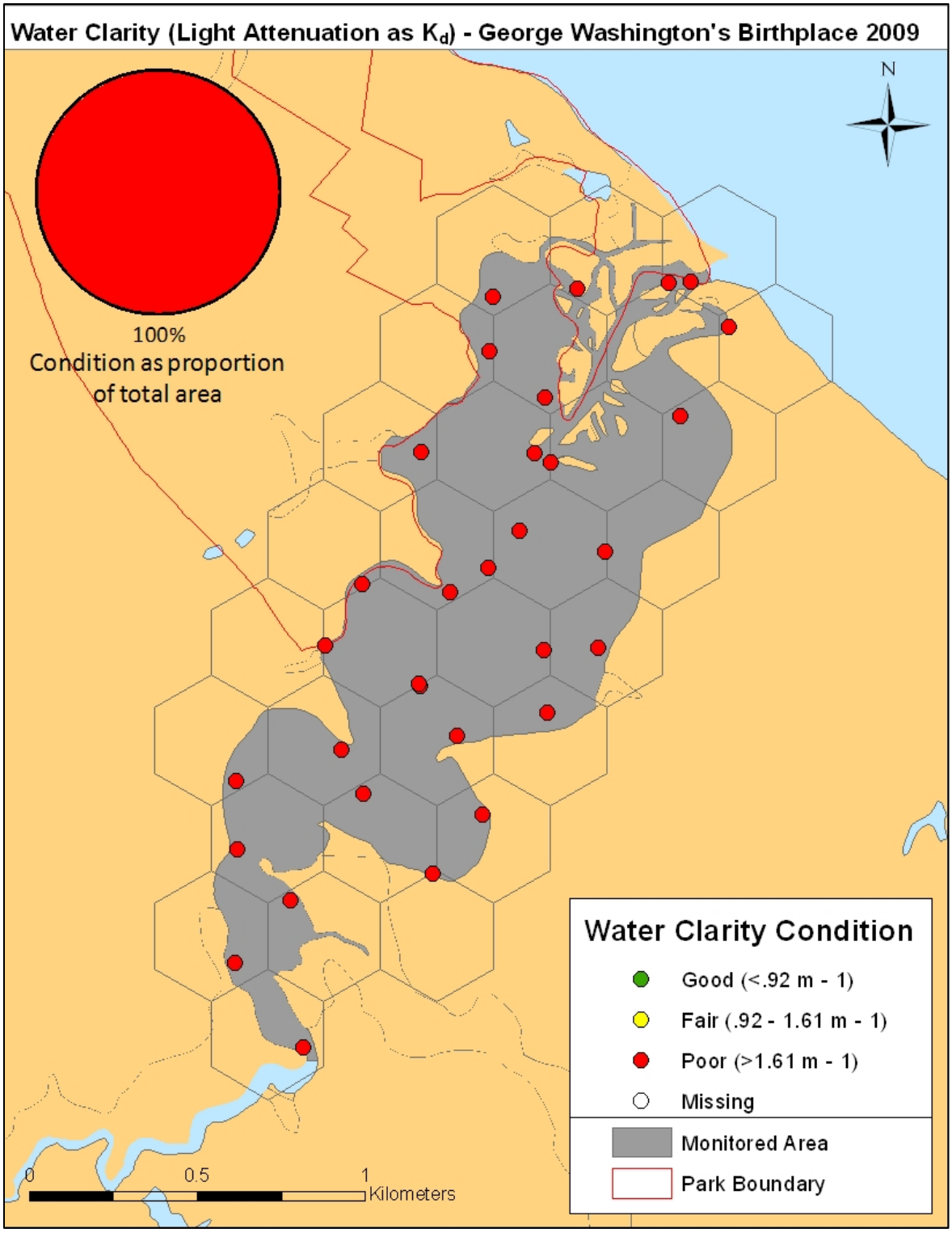


Figure 76. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2009 assessment at GEWA. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

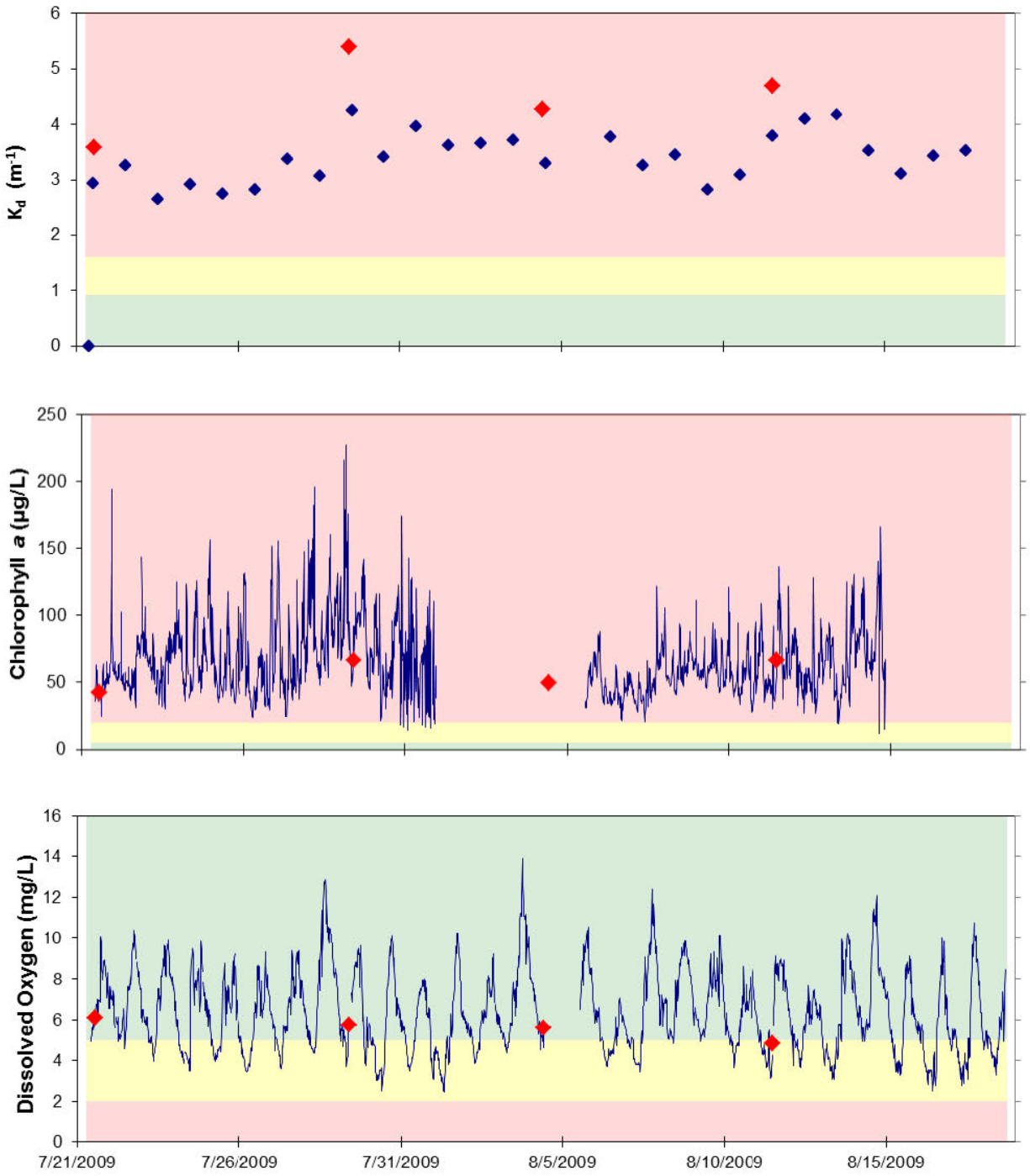


Figure 77. Continuous water-quality data from the 2009 assessment at GEWA. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Plots indicate the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

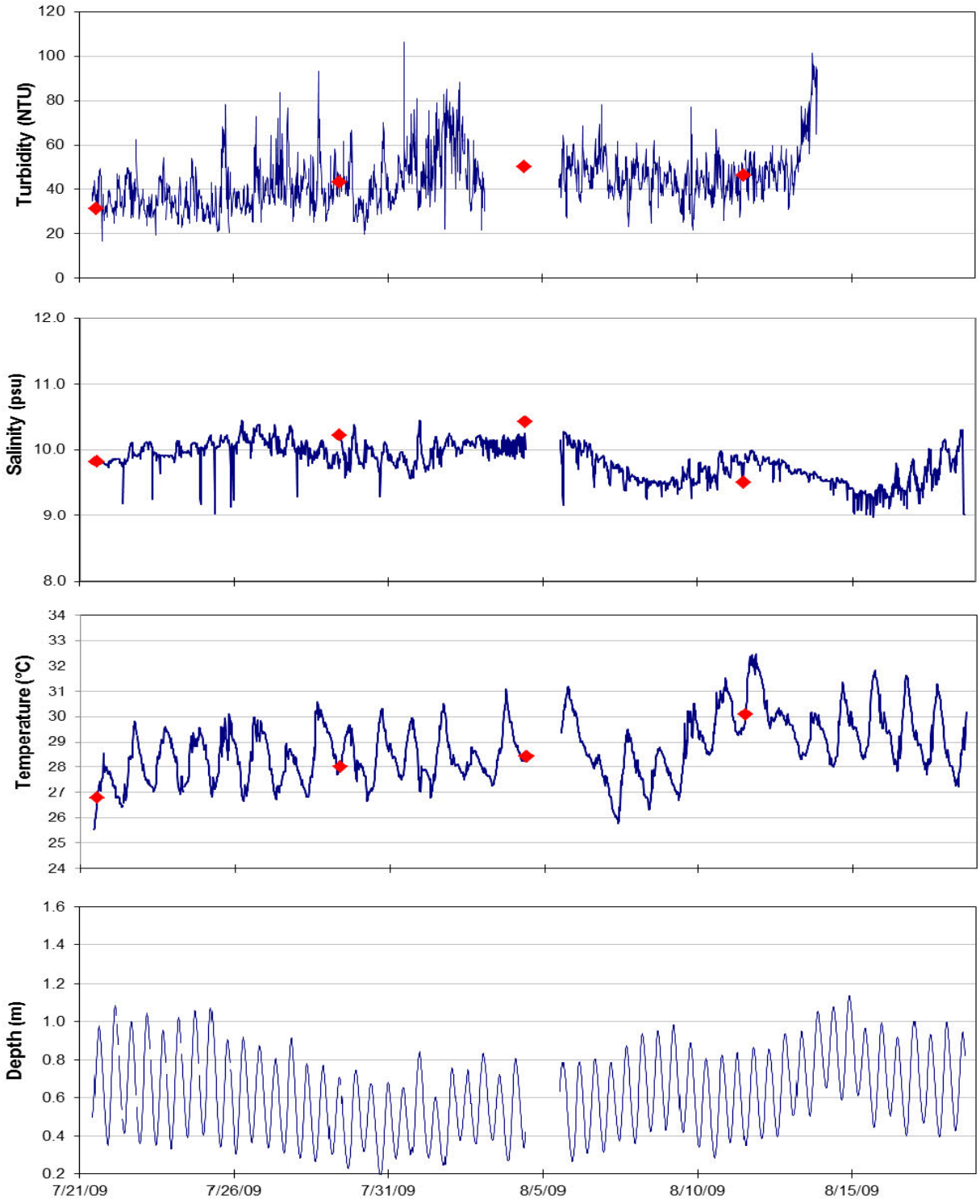


Figure 77 (cont.). Continuous water-quality data from the 2009 assessment at GEWA. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 27. Trend-station water-quality data from the 2009 assessment at GEWA.

		Trend Stations (Hexagons)					
Measure	**Statistic**	**1**	**6**	**13**	**18**	**23**	**25**
PAR attenuation	mean	4.97	4.03	4.65	4.18	4.19	3.69
(K_d (m^{-1}))	std.dev.	1.69	0.46	1.19	1.14	0.95	1.45
	n	4	4	4	4	4	4
Temperature	mean	29.12	29.38	28.85	28.53	28.62	28.55
(°C)	std.dev.	1.35	1.80	1.40	1.87	1.68	2.04
	n	4	4	4	4	4	4
Salinity	mean	9.47	9.80	9.88	9.86	9.99	10.08
(psu)	std.dev.	0.45	0.55	0.44	0.36	0.34	0.70
	n	4	4	4	4	4	4
Dissolved oxygen	mean	6.2	7.1	6.1	5.7	6.1	6.2
(mg/L)	std.dev.	2.7	0.8	1.3	1.4	1.2	2.9
	n	4	4	4	4	4	4
Turbidity	mean	30.5	27.8	37.9	32.8	36.9	21.7
(NTU)	std.dev.	5.0	4.3	9.6	8.0	7.0	11.5
	n	4	4	4	4	4	4
Chlorophyll *a*	mean	71.1	78.9	68.1	68.5	51.4	43.5
(µg/L)	std.dev.	24.8	18.5	19.9	21.5	20.7	22.4
	n	4	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Location of hexagons with trend stations is shown in Figure 6.]

