ANNUAL REPORT 1999

FACTORS INFLUENCING BENTHIC ALGAL STANDING MASS IN THE COLORADO RIVER: LIGHT, DRIFT AND VELOCITY

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INTRODUCTION:

Availability of light has been demonstrated as one of the most fundamental factors determining benthic production in Glen and Grand Canyons (Usher and Blinn 1990, Hardwick *et al.* 1992; Blinn and Cole, 1991, Shannon *et al.* 1994, Shaver 1995). Benthic production has been recognized for its overall trophic role and linkage as the aquatic foodbase to native and nonnative fishes (Angradi 1994).

Results from this research are to be used in developing predictive relationships for primary production in this aquatic system (Krause-Jensen and Sand-Jensen 1998). Conceptualizing and developing predictive models that are reliable and empirically based have direct applications to managing the aquatic food base below Glen Canyon Dam (Smith et al. 1989). Modeling availability of photosynthetically active radiation, 400 to 700 nm (PAR), provides both predictive and simulative capabilities for improving management of potential aquatic primary production in this large regulated river system. Therefore, understanding the availability and interaction of PAR and its functional role in primary production in this ecosystem is essential for developing the predictive relationships necessary for a primary production model.

RESEARCH OBJECTIVES

The findings from our research will provide the remaining empirical relationships that are necessary for refining, validating and completing components of a primary production model by developing a better understanding of the ecological role and life history requirements of *Cladophora glomerata*. Our research findings will further complement our model development by addressing the monitoring and research objectives listed below:

Objective 1. *Monitor underwater light attenuation (K_O) for spatial and intra-seasonal variability and continue to collect validation data for the primary production model.*

Objective 2. *Determine the net photosynthetic and respiration rates for Cladophora glomerata at varying irradiance, depths, temperatures and suspended sediment loads.*

Objective 3. *Determine if net loss and loss rates to Cladophora glomerata differ as a function standing masses and varying flow velocities.*

The 1999 report identifies the progress to date made toward completing the study objectives as

stated in the proposal entitled "Factors Influencing Benthic Standing Mass in the Colorado River: Light, Drift and Velocity." Our primary emphasis this year has been collecting the necessary data for addressing the first two study objectives. We intend on completing the remaining research effort to address study objective three, during FY 2000.

STUDY AREA

The study area encompasses a river distance of 389 km from Glen Canyon Dam (36°52'03"N, 111°35'40"W) to Diamond Creek (35°46'0"N, 113°22'30"W), just upstream from Lake Mead. We stratified are sampling effort into two geographical sections to address the specific research and monitoring objectives identified above. River site locations are based on distances (river kilometer, RKM) downstream from Glen Canyon Dam. The first section is the Lees Ferry/Glen Canyon reach that totals a distance of 25 km in length. This section, typifies high water clarity conditions owing to its location downstream from Glen Canyon Dam and above any major influence from sediment discharges of major tributaries. The second region encompasses the remaining Colorado River including Marble Canyon (RKM 25 to RKM 125), Central Grand Canyon (RKM 125 to RKM 259) and Western Grand Canyon (RKM 259 to RKM 389). Studies conducted in this region are associated with monitoring activities to collect model verification data.

SAMPLING METHODS:

We are only listing the pertinent methods that we used this year to avoid redundancy in describing the same sampling and statistical methods used in the data collection and analytical effort from the previous year. If there is interest in the scope of work and results from previous field season, refer to our 1998 annual report where we identify the sampling design, methodologies and types of statistical analyses used.

Sampling Schedule

The 1999 sampling effort was focused around three specific areas. The sampling schedule is listed below:

<u>Vertical Light Attenuation Chamber Experiments</u>

August 2 - 7, 1998;	October 13 - 18, 1998;	November 16 - 22, 1998;
December 15 - 20, 1998;	June 2 - 7, 1999;	July 7 - 12, 1999

Model Validation - Light Attenuation/Sediment Concentration

May 16 - 24, 1999; August 16 - 24, 1999

Primary Production Irradiant Temperature Curves

June 16 - 21, 1999 July 3 - 10, 1999; August 4 - 10, 1999

September 12 - 19, 1999

Field Collection Methods

Vertical Light Attenuation Chamber

A series of manipulative experiments was conducted to determine if local autochthonous production affected the apparent optical properties (i.e., light attenuation coefficients) of water. Secondly, if apparent optical properties covaried as a function of exposure to solar irradiance. The experimental design and methods experimentally used are described below.

Six circular steel experimental tanks (1.22 m x 0.76 m) with a volumetric capacity of 5.68 m^{-3} were lined each with clear polyvinyl plastic. One temporal control (initial light attenuation) and two experimental treatments (EU's) one with algae and one without algae were established at the onset of the experiment. All experimental tanks (treatments and control) were simultaneously filled with filtered river water (375 l) to remove coarse particulate matter. Both treatment types, Algal EU and Non-algal EU, consisted of three replicates. Each EU was suspended as a triad unit in the river with recirculating pumps and incubated under natural light conditions with moderate flow and low temperatures (10 - 14°C) for a 48-h period. 120 benthic algal samples consisting of *Cladophora glomerata* and associated epiphytes were collected locally. 40 cobbles were randomly selected and placed in each of the three Algal EU's. The total amount of irradiance (μmol s^{-1} m^{-2}) photon flux density per unit time and area (Q_i) of incidence at the water surface (LI-190SZ, LiCor, Inc.) was measured remotely during the entire treatment period measured. Post treatment EU algal samples were removed, desiccated and analyzed for total AFSM determination.

At the initiation of the experiment, and again on completion, the filtered inoculum (375 l) from the control and treatment groups were then pumped into a vertical light attenuation chamber (PVC Sched-40, 5 m x 0.3048 m). Interior walls of chamber were washed with DI water before each measurement. A halogen lamp (Sylvania, Metalarc M1000/U) emitting in the red spectral band was used as the artificial light source. Direct vertical light beam was suspended directly over the chamber approximately

0.5 m above the water surface measuring between 2100-2000 μmol s^{-1} m^{-2}.

Two types of irradiametric sensors were used to measure the visible light spectrum (400-700 nm) in units of quanta (μmol $s^{-1}m^{-2}$). The underwater sensor was a cosine-corrected sensor (QA-190, LI-Cor) that measured quantum irradiance (Q_d), an integral quantity of photon flux radiance received over all directions at a specific point. The other sensor used, measured photon flux density per unit time and area (Q_i) of incidence at the water surface (LI-190SZ, LiCor, Inc.) (Kirk 1983; Thimijan and Heins 1983). Two irradiant profiles were made at 0.25 m depth intervals to a maximum depth of 5 m for each experimental replicate.

Light attenuation coefficients were calculated using a natural log transformation of irradiance to depth (m) using the expression, $I_Z = I_O e^{-Ktz}$, where I_O and I_Z are the values of downward irradiance at the surface and at depth *z* (m) in the water column. Therefore, K_t (m^{-1}) based on a natural logarithm is the light attenuation coefficient, where *t* represents coefficients derived from the cosine-corrected irradiance (K_d). The derived coefficients, K, provide a useful index for characterizing the apparent optical properties of the water, and secondly provide a functional mathematical expression for estimating depth specific irradiance.

