Photosynthetic Response of Phytoplankton to Light Intensity in a Southcentral Alaskan Lake

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Photosynthetic Response of Phytoplankton to Changing Light Intensity in a Southcentral Alaskan Lake

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By
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Abstract

Little fresh-water work has been done (compared with published marine studies) using photosynthesis–irradiance (P–I) curves to determine photosynthetic response of natural assemblages of phytoplankton to light above and below thermal stratification structures. Limnological data including physical, chemical, and algal taxonomy and biomass were collected through the summers of 1985 and 1986 at Wasilla Lake, Alaska (approximately 61°N., 148°W.). Algal photosynthesis–irradiance relationships were also determined through the summer of 1986 by means of P–I curves. P–I curve light-limited initial slope (α) was $\approx$2.5 times higher in phytoplankton populations at 6 m than those in the wind-mixed zone when populations were separated by thermal stratification. Wasilla Lake's trophic status was estimated to fall between mesotrophic and eutrophic classifications. Phytoplankton in Wasilla Lake were found to require approximately 4-5 days to best adapt to a changing light environment.

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Introduction

Phytoplankton populations from different light environments commonly show differing photosynthetic response to light intensity as demonstrated in photosynthesis vs. irradiance (P–I) curves (Figure 1) (Steeman-Nielsen and Hansen, 1959; Steeman-Nielsen, 1961; Yentsch and Lee, 1966; Prezelin and Sweeney, 1979; Falkowski and Owens, 1980; Platt et al., 1982). Phytoplankton in the wind mixed zone almost invariably exhibit different P–I curve shapes than populations below the pycnocline (Steeman-Nielsen and Hansen, 1959; Savidge, 1979; Gallegos et al., 1983; Fahnenstiel et al., 1989). Many researchers working with laboratory cultures have found different P–I curve shapes from algae cultured at high and low relative irradiances (Steeman-Nielsen, 1961; Prezelin and Sweeney, 1979; Morris, 1981; Perry et al., 1981). Research findings have often been contradictory, even when laboratory studies are confined to comparisons with other laboratory studies and field studies compared only with other field studies.

In natural phytoplankton populations, a key question to be addressed is whether differences in P–I curves from epilimnetic and subthermocline populations are due to physiological plasticity in a population homogeneous across the thermocline or due to development of taxonomically different populations more competitively suited to the epilimmnion and subthermocline regions. Tilzer and Schwarz (1976), working in a high-latitude Austrian lake, found vertical differences in P–I relationships after the onset of thermal stratification to be mostly

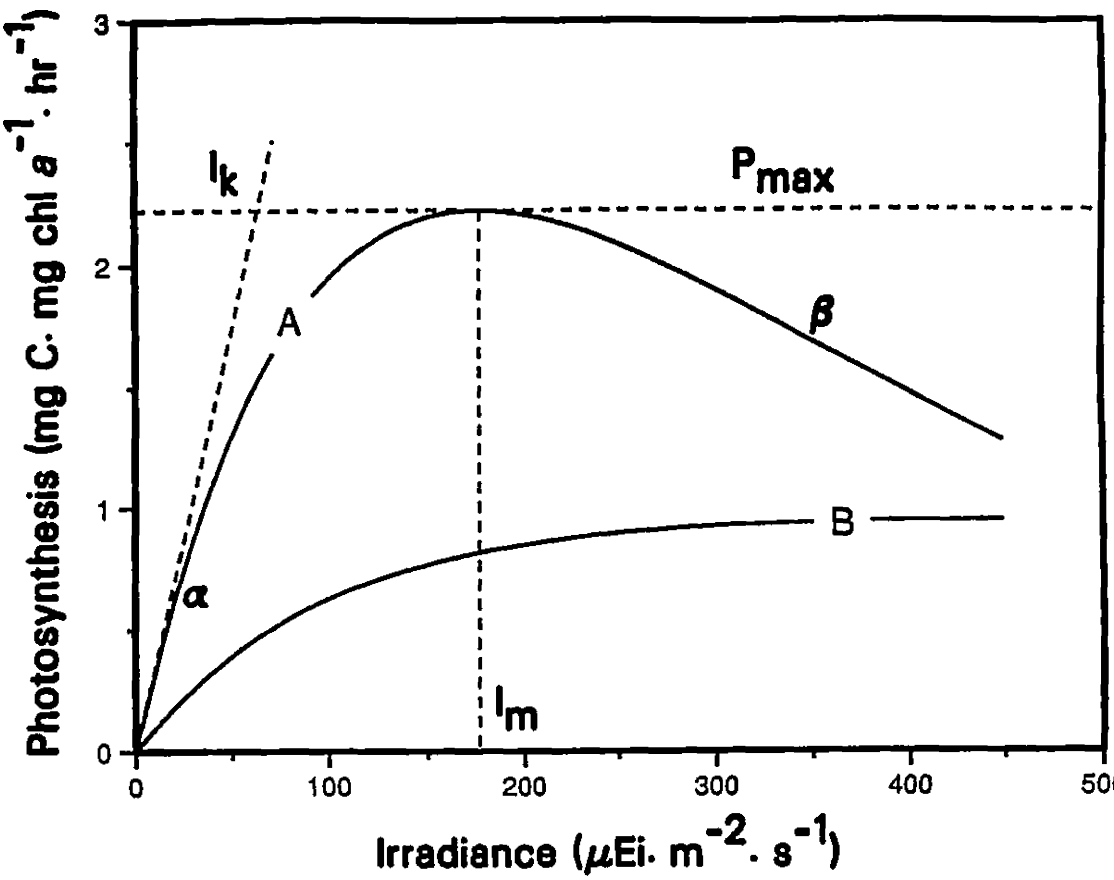

Figure 1. Illustration of photosynthesis–irradiance curves. Photosynthesis parameters illustrated are the initial light-limited slope (α), maximum photosynthetic rate (P_{max}), and slope of the photoinhibited portion of the curve (β). Derived parameters shown are the "adaptation parameter" (I_k, the irradiance at which extrapolations of α and P_{max} intersect) , and the irradiance at which P_{max} is attained (I_m). A– curve showing adaptation to low relative irradiances, B– curve showing adaptation to high relative irradiances.

due to populations of flagellates migrating to a preferred light environment. In the marine environment, changing P–I relationship with depth has been noted with vertically homogeneous algal populations (Platt et al., 1982).

The primary tool used in this study to quantify changing algal photosynthetic response to light intensity was the photosynthesis vs. irradiance (P–I) curve (Fee,

1973; Platt and Jassby, 1976; Platt et al., 1980). A P–I curve consists of three basic parts (Figure 1). The initial slope (α) of the curve indicates the efficiency of the photochemical portion of the photosynthetic machinery– a steeper initial slope indicates more efficient photosynthetic utilization of low light levels and vice versa (Yentsch and Lee, 1966; Parsons et al., 1984). The peak level of the curve, P_{max} (or P_m^B when photosynthesis is normalized to chlorophyll *a* biomass), is limited by the capacity of the "dark reactions" (i.e. carbon reduction and synthesis reactions) to fix carbon using NADPH and ATP generated in the photochemical reactions (Parsons et al., 1984). At the point where the photochemical reactions are producing ATP and NADPH faster than the dark reactions can utilize it in fixing CO_2 into $C_6H_{12}O_6$ and other storage components, P_{max} is reached and the P–I curve is said to be light-saturated (i.e. increased irradiance levels do not increase photosynthetic rate). At irradiances higher than that at which P_{max} occurs, a decrease in photosynthetic rate may occur, known as photoinhibition (β). In the example P–I curves shown in Figure 1, curve **A** shows a higher α than curve **B**, indicating more efficient utilization of low light levels by the algal population represented by curve **A**. Curve **A** also shows significant photoinhibition beyond irradiances of approximately 190 $\mu Ei \cdot m^{-2} \cdot s^{-1}$, in contrast with curve **B** which shows no photoinhibition at incubator irradiances. This indicates the population represented by curve **A** was not photosynthetically adapted to a light environment

in which irradiances exceeded 190 μEi$\cdot$m$^{-2}\cdot$s^{-1}, while the population represented by curve **B** was adapted to such a light environment (Platt et al., 1982).

While published results of photoadaptation studies centering on marine phytoplankton abound, information of this kind for freshwater phytoplankton is meager by comparison (Fahnenstiel et al., 1989). Most of this work has focused on the Laurentian Great Lakes and lakes of the Canadian Shield area. To my knowledge, no photoadaptation studies focused on phytoplankton in Alaskan lakes have been published until now. Phytoplankton adaptation to changes in light environment brought on by thermal stratification and varying cloud cover may be particularly important in high latitude Alaskan lakes in maximizing total lake primary production during the brief ice-free season.

Investigations presented here were carried out at Wasilla Lake, a 151 ha. lake approximately 72 km. (45 mi.) north of Anchorage on the Parks Highway (Figure 2). The lake is within the city limits of Wasilla and is surrounded by dense residential development. The lake was studied previously by the Alaska Department of Environmental Conservation (ADEC) (1983) and the Alaska Department of Fish and Game (ADF&G) (1984, unpublished). ADF&G found moderately high levels of some nutrients. Although this would suggest nutrient enrichment from shoreline residential development, ADEC found no fecal coliform bacteria in its investigation, indicating that sewage was not being discharged directly into the lake at that time. Septic system leaching through groundwater to the lake may

have been responsible for high nutrient levels, however. Wasilla Lake has an east and west basin connected by a short, constricted channel.

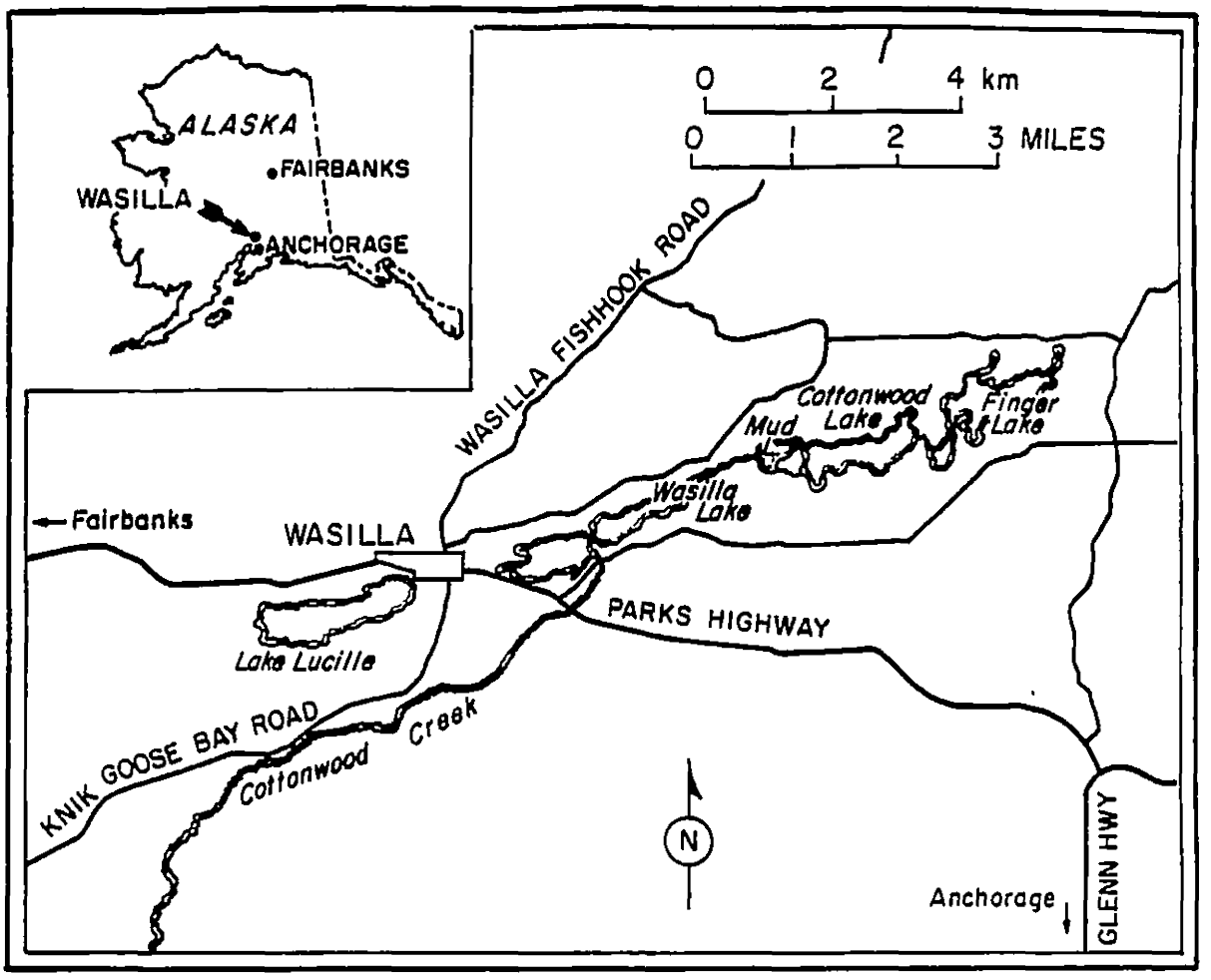

Figure 2. Location of Wasilla Lake.

The lake is fed at its east end by the outflow from Mud Lake (Figure 3), and drains through Cottonwood Creek at the east end of the west basin. The lake's mean depth is 5.2 m, with a maximum depth of approximately 15 m (Figure 3). The east basin is considerably shallower than the west, consequently much of the east basin is covered by macrophytes and *Chara* beds in the summer season.

Because of the close proximity of Wasilla Lake to nearby Wasilla and Palmer as well as Anchorage, it is heavily used for recreation such as water skiing, bathing, and power boating. Wasilla Lake also provides spawning and rearing habitat to sockeye salmon returning through Cottonwood Creek.

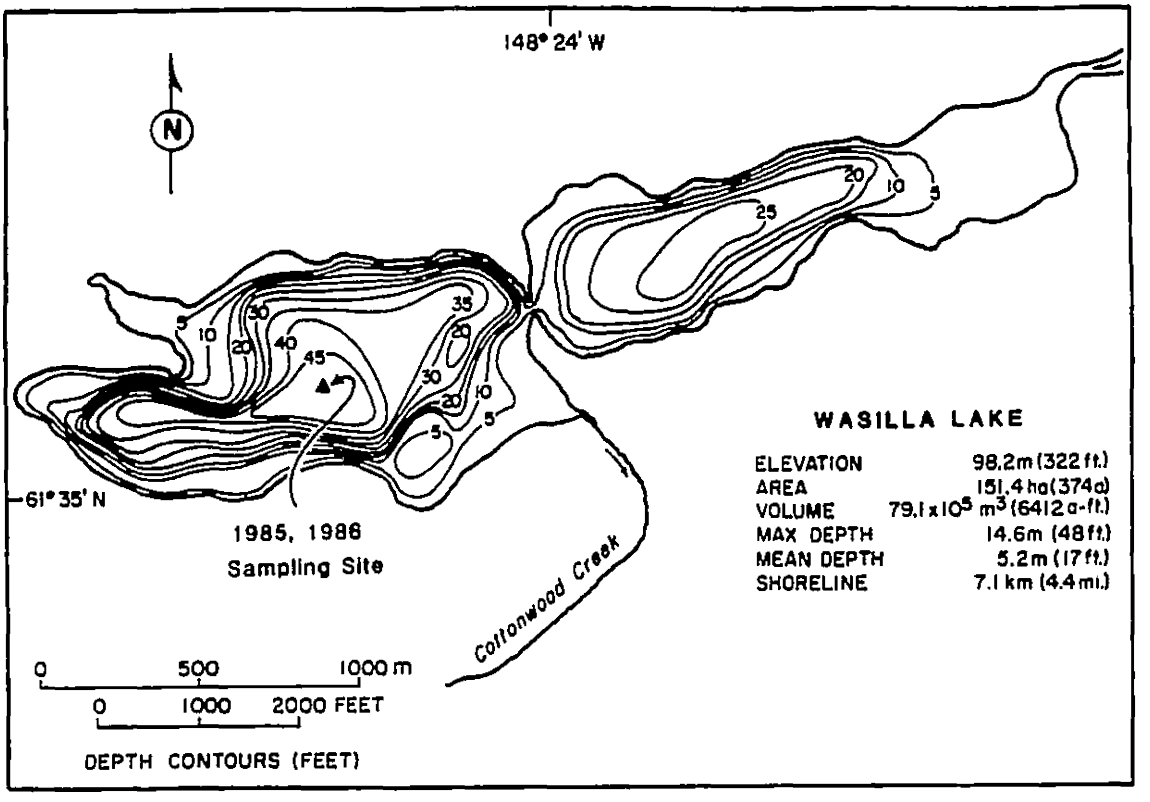

Figure 3. Morphometry of Wasilla Lake. Map and data by: Lebida and Probasco (ADF&G), 8/80.

Because of Wasilla Lake's recreational importance and its use as sockeye salmon rearing habitat, I decided that a rough estimate of trophic status would be important information that could be determined from limnological data already

being collected in this study. Trophic status of lakes has been assessed using several limnological characteristics as indices, including profiles of dissolved oxygen through the water column (Cole, 1983; Wetzel, 1983; Reynolds, 1984), mean annual total phosphorus concentration (Chapra and Reckhow, 1979; Vollenweider, 1979 in Wetzel, 1983;) and mean annual chlorophyll *a* concentration (Vollenweider, 1979 in Wetzel, 1983; Reynolds, 1984).

To learn more about phytoplankton photoadaptation in freshwater systems, a study was designed and initiated to quantitatively document photoadaptation and the primary variables influencing it. The primary objectives of the study were:

1. To determine the extent that P–I curve differences between epilimnetic and metalimnetic phytoplankton populations are influenced by differences in previous light history, algal taxonomic composition, temperature, and nutrients.

2. To estimate the time period needed for phytoplankton to adapt photosynthetically to a changing light environment.

3. To determine the probable trophic status of Wasilla Lake from data collected in pursuit of objectives one and two.

Methods and Materials

1985 Investigations

Five sampling trips were made to Wasilla Lake at approximately 3 week intervals between 19 May and 21 August, 1985. The lake was accessed by a 6.7 m (22 foot) flat-bottomed aluminum boat with a 45 h.p. outboard motor. A single sampling station was established at approximately the deepest point of Wasilla Lake's western basin (Figure 3). All sampling in the 1985 and 1986 seasons was carried out from this station. Sampling and *in situ* bottle incubations for diel primary productivity estimates in the 1985 season typically began approximately at 12 noon and continued until 12 noon the following day.

Physical and chemical limnology

Immediately prior to each 6-hour incubation period, temperature (°C), pH, conductivity, and dissolved oxygen data were collected at 0.5 m intervals through the water column with a Hydrolab multi-parameter water quality meter. Water samples were collected with a 9-L opaque polyvinylchloride (PVC) Kemmerer sampler. Aliquots for chlorophyll *a*, and dissolved inorganic carbon (DIC) measurements and ^{14}C uptake incubations were drawn from the same sample volume for each depth sampled. Aliquots for DIC analysis (300-mL) were refrigerated approximately 24 hours until analysis with a Horiba infrared carbon analyzer could be carried out at the U.S. Geological Survey (Water Resources Division) Laboratory in Anchorage. Alkalinity titration (potentiometric method) in conjunction

with *in situ* temperature and pH were used as an alternative method to estimate DIC (Wetzel and Likens, 1979).

Photosynthetically active radiation (PAR) was measured in hourly integrals ($Ei \cdot m^{-2} \cdot hour^{-1}$) through the sampling session by means of a Licor LI-1776 recording solar monitor with 2π sensor placed on a flat rooftop near the south shore of Wasilla Lake. A Licor LI-188 quantum radiometer/photometer with a Licor underwater spherical sensor was used to measure irradiance through the water column immediately prior to each incubation period. Extinction coefficients obtained from water column irradiance profiles were averaged to obtain a mean extinction coefficient for each date.

Chlorophyll a distribution

Aliquots of 250–500 mL were drawn from each sample for chlorophyll *a* analysis. Samples were filtered onto 0.7 μm effective pore size glass fiber filters and frozen immediately for later extraction. Extraction in 90% aqueous acetone was carried out by grinding filters with a teflon tissue grinder in a glass grinding flask, followed immediately by centrifugation to precipitate filter particles. Chlorophyll *a* concentration was determined by fluorometry immediately after centrifugation, using a Turner Designs Fluorometer calibrated to U.S. Environmental Protection Agency chlorophyll *a* check samples.

Diel photosynthesis studies

In the 1985 field season, diel *in situ* photosynthesis estimations were made throughout the euphotic zone (assumed to extend to the 1.0% surface light depth) to determine the daily pattern of primary production and how that pattern might change with varying daily irradiance regime. Four six-hour *in situ* incubation periods made up each diel sampling session. Groups of two light/one dark 125-mL B.O.D. bottles were suspended at four depths through the euphotic zone (1 m, 3 m, 5 m, and 7.5 m) in order to estimate integral photosynthesis. To prepare a stock volume of $NaH^{14}CO_3$, several 2.0-mL sealed ampoules of $NaH^{14}CO_3$ were broken and the contents emptied into a clean centrifuge flask, from which injection volumes were drawn. Incubation bottles were injected with approximately 74 kBq of $NaH^{14}CO_3$ immediately prior to incubation. After six hours had elapsed, bottle sets were retrieved and each bottle injected with 0.5 mL of Lugol's Acetate to kill phytoplankton and prevent further ^{14}C uptake. Additionally, at the time of $NaH^{14}CO_3$ injection, a "zero-time blank bottle" was prepared with each bottle set by first injecting 0.5 mL Lugol's Acetate, then 74 kBq $NaH^{14}CO_3$, in order to estimate particulate ^{14}C not due to photosynthetic uptake.

After retrieval and injection with Lugol's Acetate to terminate uptake, incubation bottles were refrigerated several days until filtration could be carried out. Aliquots of 100 mL from each incubation bottle were filtered onto 0.7μm effective pore size glass fiber filters under vacuum not exceeding 30 cm Hg. Uptake was

measured by liquid scintillation counting by the Alaska Department of Fish and Game Limnology Laboratory, Soldotna, Alaska.

1986 Investigations

In the 1986 field season, samples from the wind mixed zone (taken as the upper, isothermal zone of the water column) and from 6 m were collected through the summer season to compare photosynthetic response to light intensity for populations at these depths. Wasilla Lake was accessed by means of a Coleman square-sterned canoe with a 4 h.p. outboard motor.

Sampling trips were made 19 May, 8 June, 30 June, 21 July, 13 August and 22 September. Samples were collected at the station established in 1985. Samples from the wind-mixed zone were collected with an inexpensive integrating sampler constructed at the University of Alaska Fairbanks. The integrating sampler consisted of a 3.87 L (1 gal.) glass juice jug painted with a layer of black latex, then covered with duct tape to insure opaqueness. A cord harness was fitted around the jug so that a weight attached to the harness would hang from the center of the jug's base. A calibrated line was attached to the neck of the sampler by a carabiner. The sampler was lowered and raised at a uniform rate through the wind-mixed zone until full to get an integrated sample of the epilimnion. Samples from 6 m were collected the following day with a 9-L opaque PVC Kemmerer sampler. Triplicate samples were collected just before dawn to ensure that phytoplankton populations collected on all dates experienced approximately the same

light history in the several hours previous to sampling. This prevented possible confusion as to whether phytoplankton showed adaptation on a diel basis to the previous several hours light history (MacCaull and Platt, 1977; Harding et al., 1981; 1982; Rivkin and Putt, 1987) or to relatively long-term irradiance environment changes (e.g. changed irradiance environment due to onset of thermal stratification or changing daily incident irradiance).

Samples were stored in a darkened ice chest for transport to the U.S. Geological Survey (Water Resources Div.) Laboratory in Anchorage. In the laboratory, each sample was transferred to a 9-L teflon churn. Churns were agitated gently to ensure sample homogeneity before drawing off aliquots for ^{14}C uptake incubation volumes, chlorophyll *a*, nutrient, and algal taxonomy samples.

Physical and chemical limnology

Just prior to each sample collection, pH, dissolved oxygen, conductivity and temperature (°C) were measured at 0.5 m intervals through the water column, using a Hydrolab multi-parameter water quality meter. Alkalinity was measured by the potentiometric method. DIC was estimated by comparing alkalinity, and *in situ* temperature, and pH to tabulated values (Wetzel and Likens,1979). Aliquots for alkalinity titration were drawn from each sample volume before samples were transferred to churns to prevent entrainment of atmospheric CO_2 in alkalinity aliquots.

Chlorophyll a distribution

Filtration and extraction procedures for chlorophyll *a* analysis in general followed procedures used in 1985. One liter of sample water was filtered, with approximately 1 mL saturated $MgCO_3$ solution added to ensure an alkaline filter environment. Filters were frozen over dessicant immediately after filtration. Chlorophyll *a* analysis was by fluorometry after the method of Wetzel and Likens (1979), using a Turner Designs fluorometer.

Nutrient concentrations

Nutrient analysis was carried out for total and filtrable reactive forms of phosphorus (TP, FRP, respectively) and total Kjeldahl, nitrate and ammonium nitrogen (TKN, NO_3^--N, and NH_4^+-N, respectively). All aliquots (200 mL) for nutrient analysis were placed in acid rinsed (10% HCl) plastic bottles and immediately frozen. Aliquots for soluble nutrient analysis were filtered through 0.45 μm membrane filters before freezing. Nutrient analysis was carried out by the ADF&G Limnology Laboratory in Soldotna, Alaska. Data were ranked and analyzed by MANOVA anlaysis (Conover and Iman, 1981) for differences across date and depth, using a computer statistical package (SAS 3.0). Those nutrient characteristics that showed significant ($P<0.05$) interaction terms in MANOVA analysis were analyzed further by an equivalent of Fisher's protected least significant difference test (lsmeans, SAS 3.0) to determine dates when concentration differences between depths may have been significant.

Algal taxonomic composition

Aliquots of 200 mL were also collected from each replicate sample for determination of phytoplankton taxonomic composition and preserved with Lugol's Acetate according to Standard Methods for the Examination of Water and Wastewater (APHA, 1985) for later viewing. Phytoplankton were identified to genera and enumerated using an inverted microscope with 40X objective and 5-mL settling chambers. Twenty fields were viewed in each 5-mL settling chamber, corresponding to randomly generated grid coordinates (Minitab 6.1). Biovolume of algal cells was estimated by two methods:

1. Approximation of cells or filaments to three dimensional figures (cylinder, trapezoid, sphere, etc.) for phytoplankton such as bluegreen filaments, spherical green algae, and roughly trapezoidal diatoms such as *Asterionella* spp.

2. For irregular shapes (e.g. pennate diatoms such as *Synedra* or *Navicula* spp.) digitized integration of scaled illustrations were used to find "c" in the equation:

$$A = LWc$$

$$\begin{aligned} where: A &= cell\ surface\ area,\ one\ side \\ L &= cell\ length \\ W &= maximum\ cell\ width \\ c &= constant\ derived\ by\ substituting\ digitized \\ &\quad surface\ area\ for\ A \end{aligned}$$

Area was multiplied by average cell depth to find volume.

Average length, width, and depth of cells were determined through the inverted microscope with a scaled ocular micrometer. Relative biovolume data for each major algal division were ranked and analyzed by MANOVA analysis and

Fisher's protected least significant difference test as above in *Nutrient concentrations.*

Trophic status of Wasilla Lake

To estimate the trophic status of Wasilla Lake, dissolved oxygen profiles from the 1985 and 1986 seasons were reviewed for the possible condition of hypolimnetic anoxia, an important indicator of eutrophy (Cole, 1983; Wetzel, 1983; Reynolds, 1984). Mean chlorophyll *a* concentration through the euphotic zone for the 1985 summer season was compared to a predictive index that used chlorophyll *a* concentration to classify lakes by trophic state. Mean total phosphorus concentration in Wasilla Lake was estimated using data from the three dates in the 1986 season on which thermal stratification was shallower than 6 m. To determine the lake's mean total phosphorus concentration on each date, the sample from the wind mixed zone was used to estimate total phosphorus above the thermocline; the 6 m sample was used to estimate total phosphorus below the thermocline. Weighted means for each date were computed using the volume of water above and below the thermocline as the weighting factor. Algal taxanomic composition was also examined as an indicator of trophic status (Reynolds, 1984).