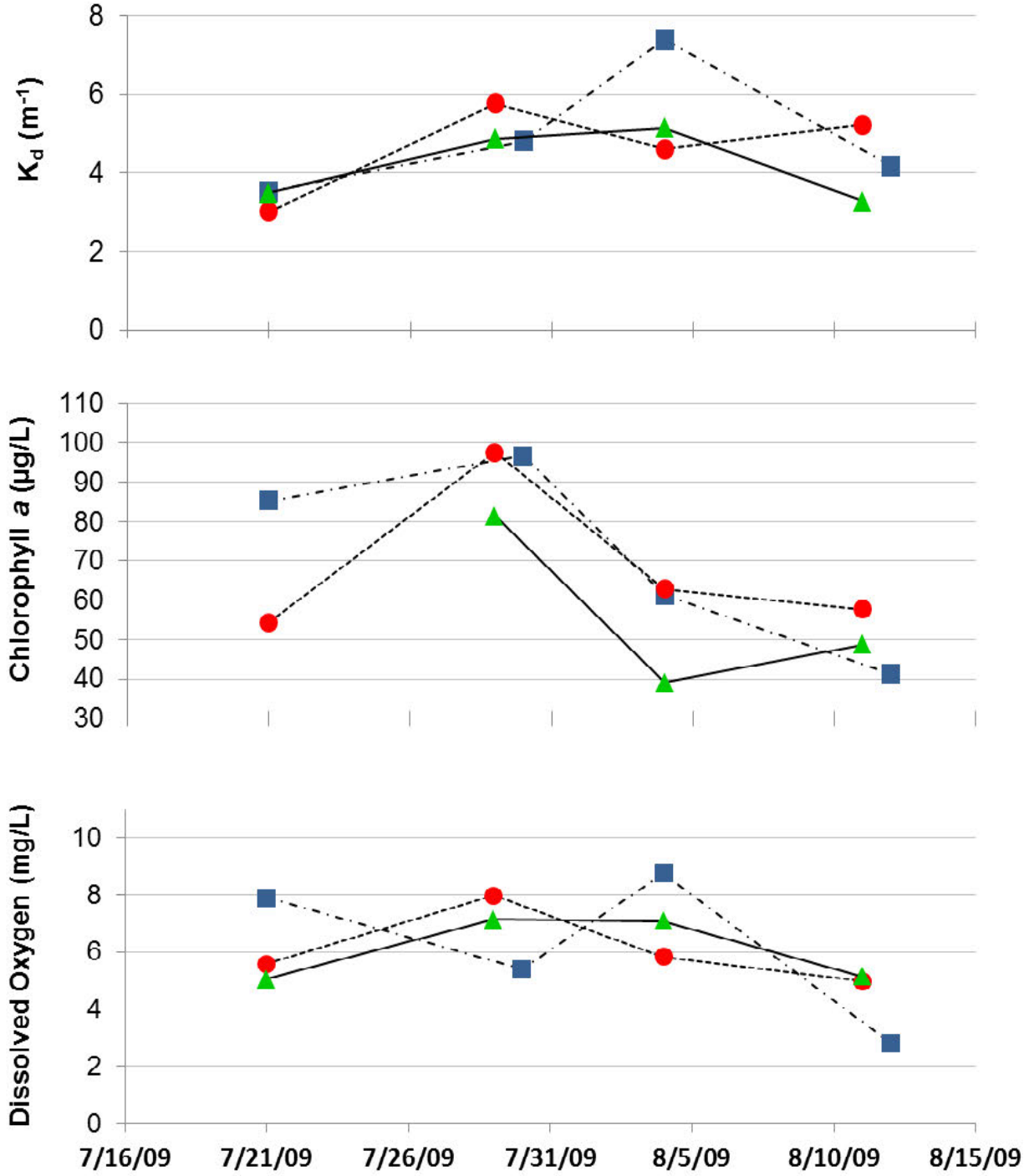


Figure 78. Trend station water-quality data from the 2009 assessment at GEWA. Data are derived from selected trend stations within different portions of the estuary. The blue square (■) represents hexagon 1 (upper estuary), the red circle (●) represents hexagon 13 (mid-estuary), and the green triangle (▲) represents hexagon 23 (lower estuary).

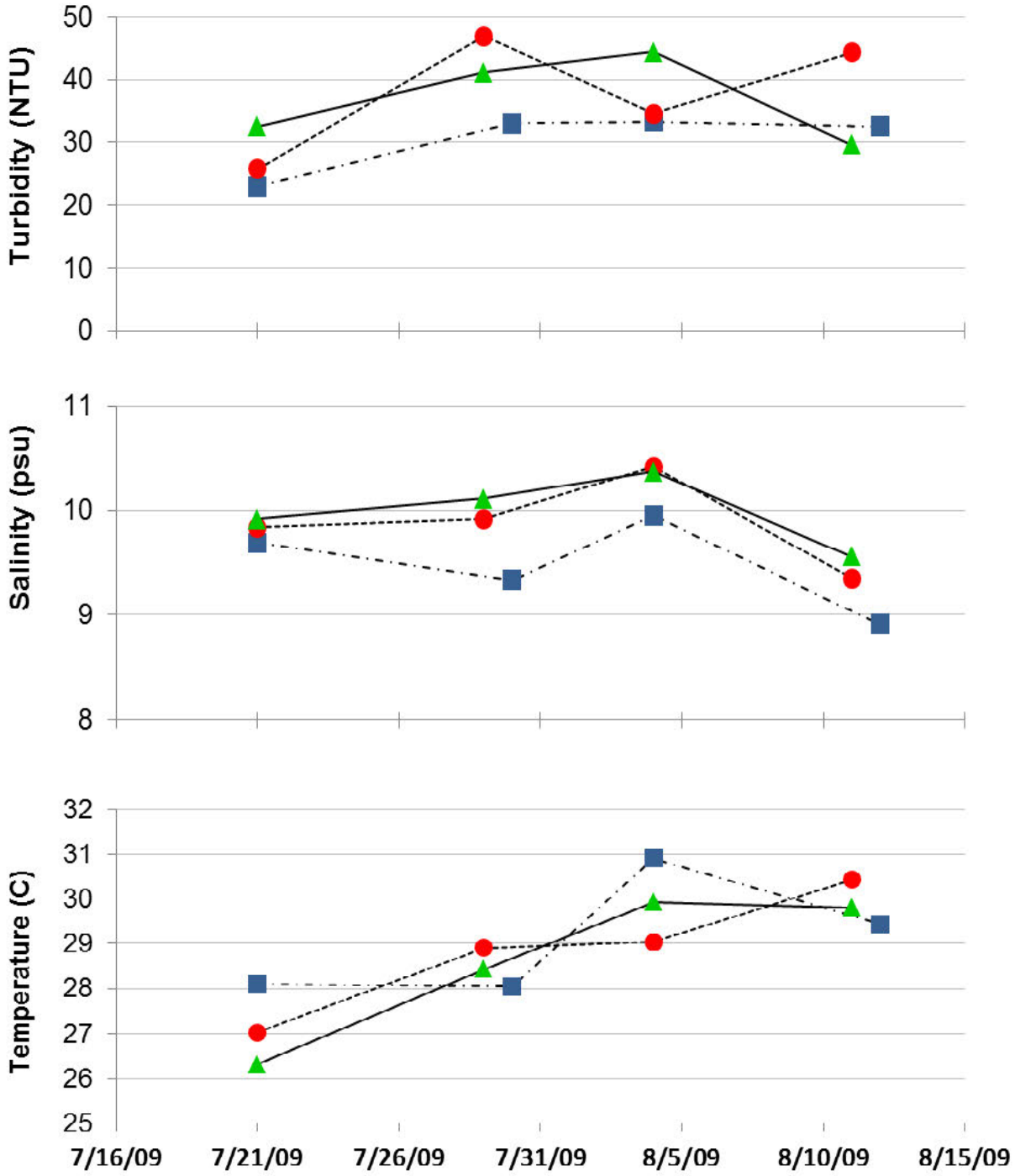


Figure 78 (cont.). Trend station water-quality data from the 2009 assessment at GEWA. Trend Station water-quality data from the 2009 assessment at GEWA. Data are derived from selected trend stations within different portions of the estuary. The blue square (■) represents hexagon 1 (upper estuary), the red circle (●) represents hexagon 13 (mid-estuary), and the green triangle (▲) represents hexagon 23 (lower estuary).

2011 Index Period

Table 28. Area-Weighted average water-quality condition at GEWA during the 2011 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	3.59	- -	- -	- -
Dissolved oxygen (mg/L)	- -	5.25	5.02	4.69
Dissolved oxygen, % Saturation	- -	71.70	69.16	63.83
Chlorophyll *a* (µg/L)	- -	75.55		
Turbidity (NTU)	- -	19.18	21.02	30.55
Temperature (°C)	- -	29.15	29.81	28.98
Salinity (psu)	- -	7.97	8.03	8.01

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable]

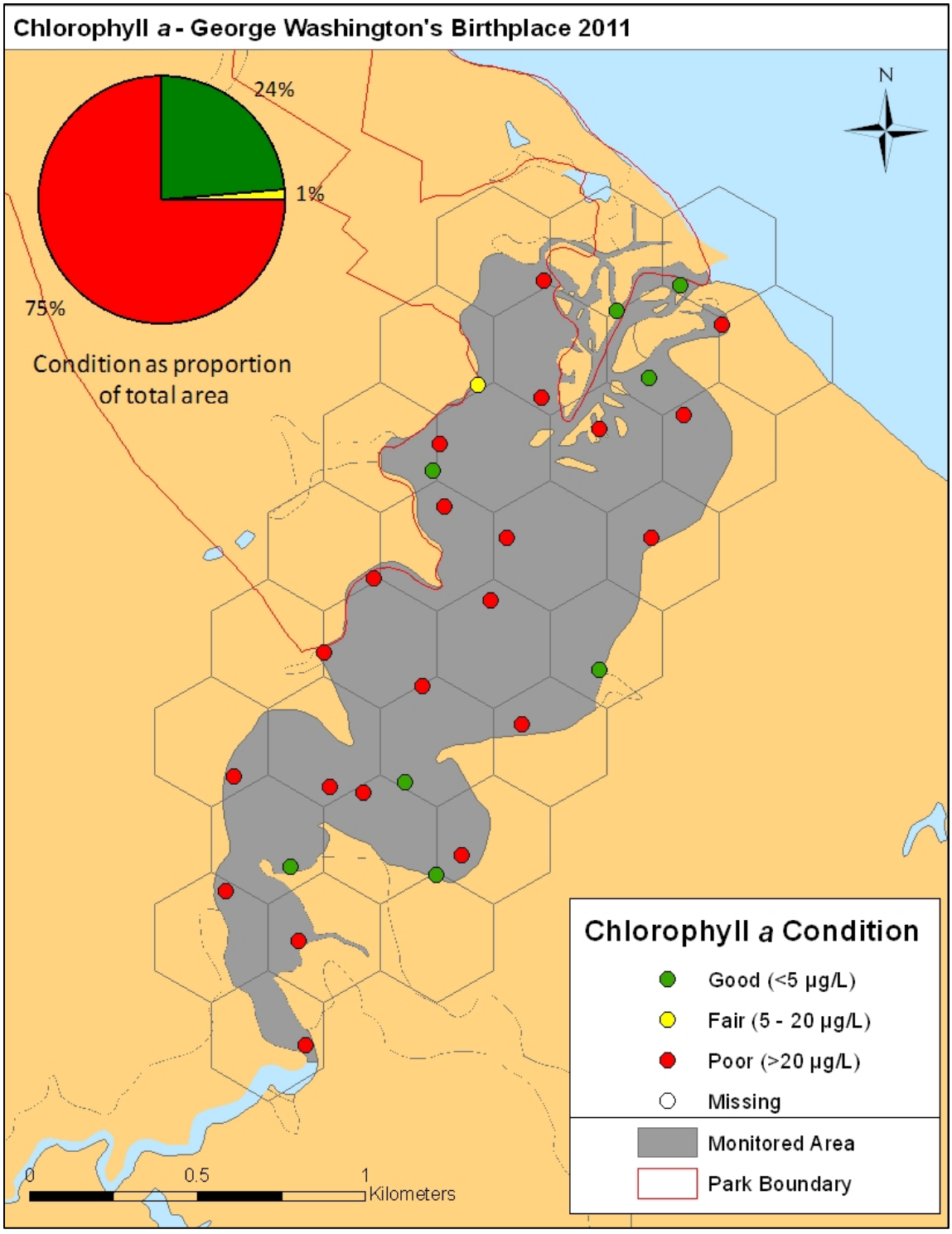


Figure 79. Chlorophyll *a* (µg/L) concentration in surface samples from the 2011 assessment at GEWA. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

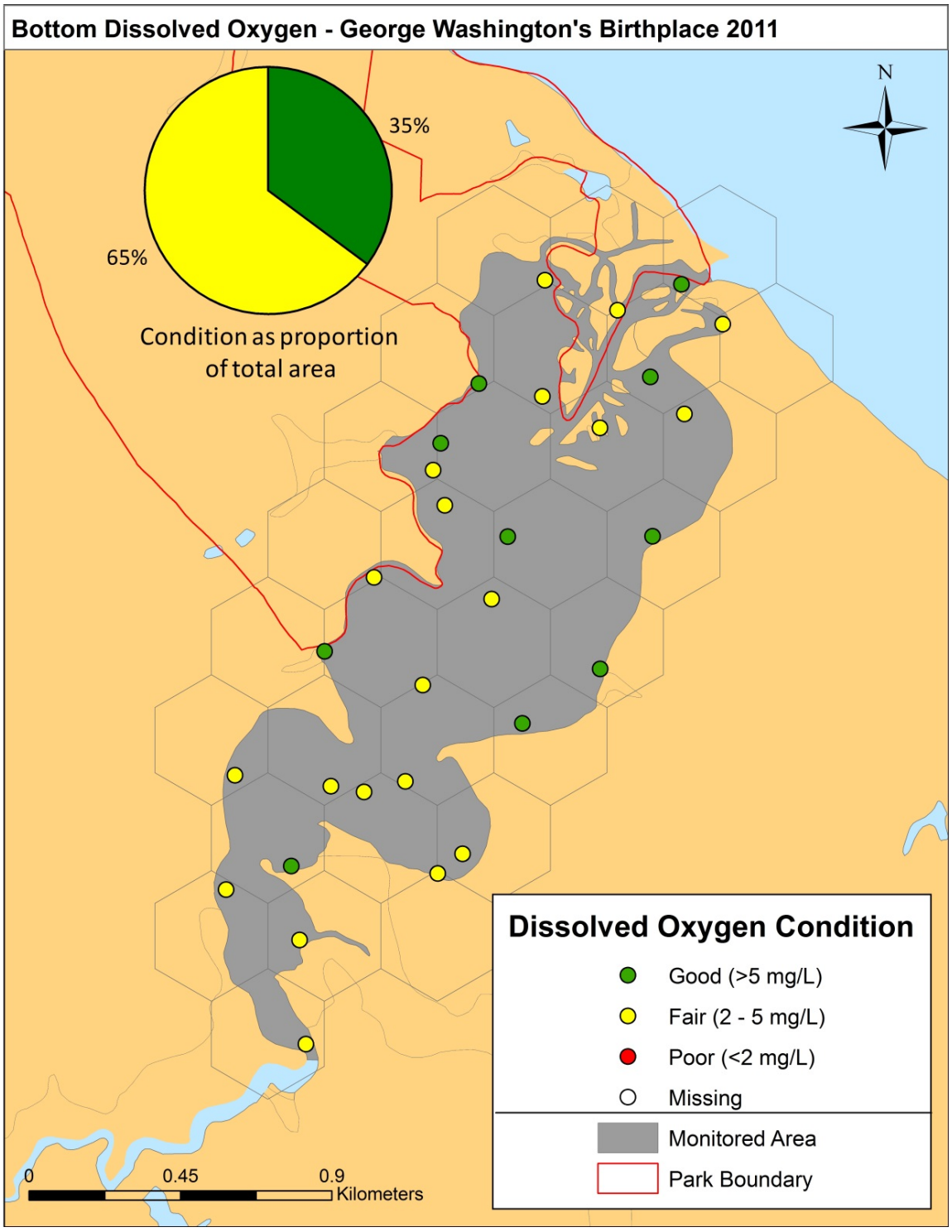


Figure 80. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2011 assessment at GEWA. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

