Ohio Sea Grant

THE ECOLOGY AND PRODUCTIVITY OF *CLADOPHORA GLOMERATA* IN WESTERN LAKE ERIE

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FOREWARD

The following technical bulletin was prepared by Mr. Mark E. Monaco as part of his Master of Science degree program in the College of Biological Sciences, Environmental Biology Program at The Ohio State University. The research for this bulletin was supported by the National Sea Grant College Program, NOAA (Grant No. D-00095) and the U.S. Environmental Protection Agency (Grant No. R005555). Dr. Charles E. Herdendorf served as advisor, and Drs. Walter E. Carey and Ronald L. Stuckey served on the reading and examination committee. Field and laboratory assistance on the project was given by Mr. Gordon Keeler, Mr. Timothy Bartish, Mr. Paul Ladd, Ms. Julie Letterhos and Mr. Gary Arico. Mr. Richard Lorenz provided technical advice for the entire study. The Ohio Sea Grant Program is pleased to make copies of this research available to the scientific community.

Charles E. Herdendorf
Director

ABSTRACT

Cladophora glomerata, an epilithic, macroscopic green alga that inhabits streams and the littoral zone of lakes in North America, can produce large quantities of standing crop in areas of the Laurentian Great Lakes where sufficient nutrients are available. This study was formulated to investigate the growth dynamics, the relationship between light attenuation and the vertical colonization of the alga, and to determine the areal distribution of Cladophora in western Lake Erie. Cladophora colonized on all suitable substrate throughout the basin, except where physical and/or chemical factors inhibited growth. The maximum amount of standing crop was found in the island region. The depth to which Cladophora was found on the island shelves and reefs varied with location. Depth of colonization was greater in the northern portion of the basin. Correspondingly, Secchi disk transparencies were greater and light extinction coefficients were smaller. The vertical distribution of Cladophora was limited by light attenuation at depth. Photosynthetically active radiation below approximately 50 $uEm^{-2}sec^{-1}$ was determined to limit vertical colonization.

TABLE OF CONTENTS

LIST OF TABLES

List of Tables cont.

LIST OF FIGURES

List of Figures cont.

List of Figures cont.

List of Figures cont.

PREFACE

This study is a continuation of the Lake Erie *Cladophora* Surveillance Program which was initiated in 1979 by the International Joint Commission as a component of the Great Lakes International Surveillance Program. For the past five years, the Center for Lake Erie Area Research (CLEAR), under sponsorship of the U.S. Environmental Protection Agency and the Ohio Sea Grant Program have investigated the growth dynamics, ecology, distribution, and the light and nutritional requirements of *Cladophora* to determine the utility of this algae to evaluate management strategies. The first two years of investigations were conducted by R.C. Lorenz. The objectives of the initial study were to monitor *in situ* growth rates, densities, and distribution of *Cladophora* in western Lake Erie and to determine possible relationships between environmental conditions and *Cladophora* growth (Lorenz and Herdendorf 1982).

Mr. Lorenz and this author have worked closely since 1980 on this investigation and I have integrated his laboratory results with the present study. Detailed methods and results of this combined effort may be found in Lorenz (1981), Lorenz and Herdendorf (1982), and this thesis. The thrust of Mr. Lorenz's work was to examine ecological factors, especially nutrients and temperature, whereas the present study stresses *Cladophora* productivity, particularly the influence of light on the vertical distribution of the algae.

INTRODUCTION

Biology of Cladophora

Cladophora glomerata (L.) Kutz. is an eplithic, macroscopic green alga that inhabits streams and the littoral zones of lakes in North America. A firm, non-shifting substrate with little net sedimentation is required for colonization. Attachment to the substrate is provided by a holdfast resulting from a basal differentiation of the filament. The branched filaments form a bush-like, green thallus of interwoven filaments. The cylindrical cells of the alga range from approximately 35 to 100 u in diameter and range between 120 to 700 u in length. Cells are coenocytic with many chloroplasts and division occurs by formation of a cross septa independent of nuclear division (Prescott 1968). The cell walls are thick and lamellate, with layered microfibrils in spirals.

Reproduction of *Cladophora glomerata* is generally considered to be asexual, although the production of sexual gametes and viable zygotes have been reported in European literature (Van Den Hoek 1963). Sexual reproduction has not been reported for *Cladophora* in the Great Lakes (Hoffman and Gerloff 1980). Flagellated zoospores is the commonly observed asexual mode of reproduction in the Great Lakes. Production of zoospores is environmentally controlled, resulting in a massive release of spores from thalli and cells simultaneously. After settling, the zoospores germinate into small plantlets within several days (Van Den Hoek 1963).

Akinete formation is a means of propagation when environmental conditions become unfavorable. The transformation of the cell into an akinete is characterized by the cell contents becoming dense, the accumulation of starch, and the thickening of the cell wall. Akinetes are capable of surviving unfavorable conditions and proliferating again under favorable conditions (Van Den Hoek 1963). Another method of asexual propagation is filament fragmentation.

Literature Review and Objectives

In areas of the Laurentian Great Lakes, where sufficient nutrient, light and substrate are available, *Cladophora* can produce large quantities of biomass. Standing crop values can reach 100 to 300 grams dry weight per m^2 of substrate with filament lengths approaching one meter (Canale and Auer 1982, Lorenz and Herdendorf 1982). Detailed descriptions of *Cladophora* growth have been reported from Lakes Erie and Ontario (Shear and Konasewich 1975), Lake Huron (Niel and Owen 1964), Lake Michigan (Lin 1977), and Lake Superior (Herbst 1969). Many aspects of the ecology of *Cladophora* have been summarized by Bellis and McLarty (1967) and Whitton (1967). This thesis was formulated as a limnological/ecological study of the environmental factors influencing the growth of *Cladophora*. It is hoped that the information contained in this thesis will be used to formulate and assess water quality management strategies for western Lake Erie and the other Great Lakes, based on the use of Cladophora.

Lake Erie was the last of the five Laurentian Great Lakes to be discovered by the Europeans in 1669 (Sly 1976), but cultural eutrophication has been most noticeable because it is the most populated and developed of the lakes. The nutrient rich western basin of Lake Erie, with a mean depth of 7.4 m, has historically been one of the most productive regions in the Great Lakes and has supported Cladophora growth since at least the mid 1800's (Taft and Kishler 1973). Cladophora is referred to as a nuisance alga because currents and wave actions often dislodge and deposit large quantities of filaments onto the shoreline, resulting in nuisance accumulations that produce noxious odors from the decaying biomass. To the public this is very tangible evidence of excessive algal growth that is frequently interpreted as environmental degradation. However, the Cladophora population plays an important role in the ecology of the nearshore region by supporting a wide diversity of organisms (Lorenz 1981, Lowe et al. 1982).

This investigation continued to monitor the stations established by Lorenz (1981) at Stony Point, Michigan (CS-1) during 1981 and at South Bass Island, Ohio (CS-2) during the 1981 and 1982 seasons (Fig. 1). This continued effort is necessary if the Cladophora Surveillance Program is to obtain its goal of utilizing Cladophora as a means of assessing water quality management strategies. In addition,

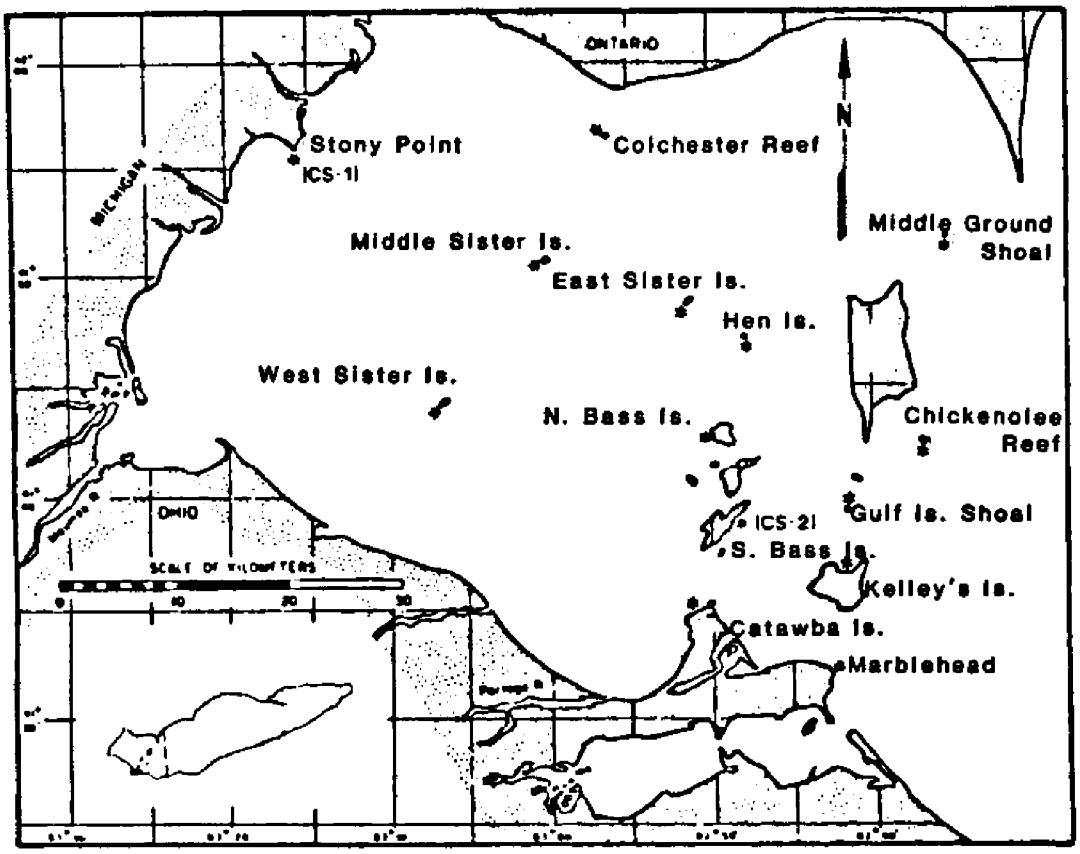


Figure 1. Locations of Cladophora Sampling Stations, Western Lake Erie, 1979-1983.

the present study was formulated to investigate the growth dynamics, areal and vertical distribution of Cladophora in western Lake Erie, and the minimal light requirements for net positive photosynthesis. The following objectives were formulated for this research effort.

1. Determine the minimal light requirements of Cladophora glomerata in western Lake Erie.

2. Determine the areal and vertical distribution of Cladophora glomerata in western Lake Erie.

3. Determine field and laboratory values for primary productivity at minimal light levels for growth.

4. Determine if Cladophora may be used as an indicator organism for water quality.

METHODS and MATERIALS

Study Sites

Site one was located at Stony Point, Michigan, 41°56'N latitude, 83°16'W longitude (Fig. 1). Stony Point is a submerged bedrock outcrop and is one of the few areas along the western shore of Lake Erie that provides adequate natural substrate for Cladophora colonization. This site was monitored for the first three years of the study, but was discontinued in 1982 for economic and logistic reasons.

Site two was established on the southeast side of South

Bass Island, Ohio 41°39'N latitude, 82°48'W longitude (Fig. 1). Substrate at this site is dolomite bedrock which gently slopes into the lake. The South Bass site is representive of the excellent substrate available for *Cladophora* colonization throughout the island region of Lake Erie. This site was monitored from 1979 through the 1982 season.

In addition 25 survey sites, 14 of which provided suitable substrate for colonization, were selected for three years to provide comprehensive data on the areal and vertical distribution of *Cladophora* in western Lake Erie.

Field Methods

At Stony Point and South Bass, five sampling stations were established to investigate variations in biomass with depth. The depths monitored were the splash zone, 0.5, 1.0, 2.0, and 3.0 meters of water. At each station, the following parameters were measured: Biological -- percent coverage of *Cladophora*, filament length (maximum and mean), standing crop expressed as wet 64° and 104° C dry, ash and ash-free weight; physical -- depth, temperature, (surface and bottom), vertical light profiles, Secchi depth, and weather; water nutrients — soluble reactive phosphorus (SRP), total phosphorus (TP), and total filterable phosphorus (TFP); *Cladophora* internal nutrients — total tissue phosphorous (TTP), total tissue nitrogen (TTN), and total tissue carbon (TTC); for calculations refer to Appendix A. At the two meter station water was collected for suspended solids analysis.

Sampling operations were conducted from a 21-foot boat and SCUBA gear was utilized for collection and observation. Standing crop samples were collected via hand harvesting within a 0.25 m^2 ring placed on the bottom. Separate sub-samples were taken for tissue chemical analysis. Water samples for nutrient analysis were collected at each depth with a Kemmerer water bottle.

Transparency of the water was measured using a 20-cm Whipple modified Secchi disk and vertical light profiles were obtained. Light was measured as photosynthetically active radiation (PAR) in micro-Einstiens per meter squared per second ($uEm^{-2}sec^{-1}$) with and underwater Li-Cor model, Li-193S spherical quantum sensor (LiCor). This sensor yields measurements of radiation from virtually all directions within the 400 to 700 nanometer wavelength spectrum, which represents the light that is available to the alga for photosynthesis.

Water temperatures were measured at 0.1 m below the surface and at each sampling depth with a mercury thermometer. Air temperature, wave height and percent cloud cover observations were recorded for each sampling date.

Shoreline accumulations of Cladophora during the die off period in July were monitored on the public beach near Perry's International Peace and Victory Memorial, South Bass Island, throughout the study. In August of 1983 splash zone rocks were incubated in the lake at 0.5, 1.0, and 2.0 meters to determine if death occurred with eulittoral

Cladophora, thus demonstrating a similar response as in infralittoral Cladophora.

Laboratory Methods

Water samples collected at the study sites were analyzed for SRP, TP, and TFP on board the Research Vessel HYDRA and on the Columbus campus of The Ohio State University. Methods of analysis are listed in Table 1. Nutrient analyses were done spectrophotometrically with an automated Technicon Auto Analyzer II.