Photosynthesis-irradiance relationships

Photosynthetic response to graded light intensities was measured by the ^{14}C uptake method in a water filled incubator (Fee, 1973). Thirty 60-ml screw cap incubation bottles (two for each sample for each of 5 light levels) were filled and injected

with $NaH^{14}CO_3$ for photosynthesis–irradiance (P–I) experiments. Approximately 74 kBq $NaH^{14}CO_3$ was injected into incubation bottles in sampling trips through 30 June, 1986. Because of particulate ^{14}C contamination discovered in this ^{14}C source, a different ^{14}C source was used beginning 21 July, 1986. Approximately 37 kBq was delivered to incubation bottles from this ^{14}C source (see Results–*1985 Diel Photosynthesis Studies*). Two incubation bottles from each triplicate sample were attached to 5 plexiglass wheels evenly spaced in a water filled incubator similar to that of Shearer et al. (1985). Fine mesh screens were used as neutral density filters to achieve desired irradiance at each plexiglass wheel. Irradiance at each wheel was measured with a Licor LI-188 quantum radiometer/photometer with a Licor underwater spherical sensor. Incubator water temperature was maintained at *in situ* temperature ± 2°C. Because of the need to maintain incubator temperature at near *in situ* (Steeman-Nielsen and Jorgensen, 1968; Harris, 1973) to avoid temperature influence on P–I curves, samples from the wind mixed zone and 6 m were collected and run through the incubator on two consecutive days, as these two samples had quite different *in situ* temperatures when separated by the thermocline. The plexiglass wheels of the incubator were rotated by a small electric motor at slow speed to simulate turbulence in the water column and ensure even illumination of all incubation bottles. After an incubation period of approximately 3 hours, incubation bottles were placed in a darkened ice chest and

filtered within 2 hours. Entire contents of bottles were filtered onto 0.30 μm effective pore size glass-fiber filters, under vacuum not exceeding 30 cm Hg. Filters from the 19 May sampling trip were rinsed with 60-mL of filtered lake water to purge unfixed $NaH^{14}CO_3$. After this date, filters were placed in glass scintillation vials, then acidified with 0.30 mL 0.50 N HCl, and placed under a fume hood for approximately 2 hours to drive off unfixed $NaH^{14}CO_3$, and 10 mL scintillation cocktail added (Lean and Burnison, 1979). Scintillation cocktail used was made up of 2 L Toluene, 1 L Triton X-100, and 8 g Omnifluor. "Zero-time blank bottles" were prepared by filling one incubation bottle from each sample, injecting with $NaH^{14}CO_3$ and filtering immediately. A triplicate estimate of total disintegrations per minute (DPMs) delivered to incubation bottles was prepared for each experiment by injecting the volume of $NaH^{14}CO_3$ normally added to incubation bottles (0.10 mL) directly into glass scintillation vials with 10 mL scintillation cocktail. Uptake was measured by liquid scintillation counting on a Beckman LS-1000 liquid scintillation counter.

Photosynthesis was estimated by the formula:

$$P^B = \frac{\overline{x}DPM_{LB} - \overline{x}DPM_B(DIC)(1000)1.06}{\overline{x}DPM_T(T)(B)}$$

$$\begin{aligned}
where: \quad P^B &= photosynthesis\ normalized\ to\ biomass\ (chlorophyll\ a) \\
\overline{x}DPM_{LB} &= mean\ (n=6)\ of\ light\ bottle\ DPM\ counts \\
\overline{x}DPM_B &= mean\ (n=3)\ of\ blank\ bottle\ DPM\ counts \\
1.06 &= isotope\ discrimination\ factor \\
1000 &= conversion\ factor\ from\ liters\ to\ m^3 \\
\overline{x}DPM_T &= mean\ (n=3)\ estimates\ of\ total\ DPMs\ delivered \\
T &= incubation\ time\ (hours) \\
B &= biomass,\ taken\ as\ chlorophyll\ a\ (mg \cdot m^{-3}) \\
DIC &= dissolved\ inorganic\ carbon\ (mg \cdot L^{-1})
\end{aligned}$$

Dark bottle uptake was not accounted for in photosynthesis calculations, thus "photosynthesis" as reported here should be considered gross photosynthesis.

Because of concern by some researchers (Arthur and Rigler, 1967; Lean and Burnison, 1979) of possible cellular rupture on filters at high filtration volumes due to head pressure above the filter, a "filter artifact detection" (Lean and Burnison, 1979) experiment was conducted. A surface water sample was collected on 2 July from Wasilla Lake and refrigerated until 9 July when laboratory analyses could be carried out at the Water Research Center, University of Alaska Fairbanks. Five 125-mL B.O.D. bottles were injected with approximately 37 kBq each and incubated at lab light and temperature for several hours. At the end of the incubation period, samples were pooled in a large beaker and placed in a darkened container until filtrations were complete. Triplicate volumes of 20, 30, 40, 50 and 60 mL were

filtered onto 0.30 μm effective pore size glass fiber filters. Filters were acidified and uptake measured by liquid scintillation counting as above. Mean DPM counts of filters from each volume were plotted against volume filtered to determine if cellular rupture was taking place at the higher filtration volumes, indicated by declining line slope at higher filtration volumes (Lean and Burnison, 1979).

The filter artifact determination experiment showed a linear relationship of DPMs per filter plotted against filtration volume, with no decline in slope at higher filtration volumes ($y = 11.72x - 53.8$, $r^2 = 0.90$). This indicates that cellular rupture was not taking place at the 60 mL incubation volumes being filtered.

Photosynthetic response by phytoplankton to the incubator irradiances experienced was expressed as mgC·mgChl $a^{-1} \cdot$ hour^{-1} and plotted against photosynthetically active radiation (PAR) in a P–I curve.

Data were fit to the equation:

$$P^B = P_s^B(1 - e^{-\alpha I/P_s^B})e^{-\beta I/P_s^B}$$

$$\begin{aligned} where: P^B &= actual\ photosynthesis,\ normalized\ to\ chl\ a \\ P_s^B &= potential\ photosynthesis,\ with\ nonexistent\ photoinhibition \\ \alpha &= slope\ of\ curve\ at\ light\ limiting\ irradiances \\ \beta &= slope\ of\ photoinhibited\ portion\ of\ curve \\ I &= PAR(\mu Ei \cdot m^{-2} \cdot s^{-1}) \end{aligned}$$

(Platt et al., 1980) by means of an iterative least squares curve-fitting computer program that simultaneously solved for the combination of α, β and P_s^B

values that produced the curve best fitting actual data points. Additional parameters derived from the above relationship included:

$$P_m^B = P_s^B \left(\frac{\alpha}{\alpha+\beta}\right)\left(\frac{\beta}{\alpha+\beta}\right)^{\beta/\alpha}$$
$$I_k = P_m^B/\alpha$$
$$I_m = P_s^B/\alpha \; ln\left(\frac{\alpha+\beta}{\beta}\right)$$

where: P_m^B = *maximum* P^B
I_k = *irradiance at which extrapolated slope* α *and asymptote* P_m^B *intersect*
I_m = *irradiance at onset of photosaturation*

Algal adaptation response time

To estimate time required by phytoplankton to best adapt to changing light environment, P–I parameters were regressed on mean epilimnetic irradiance prior to sample collection in time-series analysis. Hourly integrations of surface PAR ($Ei \cdot m^{-2} \cdot hour^{-1}$) were recorded continuously through the summer season at the same rooftop station as 1985 at Wasilla Lake using a Licor LI-1776 solar monitor with 2π sensor connected to a cassette tape recorder. A similar PAR recording station was set up on the roof of the U.S.G.S. building in Anchorage as a backup recorder in the event the Wasilla Lake recording station should malfunction. PAR through the water column profile was measured with a Licor LI-188 quantum radiometer/photometer and spherical sensor to estimate extinction coefficients each sampling trip. PAR was estimated at 0.5 m intervals through the wind-mixed

zone for each hour through the 18 day period preceding sampling, using surface PAR records and extinction coefficients. P–I curve parameters α, I_k, and P_m^B were regressed on mean epilimnetic PAR in time-series analysis. Time periods previous to sample collection over which mean epilimnetic irradiance was computed ranged from 1 to 18 days. Coefficient of determination from time-series analyses were plotted against time period to graphically show where peak r^2 values occurred, indicating the time period phytoplankton required to best adapt to changing irradiance regime.

Hourly PAR integration data from the Wasilla Lake recording station was lost for the approximately 5 week period between 13 August and 22 September due to a recorder malfunction. PAR data from the Anchorage recording station was used in calculation of mean epilimnetic PAR over this time period in place of PAR data from the Wasilla Lake recording station. A correlation of PAR values from the Wasilla Lake and Anchorage stations over a 30 day period yielded an r^2 value of 0.81 ($y= 0.96x + 0.11$, $r^2= 0.81$, appendix C).

Results

Physical and Chemical Limnology

Dissolved oxygen concentration through the water column showed a clinograde distribution soon after ice-out, turning to a positive heterograde distribution (Cole, 1983) after stable stratification developed in mid to late June (Figures 4–14). As early as 22 May, 1985, marked oxygen depletion in the water column was evident, beginning at 7 m (Figure 4), at the base of the thermocline. During July and August of both 1985 and 1986, the bottom 4–6 m of the water column was anoxic. This represents approximately 28–43% of the water column total depth at the sampling station in the west basin. Volume of anoxic water in the west basin cannot be estimated, as sampling was only carried out at one station. Profiles of pH through the water column during the period of stratification showed relatively high pH in both 1985 and 1986 seasons (pH$\approx$ 8.5–9.0) through the wind-mixed zone and metalimnion to the base of the euphotic zone (taken as the depth to 1% surface light penetration), falling rapidly to 7.5–7.0 below the euphotic zone. Thermal stratification and the anoxic hypolimnion were nearly eliminated through wind-mixing by mid to late September.

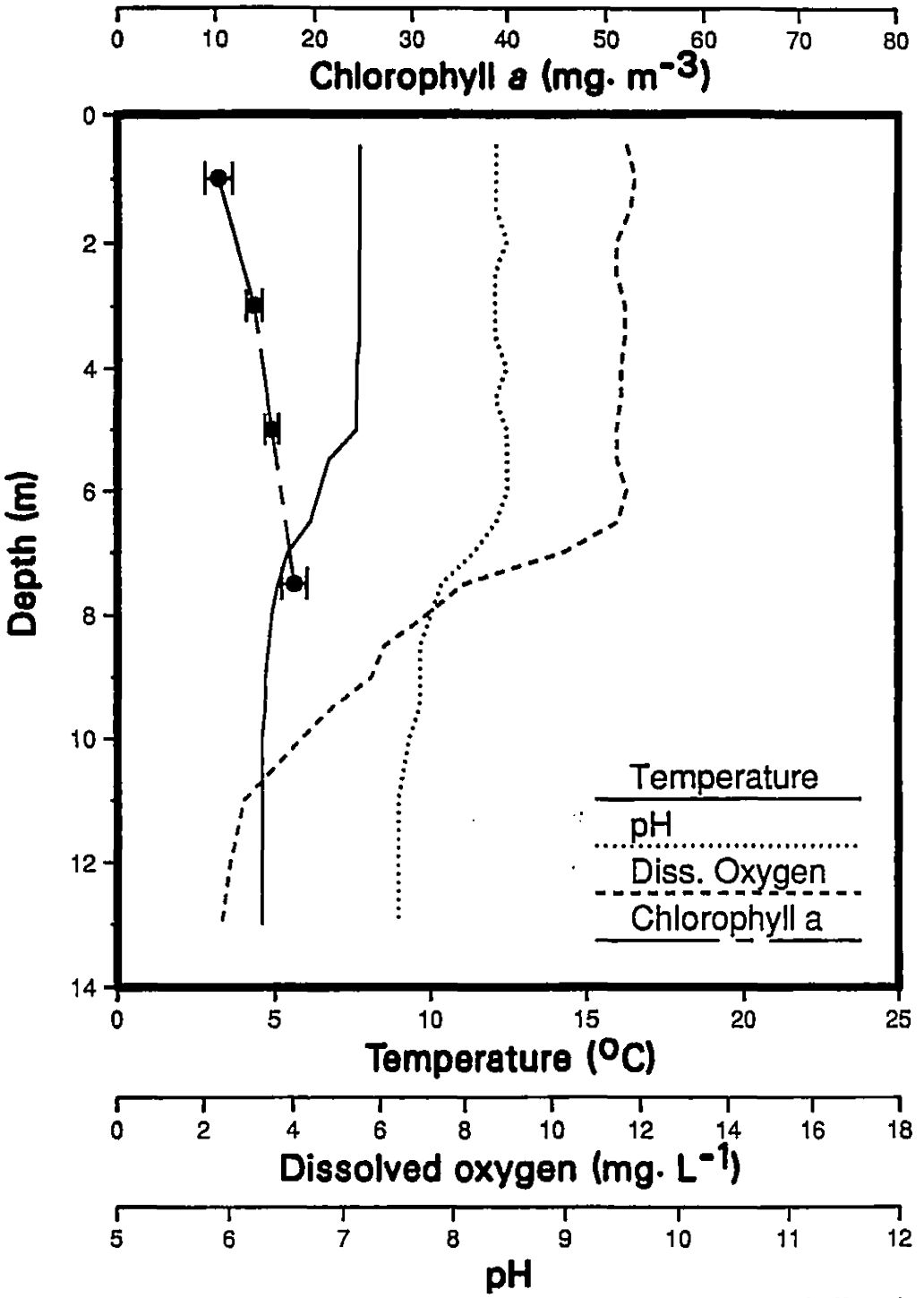

Figure 4. Plot of temperature, pH, dissolved oxygen, and chlorophyll *a* through the water column on 22 May, 1985. Chlorophyll *a* means are average of 4 measurements every six hours, error bars represent ± one standard error about the mean. Temperature, pH, and dissolved oxygen measured at approximately 1800 hrs.

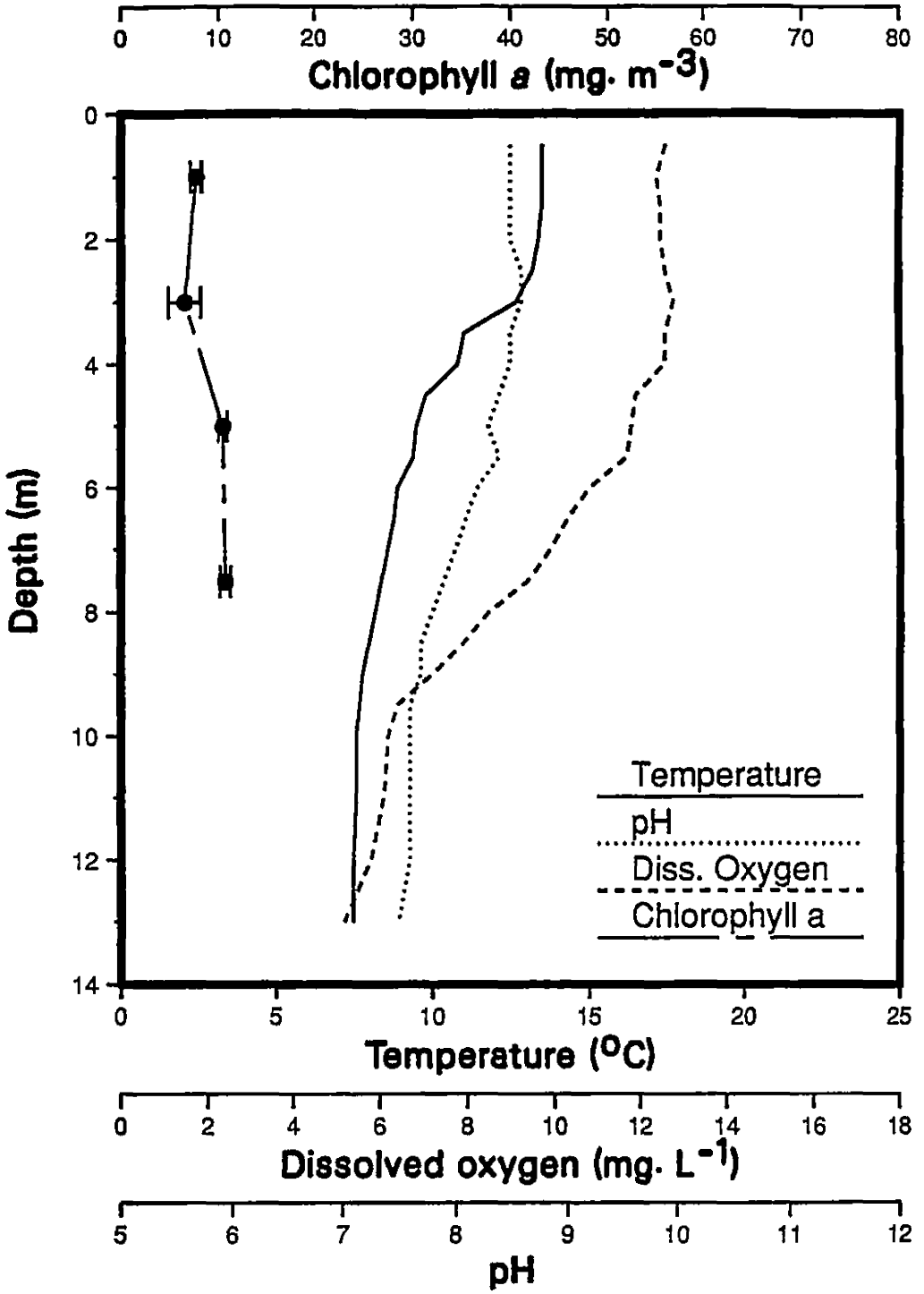

Figure 5. Plot of temperature, pH, dissolved oxygen, and chlorophyll *a* through the water column on 11 June, 1985. Chlorophyll *a* means are average of 4 measurements every six hours, error bars represent ± one standard error about the mean. Temperature, pH, and dissolved oxygen measured at approximately 1800 hrs.

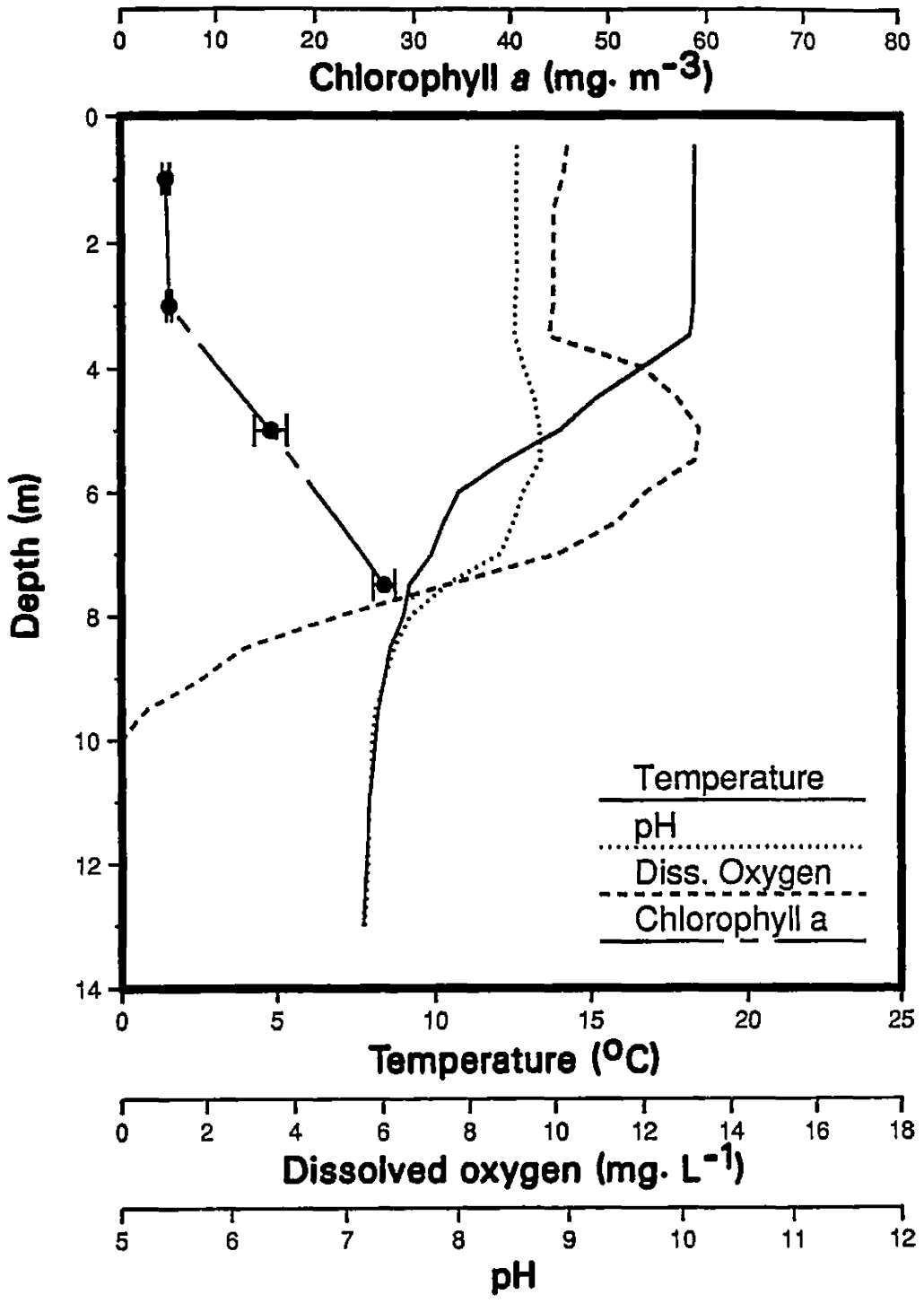

Figure 6. Plot of temperature, pH, dissolved oxygen, and chlorophyll *a* through the water column on 8 July, 1985. Chlorophyll *a* means are average of 4 measurements every six hours, error bars represent ± one standard error about the mean. Temperature, pH, and dissolved oxygen measured at approximately 1800 hrs.

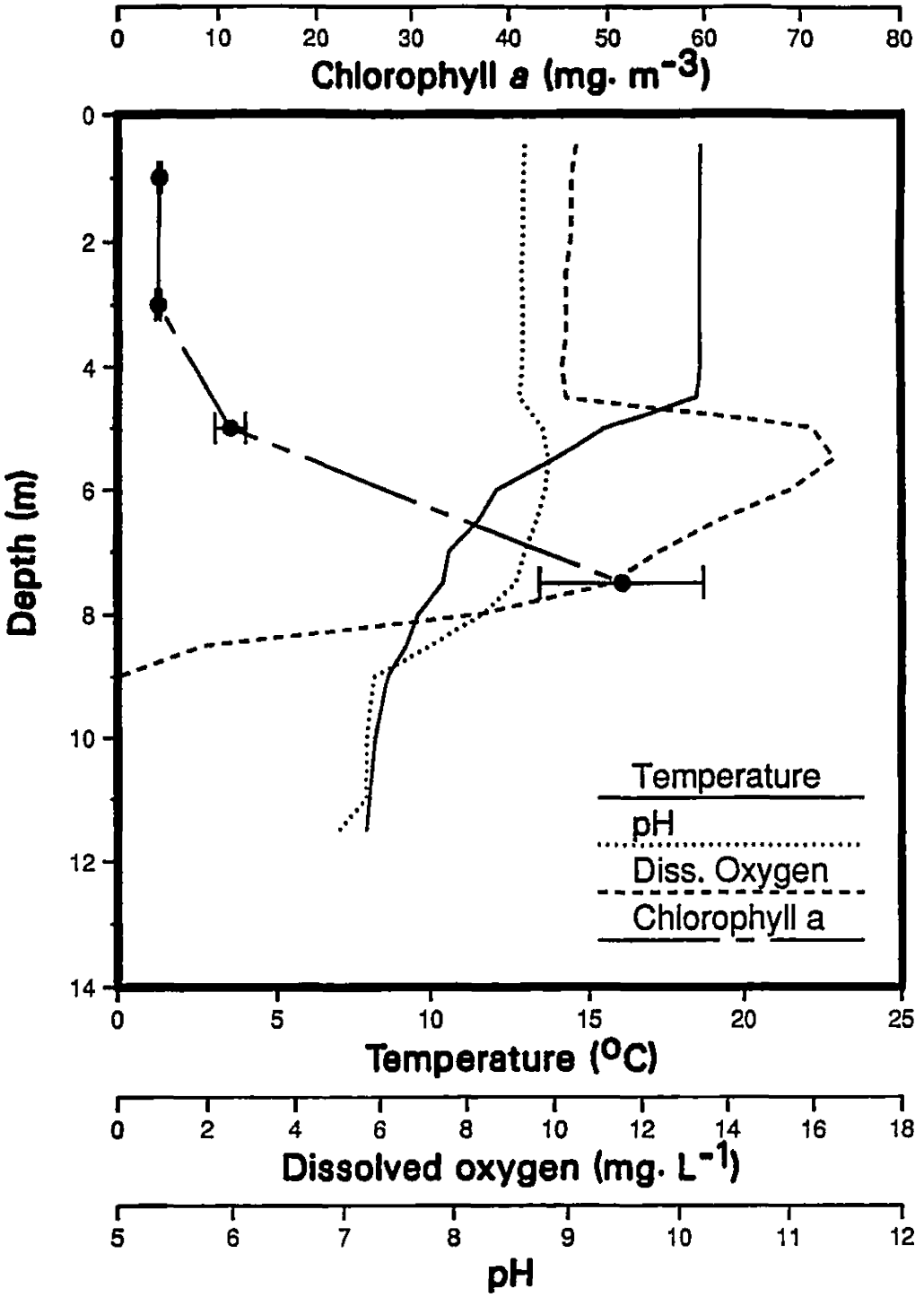

Figure 7. Plot of temperature, pH, dissolved oxygen, and chlorophyll *a* through the water column on 24 July, 1985. Chlorophyll *a* means are average of 4 measurements every six hours, error bars represent ± one standard error about the mean. Temperature, pH, and dissolved oxygen measured at approximately 1800 hrs.

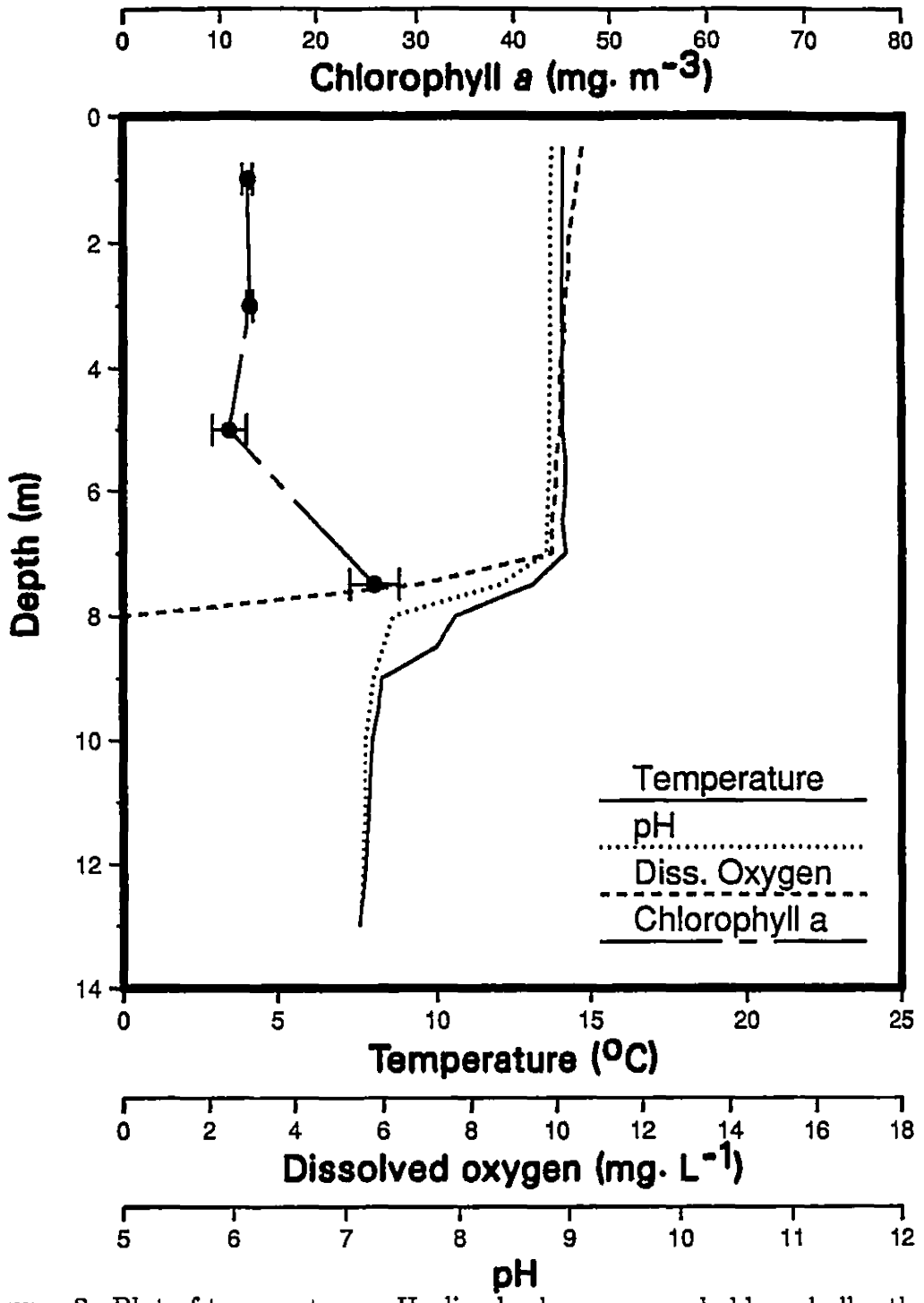

Figure 8. Plot of temperature, pH, dissolved oxygen, and chlorophyll *a* through the water column on 21 August, 1985. Chlorophyll *a* means are average of 4 measurements every six hours, error bars represent ± one standard error about the mean. Temperature, pH, and dissolved oxygen measured at approximately 1800 hrs.

