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ABSTRACT

The harmful alga *Prymnesium parvum* can be controlled with chemicals that also can kill non-target organisms including fish. Currently, there is no ecologically safe and sustainable method for controlling this alga. Therefore, we evaluated SolarBee® solar powered water circulation (SPC) for efficacy in controlling *P. parvum* blooms and ichthyotoxicity. We hypothesized that SPC can alter the ecological niche that promotes *P. parvum* blooms and toxicity, and thereby control this alga. Ecological niche variables considered were inorganic phosphorus (P) and nitrogen (N), conductivity, pH, temperature, and cations. The effects of SPC on total algal biomass and community structure and zooplankton were also investigated. The study was conducted in six 0.4-ha plastic-lined fish hatchery ponds from September 2007 to March 2008. Three ponds received SPC and another three without SPC served as control. Variables tested were *P. parvum* cell density and ichthyotoxicity, total algal density, algal population diversity, chlorophyll *a*, P, N, pH, water temperature, dissolved oxygen, conductivity, calcium, magnesium, potassium, and sodium. The algal community consisted of 69 taxa (genera and species) from eight divisions, including Haptophyta and Chlorophyta, and two unidentified algae. The SPC suppressed the chlorophytes population and otherwise had no effect on any of the tested variables. The SPC was unable to alter water quality and nutrient levels in hatchery ponds and thus failed to control *P. parvum*.

INTRODUCTION

The toxigenic haptophyte *Prymnesium parvum* has caused massive and extensive mortalities in wild and cultured fish in many parts of the world (Otterstrom and Steelmann-Nielson 1940; Aure and Rey 1992; Guo et al. 1996; Lindholm et al. 1999) and appears to be spreading in the USA (Sager et al. 2008). By 2010, this alga was reported present in 18 states. In Texas *P. parvum* has emerged from causing isolated fish kills in remote west Texas to causing frequent large fish kills in several economically important reservoirs in five river basins. These fish losses were conservatively estimated to be more than 34 million fish valued at US$13 million (Southard et al. 2010). This alga has also caused fish kills in private and public ponds in Texas since 2001.

Currently, there are no strategies to prevent bloom formation or to mitigate toxicity effects in large water bodies. Available mitigation strategies for *P. parvum* problems use chemicals to reduce blooms and ichthyotoxicity in small impoundments (Barkoh and Fries 2005; Barkoh et al. 2010). Ammonium sulfate $\{(NH_4)_2SO4\}$ or copper-based algaecides (e.g., $CuSO_4$) are used to reduce cell densities, and potassium permanganate ($KMnO_4$) is used to provide short-term control of ichthyotoxicity (Barkoh and Fries 2005; Barkoh et al. 2010). Nitrogen (N) and phosphorus (P) applications also can control *P. parvum* (Kurten et al. 2007, 2010). Weaknesses with these chemical treatments include short-term improvements that require frequent reapplications to maintain control, making them tedious and inefficient in terms of labor and chemical needs. In addition, ammonium sulfate concentrations required to control *P. parvum* may produce un-ionized ammonia levels that are harmful to fish (Barkoh et al. 2003) and fertilization with inorganic nutrients promotes elevated pH that can be lethal to sensitive fish (Kurten et al. 2007). Similarly, copper compounds indiscriminately kill non-target organisms including desirable algae, zooplankton, aquatic insects, and fish (McKnight 1981; McKnight et al. 1983; Welch et al. 1990; Guo et al. 1996) along with *P. parvum*. These chemical treatments are unsuitable for large water bodies because of cost, pollution, and ecological harm concerns.

Prevention or long-term control of *P. parvum* blooms and toxicity may require strategies that deplete or alter the ecological niche that allows this harmful alga to out-compete desirable algae. This ecological niche has not been defined but significant progress has been made in identifying the ecological requirements for bloom formation and toxicity. *P. parvum* requires salinities of 0.1% chloride concentration or more to establish populations (Shilo and Shilo 1962, cited in Sarig 1971) and thrives in wide ranges of salinities (3-30 psu or 0.3-3.0%) and temperatures (5-30^{o}C) (Shilo and Aschner 1953; Larsen et al. 1993; Larsen and Bryant 1998). Populations appear to peak at salinities of 4.0-8.0 ppt (Guo et al. 1996) and blooms are common at 15-24°C (Sabour et al. 2000). In affected Texas fish hatchery ponds, with salinities of approximately 2-4 ppt, temperatures of 28°C and higher appear to limit *P. parvum* population growth whereas blooms occur at 17-22°C. Unlike most competitors, *P. parvum* is capable of acquiring nutrients from various inorganic and organic sources (McLaughlin 1958; Paster 1973). It uses inorganic N and P in photosynthesis when these nutrients are available (Nicholls 2003). When inorganic nutrients are limiting, *P. parvum* releases toxins (prymnesins) that lyse cells of other organisms to release dissolved organic matter that becomes a

source of nutrients (Estep and McIntyre 1989). Additionally, the toxins can immobilize other organisms for *P. parvum* to ingest whole (Nygaard and Tobiesen 1993; Johansson and Granéli 1999; Skovgaard and Hansen 2003). Prymnesins also repel potential grazers of *P. parvum*, kill other algae, or inhibit their growth (Tillmann 2003; Uronen et al. 2005; Granéli et al. 2008). These characteristics are believed to give *P. parvum* a competitive advantage to dominate phytoplankton communities.

Prymnesins are not fully formed when released from the cell and require cationic cofactors and appropriate pH in the external aquatic medium to complete formation of the final toxic products (Sarig 1971; Larsen et al. 1993). Calcium, magnesium, and sodium, as well as pH 7-9 are required for toxins activation and toxicity expression (Ulitzur and Shilo 1964; Shilo and Sarig 1989). Thus, alkaline pH, availability of cations, and limiting inorganic N or P concentrations may constitute essential components of the ecological niche that promotes *P. parvum* blooms and toxicity. Additional factors that may contribute to bloom formation are quiescent or stagnant water and cool-to-cold temperatures. In Texas, blooms mostly occur between November and June in impoundments, and bloom initiation usually occurs in coves of large reservoirs.