Total tissue phosphorus (TTP), total tissue nitrogen (TTN), and total tissue carbon (TTC) analysis was performed on dried, motar and pestle ground, Cladophora. Total tissue carbon and TTN were determined with a Perkin-Elmer 240 elemental analyzer with a 1.0-to 1.5-mg sample of algal material. Total tissue phosphorus was determined with a Technicon Auto Analyzer II after a persulfate digestion.

The 0.25 m^2 Cladophora standing crop samples were cleaned of debris, organisms, and sediment by rinsing with a fast stream of water and blotted dry between paper towels prior to analysis. A series of standing crop determinations were made on each sample. Dry weight of the samples were determined at 64°C (DW 64°C) and 104°C (DW 104°C). Ash free weight (AFW) was determined by subtraction after ashing in a muffle furnace at 550 °C (DW 104°C - Ash Weight = AFW). Biomass data in the text is expressed as DW 104°C unless otherwise stated. The

TABLE 1
ANALYTICAL METHODS FOR WESTERN BASIN CLADOPHORA STUDY
1981-1983

Parameter	Method	Reference	Range
Soluble Reactive Phosphorus	AA II Stannous Chloride	CCIW, 1979	0.5-100 µgP/l
Total Filterable Phosphorus	AA II Persulfate + H_2SO_4 Digestion	CCIW, 1979	0.5-200 µgP/l
Total Phosphorus	AA II Persulfate + H_2SO_4 Digestion	CCIW, 1979	0.5-200 µgP/l
Suspended Solids	GF/C Glass Fiber Pad	APHA, 1975	0.2-250 mg/l
Total Tissue Phosphorus	AA II Persulfate + H_2SO_4 Digestion	CCIW, 1979	0.005-2.000 µgP/100 µg alga
Total Tissue Nitrogen	Perkin-Elmer Elemental Analyzer	CCIW, 1979	0.08-10.00 µgN/100 µg alga
Total Tissue Carbon	Perkin-Elmer Elemental Analyzer	CCIW, 1979	0.3-50.0C/100 µg alga
Standing Crop	0.25 m^2 *in situ* sample	Carnes & Millner 1980	
Wet	Blot Dried		0.01-500g
Dry	48 h at 60°C, then 104°C		0.001-250g
Ash Free Weight	104°C-550°C Ash Weight	APHA, 1975	0.001-200g

standing crop values were multiplied by four to arrive at the values expressed as g/m^2.

Field Surveys

Surveys over a large portion of the western basin were conducted to provide a comprehensive data base on the areal and vertical distribution of *Cladophora* during the peak standing crop period in late June of 1981, 1982, and 1983. A boat, SCUBA techniques and an aircraft were used in a coordinated effort to identify and to investigate the major areas of colonization. Twenty-five sites were visited, of these fourteen possessed suitable substrate to evaluate vertical distribution in relation to light (Fig. 1; Table 2). Sites investigated, consisted mostly of bedrock, and included shoreline areas, island shelfs, and reefs.

At each site with adequate substrate, the maximum depth that *Cladophora* colonized was determined visually by divers aided with SCUBA. Secchi disk transparencies were measured, surface and bottom temperatures recorded, and vertical light profiles were obtained as described above. Standing crop was also determined as outlined earlier.

Primary Productivity Field Procedures

Photosynthesis of *Cladophora* glomerata was monitored near Peach

TABLE 2
WESTERN LAKE ERIE SURVEY OBSERVATIONS
1981-1983

Site	Substrate	Mean Maximum Depth of Growth (m)	Mean Secchi Transparency (m)	Mean k
South Bass	Dolomite	3.1	1.7	1.00
Gull Island Shoal	Limestone	3.6	1.2	0.88
Catawba	Dolomite	1.6	0.7	2.00
Marblehead	Limestone	2.0	0.8	1.76
W. Sister	Limestone	3.4	1.3	0.81
Kelleys	Limestone	4.2	1.5	0.87
E. Sister	Limestone	3.5	1.7	1.14
Stony Point	Limestone	2.0	0.7	2.21
Middle Gr. Shoal	Limestone	4.5	1.8	0.64
Chickenolee	Limestone	4.8	1.5	0.94
Colchester	Limestone	6.7	2.6	0.55
North Bass	Dolomite	4.1	1.4	0.78
M. Sister	Limestone	2.7	1.4	1.56
Hen	Limestone	3.3	1.2	1.02
RANGE		1.5-7.1	0.5-4.2	0.52-2.5

k = extinction coefficient (see discussion).

Point, South Bass Island in the late summer of 1983. This site was selected because it supports a good growth of Cladophora and depths which yield light levels below one percent of incident light.

Cladophora filaments were hand harvested from splash zone rocks near Peach Point and brought back to the laboratory. After washing to remove epiphytes and invertebrates the filaments were acclimated 24 h in lake water aquaria. Photosynthesis was measured by the carbon-14 technique (Steeman-Nielsen 1952, Herdendorf and Carey 1978) (Fig. 2). Filaments of Cladophora were placed in a 50-ml graduated cylinder and when 5 ml of water had been displaced, this uniform quantity of Cladophora was placed in each of the incubation bottles (Jackson 1966). Each of the 16 bottles, 8 dark and 8 light, contained 300 ml of filtered lake water (FLW) from the station, which had been filtered through a 0.45 um HA millipore filter to remove all particulate material. The bottles were innoculated with 3 uCi of aqueous $NaH_{14}CO_3$ and the fresh Cladophora filaments were added in loose clumps in replicate incubation bottles. The bottles were incubated in the field for 3 h at 0.5, 1.0, 2.0 m, and at the one percent incident light level. Incubations were conducted from 1130 to 1430 h, the period of maximum light intensity. Water temperature, pH, and alkalinty were measured with a mercury thermometer, an Orion 701 pH meter, and a Hach Model AL-95 Alkalinty Kit.

The samples were then returned to the laboratory for filtration and analysis. The Cladophora filaments and incubation water were

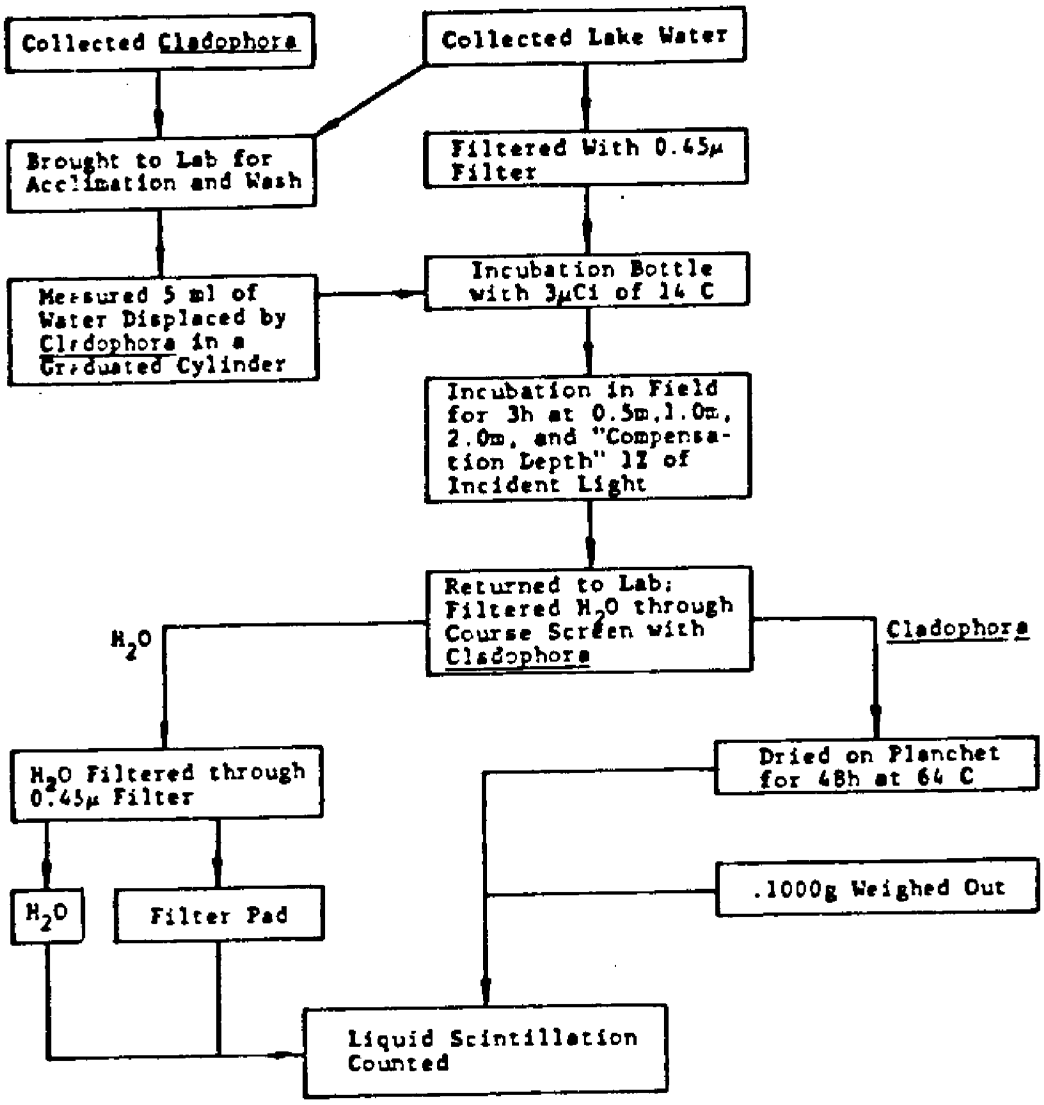


Figure 2. Primary Productivity Experiment Procedure Flow Chart.

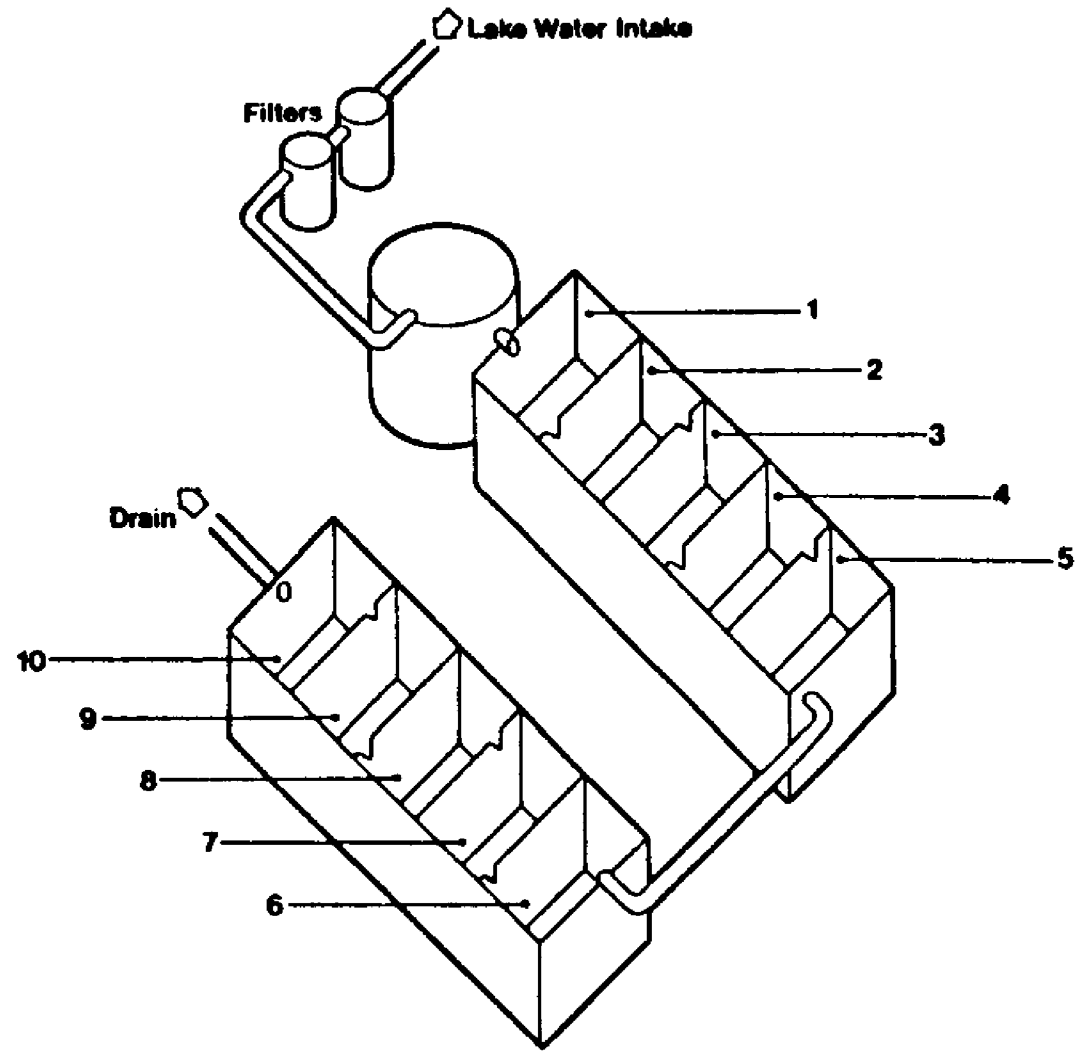
poured onto a 3 mm grid size screen over a beaker. The algal filaments were trapped on the screen and the water went into the beaker. The alga was squeezed with forceps to remove excess water, put on a planchett, and dried in an oven at 64°C for 24 h. The incubation water was filtered and the 0.45 um filters were rinsed with pH 2 FLW to eliminate the error in primary productivity measurements caused by the retention of aqueous $Na_{14}CO_3$ in the filters (American Society of Limnology and Oceanography, Inc. 1979). Cladophora samples, filters, and the rinsate were analyzed for C-14 activity by liquid scintillation counting. The log amplification system in a liquid scintillation counter allows for monitoring of the quenching in a sample based on the location of the Compton edge region of the internal Cs-137 standard (Beckman 7500). Quenching reduces the light distribution to lower pulse heights. The difference in channel settings between a quenched and unquenched sample is called the H-number method of quench monitoring and was used in this research. The counts per minute (cpm) from the algal samples, filters, and filtered rinsate were added together for the productivity calculations (Appendix B). Absolute rate of carbon fixation as mg carbon fixed per gram dry weight and hour (mg C g dry $wt^{-1}h^{-1}$) was calculated from the C-14 fixation data, water temperatures, pH, total alkalinity, volume corrections, and conversion tables to determine total carbon per liter (Adams and Stone 1983, Saunders et al. 1962). A sample calculation is shown in Appendix B.