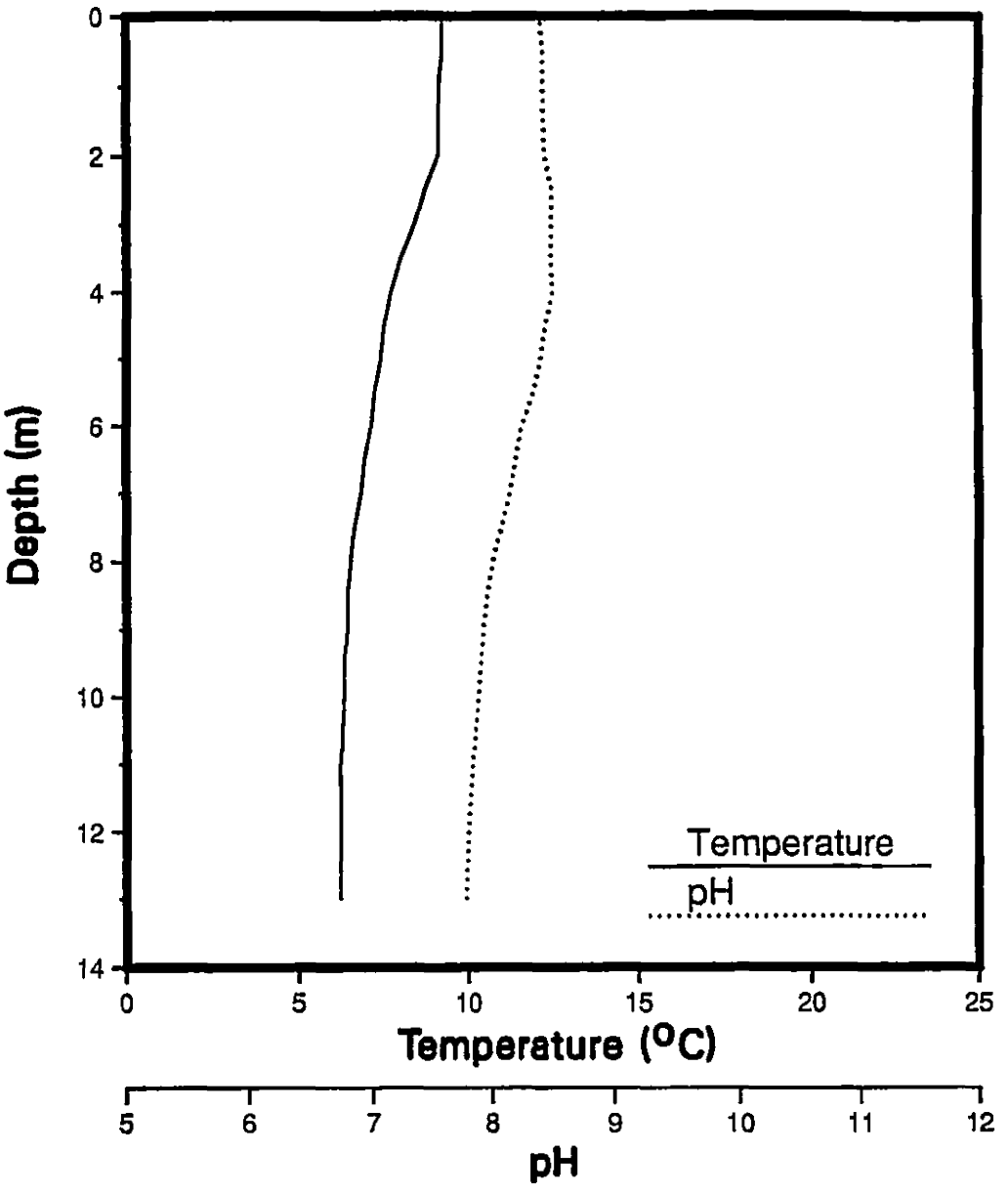

Figure 9. Plot of temperature and pH through the water column on 20 May, 1986.

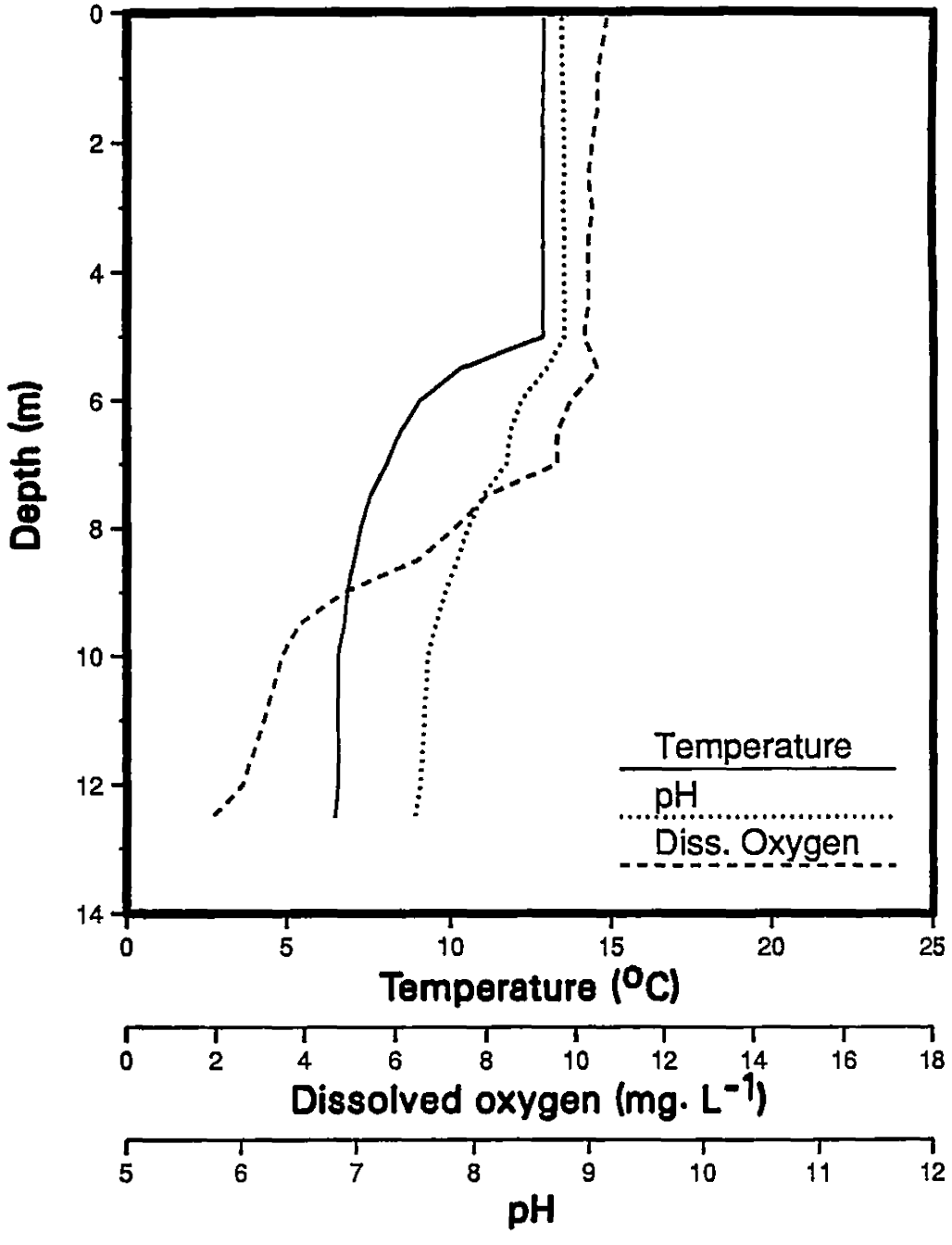

Figure 10. Plot of temperature, pH, and dissolved oxygen through the water column on 8 June, 1986.

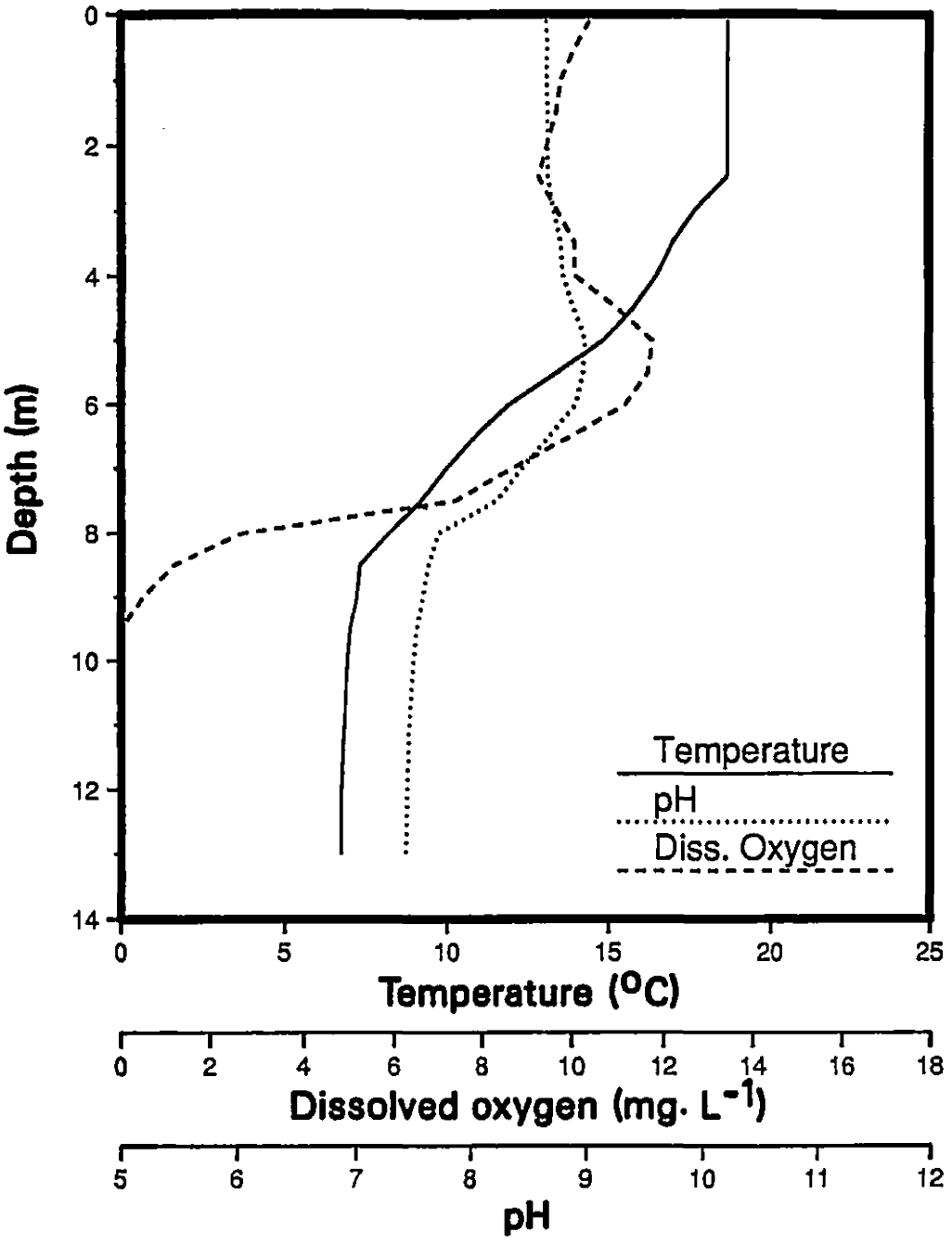

Figure 11. Plot of temperature, pH, and dissolved oxygen through the water column on 30 June, 1986.

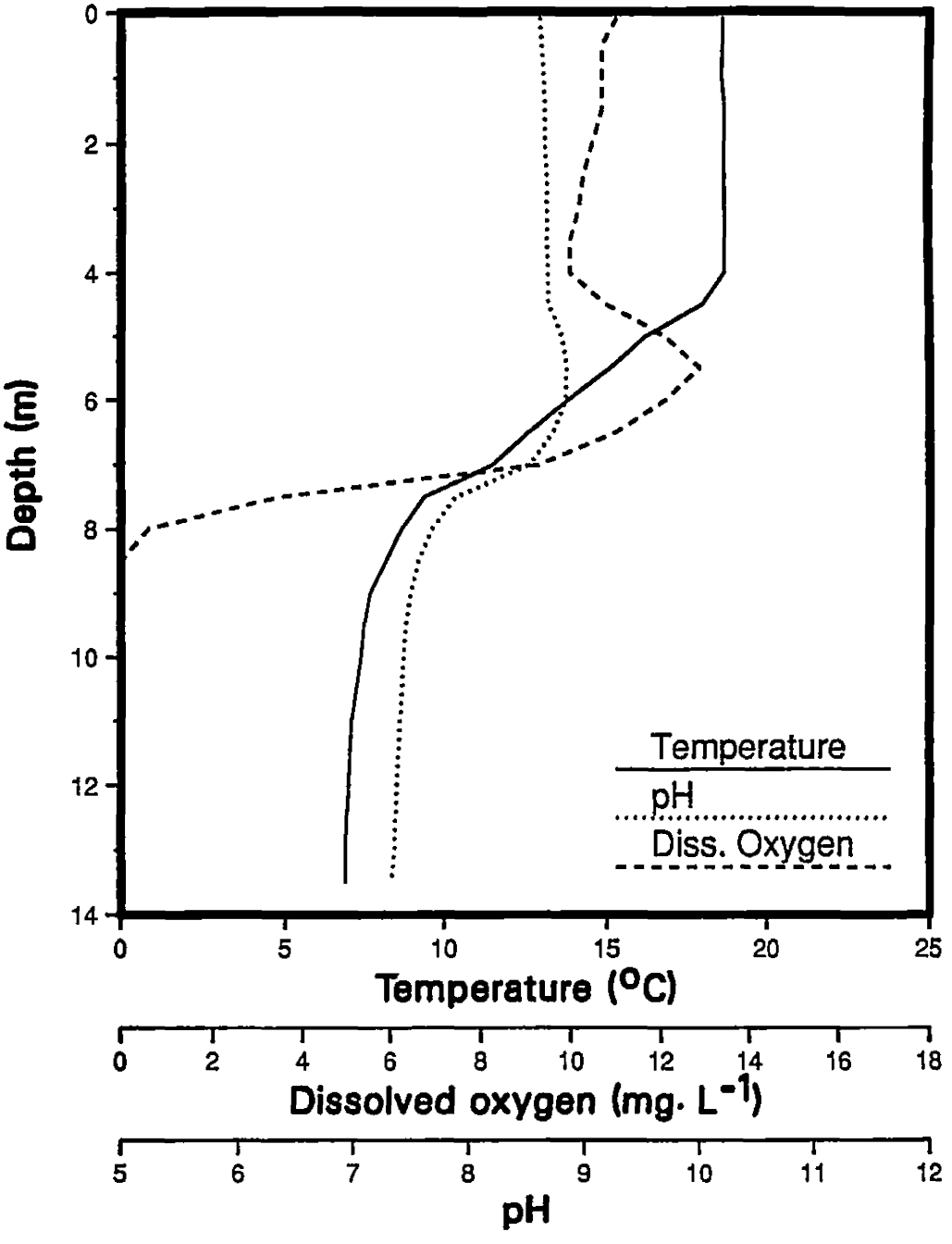

Figure 12. Plot of temperature, pH, and dissolved oxygen through the water column on 21 July, 1986.

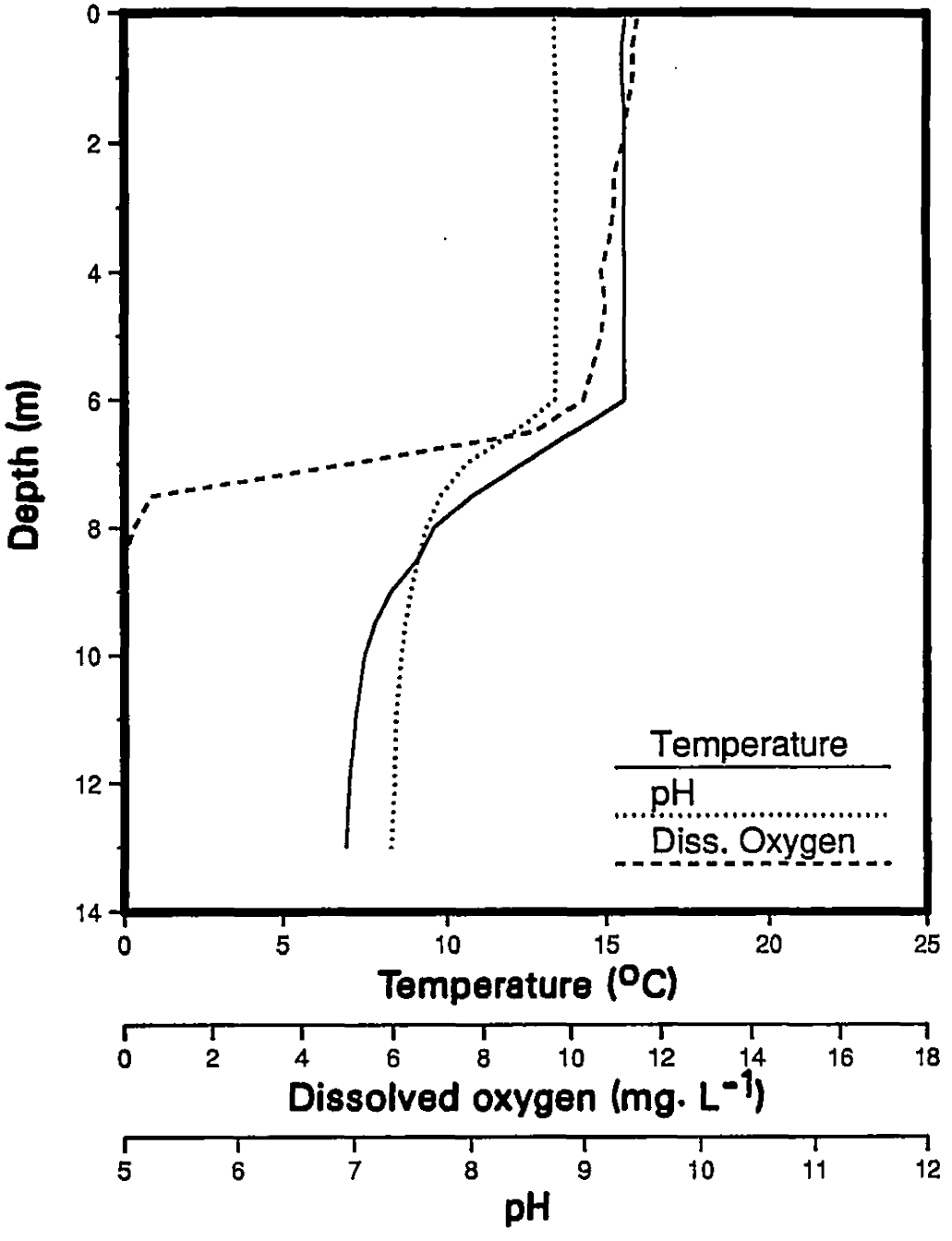

Figure 13. Plot of temperature, pH, and dissolved oxygen through the water column on 13 August, 1986.

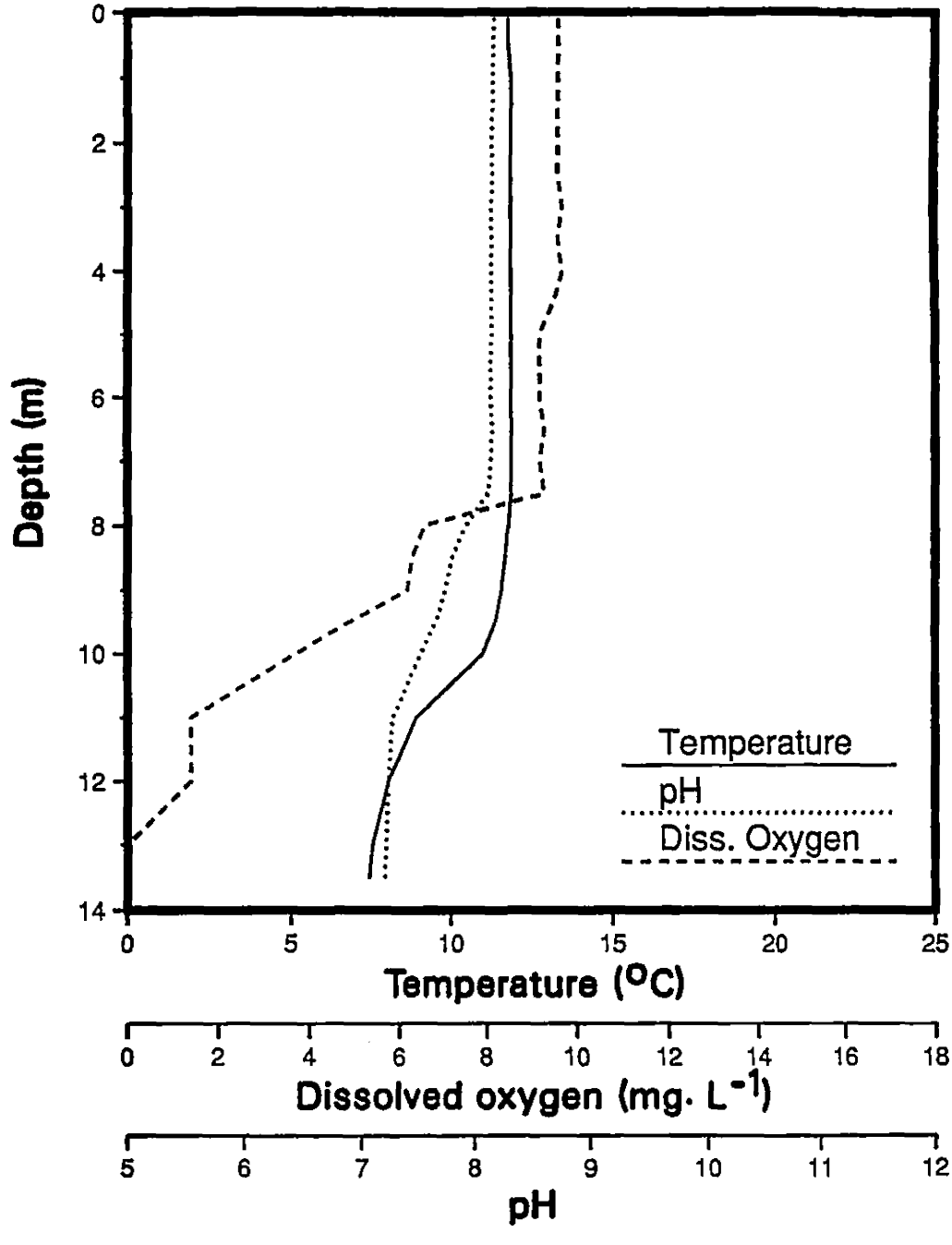

Figure 14. Plot of temperature, pH, and dissolved oxygen through the water column on 22 September, 1986.

Light extinction coefficients for the 1985 and 1986 seasons ranged from 0.553 on 8 July, 1985 to 0.820 on 22 September, 1986 (Table 1). These values correspond to 1% surface light depths of 8.3 m and 5.6 m, respectively. No distinct seasonal trends were noted in extinction coefficients.

Table 1. Extinction coefficients and depth (m) of 1% surface light intensity for 1985 and 1986 seasons. Standard errors for 1985 extinction coefficients appear in parentheses. Number of replicates per day is listed in the last column.

Date	k	$Z_{1\%}$	n
5/22/85	-0.623 (0.007)	7.4	5
6/11/85	-0.554 (0.007)	8.3	5
7/08/85	-0.553 (0.011)	8.3	5
7/24/85	-0.591 (0.017)	7.8	5
8/21/85	-0.670 (0.014)	6.9	3
5/19/86	-0.606	7.6	1
6/08/86	-0.586	7.8	1
6/30/86	-0.648	7.1	1
7/21/86	-0.772	6.0	1
8/13/86	-0.579	7.9	1
9/22/86	-0.820	5.6	1

Dissolved inorganic carbon (DIC) sampled through the euphotic zone ranged from approximately 16–30 $mg \cdot L^{-1}$ in the 1985 season, with concentrations increasing below the thermocline (Appendix A). DIC analyses in 1986 also showed higher concentrations at 6 m than in the epilimnion when the thermocline separated the two sampling depths (Appendix A).