SolarBee® is a floating, mechanical water mixer the manufacturer claims has potential to control *P. parvum*. If that were the case, SolarBee® would have application in various water bodies. According to the manufacturer, each unit can move about 37,854 L of water per minute from depths of about 30.5 m with a solar-powered pump to create solar powered water circulation (SPC). The distribution technology causes water to move long distances in a near-laminar flow. This allows a single unit to effectively mix a 14.2-ha lake and multiple units to mix larger lakes because the mixing capabilities are additive. SolarBee® alters conditions that favor dominance of blue-green algae to allow desirable green algae and diatoms to dominate algal communities. These conditions include low nutrient levels, warm temperatures, and quiescent or stagnant waters. In addition, the manufacturer claims SPC has successfully controlled blue-green algae in 90% of nearly 200 lake applications in 2001-2007. An independent study conducted by the Palmdale Water District in California appears to support the manufacturer's claim that the technology can be effective. Labisi (2004) found that SPC controlled seasonal algal blooms and improved water quality in Lake Palmdale. Dissolved oxygen distribution was uniform with a higher minimum concentration and Secchi depth was higher. Conversely, pH, turbidity, and chlorophyll-*a* levels were lower. Overall, SPC transformed the lake from eutrophic to mesotrophic state.

The apparent success of SPC has been suppression of colonial and filamentous blue-green algae, such as *Microcystis*, *Anabaena,* and *Aphanizomenon* to allow chlorophytes and diatoms to dominate algal communities. The mechanisms for the observed SPC suppression of blue-green algae or shifts in algal community structure are unknown. Theories include: (1) interference with the ability of blue-green algae to use buoyancy to optimize position in the water column to meet nutrition and sunlight requirements (Wallace et al. 2000) and (2) promotion of beneficial algae that reproduce more rapidly than blue-green algae, thereby transporting nutrients up the food chain and limiting blooms of blue-green algae (Sorokin and Kraus 1958; Hudnell et al. 2010). Because *P. parvum* is unicellular and microscopic compared to the algal forms adversely

affected by SPC, it is inappropriate to extrapolate that SPC can also directly control *P. parvum.* Therefore, the efficacy of SPC in controlling *P. parvum* was evaluated empirically with the hypothesis that SPC can alter the ecological niche that promotes *P. parvum* bloom formation and toxicity. Objectives of the study were to determine if *P. parvum* cells and ichthyotoxicity are eliminated or significantly reduced in ponds subjected to SPC and to identify the ecological factors responsible for the control. Also, the effects of SPC on the diversity and population densities of the algal community (phytoplankton) and zooplankton were evaluated.

MATERIALS AND METHODS

Study location and design

This study was conducted at the Dundee State Fish Hatchery, Archer County, Texas in six 0.4-ha plastic-lined ponds with histories of *P. parvum* blooms and ichthyotoxicity. Additional pond characteristics were: volume 4,985 m^3, maximum depth 1.83 m, average depth 1.22 m, average length 83.82 m, and average width 45.72 m. Three ponds received one SolarBee® each (treatment), and three ponds received no SolarBee® and served as the control group. Assignment of ponds to treatment and control groups was random. Ponds were filled with water from Diversion Lake on August 24-September 3, 2007 and the SolarBee® units, model SB2500 powered solely by solar energy, were deployed on September 13. The study ended on March 17, 2008, placing the study period within the November-June period when *P. parvum* blooms and toxicity are frequent in Dundee State Fish Hatchery ponds.

P. parvum Cell Density and Ichthyotoxicity

P. parvum cell density and toxicity in pond water were measured weekly. The cell density estimates and toxicity bioassays were performed on the same day for each pond by using standard Texas Parks and Wildlife Department (TPWD) fish hatchery procedures (Southard 2005a, b). Cell densities were estimated with a hemacytometer and microscope at 400X magnification to examine 10-µL aliquots of fresh unfixed pond water samples. Bioassays were performed with fathead minnow *Pimephales promelas* fry as test fish at 28°C. Each bioassay used water collected from a pond and processed into the following: 100 mL undiluted water, 100 mL undiluted water plus 2 mL cofactor, and 100 mL water diluted 1:5 (v:v) with *P. parvum*-free water plus 2 mL cofactor. *P. parvum*-free water (100 mL) was used as control. The cofactor solution, which consisted of 0.003 M 3, 3'-iminobispropylamine and 0.02 M tris buffer (pH 9.0), functioned to enhance the toxicity of the *P. parvum* ichthyotoxin, thus allowing the otherwise sublethal levels to be quantifiable. Mortality of test fish (four per assay) was determined after 2 hours exposure to assays, and the degree of toxicity was estimated in ichthyotoxicity units (ITU) as follows: zero mortality indicated no toxicity (0 ITU); mortality in undiluted water plus cofactor indicated low toxicity (1 ITU); mortality in the 1:5 (v:v) diluted water plus cofactor indicated moderate toxicity (5 ITU), and mortality in undiluted water indicated a high level of toxicity (25 ITU).

Water Quality, Nutrients, and Plankton

Water quality measurements and water samples (250 or 1,000 mL each) were taken from 25-35 cm below the water surface. Water temperature, pH, and dissolved oxygen concentration were measured twice daily (before sunrise and at 1400-1500 hours) using a YSI 650 MDS handheld meter fitted with a YSI 600 XL multiprobe sensor (Yellow Springs Instruments, Yellow Springs, Ohio). Conductivity was measured with the YSI 650 MDS meter weekly. Concentrations of nutrients, chlorophyll *a,* and selected dissolved metals (cations) were measured biweekly. These analyses were performed by the TPWD Environmental Contaminants Laboratory, San Marcos, Texas using U.S. Environmental Protection Agency (USEPA)-approved methods (USEPA 1983) or standard methods (APHA 1995). Methods and detection limits were as follows: total P (APHA 4500B-5 Digestion, 4500E Analysis; 0.020 mg P/L), orthophosphate-P (PO_4-P; APHA 4500B; 0.002 mg P/L), NO_2+NO_3-N (APHA 4110B; 0.004/0.036 mg N/L), NH_4-N (APHA 4500D; 0.025 mg N/L), chlorophyll *a* (APHA 10200H-3; 0.55 µg/L), and cations (USEPA 200.1 Digestion, 200.7 Analysis: Ca, Mg, Na, and K; 1.0 mg/L). Analysis for total Kjeldahl nitrogen (TKN) was performed by an independent laboratory (Edwards Aquifer Research and Data Center, Texas State University, San Marcos) using USEPA-approved method 351.2 with a detection limit of 0.1 mg N/L.