Primary Productivity Laboratory Procedures

Productivity experiments were conducted at various light intensities in the laboratory to complement the field data on the light requirements for productivity in Cladophora. The gradient was designed to quantify the minimal light level necessary to sustain Cladophora productivity, under conditions as close to the natural lake environment as possible.

The gradient consisted of ten, 114-liter tanks connected in series, equipped with a flow-through water system (Fig. 3). Water from Fisheries Bay which fronts Peach Point was pumped into the lakeside laboratory where it was filtered through two Aqua Pure AP-110 cartridges (Westwater Supply Co.) to remove suspended material and maintain constant water clarity. Two experiments were conducted, one at the ambient temperature of the lake (26°C) and the other with the gradient cooled down to 15°C. Light was supplied to the gradient by a bank of fluorescent light suspended above each tank. Light levels of 18, 35, 55, and 70 $uEm^{-2}sec^{-1}$ were obtained by adjusting the height of the lights and by using layers of window screen placed on top of the individual tanks as a light attenuation mechanism. Light intensities were measured in PAR units 15 cm above the bottom of each tank with the same spherical quantum sensor used for the field measurements.

The productivity measurements were conducted as described in the field procedures except for the following modifications. Lake water



Tank number	PAR $\mu E/m^2 \cdot sec$
1	acclimation tank
2	acclimation tank
3	18
4	acclimation tank
5	35
6	acclimation tank
7	55
8	acclimation tank
9	70
10	-

Tanks: 114 liters
61 L x 48 W x 38 W cm
Flow Rate: 57 l/hr
Temperature: 15°C and 26° C
Photoperiod: 14 hrs

Figure 3. Cladophora productivity gradient design.

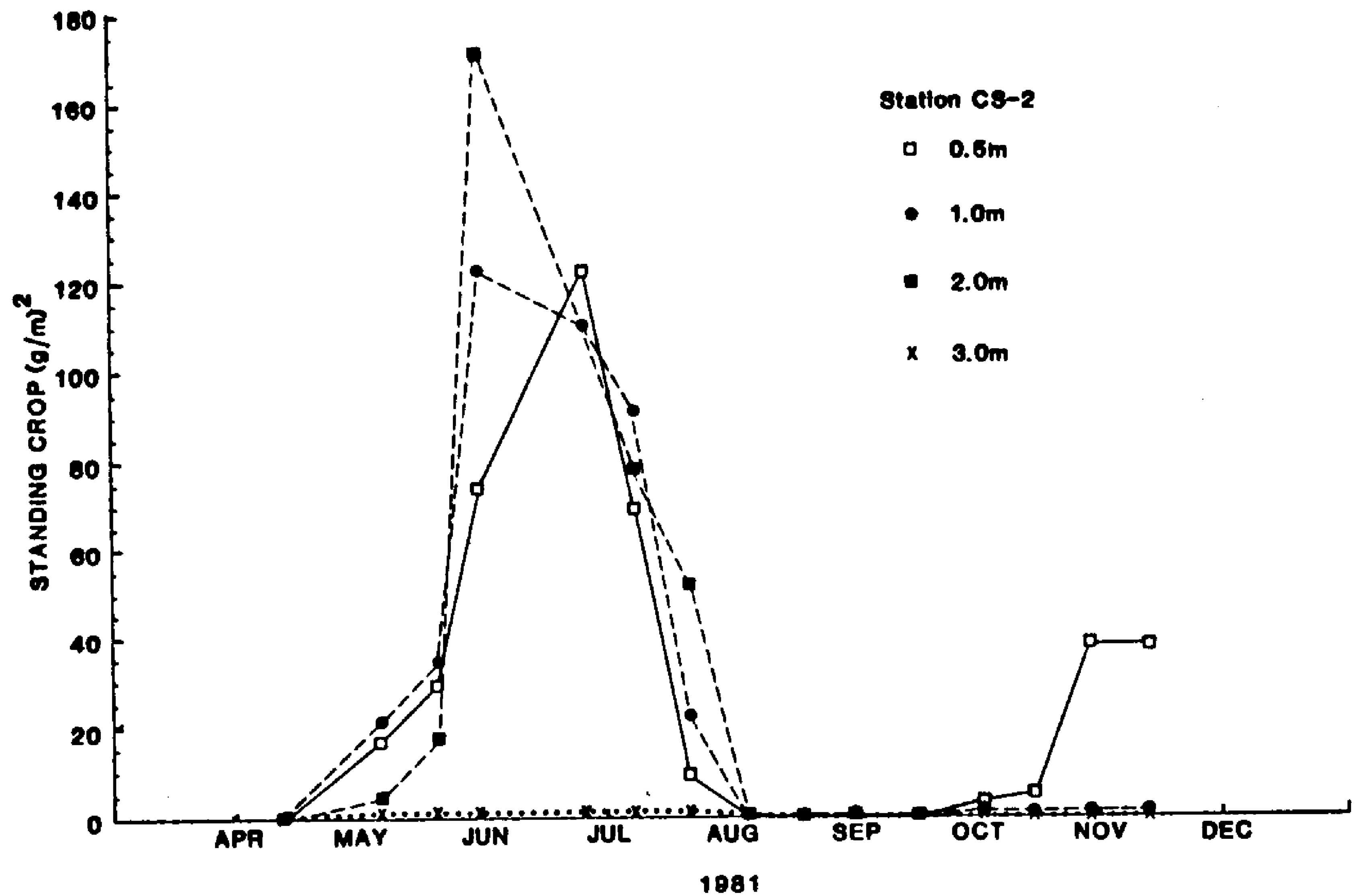


Figure 4. Cladophora Standing Crop at South Bass Island, 1981.

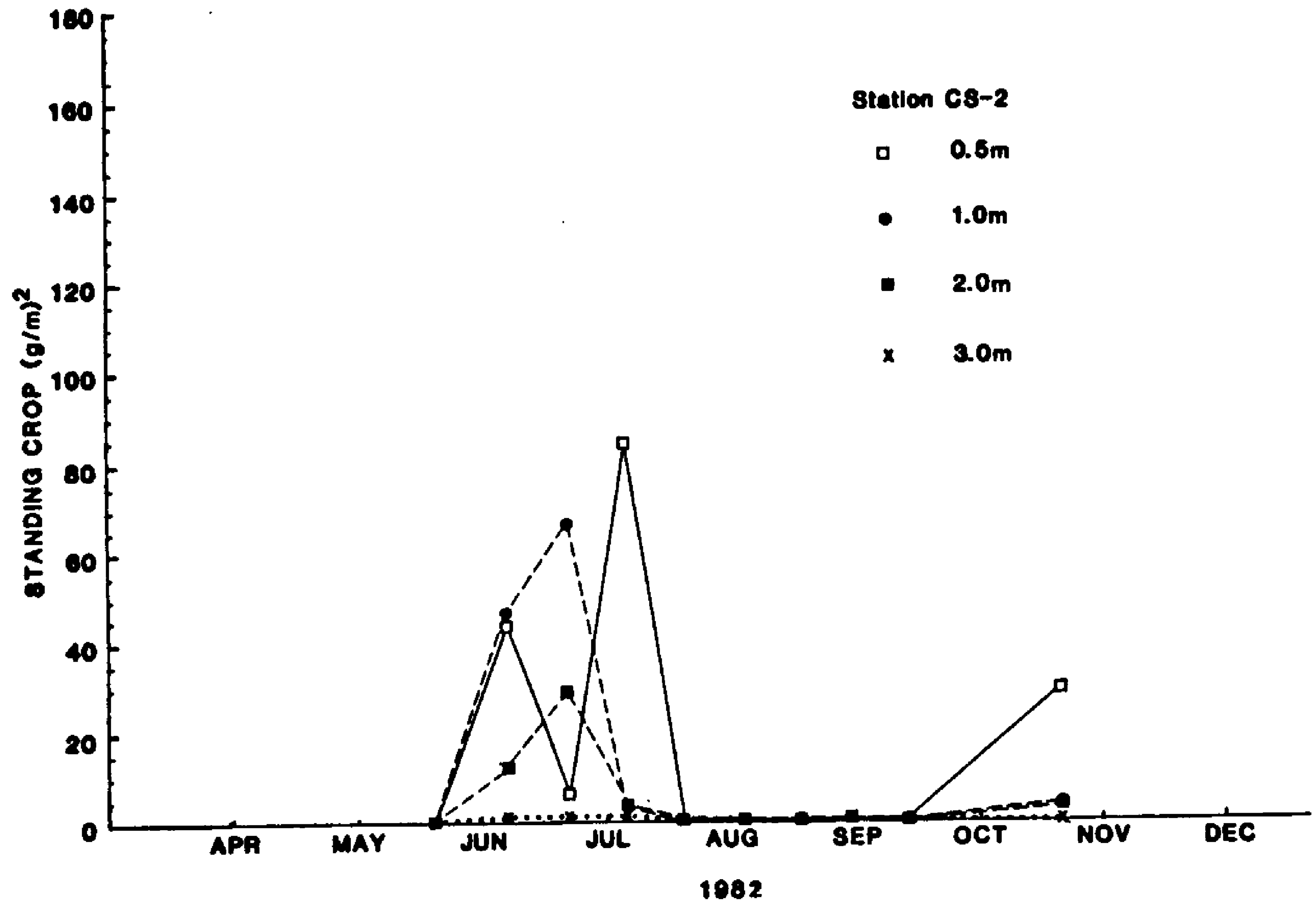


Figure 5. Cladophora Standing Crop at South Bass Island, 1982.

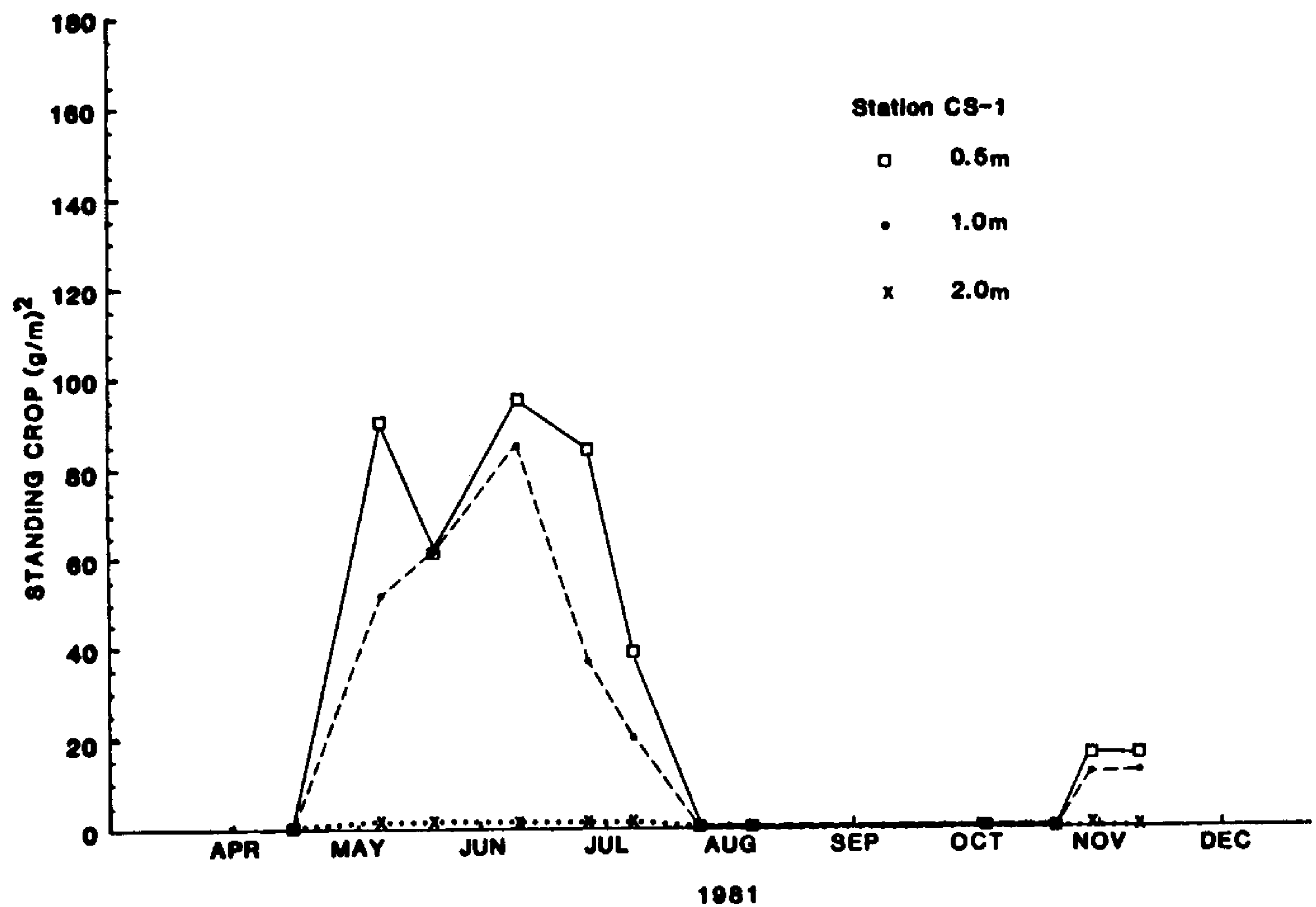


Figure 6. Cladophora Standing Crop at Stony Point, 1981.

from the gradient was filtered with 0.45 um filters into one liter Erlenmeyer flasks. These flasks were then sealed and incubated in the gradient to obtain the correct water temperature of 15°C or 26°C. Acclimated water and Cladophora filaments were placed in replicate light and dark bottles and innoculated with 3 uCi of C-14. The samples were incubated in the gradient at the prescribed light intensities for 3 h. The samples were filtered and radioassayed as described above.