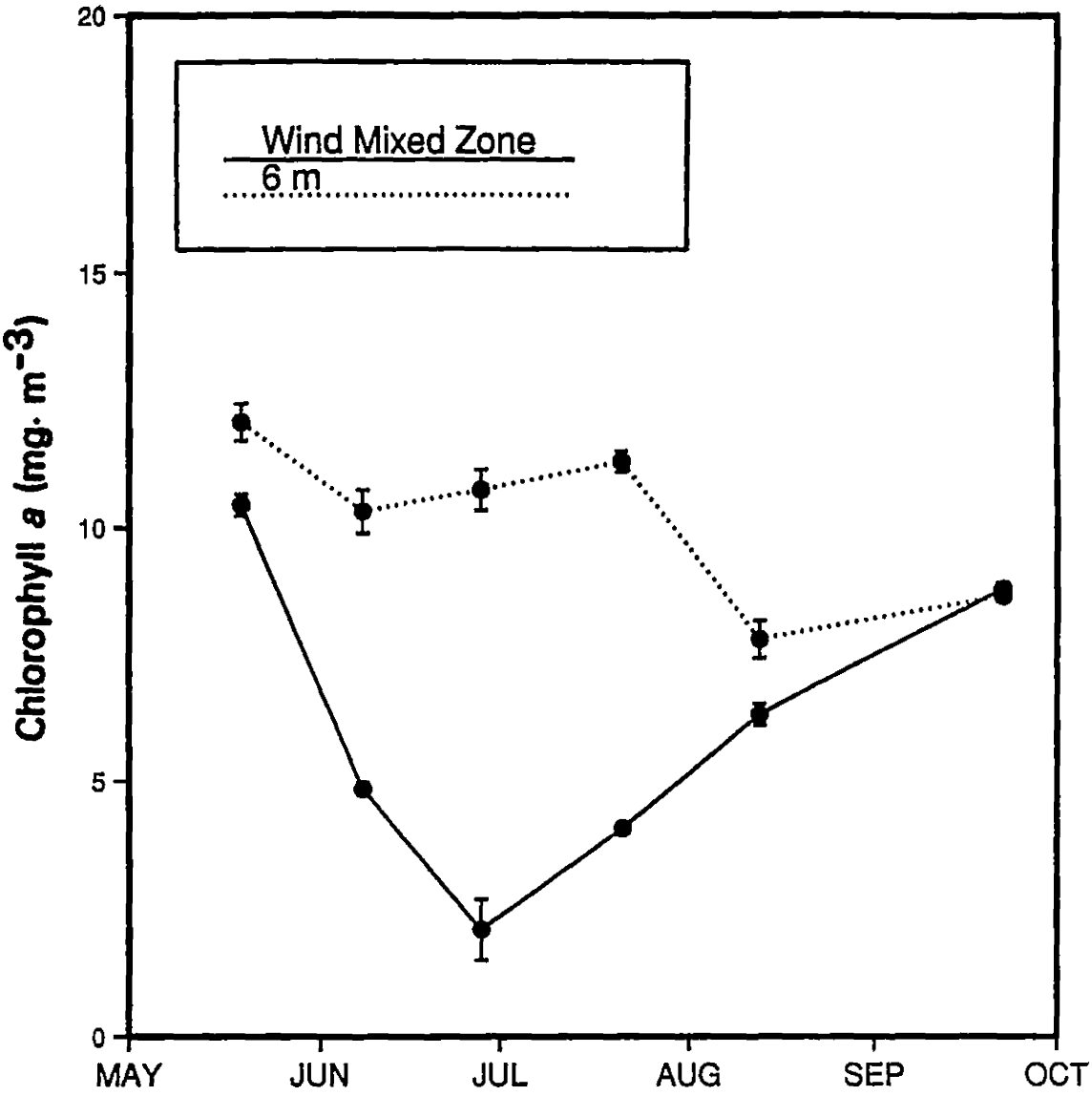

Figure 15. Chlorophyll *a* concentration in Wasilla Lake, 1986. Error bars are ± one standard error of the means.

Chlorophyll a Distribution

Mean measured chlorophyll *a* levels ranged from 2.09–12.07 $mg \cdot m^{-3}$ in the 1986 summer season. When thermal stratification separated the two sampling depths, chlorophyll *a* levels at 6 m were 2–5 times higher than those in the wind-mixed zone (Figure 15). Chlorophyll *a* samples collected in 1985 provide a more complete picture of chlorophyll *a* concentration changes with depth and season (Figures 4–8). Measured chlorophyll *a* levels below the thermocline in 1985 (expressed as means of measurements over a diel period) increased with time after the onset of stratification, reaching a concentration of 51.4 $mg \cdot m^{-3}$ on 24 July at 7.5 m, decreasing to approximately 25.8 $mg \cdot m^{-3}$ at that depth by 21 August after wind mixing was extended to a depth of 7.0 m.

1985 Diel Photosynthesis Studies

The lack of accurate measurement of total disintegrations per minute (DPMs) delivered to incubation bottles in the 1985 field season prevented representing radiocarbon uptake as carbon assimilation. Additionally, high blank bottle DPM counts (sometimes exceeding light bottle counts) persisted through 1985 uptake experiments. Laboratory tests in spring, 1986 and early in the 1986 field season isolated the cause of this problem as particulate ^{14}C contamination in the $NaH^{14}CO_3$ source used to this point (see Appendix B for these analytical procedures and conclusions). This problem disappeared with the use of a different $NaH^{14}CO_3$ source beginning 21 July, 1986. The variation in blank bottle counts

due to randomly varying particulate ^{14}C in pipette draws reduced confidence in analysis of observed uptake patterns. Because uptake at each depth of *in situ* bottle chains was calculated according to the formula:

$$U = \overline{x}DPM_{LB} - DPM_B$$

$$where: U = uptake$$
$$\overline{x}DPM_{LB} = mean\ (n = 2)\ of\ light\ bottle\ counts$$
$$DPM_B = blank\ bottle\ count$$

it became obvious that random variation in particulate ^{14}C introduced in light bottles (i.e. particulate ^{14}C contamination introduced to light bottles randomly varied from particulate ^{14}C contamination measured in blank bottles) would significantly underestimate or overestimate uptake at low photosynthetic rates. Because of this random error factor introduced by particulate ^{14}C contamination, I decided not to present 1985 diel uptake data.

Nutrient Concentrations

All nutrient characteristics except NO_3^--N showed significant concentration differences ($P<0.05$, Fisher's protected least significant difference test) between the two sample depths on at least one date (Table 2, Figures 16–20). MANOVA analysis (ranked data) showed no significant concentration changes across date for either total or filtrable reactive phosphorus, while all nitrogen species (TKN, NO_3^--N, NH_4^+-N) showed significant seasonal changes.

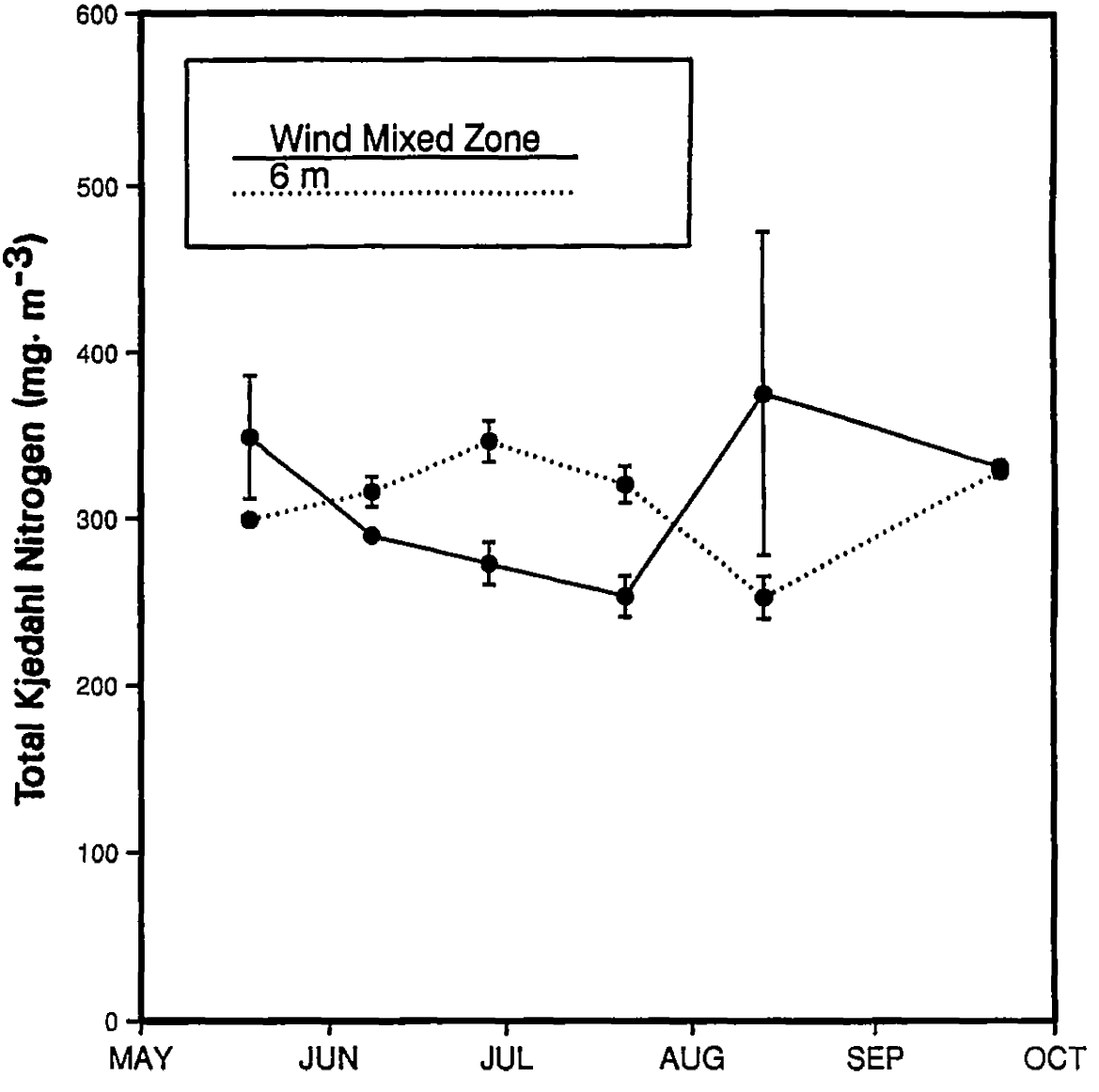

Figure 16. Total Kjeldahl nitrogen concentration in Wasilla Lake, 1986. Error bars represent ± one standard error of means.

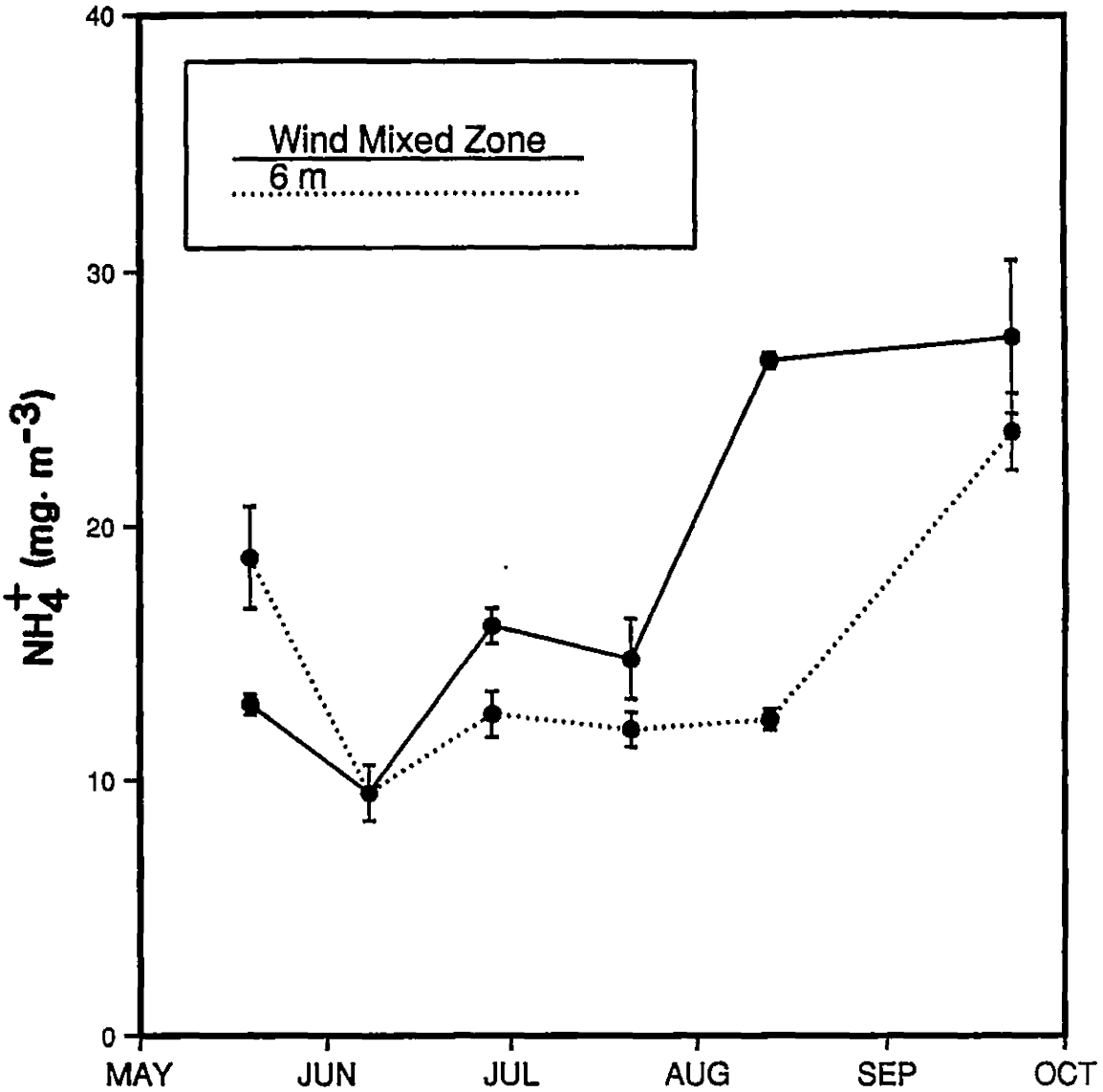

Figure 17. Ammonium nitrogen concentration in Wasilla Lake, 1986. Error bars represent ± one standard error of means.

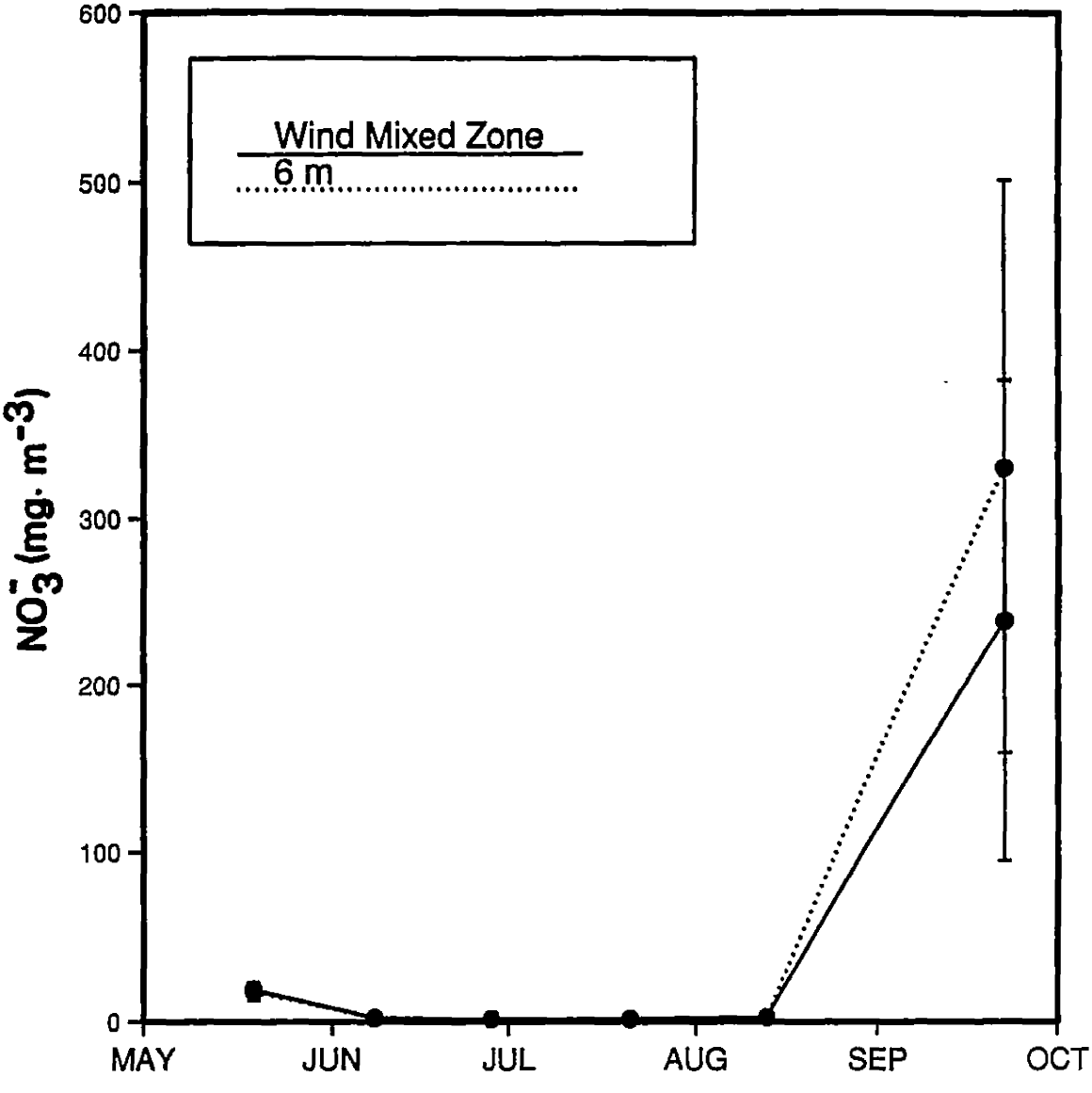

Figure 18. Nitrate nitrogen concentration in Wasilla Lake, 1986. Error bars represent ± one standard error of means.

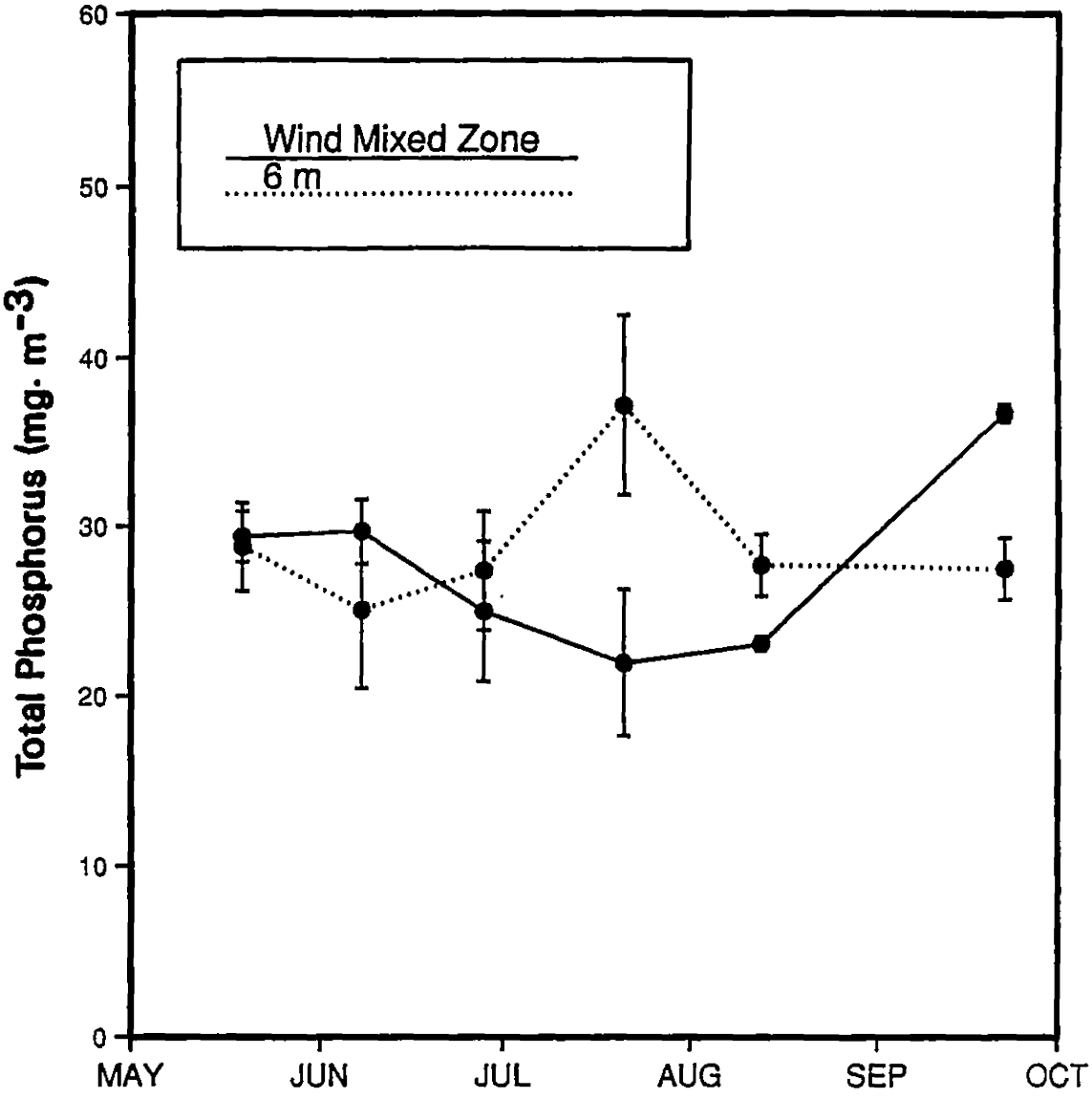

Figure 19. Total phosphorus concentration in Wasilla Lake, 1986. Error bars represent ± one standard error of means.

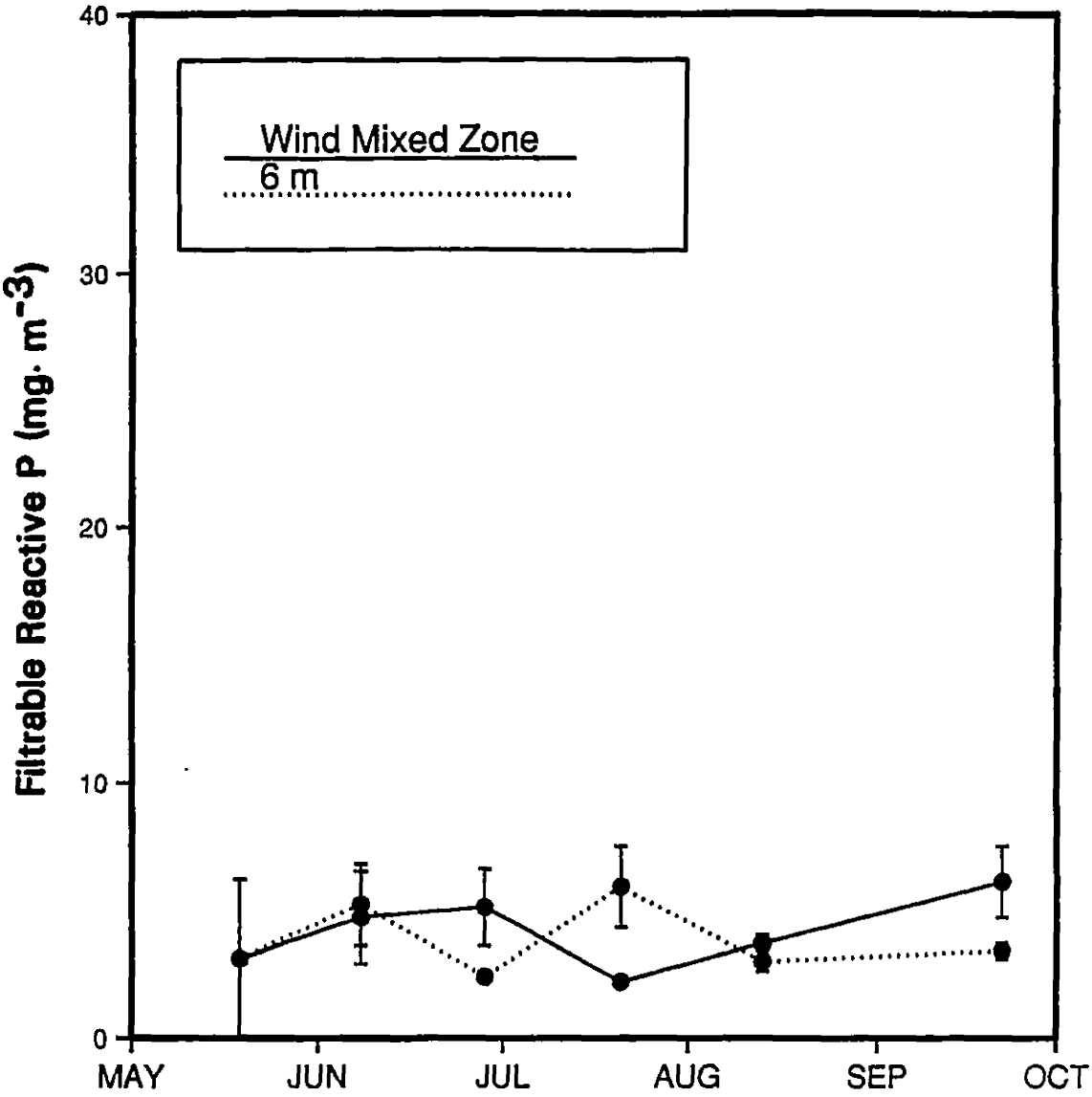

Figure 20. Filtrable reactive phosphorus concentration in Wasilla Lake, 1986. Error bars represent ± one standard error of means.

Table 2. 1986 nutrient and algal taxonomic characteristics showing significant ($P<0.05$) differences between depths.

Date	Characteristics with significant differences between depths: Nutrient	Relative Biovolume
5/19	NH_4^+-N (WMZ<6 m)	—
6/08	—	—
6/30	TN (WMZ<6 m); NH_4^+-N, FRP (WMZ>6 m)	—
7/21	FRP, TN (WMZ<6 m)	Bacillariophyceae (WMZ>6 m)
8/13	TN, NH_4^+-N (WMZ>6 m)	—
9/22	—	—

Algal Taxanomic Composition

Phytoplankton relative biovolume was dominated by bluegreen and euglenoid species through the summer of 1986 (Figure 21). Low total nitrogen:total phosphorus ratios (Schindler, 1977; Smith, 1983) and high pH levels (Shapiro, 1984) have been shown to facilitate bluegreen dominance in lake systems. This relationship between N/P ratio and relative bluegreen biovolume was not conclusively demonstrated in Wasilla Lake (Figure 22). However, Smith (1983) found lakes with N/P ratio <29 to be bluegreen dominated; Wasilla Lake's N/P ratio in the 1986 season was always less than 29. Relative bluegreen biovolume did not appear conclusively tied to pH level either, but consistently high pH levels (8.0–9.0) at the 1986 sample depths may have brought about bluegreen dominance in late June (Figure 23).

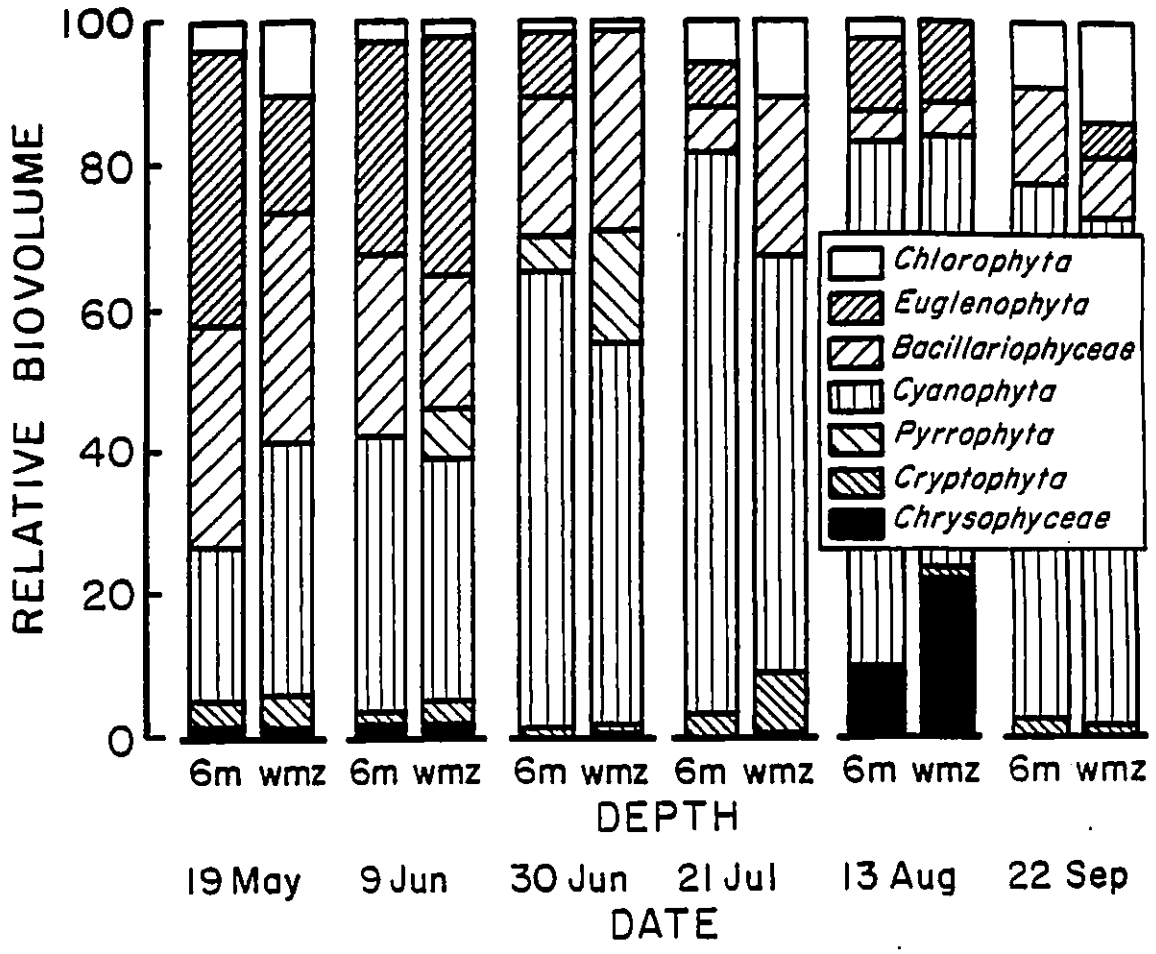

Figure 21. Histogram of relative biovolume for major algal divisions at 6 m and through the wind-mixed zone (wmz) in Wasilla Lake, 1986.