Water samples for phytoplankton analysis were collected on September 11, two days before SolarBee® deployment, and then on November 26, January 28, and March 17. The samples were preserved with approximately 1% glutaraldehyde and shipped by overnight delivery to a commercial laboratory (PBS&J, Austin, Texas) for analysis. Samples were analyzed with a Nikon Eclipse TS100 inverted microscope after settling volumes of 5, 10, or 25 mL of well-mixed samples in an Utermöhl sedimentation chamber. The analytical protocol followed a USEPA-approved method (2007). The algae were identified to the lowest taxa (genus or species) possible and counted. Density was expressed as cells/mL.

Zooplankton samples were collected weekly before sunrise with an oblique tow of 80-µm-mesh Wisconsin plankton net from one station at the deepest part of each pond. Samples were preserved with Lugol's iodine solution and stored at 4°C for later analysis. Two 1-mL aliquots of the preserved samples were separately placed on a plankton counting wheel and viewed under a dissecting microscope at variable magnification. Zooplankters were identified according to Pennak (1978) and enumerated into four categories: rotifers, cladocerans, copepod nauplii, and adult copepods. Densities were expressed as organisms per liter.

Data Analysis

All data, except those of algal community, were analyzed with PROC MIXED (SAS Institute Inc. 2002). Because data were collected repeatedly from each pond, we modeled the data assuming a repeated measures construct with ponds as subjects. We tested a variety of covariance constructs (none, variance component, compound symmetry, first order autoregressive, and spatial power structure) until we found the one that provided the best fit to the data for each response variable. The Akaike's Information Criterion and the Null Model Likelihood Ratio test were used to determine

the model of best fit for the data (Littell et al. 2000). We tested the effects of treatment, sampling date, and the treatment × sampling date interaction on each variable. Ichthyotoxicity, cell density, and zooplankton data were $\log_{10}(X + 1)$-transformed before analysis due to skewness and zeros in the data. Algal community composition was compared between control and SPC treatment by computing the Bray-Curtis similarity indices for the sampling days for each pond and then subjecting the data to a two-way analysis of similarity (ANOSIM) in Primer-e (Clarke and Warwick 2001; Clarke and Gorley 2006). The effects of SPC treatment and time (sampling date) on algal community diversity were tested at the taxa and division levels. Algal population densities were compared between control and treatment with repeated measures ANOVA. Data were log (density + 1)-transformed to down-weight the influence of very dense algae before analysis. For all analyses, differences were considered significant at *p*-values less than or equal to 0.05.

RESULTS

P. parvum Cell density and Ichthyotoxicity

P. parvum was present in low densities in all ponds at the beginning of the study and remained low (< 6000 cells/mL) throughout the study (Figure 1). By mid-December (day 98) cell densities had declined below detectable levels. From day 119 (January 7) through the end of the study, cell densities gradually increased, except for a spike of 5,667 cells/mL in control ponds compared to 1,667 cells/mL in SPC ponds on day 133. High density blooms did not develop in any pond and mean cell density did not significantly differ between control and SPC treatment throughout the study. Ichthyotoxicity was undetectable at the beginning of the study and on most sampling days (Figure 1). Moderate toxicity (mean 8.33 ITU) was present in both control and SPC ponds on day 55 (November 5, 2007). Slight toxicity was detected for both control and SPC ponds on 6 of the last 10 sampling days (March 3-17). Mean toxicity did not significantly differ because of treatment effect.

Plankton

Chlorophyll-*a* concentrations were approximately 4-6 µg/L during the first 20 days of the study then declined sharply to remain low (≤ 1 µg/L) through the end of the study (Figure 1). The mean chlorophyll-*a* concentration did not significantly differ between control and SPC. The algal community consisted of 69 taxa from eight divisions and two unidentified algae. Divisions represented in both control and SPC ponds were Cyanophyta (blue-green algae), Chlorophyta (green algae), Cryptophyta, Baccillariophyta (diatoms), Haptophyta, and Pyrrhophyta (dinoflagellates) in descending order of abundance (Figure 2). Chrysophytes were absent from control ponds and present in low numbers in SPC ponds. In contrast, euglenophytes were absent from SPC ponds and present in extremely low densities in control ponds. Mean densities of dinoflagellates, haptophytes, blue-green algae, cryptophytes, and diatoms did not significantly differ between control and SPC treatment. Conversely, green algae were significantly more abundant in control than SPC ponds. Green algae, cryptophytes, and blue-green algae varied in abundance through time while taxa of the remaining divisions showed no

consistent temporal patterns (Figure 2). Mean total algal density did not significantly differ between control and SPC but varied significantly through time and was higher in September and March and lower in November and January (Figure 3). The average Bray-Curtis similarity index for algal species composition was 48% for control ponds, 40% for SPC ponds, and 45% between the control and SPC. These results did not significantly change for algal division level. The Bray-Curtis similarity index is bound between 0 and 100%, where 0% means the two sites do not share any species and 100% means the two sites share all the species (Bray and Curtis 1957; Legendre and Legendre 1998). Based on the types of algae shared by SPC and control ponds, a two-way analysis of similarity revealed that the algal community did not significantly differ in diversity at the species or division level due to treatment effect.

The mean densities of rotifers, copepod nauplii, adult copepods, cladocerans, and total zooplankton did not significantly differ between control and SPC treatment, although densities significantly varied through time (Figure 4). Rotifers declined in abundance during the first 20 days of the study and then remained low or undetectable throughout the study. In contrast, adult copepods peaked first, followed by copepod nauplii and then cladocerans; after which all three declined steadily to non-detectable levels for various periods of time. Copepods numbers (adults and nauplii) recovered first and densities increased from their lows through the end of the study. Conversely, cladocerans and rotifers did not appreciably recover by the end of the study. The zooplankton community was dominated by copepod nauplii, followed by rotifers, adult copepods, and cladocerans in control and SPC ponds.

Nutrients and Water Quality

Throughout the study, mean values of total ammonia-N, nitrate-N, TKN, and orthophosphate-P did not significantly differ as a result of treatment effects and no consistent patterns were observed through time (Figure 5). In all cases, trends through time were similar between control and SPC. Total P was below the detectable limit (0.02 mg/L) most of the time except on two occasions when mean values of 0.043 and 0.046 mg/L were recorded for the control ponds and 0.023 and 0.086 mg/L for SPC ponds. Calcium, magnesium, potassium, and sodium concentrations and conductivity also were similar between control and SPC ponds and mean values increase throughout the study (Figures 6 and 7). Similarly, water temperature, pH, and dissolved oxygen concentration did not significantly differ between control and SPC treatment (Table 1).