RESULTS

Study Sites

Standing crop at South Bass for the 1981 and 1982 field seasons varied from 0 to 172 g/m^2 with a maximum filament length of 75 cm. Peak periods of production, as measured by an increase in filament length and standing crop, occurred from May to July with maximum standing biomass achieved from mid-June to mid-July (Figs. 4, 5). Stony Point's standing crop values ranged from 0 to 116 g/m^2 with a maximum filament length of 50 cm. Peak periods of production and maximum standing crop coincided with the South Bass results (Fig. 6). The percent coverage of Cladophora ranged from 0 to 100 percent during the growth periods. Maximum standing crop and filament length for the entire study are summarized below (Table 3).

At both sites during all years of the study the standing crop in the infralittoral zone declined during late July and by August only

TABLE 3
MAXIMUM STANDING CROP AT STONY POINT
AND SOUTH BASS ISLAND SITES
1979-1983

Site	Year	(g/m^2)*	Maximum Filament (cm)
Stony Point	1979**	107	37
	1980**	186	40
	1981	116	50
	1982	110	30
	1983	---	---
South Bass	1979	110	90
	1980	218	45
	1981	172	50
	1982	88	75
	1983	174	75

*Dry Weight 104°C
**Lorenz 1981

short (0.5-2.0 cm) brown epiphyte-laden filaments and holdfasts remained. The splash zone Cladophora remained present throughout the field season, but declined slightly in August. The loss of biomass from the Cladophora beds usually occurred during wind and storm events. At Stony Point in 1981 from August to November Cladophora was present in trace amounts until the normal fall resurgence occurred. This maximum value was considerably less than the values recorded in 1979 and 1980 at Stony Point, but relatively consistent at South Bass for the study (Table 4).

The deepest depth of colonization ranged from 1.5 to 2.0 m at Stony Point and from 3.0 to 3.5 m at South Bass. Maximum standing crop at each station depth was determined (Fig. 7).

Total tissue nutrient results are presented below (Table 5). The critical nurtients, total tissue phosphorus and nitrogen, ranged from 0.068 to 0.685 and 1.12 to 5.03 percent, respectively for the study.

Secchi disk transparencies at Stony Point averaged 0.7 m at the 2 m station in 1981 (Fig. 8) and is consistent with values of Lorenz (1981) for this depth. Light levels recorded for each site varied, with rapid attenuation occurring at depth. The deepest depth of Cladophora colonization at Stony Point was 2 m. At this depth a mean light level of 44 $uEm^{-2}sec^{-1}$ was recorded for the 1979 through 1981 field seasons. The mean total suspended solids was 31 mg/l ranging

TABLE 4
AUTUMN RESURGENCE STANDING CROP VALUES (g/m^2)*
STONY POINT (1979-1981) AND SOUTH BASS (1979-1982)

Stony Point	1979**	35
	1980**	186
	1981	16
South Bass	1979	15
	1980	50
	1981	33
	1982	28

*Dry Weight 104°
**Lorenz 1981

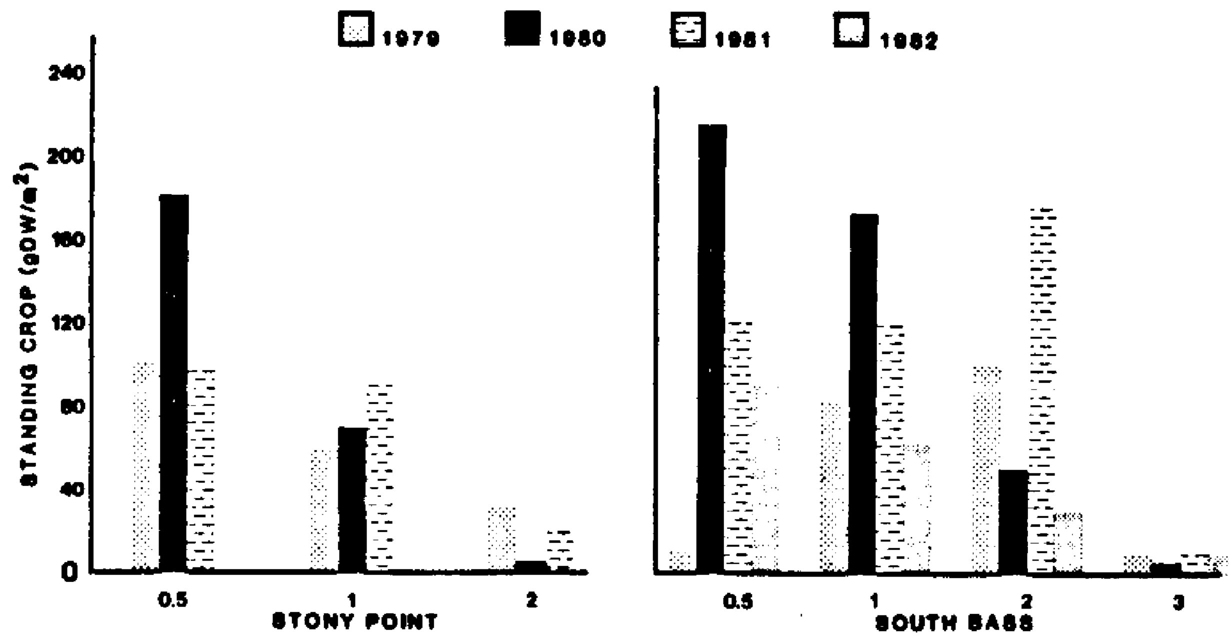


Figure 7. Maximum Standing Crop and Depth Distribution of Cladophora for Stony Point and South Bass Sites, 1979-1982.

TABLE 5
ANNUAL RANGES AND MEANS FOR *CLADOPHORA* TISSUE NUTRIENTS AT STONY POINT (1981) AND SOUTH BASS ISLAND SITES (1981, 1982), 0.5 TO 3m STATIONS

Site	Year	Total Tissue P%		Total Tissue N%		Total Tissue C%	
		Range	Mean	Range	Mean	Range	Mean
Stony Point	81	0.108-0.391	0.237	2.40-4.60	3.50	22.6-34.8	30.9
South Bass	81	0.068-0.426	0.163	1.13-5.03	2.77	9.2-44.7	27.2
	82	0.073-0.685	0.305	1.12-4.50	2.62	8.9-37.5	25.9

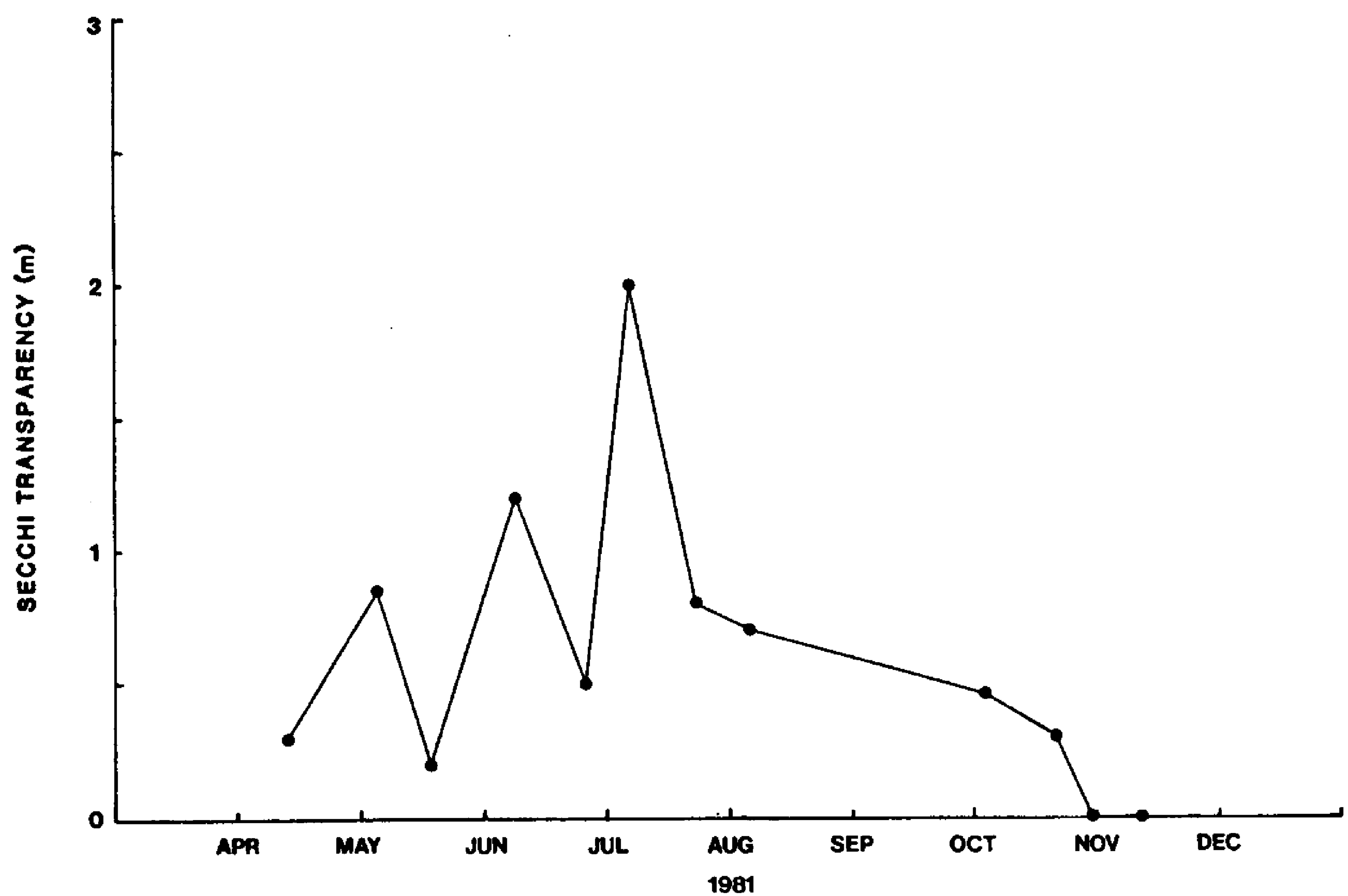


Figure 8. Secchi Transparencies, Stony Point, 2 meter Station, 1981.

from 2-100 mg/l and water temperatures ranged from 4°C to 27°C (Table 6).

The South Bass site had an average Secchi transparency of 1.2 m at the 2 m station (Fig. 9), which was the same value recorded by Lorenz (1981) for this depth. The deepest depth of *Cladophora* colonization at South Bass was 3.5 m. At this depth a mean light level of 56 $uEm^{-2}sec^{-1}$ was recorded for the 1979 through 1982 field seasons. The mean total suspended solids was 11 mg/l ranging from 4-27 mg/l and water temperatures varied from 6°C to 27°C (Table 6).

Water quality in this basin of Lake Erie exhibits wide fluctuations. The various forms of phosphorus measured generally peaked in the spring and early summer, declined throughout the summer, and increased again in the autumn (Figs. 10, 11, 12). At Stony Point SRP, TFP, and TP averaged 7.7, 11.9 and 78.2 ugP/l, respectively. At South Bass the average SRP, TFP, and TP was 3.4, 9.4 and 33.0 ugP/l, respectively (Table 6). Refer to Appendix C for complete data sets for the study.

Western Lake Erie *Cladophora* Survey

Cladophora was present throughout the western basin and was generally found wherever suitable natural or artificial substrate was available. The largest extent of natural substrate is found in the island area. Standing crop values varied annually at the sites,

TABLE 6
SUMMARY OF WATER QUALITY OBSERVATIONS
AT STONY POINT AND SOUTH BASS
1981-1982

	Stony Point 1981		South Bass 1981		South Bass 1982	
	Range	Mean	Range	Mean	Range	Mean
SRP µg P/l	1.0-36.0	7.2	0.7-8.2	3.0	1.50-8.8	3.8
TFP µg P/l	3.0-40.0	11.9	2.8-13.0	7.0	3.1-34.1	11.7
TP µg P/l	34.0-182.0	78.2	13.0-64.0	31.0	21.3-39.1	34.8
Secchi (m)	0.2-3.0	0.7	0.07-3.0	1.2	0.6-2.0	1.2
Total suspended solids mg/l	2.0-100.0	31.0	4.0-27.0	11.0	—	—
Water temp. °C	4.0-27.0		6.0-26.0		6.0-27.0	