Relative diatom biovolume was significantly higher (Table 2) in the wind mixed zone than at 6 m on 21 July. No other major algal division showed significant differences in percent of total biovolume between sampling depths for any date. Cryptomonad biovolume remained relatively constant at approximately 0.5–6.0% on each date. Although chrysophyte relative biovolume ranged from approximately 1–25%, sampling variances were relatively large and seasonal changes were not

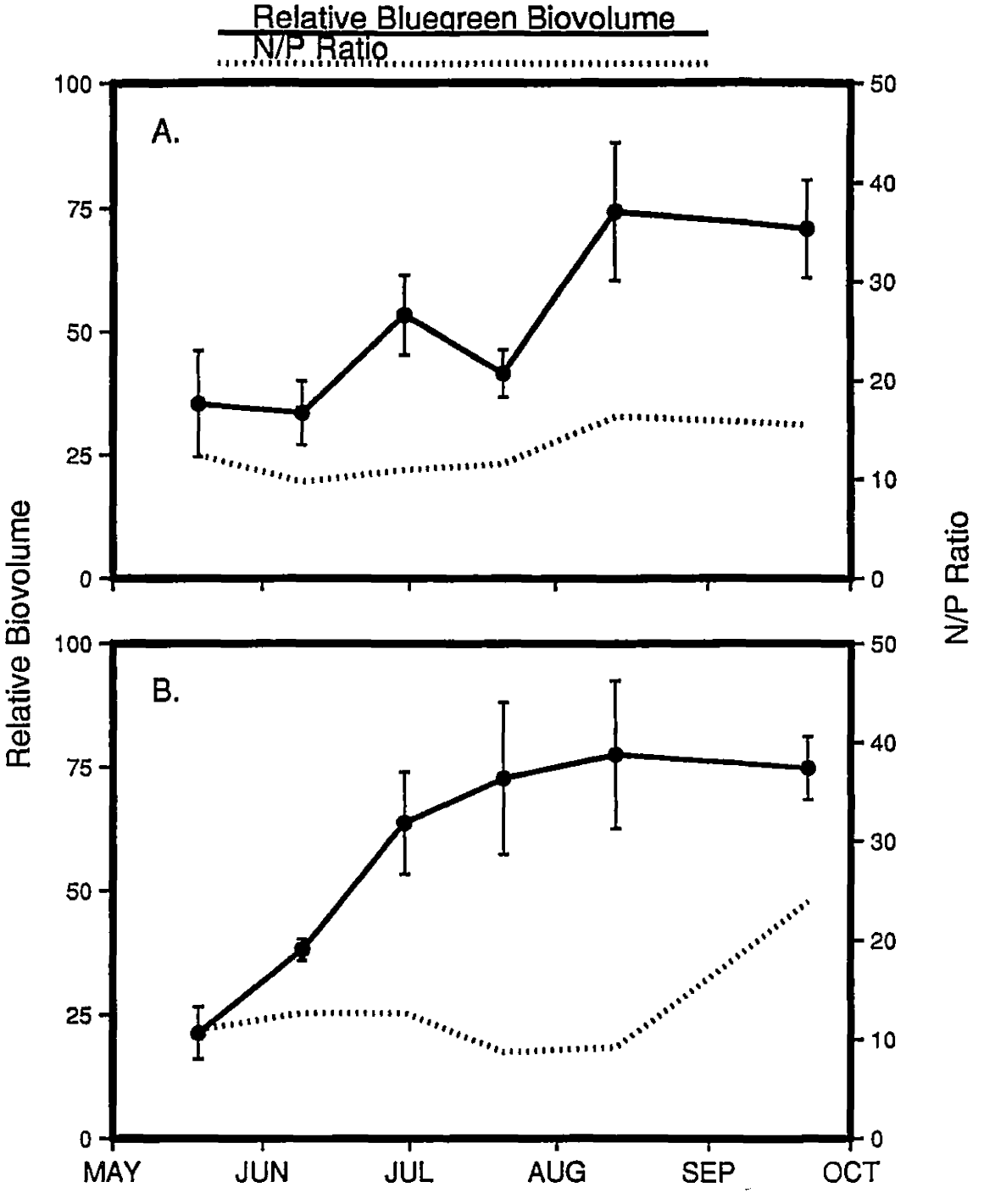

Figure 22. Ratios of total N/P and relative biovolume of bluegreen algae in Wasilla Lake, 1986. A–wind-mixed zone, B–6 m. Error bars are ± one standard error of the means.

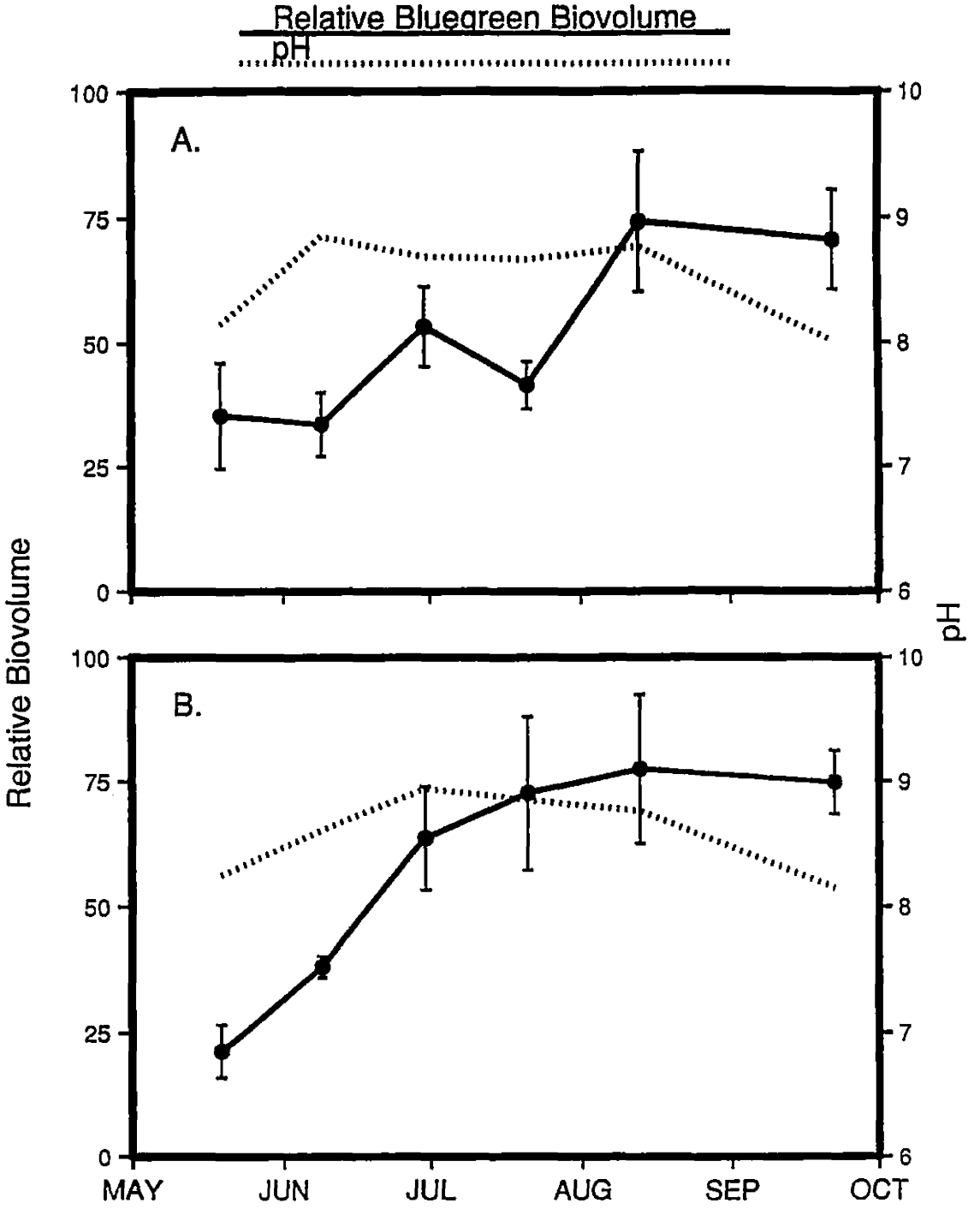

Figure 23. Mean epilimnetic pH and relative biovolume of bluegreen algae in Wasilla Lake, 1986. A–wind-mixed zone, B–6 m. Error bars are ± one standard error of the means.

significant. All other algal divisions showed significant ($P<0.05$) seasonal changes in relative biovolume.

Trophic status of Wasilla Lake

The anoxic 4–6 m of the water column over the bottom through the months of July and August in both 1985 and 1986 and the clinograde and positive heterograde shaped oxygen profiles indicate Wasilla Lake is eutrophic or moving in that direction (Cole, 1983). Mean chlorophyll *a* concentration through the euphotic zone for the 1985 season was 13.9 $mg \cdot m^{-3}$. This concentration corresponds to a eutrophic condition according to Welch (1980). Mean total phosphorus concentration for Wasilla Lake calculated from samples collected 8 June, 30 June, and 21 July was 28.4 $mg \cdot m^{-3}$. Chapra and Reckhow (1979) show this total phosphorus concentration to correspond to a eutrophic lake with an approximate probability of 80%. Mean total Kjeldahl nitrogren calculated over the same dates as total phosphorus was 305.1 $mg \cdot m^{-3}$, classifying Wasilla Lake as mesotrophic according to Vollenweider (1979). The dominance of phytoplankton composition by bluegreen and euglenoid species through the 1986 summer season further suggested a eutrophic condition in Wasilla Lake (Schindler, 1977; Wetzel, 1983; Reynolds, 1984), as did the fact that bluegreen biovolume was made up in large part by *Aphanezomenon spp.* Secchi disk depths measured in 1985 and 1986 ranged from 2.5 to 3.3 m, classifying Wasilla Lake as mesotrophic (Welch, 1980).

Photosynthesis–Irradiance Relationships

Chlorophyll *a* per cell biovolume was 1.5–3.1 times higher in phytoplankton populations below the thermocline than epilimnetic populations when stratification separated sample depths (Table 3). Chlorophyll *a* per cell biovolume in the 19 May and 13 August 6-m samples was 1.24 and 1.38 times levels in the epilimnetic samples on those dates, when mixing was occurring to or past 6 m.

Table 3. Characteristics of phytoplankton samples from Wasilla Lake, 1986, including P–I curve parameters.

Date	Depth	$\frac{mg.Chl\ a}{cm^3\ biovolume}$	♠α	♠β	♣P_s^B	♣P_m^B	◇I_k	◇I_m
5/19	WMZ	1.65	3.89	1.72	3.00	1.24	88	254
	6 m	2.04	3.89	2.50	3.00	1.00	71	200
6/09	WMZ	0.91	3.83	0.69	1.54	0.92	66	207
	6 m	2.83	8.86	0.14	1.21	1.11	34	155
6/30	WMZ	1.12	—	—	—	—	—	—
	6 m	1.68	7.08	0.00	1.63	1.61	63	399
7/21	WMZ	1.98	2.97	0.89	2.05	1.02	95	281
	6 m	2.94	7.14	0.19	1.03	0.91	35	145
8/13	WMZ	2.04	6.72	0.00	0.78	0.76	31	176
	6 m	2.82	5.81	0.03	0.87	0.83	31	206
9/22	WMZ	2.21	4.56	0.14	0.84	0.72	44	176
	6 m	2.10	4.78	0.14	0.80	0.69	40	162

♠ mgC·mg chl a^{-1}·Ei^{-1}·m^{-2}
♣ mgC·mg chl a^{-1}·hr^{-1}
◇ μEi·m^{-2}·s^{-1}

The three lowest irradiance incubations of the wind mixed zone sample in the 30 June P–I experiment (Figure 25A) showed zero photosynthetic uptake due to unusually high blank bottle DPM counts (higher than the mean of light bottle counts at the three lowest irradiances). Because of this artifact, P–I parameters from this experiment were regarded as invalid. In 1986, P–I curves from the two sample depths had noticeably different shapes on 8 June and 21 July, when samples were separated by a thermocline (Figures 24–26).

Mean values of α and P_m^B for Wasilla Lake in May–September, 1986 were 5.41 and 0.98, respectively. The initial slope of the P–I curve over which photosynthesis is light-limited (α) was approximately 2.5 times greater in phytoplankton populations at 6 m than epilimnetic populations when thermal stratification was shallower than 6 m (Table 3). P_m^B, the maximum rate of photosynthesis normalized to biomass (as chlorophyll *a*) did not uniformly decrease in metalimnetic phytoplankton communities as noted in other studies (Yentsch and Lee, 1966; Savidge, 1979; Platt et al., 1982). Photoinhibition (β), was considerably higher in epilimnetic phytoplankton populations than those from 6 m when samples were separated by a thermocline. The "adaptation parameter", I_k (Talling, 1957) indicated phytoplankton populations in the epilimnion were "adapted " to relatively higher irradiances than populations below the thermocline (I_k as an index of adaptation has been questioned, see Yentsch and Lee, 1966; Harris, 1973; Platt et al., 1982). The irradiance at which photosaturation occurs, I_m (Platt et al., 1982), followed

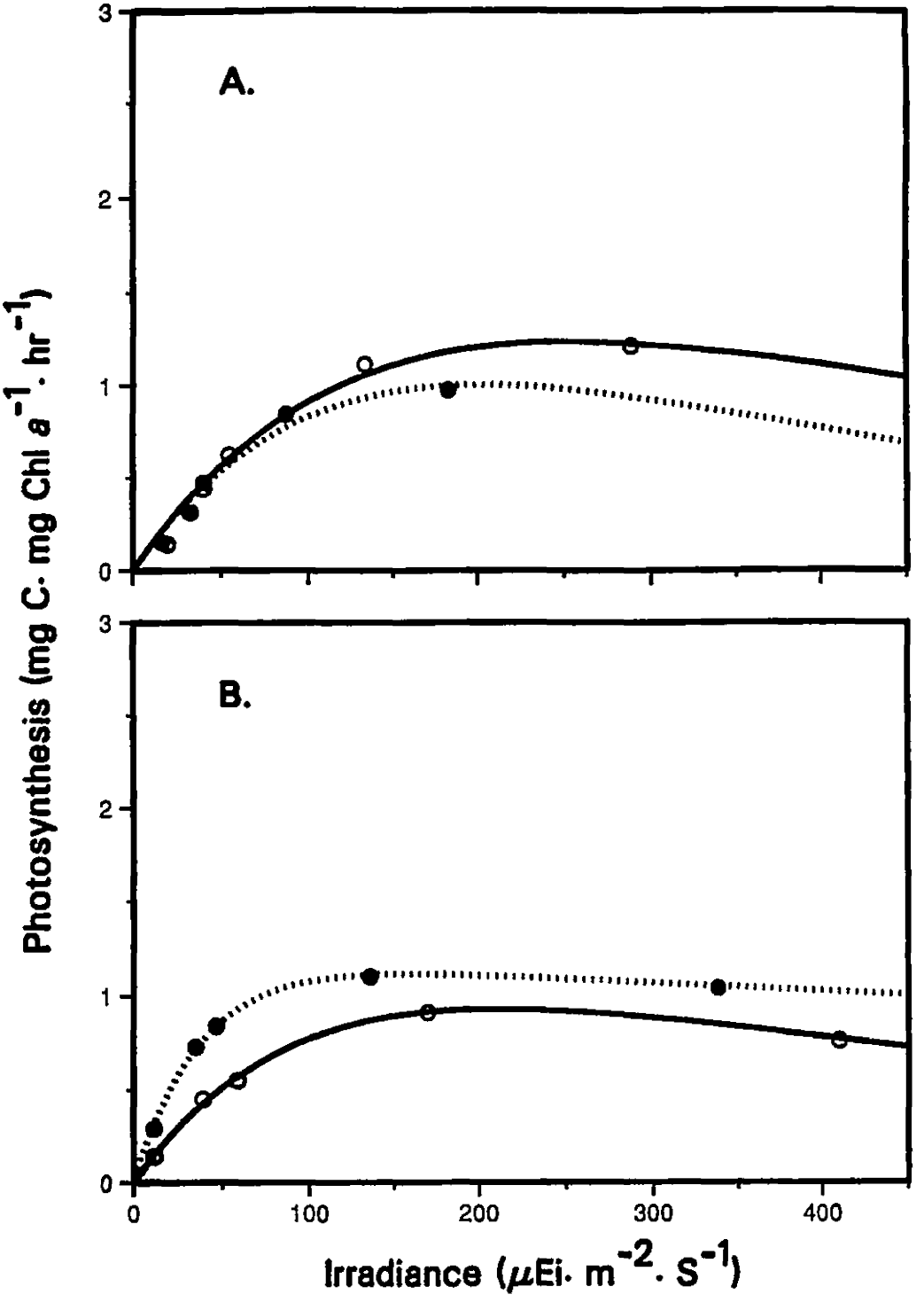

Figure 24. P–I curves from 19 May (A) and 9 June (B), 1986. Solid lines– wind-mixed zone, dotted lines– 6 m.

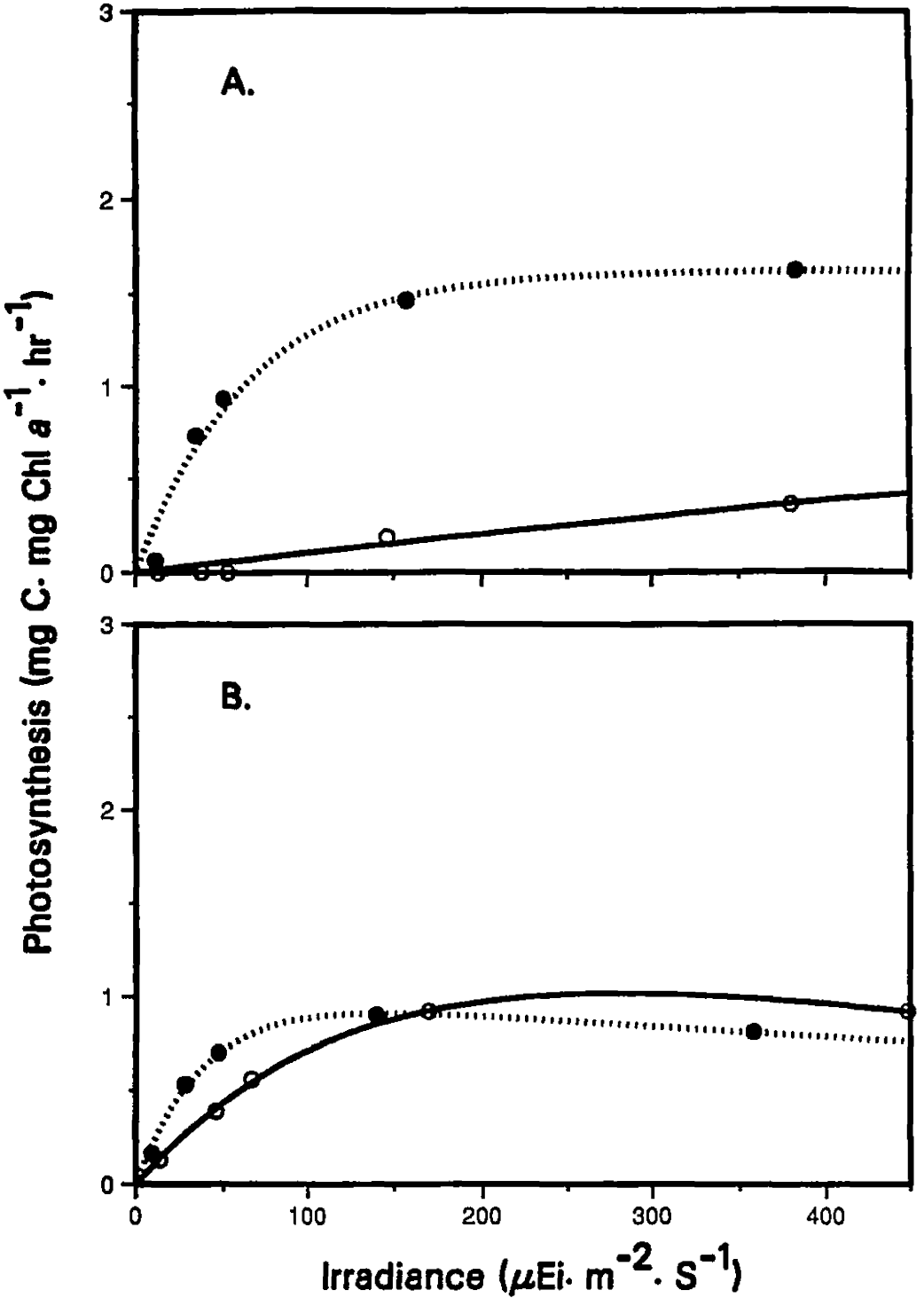

Figure 25. P–I curves from 30 June (A) and 21 July (B), 1986. Solid lines– wind-mixed zone, dotted lines– 6 m.

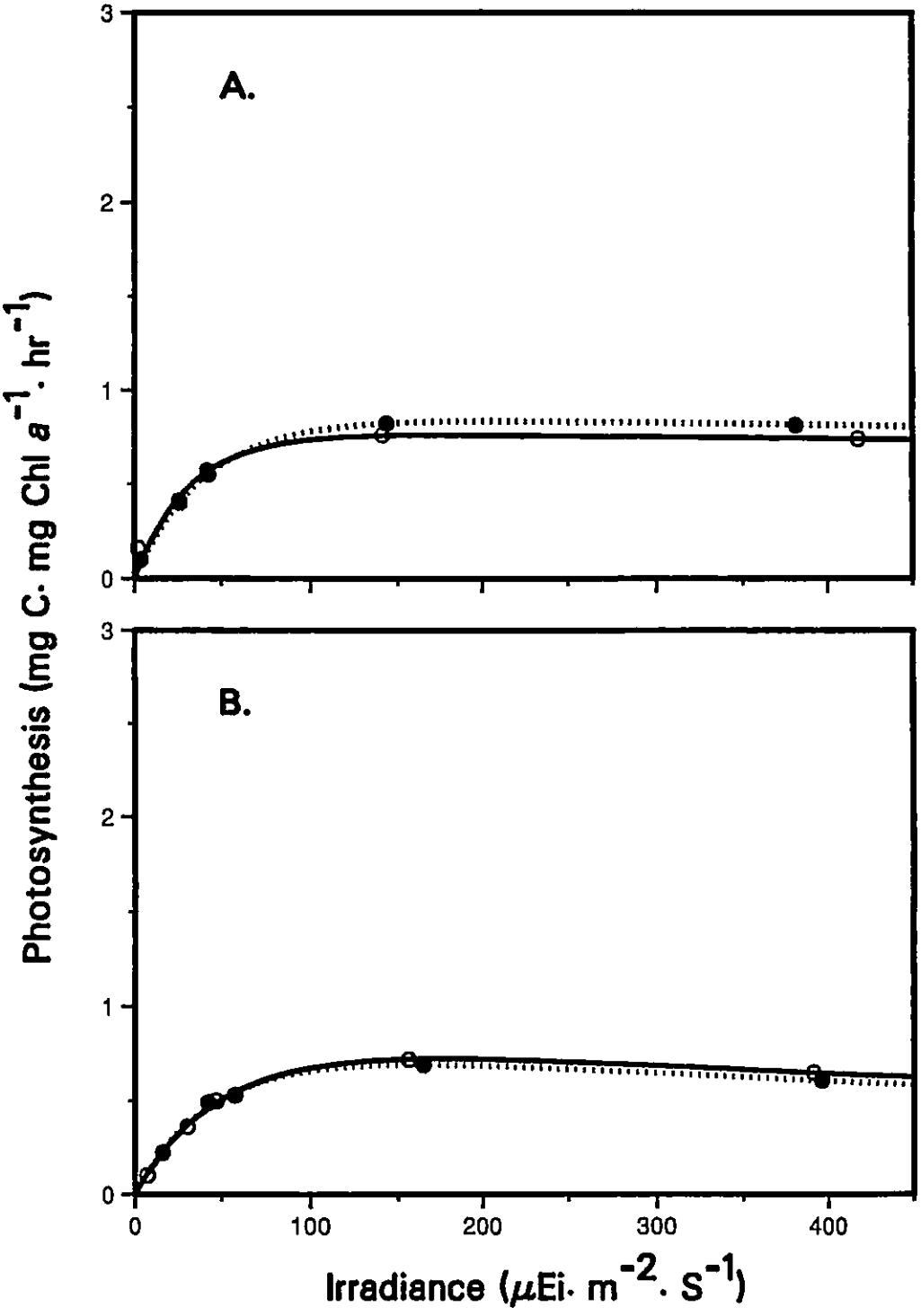

Figure 26. P–I curves from 13 August (A) and 22 September (B), 1986. Solid lines– wind-mixed zone, dotted lines– 6 m.

the pattern of I_k, with the largest differences being noted when the thermocline separated samples.

I_k has been reported by several researchers (Steeman-Nielsen and Jorgensen, 1968; Harris, 1973) to vary markedly with temperature changes. The assimilation number (P_m^B) has also been reported to be highly correlated with temperature variation (Harrison and Platt, 1980). Linear regression analysis showed none of the P–I parameters measured to be significantly influenced by temperature (Table 4).

Table 4. Statistics from regression of P–I parameters on temperature.

P–I Parameter	r^2	P	n
α	0.00	0.88	11
I_k	0.01	0.77	11
I_m	0.01	0.85	11
P_s^B	0.26	0.11	11
P_m^B	0.09	0.38	11

Algal Adaptation Response Time

Time-series analysis of α, and I_k regressed on mean epilimnetic irradiance showed peak r^2 values of 0.359 and 0.639, respectively when mean epilimnetic irradiance was calculated for the 4-day time period prior to sampling. P_m^B showed a peak r^2 value of 0.904 when irradiance was calculated over the 5-day time period prior to sampling. Thus, phytoplankton maximally adapted to the irradiance environment over a 4-5 day period (Figure 27). The best fitting regression with

P_m^B was highly significant (P=0.007), while regressions with α and I_k were not significant (P=0.064 and P=0.45, respectively).