DISCUSSION

P. parvum Cell Density and Ichthyotoxicity

The SPC had no significant effect on *P. parvum* population or ichthyotoxicity. We evaluated the efficacy of SPC in controlling *P. parvum* based on the premise that it can alter the ecological niche that promotes bloom formation and toxicity. If that were the case, we would expect either inhibition of *P. parvum* population growth, toxin production, or toxin activation, or combinations of these actions. Conductivity influences the establishment of *P. parvum* populations (Shilo and Shilo 1962; Sarig 1971).

Inorganic P and N concentrations determine whether *P. parvum* growth is inhibited or promoted and the onset of toxin production (Uronen et al. 2005; Johansson and Granéli 1999; Legrand 2001; Granéli and Johansson 2003; Kurten et al 2010). Cations and pH control toxicity expression (Shilo and Sarig 1989). These stimulatory factors did not differ between control and SPC. Therefore, we conclude that SPC failed to alter the ecological niche for *P. parvum* in hatchery ponds and thus was unable to control this harmful alga. Hudnell et al. (2010) also reported that SPC failed to control harmful algal blooms, particularly blue-green algae blooms, in aquaculture and other small ponds with depths of 1 m or less. In discussing the effects of water mixing on algal populations and the differential responses of *Microcystis* and *Oscillatoria* to water mixing, Jungo et al. (2001) emphasized that disruption of the ecological niche of the target algae was essential for bloom control.

Plankton, Nutrients, and Water Quality

The phytoplankton was examined at the community, division, and genus or species levels to assess the effects of SPC more thoroughly. This was because water circulation or mixing is reported to have different effects on different algal species (Jungo et al. 2001; Hudnell et al. 2010). In the present study, SPC did not affect algal community composition, total algal biomass, or chlorophyll-*a* level. These findings disagree with the manufacturer's claim and reports (e.g., Labisi 2004; Hudnell et al. 2010) that SPC suppresses blue-green algae and promotes growth of green algae and diatoms to achieve desirable changes in algal communities. Reported changes have included shifts in algal community composition from blue-green algae dominance to green algae or diatoms, and well-balanced planktonic communities. In addition, total algal densities and chlorophyll-*a* levels have reportedly declined through time during SPC deployment. Besides SPC, other studies have reported that artificial mixing of lakes dramatically reduced *Microcystis* biomass and resulted in a shift from blue-green algae dominance to a mixed community of flagellate, green algae, and diatoms (Visser et al., 1996; Jungo et al., 2001). These results were not achieved in the present study. Instead, blue-green algae dominated the algal communities in all ponds throughout the study, and green algae densities were approximately 50 and 20% lower than blue-green algae densities in control and SPC ponds, respectively by the end of the study. Contrary to the results of Hudnell et al. (2010), green algae were more abundant in control than in SPC ponds by the end of this study. These disparate results may be attributed to differences in the size and ecology of the water bodies used to evaluate SPC. The previous studies that showed success in changing algal communities used larger water bodies (surface area = 26-89 ha; mean depth = 3.0-7.7 m; maximum depth =7.6-10.7 m; volume = 765-4900 x 10^3 m^3) that stratified in summer whereas we used 0.4-ha hatchery ponds that were drained 1-2 times annually by the time of the study and were filled with fresh lake water a few days before SolarBee® deployment. Along with the success of SPC in suppressing blue-green algae in larger water bodies was its failure to achieve similar results in smaller water bodies such as hatchery ponds (Hudnell et al. 2010). Our results agree with those of Hudnell (2010) that showed SPC did not control blue-green algae in small impoundments. The effect of SPC on microalgae, such as *P. parvum,* appears untested in large water bodies. Future studies should examine this group of algae especially the harmful algae.

The zooplankton community also was unaffected by SPC; rather, natural conditions appear to have influenced zooplankton. The zooplankton population densities peaked during the early and late periods of the study when water temperatures were higher compared to the middle of the period. We attribute the lack of significant difference in zooplankton density between control and SPC to the similarity of the factors that influence zooplankton population growth. Phytoplankton, the main source of food for zooplankton in hatchery ponds (Geiger 1983; Ludwig et al. 1998), did not differ between the control and treatment groups. Similarly, temperature and pH that influence survival, reproduction, and growth of zooplankton (Allan 1976) were comparable between control and SPC. In contrast with the present results, Hudnell et al. (2010) reported that zooplankton density increased in a lake during SPC. The cause of the observed increase in the zooplankton population was not discussed. However, we believe the improvements in green algae and diatom populations and the concurrent decline in blue-green density may have improved zooplankton grazing efficiency, resulting in increased population growth in that study.

Nutrient levels and water quality also were similar between control and SPC. This was not surprising because SPC did not change the algal community or turbidity of the ponds. In hatchery ponds nutrient levels, pH, dissolved oxygen concentration, and temperature are controlled mainly by algal biomass and to some extent clay turbidity (Boyd 1990). Our study ponds were plastic-lined and were generally lacking bottom sediments that SPC could have re-suspended to increase turbidity and nutrient levels compared to the control ponds. Whereas SPC changed the algal composition, total algal density, chlorophyll-*a* level, and improved water quality in a large lake (Labisi 2004), it failed to produce similar results in hatchery ponds. The disagreements in these study results may be attributed to the differences in size and ecology of the water bodies used to evaluate SPC.

Conclusion

In this study SPC did not control the toxigenic microalga *P. parvum* in fish hatchery ponds. Instead, it suppressed green algae which are considered desirable in fish production ponds because they support zooplankton production and overall pond productivity. Because SPC was not efficacious in altering any of the measured ecological factors that allow *P. parvum* to dominate competitors, we conclude that it was not an ineffective method for controlling this harmful alga.

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TABLE 1.—Mean values (minimum - maximum) of water quality variables in ponds during evaluation of SolarBee® water circulation to control *Prymnesium parvum*.