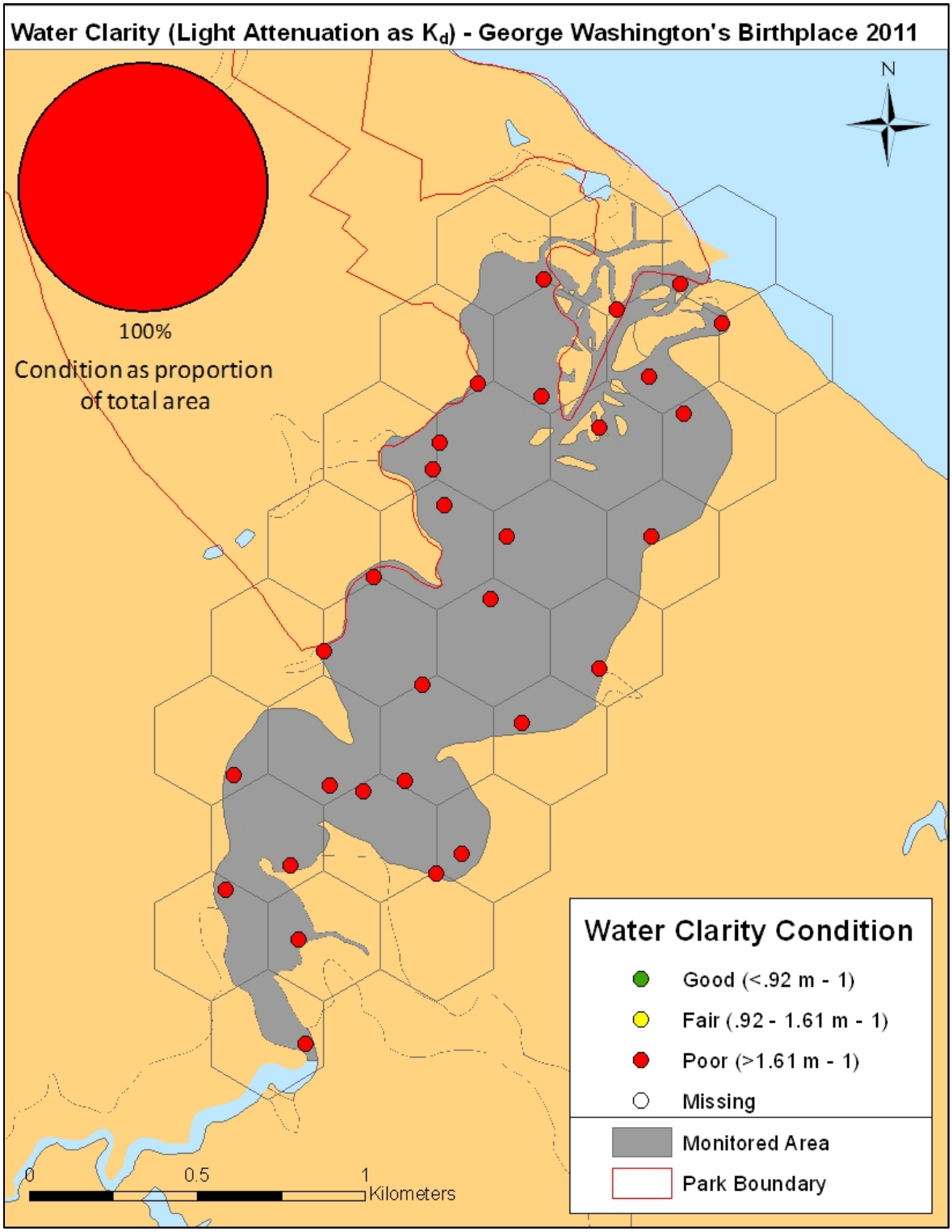


Figure 81. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2011 assessment at GEWA. Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie chart shows the proportion (area) of monitored estuarine resources falling into each category.

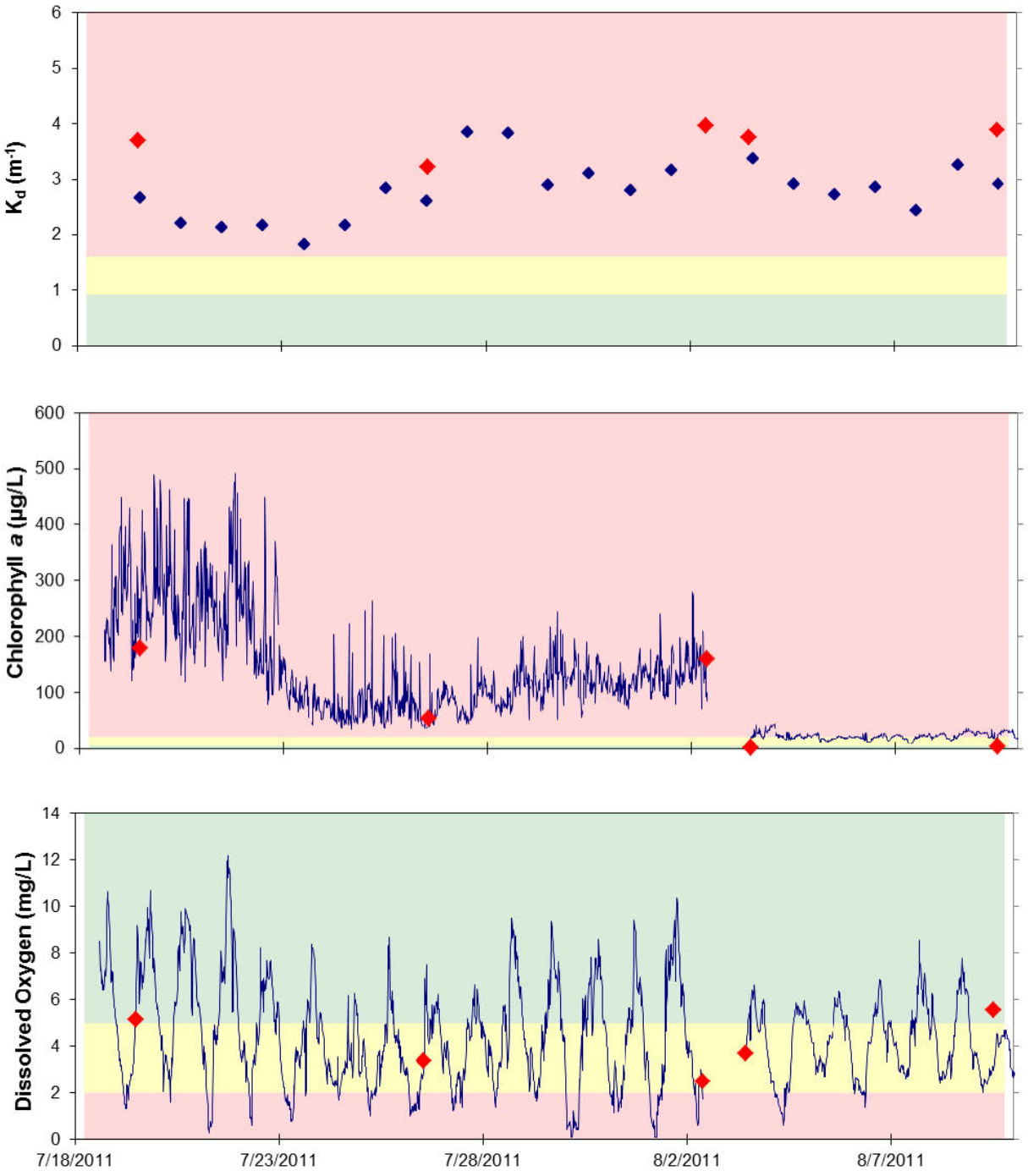


Figure 82. Continuous water-quality data from the 2011 assessment at GEWA. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Plots indicate the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

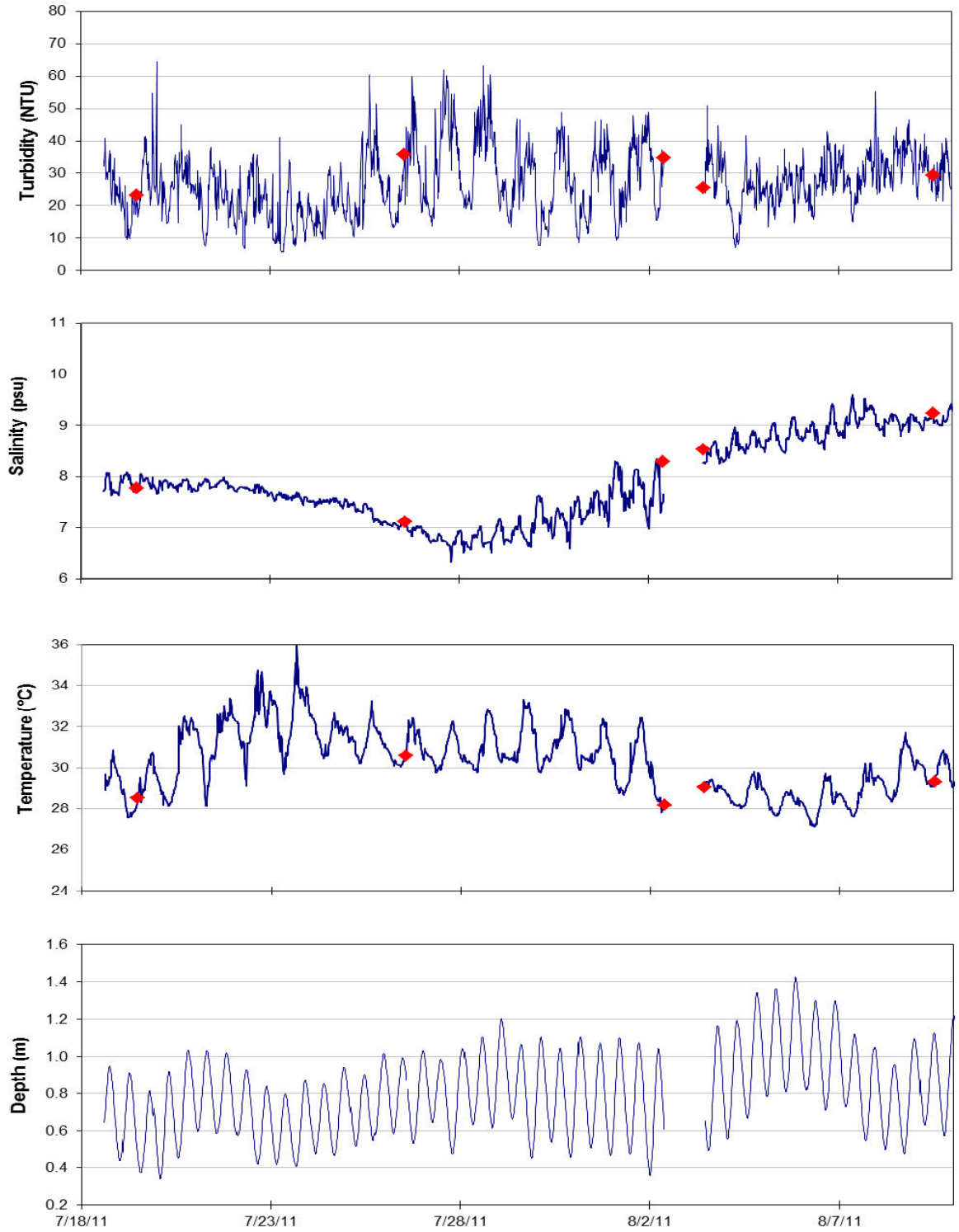


Figure 82 (cont.). Continuous water-quality data from the 2011 assessment at GEWA. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 29. Trend-station water-quality data from the 2011 assessment at GEWA.

		Trend Stations (Hexagons)					
Measure	**Statistic**	**1**	**6**	**13**	**18**	**23**	**25**
PAR attenuation	mean	3.27	3.58	4.49	3.74	3.37	3.09
(K_d (m^{-1}))	std.dev.	1.28	1.33	1.86	0.48	0.54	0.41
	n	4	4	4	4	4	4
Temperature	mean	29.25	29.25	29.41	29.37	28.96	28.99
(°C)	std.dev.	0.93	1.28	0.98	0.95	0.55	1.04
	n	4	4	4	4	4	4
Salinity	mean	7.45	7.65	8.06	8.16	8.26	8.32
(psu)	std.dev.	1.14	1.06	1.03	1.00	1.08	1.11
	n	4	4	4	4	4	4
Dissolved oxygen	mean	3.3	4.0	5.3	4.9	4.5	5.2
(mg/L)	std.dev.	1.6	0.7	1.9	0.6	1.1	1.5
	n	4	4	4	4	4	4
Turbidity	mean	19.5	22.9	24.7	20.7	17.8	16.4
(NTU)	std.dev.	7.4	9.8	7.0	3.0	3.0	4.6
	n	4	4	4	4	4	4
Chlorophyll *a*	mean	26.5	42.0	84.2	90.5	58.6	85.0
(µg/L)	std.dev.	29.9	37.8	64.0	77.0	46.0	61.8
	n	4	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Location of hexagons with trend stations is shown in Figure 4.]

