Evaluation of the Effectiveness of SolarBee® Water Circulation Devices in Reducing Algae Blooms in St. Albans Bay, Lake Champlain

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Abstract

St. Albans Bay in Lake Champlain (Vermont) has a long history of excessive phosphorus levels and summer algae blooms dominated by cyanobacteria (blue-green algae). Efforts to reduce point and nonpoint sources of phosphorus have not succeeded in controlling the algae blooms. Three SolarBee® water circulator devices were operated in St. Albans Bay during May-August 2007 with the goal of reducing algae levels and improving water clarity over a total area of approximately 100 acres at the northern end of the bay. The effectiveness of the SolarBees in achieving this goal was tested by lake monitoring during the deployment period. The monitoring program used a spatial control design in which water quality conditions within the presumed 35-acre treatment zone around each SolarBee unit were compared with conditions at greater distances from the devices. Mapping of the spatial distribution of chlorophyll-a and Secchi disk transparency data showed no consistent relationship with the treatment zones around the three SolarBee units, and no evidence of generally depressed algal growth or clear water within the treatment zones. A statistical analysis of the spatial data found that there were no significant reductions in mean chlorophyll-a concentrations or increases in Secchi disk transparency within the treatment zones when compared with levels immediately outside the treatment zones. The SolarBees did not produce a more uniform vertical distribution of chlorophyll-a in the water column than what was seen outside the treatment zones. The devices had no discernable effect in reducing the relative dominance of cyanobacteria within the phytoplankton community inside the treatment zones, based on microscopic examination of water samples. In conclusion, there was no evidence that the SolarBees in St. Albans Bay reduced algal concentrations, improved water clarity, or inhibited blue-green algae in the bay. The treatment goal of producing an approximately 100-acre zone of clear, low-algae water at the northern end of St. Albans Bay was not achieved by the SolarBee deployment.

Project Background and Purpose

St. Albans Bay is located in the northeastern portion of Lake Champlain in Vermont (Figure 1). The bay has a long history of excessive phosphorus levels and algae blooms dominated by cyanobacteria (blue-green algae). There have been significant efforts made in the past to reduce phosphorus loading to St. Albans Bay from point and nonpoint sources in the bay's watershed, and additional work is underway as part of Vermont's Clean and Clear Action Plan[1]. However, water quality in St. Albans Bay has not improved in response to phosphorus load reductions, largely because of on-going phosphorus loading from the bay's watershed and internal sediments[2,3].

Figure 1. Location map of St. Albans Bay.

The desire to gain some near-term relief from algae blooms in the bay prompted the Town of St. Albans and the St. Albans Area Watershed Association to pursue in-lake treatment using SolarBee® devices. SolarBees are solar-powered water circulators manufactured by SolarBee, Inc. of Dickenson, ND. They can be moored in a lake or pond, and are designed to lift water upwards and distribute the currents in a near-laminar, radial flow pattern with each unit affecting approximately 35 acres (14 ha) of surrounding water.

One of the applications of these devices has been to control nuisance growth of phytoplankton including cyanobacteria blooms in ponds, lakes, and reservoirs. Company technical literature[4] asserts that the water circulation induced by SolarBees reduces cyanobacteria within a 35-acre treatment zone by interfering with the buoyancy regulation mechanisms of these organisms. Other claimed benefits include improved water clarity, lower pH, reduced chlorophyll-a and total phosphorus concentrations, increased biodiversity, increased secondary production (both zooplankton and fish), reduced biochemical oxygen demand to bottom waters, higher dissolved oxygen concentrations throughout the water column above the thermocline, improved fish spawning habitat in the littoral zone, compaction of near-shore sediments, and inhibition of invasive submerged macrophytes such as Eurasian watermilfoil (*Myriophyllum spicatum*) through limitation of sediment ammonia levels.

SolarBees have been installed in many lakes, ponds, and reservoirs throughout North America, and there is significant interest among lake residents in Vermont in trying the SolarBee

devices for control of algae blooms and nuisance aquatic plants. However, there have been relatively few SolarBee installations in lakes as large as St. Albans Bay (7.2 km^2) or Lake Champlain where large-scale wind-driven currents exist that might possibly overwhelm the circulation effects of the SolarBee devices. Their effectiveness in treating small portions of large lakes has not been sufficiently demonstrated. For these reasons, the Vermont Agency of Natural Resources (ANR) conducted water quality monitoring of the SolarBee installation in St. Albans Bay during 2007. The purpose of this monitoring program was to objectively evaluate the effectiveness of SolarBees in reducing algae blooms in the northern portion of the bay.

SolarBee Installation

Funding for a one-year lease of three SolarBee units in St. Albans Bay during 2007 was provided by the St. Albans Area Watershed Association and the Vermont ANR, with support from the Town of St. Albans. The three SolarBee units were installed at the north end of the bay (Figure 2) in water depths of about 5 m. The goal of the SolarBee installation was to reduce algae levels in the vicinity of the Stevens Brook inflow and the St. Albans Town Park, located immediately to the north of the SolarBees.

The SolarBee units were placed in St. Albans Bay on May 3, 2007 and began operating on May 15, 2007. The initial locations of these units are given in Table 1. When their locations were checked on August 28, 2007 it was found that the units had shifted about 30-40 m northward. The average locations shown in Table 1 were used for the purposes of the analysis in this report. A strong south wind blew the SolarBees nearly ashore on September 14, 2007, at which point the operation ended and the units were subsequently removed from the lake.

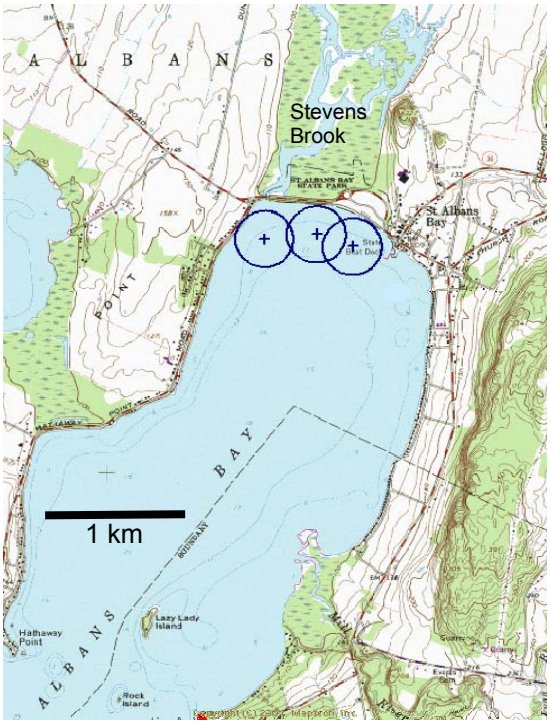

Figure 2. Average locations of SolarBee units in St. Albans Bay. Circles indicate presumed 35-acre (212 m radius) treatment zones around each unit.

Table 1. Location of SolarBee units in St. Albans Bay.

	Initial Location 5/3/07		Location on 8/28/07		Average Location	
SolarBee Unit	**Latitude**	**Longitude**	**Latitude**	**Longitude**	**Latitude**	**Longitude**
West	44.80759	-73.15178	44.80794	-73.15200	44.80777	-73.15189
Middle	44.80793	-73.14702	44.80820	-73.14714	44.80807	-73.14708
East	44.80708	-73.14387	44.80743	-73.14372	44.80726	-73.14380

Monitoring Design Rationale

A SolarBee unit being towed into place in St. Albans Bay.

The establishment of proper controls against which to measure SolarBee treatment effects was a fundamental consideration in designing this study. Since the goal of the SolarBee installation in St. Albans Bay was to reduce algae levels relative to past conditions, an experimental design that compared algal concentrations during years before vs. after the installation would have been desirable. Unfortunately, the only water quality monitoring station in St. Albans Bay that has been sampled consistently over multiple years is located much farther out in the bay, nearly two miles from the SolarBee sites at the north end of the bay. Furthermore, multiple years of monitoring with SolarBees in operation would have been needed for a valid before vs. after statistical comparison. These considerations made a temporal control infeasible for this study.

A spatial control approach was used instead, in which water quality conditions near the SolarBee units were compared with conditions at greater distances from the devices (i.e., control sites). Since the purpose of the project was to produce relatively clear and algae-free water at the north end of the bay, the effectiveness of the SolarBees in producing this effect was evaluated by comparing conditions in the treatment zone with measurements made farther away from the devices.

A complicating factor in this spatial comparison was the existence of a strong phosphorus and algal concentration gradient through St. Albans Bay. Highest phosphorus and algae levels exist at the north end of the bay and decline with greater distance south towards the outer lake[5]. The hypothesis tested by this study was that the SolarBees would suppress the algae levels at the northern end of the bay below concentrations that occurred immediately south of the treatment zone. If the SolarBees are effective as claimed, an approximately 35-acre zone of relatively clear, low-algae water should be seen around each unit and in total across about 100 acres at the northern end of the bay. Other claimed benefits of SolarBees in lakes, beyond reduced concentrations of algae and improved water clarity, were not tested by this study.

A SolarBee unit operating in St. Albans Bay.

Methods

Sampling Locations

Spatial Grid Sampling

The monitoring program design required detailed spatial assessments of water quality parameters related to algal concentration. The spatial grid of 98 points shown in Figure 3 was sampled at a depth of 1.0 m on each sampling date, with some modifications when lake level declines made it impossible to access some near-shore locations. The purpose of this grid was to define the complete spatial pattern in the bay on each sampling date, with the greatest density of points placed in the north end in order to best resolve the influence of the SolarBees.

Supplemental and Vertical Profile Sampling

Additional sampling was conducted at seven locations along a central transect in the bay and at locations within the SolarBee treatment zone (Figure 4, Table 2). Sampling at these supplemental sites included measurements made in vertical profile at approximately 0.5 m depth intervals within the water column in order to evaluate the SolarBee impact on the vertical distribution of algae.

Position Determination

The positions at which all samples were taken were determined at the time of sampling using on-board Geographic Positioning System (GPS) receivers. The longitude and latitude of all sampling points were recorded to a precision of 0.00001 degrees.

Vermont ANR sampling crews used an automated GPS logger integrated within a handheld computer that recorded chlorophyll fluorometric and multiprobe measurements simultaneously with their GPS locations. These data were later downloaded directly into computer spreadsheets. Citizen volunteer samplers conducted additional sampling at the spatial grid stations using a hand-held GPS receiver of comparable precision and accuracy. Coordinates of each sampling site and the corresponding Secchi disk measurements were manually recorded in the field by the volunteers and later transcribed into computer spreadsheets.

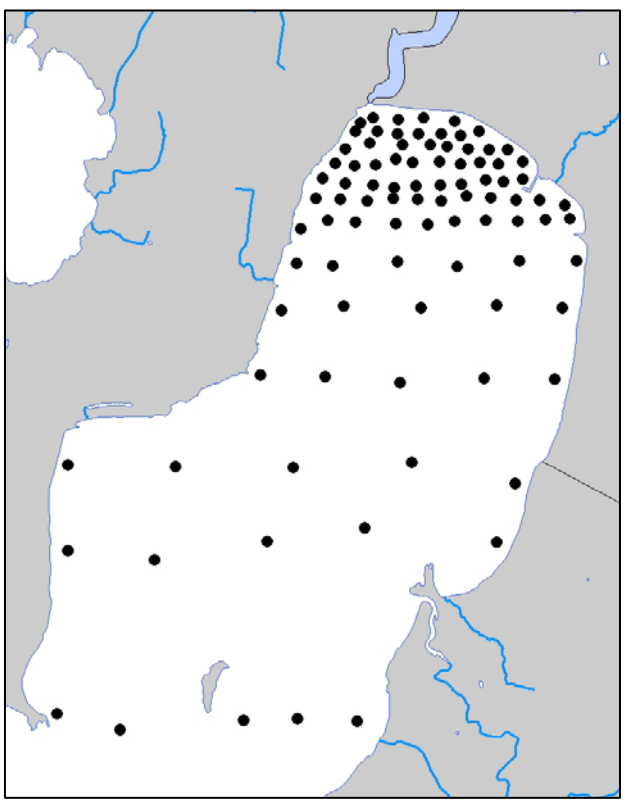

Figure 3. Locations of spatial grid sampling grid points.