Light attenuating parameters consisting of dissolved organic carbon (DOC), total suspended sediment (TSP), particulate organic matter (POM) and particulate (PIM) was collected for each experimental unit at treatment initiation, completion and following light attenuation measurements. Each sample was determined for its concentration (mg l^{-1}) in dissolved organic carbon (DOC), totals suspended sediment (TSS), and the proportion of the sample's suspended solids (SS) and particulate organic matter (POM). Suspended particles were extracted onto glass filters (Whatman 934-AH 1.5 μm pore), desiccated for 24 h at 60°C, weighed (± 0.01 mg), ashed for 1 h at 500°C, and reweighed (Greenberg *et al.* 1992). Each DOC sample (60 ml) was withdrawn and filtered (Whatman GF/F 0.7 μm pore), preserved by acidification (pH 2 - H_2SO_4) and refrigerated for storage. DOC determination was performed using a UV oxidation process (Dohrman Model Phoenix 8000 low-level TOC analyzer).

Light Attenuation/Sediment Concentration - Model Validation

The purpose of this study component has been to validate a previously established relationship between light attenuation and sediment concentration by using independently collected data. These independent data will give us a means to test the reliability of this predictive relationship and its sensitivity too spatially and temporally underwater irradiance throughout the Colorado River ecosystem. These sampling trips were used principally for collecting irradiant data and light attenuating parameters

under a wide range of optical conditions. The sampling trips were scheduled to coincide with high water clarity and sediment discharges from tributaries. For this reason, we replicated the previous sampling effort of 1998. For additional information regarding the collection methods used refer to our 1998 annual report (Blinn and Yard, 1998).

Primary Production Irradiant Temperature Curves

The purpose for this component of our study was to learn what the photosynthetic and respiration rates were for *Cladophora glomerata* at varying irradiance, depth, and temperature levels. A series of experiments was performed measuring dissolved oxygen generation under varying underwater light irradiant levels. Presently, we have only completed part of the initial data processing and data entry for the experiments conducted this year.

Three circular primary production chambers were fabricated from ® lexan, and mounted to a steel deployment frame. External plumbing (PVC Sched-40) was mounted to the base of each chamber to recirculate water within the closed system. Inflow measurements of dissolved oxygen (DO) and temperatures (°C) were monitored and logged (YSI model 52), at two minute intervals. Primary production chambers were suspended off the deck of a boat as a group of replicates. Specific irradiant levels were selected and maintained by raising and lowering the production chambers using a suspension boom and cable reel. Water temperatures in chambers were monitored individually and elevated using electrical heating elements (1500 w) powered by a generator (Honda 4500) and regulated by rheostatic control. Three to four cobbles containing an assemblage of *C. glomerata* and associated epiphytes were positioned in each chamber adjacent to the perforated outflow tubing. Clear polyvinyl tubing at top of the chamber was used for the intake structure. Nutrient samples, pH and alkalinity were measured and collected before and post experiment. Actual water volume was determined by the differences in benthic cobble displacement for each production chamber. Between experiments water was purged from chambers. Cobbles were recovered from each chamber for AFSM determination.

A 30 min deployment period was used for both the photosynthesis and respiration phases. Fig 1, is an example of a primary production chamber response that demonstrates our repeated measures technique for determining net production and respiration rates held at a constant irradiance. Photosynthesis and respiration rates (mg/L) are standardized to equivalent biomass and volume ($g/m^2/h$) to account for O^2 concentration change per unit time. The respiration phase was completed by covering the production chambers with a light impervious cover attached by velcro at base of a chamber. Battery voltage was monitored during entire deployment period to ensure proper operation of

recirculating pumps. Primary production irradiant curves for each temperature regime were calculated by regressing these calculated DO rates against irradiance. Irradiametric measurements have been adjusted to account for attenuation differences from the primary production chambers.

Lees Ferry Model Development

The sampling design and methodology used for collecting empirical data are discussed in our 1998 annual report (Blinn and Yard, 1998).

1999 RESEARCH - PRELIMINARY RESULTS AND DISCUSSION

The analyses presented in the 1999 annual progress report are considered preliminary. Our primary emphasis this year has been to complete analytically the data collected during 1997-98 for the Lees Ferry Model Development. Additionally, we have collected monitoring and experimental data in 1999 for the Model Validation - Light Attenuation/Sediment Concentration, Vertical Light Attenuation Chamber Experiments, and Primary Production Irradiant Temperature Curves. Presently, we are in the preliminary stages of processing, analyzing and conducting the data entry from this year.

Lees Ferry Model Development

Intra-annual Variation - The spatial and temporal patterns in light attenuation, illustrated by Fig 2, showed that considerable intra-annual and spatial variation was observed in Glen Canyon. The highest light attenuation was during the winter solstice and the inverse pattern occurred during the summer solstice when solar altitudes were highest. The diel pattern in light attenuation is sinusoidal in response to sampling time having the highest water transparency at solar zeniths and displays the greatest attenuation during the early morning and late afternoon periods. We regressed the effects of sampling date, sampling time and site location on light attenuation using an MLR. Our results ($F_{.95, 3,357} = 7.869$; $p<0.001$) indicate that mean light attenuation was significantly correlated to sampling dates ($p<.001$) and sampling location ($p<.001$), but not directly with sampling time ($p=.76$). Lack of significance was attributed to the nonlinear response to sampling time.

Interannual Variation - Since 1991, there has been a consistent increase in the annual mean light attenuation (K_O) for Glen Canyon (Fig 3). Using simple linear regression, we determined that inter-annual differences in underwater light attenuation in Glen Canyon ($F_{.95, 1,456} = 140$, $p<0.001$, $R^2_{Adj} = .23$) were significant and positively correlated with sampling years. Though normally distributed

(leptokurtic), our error variance was greater for 1997 and 1998 than for prior years. Residual analysis demonstrates the departure in the non-constancy of error for annual differences in light attenuation (Fig 4). However, we feel that this is primarily due to the robustness and seasonal range in our sampling during these later years. Since the relationship of light as a function of depth is exponential we would therefore expect higher variance owing to greater sensitivity for conditions observed in the early to mid-90's.

Independent Variables - We organized our analyses around possible mechanisms speculated to be causally responsible for the observed temporal variation in apparent optical properties since numerous factors can influence light attenuation (Kirk 1983). Three separate ANOVA s' were performed for concentration(s) of total suspended sediment (TSS), suspended solids (SS) and particulate organic matter (POM). Results show a spatial and seasonal differences in concentrations; however, no significant temporal difference in concentration(s) were related to sampling time (24 h cycles). Nor, was the interaction term between sampling time and sampling dates significantly related to these concentrations.

