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Photo-degradation of methylmercury in the Sacramento-San Joaquin Delta Estuary

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PHOTO-DEGRADATION OF METHYLMERCURY IN THE
SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

A Thesis

Presented to

The Faculty of the Moss Landing Marine Laboratories

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Marine Science

by

Amy Adele Byington

May 2007

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ABSTRACT

PHOTO-DEGRADATION OF METHYLMERCURY IN THE SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

by Amy Adele Byington

Degradation of methylmercury (MMHg) by sunlight could be the most effective mercury detoxification mechanism to reduce MMHg levels in the surface waters of the Sacramento – San Joaquin Delta Estuary (Delta). MMHg photo-degradation was investigated using *in situ* bottle incubation experiments. Photo-degradation in the Delta is found to be abiotic and mediated by sunlight. Light-exposed samples demonstrated that wavelengths in the PAR spectrum degraded MMHg in surface waters, and comparable rates of MMHg-degradation were observed in unfiltered and filtered samples. The change in MMHg concentration was assessed relative to total light exposure and a MMHg degradation rate of $0.00296 \pm 0.0003 \text{ ng m}^2 \text{ L}^{-1} \text{ mol}^{-1}$ was determined for the Delta. Through a mass balance assessment, it was observed that photo-degradation of MMHg is the largest sink for MMHg in surface waters. The estimated loss of MMHg to photo-degradation in the Delta is $18.9 \pm 6.4 \text{ g d}^{-1}$.

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INTRODUCTION

California's Coastal Mountain range produced 88-90% of all mercury mined in the United States during 1850-1980 (1). Twelve percent of the mined mercury from the California Coastal Range was transported to placer, hard-rock and dredging gold mining operations in the Sierra Nevada and Klamath-Trinity Mountains, while the rest was transported around the Pacific Rim and to other western states. During historic gold mining operations, large amounts of mercury were lost into California's Mountain Ranges: contaminating mountain waterways, Central Valley Rivers, and the Sacramento-San Joaquin Delta Estuary (Delta) (1 - 8).

The Delta is a part of the largest estuary on the west coast of the United States and receives 85% of its waters from the Sacramento, San-Joaquin, Mokelumne, Cosumnes, and Calaveras rivers (8). These rivers and their watersheds carry 47% of California's total runoff, which drains many historic mercury and gold mining regions. With a water surface of 61,000 acres, the Delta's physical make up includes arrays of large rivers, small tributaries, marshes, diked islands, and flooded tracts all with estuarine influences (9, 10). The nature and variety of these aquatic environments uniquely promote the conversion of the less harmful ionic and elemental species of mercury into the toxic form of the metal: methylmercury (6). This conversion occurs in the sediments at the oxic/anoxic interface principally through the action of sulfate-reducing bacteria (11). Aqueous monomethylmercury (MMHg) concentrations in the Delta range from <0.022 to 0.08 ng L⁻¹ for filtered (passing through a 0.45µm filtered) samples and 0.08 to

0.34 ng L⁻¹ for unfiltered samples with greater concentrations during the winter or wet season in northern California (2, 5, 8).

Increased levels of MMHg in upper trophic levels of an aquatic food chain are a human and ecological health risk (8, 12-15). In 1971, a human health advisory for mercury was issued for striped bass (*Morone saxatilis*) from the Delta (7), and in 1990 the Delta was identified as being impaired by mercury by the Regional Water Quality Control Board (8). As of 2005, twenty water bodies in California have fish advisories for the consumption of mercury (1). Moreover, there are currently Total Maximum Daily Load (TMDL) reduction activities for MMHg being promulgated by the Central Valley Regional Water Quality Control Board for the Delta region (see http://www.waterboards.ca.gov/central_valley/programs/tmdl/deltahg.html).

A study by Brumbaugh and others (16) showed significant correlations between MMHg fish concentrations and aqueous MMHg, concluding that aqueous MMHg is a good predictor of fish MMHg concentrations. Similar results have been seen between aqueous MMHg and fish MMHg concentrations in the Delta (8). Again, suggesting that a controlling factor of MMHg in upper trophic levels of the aquatic food chain is aqueous MMHg concentrations.

During low flow regimes in 2000, the concentration of MMHg imported into the Delta (Sacramento River at Greene's Landing, 38° 20.721' N 121° 32.812' W) was greater than the MMHg exported out of the Delta (San Francisco Bay, export pumps to Southern California) (4, 8). The same trend occurred during the 2001 summer: MMHg concentrations decreased down the Sacramento River towards San Francisco Bay with

concentrations decreasing 30 to 60% in the vicinity of Rio Vista (38° 10.030 ' N 121° 40.517 ' W) (8). A MMHg mass balance by Heim (6), showed an unidentified loss of 10 to 17 g MMHg day⁻¹ for the entire Delta region and as of June 2006 a loss of 6.7 g MMHg day⁻¹ was estimated by Woods and others (8) for the Delta. Understanding the processes responsible for this loss of MMHg in the water column will enhance our knowledge of MMHg cycling and transport in the Delta.

Solar radiation entering the water column can play an important role in MMHg cycling. Recent studies have shown that photo-degradation of MMHg by sunlight can occur in surface waters of lakes (17 - 20), seawater (21), and in the Florida Everglades (22). The lake studies show that photo-degradation is influenced by aqueous MMHg concentration and light intensity. The seawater study shows MMHg being degraded by sunlight (>280 nm), ultraviolet light A (320-400 nm), and ultraviolet light B (280-320 nm). Suda and others (21) suggested that the singlet oxygen generated by seawater exposure to sunlight was the reactive oxygen species responsible for the degradation of the aqueous MMHg. Krabbenhoft and Hurley (22) found a north-to-south increasing trend of photo-degradation in the Everglades. They suggested that this spatial trend was controlled by light penetration limitations of dissolved organic carbon (DOC).

It is hypothesized that photo-degradation is a significant sink for MMHg in the surface waters of the Delta. Photo-degradation was investigated at several locations to fill in data gaps in conceptual understanding of sources, sinks, and cycling of MMHg in the Delta. This work is part of a larger study to investigate the transport, cycling, and fate

of mercury and monomethylmercury in the San Francisco Delta and its tributaries.

Portions of this larger study as they relate to photo-degradation will be discussed here.

MATERIALS AND METHODS

Bottle Incubations. To assess the relative significance of photo-degradation, *in situ* bottle incubation experiments were conducted on July 17 and December 14, 2004; April 20 and August 24, 2005; and March 2 and July 11, 2006 at one of four locations within the Delta: Snug Harbor on Steamboat Slough, Twitchell experimental ponds on Twitchell Island, B&W Resort on the Mokelumne River, and River Port Landing on the San Joaquin River (Figure 1). Samples were incubated in Teflon[®] bottles under *in situ* light conditions and then preserved in the field by acidification to 0.5% hydrochloric acid, using reagent grade acid. After preservation, samples were kept dark and cold until analysis.

Figure 1. The Sacramento – San Joaquin Delta Estuary (Delta) and locations within the Delta where the *in situ* bottles incubation experiments were performed (stars) and the Department of Water Resources water quality sites where secchi disk depths were measured (circles).

Prior to each incubation experiment, surface water (ten liters) was pumped and filtered using a peristaltic pump with FEP Teflon® and C-flex pump head tubing with a 0.45 µm Pall Gellman capsule filter. Filtering was done to remove biological influences of photosynthetic organisms and bacteria while reducing analytical variability due to particulates. While filling the polycarbonate carboy, or within two hours of collection

(keeping sample cold and dark), a low level spike (as CH_3HgOH) was added resulting in a total concentration of about 0.2 ng L^{-1} for all incubations (in July 2004, 0.4 ng L^{-1} was added). Ambient dissolved MMHg concentrations were estimated to be one half of the unfiltered concentrations determined for the Delta (3, 8). Spike levels were four to seven times greater than ambient dissolved value for the Delta (0.058 ng L^{-1}), yet well within low environmental levels. Spiking was necessary to maintain concentrations above the method detection limits and to assure good analytical reproducibility.

After homogenization, spiked river water was distributed into 500 mL clear and opaque (solid black) FEP Teflon[®] bottles. Sample bottles on the surface were incubated with 50% head space while bottles at depth were incubated with 25% headspace. Sample bottles were kept cold and dark until deployment. For deployment in a tidal dominated system, bottles were randomly grouped and placed into mesh bags (13mm polypropylene mesh) for bottle security. Bottles at the surface floated horizontally, while bottles at depth were placed horizontally on a weighted ring that was suspended from a surface float. Suspending the bottles from the float allowed the bottles to rise and fall, maintaining the same depth below the surface during tidal cycles. Resting depths of bottles were 0.58, 0.47, 0.78, 0.79, and 0.51 meters below the surface, for experiments conducted during December 2004, April and August 2005, March and July 2006 respectively (July 2004 was surface only). Bottles at depth were not shaded by the surface float. Samples in black opaque Teflon[®] bottles were incubated as experimental controls. The resting depths for the dark bottle controls were below the photic zone,

except for the July 2004 experiments where the dark bottle controls were incubated on the surface.