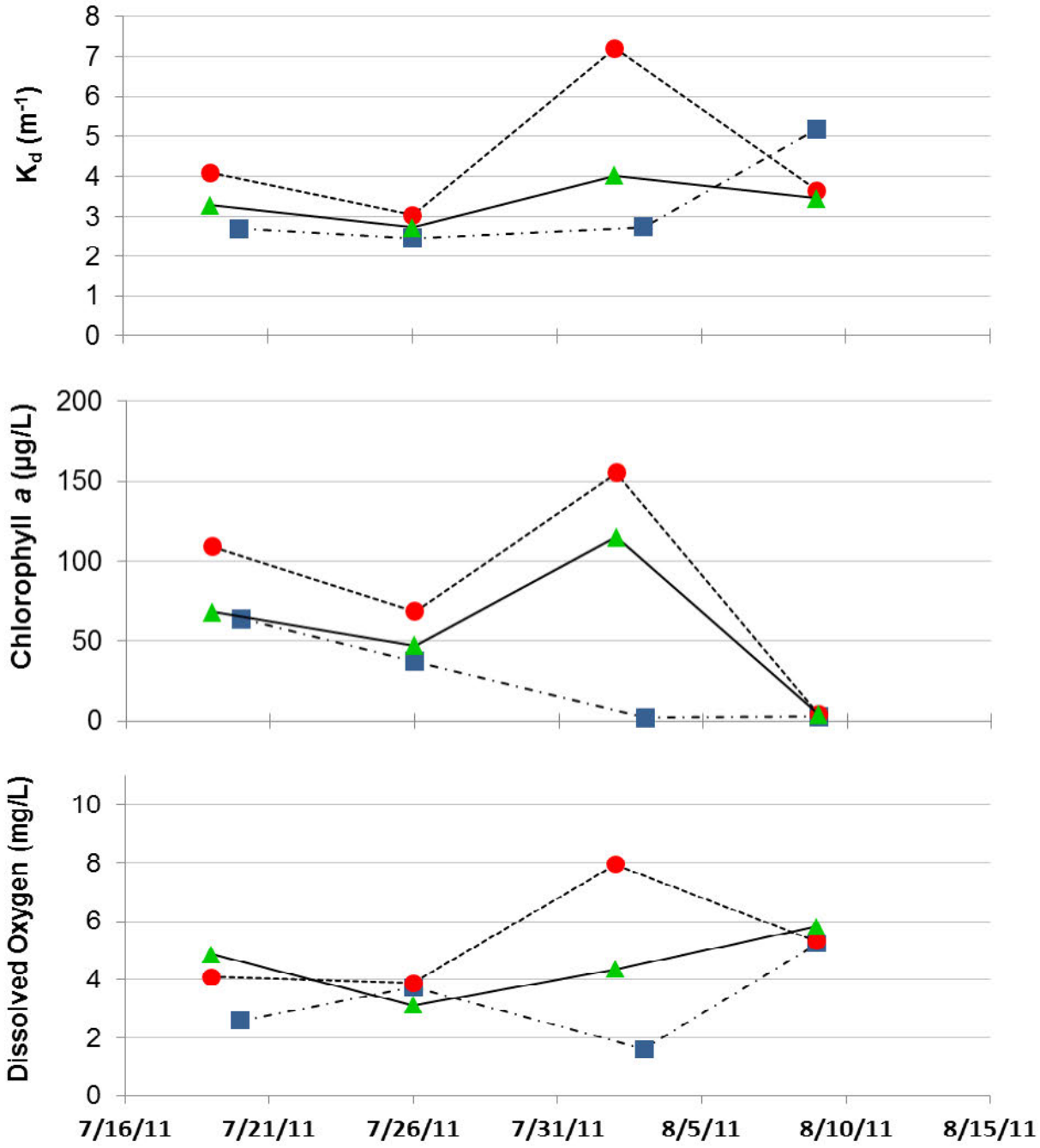


Figure 83. Trend Station water-quality data from the 2011 assessment at GEWA. Trend Station water-quality data from the 2009 assessment at GEWA. Data are derived from selected trend stations within different portions of the estuary. The blue square (■) represents hexagon 1 (upper estuary), the red circle (●) represents hexagon 13 (mid-estuary), and the green triangle (▲) represents hexagon 23 (lower estuary).

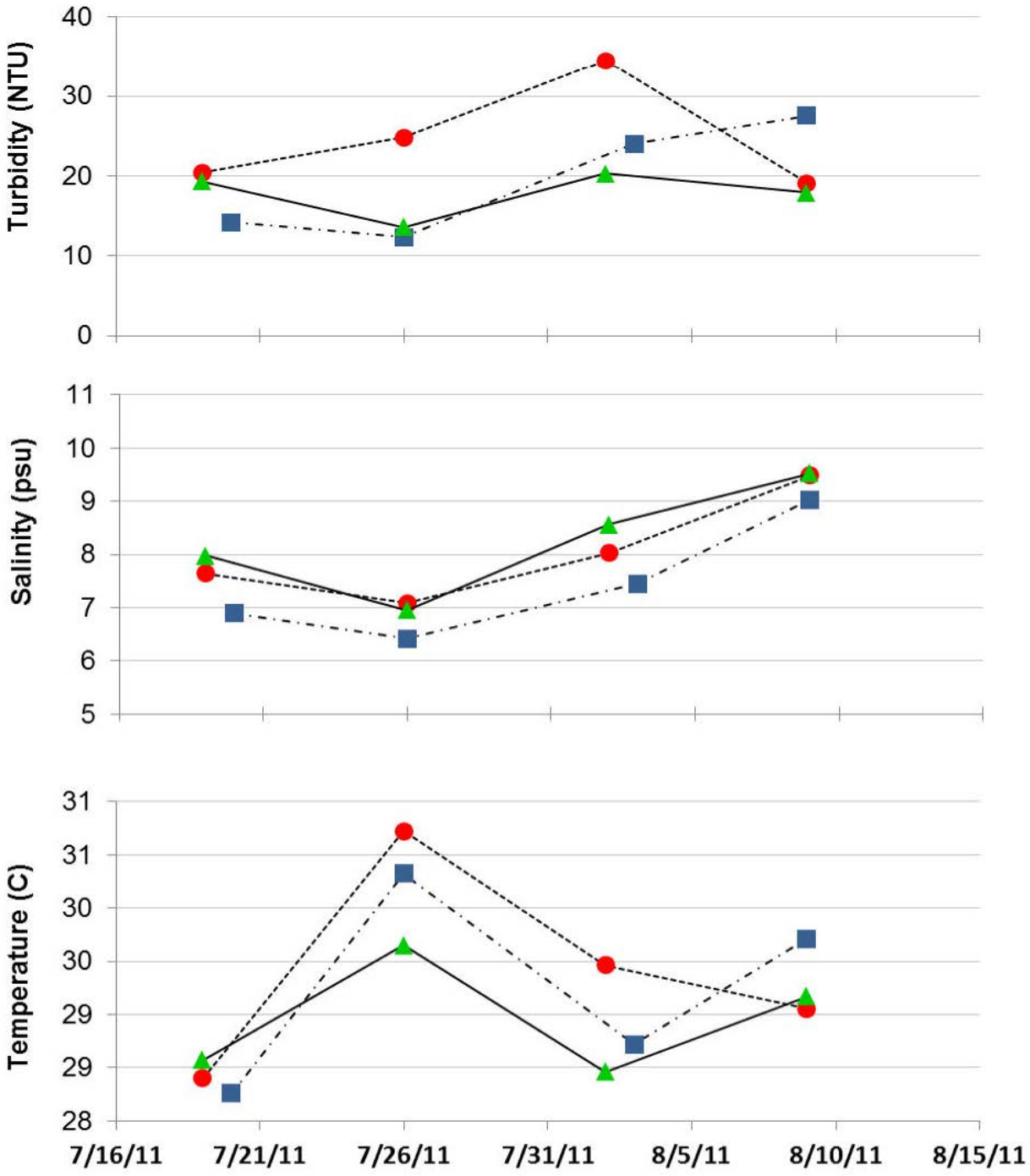


Figure 83 (cont.). Trend Station water-quality data from the 2011 assessment at GEWA. Trend Station water-quality data from the 2009 assessment at GEWA. Data are derived from selected trend stations within different portions of the estuary. The blue square (■) represents hexagon 1 (upper estuary), the red circle (●) represents hexagon 13 (mid-estuary), and the green triangle (▲) represents hexagon 23 (lower estuary).

Colonial National Historic Park

The area-weighted average chlorophyll *a* concentration ranged from 22.92 µg/L in 2008 to 27.98 µg/L in 2010, and analysis of system-wide data showed that the mean chlorophyll concentration increased between years ($P < 0.05$). The area-weighted average of daytime dissolved oxygen in bottom waters ranged from 6.21 mg/L in 2008 to 6.09 mg/L in 2010, both of which are about 83% of the saturation concentration; and the area-weighted average water-column PAR attenuation coefficient (K_d) ranged from 3.64 m^{-1} in 2008 to 3.50 m^{-1} in 2010, indicating overall poor water clarity (Table 30, Table 32). There were no differences in system-wide means of PAR attenuation coefficient (K_d) or dissolved oxygen concentration in bottom waters between 2008 and 2010 ($P > 0.70$).

The spatial distribution of water-quality conditions at COLO was very similar in 2008 and 2010. During both index periods all sampling stations fell into either fair or poor condition classes for chlorophyll *a* concentration, with a larger proportion of stations meeting "fair" criteria in the thoroughfare than the tidal creeks (Figure 84, Figure 89). Each year the majority of stations were classified as good condition for dissolved oxygen concentration (Figure 85, Figure 90) and poor condition for PAR attenuation (Figure 86, Figure 91). Continuous logging data revealed short-term peaks of chlorophyll *a* concentration that greatly exceeded seasonal means and pre-dawn concentrations of dissolved oxygen that dipped frequently into the fair condition class (Figure 87, Figure 92). Within-season variability in water-quality parameters is displayed by the trend-station data (Table 31, Figure 88, Table 33, Figure 93).

2008 Index Period

Table 30. Area-weighted average water-quality condition at COLO during the 2008 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	3.64	- -	- -	- -
Dissolved oxygen (mg/L)	- -	6.56	6.39	6.21
Dissolved oxygen, % Saturation	- -	87.50	85.40	82.56
Chlorophyll *a* (µg/L)	- -	22.92	- -	- -
Turbidity (NTU)	- -	27.67	31.55	42.55
Temperature (°C)	- -	27.69	27.94	27.55
Salinity (psu)	- -	8.46	8.04	8.33

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons, in addition to 9 probability and 3 trend stations located in the tidal creek portion of the park. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

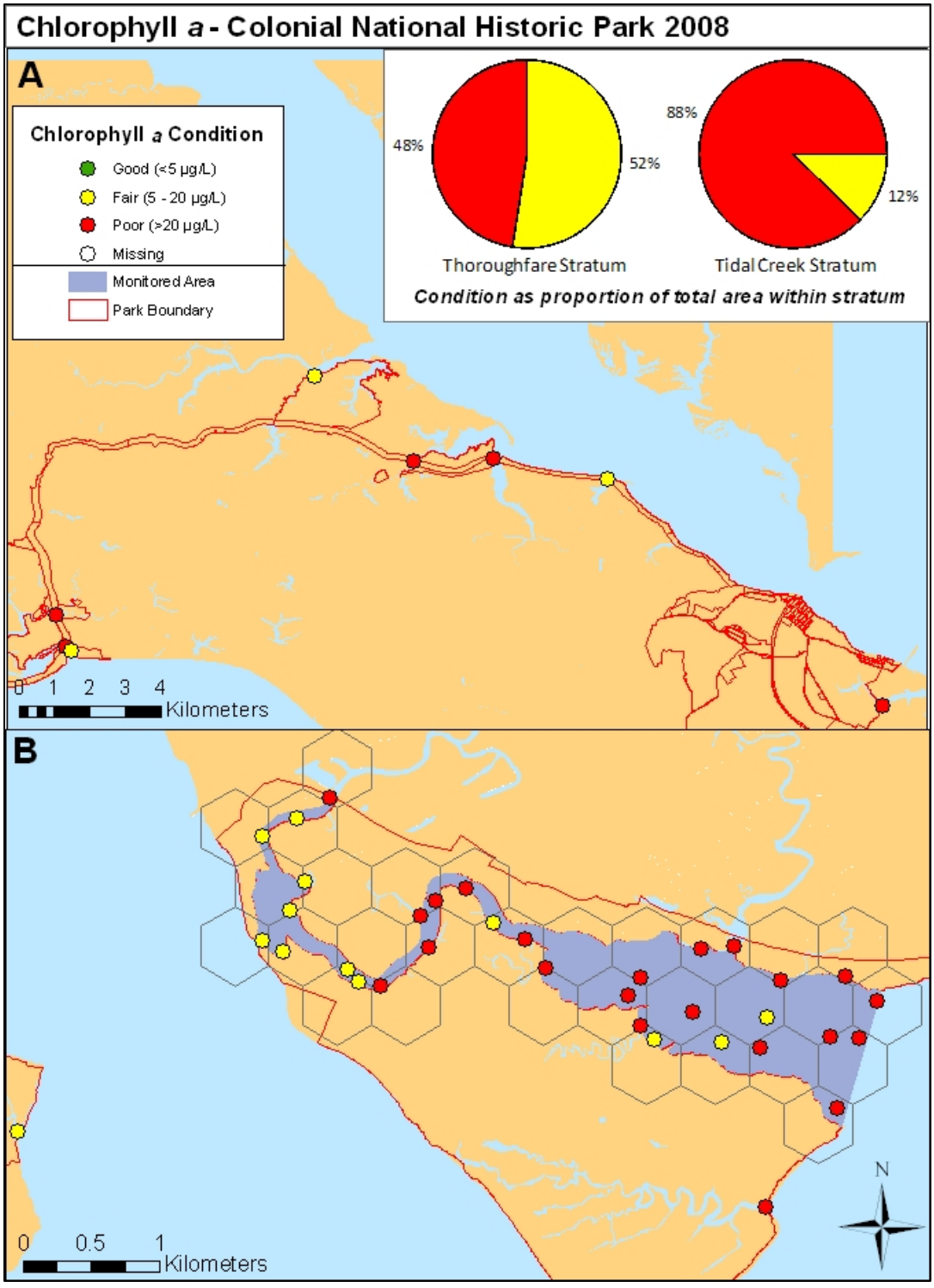


Figure 84. Chlorophyll *a* (µg/L) concentration in surface samples from the 2008 assessment at COLO in the Tidal Creek stratum (A) and the Thoroughfare stratum (B). Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