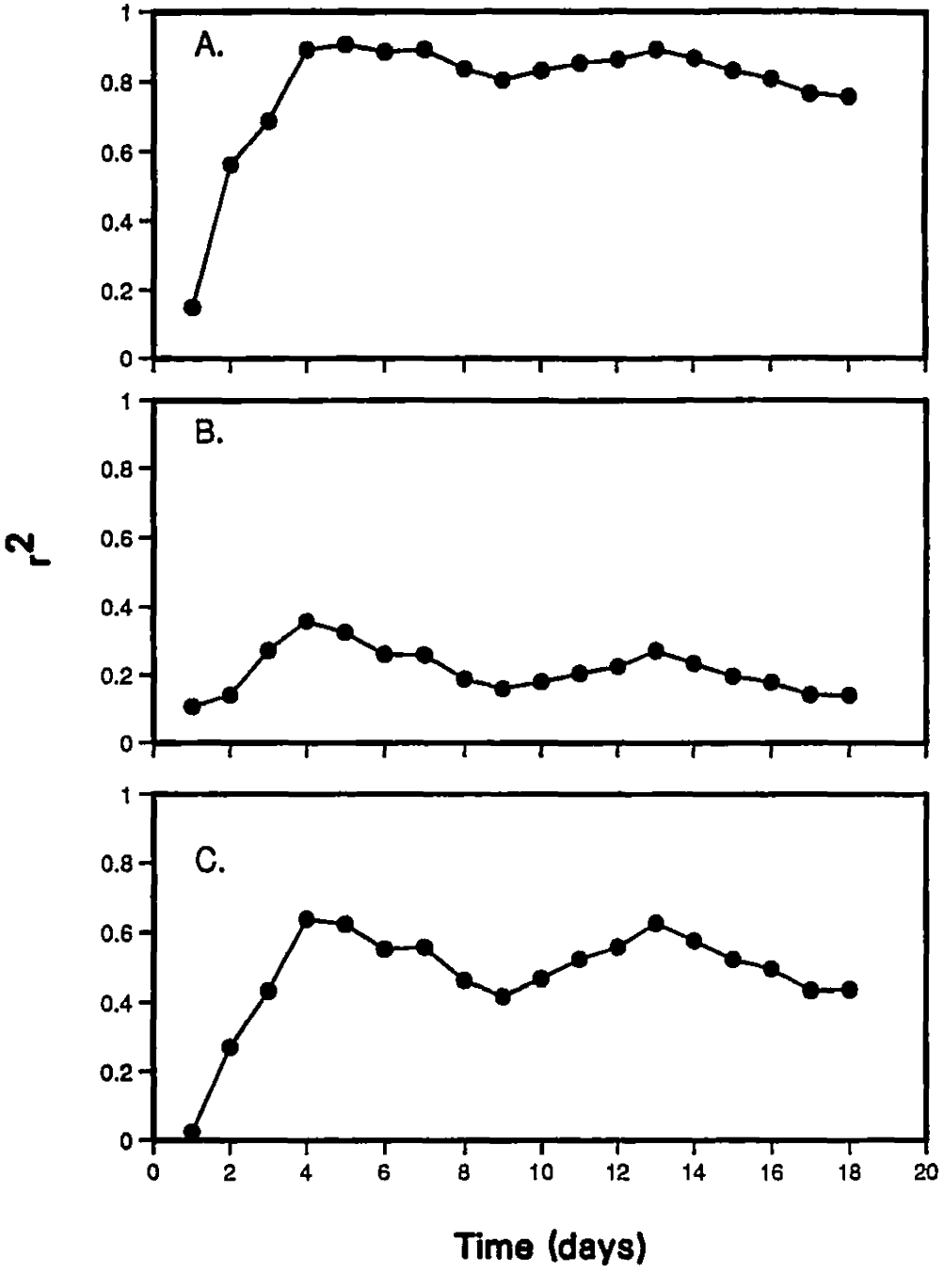

Figure 27. Coefficient of determination from P_m^B, α, and I_k time-series regressions plotted against time period prior to sampling over which mean epilimnetic irradiance was calculated. A–P_m^B, B–α, C–I_k.

Discussion

Physical and Chemical Limnology

The high pH values and high dissolved oxygen concentrations in the euphotic zone through the 1985 and 1986 seasons indicated high levels of productivity. High productivity was also indicated by the partial depletion of DIC in the euphotic zone, especially considering the well buffered water of Wasilla Lake (DIC≈25.0 $mg{\cdot}L^{-1}$). Ice-out on Wasilla Lake in 1985 was approximately May 10. The marked oxygen depletion below about 7.0 m on 22 May, 1985 was surprising after only 10–14 days of ice-free conditions. The oxygen depletion noted through the water column on this date may have been due to a lack of vernal overturn. LaPerriere (1981) reports that passive solar heating of the near surface zone through late spring ice, coupled with lack of wind at the time of ice-out facilitated the immediate onset of a stable stratified water column. Although dissolved oxygen data is missing from the 19 May, 1986 profile plot, the temperature profile indicates that vernal overturn probably did take place in 1986.

Chlorophyll a Distribution

Chlorophyll *a* levels much higher in 1985 metalimnetic samples than 1986 samples from 6 m were probably due to the fact that highest metalimnetic chlorophyll *a* concentrations in 1986 did not coincide with the 6 m depth. Fee (1976) notes metalimnetic chlorophyll *a* peaks often exist in a very narrow band. Thus, higher metalimnetic chlorophyll *a* concentrations possibly present in 1986 might

easily have been missed by only sampling to 6 m. Chlorophyll *a* distribution showing highest concentrations in the metalimnion in 1985 and 1986 may have been due to phytoplankton settling through the water column or vertical migration to a preferred light and nutrient environment by phytoplankton able to regulate their vertical position in the water column (e.g. bluegreen algae by gas vacuole regulation; flagellated species by motility). *Oscillatoria sp.*, one of the most common of the bluegeen algae present in Wasilla Lake samples in 1986, is often found in highest densities in the metalimnion (Wetzel, 1983).

Nutrient Concentrations

Although nutrient characteristics showed significant differences between the two sampling depths on several dates, it did not appear that those differences directly influenced the shape of the P–I curves representing the two sample depths. On 19 May, 1986, NH_4^+-N concentration was significantly higher at 6 m than in the wind-mixed zone (Figure 17). If epilimnetic phytoplankton populations were deficient in inorganic nitrogen, one would expect to see a lower P_m^B in the epilimnetic P–I curve than the 6 m P–I curve (Figure 24A), due to nitrogen limitation of enzyme synthesis. In fact however, the P-I curve from the wind-mixed zone had the higher P_m^B of the two curves, the opposite of what would be expected were the phytoplankton population in the wind-mixed zone nitrogen deficient. Thus, the significantly higher NH_4^+-N concentration at 6 m did not appear to directly affect the shape of the two curves on this date.

Filtrable reactive phosphorus on 21 July was significantly higher at 6 m than in the epilimnion (Figure 20). However, P_m^B was higher in the epilimnion P–I curve, rather than the 6 m P–I curve, as would be expected if FRP was deficient in the epilimnion (Figure 25B). Although α was markedly higher in the 6 m P–I curve, this portion of the curve represents the efficiency of the photochemical reactions of photosynthesis, which would be much less sensitive to nutrient deficiency than the "dark reactions", and therefore P_m^B.

Although NH_4^+-N concentration was significantly higher in the wind-mixed zone on 13 August (Figure 17), P–I curves from this date were so nearly identical as to make discussion of possible influence of NH_4^+-N concentration at the two depths unneccesary.

A large nutrient pool in Wasilla Lake may exist in the hypolimnion in summer and be circulated throughout the water column at autumnal overturn. The Alaska Department of Fish and Game (ADF&G) reports concentrations of NO_3^--N and NH_4^+-N of 220.0–346.0 and 228.0–496.0 $mg \cdot m^{-3}$, respectively at 12.0 m for May and June, 1984 (unpublished data, 1984). High levels of NO_3^--N and NH_4^+-N are also reported by ADF&G through the water column on 16 January, 1984, suggesting redistribution of a hypolimnetic nutrient pool. This was further supported by the high levels of NO_3^--N at both sampling depths on 22 September, 1986 after the water column was wind mixed to 10 m (Figure 18). Because samples in 1986

were collected no deeper than 6 m, high nutrient levels in deeper water below the thermocline could easily have been missed.

Algal Taxonomic Composition

Bluegreen species alone made up more than 40% of relative biovolume from 30 June through 22 September. ADF&G records (unpublished, 1984) also show phytoplankton biovolume domination by bluegreen algae in mid January, 1984. Schindler (1977), Barica (1980), and Smith (1983) point to low N:P ratios as one factor facilitating bluegreen dominance, particularly nitrogen-fixing bluegreens. As ratios of total N:P become increasingly lower, nitrogen-fixing bluegreens should be competitively favored over species not able to fix nitrogen. Schindler (1977) found bluegreen dominance developed when lakes in the Canadian Shield area were fertilized with a ratio of 5:1 (N:P). Smith (1983) found bluegreen dominance to be favored when N:P ratios were less than 29:1. While Figure 22 does not show increasing bluegreen dominance through the 1986 season to be due directly to decreasing N:P ratio, it is possible that bluegreen dominance was facilitated by N:P ratios that were always lower than 29:1.

Bluegreen dominance in Wasilla Lake was more likely facilitated by persistent high pH in the 1986 season. Shapiro (1984) found bluegreen dominance to be favored in high pH (≈8.5–11.0) conditions over green algal species. Talling (1976) cites a similar phenomenon showing *Selanastrum capricornutum* (a green alga) to photosynthesize at a higher rate than *Anabaena flos-aquae* (a bluegreen

alga capable of N-fixation) at pH 7.0, the situation being reversed at pH 8.0. Long (1976) showed bluegreen species to have greater inorganic carbon uptake ability than green algae. This may mean that at high pH, when dissolved CO_2 is negligible, bluegreen algae are able to more efficiently take up HCO_3^- as a carbon source than other algae. Relative biovolume of bluegreen algae in Wasilla Lake increased markedly several weeks after average pH in the euphotic zone increased to about 8.5 or higher (Figure 23). After this point, bluegreen relative biovolume remained above 40%, even though pH fell as low as 8.15 by 22 September. This supports Shapiro's findings that after bluegreen dominance was established at high pH, it was usually necessary to artificially lower pH to 7.5–5.5 in order to facilitate breakdown of bluegreen dominance.

Allen (1956) noted bluegreen algae to be most abundant in hardwater lakes. Gerloff et al. (1952) found 0.25g·m^{-3} Ca^{+2} to be necessary to maintain maximal growth of *Microcystis sp.* in culture. ADF&G (unpublished data, 1984) reported Ca^{+2} concentrations of approximately 25g·m^{-3} for Wasilla Lake. This high Ca^{+2} concentration may contribute to the observed bluegreen abundance in Wasilla Lake.

Relative biovolume contributed by diatoms was significantly higher in the wind-mixed zone than at 6 m on 21 June, 1986. The possible influence this may have had on P–I curves from this date will be discussed in the following section.

Trophic Status of Wasilla Lake

Wasilla Lake appeared to be eutrophic based on data considered here. The lake's anoxic zone extending 4–6 m above the bottom at the 1985–1986 sampling site through July and August of both seasons was a strong indication of eutrophy. The bluegreen algal dominance that persisted through most of the 1986 season, high 1985 chlorophyll *a* levels, and high mean total phosphorus concentration in 1986 all support the conclusion that Wasilla Lake is eutrophic. These data outweigh the fact that secchi disk depth and mean 1986 TKN concentration classified Wasilla Lake as mesotrophic. It is possible that Vollenweider's (1979) published ranges of total nitrogen for each lake trophic state may be artificially high because reservoirs were included in his survey (LaPerriere, pers. comm., 1989). This assessment of trophic status for Wasilla Lake should be regarded as a rough estimate. More thorough data collection through all seasons of at least one year is necessary to provide a more complete picture of Wasilla Lake's trophic status.

Although data collected in this study do not indicate possible sources of enrichment causing Wasilla Lakes's eutrophic state, the considerable residential and commercial development around the lake's shoreline suggest that nutrient leaching through septic system drainfields may contribute considerable nutrient inputs. Additionally, a storm drain entering the lake at the extreme west end may contribute to nutrient enrichment.

Photosynthesis–Irradiance Relationships

Previous light history experienced by phytoplankton probably had the greatest influence on differences in P–I curve shape in populations separated by a thermocline. Although regressions of α, and I_k on a four-day average of mean epilimnetic irradiance were not significant, the P_m^B regression was highly significant (P=0.007), and the α regression was nearly significant (P=0.064). The Coefficient of Determination for each of the above three P–I parameters on previous light history was much higher than r^2 value for regressions of each of these parameters on temperature. Because α represents the photochemical reactions of photosynthesis, and is supposedly influenced primarily by previous light history (Platt and Jassby, 1976), α should show higher r^2 and more significant regressions against previous light history than P_m^B. The fact that I observed the opposite is at this point unexplainable.

Temperature difference between the epilimnion and the subthermocline region was apparently not directly responsible for differences in P–I curves from phytoplankton populations separated by a thermocline. No correlation was found between temperature and P–I parameters in this study, compared with the findings of Harrison and Platt (1980) and Harris and Piccinin (1977) that temperature is a major determinant of assimilation number. Fee et al. (1987) found P–I parameters were *not* noticeably influenced by temperature.

When significant nutrient concentration differences existed between sample depths, these concentration differences did not appear to be responsible for P–I curve differences between sample depths. This contrasts with the findings of Fee et al. (1987) that nutrient concentrations caused differences in photosynthetic parameters from lakes of three different latitudes in Canada. Harrison et al. (1982) found nutrient concentrations to significantly influence P–I parameters. Harrison and Platt (1980) note that comparing inorganic nutrient concentrations across depth may not be a good indicator of the nutrient dynamics possibly affecting photosynthetic response to irradiance, as these pools are quite labile.

Differences in algal community composition between sampling depths were also apparently not *directly* determinant of P–I curve differences when stratification separated sampling depths. Although diatom relative biovolume was significantly higher in the wind mixed zone than at 6 m on 21 July, bluegreen algae clearly dominated at both depths on this date. Influences that changing algal community composition may have had on P–I curves in an *indirect* manner are discussed below.

My findings of higher α values in subthermocline populations than epilimnetic populations is contrary to findings of several researchers working with marine phytoplankton populations. Several lab culture studies (Prezelin and Sweeney, 1978; Falkowski and Owens, 1980; Perry et al., 1981) have found algal cultures of marine species grown at high relative light intensities to have higher α and/or P_{max}

than cultures at low light intensity, indicating algal populations responding more favorably to a high irradiance environment than to a lower irradiance environment. Earlier studies demonstrating this phenomenon include Steeman-Nielsen (1961), Yentsch and Lee (1966), Steeman-Nielsen and Jorgensen (1968), and Jorgensen (1969). Marine field studies showing favorable algal response to high irradiance environments include Platt et al. (1982), Platt et al. (1980), Savidge (1979) and Yentsch and Lee (1966). Diatoms and green algae were primarily used in the above laboratory studies, and the marine field studies determining algal composition also found diatoms dominating (Platt et al., 1980; Platt et al., 1982).

That Wasilla Lake's algal community composition was dominated by bluegreen algae may explain why my findings of higher α values in subthermocline populations differ from those of some marine researchers studying diatom-dominated populations. Richardson et al. (1983) define the terms *genotypic* and *phenotypic* light adaptation as: *genotypic*–the general range of irradiances an algal taxon can grow and photosynethsize at (determined by genetic components common to most species of the division), and *phenotypic*– how well an algal taxon responds photosynthetically to various culture irradiances. Diatoms are categorized by Richardson et al. (1983) as intermediate-to-high light adapted algae, listed second only to green algae. Richardson et al. (1983) categorize bluegreen algae as one of the genotypically lowest light adapted major algal divisions based on light intensity at

which maximum growth is attained (I_o–μ_{max}). Thus, bluegreen-dominated populations would be expected to respond more favorably to the low-light conditions in the metalimnion than than to the relatively bright irradiance conditions of the epilimnion, while diatom-dominated populations would be expected to respond more favorably to epilimnetic irradiance conditions than to subthermocline conditions.

Lower α in epilimnetic phytoplankton populations, separated from populations at 6 m by a thermocline, may have been due to photodamaged epilimnetic populations, rather than metalimnetic populations adapting to a low-irradiance environment by becoming more photosynthetically efficient at photosynthesis-limiting irradiances. Thus, bluegreen algae may appear to be "low-light adapted" because they lack an adequate mechanism of protection from photodamage at high relative irradiances. Agel et al. (1987) found *Anabaena variabilis* cultures to be light stressed at irradiance levels as low as $27\mu Ei \cdot m^{-2} \cdot s^{-1}$. Cultures exposed for two days to 400 $\mu Ei \cdot m^{-2} \cdot s^{-1}$ of monochromatic light between 520 and 680 nm showed dramatically reduced α and P_{max} in P–I curves with photosynthesis measured in relative units. A noticeable but smaller decrease in α and P_{max} was seen in cultures pre-irradiated at $27\mu Ei \cdot m^{-2} \cdot s^{-1}$ white light compared with cultures pre-irradiated at $2.7\mu Ei \cdot m^{-2} \cdot s^{-1}$. It was determined that this photostress was due exclusively to damage to the PS II system, probably at or near the reaction center, caused by 520–680 nm light.

Markedly lower chlorophyll *a* per cell volume in epilimnetic samples separated from 6 m samples by stratification may have been due to photobleaching of shallow phytoplankton populations rather than increased cellular chlorophyll *a* in metalimnetic populations. Nultsch and Agel (1986), working with lab cultures of *Anabaena variabilis* report that light of 520–680 nm wavelength caused photobleaching of chlorophyll *a* and phycobiliproteins. After 5 days of pre-irradiating cultures at $67.5\mu\text{Ei}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, chlorophyll *a* absorption at 480 nm (PS I) decreased by 20%, and chlorophyll *a* absorption at 680 nm (PS II) decreased by about 45%. It has been established that the mechanism of photodamage at the PS II reaction center is different than the phenomenom of photobleaching of chlorophyll in *Anabaena variabilis.* The phenomenon of photobleaching in *Ananaena variabilis* was found to be dependent on the presence of dissloved oxygen (Nultsch and Agel, 1986), while the phenomenon of photodamage at the PS II reaction center took place regardless of the presence of dissolved oxygen (Agel et al., 1987).

In an *indirect* way, algal dominance structure may have had a great deal to do with P–I curve differences across depth in the 1986 summer season at Wasilla Lake. Highest diatom relative biovolume at both sample depths occurred on 19 May, with diatom and bluegreen biovolume approximately equal in the surface population, and diatoms approximately 1.5 times bluegreen relative biovolume at 6 m. Both P–I curves on this date show equal α, but a higher P_m^B in the "epilimnetic" sample. This agrees with other studies in which principal species (e.g. diatoms) were

high-light adapted (Steeman-Nielsen and Jorgensen, 1968; Jorgensen, 1969; Perry et al., 1981). On 9 June and 21 July, when sample depths were separated by thermal stratification, epilimnetic P–I curves showed lower α than 6 m curves, as might be expected from the bluegreen dominated algal taxonomic structure. On 9 June, P_m^B was also lower in the epilimnetic phytoplankton population than that at 6 m. It is possible that the higher P_m^B seen in the epilimnetic phytoplankton population on 21 July (Figure 25**B**) was due to the significantly higher relative biovolume of diatoms in the epilimnion than at 6 m, but this seems doubtful, as bluegreens still made up approximately twice the relative biovolume of diatoms in the epilimnion (Figure 21). The pattern I observed on 9 June and 21 July of lower α in epilimnetic than metalimnetic phytoplankton populations agrees with recent findings of researchers studying the photosynthetic characteristics of *Synechococcus*, a small marine bluegreen alga. Both Glover et al. (1985) and Prezelin et al. (1986) showed higher α values with increasing depth in *Synechococcus*-dominated size fractions (picoplankton). Glover et al. (1985) also showed P_{max} to increase with depth in *Synechococcus* populations in the Gulf of Maine.

The classifying of algal divisions as genotypically "high" or "low" light-adapted based on P–I curves from algae grown at high and low irradiances should at this point be regarded as a well supported working hypothesis for future studies. Exceptions to how algae might be expected to respond photosynthetically to high or low irradiance according to their proposed genotypic light adaptation

exist in the literature. An example is the diatom *Ditylum brightwellii* (Perry et al., 1981), which showed decreased α and P_m^B at 300 μEi·m^{-2}·s^{-1} culture irradiance compared to cultures grown at 4 μEi·m^{-2}·s^{-1}. More work must be done to test many species in each algal division to better delineate genetic light adaptation differences. Much of the work done to date has centered on a few species of diatoms, green algae, and dinoflagellates well established as laboratory cultures and easily available.

Algal Adaptation Response Time

The 4–5 day response time for phytoplankton to adapt to a new irradiance environment agrees well with findings of Collins and Boylen (1982), estimating photoadaptation to an increased or decreased light intensity to be 4 days with cultures of *Anabaena variabilis*. Similarly, Steeman-Nielsen and Park (1964), estimate phytoplankton in Friday Harbor, Washington to require 3.5–4.25 days to adapt to a changed light regime. The method of time-series analysis used in my study would be more reliable if sampling trips were made more frequently, adding more data points to linear regressions. A more direct method such as that used by Steeman-Nielsen and Park (1964) of holding a subthermocline sample in a large transparent container in the epilimnion and conducting P–I experiments with aliquots of this sample at regular time intervals would be logistically and analytically easier to carry out. However, the holding of phytoplankton populations in containers for several days may introduce substantial artifacts to the

containers for several days may introduce substantial artifacts to the rate of adaptation by phytoplankton to a new irradiance environment, due to DIC depletion, nutrient depletion, etc, within the containers (Cohen and Church, 1981).

Summary

Wasilla Lake appears to be eutrophic based on data considered here. The lake's urban setting gives it a high economic value, especially to homeowners with lakeshore property. Wasilla Lake's heavy recreational use also makes water quality important. Further work with more thorough sampling is needed to determine possible future concerns regarding the water quality of the lake. Future work should provide thorough sampling through the water column in several locations in both east and west basins of Wasilla Lake through a period of one or more years. Nutrient concentrations, algal taxonomy and biomass, dissolved oxygen concentrations, and primary production should be part of such a study. Results of future work may dictate consideration of lake management alternatives to improve water quality.

To my knowledge, this study presents the first P–I curves from natural algal assemblages dominated by bluegreen species. Data presented here suggest that the pattern of P–I curve shape above and below the thermocline in Wasilla Lake was very different than the pattern usually observed in the oceanic environment, primarily because of different algal community composition. The fact that bluegreen dominated phytoplankton in Wasilla Lake showed a pattern of P–I curve shapes from populations above and below the thermocline very different from P–I curve shapes of oceanic diatom or green algae populations across pycnocline structures, supports the classification of algal groups by "genotypic adaptation" to irradiance proposed by Richardson et al. (1983). The findings of Agel et al. (1987)

suggest that planktonic bluegreen algae may be "adapted" to low irradiance environments simply in that they do not posess an adequate system of protection from photodamage at relatively high irradiances.

Phytoplankton communities in high latitude lakes do not appear to compensate for the short ice-free season by adapting more quickly to a changing irradiance environment than do temperate phytoplankton communities. The response time of 4–5 days estimated here does not differ markedly from the 3.5–4.25 day response time found by Steeman-Nielsen and Park (1964) for phytoplankton in Friday Harbor, Washington.

Because the $NaH^{14}CO_3$ stock used in P–I experiments on the first three sampling trips in 1986 was found to be contaminated with particulate ^{14}C, P–I curves presented here must be viewed critically. Although the 30 June 1986 epilimnetic P–I experiment was the only one in which some mean blank DPM counts were higher than mean incubation bottle DPM counts, some distinctions in P–I curve shape in the 19 May and 9 June experiments may have been blurred due to random variation in particulate ^{14}C contamination dispensed to individual incubation bottles.

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Appendix A

— Temperature (°C), conductivity, and DIC through depth, 1985 (Figures 28–32).

— DIC concentration in the wind mixed zone and at 6 m, 1986 (Figure 33).

— Temperature(°C) and conductivity through depth, 1986 (Figures 34–39).

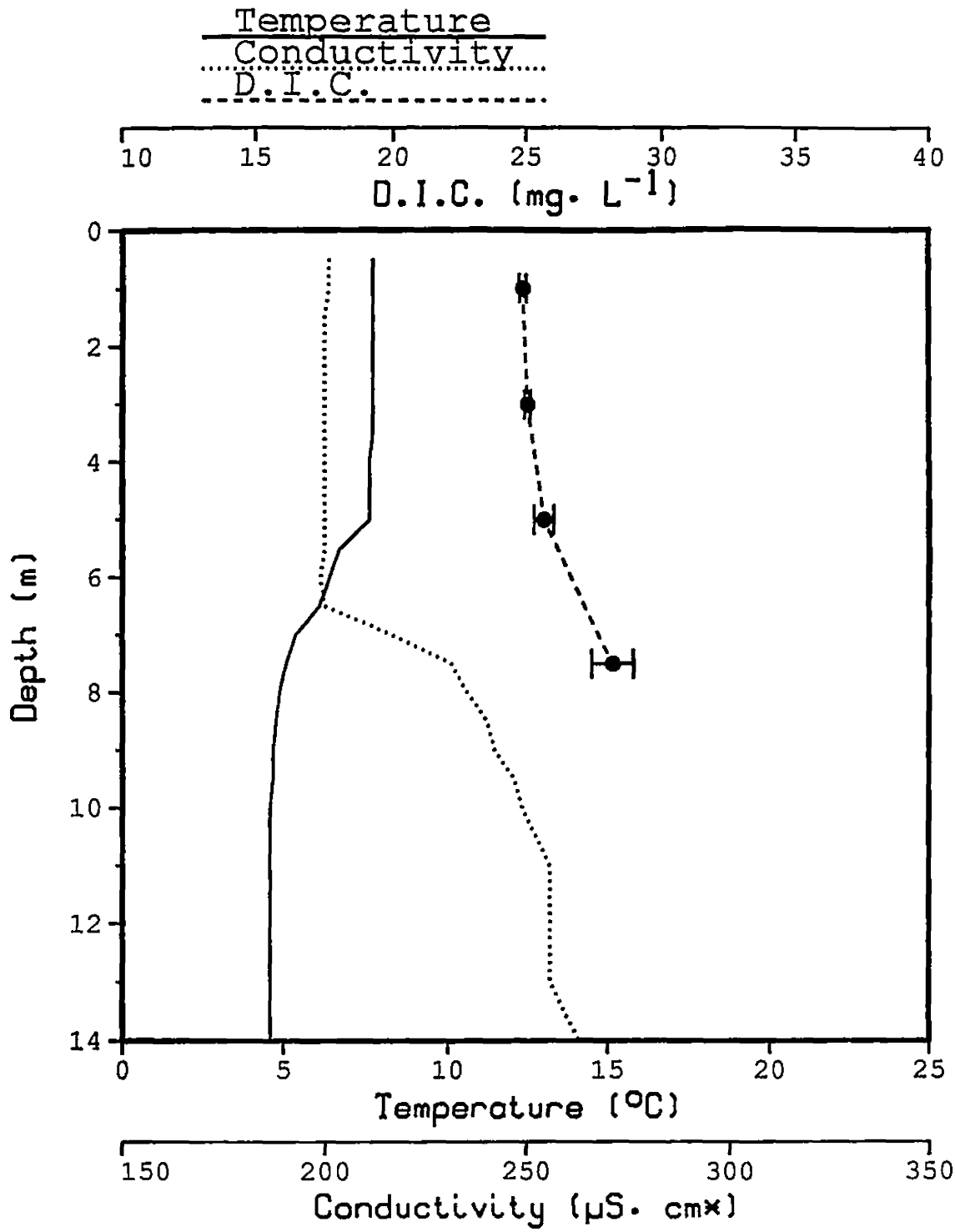


Figure 28. Temperature, conductivity, and D.I.C. with depth on 22 May, 1985. Error bars represent ± one standard error about the mean.