A series of post hoc spatial comparisons, using Tukey HSD test for unequal sample size, were conducted. Results indicated that mean annual concentration of SS (0 = .195, Site 1 = .42; and Site 2 = .619 mg l^{-1}) differed significantly for all sites ($p < .001$). Using an SLR revealed a significant difference in SS concentration with distance downstream ($F_{.95, 1,1179} = 50.82$, $p < .001$). This spatial pattern was also true for POM ($F_{.95, 1,1184} = 28.87$, $p < .001$). Post-hoc comparisons using Tukey HSD tests revealed that annual mean concentrations of POM differed significantly ($p<.02$) among all sampling sites. Concentrations of POM increased from the reservoir penstocks (Site 0 - 0.657 mg l^{-1}) to the sampling stations on the river (Site 1 - 0.738 and Site 2 - 0.804 mg l^{-1}). This suggested that suspended concentrations (TSS, SS and POM) might explain some observed temporal and spatial patterns in light attenuation. We used an MLR with a forward step-wise procedure to test if K_0 were correlated with these possible light attenuating constituents. The model excluded all variables except POM, yet the results though almost significant ($F_{.95,1,250} = 3.856$, $p = .051$) were considered spurius and not physically significant owing to the negative correlation ($r = - 0.12$) to light availability. Our results indicate that concentrations of suspended particles (i.e., organic or inorganic) cannot be considered a significant factor influencing light attenuation in Glen Canyon.

We tested for the effects using an MLR of angular distribution in direct solar incidences, as a possible source for the unexplained intra-annual and diel variation in light attenuation. All attenuation coefficients were temporally adjusted to solar time to calculate declination (δ), angle of incidence (θ),

and hour angle ($\tilde{\omega}$) for each profile. These angles were used as independent variables and regressed to K_O. Angularity was significantly correlated to intra-annual light attenuation ($F_{3,439} = 91.26$, $p<0.001$, $R^2_{Adj} = .38$). In doing a series of post hoc-tests using SLR's, results showed that the diel response in light attenuation was significantly related to angle of incidence ($F_{1,441} = 257$, $p<0.001$, $R^2_{Adj} = .37$), and seasonal differences in mean light attenuation was significantly correlated to declination ($F_{1,441} = 101$, $p<0.001$, $R^2_{Adj} = .19$). Multi-collinearity existed between the two explanatory variables due to the dependent relationship used in calculating θ from δ and $\tilde{\omega}$. Therefore, we consider the collinear effect acceptable to our ability to account for the diel response in light attenuation for all observed seasons statistically.

Independent variables characterizing incoming solar radiation were significantly correlated to light attenuation ($F_{6,436} = 34.5$, $p<0.001$, $R^2_{Adj} = .31$), and of the overall independent variables tested, mean, minimum, and % flux of irradiant intensity, with a conditional factor representing direct/indirect light conditions were all significant ($p < .001$). Variables such as atmospheric conditions (i.e., rain cloud and cloud cover) ($p = .19$), and maximum solar intensities ($p = .96$) were not significantly correlated to light attenuation.

There were significant patterns with the observed optical responses in Glen Canyon with specific water quality parameters associated with both Lake Powell and instream flow characteristics (Hueftle and Vernieu 1998). Water quality data used in our analyses were provided by GCMRC Biology Program. We performed an MLR to evaluate the effects of water quality parameters (DO, pH, µS, and °C) on light attenuation. Our results indicated that all parameters tested were highly significant ($F_{4,438} = 71.12$, $p<0.001$, $R^2_{Adj} = .39$) and were normal with a leptokurtic distribution ($W = 0.975$). Correlation tests revealed that °C ($r = 0.35$), DO ($r = 0.29$), and pH ($r = 0.52$) were positively correlated, whereas, µS ($r = -0.54$) showed a negative correlation with light attenuation. These parameters appear to have some colligative value for predicting the underwater characteristics whether or not they are causal mechanisms responsible for light attenuation presently in the Glen Canyon/Lees Ferry reach.

Using an all possible regression modeling approach with C_p as a selection criterion, we selected a model that included a total of nine explanatory variables ($F_{9,442} = 85.5$, $p<0.001$, $R^2_{Adj} = .63$) from a total possible of 12 evaluated. Their inclusion in the model takes into account spatial differences, angular distribution, irradiant characteristics and water quality parameters and their additive effects on light attenuation. It remains to be seen whether dissolved organic carbon (DOC) will be correlated to the water quality parameters, yet the results to date are very suggestive. We hypothesize that the dissolved organic component, rather than suspended particulates were the primary factor determining inter-annual

light attenuation. We are presently analyzing DOC expected to be completed by this winter.

Vertical Light Attenuation Chamber

A total of six experimental trials has been conducted to date. Preliminary results using a one-way ANCOVA for a fixed effect model indicated that there was a significant difference between treatment type that covaried as a function of trial ($F_{2, 35} = 5.21$, $p = 0.01$). Performing a post hoc comparison, using Tukey HSD test for unequal sample size indicated that the treatment type (initial, algae and non-algae) as a main factor effect differed significantly between algae and non-algae ($p < 0.016$) and initials and non-algae ($p < 0.022$). Fig 5, graphically depicts how the mean coefficient for diffuse light attenuation (K_d) for the treatment types deviates from initial condition during a 48 h period.

These results indicate that within a 48-hr period, apparent optical properties in the water can become altered significantly. This is very suggestive that a photoreactive response was occurring either due to natural light conditions or bacterial respiration functionally results in higher water clarity. Secondly, algae may at times offset the increase in water clarity through autotrophic production by the production of extracellular exudates. We will be evaluating how differences in light attenuation may covary in response to total irradiance, DOC and algal biomass for each treatment.

Primary Production Irradiant Temperature Curves

Our results using a multiple linear regression approach indicated that net primary production occurring under ambient water temperatures (10 - 12 °C) were significantly correlated to changes in irradiant levels and AFSM ($F_{.95, 2, 73} = 44.6$, $p < 0.001$). Dissolved oxygen production covaried as a function of AFSM. We infer that this negative correlation between algal biomass and oxygen production is due either to the accumulation of senescent growth, and by impeding light penetration. Secondly, respiration rates were significantly and negatively correlated with AFSM ($F_{.95, 1,79} = 32.7$, $p < .001$), (Fig 6).

Fig 7 - 8, graphically show gross primary production and net primary production increases in dissolved oxygen generation in response to a range of underwater irradiance at ambient water temperatures (10 to 11° C). All replicate samples for dissolved oxygen (mg) rates (±) have been standardized to a unit value equivalent to the amount of dissolved oxygen produced per gram of ash-free standing mass (AFSM) per meter squared per hour ($g/m^2/h$). In the future we will be developing additional primary production rates under elevated temperatures (16° C), yet speculating on how algal response will covary as a function of temperature remains premature.