Treatment	Temperature (°C)	Dissolved oxygen (mg/L)	pH
Control	12.51 (2.15 - 27.51)	10.72 (6.39 - 14.88)	8.24 (7.50 - 9.09)
SolarBee®	12.49 (2.07 -27.53)	10.72 (6.87 - 15.29)	8.18 (7.50 - 9.03)

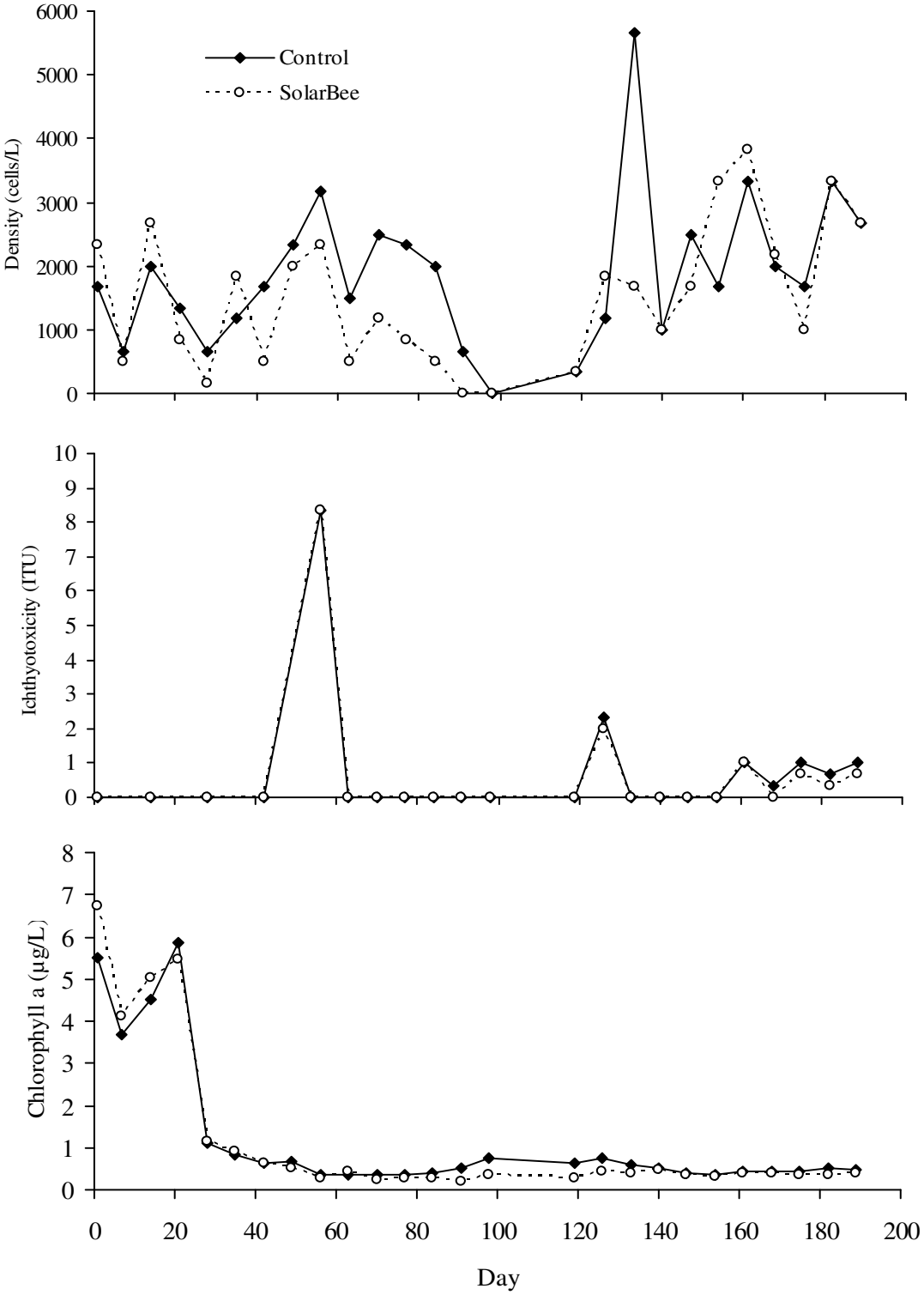

FIGURE 1.—Mean *Prymnesium parvum* cell densities and ichthyotoxicity, and chlorophyll-*a* concentrations in ponds during evaluation of SolarBee® water circulation to control this harmful alga. There were no significant differences ($P > 0.05$) between treatment and control.