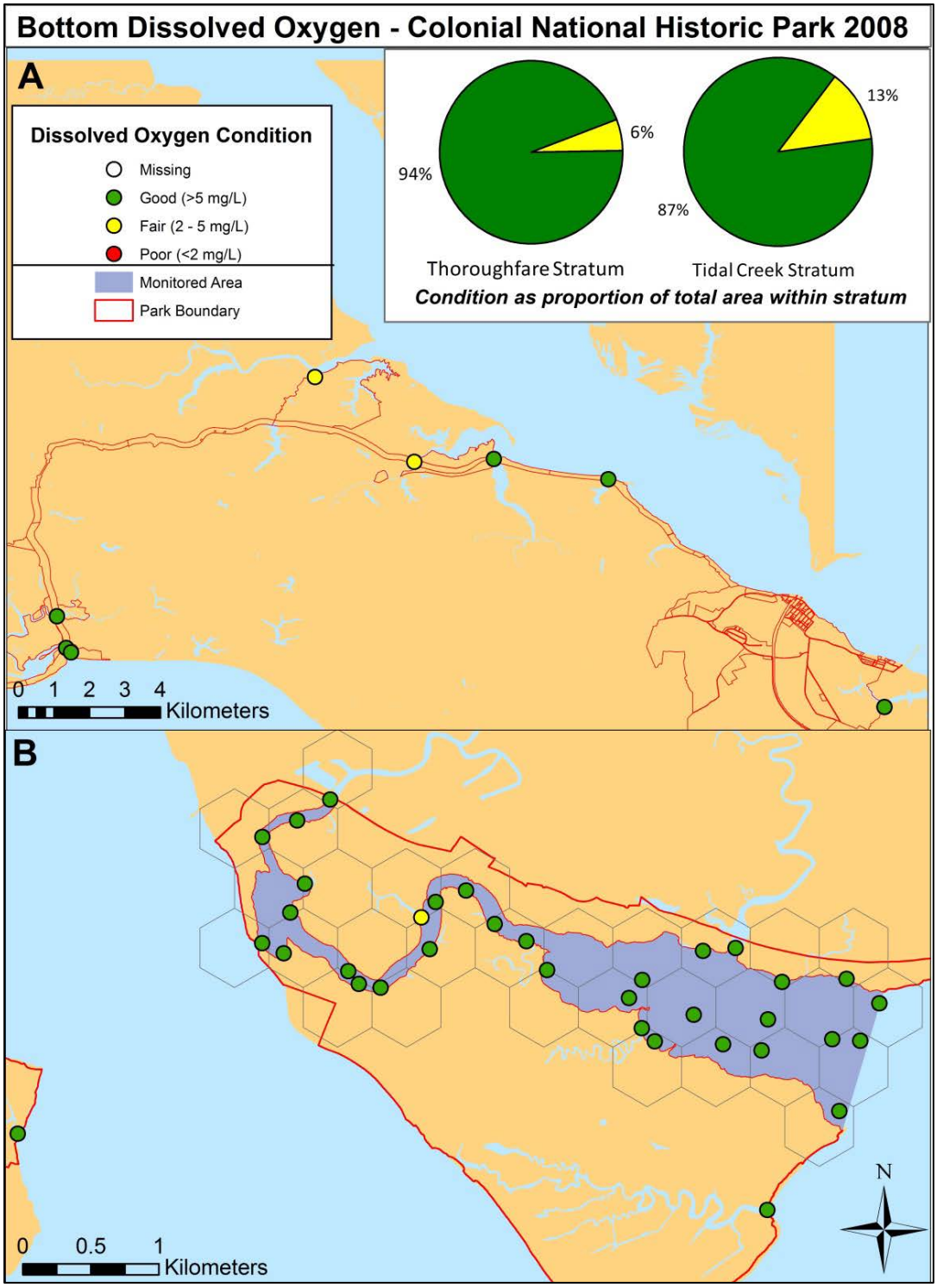


Figure 85. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2008 assessment at COLO in the Tidal Creek stratum (A) and the Thoroughfare stratum (B). Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

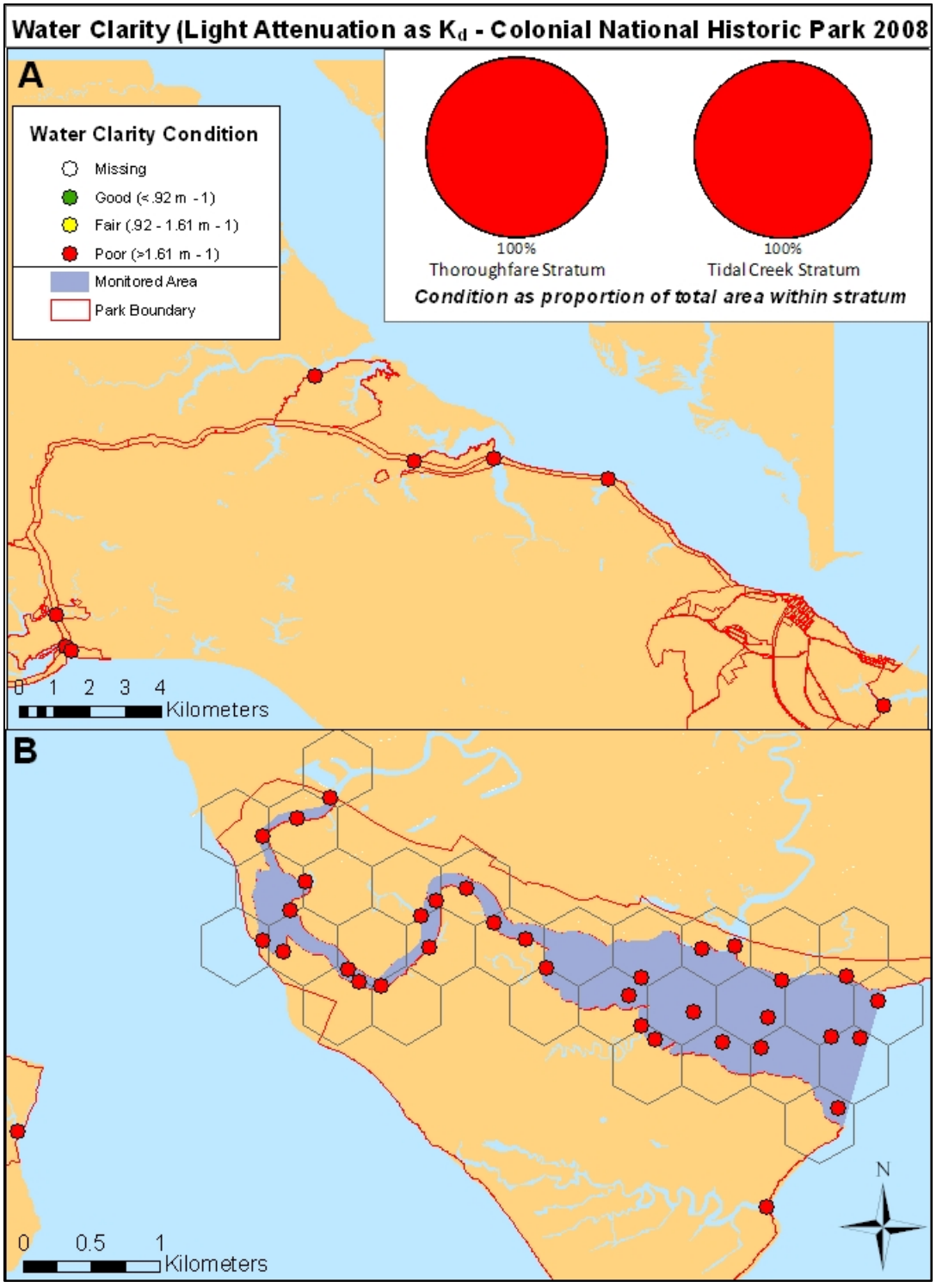


Figure 86. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2008 assessment at COLO in the Tidal Creek stratum (A) and the Thoroughfare stratum (B). Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

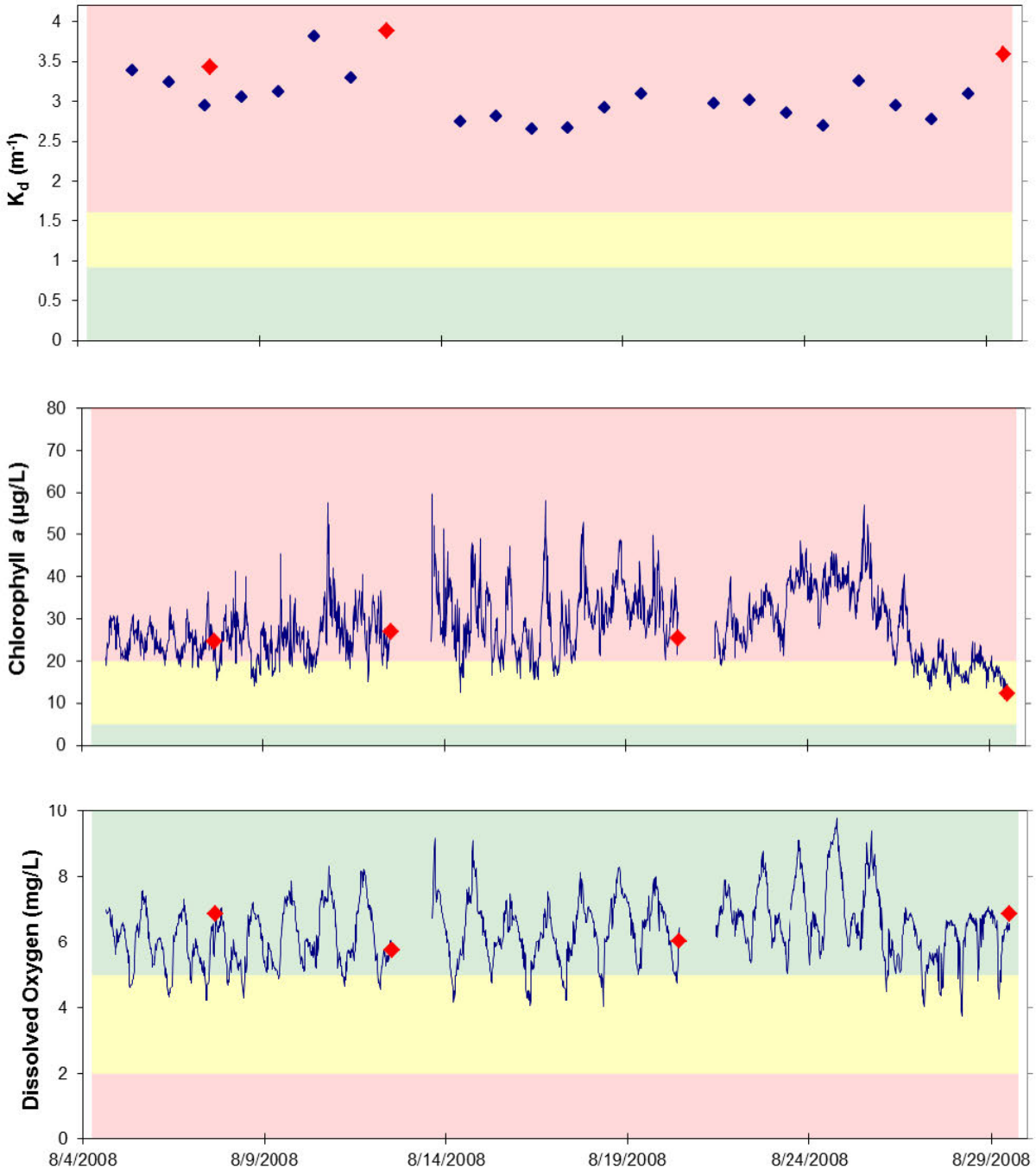


Figure 87. Continuous water-quality data from the 2008 assessment at COLO. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Plots indicate the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

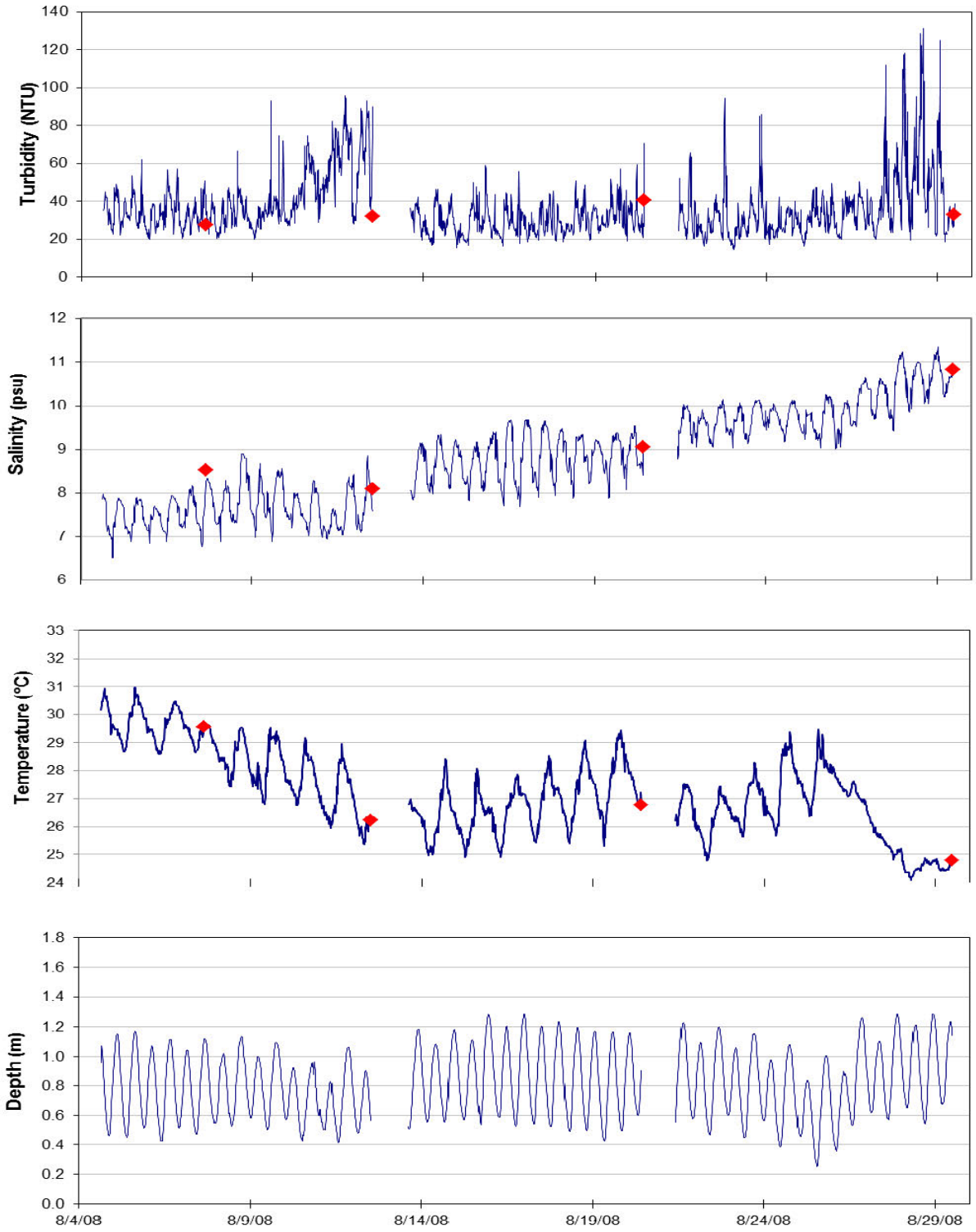


Figure 87 (cont.). Continuous water-quality data from the 2008 assessment at COLO. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 31. Trend-station water-quality data from the 2008 assessment at COLO.