FY 2000 - DATA ANALYSES

Lees Ferry Light Attenuation Relationship -

We have completed all of the data collection aspects necessary for developing a predictive light attenuation relationship for the Lees Ferry Glen Canyon Reach. However, two remaining areas are requiring additional analytical and statistical analyses before we complete the model. We have hypothesized that DOC is the primary light attenuating component regulating underwater light availability in the Colorado River, yet its functionality remains unclear right now. DOC concentrations are measured using a UV oxidation process (Dohrman, Phoenix 8000 low-level TOC analyzer). The chemical analysis for DOC has not been entirely completed due to a series of instrumentation problems preventing its completion. Consequently, the role this parameter acts is critical in our understanding of how this ecosystem functions.

Secondly, the inter-annual optical properties of the river may be governed by the physical and chemical processes occurring in the reservoir. We have shown strong correlations between water quality parameters and light availability. We will be evaluating the effects of varying reservoir height compared with the stationary intake structure at Glen Canyon Dam as the mechanism regulating optical properties. The vertical relationship to water clarity may be very important to primary production if the structural design component for the modified intake structure removes water from different vertically stratified regions within the reservoir. Therefore, understanding the linkages between the reservoir and river are essential in developing a reliable predictive relationship for primary production.

Light Attenuation Sediment Relationship -

Certain data collected during the Light/Sediment Validation Trips (May 23 - June 1, and August 16 - 23, 1998; May 16 - 24, and August 16 - 24, 1999) are not completed to date and require some additional processing before we validate the pre-existing relationship between light attenuation and sediment concentration.

Primary Production Irradiant/Temperature Curves -

We intend to complete the remaining data analyses for the thermal manipulation experiments at 16°C conducted this year.

2000 RESEARCH PLANS

Summarized below, is the experimental work scheduled for 1999. The two primary areas remaining are:

Primary Production Irradiant/Temperature Curves

Not all of the scheduled PI experiments doing thermal manipulations have been conducted to date. We intend on collecting additional data on algal production rates in response to temperatures at 20°C. Upon completion of these experiments we will explore different models to develop predictive relationships for primary production under a range of varying temperatures to address the biological implications of thermal modifications at Glen Canyon Dam.

Experimental Drift Chambers

The experimental drift experiments are scheduled to be conducted during the summer of 2000. The methods to be used are as described in the original proposal (Blinn and Yard, 1997).

SUMMARY OF FINDINGS

Understanding the availability and interaction of PAR and its functional role in primary production in this ecosystem is essential for developing predictive relationships necessary for our primary production model. Our research findings to date provide some empirical relationships necessary for understanding the life history requirements and limiting factors that regulate *Cladophora glomerata* in the Colorado River ecosystem. The bullet items listed below, summarized our research results and identified the potential implications of our findings.

- Apparent optical properties are temporally variable on a diel and seasonal basis and are a predictable consequence of the angular distribution (hour angle, declination and angle of incidence) of direct solar incidence owing to the refractive characteristics of the water.
- The topographic obstruction of solar insolation affects the apparent optical properties. Therefore, spatial location, channel orientation and seasonality should influence benthic algal production in Glen Canyon.
- Suspended sediment and particulate organic matter derived from either the reservoir or Glen Canyon reach is not significantly correlated to light attenuation. The opposite is true for Grand Canyon, where suspended sediment loads are the primary determinants of apparent optical

properties due to periodic tributary inputs and sediment transport in the river system (Blinn and Yard 1998).

- Longitudinal differences between study sites, are suggestive that in-stream autotrophic production and extracellular loss are responsible for differences in the apparent optical properties.
- Manipulative experiments using vertical light attenuation chambers showed that algal production has a significant effect on light attenuation. We attribute the significant and positive correlation in light attenuation observed between sites (Glen Canyon Dam to Lees Ferry) a distance of 25 km to in-stream autotrophic production.
- Inter- and intra-annual differences in water quality parameters are strongly significant and correlated to the optical properties. Whether or not the water quality parameters are the causal mechanisms responsible for light attenuation, they are effective correlates to predict light attenuation in the Glen Canyon/Lees Ferry reach.
- Since 1991, inter-annual differences for optical properties in Glen Canyon have significantly changed. The annual mean optical differences account for a significant reduction in light availability for photosynthesis. This demonstrates that a strong linkage does exists between the physical and chemical processes occurring within the reservoir and the Colorado River ecosystem.
- Our preliminary results strongly support the hypothesis that dissolved organic carbon (DOC) is the primary light attenuating component regulating the availability of underwater light for primary production in the Glen Canyon reach.
- Manipulative experiments using vertical light attenuation chambers have shown that the apparent optical properties can become significantly altered for treatments lacking algal production within a 48-hr period that resulted in higher water clarity. This suggests that the light attenuating component be reactive to either natural light conditions (PAR and UV) from photo-oxidation or bacterial respiration. We infer that prolonged exposure to natural light conditions especially in the stratified region of the epilimnion of Lake Powell can significantly alter the optical properties of the water. High water clarity conditions seem dependent on the water surface elevation of the reservoir compared with the intake structure. Additionally, benthic autotrophic production in these clear waters may be adversely affected by UV irradiance. The implications of our findings are significant and have direct relevance to the proposed thermal control device.
- The empirical relationship for determining apparent optical properties in the Lees Ferry/Glen Canyon reach provides predictive capabilities for calculating underwater irradiance at spatial (depth and location) and temporal scales.

- Primary production irradiant curves (PI) for gross and net primary production occurring at ambient water temperatures (10 - 12 °C) were significantly correlated to changes in irradiant levels. The observed variance is explained by differences in biomass. We infer that this negative correlation between algal biomass and oxygen production is due either to the accumulation of senescent growth, and by impeding light penetration.
- These PI curves provide the necessary predictive relationship for algal production at ambient water temperature for a range of underwater irradiance encountered in the Colorado River ecosystem.
- Using the relationships for predicting apparent optical properties and primary production irradiant curves provides a model for simulating and understanding the potential consequences of management decisions on the benthic algal community in this large regulated river ecosystem.

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APPENDIX A

FIG 1.