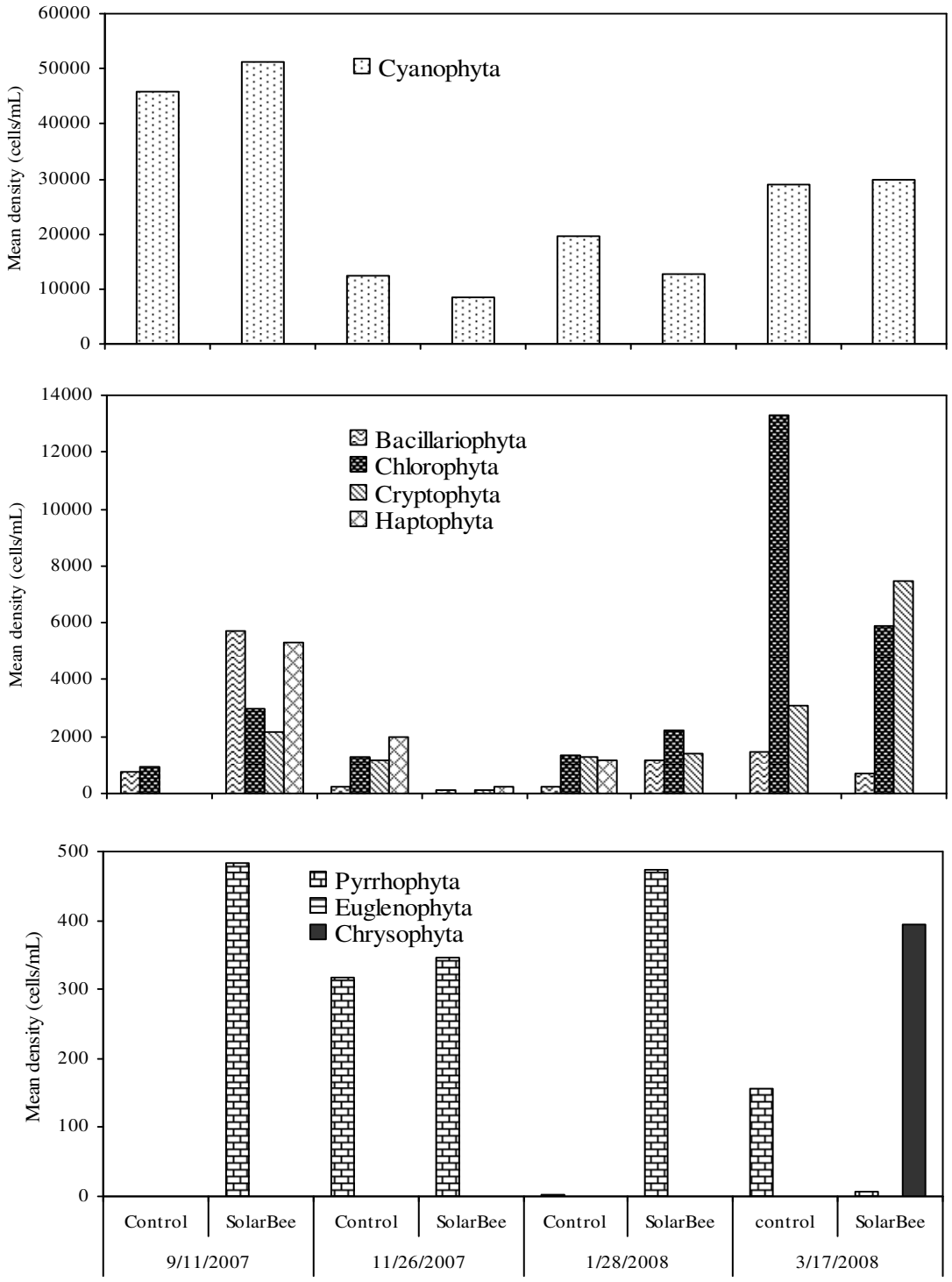

FIGURE 2.—Mean densities of phytoplankton taxa in ponds during evaluation of SolarBee® water circulation to control *Prymnesium parvum*. There were no significant differences ($P > 0.05$) between treatment and control, except for Chlorophyta.

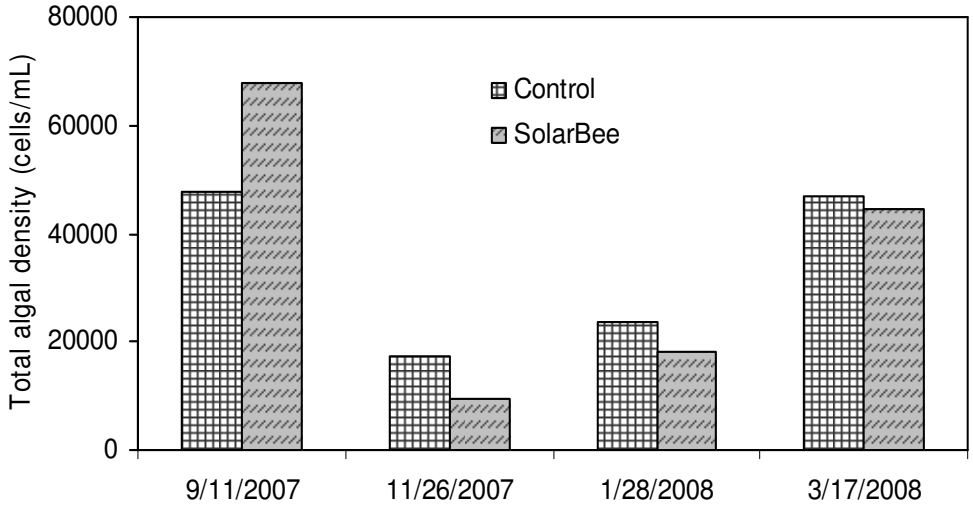

FIGURE 3.—Mean total alga densities in ponds during evaluation of SolarBee® water circulation to control *Prymnesium parvum*. There were no significant differences ($P > 0.05$) between treatment and control.