Sample bottles, carboys, and tubing were cleaned using 7.5 N reagent grade nitric acid (HNO_3) except for C-flex tubing which was cleaned using 1.2 N reagent grade hydrochloric acid (HCl). All bottles and carboys were filled with 0.5% v/v reagent grade HCl and stored until use. Ultra clean handling protocols were followed throughout equipment cleaning, sample collection, experimental manipulation, and analysis (23).

Clear FEP Teflon[®] bottles were shown to be optically transparent for 280-800 nm light wavelengths (25). Using a spectrophotometer (UV-VIS TU-1901), the transmission through a clear Teflon[®] bottle was also determined for wavelengths 280-700 nm. The bottle was determined to be nearly optically clear with respect to photosynthetically available radiation (PAR) (400-700 nm) (Supporting Information Figure S1). Two experiments were conducted to quantify the light attenuation due to the Teflon[®] bottles and mesh. PAR readings were recorded every two to four minutes alternating a PAR sensor into and out of a Teflon[®] bottle inside mesh.

In the field, two types of photo-degradation experiments were performed. One type of experiment consisted of a two point determination, an initial and final value, while the second type used multiple time point determinations during the experimental period. The field experiment on July 17, 2004 was conducted at Steamboat Slough and at Twitchell Island experimental ponds as a pilot study with one 500 mL bottle for each time point. At Steamboat Slough, the last time point had replicate samples. July 2004 was the only field event where unfiltered and filtered samples were incubated on the river

surface. In this experiment, the unfiltered surface sample was spiked and continuously mixed while aliquoting into the 500 mL bottles. Twitchell pond samples were not spiked since ambient dissolved concentrations were about 0.2 ng L^{-1} . All other field experiments consisted of multiple time point determinations with field duplicate samples at every other time point.

For the duration of each experiment, PAR was measured above the water surface using a quantum sensor with nanologger from Apogee Instruments, Inc. Any missing data was filled in with PAR data that was continuously measured at the University of California at Davis (UCD) climate station (25), which is located within 43 miles of all sites. PAR measurements ($\text{mol m}^{-2} \text{ s}^{-1}$) refer to the moles of photons in the PAR wavelengths striking a square meter of water surface every second. PAR measurements were multiplied by the number of seconds for each PAR integration interval, giving an estimate of total light exposure (mol m^{-2}): the moles of photons per square meter. For the remainder of this paper, MMHg concentrations will be presented in ng L^{-1} whereas light will be presented in units of mol m^{-2} .

For all experiments except July 2004, five PAR depth profiles of the water column were recorded using a Seabird-Seacat-19 CTD with a licor quantum sensor. Other water parameters measured were DOC, total suspended solids (TSS), water temperature, and specific ultraviolet absorbance at 254 nm (SUVA). Water temperature was recorded during CTD casts and averaged. Samples for DOC and SUVA were filtered ($0.45 \text{ }\mu\text{m}$) at time of initial water collection and frozen within 24 hours until

analysis (26-29). Samples for TSS were collected from the surface, at time of Teflon[®] bottle deployment, and placed on ice and kept cold and dark until analysis (30).

All statistical analyses were performed using the statistical package SYSTAT 10 with an alpha value of 0.05. Duplicate samples were pooled for all regressions when testing the significance, slope is not equal to zero, to satisfy the assumption of independence.

The percent light level for bottles that were incubated at depth, $E_d(z)\%$, were calculated using a daily vertical attenuation coefficient (K_d) that was calculated from the PAR depth profiles and the equations

$$K_d = -\ln[E_d(z) / E_d(0)] / z \quad (1)$$

$$E_d(z)\% = 100 \times e^{-K_d z} \quad (2)$$

where $E_d(z)$ is the light reaching the bottle at depth z and $E_d(0)$ is the light reaching the bottle on the surface (31). The calculated percent light level was then corrected for light attenuation due to the Teflon[®] bottle and mesh.

Analysis. The MMHg concentration in the incubated waters was determined using a distillation and aqueous phase ethylation method with cold vapor atomic fluorescence spectrometry (CVAFS) detection (32, 33). Prior to analysis, 45 to 80 mL aliquots were distilled to minimize recovery artifacts associated with the sample matrix. The distilled sample was buffered to pH 5.0 with 2 M acetate buffer, and reacted with 35 μ L of a 1% sodium tetraethylborate (NaTEB) solution to create volatile ethyl analogs of the solution mercury species. The sample was then purged with nitrogen and the ethylated complexes (e.g. monomethylmercury becomes methylethylmercury) are

collected onto a CarbotrapTM. The trap is then heated and the products flow into an isothermal gas chromatography (GC) column where separation occurs. At the exit of the GC the mercury species were pyrolyzed at high temperature (>500 °C) and converted to elemental mercury (Hg⁰) for subsequent determination by Cold Vapor Atomic Fluorescence Spectrometry (CVAFS).

The method detection limits for MMHg determinations ranged from 0.008 to 0.021 ng L⁻¹ for this study as determined by three times the standard deviation of method blanks for samples analyzed at Texas A&M University at Galveston and by replicate measurements of a low level water sample for samples analyzed at the Marine Pollution Studies Laboratory at Moss Landing Marine Laboratories. Analytical recovery was checked by running the certified reference material, DORM-2 (dog fish muscle, 4,470 ± 320 MMHg ng g⁻¹ dw tissue) supplied by the National Research Council of Canada. Recoveries averaged 96.5 ± 18.2 % (n = 19). Analytical precision, determined using means of relative percent difference measurements, was 7.3 ± 6.7 % (n = 21 pairs). Matrix spike recoveries averaged 96.4 ± 8.6 % (n = 21).

Estimating the Photic-Zone. Secchi disk depths for years 2000 – 2005 were obtained for six locations within the Delta (34) (Figure 1). For each location, a monthly vertical attenuation coefficient for downward irradiance (K_d) was calculated using equation

$$K_d = 1.44 / K_{sd} \quad (3)$$

from Kirk (31) where K_{sd} is the average monthly secchi disk depth. Continuous surface PAR measurements from the UCD climate station (25) for years 2004 and 2005 were

used to estimate average daily light exposure for the Delta. Each month's measurements were then summed and divided by the number of days measurements were recorded. This gave an estimate of the total light exposure ($\text{mol m}^{-2} \text{d}^{-1}$) for the Delta for each month. Using this estimate to represent PAR at the water's surface ($E_d(0)$) and the monthly K_d from equation (3), monthly PAR depth profiles were estimated using equation (2) in the form of

$$E_d(z) = E_d(0) \times e^{-K_d z} \quad (4)$$

where $E_d(z)$ is PAR at depth z . $E_d(z)$ was calculated over the water column at 0.1 cm intervals for integration purposes.

RESULTS AND DESCUSION

Photic-Zone. The depth of the photic-zone was estimated for the Delta down to the 1% light level. Monthly vertical attenuation coefficients for downward irradiance (K_d) range from 1.3 in November to 2.4 in February. The mean depth of the photic-zone for the entire Delta was 2.6 m and ranges from 1.9 to 3.6 m through out the year. The Delta receives greater PAR exposure in the dry season (April – September) than the wet season (October – March).

Bottle and Mesh Correction. The sample inside the Teflon[®] bottle with mesh receives 31% less PAR than the water surrounding the bottle (Supporting Information Figure S2). Samples on the surface which are at 100% light level, are actually receiving 69% of the PAR hitting the surface. All PAR data were corrected for the attenuation associated with light transmission through the Teflon[®] bottle and mesh used in the experiments.

Mechanisms of MMHg Degradation. The difference in MMHg loss between water incubated with and without light exposure shows that sunlight mediates the degradation of MMHg in the surface waters of the Delta. Light-exposed samples demonstrate that wavelengths in the PAR spectrum degraded MMHg in surface waters of the Delta. All dark bottle controls, except for December 2004, showed no significant change in MMHg concentration for the duration of each experiment (8.2 ± 0.6 hours). December 2004 dark controls had a significant increase in MMHg concentration over time. This change in MMHg concentration was within typical analytical precision

(analytical error), so no concentration correction for dark bottle controls was applied to the light exposed sample bottles for all experiments.

In previous lake studies (17, 20), photo-degradation rates between unfiltered and filtered samples did not differ, leading the authors to suggest that the principle mechanism of MMHg photo-degradation is abiotic. This is consistent with our findings from the July 2004 experiments. Unfiltered samples from Steamboat Slough did not show enhanced degradation rates in comparison with filtered samples (Figure 2). The regression coefficients for the unfiltered and filtered samples at Steamboat Slough were tested and they were not significantly different ($t = 0.061$, $p > 0.061$). There was also no significant change in MMHg concentration in the unfiltered dark controls, again supporting the hypothesis that an abiotic, sunlight-mediated mechanism is the major factor in MMHg degradation rates in the Delta.

Figure 2. MMHg concentration with respect to total light exposure for unfiltered (diamonds) and filtered (squares) samples during an 8 hour incubation experiment. The slopes are not significantly different indicating that the photo-degradation rate is essentially the same in biotic and abiotic cases. Unfiltered and filtered two point determination experiments (initial and final) at Twitchell Island Experimental ponds show similar results but were not tested. Error bars represent the difference between analytical duplicates.