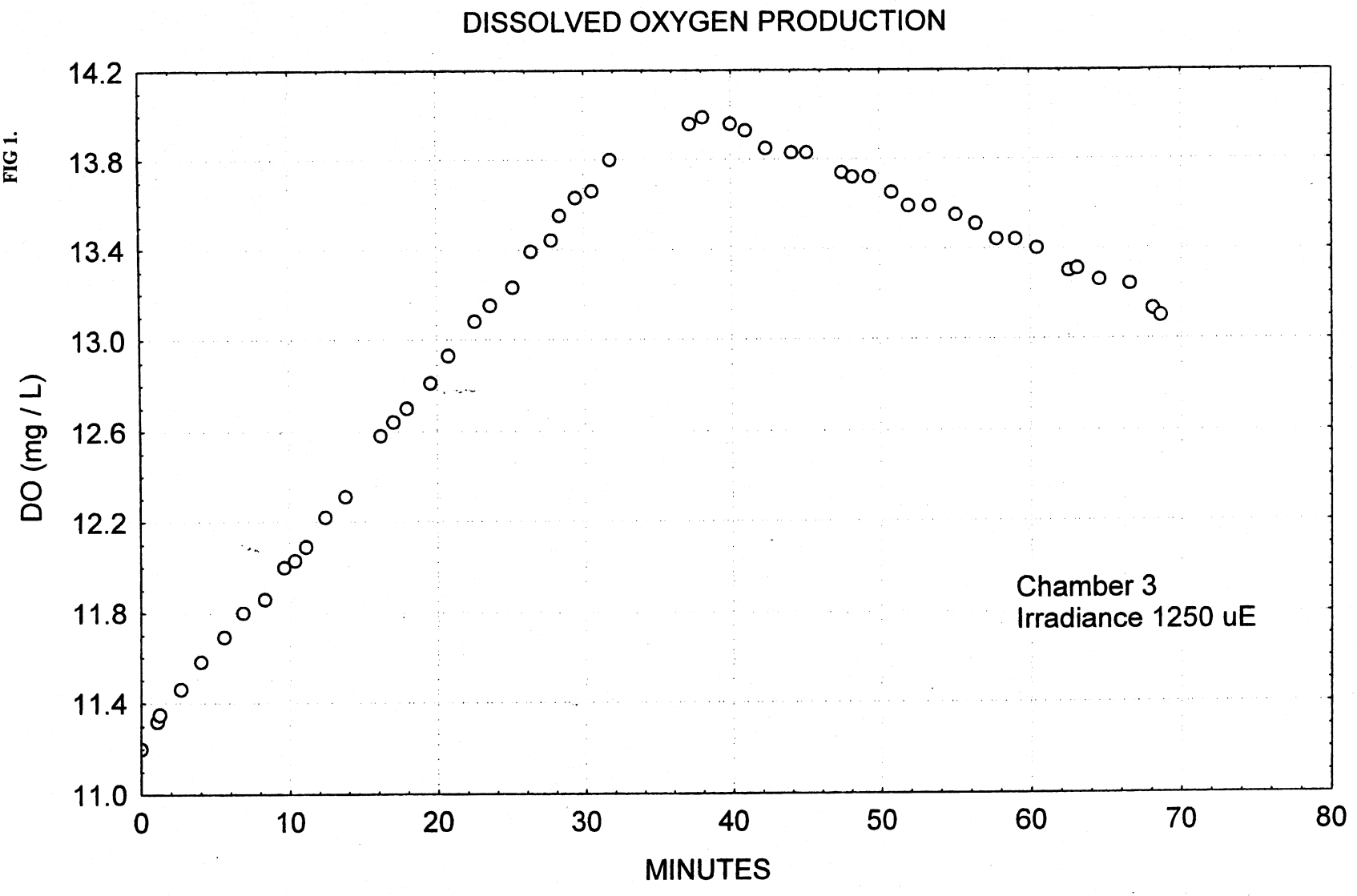

DISSOLVED OXYGEN PRODUCTION
DO (mg / L)
14.2
13.8
13.4
13.0
12.6
12.2
11.8
11.4
11.0
0
10
20
30
40
50
60
70
80
MINUTES
Chamber 3
Irradiance 1250 uE

FIG 2.