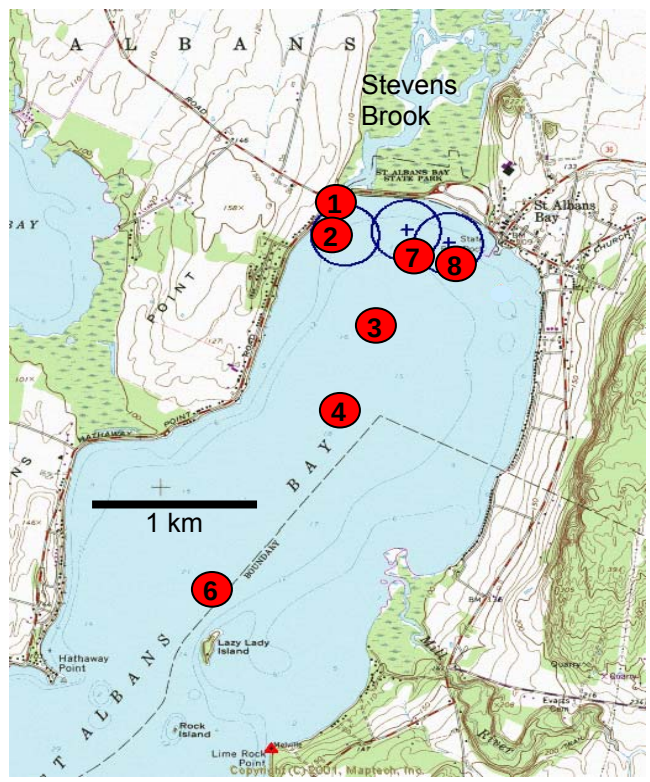

Figure 4. Locations of supplemental sampling stations. Station 5 (not shown) was discontinued early in the study.

Sampling Parameters

Spatial Grid Sampling

The large number of sampling points shown in Figure 3 necessitated the use of rapid field measurements of water quality parameters, rather than laboratory analysis of samples, as the primary monitoring approach for the spatial grid sampling. The spatial grid sampling included the following field measurements recorded at a depth of 1.0 m at each sampling location.

- Chlorophyll-a using field fluorometry
- Secchi disk water transparency
- Multiprobe measurements[a] (temperature, dissolved oxygen, pH, conductivity)

Table 2. Coordinates of the supplemental sampling stations in St. Albans Bay (Figure 4).

Station	Latitude	Longitude
1	44.8100	-73.1525
2	44.8078	-73.1530
3	44.8020	-73.1495
4	44.7967	-73.1523
6	44.7853	-73.1622
7	44.8064	-73.1465
8	44.8055	-73.1433

Supplemental and Vertical Profile Sampling

The following measurements were made on each day of sampling at the supplemental sites. Samples were obtained at a depth of 1.0 m using a Kemmerer water sampler, except for the field chlorophyll-a and multiprobe measurements which were made in vertical profile. The purpose of measuring chlorophyll-a by extraction in the laboratory was to calibrate the field fluorometric analyses to standard quantitative measurements.

- Total phosphorus
- Chlorophyll-a by laboratory extraction and by field fluorometry
- Phytoplankton cell density and taxonomic composition
- Microcystin[b] (a cyanobacteria toxin)
- Multiprobe measurements (temperature, dissolved oxygen, pH, conductivity)

Vermont ANR staff member deploying the fluorometer and multiprobe.

Sampling Period

Complete sets of measurements were made on eight dates between May 21 and August 28, 2007 by Vermont ANR staff. One additional set of spatial grid data on Secchi depth only was obtained on July 22 by citizen volunteers from the St. Albans Area Watershed Association.

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[a] Temperature, dissolved oxygen, pH, and conductivity were recorded by the multiprobe at each location, but these data were not analyzed in detail for this report. They are available on request.

[b] A concern at the outset of the study was that if SolarBees are successful in reducing the concentration of toxin-producing cyanobacteria or in disrupting visually obvious algal scums on the surface, lake users might be more inclined to enter the water or allow their pets to drink from the lake. However, if algal toxins remained present in spite of the improved appearance of the water, this unknowing exposure could pose a health risk.

Analytical Methods

Chlorophyll-a by Field Fluorometry and Other Multiprobe Measurements

Relative chlorophyll-a fluorescence was measured using a Turner Designs "SCUFA" apparatus side-mounted on a Hach-Hydrolab Series 5 multiprobe. This multiprobe system was integrated with a GPS-enabled handheld computer so that individual records contained geographic coordinates, relative fluorescence, and the standard multiprobe parameters (depth, temperature, pH, DO, conductivity) at each sampling location. The multiprobe device was calibrated and maintained according to specifications in the Vermont Department of Environmental Conservation (DEC) Field Methods Manual.

Secchi Depth

Secchi disk depth was measured using a standard black and white disk with a line marked in 0.1 m increments, following procedures detailed in the Vermont DEC Field Methods Manual[6].

Total Phosphorus

Total phosphorus was analyzed at the Vermont DEC Laboratory by the ascorbic acid method following acid-persulfate digestion, in a manner consistent with methods used by the Lake Champlain Long-Term Water Quality and Biological Monitoring Program[7].

Chlorophyll-a by Laboratory Extraction

Chlorophyll-a samples for laboratory analysis were filtered in the field onto glass fiber filters and frozen for later fluorometric analysis after grinding and extraction in 90% acetone[6,7]. The chlorophyll-a results from the supplemental monitoring sites analyzed by laboratory extraction were paired with the field fluorometric measurements obtained at the same depth and time in order to calibrate the field values to standard laboratory methods. The regression equation shown in Figure 5 was used to convert all field chlorophyll-a results from this study to standard quantitative units of µg/L. Visual examination of regression residual plots revealed no obvious patterns or bias with date, location, chlorophyll concentration, or Secchi depth, except for a possible positive bias at the lowest chlorophyll concentrations.

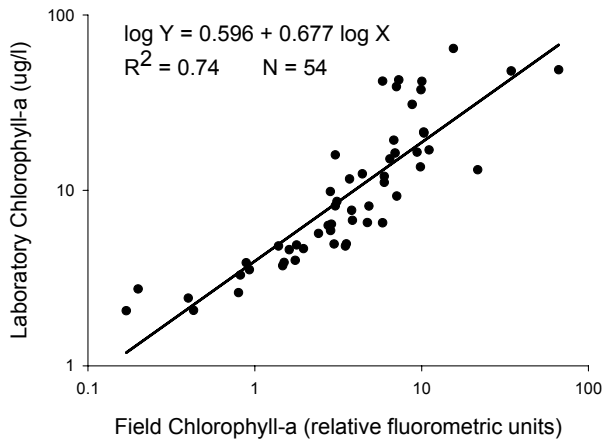

Figure 5. Calibration of field chlorophyll-a results to standard laboratory units.

Phytoplankton Composition

The composition of the phytoplankton algal community was assessed by microscopic examination. Whole-water samples (1.0 m depth) were obtained and preserved with Lugol's solution. Samples were placed in a settling chamber and organisms were identified to the lowest feasible taxonomic level and quantified as both cell densities (cells/L) and natural unit densities (units/L) using methods consistent with those employed for the Lake Champlain Long-Term Water Quality and Biological Monitoring Program.

Microcystin

Whole-water samples were obtained at the supplemental monitoring stations along with the phytoplankton samples and submitted for microcystin analysis to the University of Vermont's Rubenstein Ecosystem Science Laboratory under the direction of Dr. Mary Watzin. The samples were analyzed for the concentration of microcystin using the ELISA (Enzyme-Linked ImmunoSorbent Assay) method according to procedures established for the Lake Champlain Basin Program[8].

Wind and Stream Flow Conditions

Wind conditions associated with each sampling date were obtained from hourly data reported by the National Weather Service for the Burlington (VT) International Airport. Average wind directions and speeds were calculated for the 24-hour period beginning at noon on the day preceding each sampling date. Provisional stream flow data for the St. Albans Bay watershed were obtained during the monitoring period from the U.S. Geological Survey gage on the Stevens Brook (Station No. 04292770).

Mapping of Data

The spatial grid water quality data were mapped using GPS technology and ESRI's ArcGIS® software. Latitude and longitude decimal degree values representing sampling point locations as well as the associated water quality sampling data were imported into ArcGIS software to create a point feature class. Interpolation methods were employed using ESRI's Spatial Analyst® extension for ArcGIS to visualize the spatial trends of the data.

Various interpolation methods available in Spatial Analyst were researched and trial runs were conducted of each method including kriging, inverse distance weighting, natural neighbor, and spline. Natural neighbor interpolation was chosen to create chlorophyll-a concentration and Secchi disk transparency surfaces for each sampling date. Natural neighbor was used since the interpolated values stay within the range of sample values and do not infer trends or other surfaces other than what is represented by the input sampling point values. The surface that is generated passes through the input samples. Natural neighbor produces an appropriate level of smoothing between actual data points, and the analysis results are confined within the spatial extent of the sampling points.

The interpolated surface rasters were extracted using the Lake Champlain data layer as a mask. The surface was illustrated using the minimum-maximum stretch symbolization method. Low and high values for chlorophyll-a concentration were 2 and 20 µg/L respectively, and 0.5 and 4.0 m for Secchi disk transparency. These low and high values were chosen for the color symbolization because they best illustrated the spatial variations in the data while maintaining a consistent scale across all sample dates.

Results

Environmental Conditions on Sampling Dates

Table 3 provides a list of the dates sampled for this study during 2007, along with the wind conditions associated with each sampling date and the spatial grid parameters sampled. Flow conditions in Stevens Brook throughout the study period are shown in Figure 6.

Average wind speeds were in the "light" or "gentle breeze" category on all sampling dates. Average wind directions varied from south to northwest among the sampling dates, representing typical wind directions seen on Lake Champlain.

Sampling results obtained on June 1, June 28, and July 12 coincided with moderate runoff events in Stevens Brook. Other sampling dates occurred under typical summer low flow conditions.

Table 3. Wind conditions associated with each sampling date, and spatial grid parameters sampled. Average wind directions and speeds are for the 24-hour period beginning at noon on the day preceding each sampling date.

Sampling Date	Average Wind Direction	Average Wind Speed (mph)	Chlorophyll-a Sampled	Secchi Depth Sampled
5/21/07	NW	11.1	X	X
6/1/07	SW	3.8	X	X
6/15/07	W	5.5	X	X
6/28/07	SW	10.2	X	X
7/12/07	W	7.0	X	X
7/22/07	NW	4.3		X
7/26/07	S	6.0	X	X
8/14/07	W	7.7	X	X
8/28/07	SW	2.6	X	X

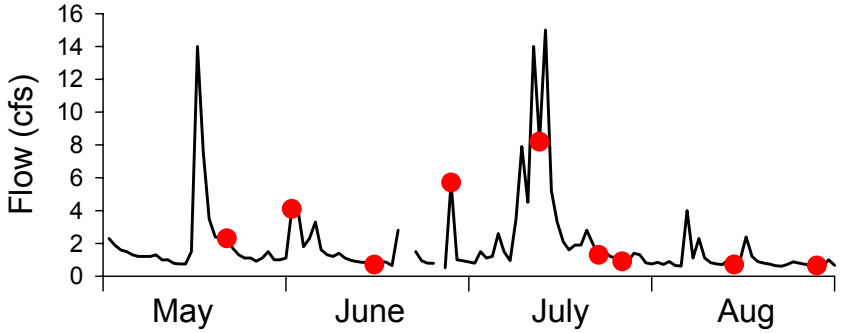

Figure 6. Average daily flow (cubic feet per second) at the U.S. Geological Survey gage on Stevens Brook during the study period. Dots indicate dates of sampling.

Spatial Distribution of Chlorophyll-a and Secchi Disk Transparency

The interpolated chlorophyll-a and Secchi disk transparency gradients from the spatial grid sampling points (Figure 3) are shown in Figures 7-11. Blank regions on the Secchi disk maps are areas where the disk was either visible on the bottom in shallow water or obscured by a dense growth of aquatic plants.

These data maps were visually examined for evidence of low chlorophyll-a concentrations or high Secchi disk readings within the three 35-acre SolarBee treatments zones, relative to conditions in the surrounding waters. The spatial distributions of chlorophyll-a and Secchi disk transparency showed no consistent relationship with the treatment zones around the SolarBee units. Bay-wide maximum chlorophyll-a concentrations and minimum water transparencies on a given date were usually found within the SolarBee treatment zones, and there was no evidence of generally depressed algal growth or clear-water regions within these treatment zones.