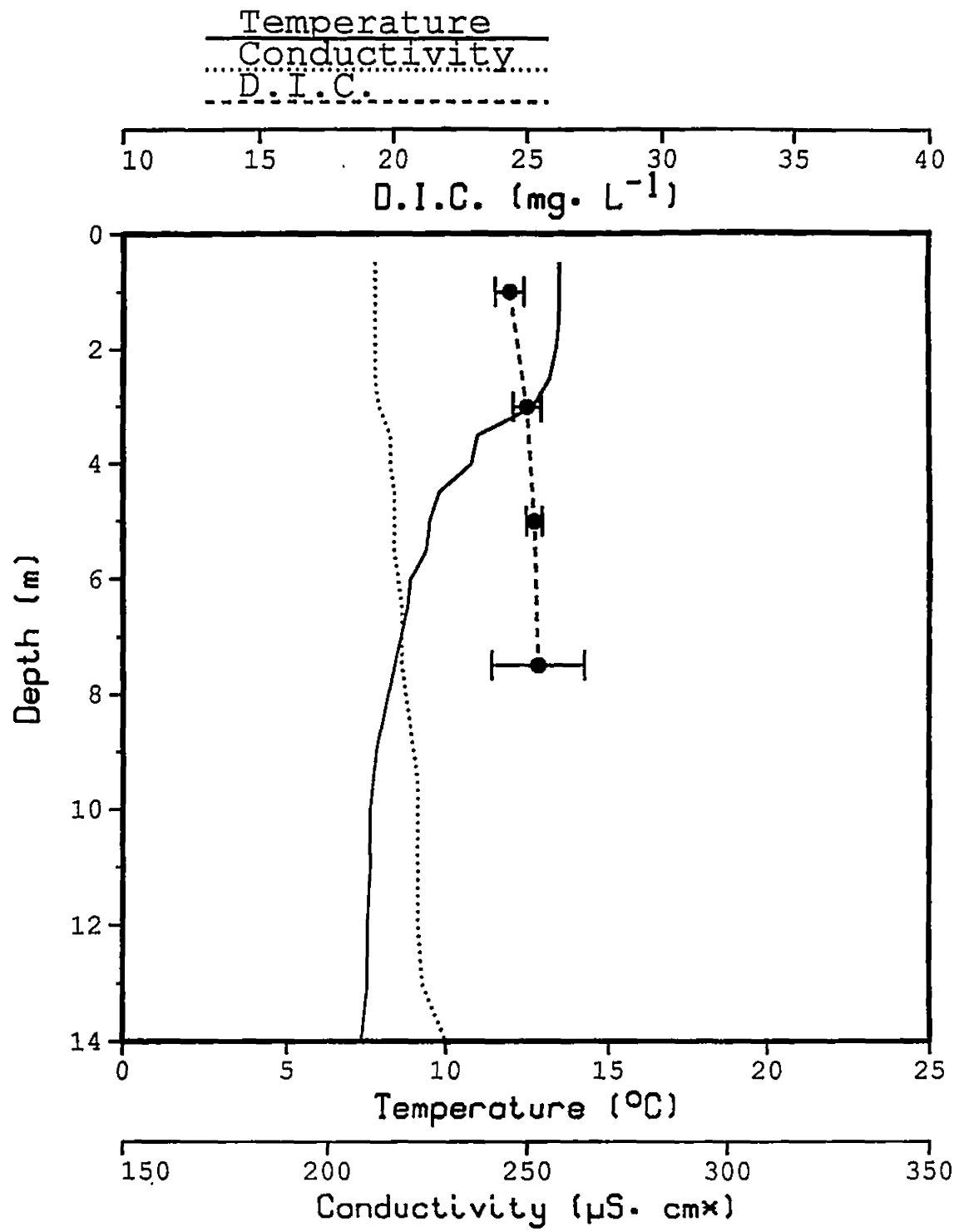


Figure 29. Temperature, conductivity, and D.I.C. with depth on 11 June, 1985. Error bars represent ± one standard error about the mean.

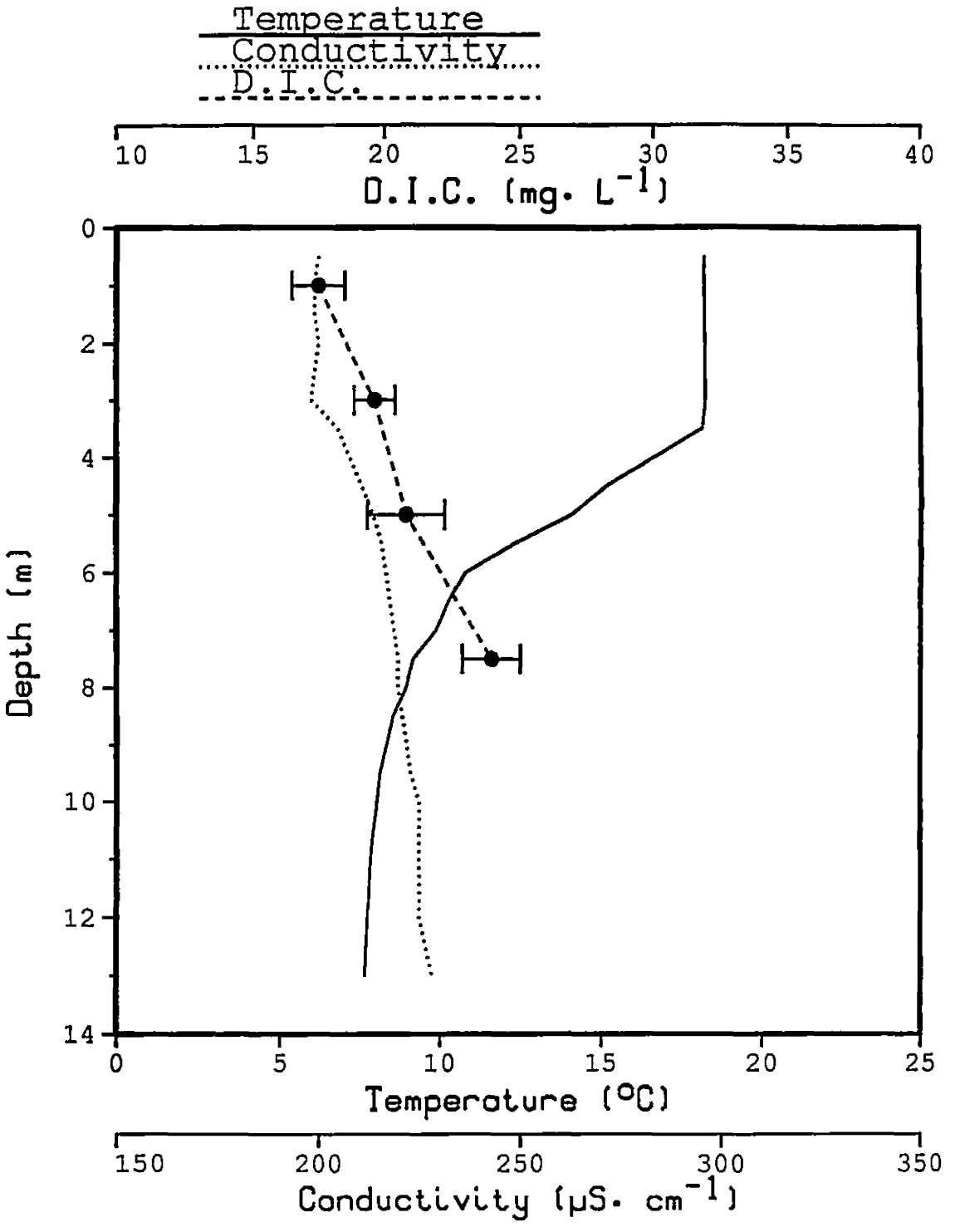


Figure 30. Temperature, conductivity, and D.I.C. with depth on 8 July, 1985. Error bars represent ± one standard error about the mean.

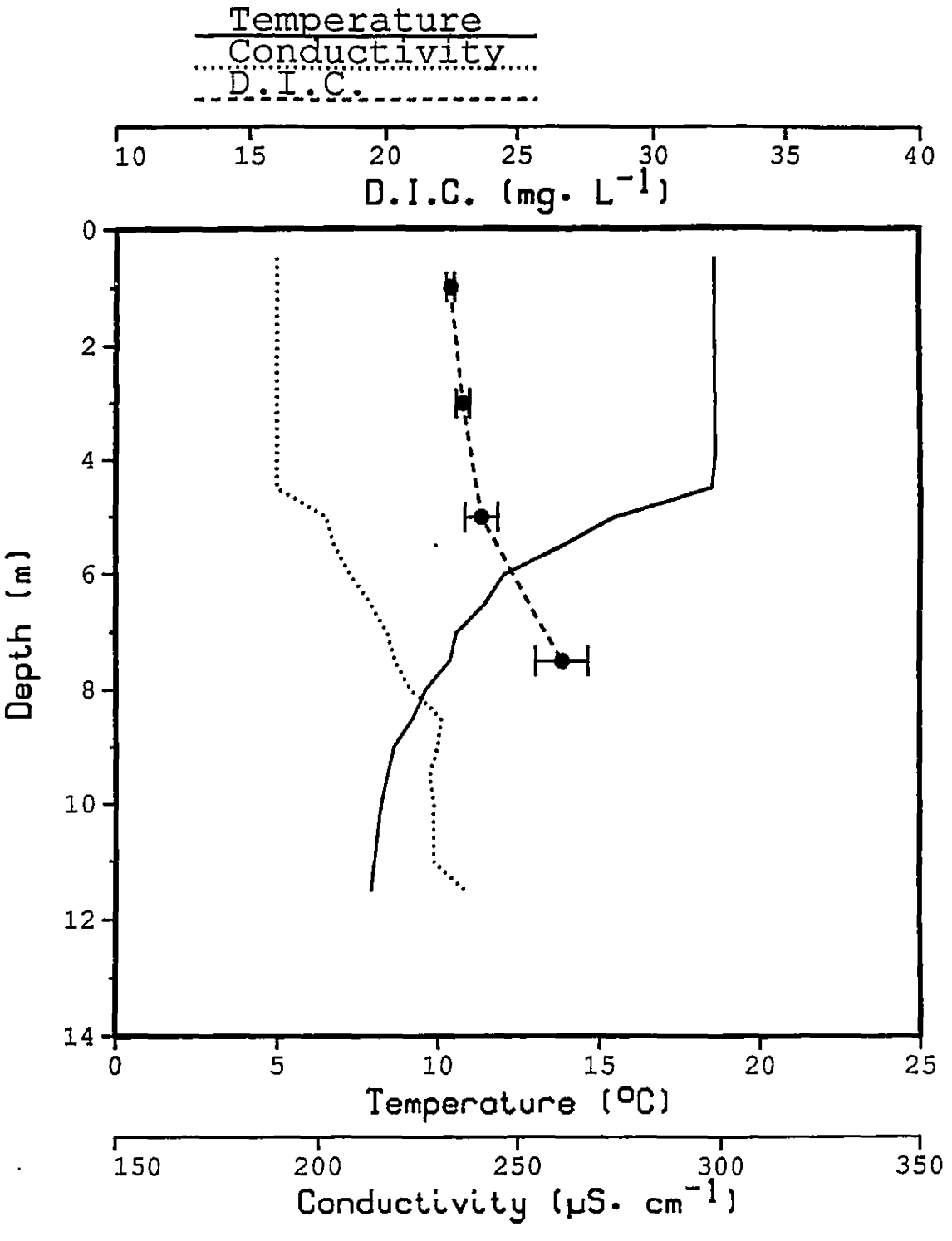


Figure 31. Temperature, conductivity, and D.I.C. with depth on 24 July, 1985. Error bars represent ± one standard error about the mean.

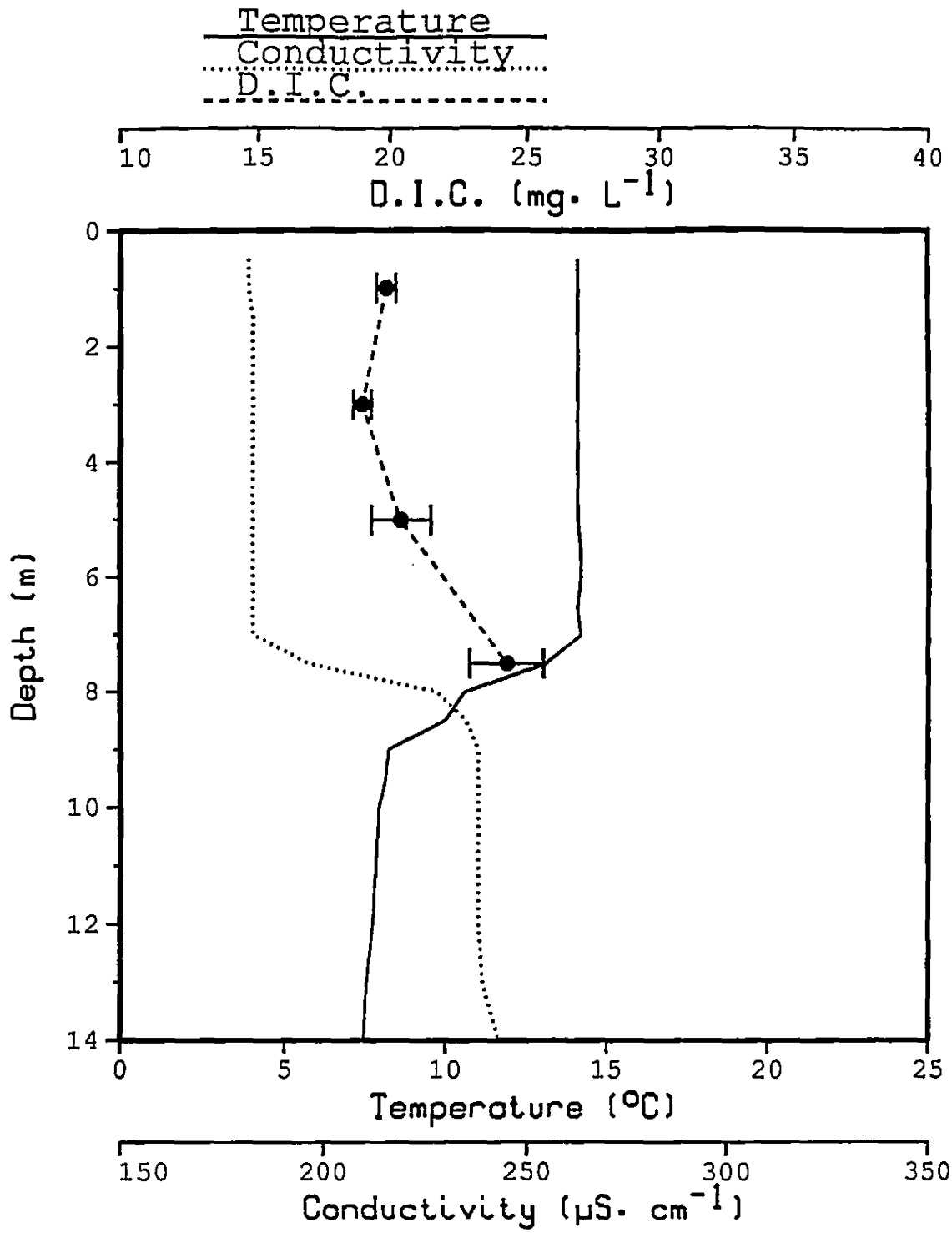


Figure 32. Temperature, conductivity, and D.I.C. with depth on 21 August, 1985. Error bars are ± one standard error about the mean.

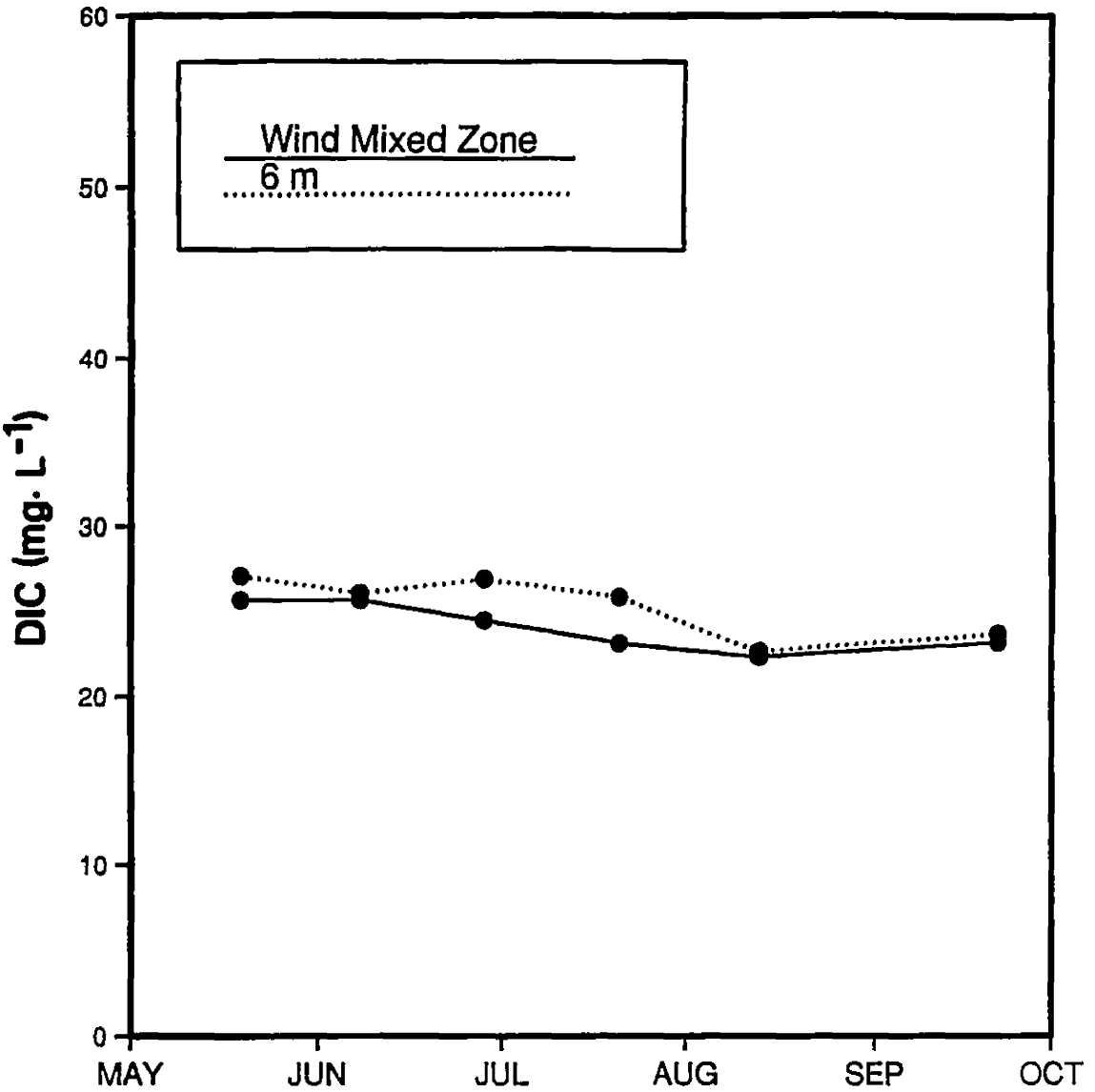


Figure 33. DIC concentration in Wasilla Lake, 1986. Error bars (obscured by mean symbols) are ± one standard error of the means.

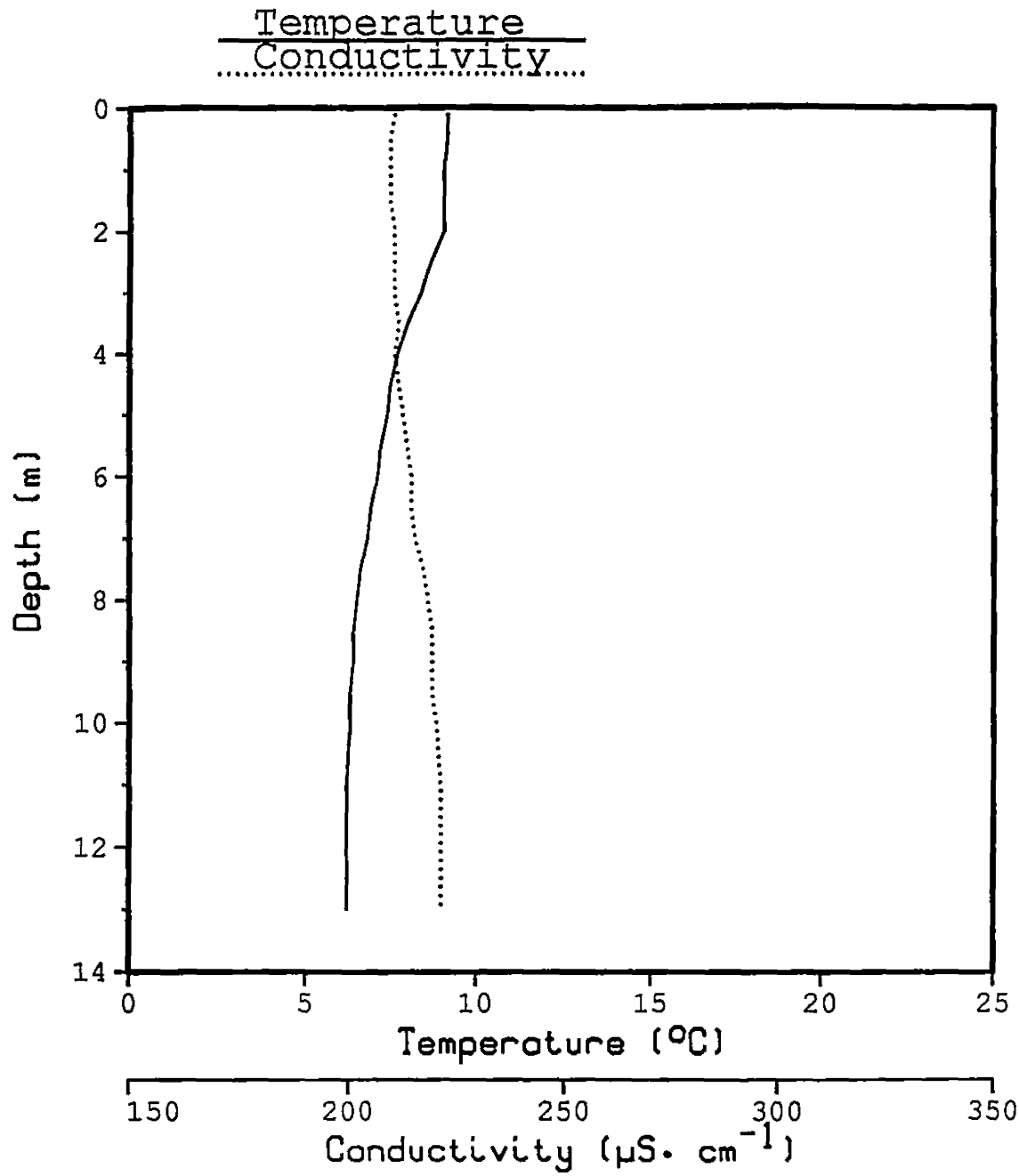


Figure 34. Temperature and conductivity with depth on 20 May, 1986.

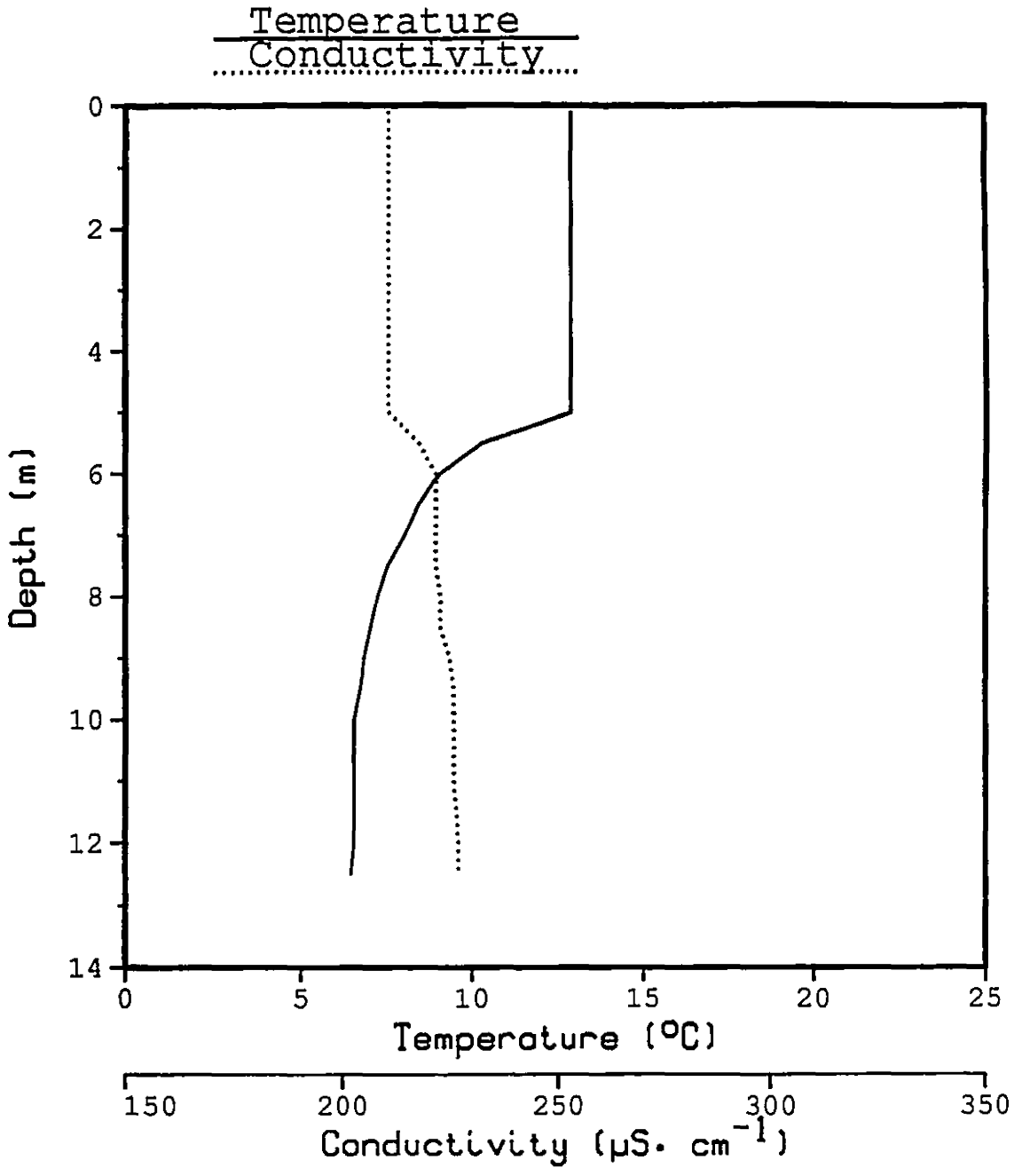


Figure 35. Temperature and conductivity with depth on 8 June, 1986.

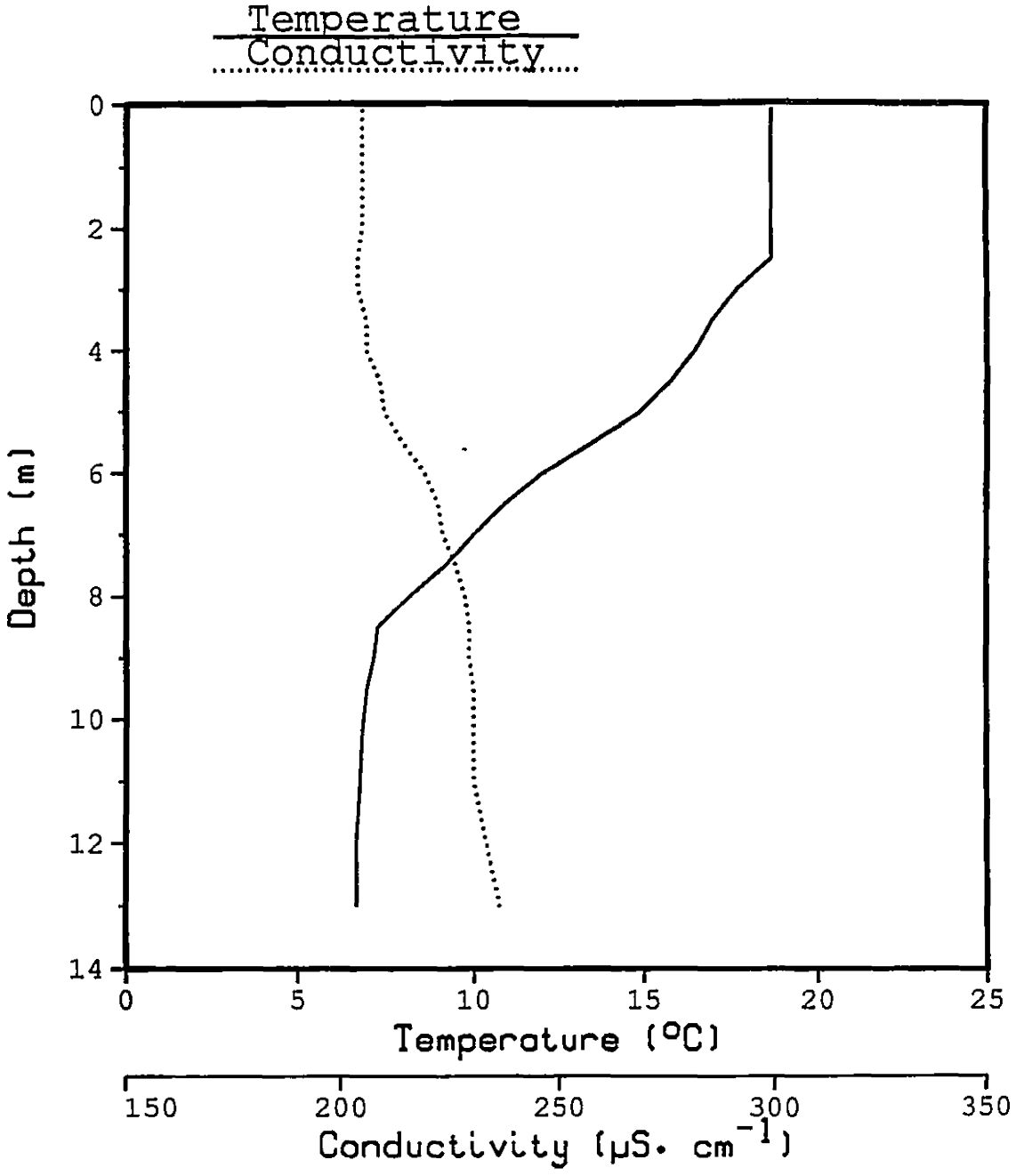


Figure 36. Temperature and conductivity with depth on 30 June, 1986.