Measure	Statistic	Trend Stations (Hexagons)								
		5 (TH)	**10 (TH)**	**15 (TH)**	**20 (TH)**	**25 (TH)**	**30 (TH)**	**33 (TC)**	**37 (TC)**	**38 (TC)**
PAR attenuation	mean	3.56	4.49	3.18	2.90	3.57	2.95	2.50	2.49	3.80
(K_d (m^{-1}))	std.dev.	0.97	0.49	0.22	0.25	0.42	0.16	0.49	0.62	0.38
	n	4	4	4	4	4	4	4	4	4
Temperature	mean	27.40	27.00	27.20	27.26	27.03	27.16	26.33	27.56	27.06
(°C)	std.dev.	1.56	1.73	1.73	1.67	1.80	1.27	1.73	1.73	2.38
	n	4	4	4	4	4	4	4	4	3
Salinity	mean	9.44	8.28	7.43	8.49	7.38	7.03	21.29	10.49	9.46
(psu)	std.dev.	1.55	1.36	1.20	2.18	1.16	1.65	0.28	1.24	1.21
	n	4	4	4	4	4	4	4	4	3
Dissolved oxygen	mean	6.5	6.0	6.5	6.4	6.3	5.3	6.8	7.0	6.4
(mg/L)	std.dev.	0.4	0.4	0.7	0.7	0.8	1.3	0.9	0.7	0.6
	n	4	4	4	4	4	4	4	3	4
Turbidity	mean	33.9	36.7	23.4	23.5	24.9	19.1	18.4	20.0	32.5
(NTU)	std.dev.	9.5	6.0	3.9	3.0	5.5	1.8	3.9	8.1	4.7
	n	4	4	4	4	4	4	4	4	3
Chlorophyll *a*	mean	27.2	20.2	17.7	17.6	18.2	22.7	23.8	19.1	22.3
(µg/L)	std.dev.	17.2	2.4	2.0	4.3	2.7	5.4	11.9	9.1	6.8
	n	4	4	4	4	4	4	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Location of hexagons with trend stations is shown in Figure 7. Stratum indicated in parentheses below hexagon number (TH – Thoroughfare, TC – Tidal Creek).]

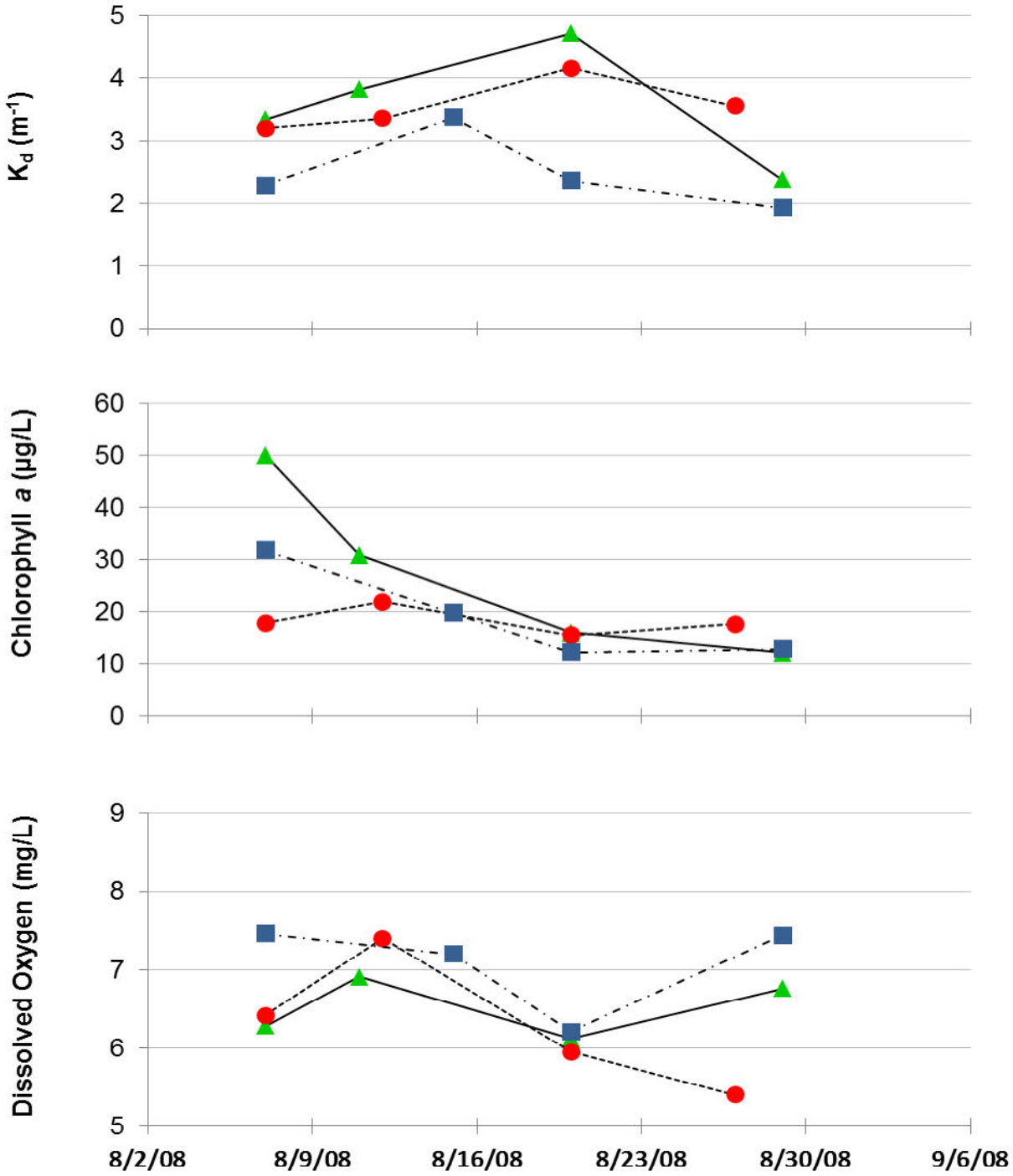


Figure 88. Trend station water-quality data from the 2008 assessment at COLO. Data are derived from selected trend stations within different portions of the monitored area. The blue square (■) represents hexagon 37 (tidal creek stratum), the red circle (●) represents hexagon 25 (western end of Thoroughfare stratum), and the green triangle (▲) represents hexagon 5 (eastern end of Thoroughfare stratum).

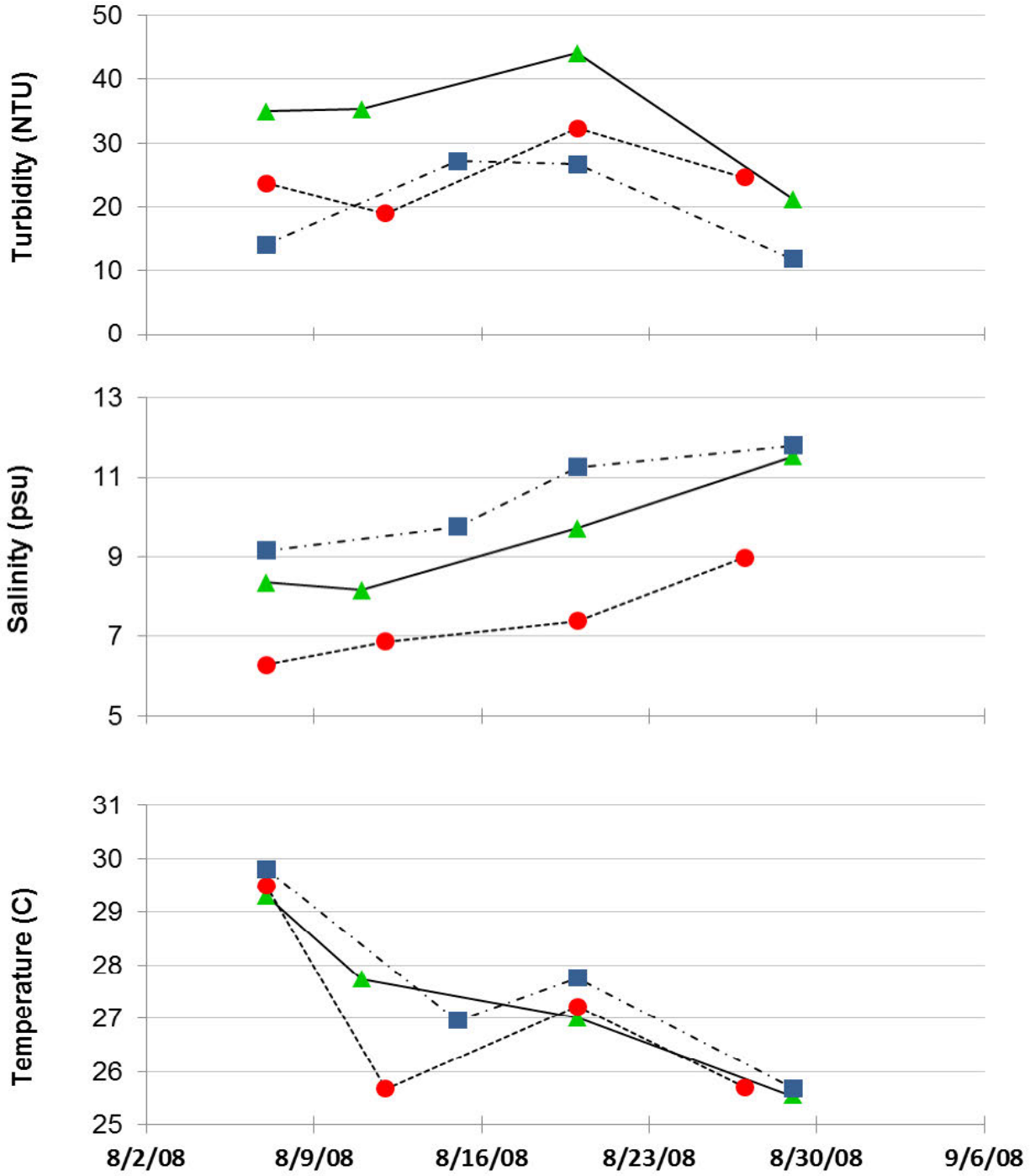


Figure 88 (cont.). Trend Station water-quality data from the 2008 assessment at COLO. Data are derived from selected trend stations within different portions of the monitored area. The blue square (■) represents hexagon 37 (tidal creek stratum), the red circle (●) represents hexagon 25 (western end of Thoroughfare stratum), and the green triangle (▲) represents hexagon 5 (eastern end of Thoroughfare stratum).

2010 Index Period

Table 32. Area-weighted average water-quality condition at COLO during the 2010 index period.

Measure	Water Column	Surface	Mid-Depth	Bottom
PAR attenuation (K_d (m^{-1}))	3.50	- -	- -	- -
Dissolved oxygen (mg/L)	- -	2.18	6.31	6.09
Dissolved oxygen, % Saturation	- -	89.76	86.15	83.22
Chlorophyll *a* (µg/L)	- -	27.98	- -	- -
Turbidity (NTU)	- -	27.56	30.05	42.82
Temperature (°C)	- -	29.17	28.90	28.97
Salinity (psu)	- -	8.88	9.14	9.02

[Reported values are means of measurements from 24 probability and 6 trend stations located within 30 tessellated hexagons, in addition to 9 probability and 3 trend stations located in the tidal creek portion of the park. Each measure is weighted by the estuarine area within the respective hexagon. For trend stations, only the first data set (one date) that met data-quality objectives of the ENE protocol were used for these calculations. "- -", not applicable.]

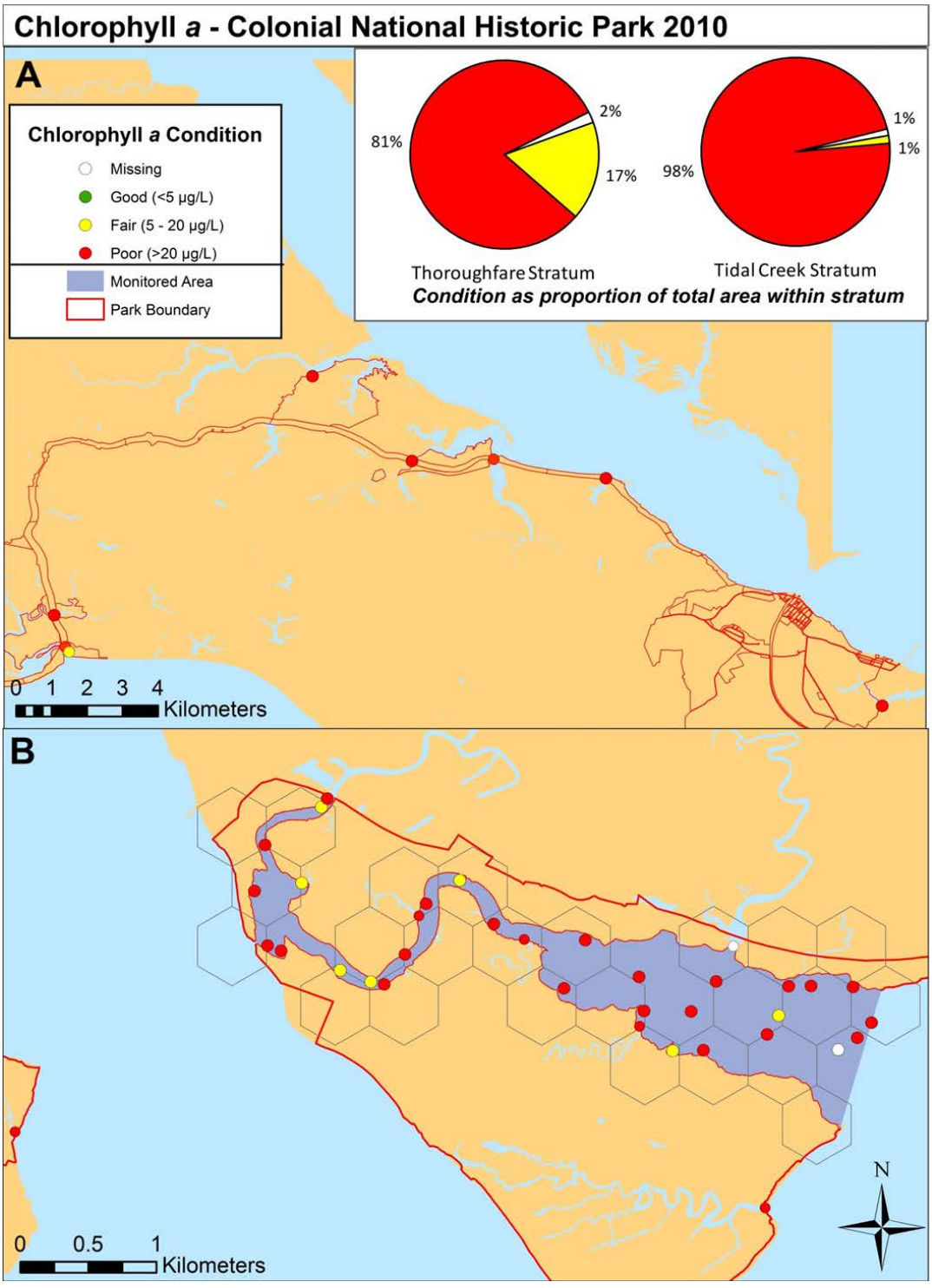


Figure 89. Chlorophyll *a* (µg/L) concentration in surface samples from the 2010 assessment at COLO in the Tidal Creek stratum (A) and the Thoroughfare stratum (B). Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