The one possible exception to these observations occurred on August 14 (Figure 10) in which lower chlorophyll-a concentrations and higher Secchi disk transparencies occurred within significant portions of the SolarBee treatment zones, relative to levels observed just to the south. However, a similar pattern of relatively low chlorophyll-a concentrations along the east shore of St. Albans Bay extending to the northern end of the bay existed on at least one date during previous years. Multispectral sensor data from the SPOT satellite were processed by Wheeler *et al.* (2007)[9] with field measurements of chlorophyll-a obtained on August 8, 2003 to produce the image shown in Figure 12. This was the only date for which spatially comprehensive data on St. Albans Bay were obtained and processed by Wheeler *et al*. The similarities in the spatial distribution of chlorophyll-a in Figure 12 to patterns observed on August 14 suggest that these patterns were most likely the result of pre-existing circulation features in the bay, and not related to the SolarBee deployment during 2007.

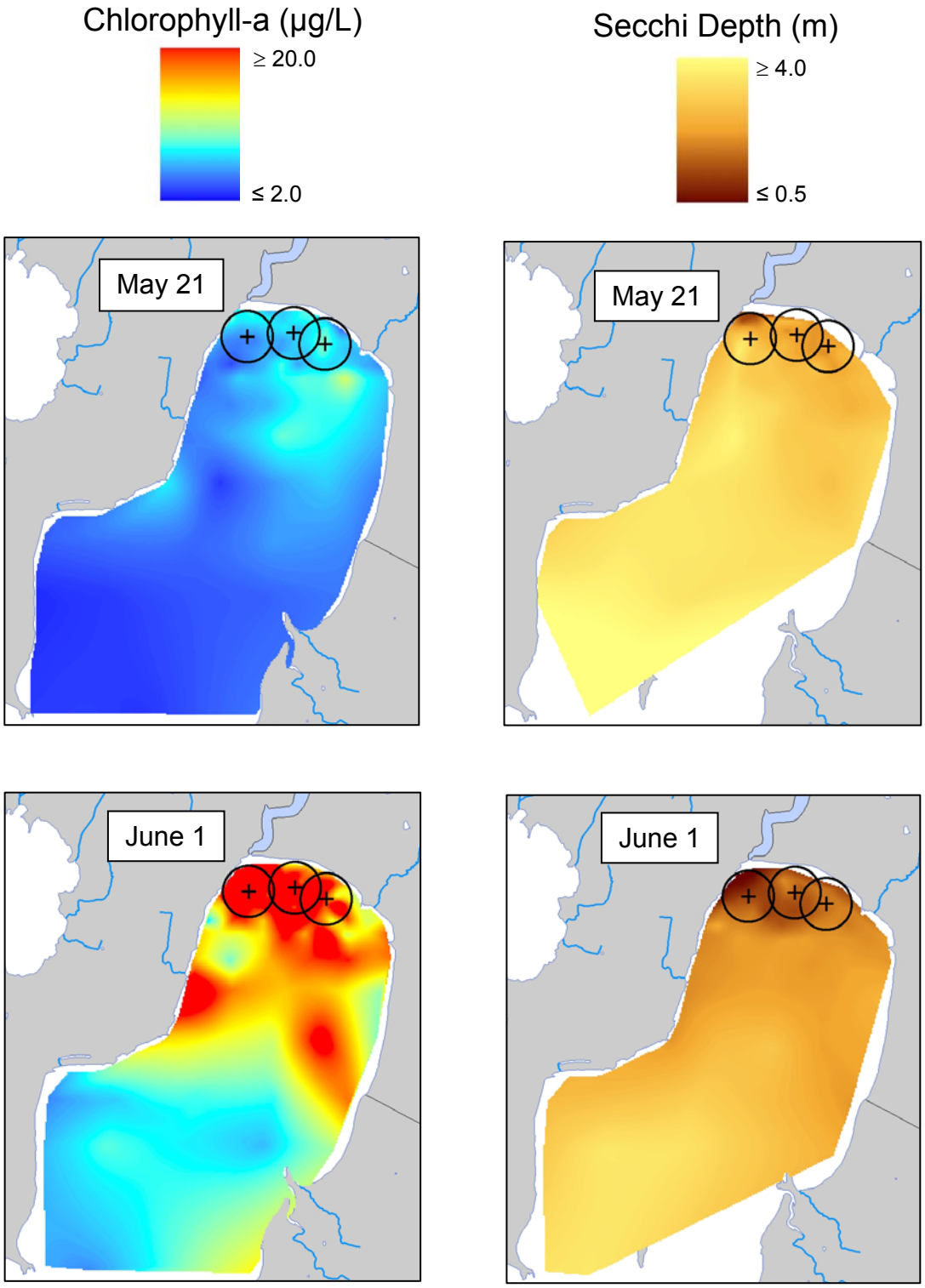

Figure 7. Spatial distributions of chlorophyll-a (left) and Secchi disk transparency (right) in relation to SolarBee treatment zones (circles) on two sampling dates during 2007.

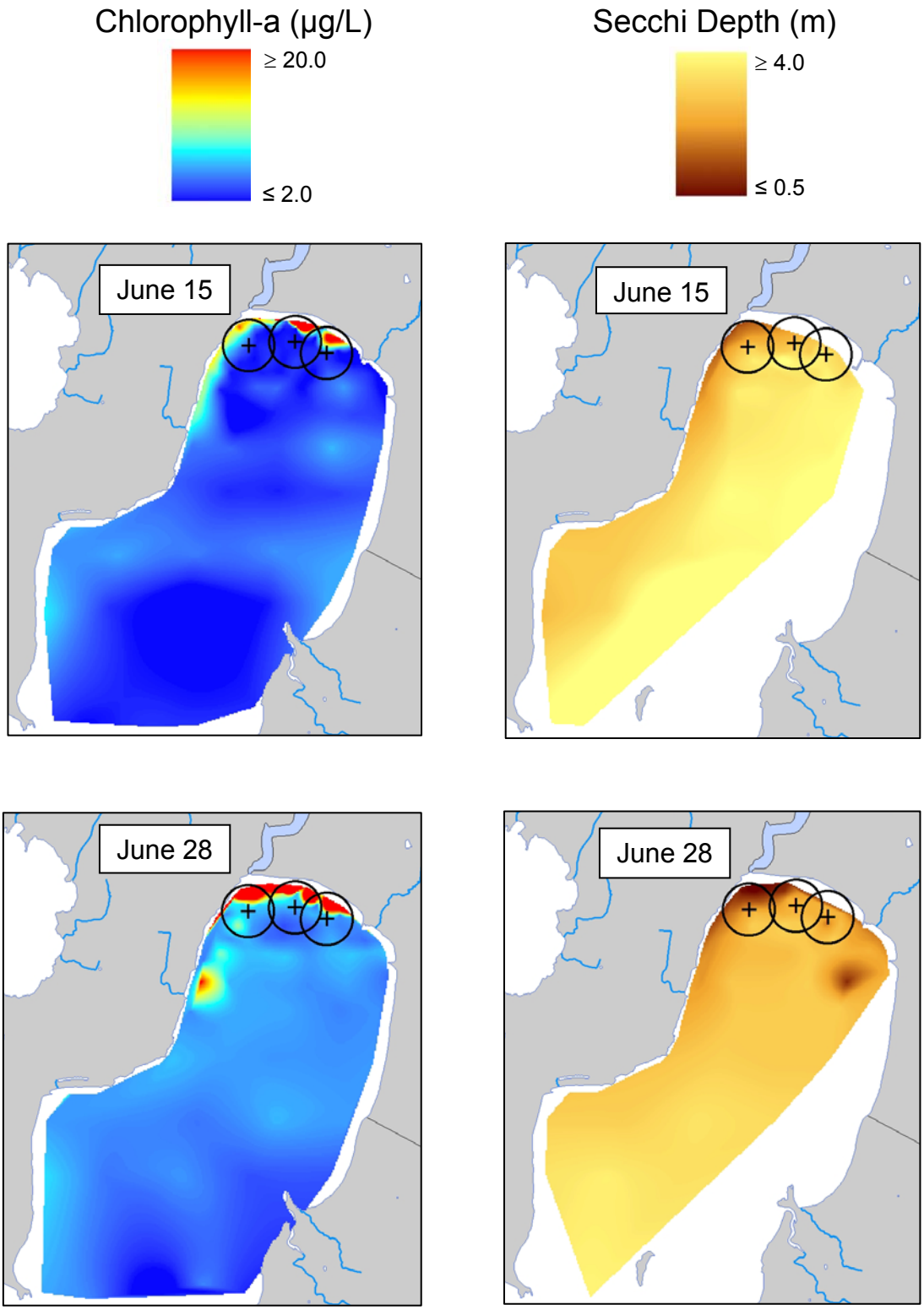

Figure 8. Spatial distributions of chlorophyll-a (left) and Secchi disk transparency (right) in relation to SolarBee treatment zones (circles) on two sampling dates during 2007.

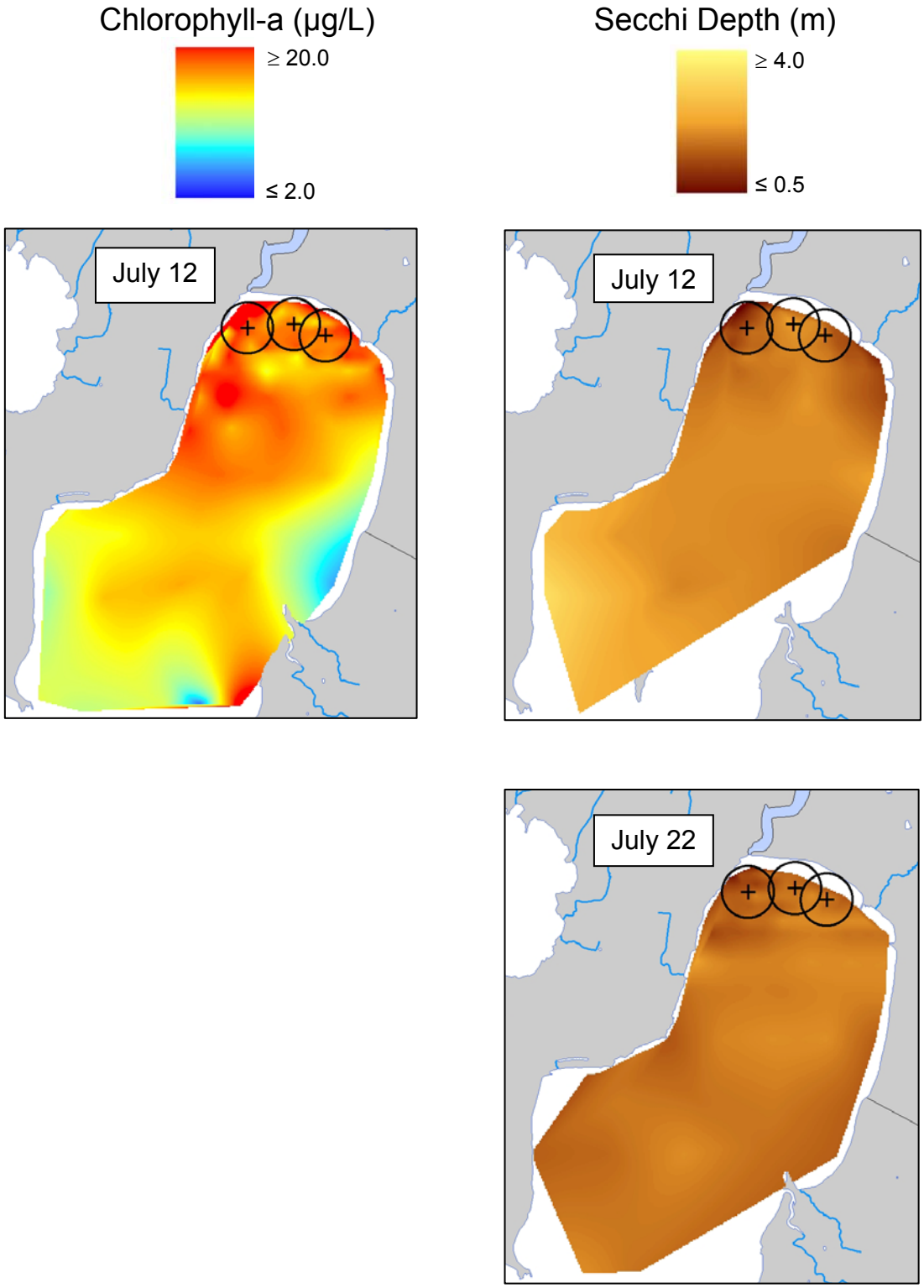

Figure 9. Spatial distributions of chlorophyll-a (left) and Secchi disk transparency (right) in relation to SolarBee treatment zones (circles) on two sampling dates during 2007. Citizen volunteers monitored Secchi depth only on July 22.