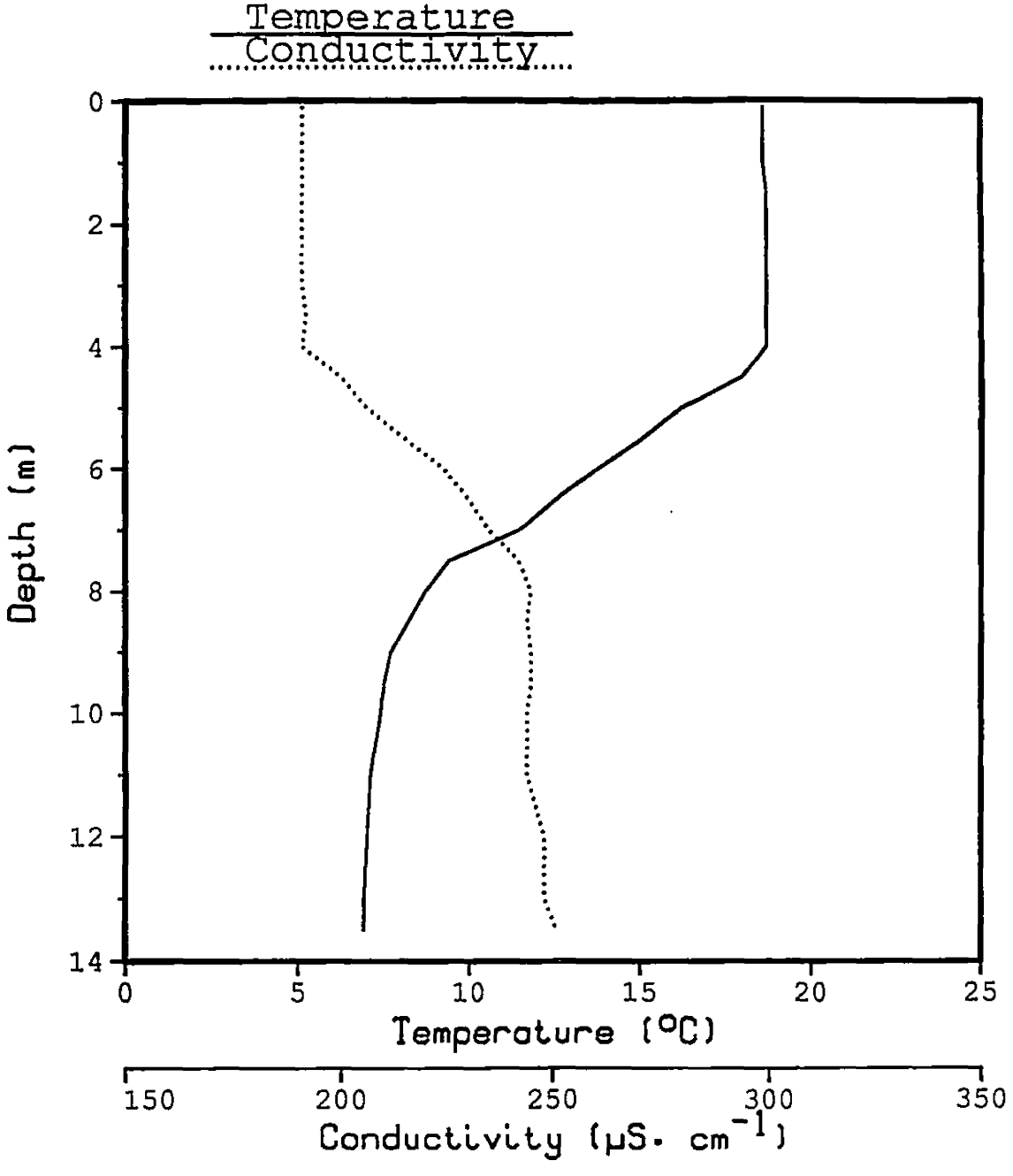


Figure 37. Temperature and conductivity with depth on 21 July, 1986.

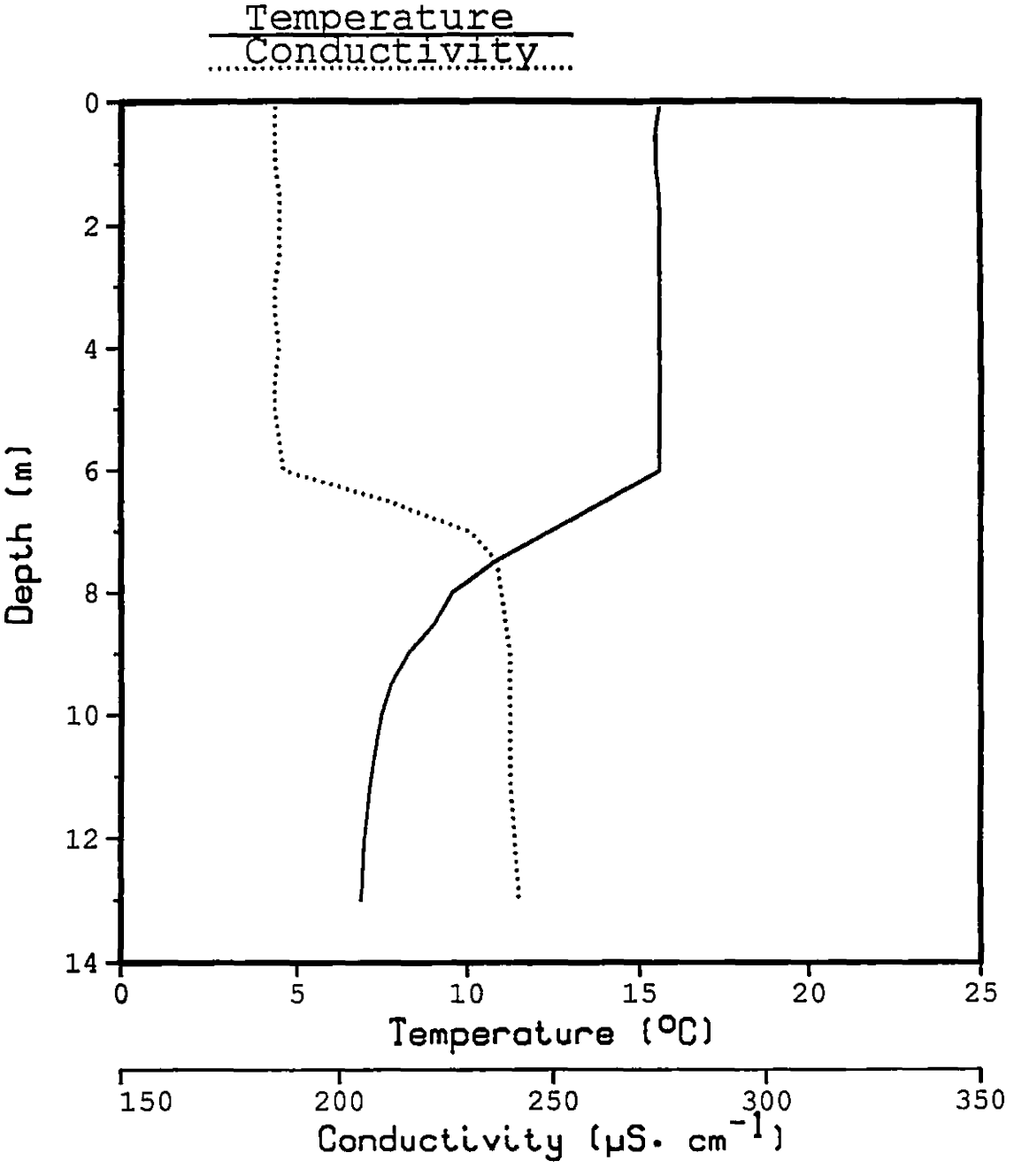


Figure 38. Temperature and conductivity with depth on 13 August, 1986.

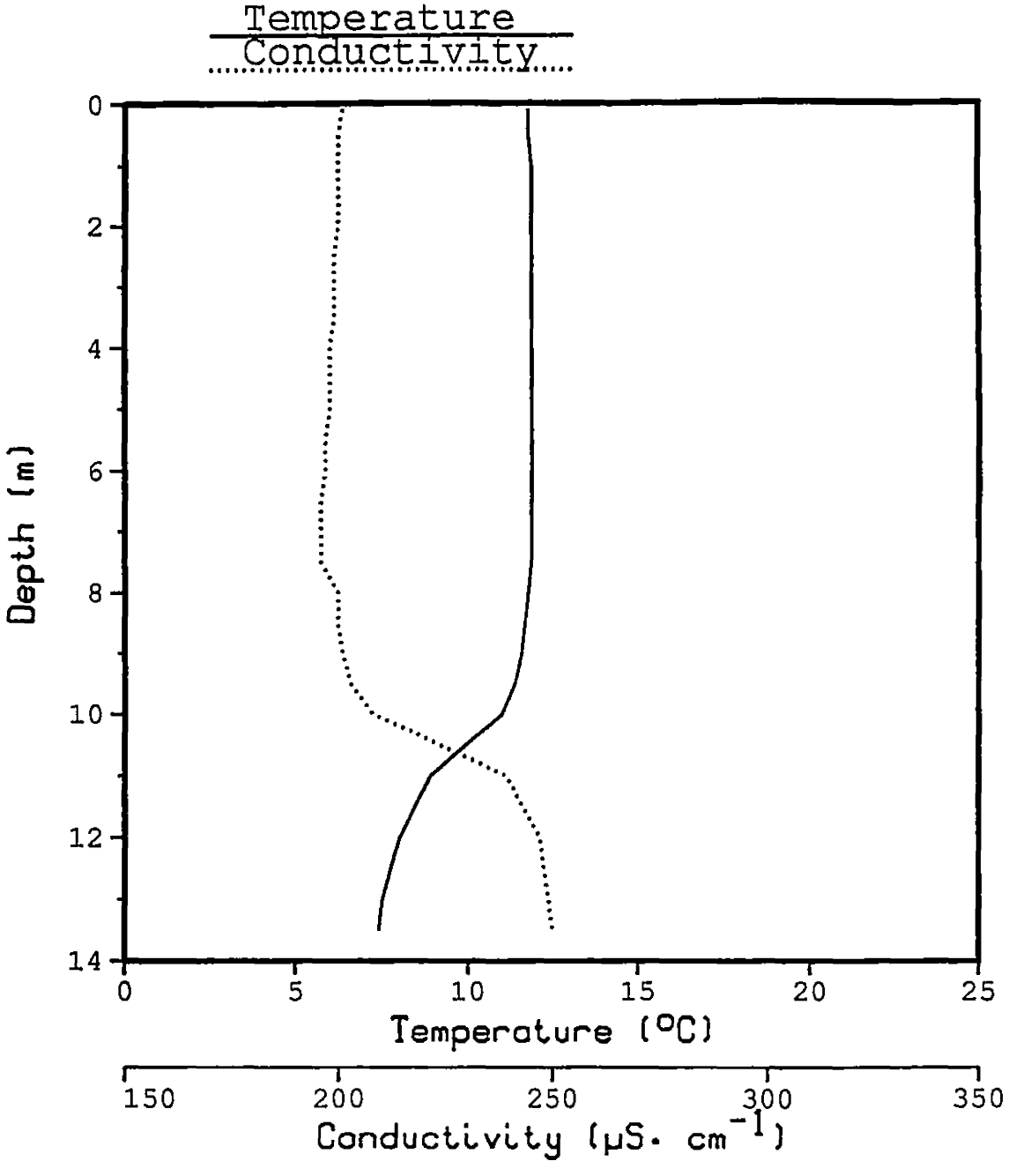


Figure 39. Temperature and conductivity with depth on 22 September, 1986.

Appendix B

— Letter to ADF&G Limnology Laboratory narrating analytical procedures in determining cause of high blank bottle values in 1985.
— Laboratory notes from analytical procedures described in above letter.

P.O. Box 1075
Fairbanks, Ak 99775
Nov. 18, 1986

Jim Edmundson
Alaska Department of Fish and Game
Limnology Lab
P.O. Box 3150
Soldotna, AK 99669-3150

Dear Jim:

My apologies for the delay in getting this letter off after I last talked with you on the phone. Enclosed are the data from experiments I ran this summer, trying to find out what was causing high blank values in my early photosynthesis/irradiance experiments. As I mentioned on the phone, I concluded that there was some sort of ^{14}C labeled particulate in the ampoules themselves, probably a bacterial culture from unfiltered lab water, or unautoclaved ^{14}C ampoules.

The first experiment that got me thinking the source of the high blank values might be within the ampoules was run on 9 July, 1986. I found no statistical difference in DPMs for filters from blank bottles of two treatments:

1. Wasilla Lake water injected with ^{14}C and filtered immediately.
2. Wasilla Lake water injected and filtered as in 1., but first autoclaved and cooled.

This indicated that high blank values weren't coming from immediate uptake by algae or bacteria in the lake water.

After this, I decided to compare the ^{14}C stock I was using from your lab with some ^{14}C stock that an Institute of Marine Science prof., Dr. Don Schell had. This solution had an activity of .75 $\mu Ci.ml^{-1}$. I injected bottles with .6 ml to get appr. 10^6 DPM. The bottles injected with your ^{14}C(called USGS ^{14}C in my lab notes) recieved .05 ml; this this usually produced about 2 x 10^6 DPM per bottle. I used plain tap-distilled water in the bottles, rather than lake water. All bottles were

injected with ^{14}C then inverted several times and immediately filtered. Filters were acidified before adding scintillation cocktail. Filters from bottles injected with your ^{14}C stock had a mean DPM about 5 times higher than those injected with Schell's ^{14}C (n=6). However, results were muddled by the fact that the ^{14}C ampoules from your lab had been opened several days prior and placed in a scint vial. Schell's ^{14}C ampoules were opened immediately before this experiment and also placed in a scint vial. Thus, it seemed possible that a culture had developed in your ^{14}C after the ampoules were opened but before the experiment was run.

The final experiment was performed in the field with Wasilla Lake water collected several hours before experiments were run. Here again, filters from your ^{14}C stock had means 5 to 6 times higher than Schell's ^{14}C stock(n=3). Radiocarbon from both sources was placed in clean scint vials the day before the experiment; this eliminates the possibility of bias that concerned me in the last experiment. The fact that the two ^{14}C sources yield such different blank values also eliminates the possibility that high blanks might be a result of some reaction between the lake water and the ^{14}C, precipitating ^{14}C in a form that acidification does not drive off. I concluded the difference between blanks from the two different ^{14}C sources was particulate contamination in the ^{14}C obtained from your lab. At this point, it might be interesting to filter some ampoules and look at them under the microscope to see exactly what is in the ampoules.

You may recall last year Paul Woods and I were concerned that the source of high blanks in 1985 may have been that the Lugol's acetate injected into blank bottles with ^{14}C did not kill phytoplankton immediately. I have found that most of my blanks from the 1985 field season fall within the range of those counted this field season(about 200—1000 DPM), thus the particulate ^{14}C contamination would explain this. However, the last two field trips of 1985 have still got me scratching my head over what happened to the blanks. It is still possible that the species composition in the lake at that time was able to continue autotrophic

or heterotrophic uptake in the presence of Lugol's. This season, field trips were within a week of the same times at which blanks were so high last year, but the problem didn't come up again. I missed 6 weeks between Aug 14 and Sep 22, however. Afield trip in the middle of this period may have shown something.

I am sending along results of two experiments on Wasilla Lake water testing the hypothesis that algae or bacteria continue to take up ^{14}C in the presence of Lugol's acetate. Both experiments indicate that phytoplankton were killed immediately, as significant uptake did not take place after Lugol's was added. However, these experiments were run 9 to 14 days after water was collected from Wasilla Lake. Samples were stored at appr. 10°C. Controls with ^{14}C but no Lugol's showed uptake was still taking place at the time of the experiment, but of course species composition may not have been the same after several days storage.

If you folks do any further work concerning the ^{14}C contamination question or the use of Lugol's as a kill agent, I'd appreciate a copy of your notes, to satisfy my curiosity.

Sincerely,

Kyle Vaught

The following represent laboratory notes originally copied from a laboratory notebook and enclosed with the previous letter in this appendix. These originally handwritten notes are typed here to aid in clarity.

7/9/86

Experiment to determine where high zero-time blank values are coming from

Question: What is responsible for high blank values encountered thus far?

Possible Answers:

1. Rapid uptake of ^{14}C.
2. Radiotagged bacteria in ^{14}C ampoules.
3. Radiocarbon contamination of Wasilla Lake water.
4. Adsorption of ^{14}C to abiotic or dead organic material that is not driven off by acidification.

Procedure:

1. In the field, filter zero time blanks(triplicate) and treat 2 ways:1) put filters directly into scint cocktail, 2)acidify filters with 300 μL 0.5N HCl in fume hood for 2 hrs., then add scint cocktail. Prepare triplicates of both treatments for 0-2 m sample and 6 m sample.
2. In the lab, filter 3 zero time blanks of filtered lake water(FLW) to be added directly to scint cocktail, and 3 to be acidified and then added to scint cocktail.
3. Autoclave 3 zero time blank bottles of FLW and whole lake water(WLW). Inject w/ ^{14}C and filter immediately. Acidify filters before adding scint. cocktail.
4. Prepare a series of "blanks" or "background" counts. First, make counts of 6 empty scint vials . Next, add 10 mls of scint cocktail and count again. Filter 3 incubation bottles of uninjected WLW and add filters to 3 of scint vials. Add clean filters to other 3 scint vials, count again. Finally, add 300 μL HCl(0.5N) to vials and count again.

Results of Experiment

Sample	Treatment	$\overline{X}$DPM	s.d.
0-2 m	WLW,plain	1229.0	247.7
	WLW, acidif.	806.4	169.4
6 m	WLW,plain	960.2	387.5
	WLW,acidif.	405.5	50.7
surface	FLW,plain	497.2	171.3
	FLW,acidif.	524.7	229.6
	FLW,acidif.,autocl.	377.4	49.2
	WLW,acidif.,autocl.	501.5	224.8
	WLW,acidif.,no ^{14}C	48.4	2.5
surface	WLW,no ^{14}C,unacidif.	53.0	8.2
	filter,scint,acidif.	111.9	3.2
	scint cock.	53.1	9.8
	empty vials	—	—
	50 μL ^{14}C,scint	1.084×10^6	1.352×10^3

Analysis of 7/9/86 Experiment to Find
Cause of High Blanks

Comparison of FLW,WLW: bottles autocl., filters acidified

FLW, autocl.,acidif.— $\overline{X}$DPM=377.4, $s^2=2.42 \times 10^3$
WLW, autocl., acidif.—$\overline{X}$DPM=501.5, $s^2=5.05 \times 10^4$
$t = \frac{501.5-377.4}{132.8} = 0.935$, 3 d.f. $P>0.40$

FLW and WLW are insig. different in means because of high s^2 on WLW triplicate.

Comparison of WLW,filters acidif. vs. WLW autocl., acidif.

WLW(0-2 m), acidif., $\overline{X}$DPM= 806.4, $s^2= 2.87 \times 10^4$
WLW(surf),autocl.,acidif., $\overline{X}$DPM= 501.5, $s^2= 5.05 \times 10^4$
$t = \frac{806.4-501.5}{162.5} = 1.88$ $P>0.20$
means not sig. different

Comparison of WLW, acidif. vs. WLW, autocl., acidif.

WLW(6 m), acidif. $\overline{X}$DPM= 405.5, $s^2=2.57 \times 10^3$
WLW(surf),autocl.,acidif.,$\overline{X}$DPM=501.5, $s^2=5.05 \times 10^4$
$t = \frac{501.5-405.5}{133.0} = 0.72$ $P>0.50$
means not sig. different.

From the above results, the following conclusions can be drawn.

1) Wasilla Lake water is not radiocarbon contaminated.
2) It appears that filters are ^{14}C contaminated, as plain filters are higher in counts than filters that plain lake water was run through. The acidification step will remove this contamination.

3) From these data, it appears that the source of high blanks is coming from ^{14}C ampoules themselves, as bottles autoclaved before inoculation are not sig. lower in DPMs after acidification than bottles of WLW not autoclaved. However, the s.d. of the WLW, autocl, acidif. treatment is quite high, making statistical comparisons somewhat shakey.

7/29/86

Results of Field Trip 4 Zero-time Blank Bottle Experiment

The below table represents $\overline{X}$DPM of 3 replicates for zero-time blanks prepared from Schell's ^{14}C, at two depths. Standard deviations follow mean values in parentheses.

	^{14}C Source			
Depth	Schell's	USGS	t	P
0–3.5 m	46.8(0.5)	288.9(71.8)	5.83	<0.05
6 m	45.6(1.0)	250.9(24.3)	14.7	<0.01

Analysis:

These zero-time blanks were all treated equally, ^{14}C from both sources was taken from fresh ampoules approx. 24 hrs. before inoculation and placed in a clean container for pipetting. These data seem to conclude that ^{14}C obtained from the ADF&G Limnology Lab contained ^{14}C labeled particulate matter that retained it's ^{14}C label through acidification. It seems most likely this is a radiolabeled bacterial culture resulting from unfiltered lab water or unautoclaved ampoules. The fact that blanks from Schell's ^{14}C and USGS ^{14}C do not vary with depth appreciably further supports the conclusion that the high blanks are not due to rapid algal or bacterial uptake, but particulate ^{11}C contamination. Dark bottle triplicates at 0-3.5 m($\overline{X}$=70.5, s.d.=10.78) and at 6 m($\overline{X}$=127.7, s.d.=3.3) varied by a factor of nearly 2 and the fact that the blanks do not show this variance adds weight to the conclusion that the high blanks are not due to rapid uptake.

First comparison of blank bottles using two different ^{14}C stocks. †

	DPMs after filtration, acidification	
	Schell's ^{14}C stock	USGS ^{14}C stock
	80.5	286.9
	70.9	426.2
	65.5	856.8
	77.9	282.3
	74.7	302.6
	70.6	314.4
$\overline{X}$	73.4	411.5
s^2	29.8	50402.7

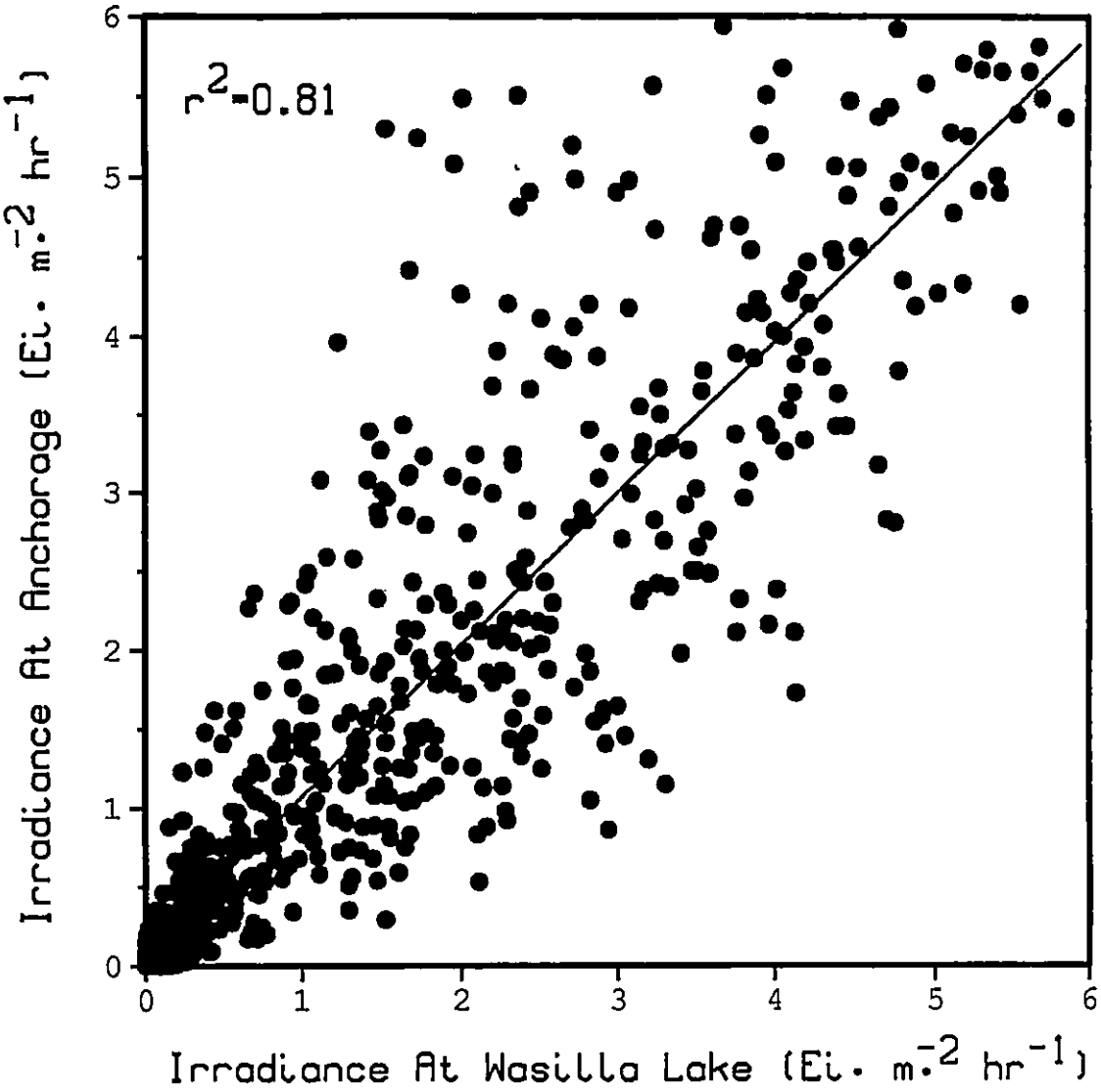
$\overline{X}$ total DPMs injected with USGS ^{14}C(50 μL)= 2586.2, s.d.= 451.5(n=3)
Total DPMs injected with Schell's ^{14}C(600μL)= 291,866.8(n=1).

t= 3.69, P<0.02

† Analysis done at Water Research Center lab, distilled water used in bottles.

Appendix C

— Correlation of irradiance recorded at Wasilla Lake and Anchorage.


r^2=0.81
Irradiance At Anchorage (Ei. m^{-2} hr^{-1})
Irradiance At Wasilla Lake (Ei. m^{-2} hr^{-1})
0
1
2
3
4
5
6