The Twitchell pond experiments demonstrated that open water has greater photo-degradation rates than areas with tule or marsh coverage. Filtered and unfiltered light exposed samples showed greater decreases of MMHg in open water than in the tules, where PAR penetration was reduced by shading from emergent plant species. Actual

PAR penetrating into the tules was not recorded in this study. The Twitchell pond events were two point determinations and were not tested for significance.

Relation to Total Light Exposure. In several previous investigations by other researchers (17, 18, 20), average daily PAR was used to assess photo-degradation rates relative to the abundance of light exposure. In this study, the change in MMHg concentration was assessed relative to total light exposure or total photon flux (ng of MMHg degraded in a liter of water relative to the total number of moles of light reaching the surface water per meter squared). This rate assessment approach does not have the limitation of temporal variations of solar light intensity associated with seasonal differences or cloudy days. An overall MMHg degradation rate with respect to light exposure is estimated for the Delta by pooling all data points for all open water experiments.

The Steamboat Slough samples were spiked to a higher initial MMHg concentration (0.419 ng L^{-1}) than that of all the other open water incubations experiments ($0.265 \pm 0.016 \text{ ng L}^{-1}$). Past lakes studies have shown that photo-degradation rates are first order with respect to concentration (17, 20). Since initial MMHg concentration might be influencing degradation rates the slopes for the two data sets were tested. They were not significantly different ($t = 0.181$, $p > 0.181$). To get the best estimate of MMHg photo-degradation, the 0.419 ng L^{-1} samples from Steamboat Slough were normalized to the average initial concentration (0.265 ng L^{-1}) of the other samples. All filtered open water data were pooled and regressed; MMHg concentration with respect to total light exposure (Figure 3). Total light exposures for individual sample incubations were

obtained by integrating over time the PAR values (mol m^{-2}) that corresponded to the time for the individual sample. The MMHg degradation rate determined using this approach is $0.00296 \pm 0.0003 \text{ ng m}^{-2} \text{ L}^{-1} \text{ mol}^{-1}$. This estimate compares favorably with degradation rates from other studies (Table 1). Degradation rates in the Delta are about 33% of the rates observed in an Arctic Lake, and 39% greater than the rates observed on lakes in NW Ontario. The present study provides the first known estimates of photo-degradation of MMHg in the Delta using *in situ* bottle incubation experiments. It is not clear how widely the rates determined in this work can be applied beyond the Delta.

Figure 3. MMHg concentration as a function of total light exposure for each individual bottle incubation.

Table 1. MMHg photo-degradation rates from three different aquatic systems.

System	Rate ($\text{ng m}^2 \text{L}^{-1} \text{mol}^{-1}$)	Initial MMHg (ng L^{-1})	Source
Experimental Lakes Area, Northwestern Ontario	0.0018	0.9	17, 20
Arctic Alaskan Lake	0.0090	4.5	20
Sacramento- San Joaquin Delta	0.00296	0.265	this study

The rate of photo-degradation was observed to decrease with depth below the water surface in relation to light attenuation. This has been observed in other studies (17 - 20), where photo-degradation rates follow closely the exponential decrease in light intensity with depth. Actual light levels for samples at depth in this study were 19, 43, 21, 19, and 32% of surface light levels, respectively, starting with December 2004 and all surface samples were at 69% of ambient light level. *In situ* bottle incubations with low light levels made changes in MMHg concentration at depth sometimes difficult to detect. Photo-degradation may be most active above the 33% light level or down to a mean depth of 0.63 ± 0.12 m within the Delta. Samples at depth with light levels less than 33% did not show significant changes in MMHg concentration. Previous studies found that photo-degradation in lakes are most active within 1.0 m of the surface (18 - 20).

Krabbenhof and others (35) showed no apparent change in MMHg concentration during a four day incubation experiment conducted in the Florida Everglades Agricultural Area, suggesting that MMHg photo-degradation was not significant at that site. The authors suggested that high DOC levels limited light penetration into the water column. Table 2 shows results from water quality parameters measured during the course of this

study. No significant relationships were observed between degradation rates for each surface and depth experiment and mean water temperature, TSS, SUVA, or DOC. All parameters except for water temperature were only measured at the initial time point of each experiment and were not measured through out the course of each experiment.

Table 2. Water quality parameters measured during incubation experiments. Water temperature and salinity are means from CTD casts for each experiment (error is one standard deviation). Errors for TSS, DOC, and SUVA measurements are the differences between field duplicates.

Date	Location	Water Temperature (° C)	Salinity (ppt) PSU	TSS (mg L ⁻¹)	DOC (µM)	SUVA @ 254
July 17, 2004	Steamboat Slough	22.33 ± 0.86		15.84		
July 17, 2004	Twitchell-east pond	20.10 ± 0.83		5.21		
July 17, 2004	Twitchell-west pond	19.01 ± 0.10		<MDL of 1.00		
December 14, 2004	Mokelumne River	10.97 ± 0.13	0.09 ± 0.01	3.42 ± 0.63	395 ± 0.01	
April 26, 2005	Mokelumne River	16.27 ± 0.34	0.09 ± 0.05	5.65 ± 0.03	200.5	
August 24, 2005	Mokelumne River	22.78 ± 0.35	0.11 ± 0.06	6.39 ± 0.24	156.05 ± 0.16	2.54 ± 0.18
March 2, 2006	San Joaquin River	12.47 ± 0.26		4.53 ± 0.01	230.6 ± 0.07	2.72 ± 0.08
July 11, 2006	San Joaquin River	25.16 ± 0.80	0.17 ± 0.09	6.85 ± 0.39	263.55 ± 0.05	2.76 ± 0.12

Modeling MMHg photo-degradation in the Delta. An estimate of MMHg photo-degradation for the entire Delta can be obtained by multiplying an average flux by the area of the Delta. A daily photo-degradation rate (K_{degrad} , ng L⁻¹ d⁻¹) with respect to each month, was calculated using the equation

$$K_{degrad} = 0.00296 \times TDL \quad (5)$$

where TDL is the average total daily light exposure (mol m⁻² d⁻¹) for each month as explained above in estimating the photic-zone. Rate estimates for April through October are greater than what is seen in other aquatic systems (Table 3). Results in this study have demonstrated that marsh coverage prohibits photo-degradation of MMHg. The mass of dissolved MMHg that is photo-degraded per day was estimated using the following assumptions: 238 km² for the area of open water in the Delta (4, 6); accounting for light attenuation with depth to the 1% light level; and using average daily total light exposures predicted using light data from the UCD climate station (Figure 4). In this model dissolved MMHg concentrations (0.038 – 0.080 ng L⁻¹) are assumed to be one half unfiltered MMHg concentrations for the Delta (4, 8). This modeling assessment predicts that December, January, and February have the lowest loss rates. The average daily loss estimated on an annual basis is 18.9 ± 6.4 g d⁻¹ of dissolved MMHg.

Table 3. Daily MMHg photo-degradation rate constants from different aquatic systems.

System	Rate Constant (ng L ⁻¹ d ⁻¹)	Depth Integrated (m)	Initial MMHg (ng L ⁻¹)	DOC (µM)	Source
Experimental Lakes Area, Northwestern Ontario	0.043	4.0	0.9	550-640	17
Experimental Lakes Area, Northwestern Ontario	0.040 - 0.109	surface	1.0 - 3.0	440-1,010	18
Rocky Mountain National Park	0.019	1.0	0.4	433	19
Arctic Alaskan Lake	0.230	0.3	4.5	370	20
Florida Everglades	0.02 - 0.15				22
Florida Everglades Agricultural Area	0				35
Sacramento- San Joaquin Delta	0.178 - 0.928	2.6	0.265	156-395	this study

Figure 4. Mean daily photo-degradation loss of MMHg in the Delta for monthly periods. Estimates are down to the 1% light level. Error bars are the difference in estimates for years 2004 and 2005.

The significance of MMHg photo-degradation to the transport and cycling of MMHg in the Delta can be placed in broader context by comparing it to other fluxes of MMHg in a mass balance assessment of sources and sinks of MMHg for the Delta. Estimates of riverine fluxes, sediment production of MMHg in open water areas, and sediment production of MMHg in wetlands and marshes are illustrated in Figure 5 (4, 6, 8). The wet deposition flux of MMHg in the Delta is estimated to be 0.3 g d^{-1} . This flux was determined using a volume-weighted rainfall MMHg concentration of 0.10 ng L^{-1} (G. Gill personal communication), a total annual rainfall volume for the Delta region of 38 cm yr^{-1} (36), and the open water area for the Delta of 238 km^2 .

Figure 5. Mass balance assessment of various sources and sinks of MMHg for the Delta without consideration of photo-degradation (a) and with photo-degradation considered (b).