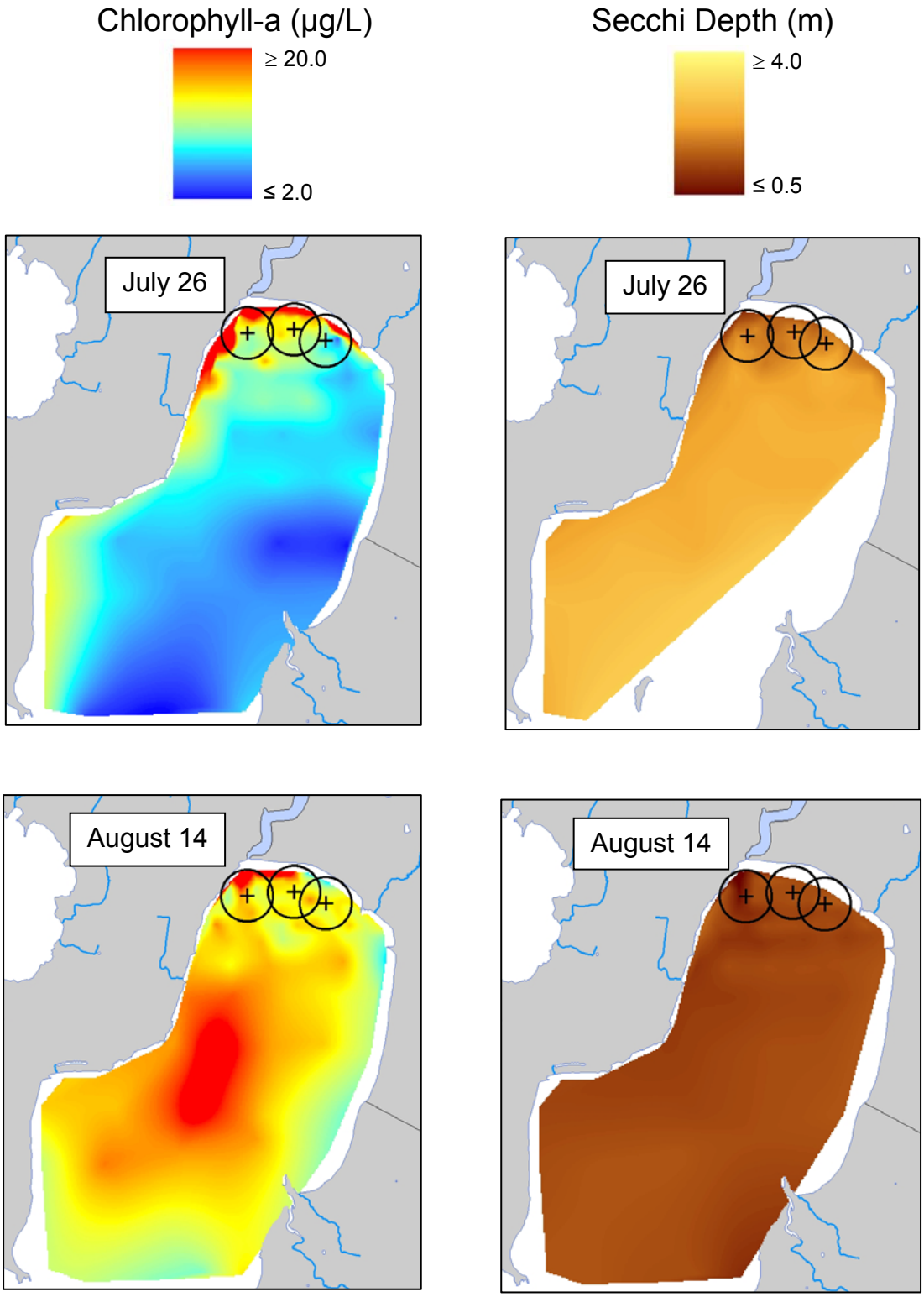

Figure 10. Spatial distributions of chlorophyll-a (left) and Secchi disk transparency (right) in relation to SolarBee treatment zones (circles) on two sampling dates during 2007.

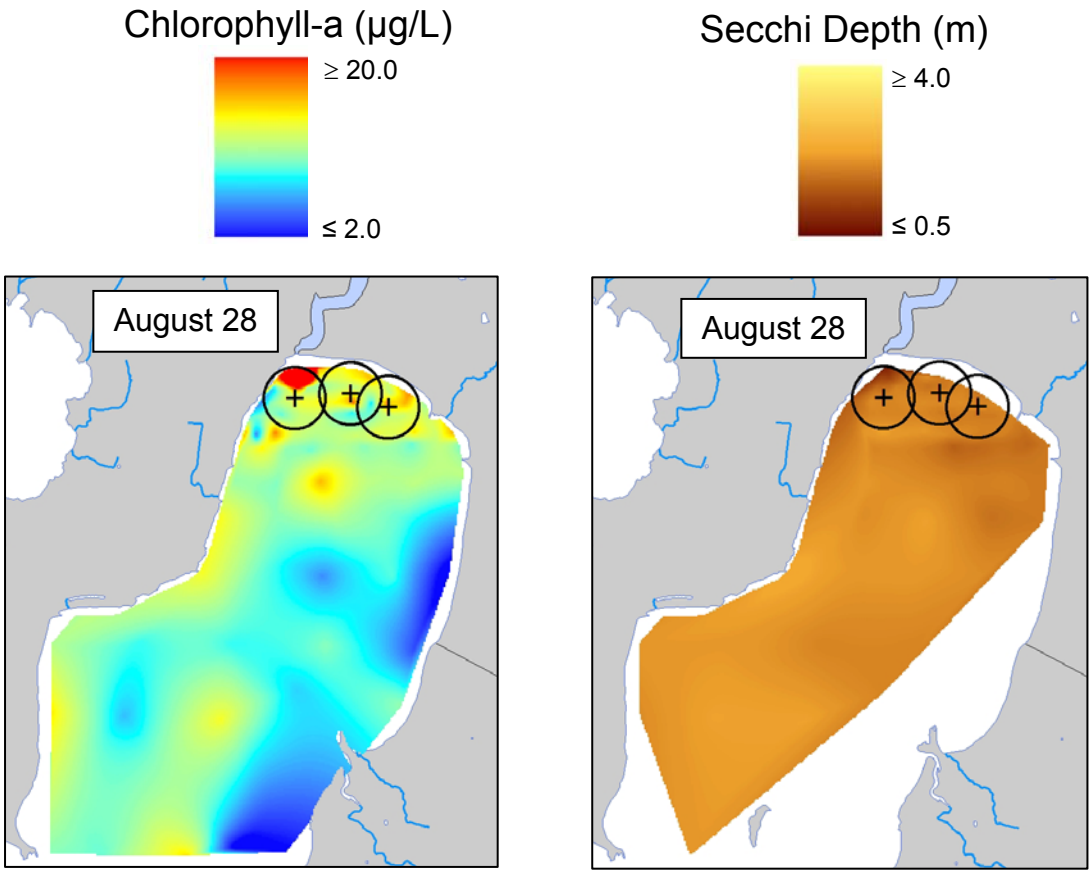

Figure 11. Spatial distributions of chlorophyll-a (left) and Secchi disk transparency (right) in relation to SolarBee treatment zones (circles) on one sampling date during 2007.

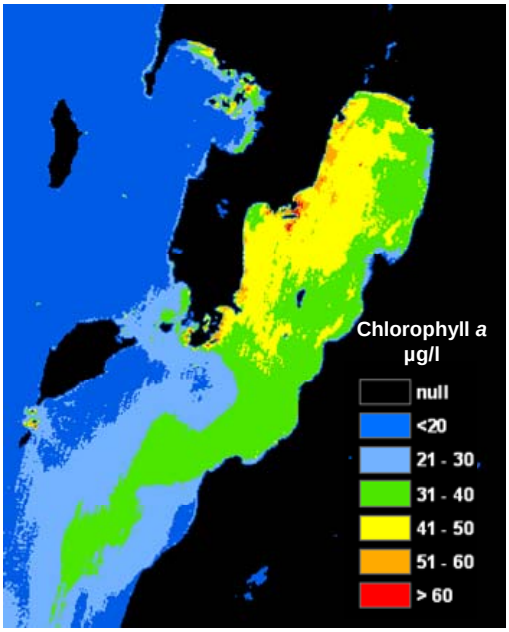

Figure 12. Chlorophyll-a concentrations extrapolated across St. Albans Bay using SPOT satellite derived radiances and field measurements obtained on August 8, 2003. Winds were light from the south. From Wheeler *et al.* (2007).

Relationship with Distance from SolarBees

The chlorophyll-a and Secchi disk spatial grid data were analyzed statistically to determine whether water quality conditions within the 35-acre treatment zones near the SolarBees were significantly improved relative to conditions outside the treatment zones. In order to conduct the statistical analysis, the data were grouped into one of five intervals of distance from the nearest SolarBee unit, using the coordinates of the individual sampling positions to calculate the distances. All values obtained within 212 m of the nearest SolarBee were placed in the first group, representing the 35-acre treatment zones. The other distance intervals were 212-500, 501-1000, 1001-2000, and >2000 m.

The mean chlorophyll-a concentrations and Secchi depths were calculated for each distance interval for four different time periods including May-June, July, August, and the entire sampling period (May-August). The chlorophyll-a data were $\log_{10}$-transformed to improve normality prior to statistical analysis. The means were compared statistically within each time period using a Holm-Sidak pair-wise multiple comparison procedure with an overall significance criterion of 0.05. The results are shown in Figures 13 and 14.

In no cases were the chlorophyll-a means lower or the Secchi depth means higher within the <212 m SolarBee treatment zones than the means in the 212-500 m distance interval immediately outside the treatment zones. Generally, there were no statistically significant differences in chlorophyll-a or Secchi disk transparency within the 35-acre treatment zones when compared with conditions immediately outside the treatment zones (212-500 m interval). Conditions improved with greater distance from the SolarBees, reflecting the pre-existing water quality gradient in the bay.

Vertical Distribution of Chlorophyll-a and Dissolved Oxygen

The vertical distributions of chlorophyll-a on each sampling date at the seven supplemental sampling stations (Figure 4) are shown in Figures 15 and 16. The four stations within the SolarBee treatment zones (Stations 1, 2, 7, and 8) were grouped together in these figures for comparison with the three stations outside the treatment zones (Stations 3, 4, and 6).

Severe floating algal scums were not observed in St. Albans Bay during 2007, and few of the chlorophyll-a profiles in Figures 15 and 16 show maximum concentrations near the surface. Where strong vertical differences in chlorophyll-a concentrations existed, these conditions generally occurred at stations within the SolarBee treatment zones, rather than outside the treatment zones. There was no evidence from Figures 15 and 16 that the SolarBees produced a more uniform vertical distribution of algae in the water column than what was seen outside the treatment zone.

Because of its shallow nature, St. Albans Bay has never been known to develop stable thermal stratification or persistent anoxia within the water column. Dissolved oxygen data from this study confirmed that the water column in St. Albans Bay remained well-oxygenated at all depths and times sampled. The minimum dissolved oxygen concentration observed from 402 vertical profile measurements was 4.6 mg/L, recorded at Station 1 at a depth of 1.0 m on July 17. Over 98% of all dissolved oxygen values recorded at the seven supplemental sampling stations (Figure 4) were above 6.0 mg/L.