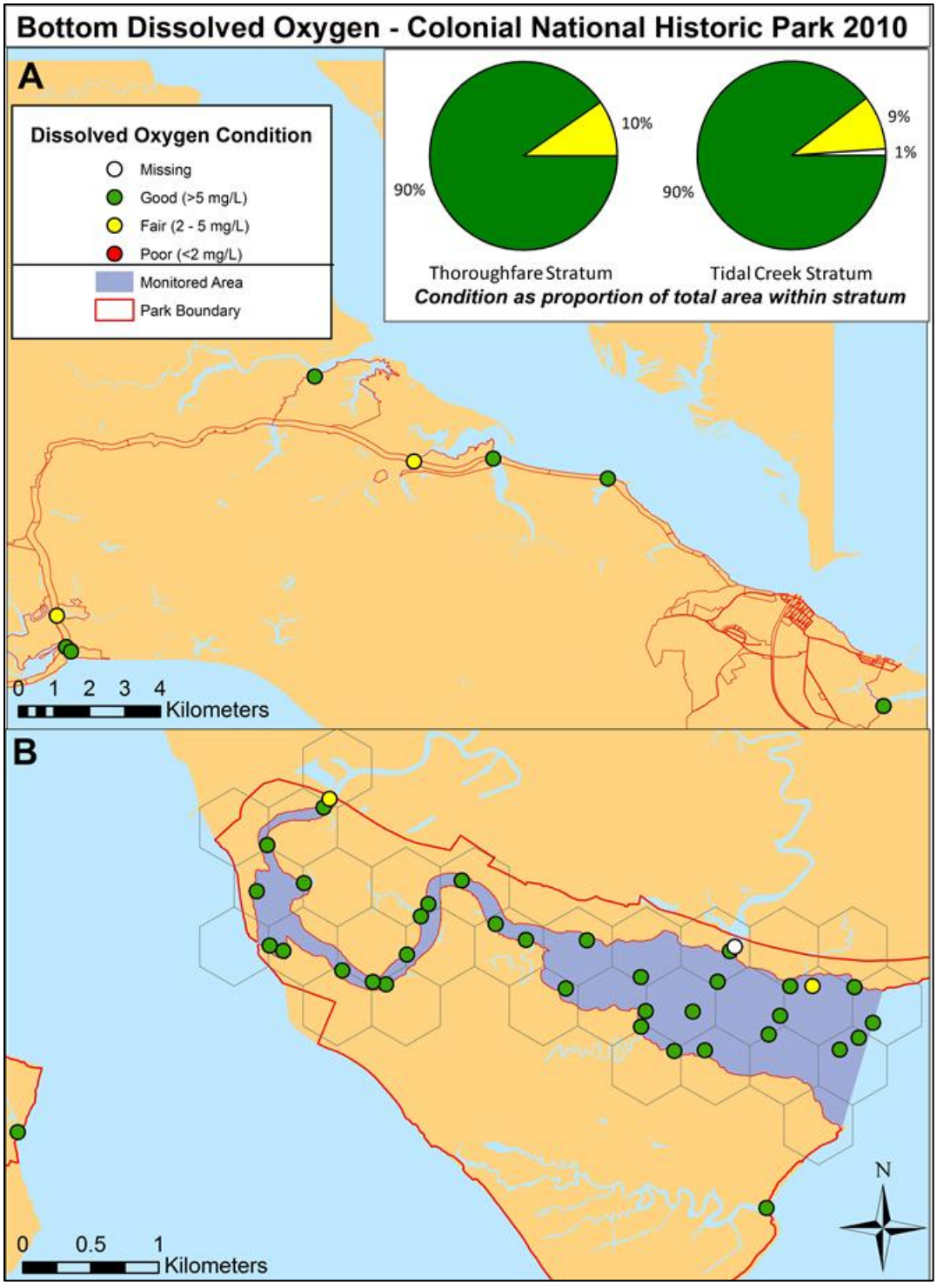


Figure 90. Dissolved-oxygen concentration (mg/L) in bottom samples from the 2010 assessment at COLO in the Tidal Creek stratum (A) and the Thoroughfare stratum (B). Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

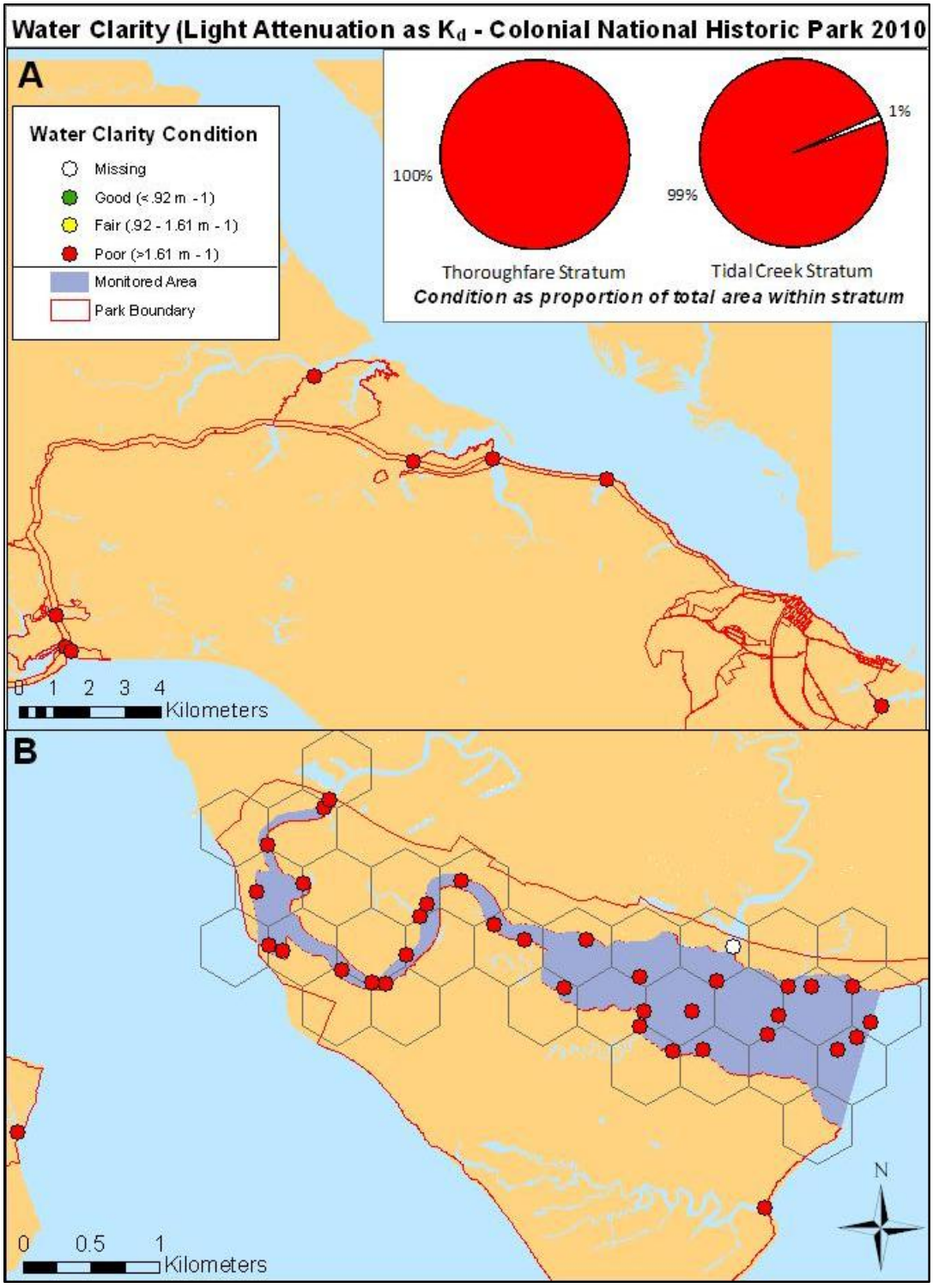


Figure 91. Attenuation coefficient of PAR, K_d (m^{-1}), from the 2010 assessment at COLO in the Tidal Creek stratum (A) and the Thoroughfare stratum (B). Station icons are color coded based on threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3) as adopted by the NPS NCBN. For trend stations, the value reported is from the first visit generating data meeting ENE data-quality objectives. Missing values (white) either were never measured or were rejected during data-reduction steps because they failed to meet data-quality objectives. The pie charts show the proportion (area) of monitored estuarine resources falling into each category.

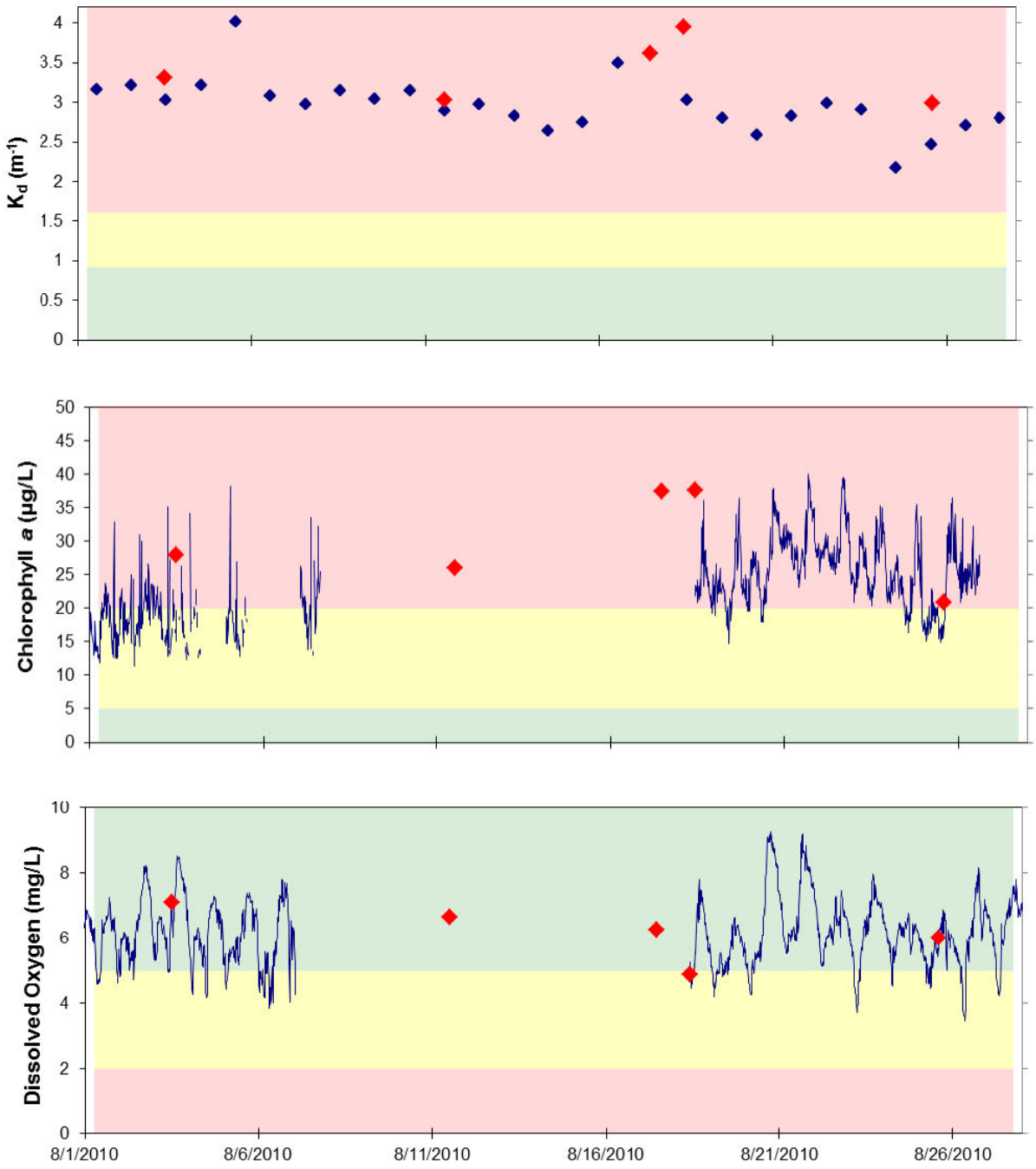


Figure 92. Continuous water-quality data from the 2010 assessment at COLO. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Daily K_d (♦) was calculated using integrated irradiance for the period within 3 hours of local apparent noon. Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦). Plots indicate the threshold criteria for good (green), fair (yellow), or poor (red) conditions (see Table 3), as adopted by the NPS NCBN.