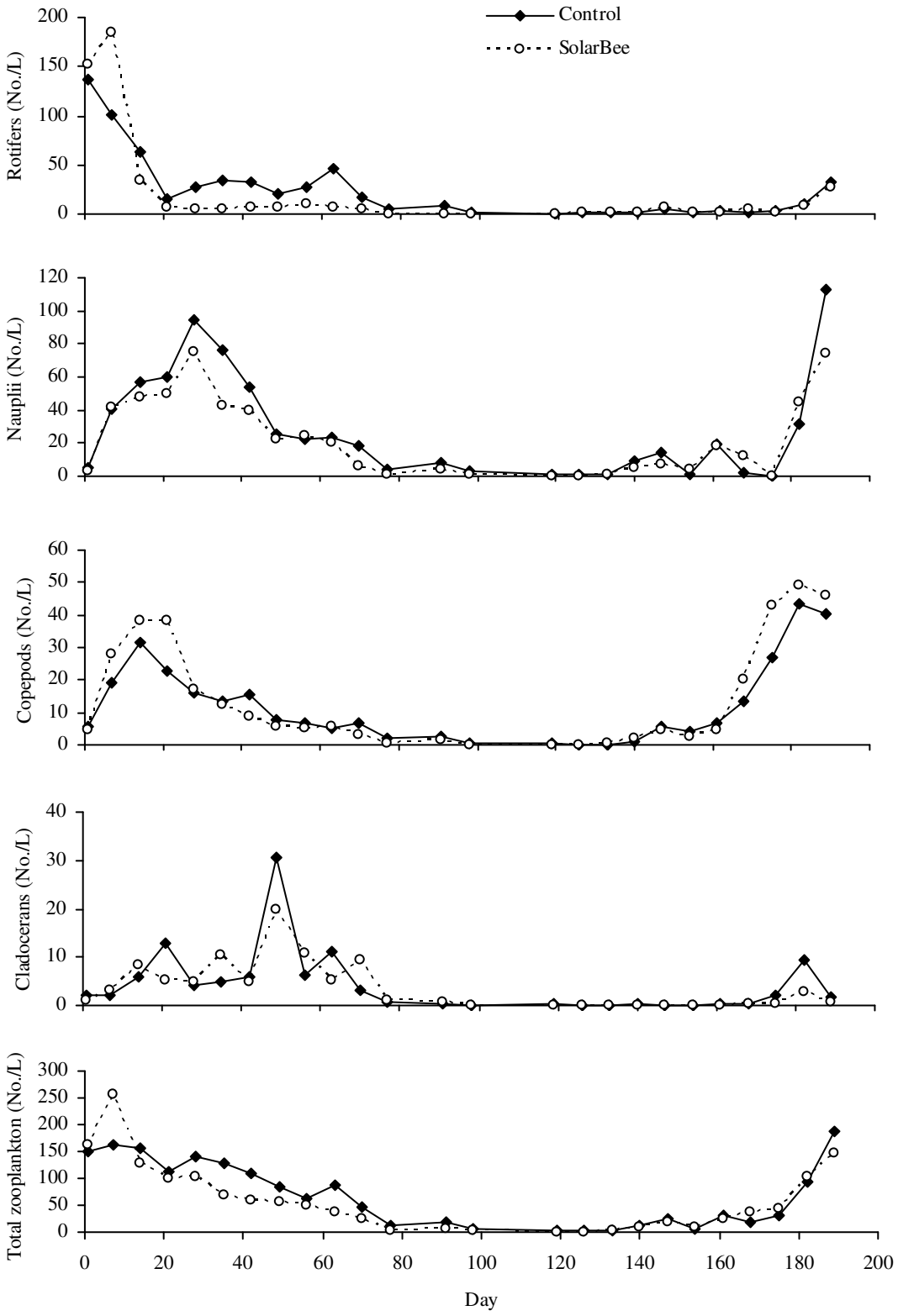

FIGURE 4.—Mean zooplankton densities in ponds during evaluation of SolarBee® water circulation to control *Prymnesium parvum*. There were no significant differences ($P > 0.05$) between treatment and control.

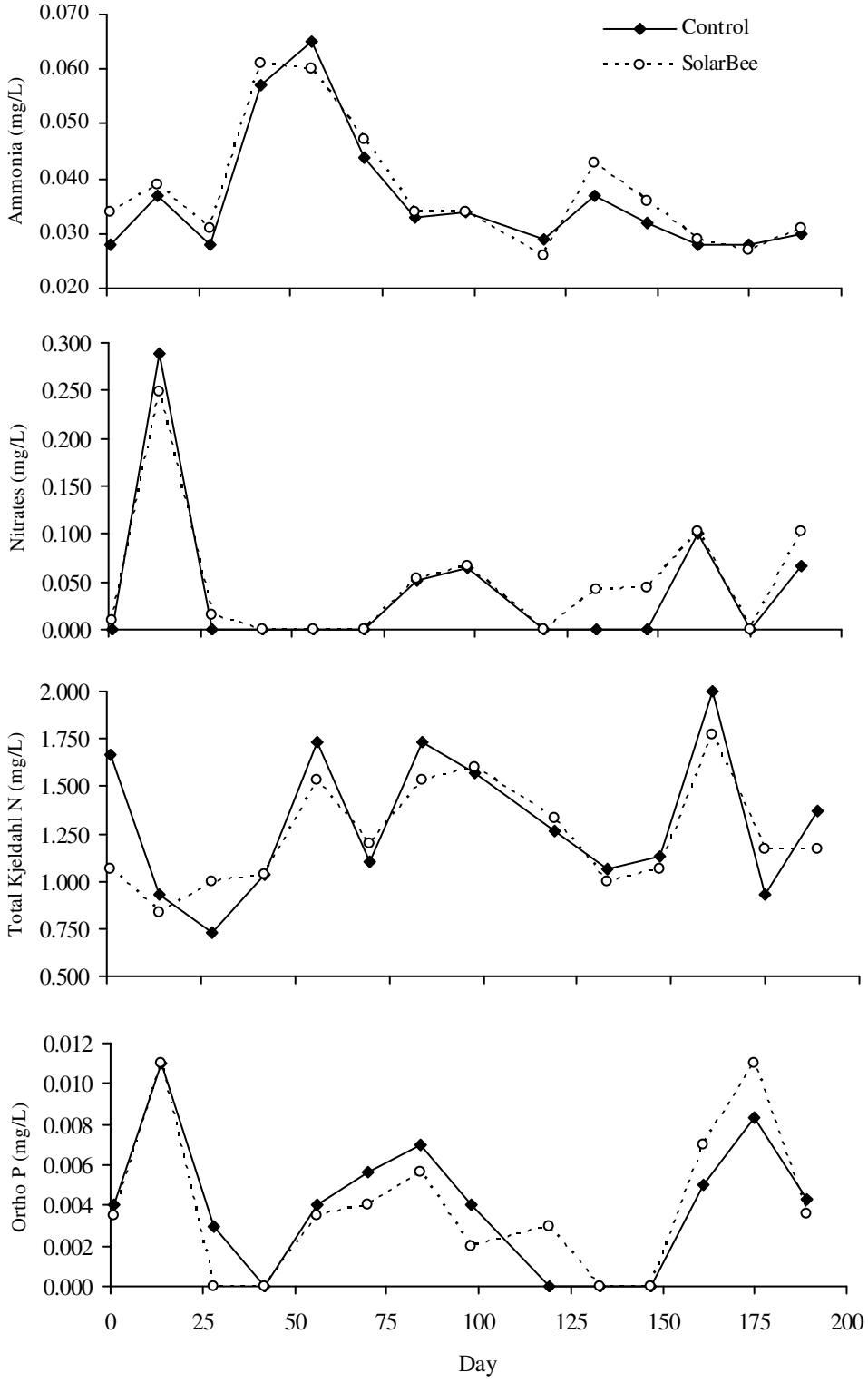

FIGURE 5.—Mean nutrient concentrations in ponds during evaluation of SolarBee® water circulation to control *Prymnesium parvum*. There were no significant differences ($P > 0.05$) between treatment and control.