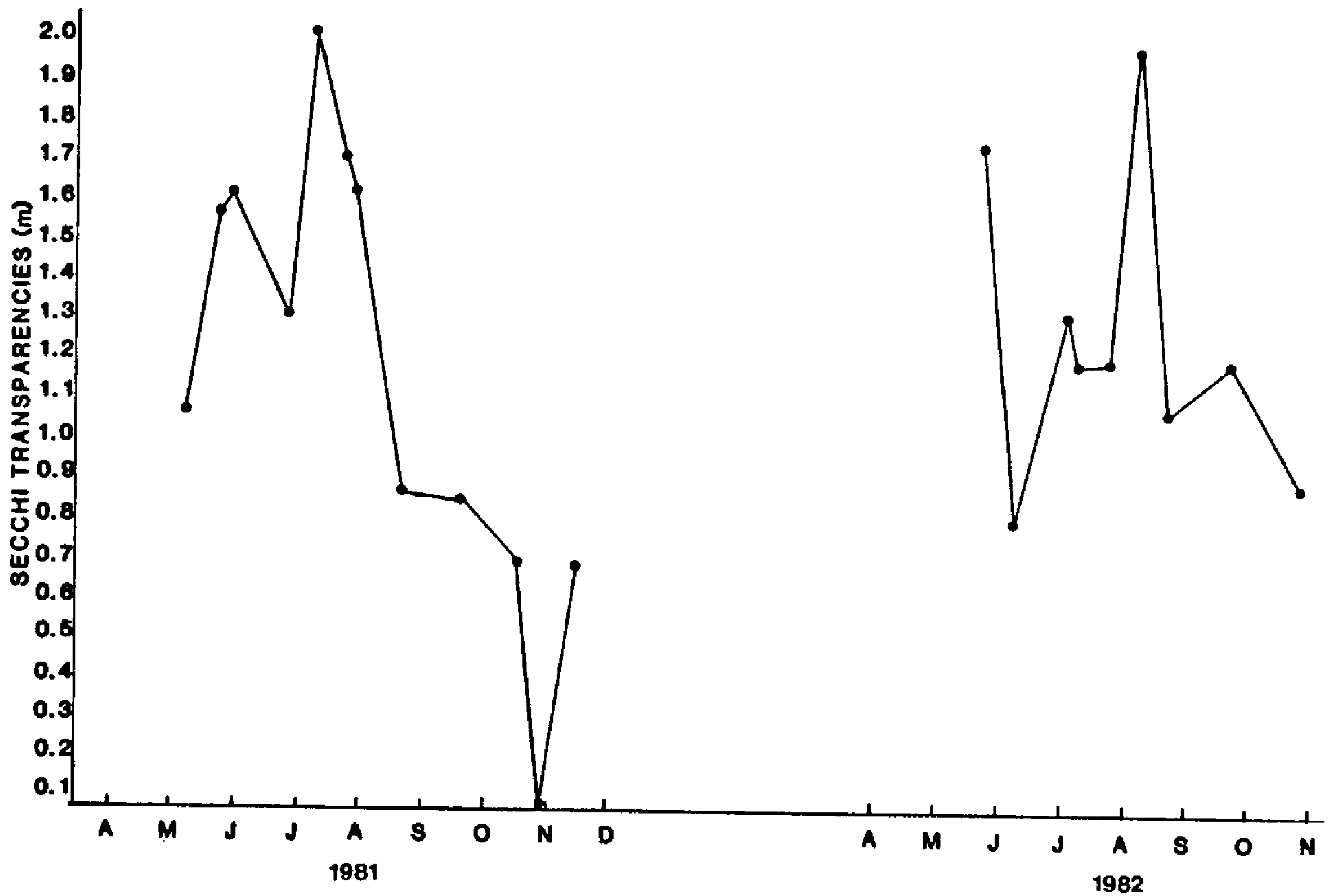


Figure 9. South Bass Secchi Transparencies, 2 meter Station, 1981 and 1982.

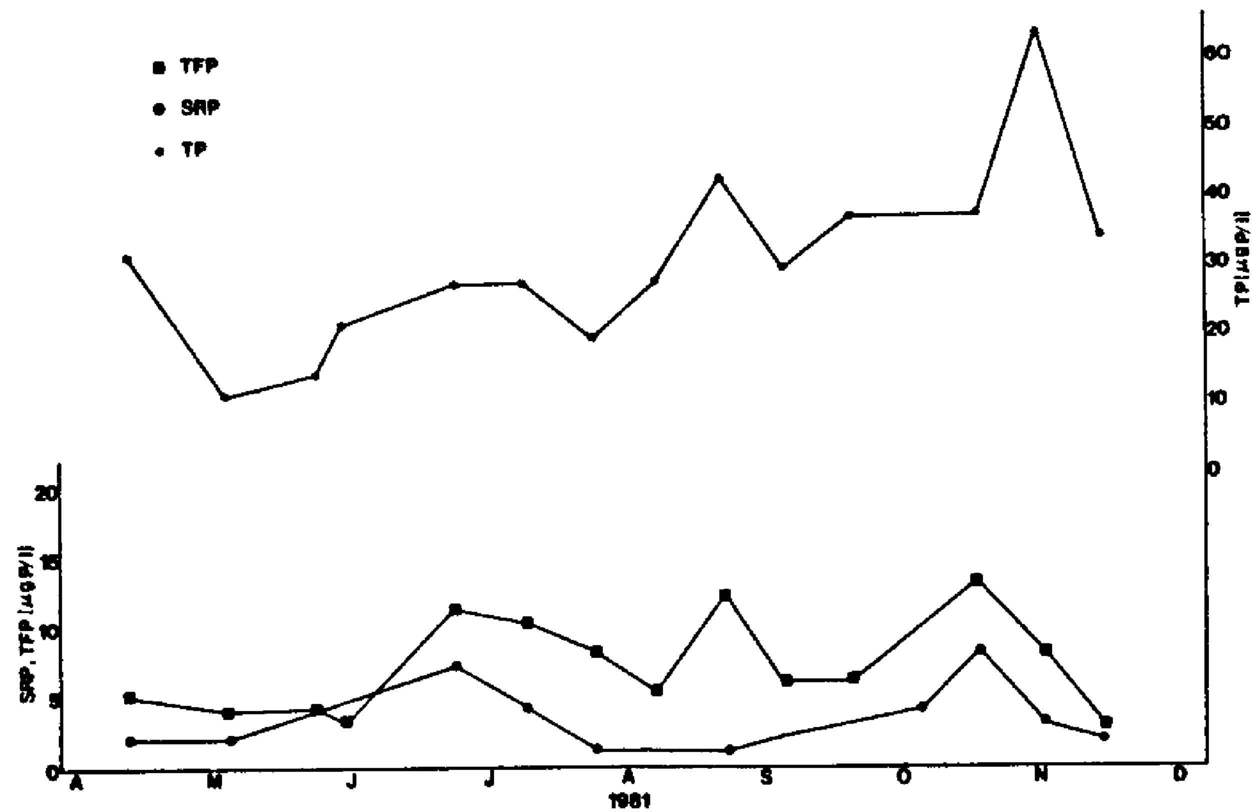


Figure 10. Water Nutrient Data, South Bass Island, 1 meter Station, 1981.

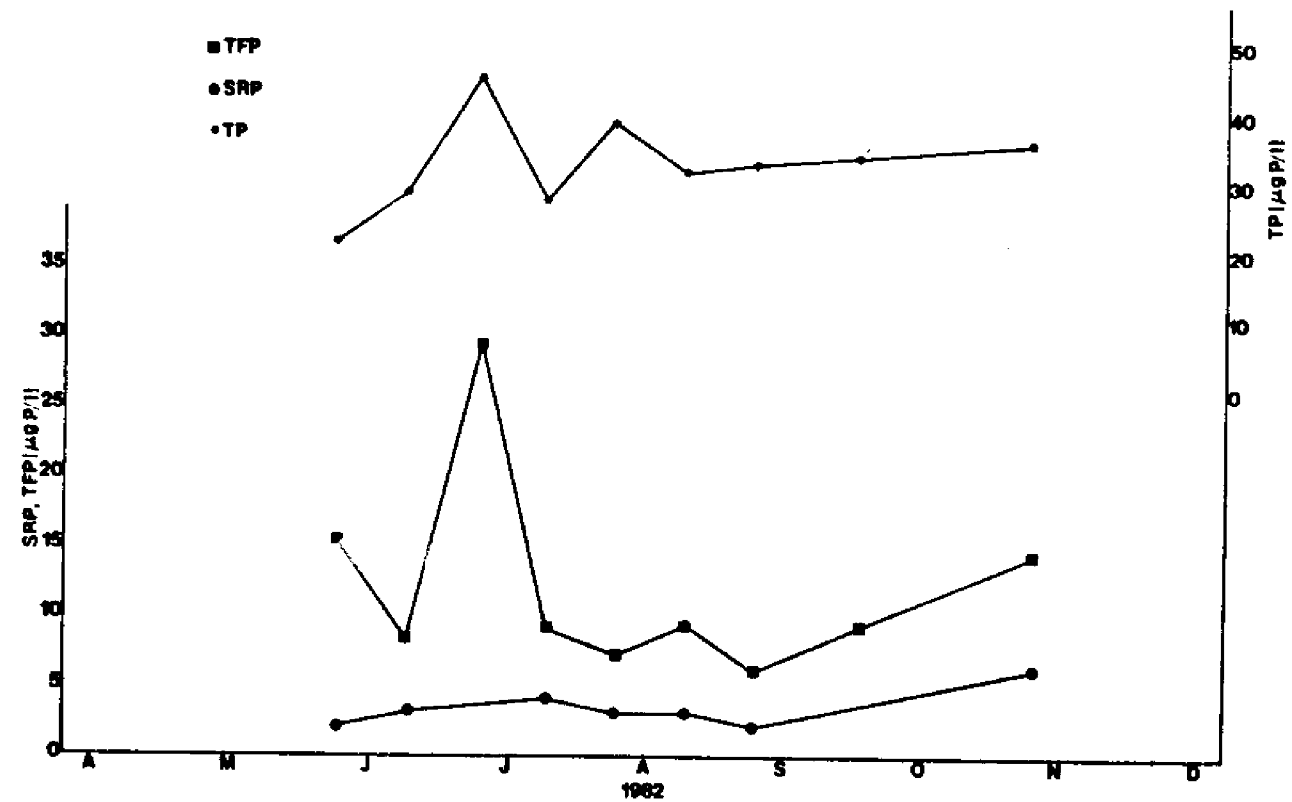


Figure 11. Water Nutrient Data, South Bass Island, 1 meter Station, 1982.

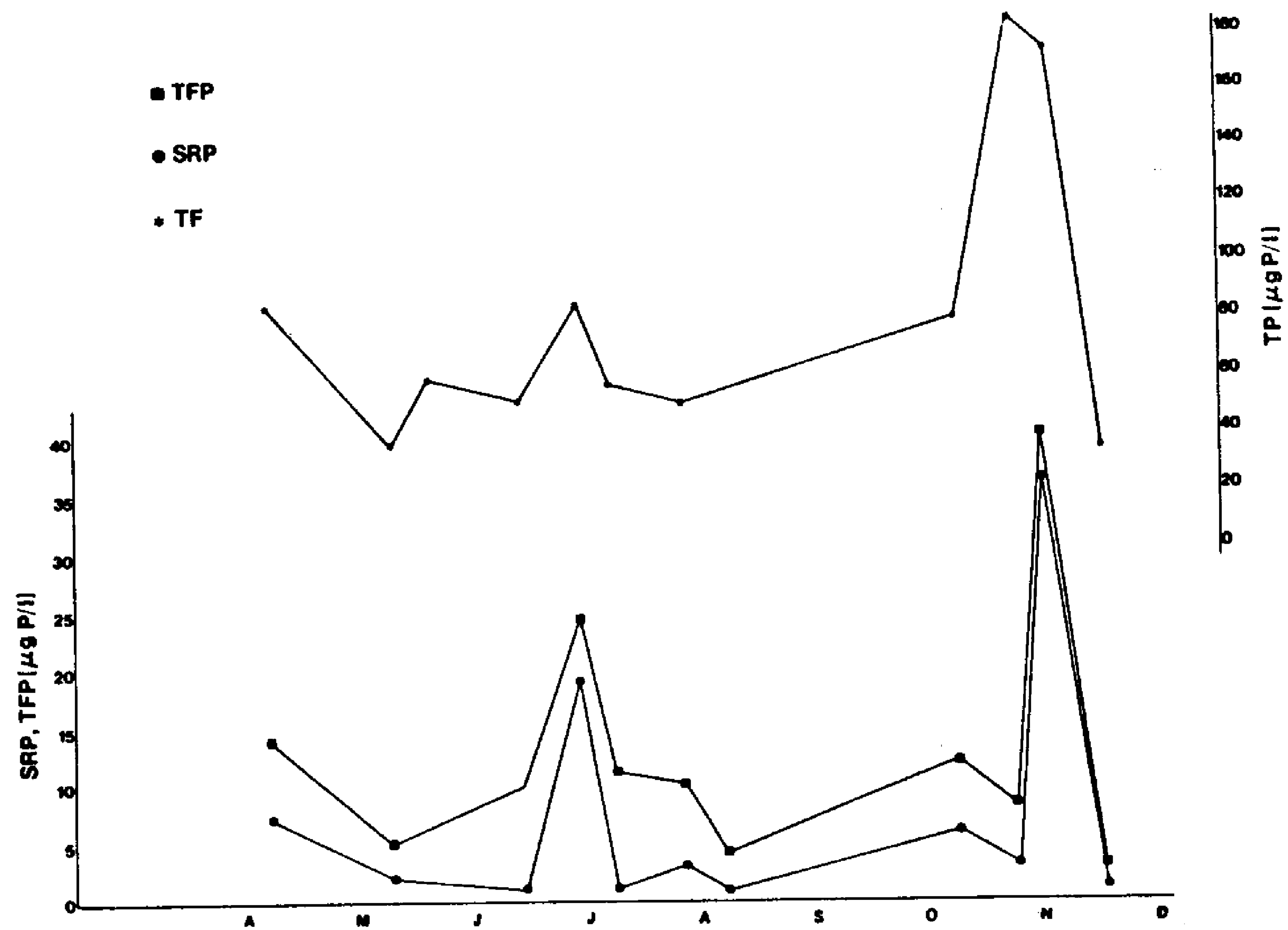


Figure 12. Water Nutrient Data, Stony Point, 1 meter Station, 1981.

ranging from trace amounts (Grecian Shoal, 1983) to 240 g/m^2 (Kelleys Island, 1984). The island region consistently produced the largest amount of biomass with the largest concentrations found at Kelleys Island (Fig. 13).

Smaller extinction coefficients were recorded for the northern portion of the basin with deeper light penetration into the water column (Table 2). It was in this area where the deepest colonization of Cladophora was observed, with Colchester Reef (Fig. 1) averaging the deepest depth of growth at 6.7 m. The maximum depth of colonization at the 14 sites investigated ranged from 1.5 to 7.1 m (Table 2). Offshore sites supported Cladophora colonization to a greater depth than nearshore sites. The mean depth to which the alga colonized corresponded directly with mean Secchi transparency ($r=0.89$) and inversely to the mean extinction coefficient of light ($r=-0.84$) (Figs. 14, 15). Secchi depths within the turbid western basin ranged from 0.5 to 4.2 m and the extinction coefficient of light varied from 0.52 to 2.5 (Table 2).

Field and Laboratory Experiments

The results from the incubation of splash zone rocks in the lake during the die off period are reported below (Table 7). Algal filaments were 25 percent of their initial length by day three of incubation and of these filaments only 25 percent appeared viable under microscopic examination.