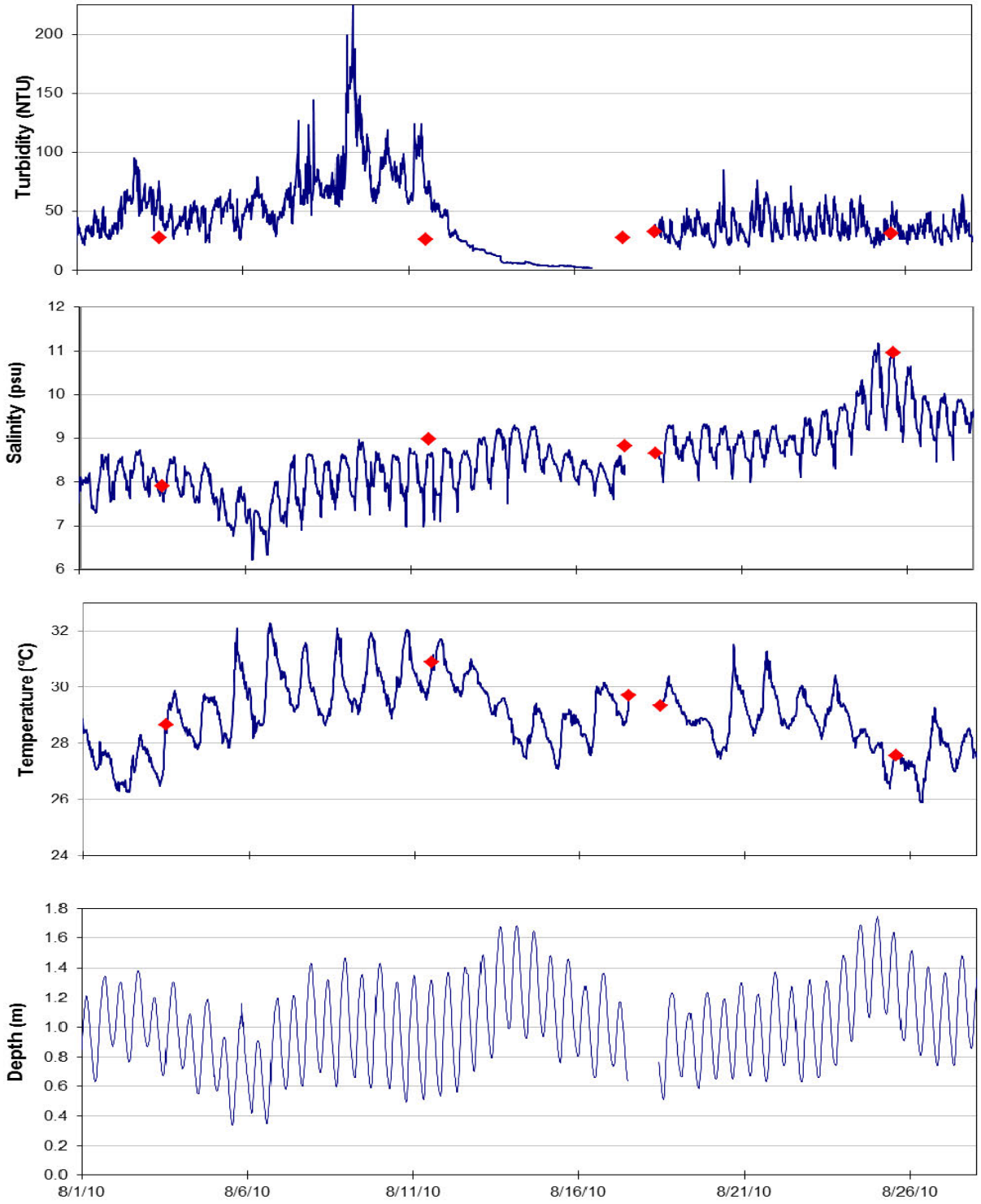


Figure 92 (cont.). Continuous water-quality data from the 2010 assessment at COLO. All measurements were made using a YSI6600EDS multiparameter sonde with wiped LiCor PAR sensors following the NCBN ENE protocol (Kopp and Neckles 2009). Data were recorded every 15 minutes (solid blue traces). Data were corrected for drift using post-deployment calibration checks and independent measurements made during site visits (♦).

Table 33. Trend-station water-quality data from the 2010 assessment at COLO.

Measure	Statistic	Trend Stations (Hexagons)							
		5 (TH)	**10 (TH)**	**15 (TH)**	**20 (TH)**	**25 (TH)**	**30 (TH)**	**33 (TC)**	**37 (TC)**
PAR attenuation	mean	3.32	3.79	3.18	3.25	3.77	3.23	2.87	2.44
(K_d (m^{-1}))	std.dev.	0.50	0.79	0.45	0.38	0.25	0.61	1.10	0.26
	n	3	3	3	3	3	4	4	4
Temperature	mean	29.10	28.96	30.10	28.92	29.16	29.12	28.07	29.27
(°C)	std.dev.	1.02	1.25	2.56	1.38	1.74	1.29	0.93	1.32
	n	3	3	3	3	3	4	4	4
Salinity	mean	9.75	9.17	7.38	9.36	7.31	7.58	22.68	10.22
(psu)	std.dev.	1.27	1.37	1.54	1.45	1.44	1.16	0.47	1.22
	n	3	3	3	3	3	4	4	4
Dissolved oxygen	mean	5.8	5.6	6.8	5.7	6.4	5.8	5.5	6.8
(mg/L)	std.dev.	0.2	0.7	0.8	0.4	1.3	1.2	1.6	1.2
	n	3	3	3	3	3	4	4	4
Turbidity	mean	30.7	30.7	33.3	31.4	29.1	30.5	18.3	19.8
(NTU)	std.dev.	11.3	10.1	14.5	2.4	5.6	13.4	6.6	4.8
	n	3	3	3	3	3	4	4	4
Chlorophyll *a*	mean	25.2	35.2	26.6	26.8	21.9	25.0	37.2	30.2
(µg/L)	std.dev.	2.8	13.7	4.4	9.8	5.0	5.7	29.1	4.1
	n	3	3	3	3	3	4	4	4

[Values are means, standard deviations (std.dev.), and number of measurements (n) for all monitoring events at each trend station. K_d values are from water column profiles and chlorophyll *a* is from discrete water grab samples. Temperature, salinity, and turbidity are from near-surface readings of the sonde, whereas dissolved-oxygen readings were from the near-bottom. Location of hexagons with trend stations is shown in Figure 7. - -, no data. Stratum indicated in parentheses below hexagon number (TH – Thoroughfare, TC – Tidal Creek).]

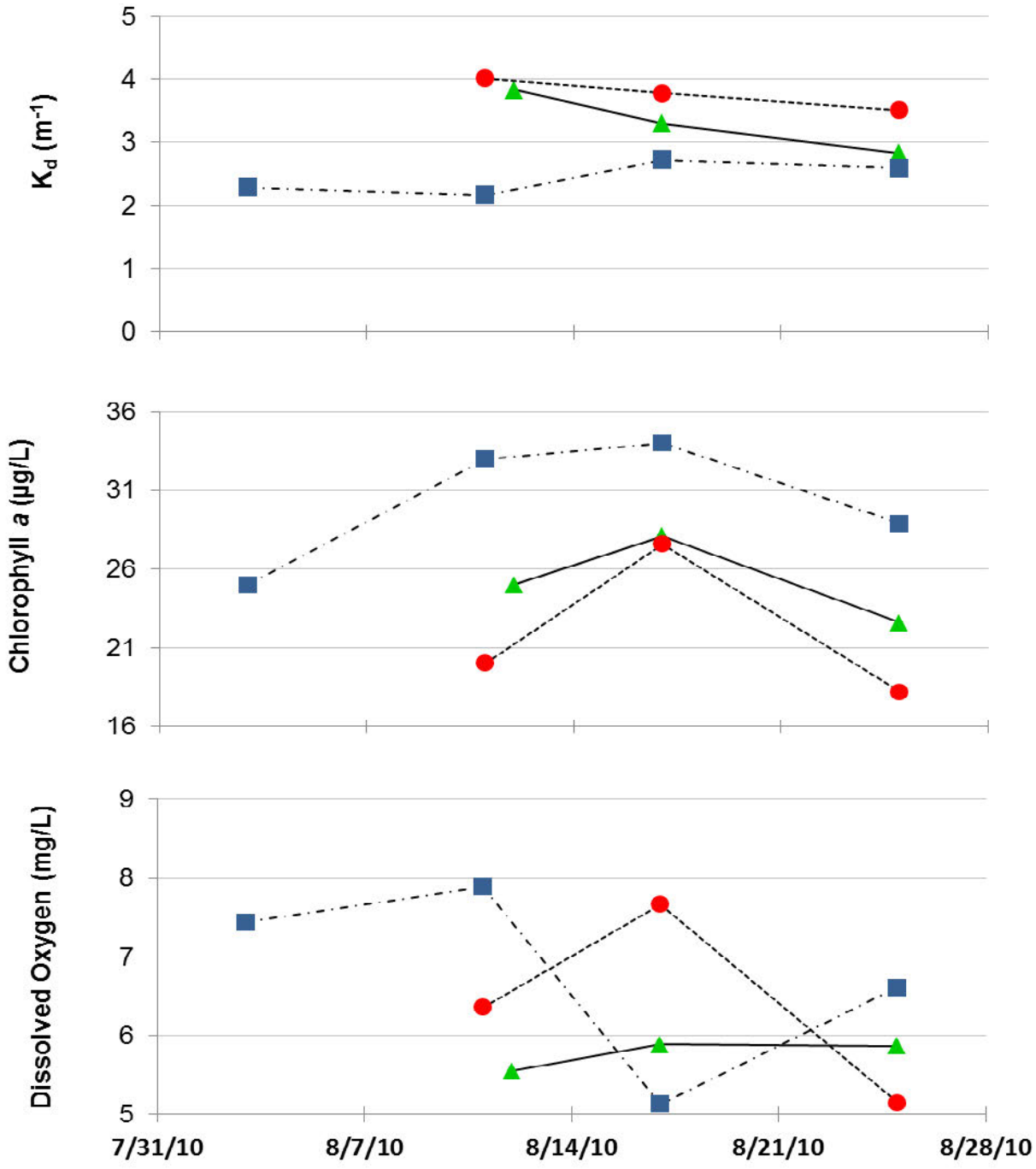


Figure 93. Trend station water-quality data from the 2010 assessment at COLO. Data are derived from selected trend stations within different portions of the monitored area. The blue square (■) represents hexagon 37 (tidal creek stratum), the red circle (●) represents hexagon 25 (western end of Thoroughfare stratum), and the green triangle (▲) represents hexagon 5 (eastern end of Thoroughfare stratum).

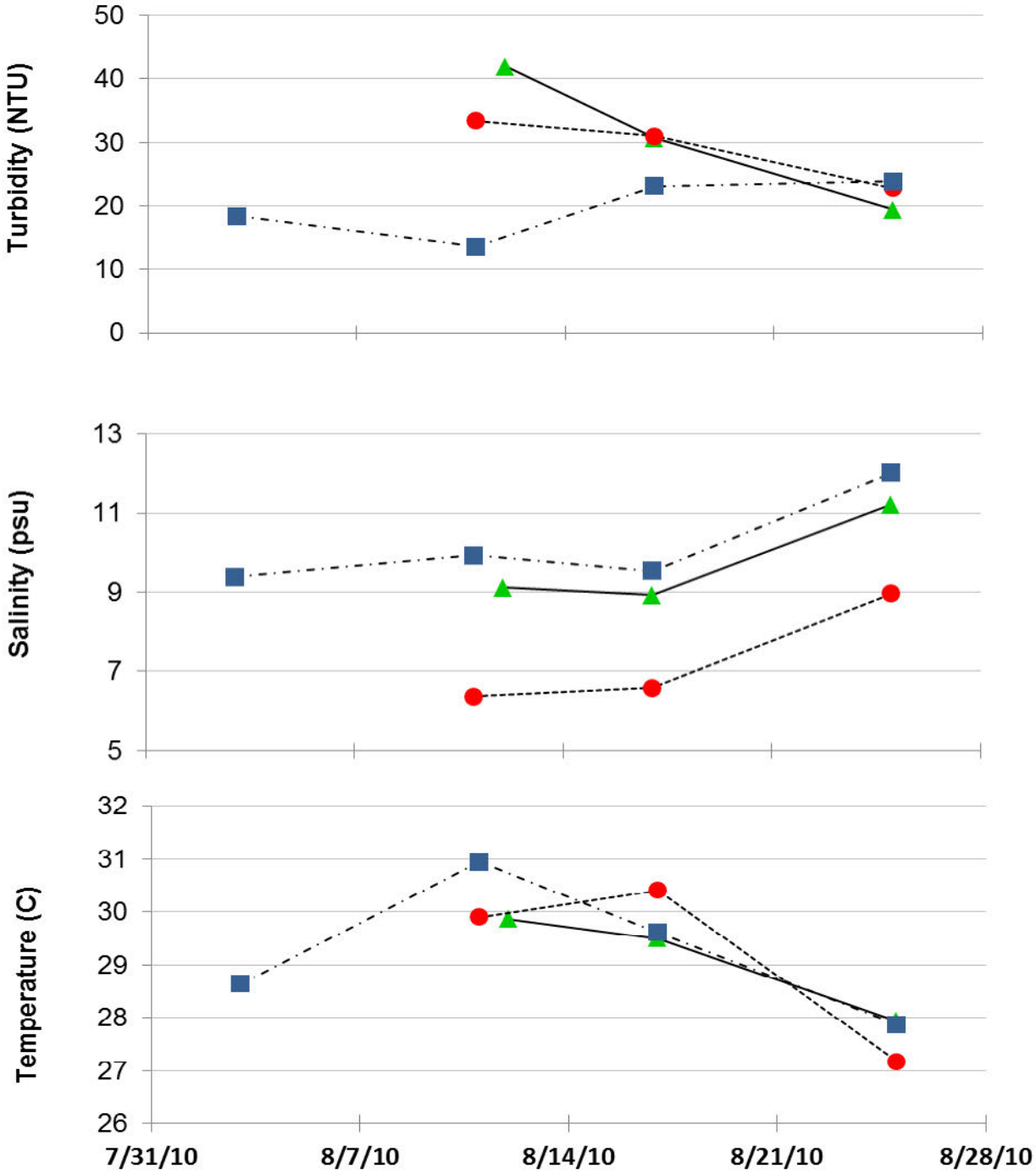


Figure 93 (cont.). Trend station water-quality data from the 2010 assessment at COLO. Data are derived from selected trend stations within different portions of the monitored area. The blue square (■) represents hexagon 37 (tidal creek stratum), the red circle (●) represents hexagon 25 (western end of Thoroughfare stratum), and the green triangle (▲) represents hexagon 5 (eastern end of Thoroughfare stratum).

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