Without photo-degradation, average annual MMHg inputs from all sources are approximately 23 g d⁻¹ with 6.0 g d⁻¹ of MMHg being exported through riverine transport (Figure 5a). This mass balance assessment means that there is an unidentified net internal loss of 17.1 g MMHg d⁻¹. The unidentified loss term is very near the estimate for photo-degradation loss of 18.9 g d⁻¹. Incorporating the assessment for photo-degradation into the model, results in a near closure of the mass balance (Figure 5b). With photo-degradation considered, the mass balance assessment has an unidentified positive internal

source of about 1.8 g MMHg d⁻¹. However, it is reasonable to conclude that this unidentified source simply results from small inaccuracies associated with the various flux estimates.

MMHg photo-degradation is shown to be a very important sink for MMHg in the Delta. With the incorporation of photo-degradation, the major sources and sinks have been identified and quantified. The magnitude of photo-degradation in the Delta suggests that sunlight mediated degradation does decrease MMHg in the surface waters, possibly competing with and thereby inhibiting MMHg uptake into the aquatic food web. After degradation with possible further reduction to elemental mercury, volatilization to the atmosphere can occur (24) removing the mercury from the system. Knowledge of photo-degradation may be useful in methods to mitigate MMHg problems in the Delta or for controlling high MMHg inputs into the Delta. Thus light intensity, water clarity, and surface vegetation are important water quality features that directly affect rates of photo-degradation of MMHg. Current decisions regarding water flow rates, residence times, sources, and depth will all have an effect on photochemical processes that influence MMHg cycling in the Delta. Based on this model, photo-degradation seems to be the largest sink for MMHg in the Delta and it could be the most effective mercury detoxification mechanism to reduce MMHg levels in upper trophic levels of an aquatic food chain.

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Supporting Information Available

Supporting Information Figure S1 and Figure S2 as mentioned in the text (page 29 and 30, respectively). Appendixes include: MMHg bottle incubation data, surface PAR data, PAR depth profile data, and PAR data from Teflon[®] bottle and mesh correction experiment.

Figure S1. Using a spectrophotometer, the transmission through a Teflon[®] bottle was determined for wavelengths 200-700. A Teflon bottle is nearly optically clear with respect to PAR.

Figure S2. Correction experiments for PAR attenuation through a Teflon[®] bottle and mesh. Both experiments show a 31% difference in PAR levels between outside (squares) and inside (triangles) the Teflon[®] bottle and mesh.

Appendix 1

Table A1-1. MMHg concentrations for individual *in situ* bottles for July 17, 2004.

Location	Sample Name	Incubation Time (hours)	Unfiltered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
Steamboat Slough	surface T0	0.00	0.475	0.000	0.419	0.060
Steamboat Slough	surface T2	2.00	0.425	0.010	0.359	0.037
Steamboat Slough	surface T4	4.00	0.399	0.020	0.337	0.019
Steamboat Slough	surface T6	6.00	0.396	0.031	0.320	0.014
Steamboat Slough	surface T8	8.00	0.368	0.017	0.307	0.027
Steamboat Slough	surface T8 dup	8.00	0.380	0.024	0.290	0.021
Steamboat Slough	surface T8 dup	8.00			0.299	0.024
Steamboat Slough	dark bottle T0	0.00	0.462	0.028	0.417	0.021
Steamboat Slough	dark bottle T2	2.00	0.442	0.030	0.429	0.020
Steamboat Slough	dark bottle T4	4.00	0.458	0.008	0.387	0.027
Steamboat Slough	dark bottle T6	6.00	0.478	0.002	0.385	0.007
Steamboat Slough	dark bottle T8	8.00	0.451	0.001	0.382	0.016

Table A1-1. cont.

Location	Sample Name	Incubation Time (hours)	Unfiltered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
Steamboat Slough	dark bottle T8 dup	8.00	0.472	0.024	0.390	0.024
Steamboat Slough	field blank dark T8	8.00			-0.004	0.024
Twitchell West pond	surface T0	0.00	0.144	0.061	0.136	0.013
Twitchell West pond	surface T1	6.77	0.142	0.012	0.138	0.008
Twitchell West pond	dark bottle T0	0.00	0.144	0.002	0.145	0.002
Twitchell West pond	dark bottle T1	6.77	0.154	0.009	0.145	0.008
Twitchell East pond	surface T0	0.00	0.261	0.002	0.254	0.014
Twitchell East pond	Surface T1	8.33	0.190	0.009	0.132	0.011
Twitchell East pond	dark bottle T0	0.00	0.268	0.011	0.256	0.004
Twitchell East pond	dark bottle T1	8.33	0.267	0.028	0.260	0.027

Table A1-2. MMHg concentrations for individual *in situ* bottles for December 14, 2004.

Bottles incubated at depth (0.58 m below the surface) are denoted by a star (*). Dark bottle controls were incubate below the photic zone.

Sample Name	Incubation Time (hours)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
surface T0	0.00	0.273	0.024
surface T0 dup	0.00	0.285	0.024
surface T2	2.75	0.273	0.024
surface T4	4.83	0.267	0.024
surface T4 dup	4.83	0.246	0.024
surface T6	7.08	0.237	0.024
surface T8	9.33	0.251	0.024
surface T8 dup	9.33	0.251	0.024
depth T0*	0.00	0.273	0.024
depth T0* dup	0.00	0.285	0.024
depth T2*	2.75	0.274	0.024
depth T4*	4.83	0.274	0.024
depth T4* dup	4.83	0.268	0.024
depth T6*	7.08	0.272	0.024
depth T8*	9.33	0.273	0.024
depth T8* dup	9.33	0.271	0.024
dark bottle T0	0.00	0.249	0.024
dark bottle T0 dup	0.00	0.264	0.024
dark bottle T2	2.75	0.263	0.024

Table A1-2. cont.

Sample Name	Incubation Time (hours)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
dark bottle T4	4.83	0.267	0.024
dark bottle T4 dup	4.83	0.265	0.024
dark bottle T6	7.08	0.268	0.024
dark bottle T8	9.33	0.266	0.024
dark bottle T8 dup	9.33	0.285	0.024

Table A1-3. MMHg concentrations for individual *in situ* bottles for April 26, 2005.

Bottles incubated at depth (0.47 m below the surface) are denoted by a star (*). Dark bottle controls were incubate below the photic zone.

Sample Name	Incubation Time (hours)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
surface T0	0.00	0.271	0.048
surface T0 dup	0.00	0.286	0.048
surface T2	2.52	0.269	0.048
surface T4	4.52	0.249	0.048
surface T4 dup	4.52	0.233	0.006
surface T6	6.52	0.230	0.048
surface T8	8.43	0.234	0.048
surface T8 dup	8.43	0.239	0.048
depth T0*	0.00	0.271	0.048

Table A1-3. cont.

Sample Name	Incubation Time (hours)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
depth T0* dup	0.00	0.286	0.048
depth T2*	2.52	0.279	0.048
depth T4*	4.52	0.274	0.002
depth T4* dup	4.52	0.267	0.048
depth T6*	6.52	0.273	0.048
depth T8*	8.43	0.260	0.015
depth T8* dup	8.43	0.262	0.048
dark bottle T0	0.00	0.284	0.048
dark bottle T0 dup	0.00	0.287	0.048
dark bottle T2	2.52	0.282	0.048
dark bottle T4	4.52	0.279	0.064
dark bottle T4 dup	4.52	0.285	0.016
dark bottle T6	6.52	0.284	0.018
dark bottle T8	8.43	0.267	0.048
dark bottle T8 dup	8.43	0.279	0.036

Table A1-4. MMHg concentrations for individual in situ bottles for August 24, 2005.

Bottles incubated at depth (0.78 m below the surface) are denoted by a star (*). Dark bottle controls were incubate below the photic zone.

Sample Name	Incubation Time (hours)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
surface T0	0.00	0.251	0.060
surface T0 dup	0.00	0.263	0.060
surface T2	2.23	0.228	0.060
surface T4	4.30	0.206	0.060
surface T4 dup	4.30	0.206	0.060
surface T6	6.30	0.179	0.060
surface T8	8.08	0.186	0.060
surface T8 dup	8.08	0.181	0.060
depth T0*	0.00	0.251	0.060
depth T0* dup	0.00	0.263	0.060
depth T2*	2.23	0.244	0.060
depth T4*	4.30	0.234	0.060
depth T4* dup	4.30	0.237	0.060
depth T6*	6.30	0.259	0.060
depth T8*	8.08	0.232	0.060
depth T8* dup	8.08	0.235	0.060
dark bottle T0	0.00	0.236	0.060
dark bottle T0 dup	0.00	0.248	0.060
dark bottle T2	2.23	0.249	0.060

Table A1-4. cont.

Sample Name	Incubation Time (hours)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
dark bottle T4	4.30	0.284	0.060
dark bottle T4 dup	4.30	0.230	0.060
dark bottle T6	6.30	0.238	0.060
dark bottle T8	8.08	0.258	0.060

Table A1-5. MMHg concentrations for individual in situ bottles for March 2, 2006.

Bottles incubated at depth (0.79 m below the surface) are denoted by a star (*). Dark bottle controls were incubate below the photic zone.