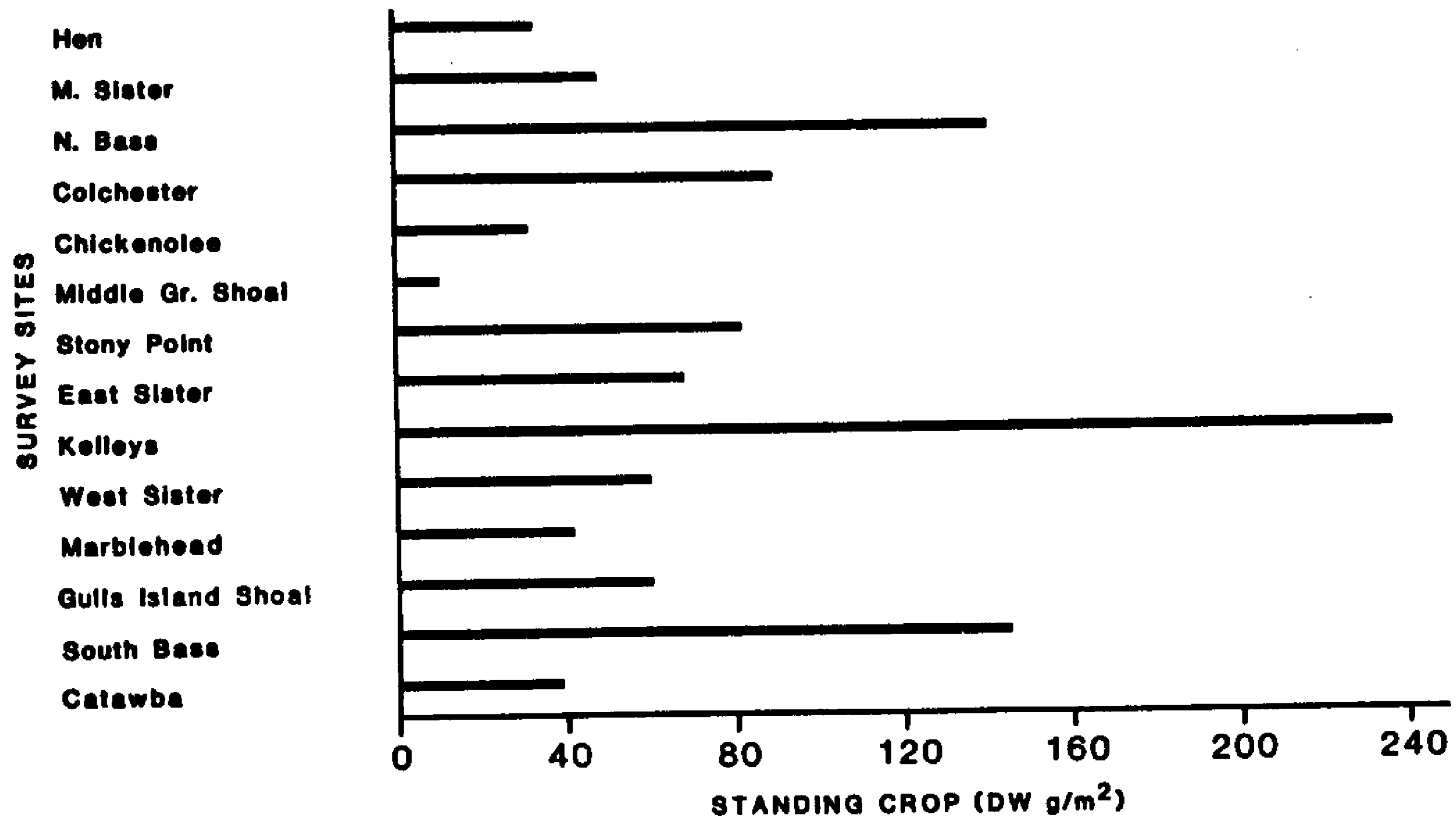


Figure 13. Mean Standing Crop for Cladophora Surveys, 1981-1983.

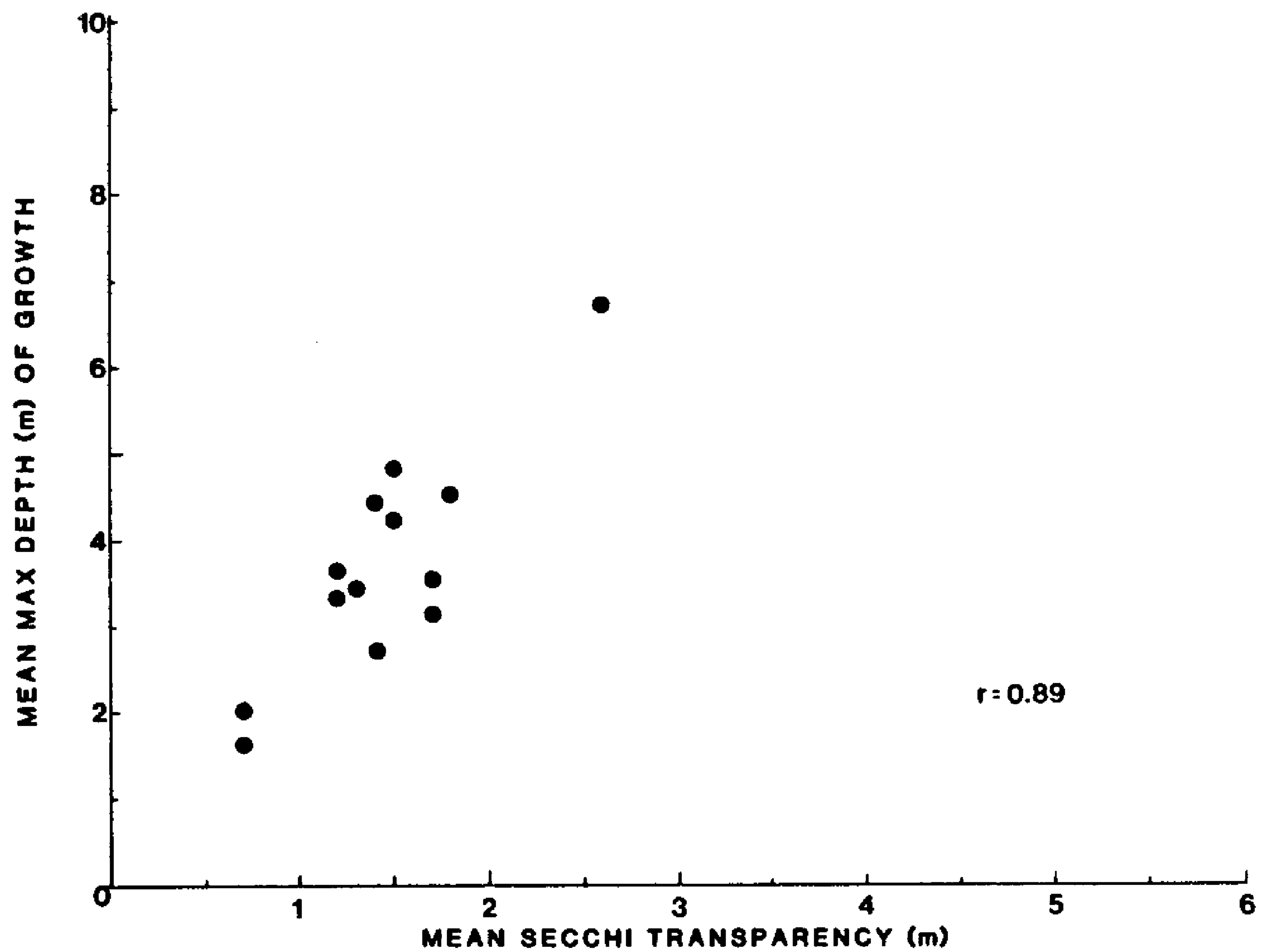


Figure 14. Mean Secchi Transparencies vs. Mean Maximum Depth of Colonization for Western Lake Erie Survey Sites, 1981-1983.

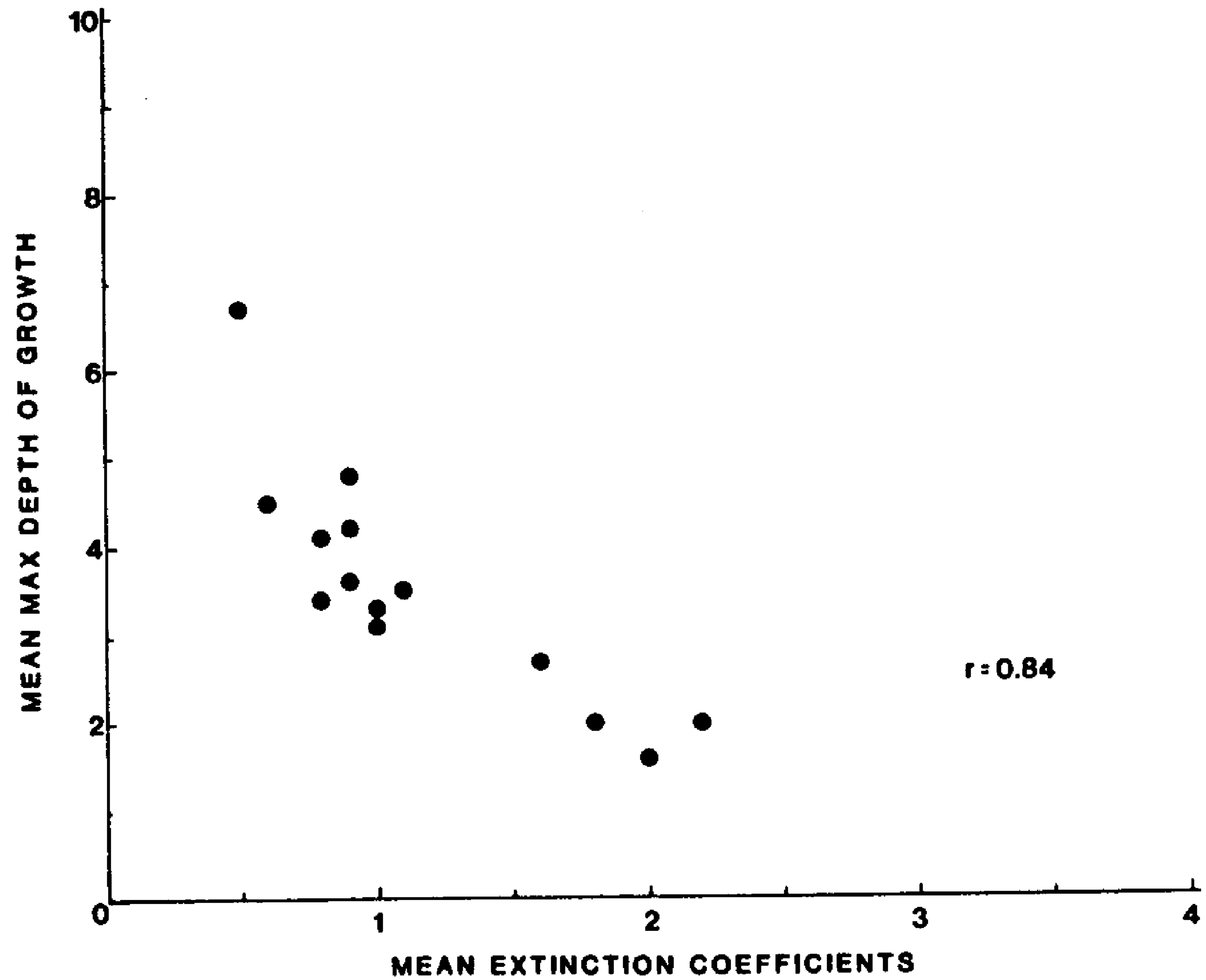


Figure 15. Mean Extinction Coefficients vs. Mean Maximum Depth of Colonization for Western Lake Erie Survey Sites, 1981-1983.

TABLE 7
IN SITU INCUBATION RESULTS
PEACH POINT, SOUTH BASS ISLAND, OHIO
1983

Day	Filament Length (cm)		percent Coverage
1	8		100
2	5		80
3	2	~25% of filaments contained chlorophyll	30
4	1		20
5	0		TRACE

Field productivity. The primary productivity results from the two field experiments are summarized in Table 8. The mean lake temperature, alkalinity, and pH were 26.5°C, 88 mg/l $CaCO_3$, and 7.8, respectively. Productivity ranged from 0.13 mg C g dry $wt^{-1}h^{-1}$ at the calculated one percent incident light level to 5.39 mg C g dry $wt^{-1}h^{-1}$ at 0.5 m. A decrease in light intensity correlated with reduced productivity values (Figs. 16, 17, 18, 19).

Laboratory productivity. The results from the two laboratory productivity experiments are reported in Table 8. The first experiment was performed at the ambient lake temperature of 26°C. Values of 102 mg/l $CaCO_3$ and 7.9 were obtained for alkalinty and pH, respectively. Productivity ranged from 0.0081 mg C g dry $wt^{-1}h^{-1}$ with higher values at increased light intensities (Fig 20).

The second laboratory experiment in the light gradient was conducted at the reduced water temperature of 15°C. The alkalinty of the water was 86 mg/l of $CaCO_3$ with a pH of 8.0. Productivity ranged from 0.0866 mg C g dry $wt^{-1}h^{-1}$ to 0.3006 mg C g dry $wt^{-1}h^{-1}$. At 15°C net productivity was negligible below 35 $uEm^{-2}sec^{-1}$, but increased 3.5 times at 35 $uEm^{-2}sec^{-1}$. At this reduced temperature productivity values were relatively consistent above 35 $uEm^{-2}sec^{-1}$ and greater (Fig. 21).