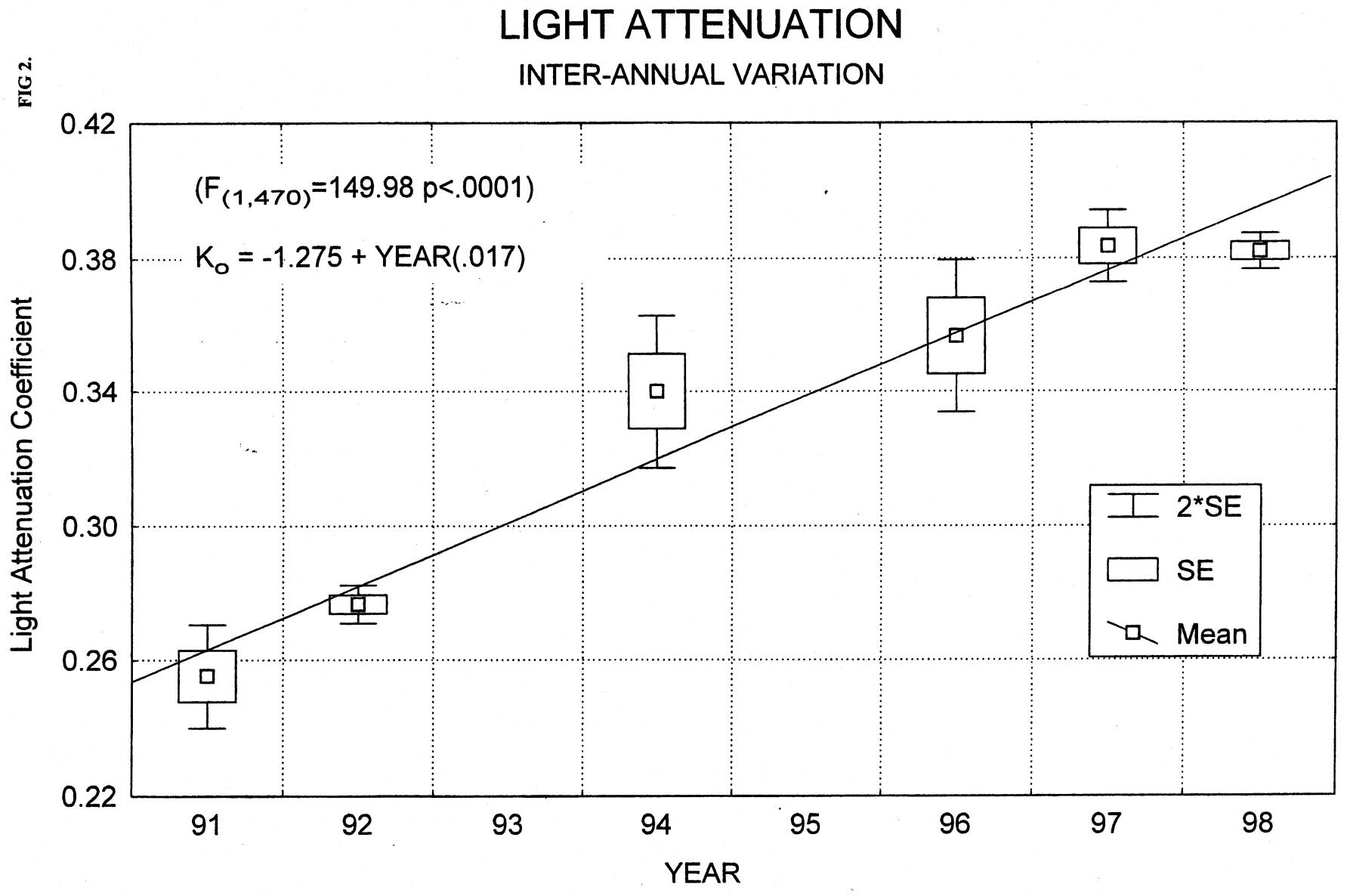
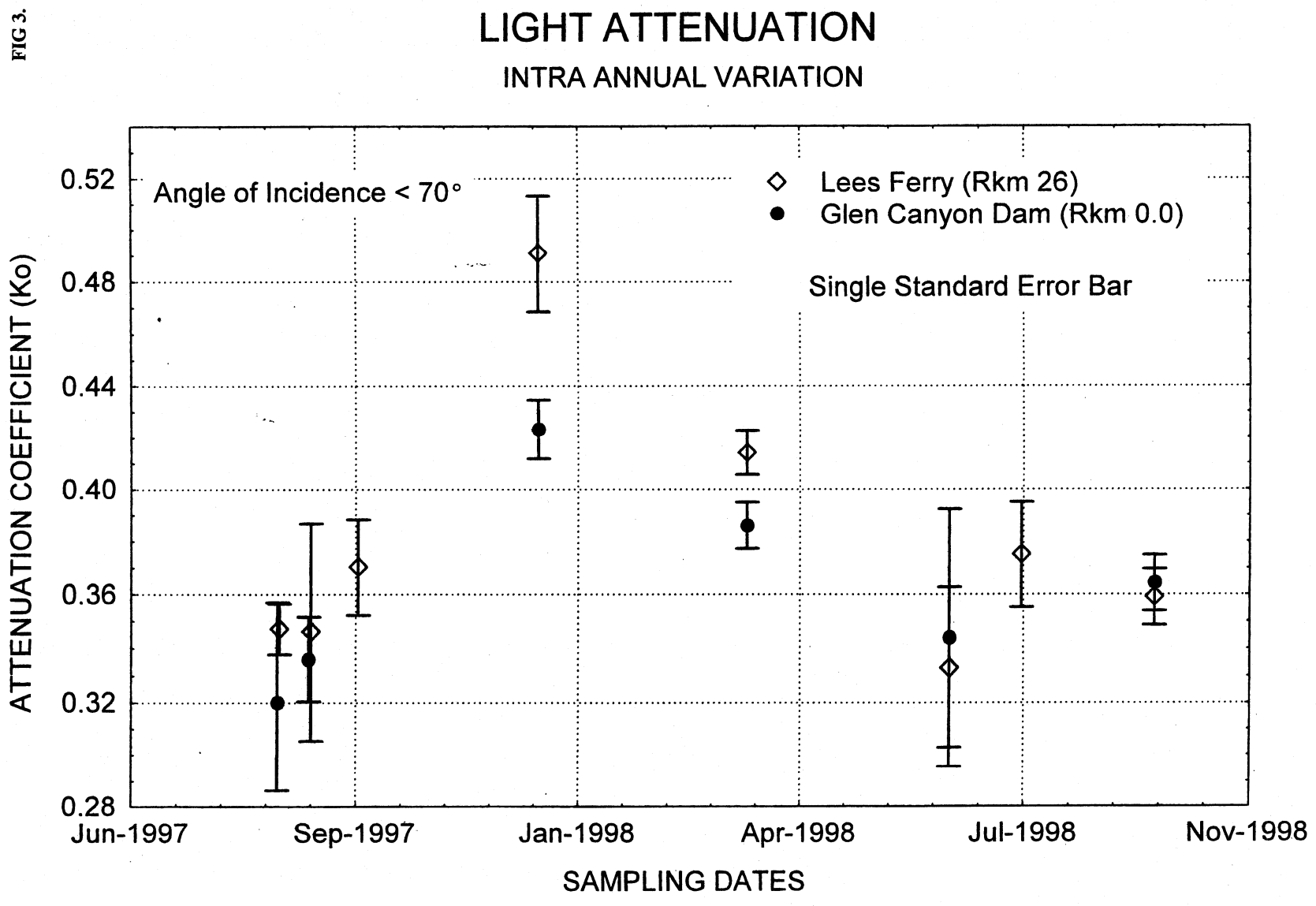
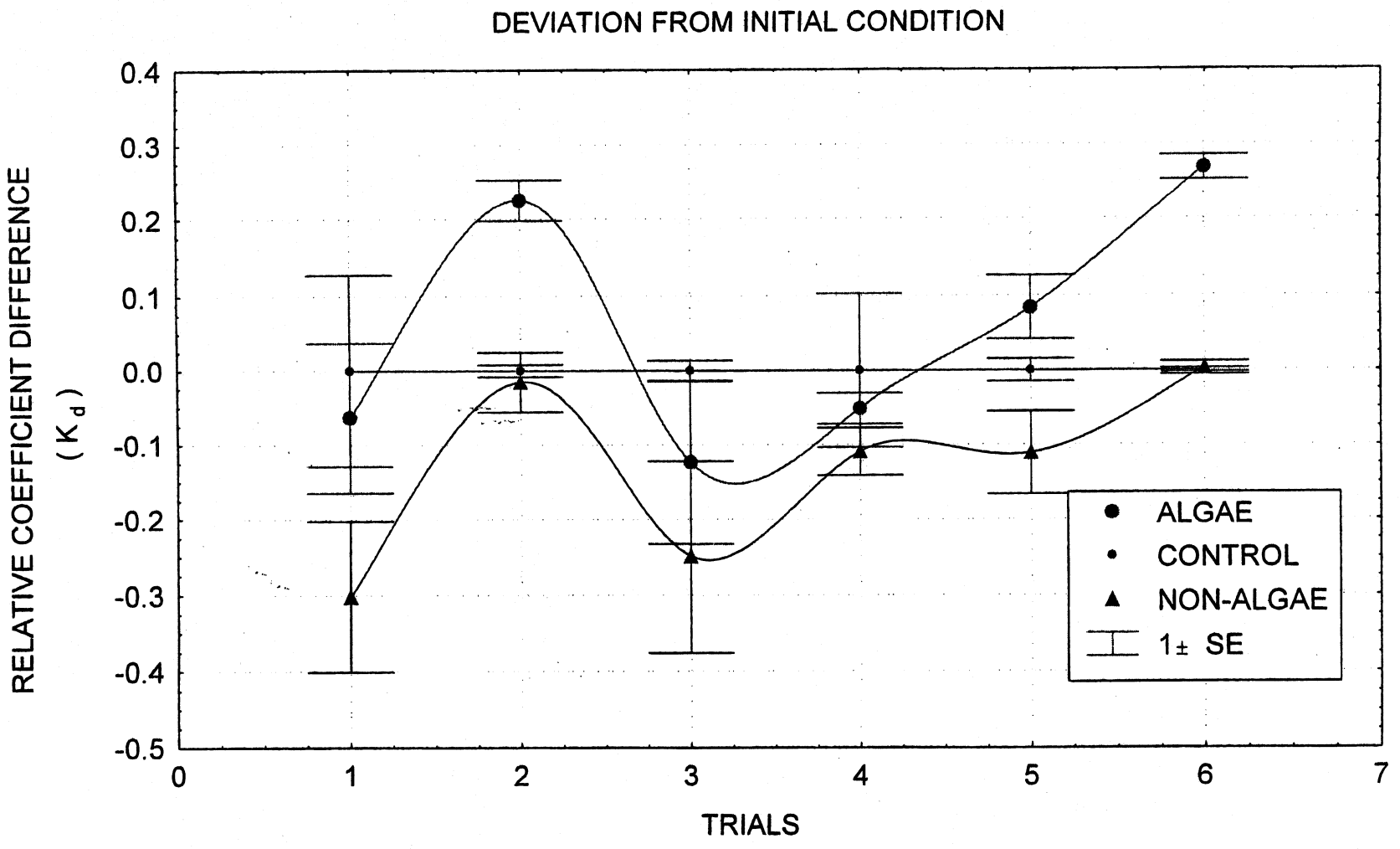