Sample Name	Incubation Time (hours)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
surface T0	0.00	0.241	0.070
surface T0 dup	0.00	0.240	0.063
surface T2	2.17	0.226	0.040
surface T4	4.00	0.231	0.014
surface T4 dup	4.00	0.217	0.063
surface T6	6.00	0.224	0.035
surface T8	7.75	0.228	0.013
surface T8 dup	7.75	0.223	0.091
depth T0*	0.00	0.241	0.063
depth T0* dup	0.00	0.240	0.063
depth T2*	2.17	0.250	0.056

Table A1-5. cont.

Sample Name	Incubation Time (hours)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
depth T4*	4.00	0.237	0.063
depth T4* dup	4.00	0.246	0.063
depth T6*	6.00	0.261	0.021
depth T8*	7.75	0.221	0.079
depth T8* dup	7.75	0.247	0.066
depth T8* field blank	7.75	0.026	0.063
dark bottle T0	0.00	0.259	0.063
dark bottle T0 dup	0.00	0.246	0.063
dark bottle T2	2.17	0.264	0.072
dark bottle T4	4.00	0.253	0.063
dark bottle T4 dup	4.00	0.244	0.063
dark bottle T6	6.00	0.244	0.063
dark bottle T8	7.75	0.281	0.063
dark bottle T8 dup	7.75	0.245	0.063
dark bottle T8 field blank	7.75	0.009	0.063

Table A1-6. MMHg concentrations for individual in situ bottles for July 11, 2006.

Bottles incubated at depth (0.51 m below the surface) are denoted by a star (*). Dark bottle controls were incubate below the photic zone.

Sample Name	Incubation Time (hours)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
surface T0	0.00	0.285	0.060
surface T0 dup	0.00	0.271	0.060
surface T2	2.03	0.273	0.060
surface T4	4.00	0.262	0.060
surface T4 dup	4.00	0.245	0.060
surface T6	6.25	0.249	0.060
surface T8	7.40	0.197	0.060
surface T8 dup	7.40	0.209	0.060
surface T8 field blank	7.40	< 0.020	0.060
depth T0*	0.00	0.285	0.060
depth T0* dup	0.00	0.271	0.060
depth T2*	2.03	0.275	0.060
depth T4*	4.00	0.257	0.060
depth T4* dup	4.00	0.268	0.060
depth T6*	6.25	0.278	0.060
depth T8*	7.40	0.271	0.060
depth T8* dup	7.40	0.255	0.060
dark bottle T0	0.00	0.060	0.060
dark bottle T0 dup	0.00	0.060	0.060

Table A1-6. cont.

Sample Name	Incubation Time (hours)	Filtered MMHg (ng L ⁻¹)	Analytical Error (ng L ⁻¹)
dark bottle T2	2.03	0.060	0.060
dark bottle T4	4.00	0.060	0.060
dark bottle T4 dup	4.00	0.060	0.060
dark bottle T6	6.25	0.060	0.060
dark bottle T8	7.40	0.060	0.060
dark bottle T8 dup	7.40	0.060	0.060
dark bottle T8 field blank	7.40	< 0.020	0.060

Table A1-7. Station Information.

Location	Latitude	Longitude
Steamboat Slough @ Snug Harbor	38.1970	121.61526
Twitchell Island Experimental Ponds		
East Pond	38.1074	121.64655
West Pond	38.1075	121.64791
Mokelumne River @ B&W Resort	38.1286	121.57905
San Joaquin River @ River Point Landing	38.9769	121.37705

Appendix 2

Table A2-1. Surface PAR measurements recorded during each experiment at location. Stars (*) indicate PAR data from the USDA UV-B Monitoring and Research Program site at The University of California at Davis that was used to fill in data gaps.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Steamboat Slough	7/17/04	10:30	1470*	Mokelumne River	4/26/05	8:45	623*
Steamboat Slough	7/17/04	10:33	1480*	Mokelumne River	4/26/05	8:48	617*
Steamboat Slough	7/17/04	10:36	1500*	Mokelumne River	4/26/05	8:51	644*
Steamboat Slough	7/17/04	10:39	1510*	Mokelumne River	4/26/05	8:54	598*
Steamboat Slough	7/17/04	10:42	1520*	Mokelumne River	4/26/05	8:57	623*
Steamboat Slough	7/17/04	10:45	1530*	Mokelumne River	4/26/05	9:00	624*
Steamboat Slough	7/17/04	10:48	1540*	Mokelumne River	4/26/05	9:03	673*
Steamboat Slough	7/17/04	10:51	1560*	Mokelumne River	4/26/05	9:06	706*
Steamboat Slough	7/17/04	10:54	1570*	Mokelumne River	4/26/05	9:10	628.68
Steamboat Slough	7/17/04	10:57	1580*	Mokelumne River	4/26/05	9:20	689.29
Steamboat Slough	7/17/04	11:00	1590*	Mokelumne River	4/26/05	9:30	670.30
Steamboat Slough	7/17/04	11:03	1600*	Mokelumne River	4/26/05	9:40	707.29

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Steamboat Slough	7/17/04	11:06	1620*	Mokelumne River	4/26/05	9:50	893.94
Steamboat Slough	7/17/04	11:09	1620*	Mokelumne River	4/26/05	10:00	991.97
Steamboat Slough	7/17/04	11:12	1630*	Mokelumne River	4/26/05	10:10	1048.20
Steamboat Slough	7/17/04	11:15	1650*	Mokelumne River	4/26/05	10:20	1035.65
Steamboat Slough	7/17/04	11:18	1650*	Mokelumne River	4/26/05	10:30	1136.06
Steamboat Slough	7/17/04	11:21	1670*	Mokelumne River	4/26/05	10:40	1132.79
Steamboat Slough	7/17/04	11:24	1670*	Mokelumne River	4/26/05	10:50	1288.03
Steamboat Slough	7/17/04	11:27	1680*	Mokelumne River	4/26/05	11:00	1280.92
Steamboat Slough	7/17/04	11:30	1699.72	Mokelumne River	4/26/05	11:10	1229.09
Steamboat Slough	7/17/04	11:40	1803.69	Mokelumne River	4/26/05	11:20	1294.89
Steamboat Slough	7/17/04	11:50	1841.93	Mokelumne River	4/26/05	11:30	1187.19
Steamboat Slough	7/17/04	12:00	1859.78	Mokelumne River	4/26/05	11:40	1283.86
Steamboat Slough	7/17/04	12:10	1894.68	Mokelumne River	4/26/05	11:50	1472.60
Steamboat Slough	7/17/04	12:20	1920.89	Mokelumne River	4/26/05	12:00	1519.37

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Steamboat Slough	7/17/04	12:30	1945.56	Mokelumne River	4/26/05	12:10	1368.99
Steamboat Slough	7/17/04	12:40	1961.10	Mokelumne River	4/26/05	12:20	1494.19
Steamboat Slough	7/17/04	12:50	1962.00	Mokelumne River	4/26/05	12:30	1511.82
Steamboat Slough	7/17/04	13:00	1978.34	Mokelumne River	4/26/05	12:40	1413.62
Steamboat Slough	7/17/04	13:10	1975.77	Mokelumne River	4/26/05	12:50	1457.94
Steamboat Slough	7/17/04	13:20	1975.57	Mokelumne River	4/26/05	13:00	1593.20
Steamboat Slough	7/17/04	13:30	1973.33	Mokelumne River	4/26/05	13:10	1727.00
Steamboat Slough	7/17/04	13:40	1914.24	Mokelumne River	4/26/05	13:20	1497.09
Steamboat Slough	7/17/04	13:50	2079.80	Mokelumne River	4/26/05	13:30	1577.70
Steamboat Slough	7/17/04	14:00	2030.02	Mokelumne River	4/26/05	13:40	1551.24
Steamboat Slough	7/17/04	14:10	2060.29	Mokelumne River	4/26/05	13:50	1426.23
Steamboat Slough	7/17/04	14:20	1978.15	Mokelumne River	4/26/05	14:00	1420.03
Steamboat Slough	7/17/04	14:30	1920.97	Mokelumne River	4/26/05	14:10	1356.41
Steamboat Slough	7/17/04	14:40	1949.84	Mokelumne River	4/26/05	14:20	1398.30
Steamboat Slough	7/17/04	14:50	1914.57	Mokelumne River	4/26/05	14:30	1394.27