TABLE 8
PRODUCTIVITY EXPERIMENTS RESULTS

	Depth (m)	Intensity ($uEm^{-2}sec^{-1}$)	Productivity Mg C g dry wt^{-1} h^{-1}	Water Temp. °C
Field 1	0.5	1,620	5.39	26.0
	1.0	972	4.80	
	2.0	275	2.02	
1% INCIDENT LIGHT		29	0.13	
Field 2	0.5	891	3.46	27.0
	1.0	567	3.67	
	2.0	227	2.28	
1% INCIDENT LIGHT		30	0.13	
Lab 1	—	18	0.0081	26.0
	—	35	0.0311	
	—	55	0.0579	
Lab 2	—	70	0.1401	15.0
	—	18	0.0866	
	—	35	0.3006	
	—	55	0.2715	
	—	70	0.2900	

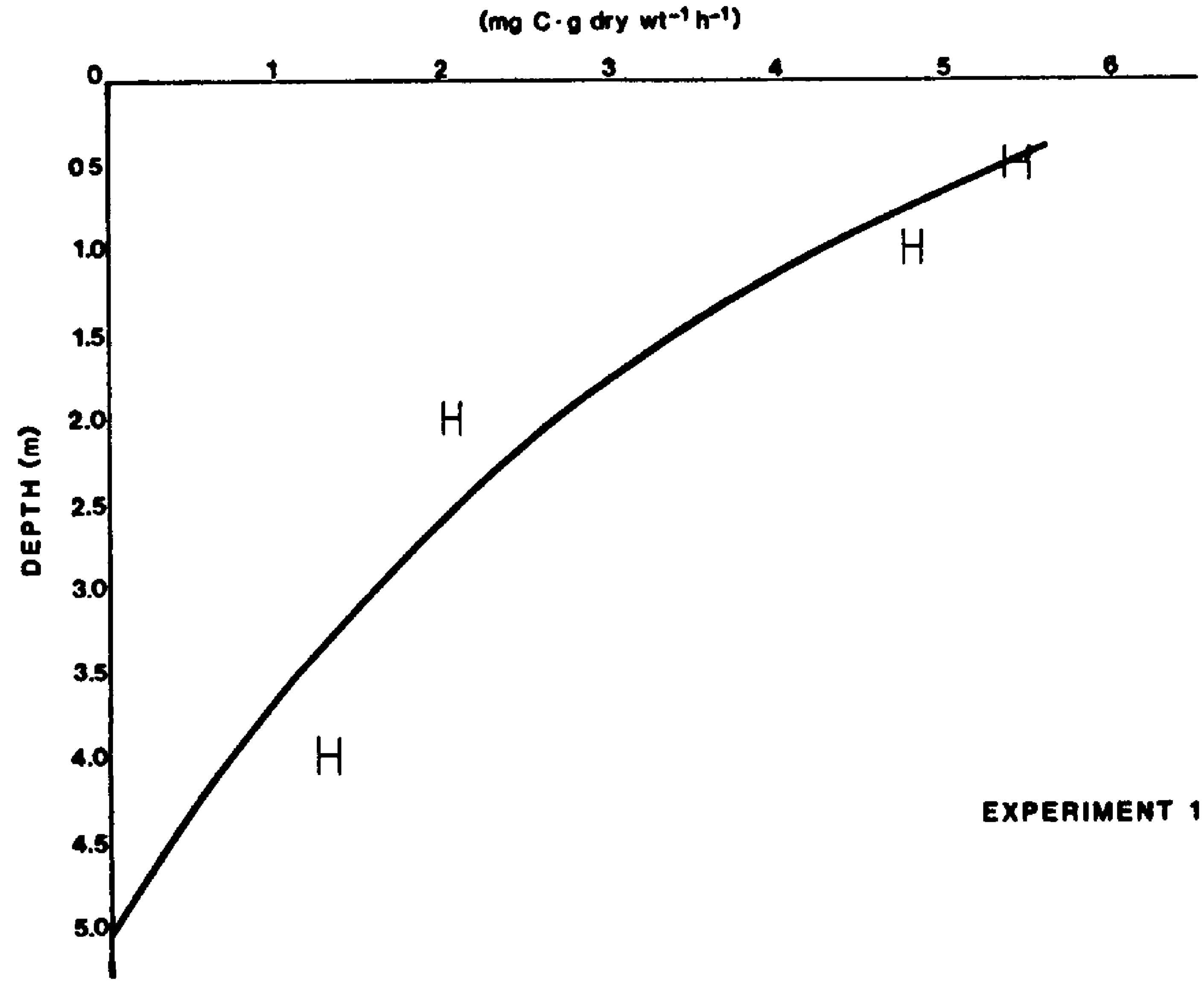


Figure 16. <u>Cladophora</u> Field Productivity vs. Depth at South Bass Island, 1983.

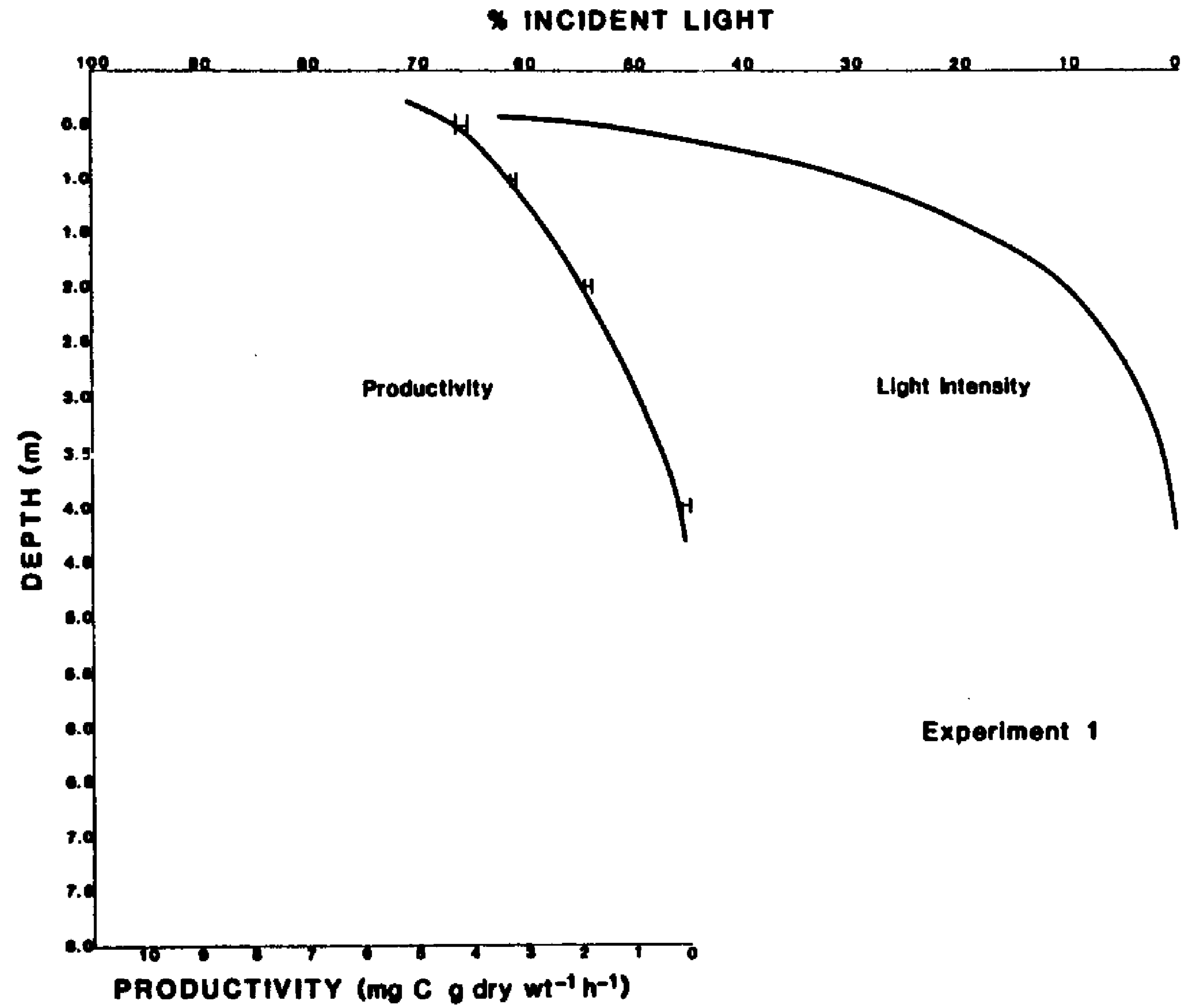


Figure 17. Cladophora Field Productivity Values and % Incident Light vs. Depth, South Bass Island, 1983.

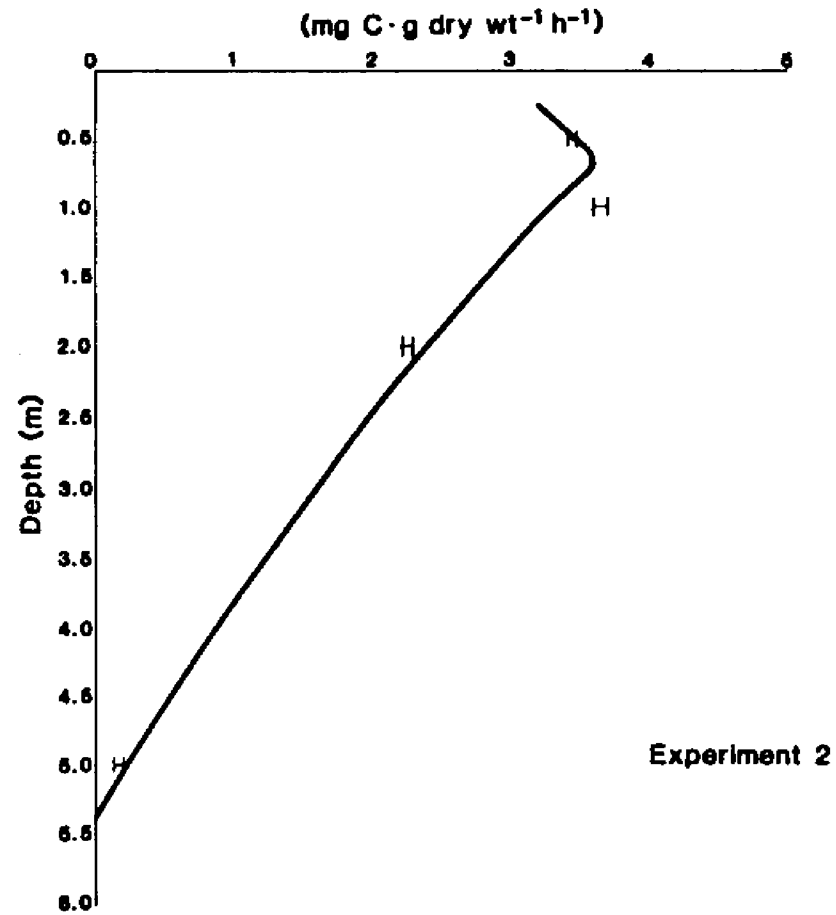


Figure 18. *Cladophora* Field Productivity vs. Depth at South Bass Island, 1983.

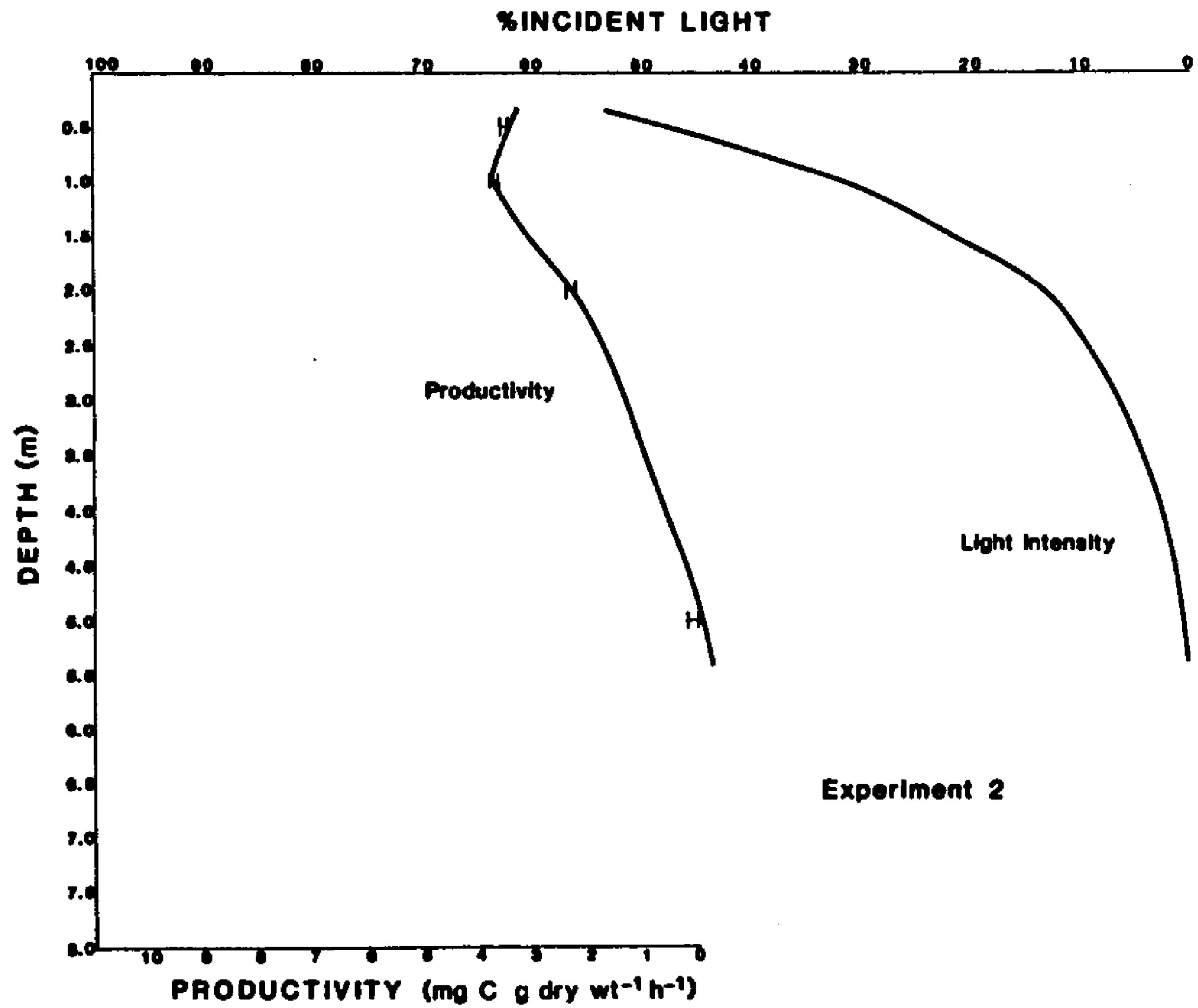


Figure 19. *Cladophora* Field Productivity Values and % Incident Light vs. Depth, South Bass Island, 1983.