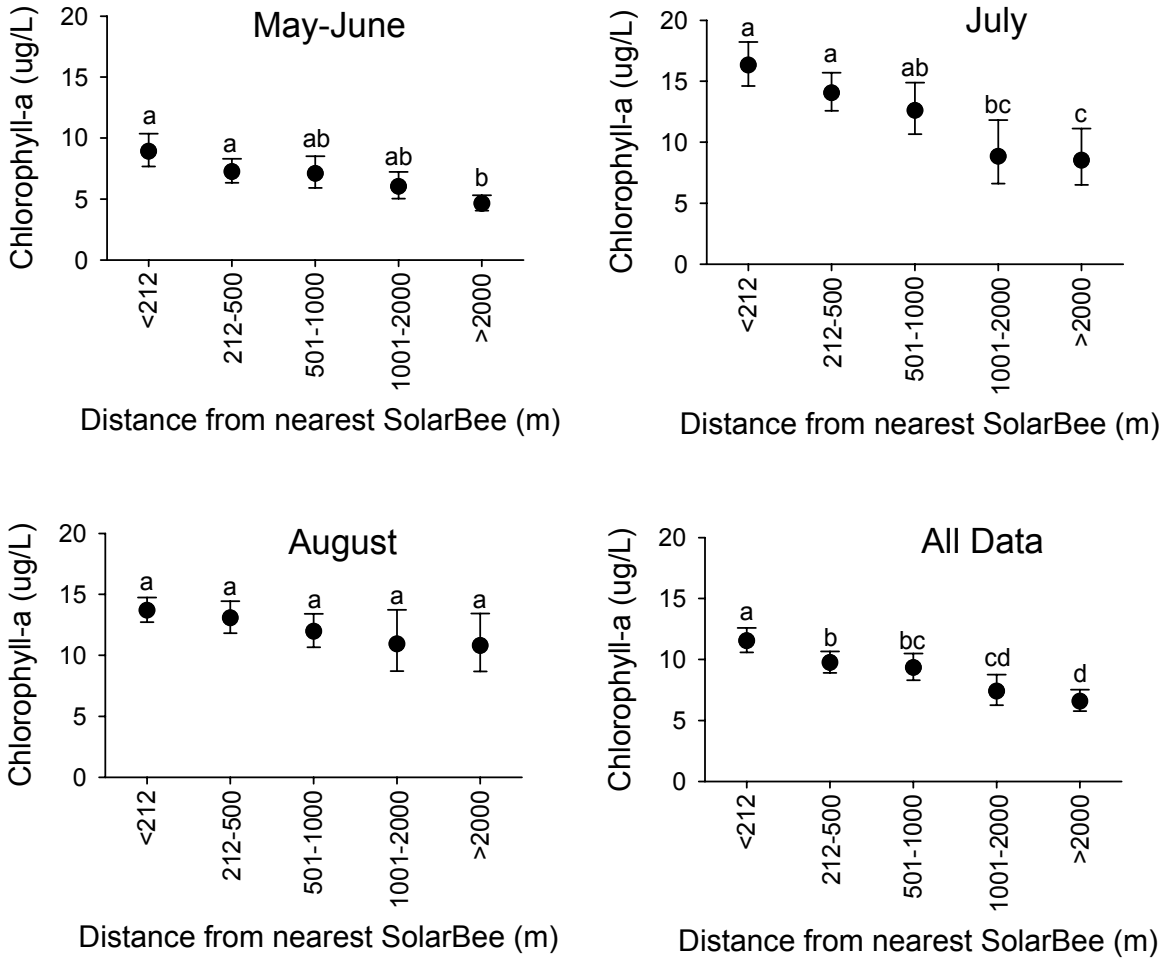

Figure 13. Mean chlorophyll-a concentrations in relation to distance from the nearest SolarBee unit. Samples less than 212 m from the nearest SolarBee were within the presumed 35-acre treatment zones. Means and 95% confidence intervals (error bars) were calculated on log-transformed data for normality, but plotted on a linear scale. Means within a plot with no letters in common (a,b,c,d) were significantly different, based on a Holm-Sidak pair-wise multiple comparison procedure with an overall significance level of 0.05.

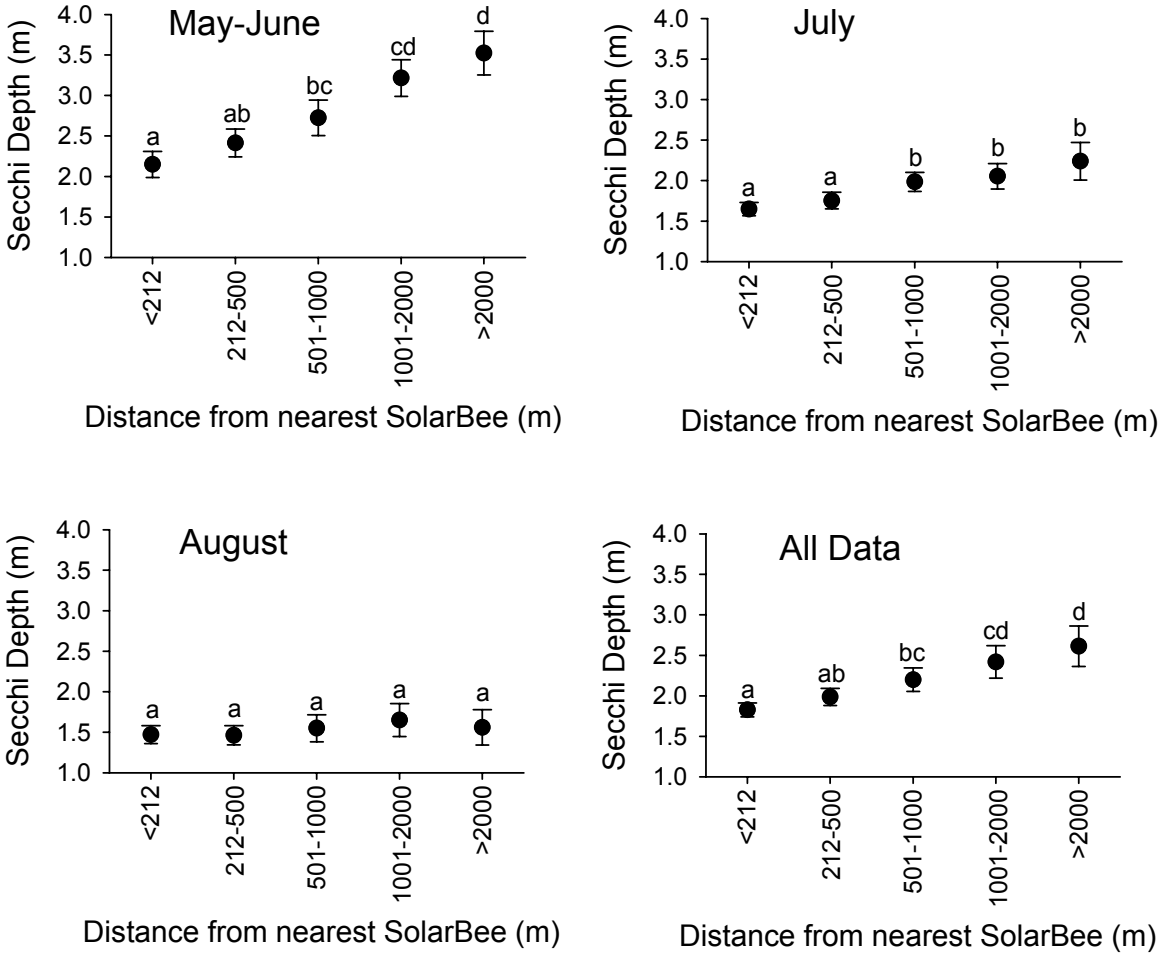

Figure 14. Mean Secchi disk depths in relation to distance from the nearest SolarBee unit. Samples less than 212 m from the nearest SolarBee were within the presumed 35-acre treatment zones. Means and 95% confidence intervals (error bars) were calculated on original data without transformation. Means within a plot with no letters in common (a,b,c,d) were significantly different, based on a Holm-Sidak pair-wise multiple comparison procedure with an overall significance level of 0.05.

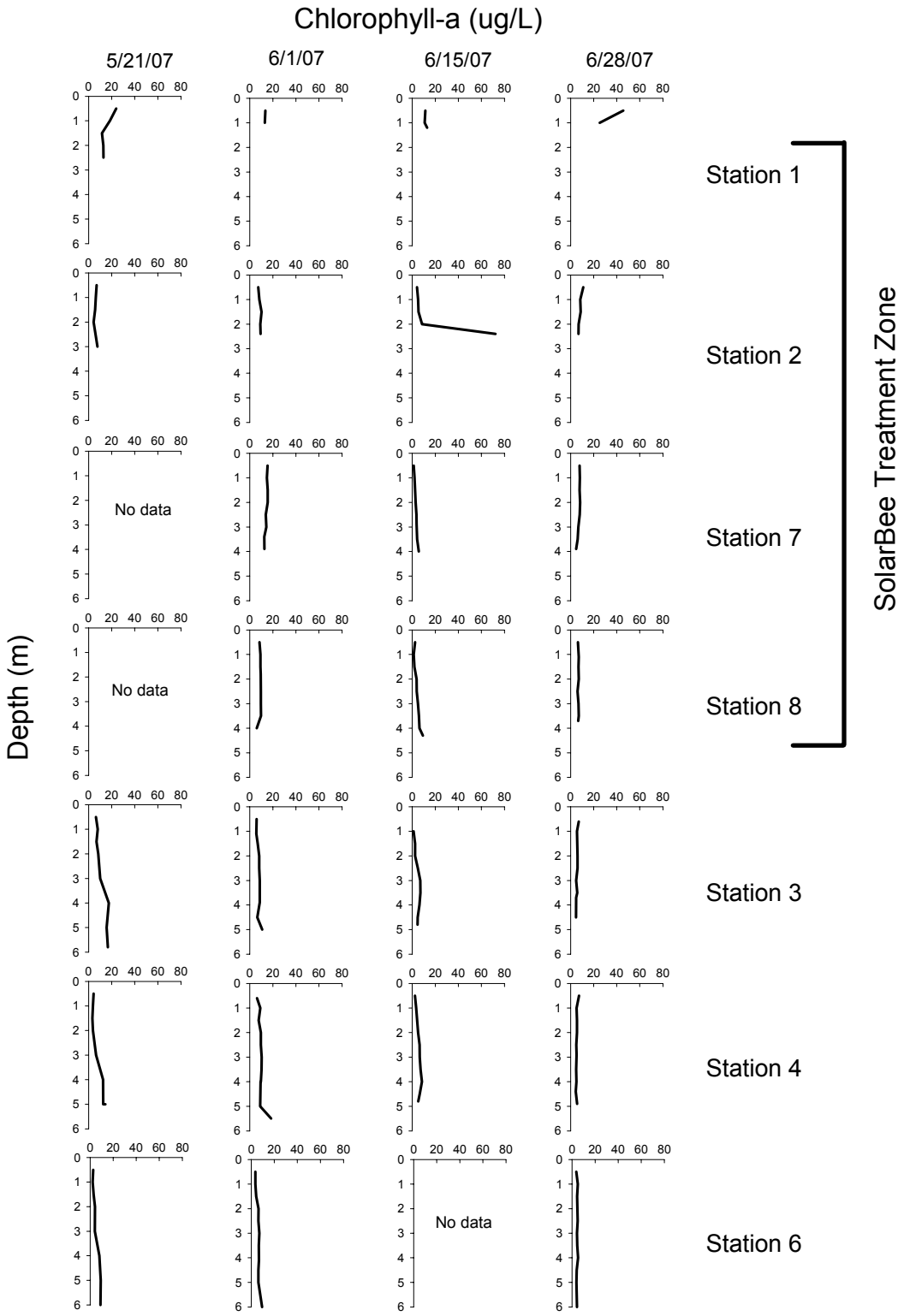

Figure 15. Vertical distributions of chlorophyll-a on four sampling dates during 2007.