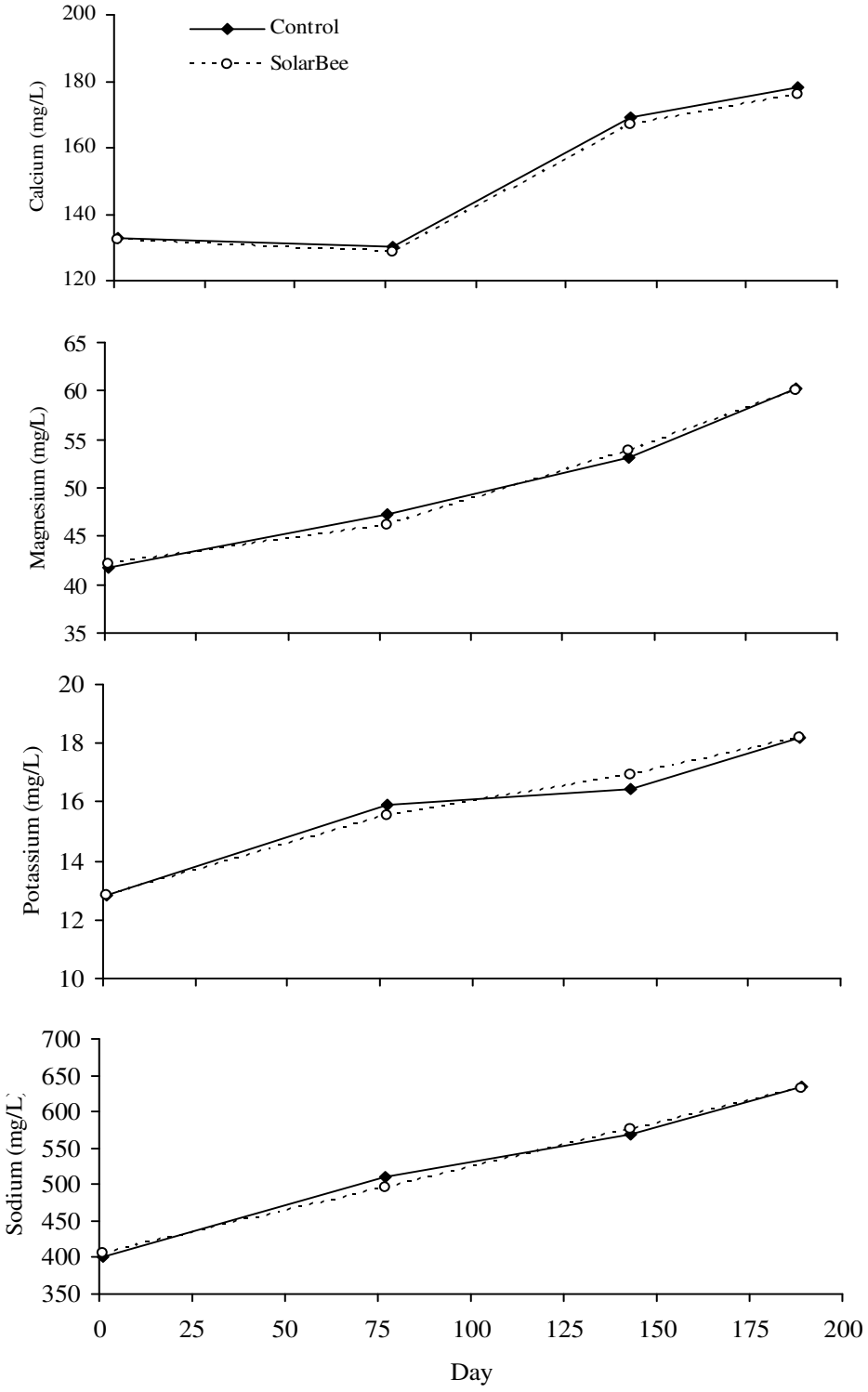

FIGURE 6.—Mean cations concentrations in ponds during evaluation of SolarBee® water circulation to control *Prymnesium parvum*. There were no significant differences ($P > 0.05$) between treatment and control.

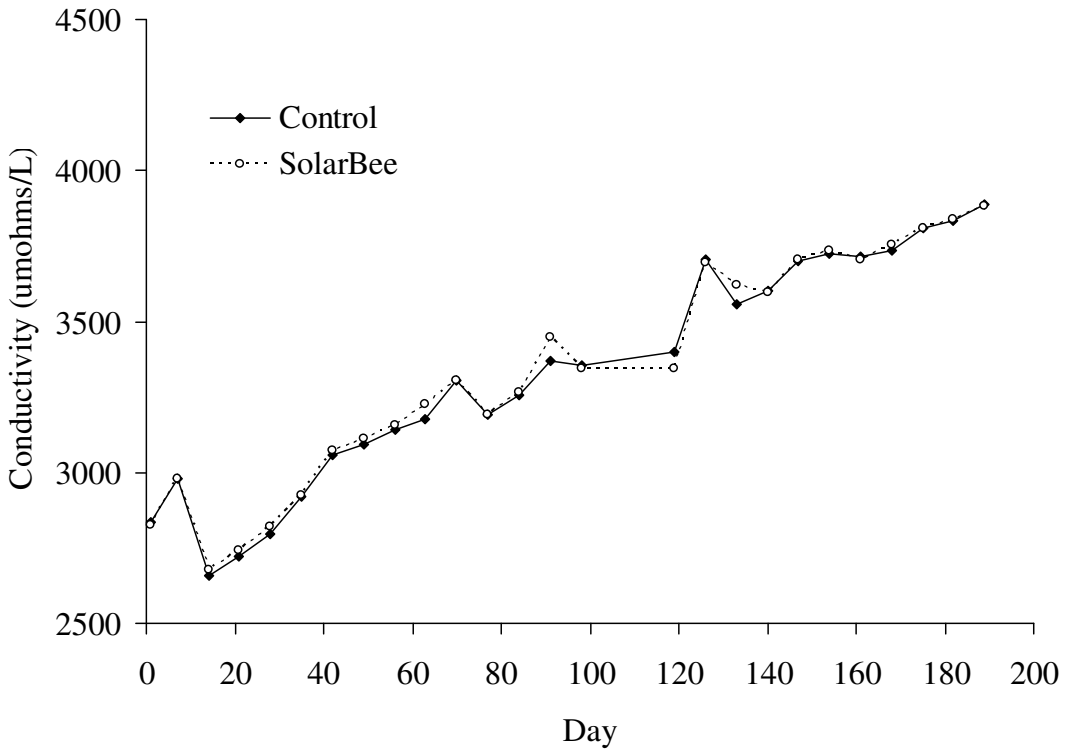

FIGURE 7.—Mean daily conductivity values in ponds during evaluation of SolarBee® water circulation to control *Prymnesium parvum*. There were no significant differences ($P > 0.05$) between treatment and control.

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