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Steamboat Slough	7/17/04	15:00	1898.25	Mokelumne River	4/26/05	14:40	1366.86
Steamboat Slough	7/17/04	15:10	1784.51	Mokelumne River	4/26/05	14:50	1402.63
Steamboat Slough	7/17/04	15:20	1737.13	Mokelumne River	4/26/05	15:00	1440.70
Steamboat Slough	7/17/04	15:30	1691.39	Mokelumne River	4/26/05	15:10	1351.52
Steamboat Slough	7/17/04	15:40	1645.42	Mokelumne River	4/26/05	15:20	1368.41
Steamboat Slough	7/17/04	15:50	1599.19	Mokelumne River	4/26/05	15:30	1454.13
Steamboat Slough	7/17/04	16:00	1548.24	Mokelumne River	4/26/05	15:40	1112.67
Steamboat Slough	7/17/04	16:10	1433.69	Mokelumne River	4/26/05	15:50	884.36
Steamboat Slough	7/17/04	16:20	1359.23	Mokelumne River	4/26/05	16:00	1247.20
Steamboat Slough	7/17/04	16:30	1302.14	Mokelumne River	4/26/05	16:10	917.14
Steamboat Slough	7/17/04	16:40	1317.38	Mokelumne River	4/26/05	16:20	903.04
Steamboat Slough	7/17/04	16:50	1257.34	Mokelumne River	4/26/05	16:30	919.45
Steamboat Slough	7/17/04	17:00	1063.81	Mokelumne River	4/26/05	16:40	921.06
Steamboat Slough	7/17/04	17:10	1093.56	Mokelumne River	4/26/05	16:50	776.87
Steamboat Slough	7/17/04	17:20	1059.17	Mokelumne River	4/26/05	17:00	840.01

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Steamboat Slough	7/17/04	17:30	999*	Mokelumne River	4/26/05	17:10	769.38
Steamboat Slough	7/17/04	17:33	982*	Mokelumne River	8/24/05	9:50	1092.89
Steamboat Slough	7/17/04	17:36	960*	Mokelumne River	8/24/05	10:00	1153.54
Steamboat Slough	7/17/04	17:39	944*	Mokelumne River	8/24/05	10:10	1203.51
Steamboat Slough	7/17/04	17:42	925*	Mokelumne River	8/24/05	10:20	1272.88
Steamboat Slough	7/17/04	17:45	906*	Mokelumne River	8/24/05	10:30	1326.66
Steamboat Slough	7/17/04	17:48	887*	Mokelumne River	8/24/05	10:40	1375.78
Steamboat Slough	7/17/04	17:51	870*	Mokelumne River	8/24/05	10:50	1426.74
Steamboat Slough	7/17/04	17:54	850*	Mokelumne River	8/24/05	11:00	1473.01
Steamboat Slough	7/17/04	17:57	833*	Mokelumne River	8/24/05	11:10	1515.40
Steamboat Slough	7/17/04	18:00	813*	Mokelumne River	8/24/05	11:20	1554.49
Steamboat Slough	7/17/04	18:03	793*	Mokelumne River	8/24/05	11:30	1591.03
Steamboat Slough	7/17/04	18:06	774*	Mokelumne River	8/24/05	11:40	1623.62
Steamboat Slough	7/17/04	18:09	755*	Mokelumne River	8/24/05	11:50	1655.10
Steamboat Slough	7/17/04	18:12	734*	Mokelumne River	8/24/05	12:00	1681.15

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Steamboat Slough	7/17/04	18:15	716*	Mokelumne River	8/24/05	12:10	1700.14
Steamboat Slough	7/17/04	18:18	697*	Mokelumne River	8/24/05	12:20	1724.94
Steamboat Slough	7/17/04	18:21	678*	Mokelumne River	8/24/05	12:30	1744.39
Steamboat Slough	7/17/04	18:24	657*	Mokelumne River	8/24/05	12:40	1758.32
Steamboat Slough	7/17/04	18:27	641*	Mokelumne River	8/24/05	12:50	1765.84
Steamboat Slough	7/17/04	18:30	620*	Mokelumne River	8/24/05	13:00	1773.16
Twitchell East Pond	7/17/04	11:40	1803.69	Mokelumne River	8/24/05	13:10	1773.39
Twitchell East Pond	7/17/04	11:50	1841.93	Mokelumne River	8/24/05	13:20	1775.02
Twitchell East Pond	7/17/04	12:00	1859.78	Mokelumne River	8/24/05	13:30	1769.69
Twitchell East Pond	7/17/04	12:10	1894.68	Mokelumne River	8/24/05	13:40	1760.62
Twitchell East Pond	7/17/04	12:20	1920.89	Mokelumne River	8/24/05	13:50	1748.20
Twitchell East Pond	7/17/04	12:30	1945.56	Mokelumne River	8/24/05	14:00	1728.19
Twitchell East Pond	7/17/04	12:40	1961.10	Mokelumne River	8/24/05	14:10	1705.60
Twitchell East Pond	7/17/04	12:50	1962.00	Mokelumne River	8/24/05	14:20	1680.91
Twitchell East Pond	7/17/04	13:00	1978.34	Mokelumne River	8/24/05	14:30	1650.56

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Twitchell East Pond	7/17/04	13:10	1975.77	Mokelumne River	8/24/05	14:40	1622.40
Twitchell East Pond	7/17/04	13:20	1975.57	Mokelumne River	8/24/05	14:50	1590.05
Twitchell East Pond	7/17/04	13:30	1973.33	Mokelumne River	8/24/05	15:00	1549.71
Twitchell East Pond	7/17/04	13:40	1914.24	Mokelumne River	8/24/05	15:10	1507.82
Twitchell East Pond	7/17/04	13:50	2079.80	Mokelumne River	8/24/05	15:20	1466.40
Twitchell East Pond	7/17/04	14:00	2030.02	Mokelumne River	8/24/05	15:30	1419.02
Twitchell East Pond	7/17/04	14:10	2060.29	Mokelumne River	8/24/05	15:40	1369.95
Twitchell East Pond	7/17/04	14:20	1978.15	Mokelumne River	8/24/05	15:50	1316.12
Twitchell East Pond	7/17/04	14:30	1920.97	Mokelumne River	8/24/05	16:00	1260.68
Twitchell East Pond	7/17/04	14:40	1949.84	Mokelumne River	8/24/05	16:10	1201.53
Twitchell East Pond	7/17/04	14:50	1914.57	Mokelumne River	8/24/05	16:20	1140.48
Twitchell East Pond	7/17/04	15:00	1898.25	Mokelumne River	8/24/05	16:30	1077.11
Twitchell East Pond	7/17/04	15:10	1784.51	Mokelumne River	8/24/05	16:40	1013.89
Twitchell East Pond	7/17/04	15:20	1737.13	Mokelumne River	8/24/05	16:50	946.51
Twitchell East Pond	7/17/04	15:30	1691.39	Mokelumne River	8/24/05	17:00	878.87

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Twitchell East Pond	7/17/04	15:40	1645.42	Mokelumne River	8/24/05	17:09	896*
Twitchell East Pond	7/17/04	15:50	1599.19	Mokelumne River	8/24/05	17:12	878*
Twitchell East Pond	7/17/04	16:00	1548.24	Mokelumne River	8/24/05	17:15	858*
Twitchell East Pond	7/17/04	16:10	1433.69	Mokelumne River	8/24/05	17:18	840*
Twitchell East Pond	7/17/04	16:20	1359.23	Mokelumne River	8/24/05	17:21	815*
Twitchell East Pond	7/17/04	16:30	1302.14	Mokelumne River	8/24/05	17:24	796*
Twitchell East Pond	7/17/04	16:40	1317.38	Mokelumne River	8/24/05	17:27	779*
Twitchell East Pond	7/17/04	16:50	1257.34	Mokelumne River	8/24/05	17:30	760*
Twitchell East Pond	7/17/04	17:00	1063.81	Mokelumne River	8/24/05	17:33	743*
Twitchell East Pond	7/17/04	17:10	1093.56	Mokelumne River	8/24/05	17:36	726*
Twitchell East Pond	7/17/04	17:20	1059.17	Mokelumne River	8/24/05	17:39	708*
Twitchell East Pond	7/17/04	17:30	999*	Mokelumne River	8/24/05	17:42	691*
Twitchell East Pond	7/17/04	17:33	982*	Mokelumne River	8/24/05	17:45	671*
Twitchell East Pond	7/17/04	17:36	960*	Mokelumne River	8/24/05	17:48	654*
Twitchell East Pond	7/17/04	17:39	944*	Mokelumne River	8/24/05	17:51	634*

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Twitchell East Pond	7/17/04	17:42	925*	Mokelumne River	8/24/05	17:54	617*
Twitchell East Pond	7/17/04	17:45	906*	San Joaquin River	3/2/06	8:00	164.37
Twitchell East Pond	7/17/04	17:48	887*	San Joaquin River	3/2/06	8:01	345.34
Twitchell East Pond	7/17/04	17:51	870*	San Joaquin River	3/2/06	8:20	530.51
Twitchell East Pond	7/17/04	17:54	850*	San Joaquin River	3/2/06	8:30	487.12
Twitchell East Pond	7/17/04	17:57	833*	San Joaquin River	3/2/06	8:40	480.67
Twitchell East Pond	7/17/04	18:00	813*	San Joaquin River	3/2/06	8:50	256.87
Twitchell East Pond	7/17/04	18:03	793*	San Joaquin River	3/2/06	9:00	287.97
Twitchell East Pond	7/17/04	18:06	774*	San Joaquin River	3/2/06	9:10	468.19
Twitchell East Pond	7/17/04	18:09	755*	San Joaquin River	3/2/06	9:20	660.63
Twitchell East Pond	7/17/04	18:12	734*	San Joaquin River	3/2/06	9:30	527.85
Twitchell East Pond	7/17/04	18:15	716*	San Joaquin River	3/2/06	9:40	699.26
Twitchell East Pond	7/17/04	18:18	697*	San Joaquin River	3/2/06	9:50	393.98
Twitchell East Pond	7/17/04	18:21	678*	San Joaquin River	3/2/06	10:00	555.50
Twitchell East Pond	7/17/04	18:24	657*	San Joaquin River	3/2/06	10:10	416.47