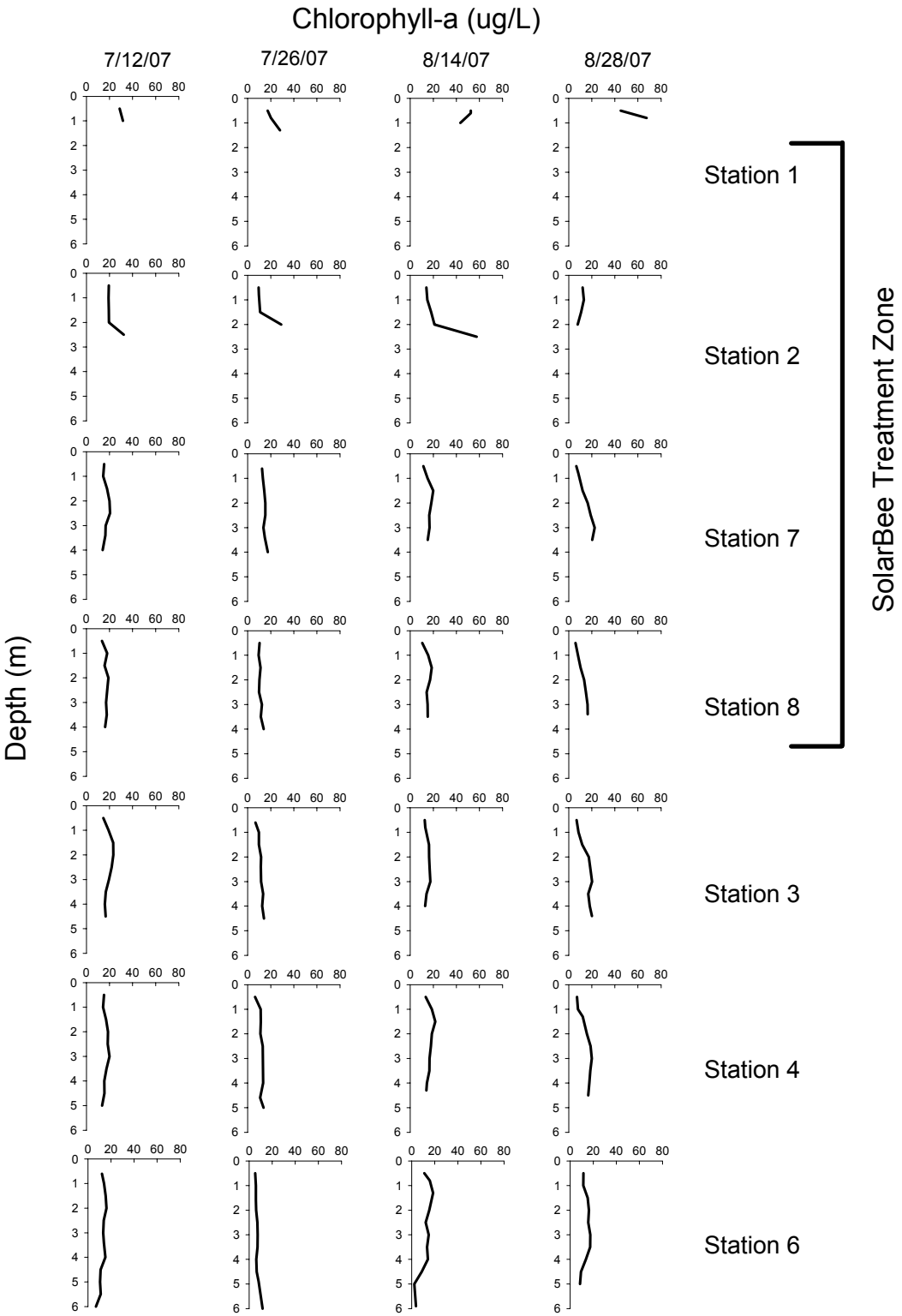

Figure 16. Vertical distributions of chlorophyll-a on four sampling dates during 2007.

Phytoplankton, Microcystin, and Phosphorus

Phytoplankton community composition

The taxonomic composition of the phytoplankton community was evaluated at the supplemental monitoring stations (Figure 4) on each sampling date. The top three most common taxa present in each sample based on individual cell density are listed in Table 4. The three most common taxa in each sample based on natural unit density are listed in Table 5. Natural unit counts treat entire filaments or colonies as a single unit, and thus tend to minimize the dominance of some common bloom species of cyanobacteria. The four stations within the SolarBee treatment zones (Stations 1, 2, 7, and 8) were grouped together in these tables for comparison with the three stations outside the treatment zones (Stations 3, 4, and 6).

Tables 4 and 5 show that there was a seasonal succession pattern of phytoplankton in St. Albans Bay, starting with Bacillariophytes (diatoms), Chrysophytes, and Cryptophytes in the early summer, followed by Chlorophytes (green algae) in mid-summer, and progressing to Cyanophyta (blue-green algae) dominance in August, especially when expressed as individual cell densities. This seasonal succession pattern was similar across all sampling stations regardless of proximity to the SolarBees. When cyanobacteria became prominent during August, they were about equally likely to be among the top three most common taxa within the SolarBee treatment zone as outside the treatment zone. There was no evidence from this analysis that the SolarBees had any effect in reducing the relative dominance of cyanobacteria in St. Albans Bay.

The proportions of all cyanobacteria within the total phytoplankton community based on individual cell densities are shown in Figure 17. With the exception of Station 1 which was under the immediate influence of the Stevens Brook inflow and where cyanobacteria proportions tended to be low, there were no consistent differences in cyanobacterial dominance inside the SolarBee treatment zone compared with conditions outside the treatment zone.

Microcystin

Microcystin concentrations were measured at the supplemental stations on the last three sampling dates in 2007 when phytoplankton levels were highest (Figure 18). With the exception of Station 1 where cyanobacteria proportions tended to be low, there were no consistent differences in microcystin concentrations inside the SolarBee treatment zone compared with levels measured outside the treatment zone. In all cases, microcystin concentrations remained well below the recreational use criterion of 6.0 µg/L used by the Vermont Department of Health as part of the tiered alert framework for cyanobacteria monitoring in Lake Champlain.

Phosphorus

Total phosphorus concentrations at the supplemental monitoring stations are shown in Figure 19. Some extremely high phosphorus levels were measured at Station 1 immediately off the mouth of the Stevens Brook inflow, especially around the high flow events of June 28 and July 12 (Figure 6). With the exceptions of Stations 1 and 2 which were strongly influenced by the inflow plume from Stevens Brook, total phosphorus concentrations were similar throughout the bay during 2007. One of the claims about SolarBees is that they will control cyanobacteria blooms without necessarily reducing nutrient levels. To examine this possible effect, the ratios of chlorophyll-a to total phosphorus concentration at the supplemental sampling stations are shown in Figure 20. With the exception of Station 1 where algal growth may have been partially suppressed by high turbidity levels in the Stevens Brook inflow on some dates, there were no consistent differences between the chlorophyll to phosphorus ratios inside the SolarBee treatment zone compared with ratios outside the treatment zone.

Table 4. Top three most dominant phytoplankton taxa based on individual cell density rank at each sampling station on each date. Colors indicate Divisions: Cyanophyta (pink); Chlorophyta (green); Bacillariophyta/Chrysophyta/Cryptophyta (yellow).

		SolarBee Treatment Zone						
Date	**Cell Density Rank**	**Station 1**	**Station 2**	**Station 7**	**Station 8**	**Station 3**	**Station 4**	**Station 6**
5/21/07	1	*Centrales spp*	*Chroomonas spp*	No data	No data	*Chroomonas spp*	*Chrysophyta flagellate*	No data
	2	*Chroomonas spp*	*Chrysophyta flagellate*	No data	No data	*Chrysophyta flagellate*	*Chroomonas spp*	No data
	3	*Chrysophyta flagellate*	*Asterionella formosa*	No data	No data	*Asterionella formosa*	*Asterionella formosa*	No data
6/1/07	1	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*
	2	*Fragilaria spp*	*indeterminate flagellate*	*Cryptomonas spp*	*Fragilaria crotonensis*	*Fragilaria crotonensis*	*indeterminate flagellate*	*indeterminate flagellate*
	3	*Pediastrum duplex*	*Cryptophyta flagellate*	*Cryptophyta flagellate*	*indeterminate flagellate*	*Chrysophyta flagellate*	*Chrysophyta flagellate*	*Asterionella formosa*
6/15/07	1	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	No data
	2	*Cryptomonas spp*	*Cryptomonas spp*	*Chroococcales spp*	*Cryptomonas spp*	*Chroococcales spp*	*Chroococcales spp*	No data
	3	*Centrales spp*	*Chrysophyta flagellate*	*Cryptomonas spp*	*indeterminate flagellate*	*indeterminate flagellate*	*Cryptomonas spp*	No data
6/28/07	1	*Micractinium pusillum*	*Micractinium pusillum*	*Micractinium pusillum*	*Anabaena flos-aquae*	*Chlorophyta spp*	*Chlorophyta colony*	*Chroomonas spp*
	2	*Sphaerocystis spp*	*Anabaena flos-aquae*	*Chlorophyta colony*	*Micractinium pusillum*	*Chroomonas spp*	*Pediastrum duplex*	*Cryptomonas spp*
	3	*Centrales spp*	*Pediastrum duplex*	*Chlorophyta spp*	*Sphaerocystis spp*	*Micractinium pusillum*	*Chroomonas spp*	*indeterminate flagellate*
7/12/07	1	*Centrales spp*	*Chlorophyta spp*	*Microcystis wesenbergii*	*Chlorophyta colony*	*Chlorophyta spp*	*Chlorophyta spp*	*Chlorophyta colony*
	2	*Chroomonas spp*	*Chlorophyta colony*	*Chlorophyta colony*	*Fragilaria spp*	*Pediastrum duplex*	*Microcystis spp*	*Micractinium pusillum*
	3	*Cryptophyta flagellate 2*	*Chroomonas spp*	*Chlorophyta spp*	*Pediastrum duplex*	*Chlorophyta flagellate*	*Coelastrum microporum*	*Chlorophyta spp*
7/26/07	1	*Scenedesmus spp*	*Chroococcales*	*Scenedesmus spp*	*Scenedesmus spp*	*Chroococcales*	*Aphanothece spp*	*Microcystis spp*
	2	*Geminella spp*	*Aphanothece spp*	*Aphanothece spp*	*Woronichinia spp*	*Scenedesmus spp*	*Hormonogonales spp*	*Scenedesmus spp*
	3	*Chlorophyta colony*	*Scenedesmus spp*	*Fragilaria crotonensis*	*Chroococcales*	*Fragilaria crotonensis*	*Scenedesmus spp*	*Aphanizomenon flos-aquae*
8/14/07	1	*Centrales spp*	*Anabaena circinalis*	*Anabaena circinalis*	*Anabaena circinalis*	*Anabaena circinalis*	*Anabaena circinalis*	*Anabaena circinalis*
	2	*Anabaena circinalis*	*Coelosphaerium spp*	*Anabaena spp*	*Anabaena spp*	*Hormonogonales spp*	*Anabaena spp*	*Anabaena spp*
	3	*Geminella spp*	*Anabaena spp*	*Aphanothece spp*	*Chroococcales colony*	*Anabaena spp*	*Aphanothece spp*	*Aphanothece spp*
8/28/07	1	*Aphanothece spp*	*Aphanothece spp*	*Aphanothece spp*	*Aphanocapsa spp*	*Chroococcus sp*	*Chroococcales*	*Aphanothece spp*
	2	*Chroococcus sp*	*Aphanocapsa spp*	*Microcystis spp*	*Aphanothece spp*	*Aphanothece spp*	*Coelosphaerium spp*	*Aphanocapsa spp*
	3	*Centrales spp*	*Hormonogonales spp*	*Chroococcus sp*	*Chroococcus sp*	*Hormonogonales spp*	*Aphanothece spp*	*Coelosphaerium spp*

Table 5. Top three most dominant phytoplankton taxa based on natural unit density rank at each sampling station on each date. Colors indicate Divisions: Cyanophyta (pink); Chlorophyta (green); Bacillariophyta/Chrysophyta/Cryptophyta (yellow).