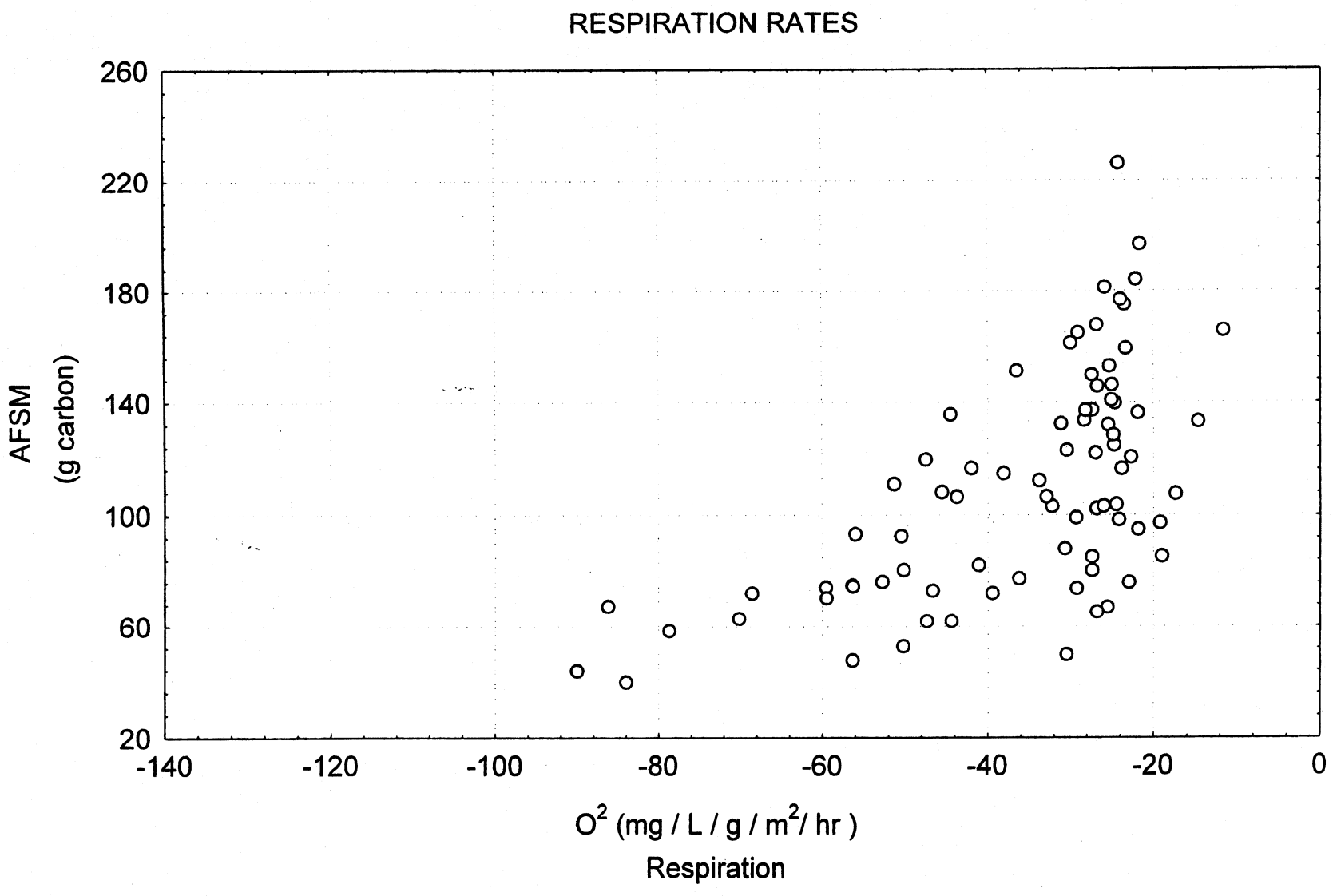
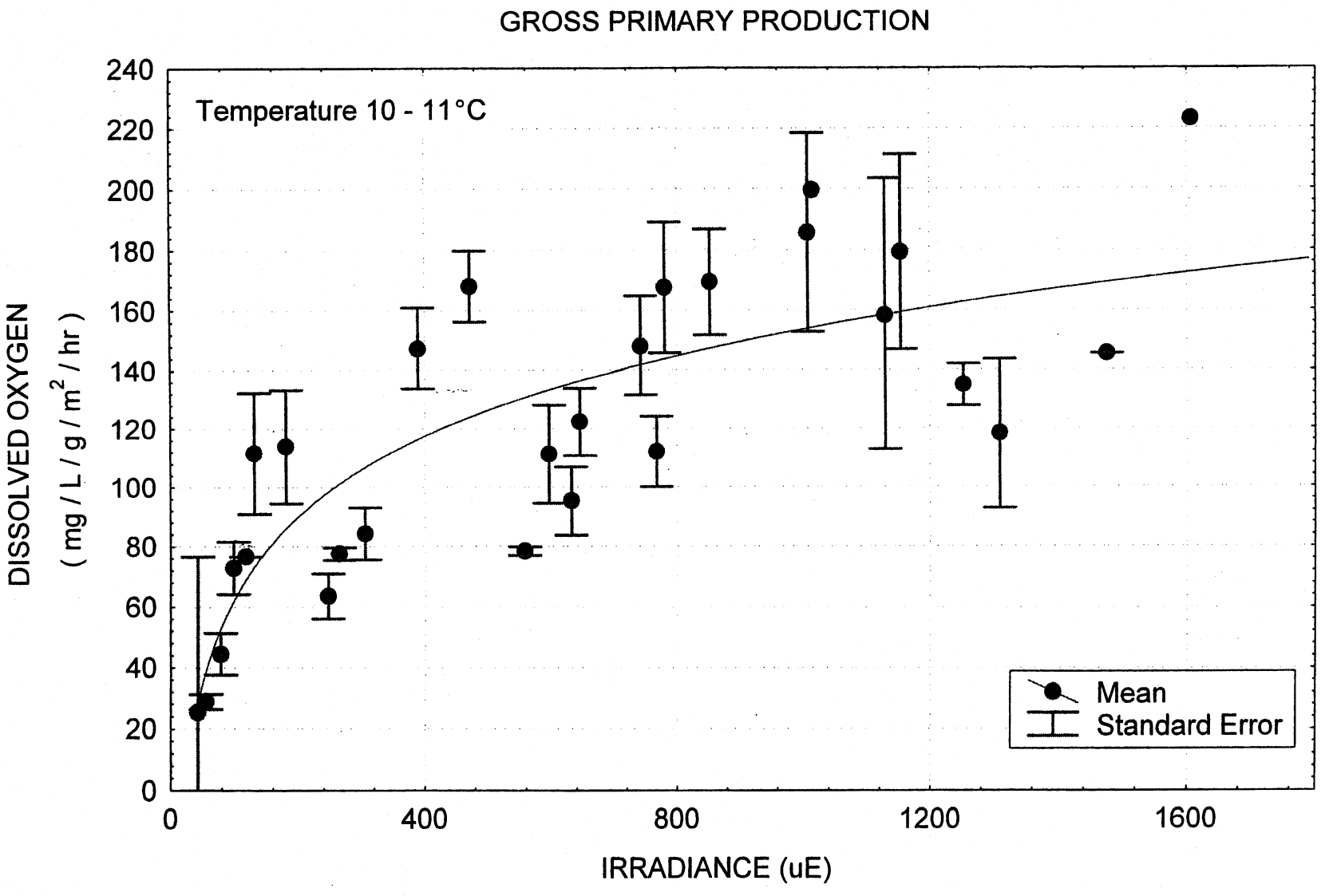