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Twitchell East Pond	7/17/04	18:27	641*	San Joaquin River	3/2/06	10:20	442.99
Twitchell East Pond	7/17/04	18:30	620*	San Joaquin River	3/2/06	10:30	1032.11
Twitchell East Pond	7/17/04	18:33	600*	San Joaquin River	3/2/06	10:40	916.89
Twitchell East Pond	7/17/04	18:36	580*	San Joaquin River	3/2/06	10:50	1144.61
Twitchell East Pond	7/17/04	18:39	559*	San Joaquin River	3/2/06	11:00	680.07
Twitchell East Pond	7/17/04	18:42	538*	San Joaquin River	3/2/06	11:10	1302.03
Twitchell East Pond	7/17/04	18:45	516*	San Joaquin River	3/2/06	11:20	780.07
Twitchell East Pond	7/17/04	18:48	499*	San Joaquin River	3/2/06	11:30	710.26
Twitchell East Pond	7/17/04	18:51	481*	San Joaquin River	3/2/06	11:40	907.18
Twitchell East Pond	7/17/04	18:54	462*	San Joaquin River	3/2/06	11:50	928.36
Twitchell East Pond	7/17/04	18:57	439*	San Joaquin River	3/2/06	12:00	962.21
Twitchell East Pond	7/17/04	19:00	424*	San Joaquin River	3/2/06	12:10	1034.78
Twitchell East Pond	7/17/04	19:03	404*	San Joaquin River	3/2/06	12:20	1361.02
Twitchell East Pond	7/17/04	19:06	389*	San Joaquin River	3/2/06	12:30	775.21
Twitchell East Pond	7/17/04	19:09	374*	San Joaquin River	3/2/06	12:40	737.33

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Twitchell East Pond	7/17/04	19:12	357*	San Joaquin River	3/2/06	12:50	555.05
Twitchell East Pond	7/17/04	19:15	339*	San Joaquin River	3/2/06	13:00	1107.81
Twitchell East Pond	7/17/04	19:18	323*	San Joaquin River	3/2/06	13:10	1412.93
Twitchell East Pond	7/17/04	19:21	305*	San Joaquin River	3/2/06	13:20	1288.34
Twitchell East Pond	7/17/04	19:24	289*	San Joaquin River	3/2/06	13:30	1264.46
Twitchell East Pond	7/17/04	19:27	272*	San Joaquin River	3/2/06	13:40	1198.73
Twitchell East Pond	7/17/04	19:30	255*	San Joaquin River	3/2/06	13:50	1237.13
Twitchell East Pond	7/17/04	19:33	241*	San Joaquin River	3/2/06	14:00	1199.85
Twitchell East Pond	7/17/04	19:36	227*	San Joaquin River	3/2/06	14:10	1157.87
Twitchell East Pond	7/17/04	19:39	211*	San Joaquin River	3/2/06	14:20	1106.53
Twitchell East Pond	7/17/04	19:42	196*	San Joaquin River	3/2/06	14:30	1060.39
Twitchell East Pond	7/17/04	19:45	162*	San Joaquin River	3/2/06	14:40	1028.12
Twitchell East Pond	7/17/04	19:48	97.2*	San Joaquin River	3/2/06	14:50	870.56
Twitchell East Pond	7/17/04	19:51	94.1*	San Joaquin River	3/2/06	15:00	421.27
Twitchell East Pond	7/17/04	19:54	61*	San Joaquin River	3/2/06	15:10	333.53

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Twitchell East Pond	7/17/04	19:57	83.3*	San Joaquin River	3/2/06	15:20	604.87
Twitchell East Pond	7/17/04	20:00	57.9*	San Joaquin River	3/2/06	15:30	774.91
Mokelumne River	12/14/04	7:30	3.79	San Joaquin River	3/2/06	15:40	803.33
Mokelumne River	12/14/04	7:40	5.05	San Joaquin River	3/2/06	15:50	598.96
Mokelumne River	12/14/04	7:50	6.77	San Joaquin River	7/11/06	6:10	15.40
Mokelumne River	12/14/04	7:59	6.77	San Joaquin River	7/11/06	6:20	27.94
Mokelumne River	12/14/04	8:10	11.36	San Joaquin River	7/11/06	6:30	42.64
Mokelumne River	12/14/04	8:20	16.73	San Joaquin River	7/11/06	6:40	53.32
Mokelumne River	12/14/04	8:30	20.88	San Joaquin River	7/11/06	6:50	64.23
Mokelumne River	12/14/04	8:40	21.69	San Joaquin River	7/11/06	7:00	74.43
Mokelumne River	12/14/04	8:50	20.53	San Joaquin River	7/11/06	7:10	129.16
Mokelumne River	12/14/04	9:00	24.19	San Joaquin River	7/11/06	7:20	271.47
Mokelumne River	12/14/04	9:10	34.23	San Joaquin River	7/11/06	7:30	324.12
Mokelumne River	12/14/04	9:20	63.45	San Joaquin River	7/11/06	7:40	388.29
Mokelumne River	12/14/04	9:30	60.03	San Joaquin River	7/11/06	7:50	450.98

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Mokelumne River	12/14/04	9:40	71.55	San Joaquin River	7/11/06	8:00	518.50
Mokelumne River	12/14/04	9:49	71.55	San Joaquin River	7/11/06	8:10	586.02
Mokelumne River	12/14/04	10:00	99.66	San Joaquin River	7/11/06	8:20	648.57
Mokelumne River	12/14/04	10:10	110.13	San Joaquin River	7/11/06	8:30	720.09
Mokelumne River	12/14/04	10:20	101.68	San Joaquin River	7/11/06	8:40	793.28
Mokelumne River	12/14/04	10:30	107.53	San Joaquin River	7/11/06	8:50	858.07
Mokelumne River	12/14/04	10:40	115.57	San Joaquin River	7/11/06	9:00	926.59
Mokelumne River	12/14/04	10:50	88.23	San Joaquin River	7/11/06	9:10	994.04
Mokelumne River	12/14/04	11:00	82.59	San Joaquin River	7/11/06	9:20	1059.63
Mokelumne River	12/14/04	11:10	103.53	San Joaquin River	7/11/06	9:30	1112.40
Mokelumne River	12/14/04	11:20	104.73	San Joaquin River	7/11/06	9:40	1177.61
Mokelumne River	12/14/04	11:30	100.51	San Joaquin River	7/11/06	9:50	1243.33
Mokelumne River	12/14/04	11:39	100.51	San Joaquin River	7/11/06	10:00	1300.15
Mokelumne River	12/14/04	11:50	98.97	San Joaquin River	7/11/06	10:10	1356.61
Mokelumne River	12/14/04	12:00	106.62	San Joaquin River	7/11/06	10:20	1413.02

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Mokelumne River	12/14/04	12:10	105.52	San Joaquin River	7/11/06	10:30	1468.64
Mokelumne River	12/14/04	12:20	116.27	San Joaquin River	7/11/06	10:40	1519.16
Mokelumne River	12/14/04	12:30	133.18	San Joaquin River	7/11/06	10:50	1566.06
Mokelumne River	12/14/04	12:40	137.32	San Joaquin River	7/11/06	11:00	1610.92
Mokelumne River	12/14/04	12:50	132.54	San Joaquin River	7/11/06	11:10	1650.81
Mokelumne River	12/14/04	13:00	121.56	San Joaquin River	7/11/06	11:20	1693.44
Mokelumne River	12/14/04	13:10	112.78	San Joaquin River	7/11/06	11:30	1729.91
Mokelumne River	12/14/04	13:20	109.98	San Joaquin River	7/11/06	11:40	1759.02
Mokelumne River	12/14/04	13:29	109.98	San Joaquin River	7/11/06	11:50	1791.13
Mokelumne River	12/14/04	13:40	112.18	San Joaquin River	7/11/06	12:00	1819.53
Mokelumne River	12/14/04	13:50	121.01	San Joaquin River	7/11/06	12:10	1840.91
Mokelumne River	12/14/04	14:00	109.80	San Joaquin River	7/11/06	12:20	1859.89
Mokelumne River	12/14/04	14:10	107.59	San Joaquin River	7/11/06	12:30	1876.59
Mokelumne River	12/14/04	14:20	119.19	San Joaquin River	7/11/06	12:40	1890.16
Mokelumne River	12/14/04	14:30	112.75	San Joaquin River	7/11/06	12:50	1900.13

Table A2-1. cont.

Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Location	Date	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Mokelumne River	12/14/04	14:40	105.49	San Joaquin River	7/11/06	13:00	1912.70
Mokelumne River	12/14/04	14:50	98.52	San Joaquin River	7/11/06	13:10	1918.38
Mokelumne River	12/14/04	15:00	92.01	San Joaquin River	7/11/06	13:20	1920.11
Mokelumne River	12/14/04	15:10	80.63	San Joaquin River	7/11/06	13:30	1916.70
Mokelumne River	12/14/04	15:20	74.26	San Joaquin River	7/11/06	13:40	1908.43
Mokelumne River	12/14/04	15:30	64.31	San Joaquin River	7/11/06	13:50	1900.38
Mokelumne River	12/14/04	15:40	61.13	San Joaquin River	7/11/06	14:00	1890.56
Mokelumne River	12/14/04	15:50	56.67	San Joaquin River	7/11/06	14:10	1876.27
Mokelumne River	12/14/04	16:00	46.96	San Joaquin River	7/11/06	14:20	1865.40
Mokelumne River	12/14/04	16:10	35.91	San Joaquin River	7/11/06	14:30	1848.81
Mokelumne River	12/14/04	16:20	27.22	San Joaquin River	7/11/06	14:40	1823.30
Mokelumne River	12/14/04	16:30	17.08				
Mokelumne River	12/14/04	16:40	10.19				
Mokelumne River	12/14/04	16:50	5.10				

Figure A2-1. PAR depth profiles and their extinction coefficients (K_d) are shown for the five CTD cast on December 14, 2004.

Cast	Date	Time	Equation of Line	Extinction Coefficient (K_d)
1	12/14/2004	7:47:05	$y = -0.476\ln(x) + 1.877$	2.10
2	12/14/2004	10:05:41	$y = -0.456\ln(x) + 2.888$	2.20
3	12/14/2004	12:06:19	$y = -0.494\ln(x) + 3.147$	2.02
4	12/14/2004	14:38:38	$y = -0.434\ln(x) + 2.340$	2.31
5	12/14/2004	16:36:59	$y = -0.387\ln(x) + 1.132$	2.58

Figure A2-2. PAR depth profiles and their extinction coefficients (K_d) are shown for the five CTD cast on April 26, 2005.

Cast	Date	Time	Equation of Line	Extinction Coefficient (K_d)
1	4/26/2005	8:16:43	$y = -0.960\ln(x) + 6.852$	1.04
2	4/26/2005	10:05:25	$y = -1.067\ln(x) + 8.129$	0.94
3	4/26/2005	12:07:53	$y = -1.065\ln(x) + 8.296$	0.84
4	4/26/2005	14:09:46	$y = -0.953\ln(x) + 7.377$	1.05
5	4/26/2005	16:06:11	$y = -0.845\ln(x) + 6.502$	1.18

Figure A2-3. PAR depth profiles and their extinction coefficients (K_d) are shown for the five CTD cast on August 24, 2005.

Cast	Date	Time	Equation of Line	Extinction Coefficient (K_d)
1	8/24/2005	8:16:43	$y = -0.657\ln(x) + 4.922$	1.52
2	8/24/2005	11:54:03	$y = -0.736\ln(x) + 5.836$	1.36
3	8/24/2005	13:57:18	$y = -0.622\ln(x) + 5.074$	1.61
4	8/24/2005	16:02:01	$y = -0.723\ln(x) + 5.652$	1.38
5	8/24/2005	17:48:56	$y = -0.541\ln(x) + 4.005$	1.85

Figure A2-4. PAR depth profiles and their extinction coefficients (K_d) are shown for the five CTD cast on March 2, 2006.

Cast	Date	Time	Equation of Line	Extinction Coefficient (K_d)
1	3/2/2006	9:37:10	$y = -0.601\ln(x) + 4.028$	1.66
2	3/2/2006	11:06:43	$y = -0.682\ln(x) + 5.188$	1.47
3	3/2/2006	12:26:40	$y = -0.493\ln(x) + 3.968$	2.03
4	3/2/2006	14:56:40	$y = -0.873\ln(x) + 6.779$	1.15
5	3/2/2006	16:43:25	$y = -0.503\ln(x) + 3.539$	1.99

Figure A2-5. PAR depth profiles and their extinction coefficients (K_d) are shown for the five CTD cast on July 11, 2006.

Cast	Date	Time	Equation of Line	Extinction Coefficient (K_d)
1	7/11/2006	6:36:14	$y = -0.423\ln(x) + 2.324$	2.37
2	7/11/2006	8:07:40	$y = -0.552\ln(x) + 3.985$	1.81
3	7/11/2006	10:07:26	$y = -0.765\ln(x) + 5.846$	1.31
4	7/11/2006	12:18:02	$y = -0.951\ln(x) + 7.300$	1.05
5	7/11/2006	14:28:21	$y = -1.077\ln(x) + 8.327$	0.929

Appendix 3

Table A3-1. Correction experiments for PAR attenuation through a Teflon® bottle and mesh. PAR measurements inside and outside a bottle and mesh are listed.

Date	Sensor Location	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
3/2/2006	inside	10:00	805.9
3/2/2006	inside	10:04	744.0
3/2/2006	inside	10:12	793.1
3/2/2006	inside	10:20	695.7
3/2/2006	inside	10:28	636.3
3/2/2006	inside	10:36	615.1
3/2/2006	inside	10:44	624.9
3/2/2006	inside	10:52	725.0
3/2/2006	inside	11:00	677.5
3/2/2006	inside	11:08	789.2
3/2/2006	inside	11:16	831.3
3/2/2006	inside	11:24	862.8
3/2/2006	inside	11:32	955.7
3/2/2006	inside	11:38	866.2
3/2/2006	inside	11:42	1023.5
3/2/2006	inside	11:46	758.4
3/2/2006	inside	11:50	864.8
3/2/2006	inside	11:54	799.5
3/2/2006	inside	11:58	879.8

Table A3-1. cont.

Date	Sensor Location	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
3/2/2006	inside	12:02	736.6
3/2/2006	outside	9:52	1007.0
3/2/2006	outside	9:56	1042.1
3/2/2006	outside	10:08	974.0
3/2/2006	outside	10:16	1078.4
3/2/2006	outside	10:24	822.6
3/2/2006	outside	10:32	980.9
3/2/2006	outside	10:40	999.6
3/2/2006	outside	10:48	1034.2
3/2/2006	outside	10:56	1059.9
3/2/2006	outside	11:04	1151.2
3/2/2006	outside	11:12	1218.9
3/2/2006	outside	11:20	1292.5
3/2/2006	outside	11:28	1360.7
3/2/2006	outside	11:36	1326.5
3/2/2006	outside	11:40	1429.0
3/2/2006	outside	11:44	1303.3
3/2/2006	outside	11:48	1253.0
3/2/2006	outside	11:52	1242.4
3/2/2006	outside	11:56	1317.0
3/2/2006	outside	12:00	1224.8
7/9/2006	inside	15:48	837.3
7/9/2006	inside	15:52	803.3

Table A3-1. cont.

Date	Sensor Location	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
7/9/2006	inside	15:56	1057.7
7/9/2006	inside	16:00	827.4
7/9/2006	inside	16:04	1006.8
7/9/2006	inside	16:08	958.2
7/9/2006	inside	16:12	972.1
7/9/2006	inside	16:16	1051.3
7/9/2006	inside	16:20	801.5
7/9/2006	inside	16:24	826.4
7/9/2006	inside	16:28	1081.8
7/9/2006	inside	16:32	1058.2
7/9/2006	inside	16:36	986.8
7/9/2006	inside	16:40	661.2
7/9/2006	inside	16:44	NA
7/9/2006	inside	16:48	961.2
7/9/2006	inside	16:52	994.5
7/9/2006	inside	16:56	946.1
7/9/2006	inside	17:00	420.7
7/9/2006	inside	17:04	1022.0
7/9/2006	inside	17:08	507.3
7/9/2006	inside	17:12	542.1
7/9/2006	inside	17:16	173.9
7/9/2006	outside	15:50	1298.6
7/9/2006	outside	15:54	1240.2

Table A3-1. cont.

Date	Sensor Location	Time (hh:mm)	PAR ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
7/9/2006	outside	15:58	1485.9
7/9/2006	outside	16:02	1351.7
7/9/2006	outside	16:06	1441.8
7/9/2006	outside	16:10	1365.5
7/9/2006	outside	16:14	1441.3
7/9/2006	outside	16:18	1526.0
7/9/2006	outside	16:22	1486.5
7/9/2006	outside	16:26	1441.7
7/9/2006	outside	16:30	1334.1
7/9/2006	outside	16:34	1184.0
7/9/2006	outside	16:38	1356.2
7/9/2006	outside	16:42	1290.7
7/9/2006	outside	16:46	NA
7/9/2006	outside	16:50	1097.3
7/9/2006	outside	16:54	1278.7
7/9/2006	outside	16:58	1047.3
7/9/2006	outside	17:02	1100.1
7/9/2006	outside	17:06	1174.0
7/9/2006	outside	17:10	813.6
7/9/2006	outside	17:14	653.6
7/9/2006	outside	17:18	447.0