		SolarBee Treatment Zone						
Date	**Natural Unit Rank**	**Station 1**	**Station 2**	**Station 7**	**Station 8**	**Station 3**	**Station 4**	**Station 6**
5/21/07	1	*Centrales spp*	*Chroomonas spp*	No data	No data	*Chroomonas spp*	*Chrysophyta flagellate*	No data
	2	*Chroomonas spp*	*Chrysophyta flagellate*	No data	No data	*Chrysophyta flagellate*	*Chroomonas spp*	No data
	3	*Chrysophyta flagellate*	*Centrales spp*	No data	No data	*Centrales spp*	*Asterionella formosa*	No data
6/1/07	1	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*
	2	*Cryptomonas spp*	*indeterminate flagellate*	*Cryptomonas spp*	*indeterminate flagellate*	*Chrysophyta flagellate*	*indeterminate flagellate*	*indeterminate flagellate*
	3	*Centrales spp*	*Cryptophyta flagellate*	*Cryptophyta flagellate*	*Chrysophyta flagellate*	*indeterminate flagellate*	*Chrysophyta flagellate*	*Cryptomonas spp*
6/15/07	1	*Chroomonas spp*	*Chroomonas spp*	No data	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	No data
	2	*Cryptomonas spp*	*Cryptomonas spp*	No data	*Cryptomonas spp*	*indeterminate flagellate*	*Cryptomonas spp*	No data
	3	*Centrales spp*	*Chrysophyta flagellate*	No data	*indeterminate flagellate*	*Cryptomonas spp*	*indeterminate flagellate*	No data
6/28/07	1	*Centrales spp*	*Centrales spp*	*Chlorophyta spp*	*Chroomonas spp*	*Chlorophyta spp*	*Chroomonas spp*	*Chroomonas spp*
	2	*Cryptomonas spp*	*Cryptomonas spp*	*Chroomonas spp*	*Chlorophyta spp*	*Chroomonas spp*	*indeterminate flagellate*	*Cryptomonas spp*
	3	*Chlorophyta spp*	*Chlorophyta spp*	*Cryptomonas spp*	*Cryptomonas spp*	*indeterminate flagellate*	*Cryptomonas spp*	*indeterminate flagellate*
7/12/07	1	*Centrales spp*	*Chlorophyta spp*	*Chlorophyta spp*	*Chlorophyta spp*	*Chlorophyta spp*	*Chlorophyta spp*	*Chlorophyta spp*
	2	*Chroomonas spp*	*Chroomonas spp*	*Chlorophyte flagellate*	*Chlorophyte flagellate*	*Chlorophyte flagellate*	*Chlorophyte flagellate*	*Chroomonas spp*
	3	*Cryptophyta flagellate*	*Chlorophyte flagellate*	*Centrales spp*	*Oocystis spp*	*Chroomonas spp*	*Chroomonas spp*	*indeterminate flagellate*
7/26/07	1	*Scenedesmus spp*	*Scenedesmus spp*	*Scenedesmus spp*	*Scenedesmus spp*	*Scenedesmus spp*	*Scenedesmus spp*	*Scenedesmus spp*
	2	*Geminella spp*	*Chroomonas spp*	*Chroomonas spp*	*Chroomonas spp*	*Chlorophyta spp*	*Chroomonas spp*	*Chlorophyta spp*
	3	*Centrales spp*	*Chlorophyta spp*	*Chlorophyta spp*	*Chlorophyta spp*	*indeterminate flagellate*	*Chlorophyta spp*	*Chroomonas spp*
8/14/07	1	*Centrales spp*	*Centrales spp*	*Chroomonas spp*	*Chroomonas spp*	*Anabaena circinalis*	*Chroomonas spp*	*Chroomonas spp*
	2	*Geminella spp*	*Chroomonas spp*	*Chrysophyta flagellate*	*indeterminate flagellate*	*Anabaena spp*	*Chrysophyta flagellate*	*indeterminate flagellate*
	3	*Cryptomonas spp*	*Anabaena circinalis*	*Anabaena circinalis*	*Anabaena circinalis*	*Chlorophyta colony*	*indeterminate flagellate*	*Chrysophyta flagellate*
8/28/07	1	*Centrales spp*	*indeterminate flagellate*	*indeterminate flagellate*	*indeterminate flagellate*	*indeterminate flagellate*	*Aphanothece spp*	*indeterminate flagellate*
	2	*Chroococcales colony*	*Hormonogonales spp*	*Chroococcales colony spp*	*Chroococcales colony*	*Hormonogonales spp*	*indeterminate flagellate*	*Hormonogonales spp*
	3	*Ankistrodesmus convolutus*	*Centrales spp*	*Hormonogonales spp*	*Centrales spp*	*Chlorophyta spp*	*Centrales spp*	*Centrales spp*

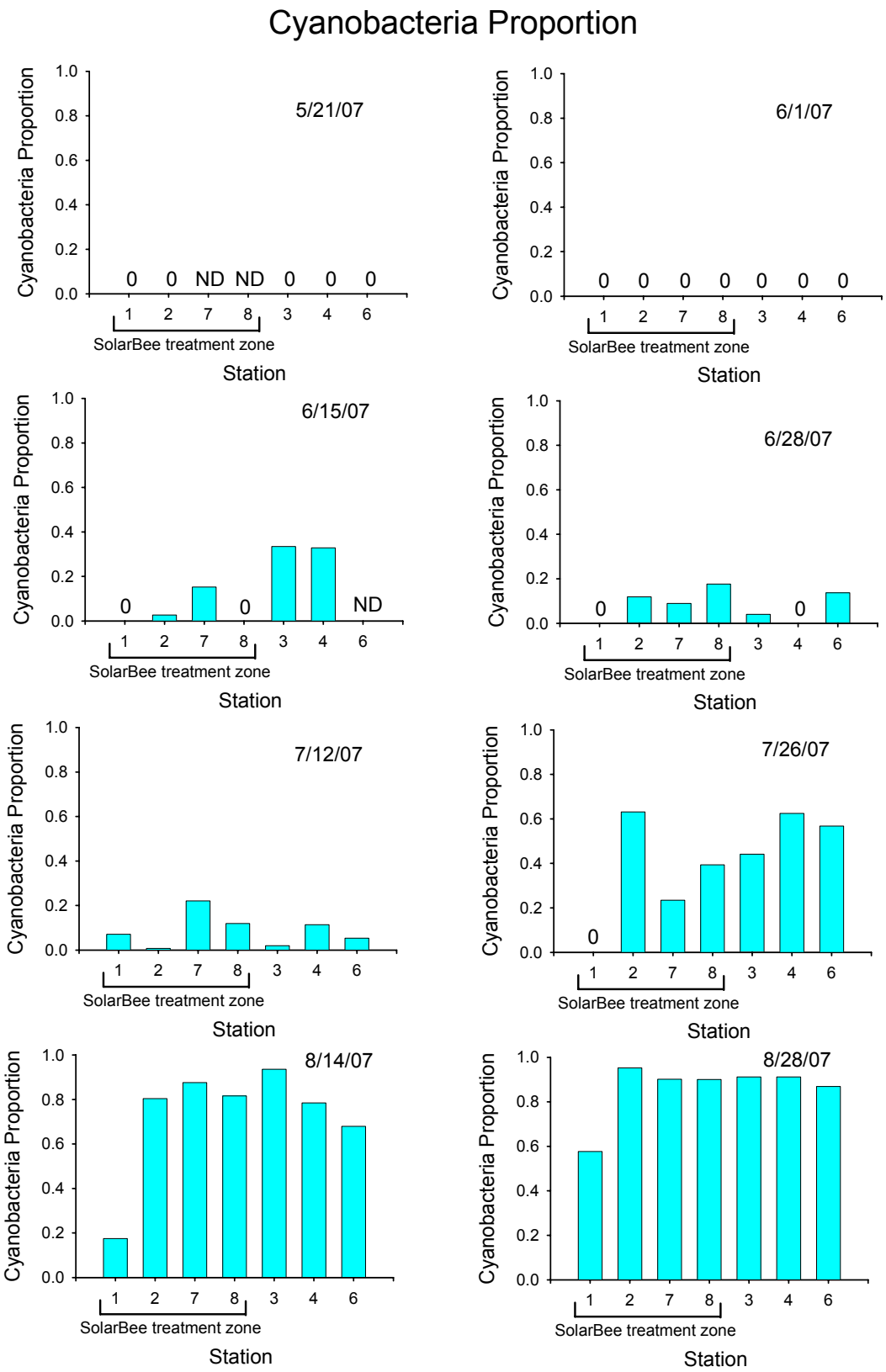

Figure 17. Proportion of cyanobacteria relative to total phytoplankton cell densities at the seven supplemental sampling stations on each sampling date. "0" indicates zero cell count values. "ND" indicates no data were obtained.

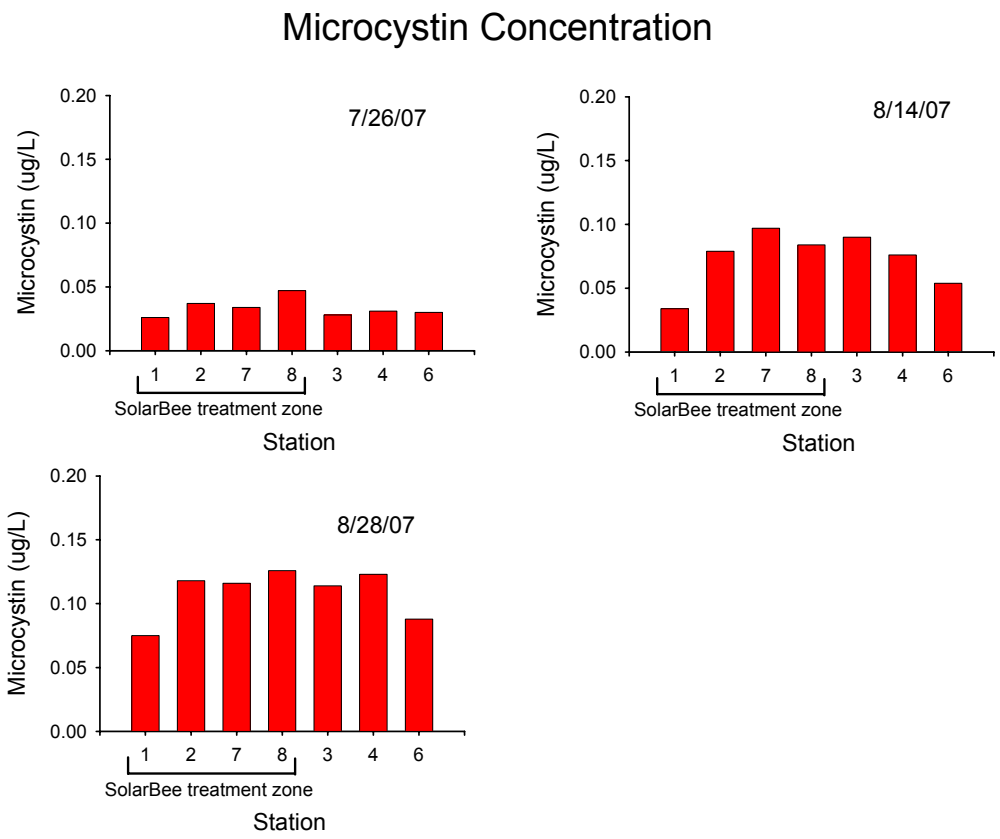

Figure 18. Microcystin concentrations at the seven supplemental sampling stations on each sampling date.

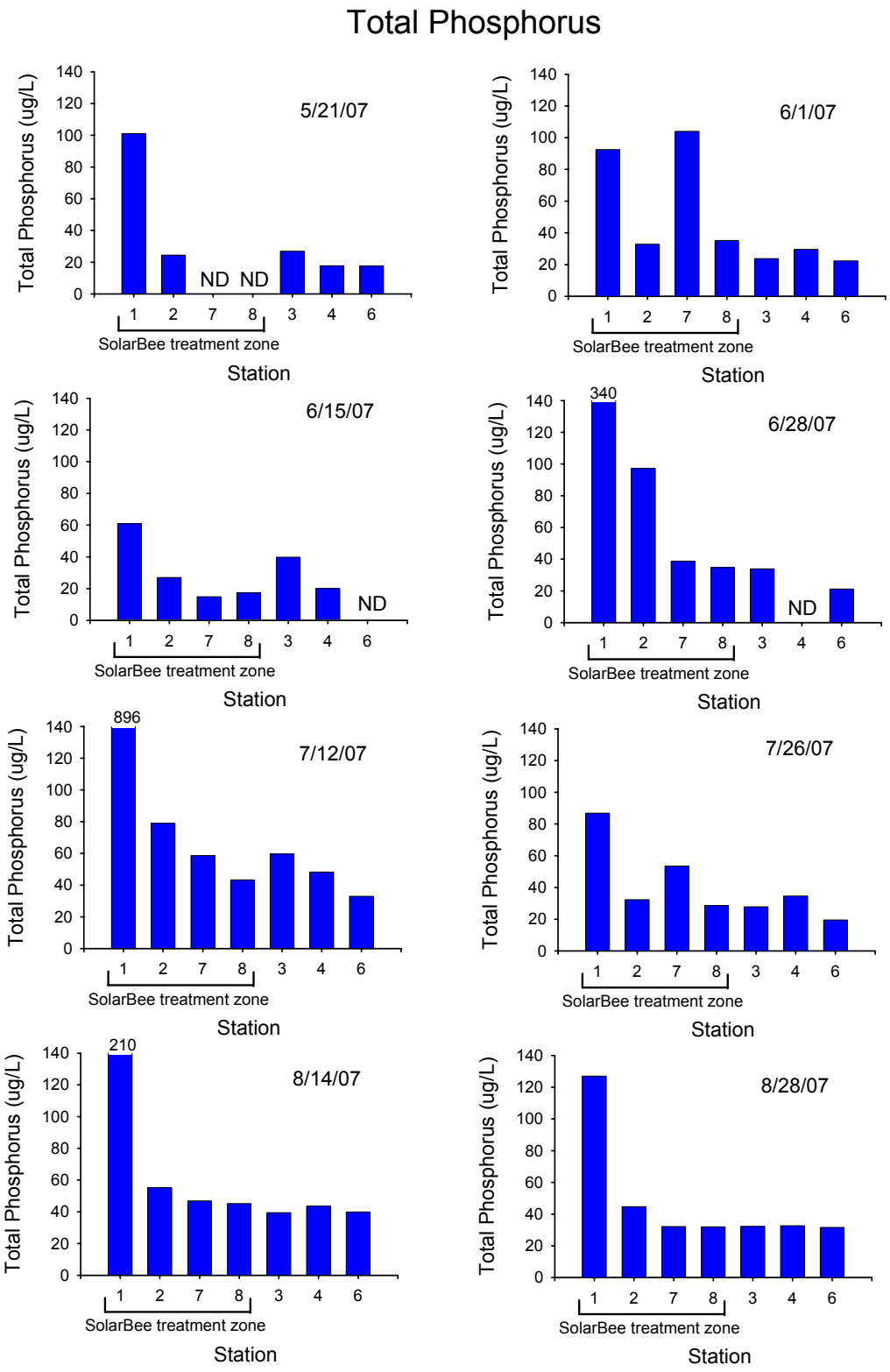

Figure 19. Total phosphorus concentrations at the seven supplemental sampling stations on each sampling date. "ND" indicates no data were obtained.