LIGHT ATTENUATION
INTER-ANNUAL VARIATION
($F_{(1,470)}$=149.98 p<.0001)
K_o = -1.275 + YEAR(.017)
Light Attenuation Coefficient
0.42
0.38
0.34
0.30
0.26
0.22
91
92
93
94
95
96
97
98
YEAR
2*SE
SE
Mean

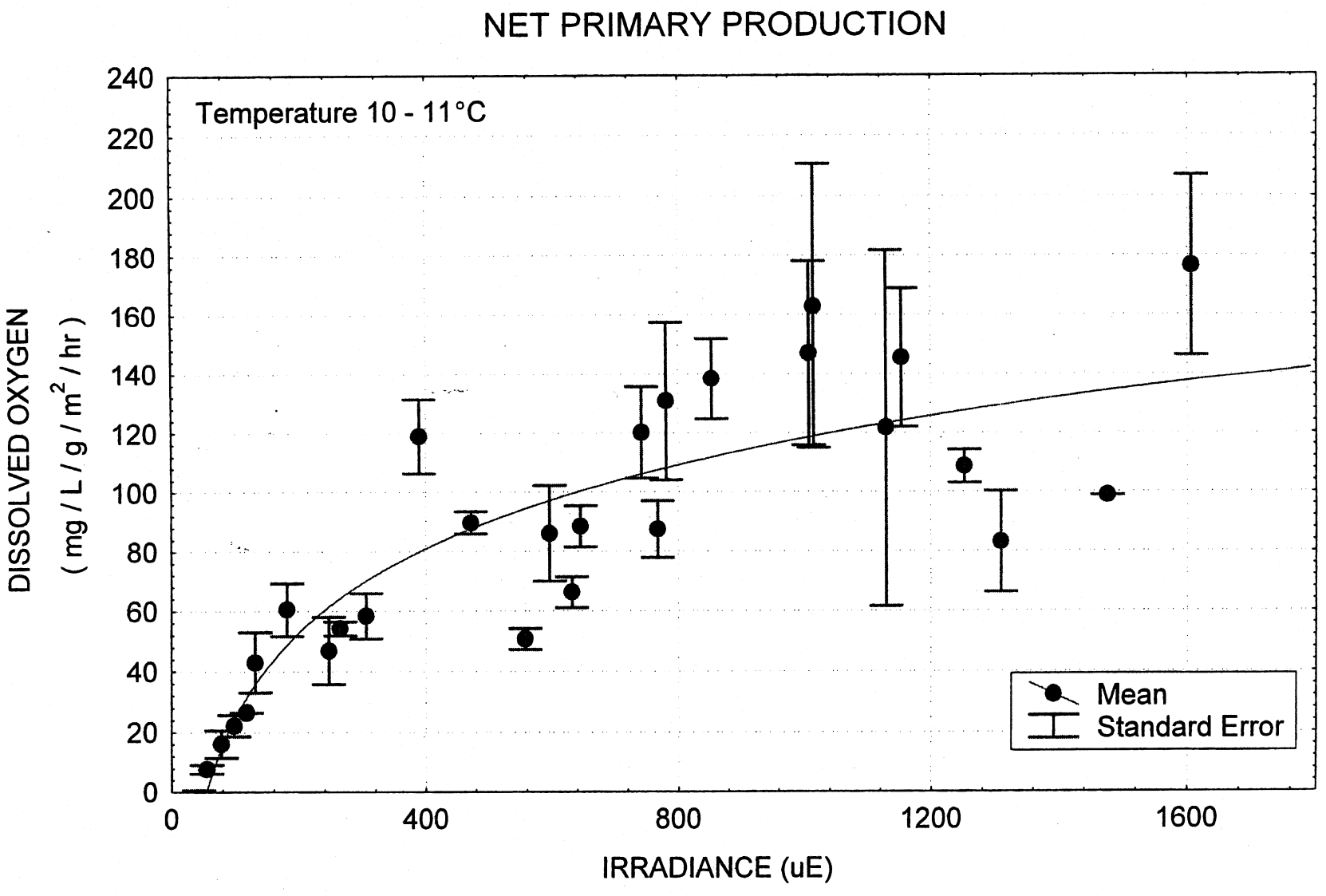
FIG 3.


LIGHT ATTENUATION
INTRA ANNUAL VARIATION
Angle of Incidence < 70°
Lees Ferry (Rkm 26)
Glen Canyon Dam (Rkm 0.0)
Single Standard Error Bar
ATTENUATION COEFFICIENT (Ko)
0.52
0.48
0.44
0.40
0.36
0.32
0.28
Jun-1997
Sep-1997
Jan-1998
Apr-1998
Jul-1998
Nov-1998
SAMPLING DATES


DEVIATION FROM INITIAL CONDITION
RELATIVE COEFFICIENT DIFFERENCE
(K d)
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
7
TRIALS
ALGAE
CONTROL
NON-ALGAE
1± SE


RESPIRATION RATES
AFSM
(g carbon)
260
220
180
140
100
60
20
-140
-120
-100
-80
-60
-40
-20
0
O2 (mg / L / g / m2/ hr)
Respiration


GROSS PRIMARY PRODUCTION
Temperature 10 - 11°C
DISSOLVED OXYGEN
(mg / L / g / m2 / hr)
240
220
200
180
160
140
120
100
80
60
40
20
0
0
400
800
1200
1600
IRRADIANCE (uE)
Mean
Standard Error


NET PRIMARY PRODUCTION
Temperature 10 - 11°C
DISSOLVED OXYGEN
(mg / L / g / m2 / hr)
240
220
200
180
160
140
120
100
80
60
40
20
0
0
400
800
1200
1600
IRRADIANCE (uE)
Mean
Standard Error