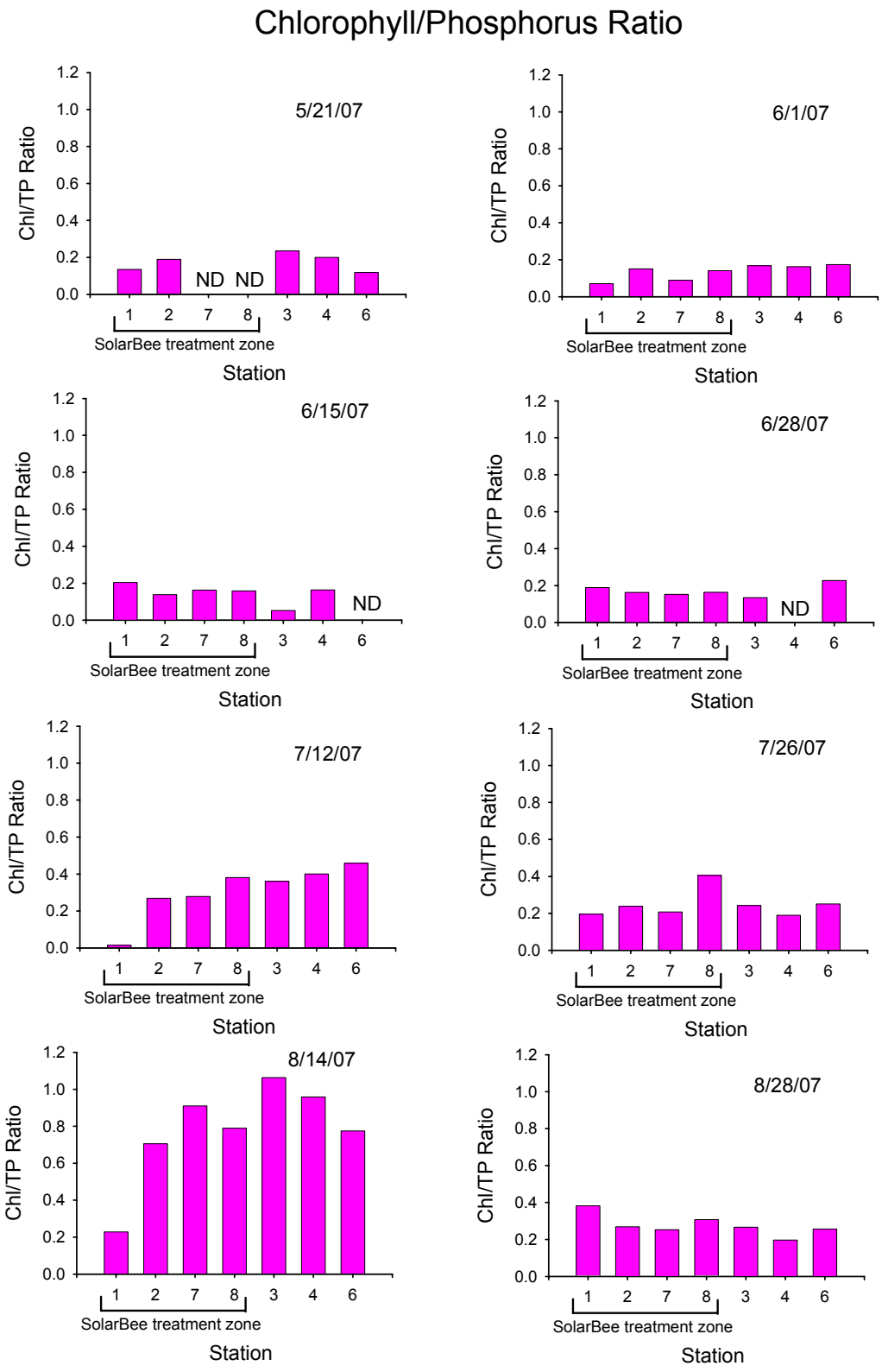

Figure 20. Ratios of chlorophyll-a to total phosphorus concentration at the seven supplemental sampling stations on each sampling date. "ND" indicates no data were obtained.

Long-Term Monitoring Results

A long-term water quality and biological monitoring program has been conducted on Lake Champlain by the States of Vermont and New York through the Lake Champlain Basin Program since 1992[10]. This long-term program has included a sampling station in St. Albans Bay (station 40), co-located with supplemental sampling station 6 used in the present study (Figure 4). As discussed earlier in this report, the data from the long-term monitoring station in St. Albans Bay cannot be used to evaluate the effectiveness of the SolarBee devices because the station is located too far from the SolarBees, well outside their treatment zones.

The long-term monitoring data do, however, provide a perspective on how water quality in St. Albans Bay during the summer of 2007 compared with conditions during previous years. The annual distributions of June-September total phosphorus, chlorophyll-a, and Secchi depth at the long-term monitoring station in St. Albans Bay are shown in Figure 21. Median phosphorus and chlorophyll-a concentrations were slightly lower during 2007 than what has been recorded during most recent years. This is consistent with the general impression of lake residents and sampling crews that algal blooms were relatively mild in St. Albans Bay (and throughout northern Lake Champlain) during 2007, but substantial amounts of algae were still apparent in the water. The overall ranges of total phosphorus, chlorophyll-a, and Secchi depth during 2007 were typical of long-term conditions at the monitoring station.

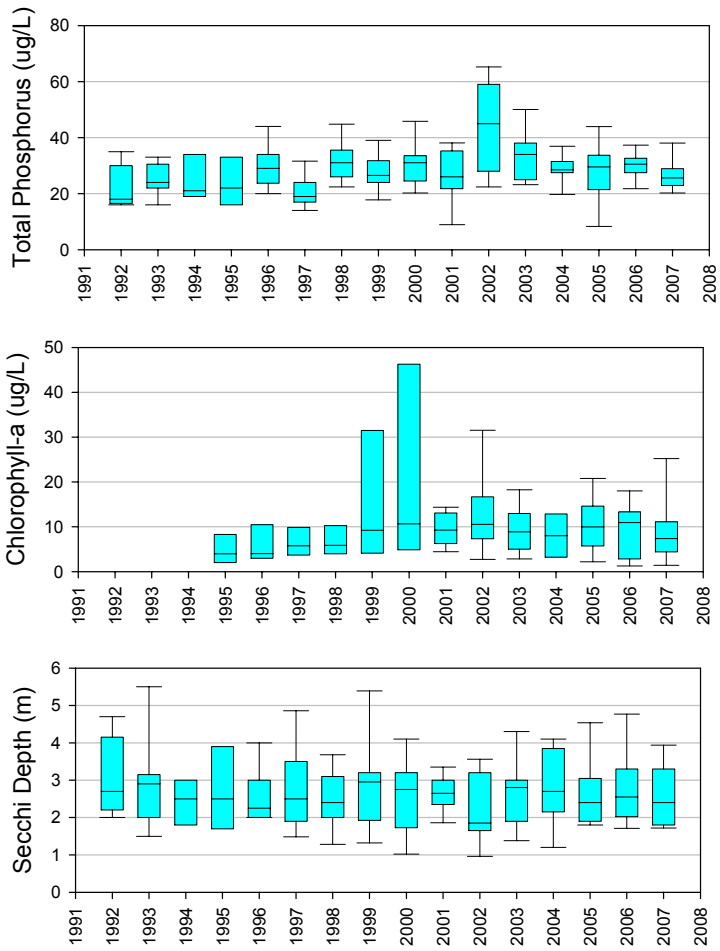

Figure 21. Annual distributions of summer (June-September) total phosphorus, chlorophyll-a, and Secchi depth at the long-term monitoring station in St. Albans Bay, 1992-2007. Box plots show annual medians and 5th, 25th, 75th, and 95th percentiles.

Summary and Conclusions

The goal of the SolarBee deployment in St. Albans Bay during 2007 was to reduce algae levels and improve water clarity in the northern end of the bay where cyanobacteria blooms have been severe during the summer months. The effectiveness of the SolarBees in achieving this goal was tested by lake monitoring using a spatial control design in which water quality conditions near the three SolarBee units were compared with conditions at greater distances from the devices. A spatial grid of over 90 sites was sampled on nine dates during May-August 2007 for chlorophyll-a and Secchi disk transparency. A number of other parameters including phytoplankton community composition and vertical distribution of chlorophyll-a were sampled at supplemental sites both inside and outside of the expected 35-acre treatment zone around each SolarBee unit.

The spatial distribution of chlorophyll-a and Secchi disk transparency showed no consistent relationship with the treatment zones around the three SolarBee units, based on visual examination of the mapped data. The highest chlorophyll-a concentrations and lowest water clarities within the bay on a given date were usually found within the SolarBee treatment zones. There was no evidence of generally depressed algal growth or clear water within the treatment zones. There was one date (August 14) out of nine dates sampled in which lower chlorophyll-a concentrations and higher Secchi disk transparencies occurred within significant portions of the SolarBee treatment zones, relative to levels observed just to the south. However, the chlorophyll-a spatial distribution observed in the bay on August 14 was similar to the chlorophyll-a patterns found by researchers at the University of Vermont on an August date during 2003, suggesting that these patterns were most likely the result of pre-existing circulation features in the bay, and not related to the SolarBee deployment during 2007.

Mean chlorophyll-a concentrations were not lower, and mean Secchi disk transparencies were not higher within the treatment zone around each SolarBee unit when compared with conditions immediately outside the treatment zone. A statistical analysis of the spatial grid data found that there were generally no significant differences in chlorophyll-a or Secchi disk transparency within the treatment zones vs. levels immediately outside the treatment zones.

This analysis using a spatial, rather than temporal, control cannot rule out the possibility that chlorophyll-a concentrations were lower and water clarities were higher in the treatment zones than would have been the case if the SolarBees had not been operating during 2007. However, any effects the SolarBees may have had in improving water quality were not detectable with this study design, and were not sufficient to improve conditions beyond what was found in the immediately adjoining waters, which was the primary goal of the project.

The SolarBees did not produce a more uniform vertical distribution of chlorophyll-a in the water column than what was seen outside the treatment zone. Direct examination of the composition of the phytoplankton community indicated that the SolarBees had no discernable effect in reducing the relative dominance of cyanobacteria in the treatment zone. There were no consistent differences between the chlorophyll to phosphorus ratios inside the SolarBee treatment zone compared with ratios outside the treatment zone.

In conclusion, there was no evidence that the SolarBees in St. Albans Bay reduced algal concentrations, improved water clarity, or inhibited blue-green algae in the north end of the bay. The treatment goal of producing an approximately 100-acre zone of clear, low-algae water at the northern end of St. Albans Bay was not achieved by the SolarBee deployment. It is likely that natural wind-driven currents overwhelm any circulation effects of SolarBees in lakes as large as St. Albans Bay and Lake Champlain.

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