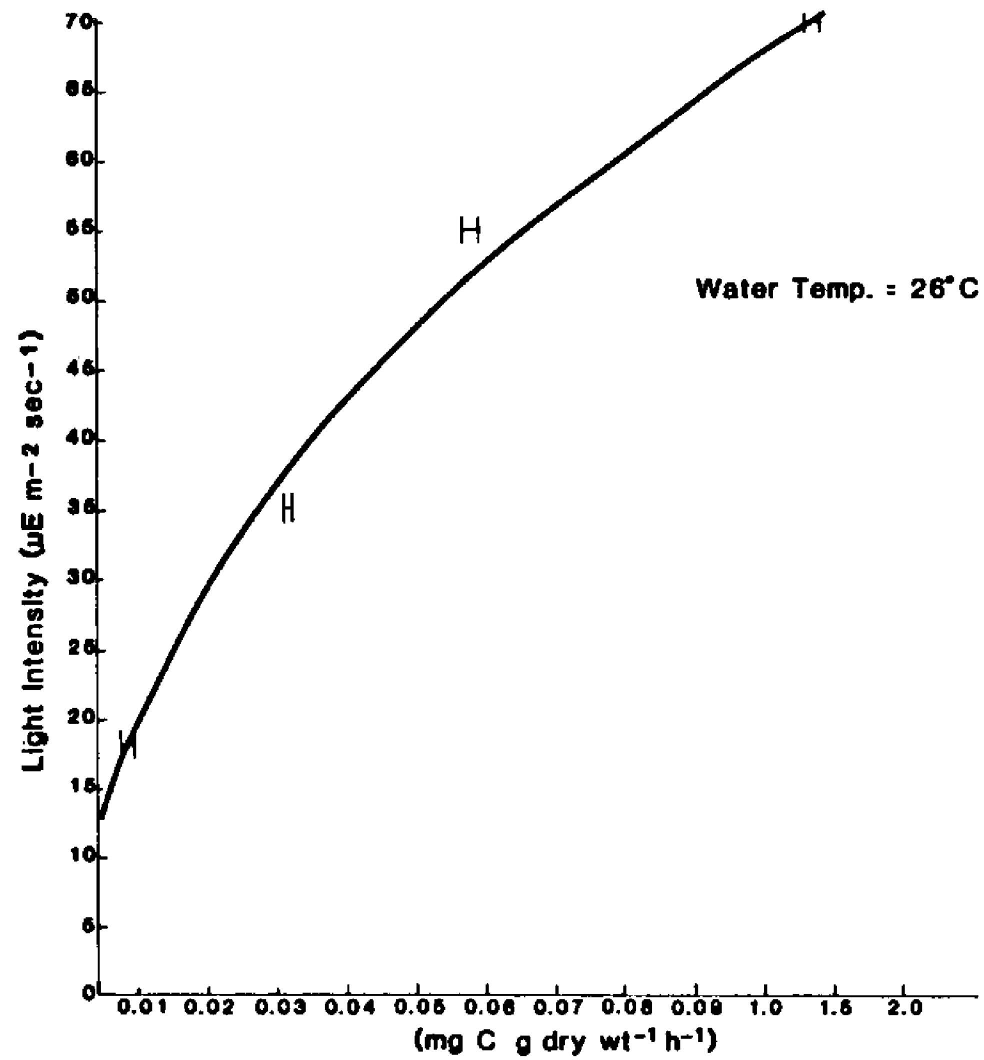


Figure 20. Cladophora Laboratory (1) Productivity vs. Light Intensity, 1983.

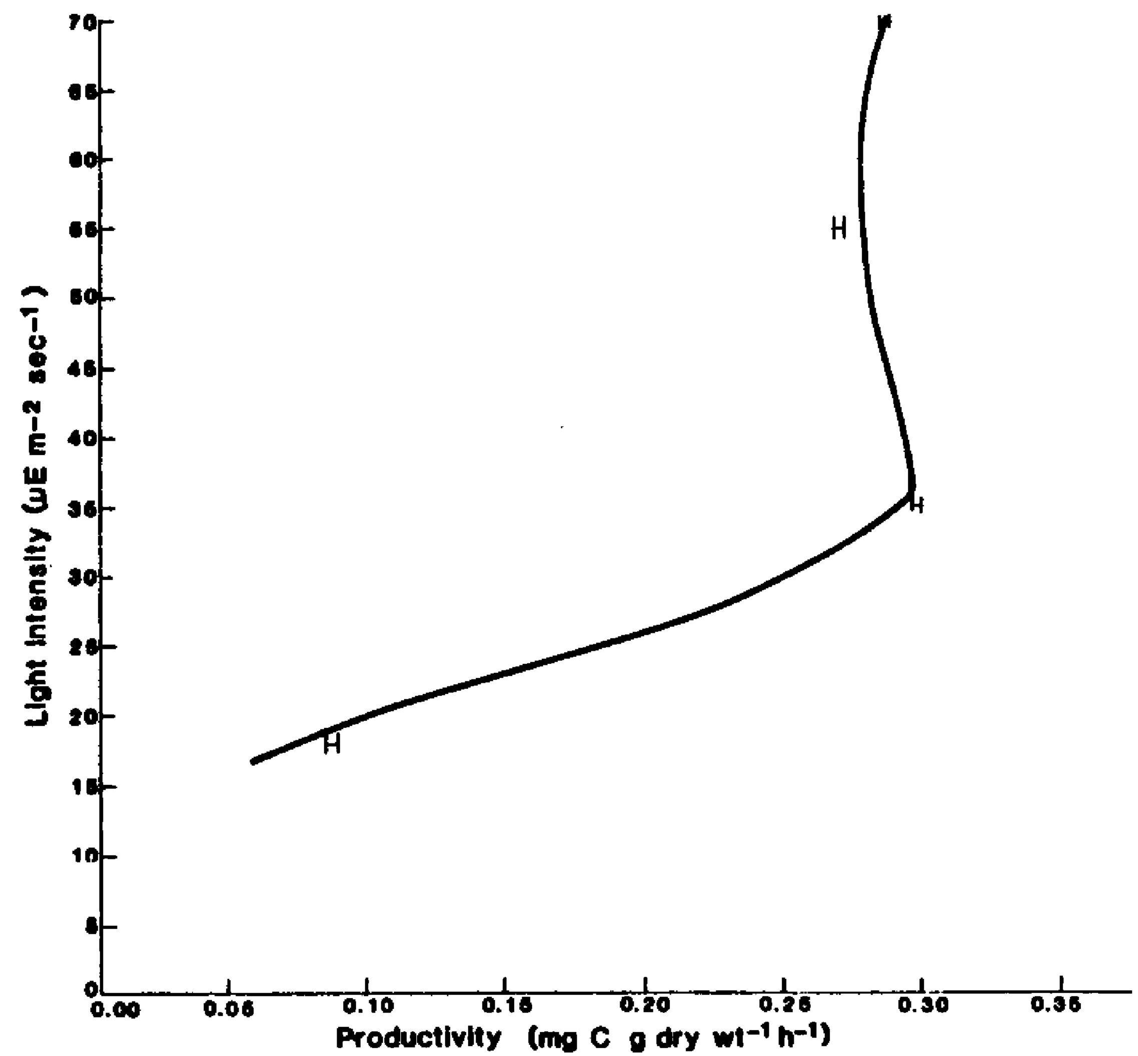


Figure 21. Cladophora Laboratory Productivity (2) vs. Light Intensity, 1983.

DISCUSSION

Cladophora growth in the Laurentian Great Lakes is well known and has been documented in the earliest records (Bailey 1847). The distribution of Cladophora in the Great Lakes has increased in response to cultural eutrophication around the heavily populated areas of the basin. Auer and Canale (1981) have compiled distribution data for all of the Great Lakes from numerous experienced investigators. Depending on the system, growth of Cladophora is generally restricted by requirements for light, phosphorus, or suitable substrate.

Biomass

Previous quantitative biomass data for western Lake Erie are scattered and incomplete except for the data of Kishler (1967) and Lorenz and Herdendorf (1982). Some of the wide ranges of standing crop reported for Lake Erie may be due to different sampling mechanisms by investigators, dead algal mats, and splash zone biomass incorporated into standing crop calculations. In the present investigation, considerable variation was encountered in maximum standing crops and seasonal distribution. Thus, short-term trends were difficult to determine (Fig. 7). In similar studies in the island region of Lake Erie, Lorenz (1981) and Kishler (1967) also noted that peak standing crop and seasonal distribution varied from year-to-year, depending on environmental conditions. To eliminate this problem caused by numerous environmental components, a long-term data base must be established over a number of years; this author suggests a ten-year study.

The distribution of biomass in relation to depth varied with sites (Fig. 7). Cladophora colonized to approximately 2 m at Stony Point and to approximately 3 m at South Bass Island. The deeper colonization at South Bass than at Stony Point should be expected because mean Secchi and light intensities were greater at the mid-basin site.

Seasonal Growth Dynamics

Maximum standing crop of Cladophora in the infralittoral zone generally occurred from May through June (Figs. 4, 5, 6). Growth was absent from early July through September, and a fall pulse was observed at both sites in mid-October after water temperatures had cooled down below 20°C. The bimodal growth dynamics of Cladophora, with a large decrease in standing crop occurring during the hottest months, is well documented for Lake Erie (Kishler 1967, Mantai 1974).

The basin wide distribution of Cladophora is most limited by the availability of suitable substrate for attachment. Verber (1957) reported only 3 percent of the lake bottom is composed of bedrock. The largest extent of this bedrock is found in the island region, with 6 percent of this area available for Cladophora colonization (Herdendorf 1970). Cladophora was generally found where suitable substrate was available. In flat bedrock areas, such as the Colchester

Reef area, (Fig. 1) Cladophora was not capable of colonizing the smooth bedrock, but did grow in the fractures of the lake bottom.

Growth of Cladophora occurs when environmental conditions enable gross photosynthesis to be greater than respiration, resulting in a positive net photosynthetic rate (Lorenz 1981). The photosynthetic and respiration rate are controlled by light and temperature. In the spring when water temperatures rise to 4°C the photosynthetic/respiration (P/R) ratio approaches one, enabling the alga to initiate growth. Rapid growth was observed once temperatures reached 10°C. The maximum net photosynthesis and hence biomass production occurs at temperatures in the range of 10 to 20°C (Graham et al. 1982). A wide variation for the maximum temperature for Cladophora growth has been reported... 18°C Taft and Kishler 1973, 25°C Storr and Sweeney 1971, and 30°C Whitton 1970. When water temperatures reach the maximum for sustaining Cladophora growth a P/R ratio of less than one is obtained, leading to tissue nutrient decline, detachment of the filaments, and death of the alga (Lorenz 1981). The fall resurgence of growth occurs as lake temperatures drop from 20 to 10°C. The bimodal growth pattern is therefore the result of a negative energy budget in the summer caused by temperature and light conditions creating a P/R ratio of less than one.

These growth dynamics were not observed for Cladophora found in the splash zone. This phenomenon has not been explained by previous investigations. The P/R ratio must remain above one for the entire growing season for splash zone *Cladophora*. To determine if splash zone *Cladophora* encountered the energy budget phenomenon, as in infralittoral *Cladophora*, an incubation experiment was performed (Table 7). The results indicate that the splash zone *Cladophora* can not adapt to the infralittoral environment at a water temperature of 26°C. Thus, future work should address the differences encountered by the alga exposed to the atmosphere, such as the energy requirements to obtain carbon forms from the water or the air to which splash zone *Cladophora* is exposed.

Minimal Light Requirements for Colonization

This section discusses the coordinated research effort by Mr. R.C. Lorenz and this investigator in the laboratory and field. This component of the *Cladophora* study was formulated to define the relationship between light attenuation and the vertical distribution of *Cladophora*. We utilized an intergrated laboratory (Lorenz 1981) and field (Monaco and Herdendorf 1983) approach to determine the minimal light requirements necessary to support the alga. From laboratory results and field light attenuation data a mathematical model was developed to predict the maximum depth of *Cladophora* colonization.

Lorenz (1981) provided the laboratory results for this model. He conducted a growth versus light intensity experiment to complement this investigator's field data on the light requirements of *Cladophora*.

The light gradient was designed to quantify the minimal light level necessary to sustain Cladophora growth, under conditions as close to the natural lake environment as possible. For detailed methods and results refer to Lorenz (1981). Under laboratory conditions Lorenz (1981) determined that the minimal PAR capable of supporting Cladophora growth was 30 $uEm^{-2}sec^{-1}$ with values between 30 and 55 $uEm^{-2}sec^{-1}$ promoting minimal growth. With a Lake Huron sample of Cladophora Graham et al. (1982) reported a similar laboratory value of 35 $uEm^{-2}sec^{-1}$ as the minimal PAR necessary for positive net photosynthesis. Two growth regimes were evident over the course of the experiment (Fig. 22). At light levels between 30 to 55 $uEm^{-2}sec^{-1}$ filament length increase was marginal whereas at light intensities above 55 $uEm^{-2}sec^{-1}$ growth was substantial.

The surveys of the present investigation revealed that the vertical distribution of Cladophora in the western basin of Lake Erie varied at the different sites due to light attenuation (Fig. 15). From the observed maximum depth of colonization and the light profiles generated during the surveys a field PAR value of approximately 50 $uEm^{-2}sec^{-1}$ or less was hypothesized to be limiting the vertical colonization of Cladophora.

Several factors must be considered when extrapolating the laboratory light gradient results to the natural environment. The conditions present in the laboratory such as constant light, optimal temperatures, and water movement are not necessarily provided in the

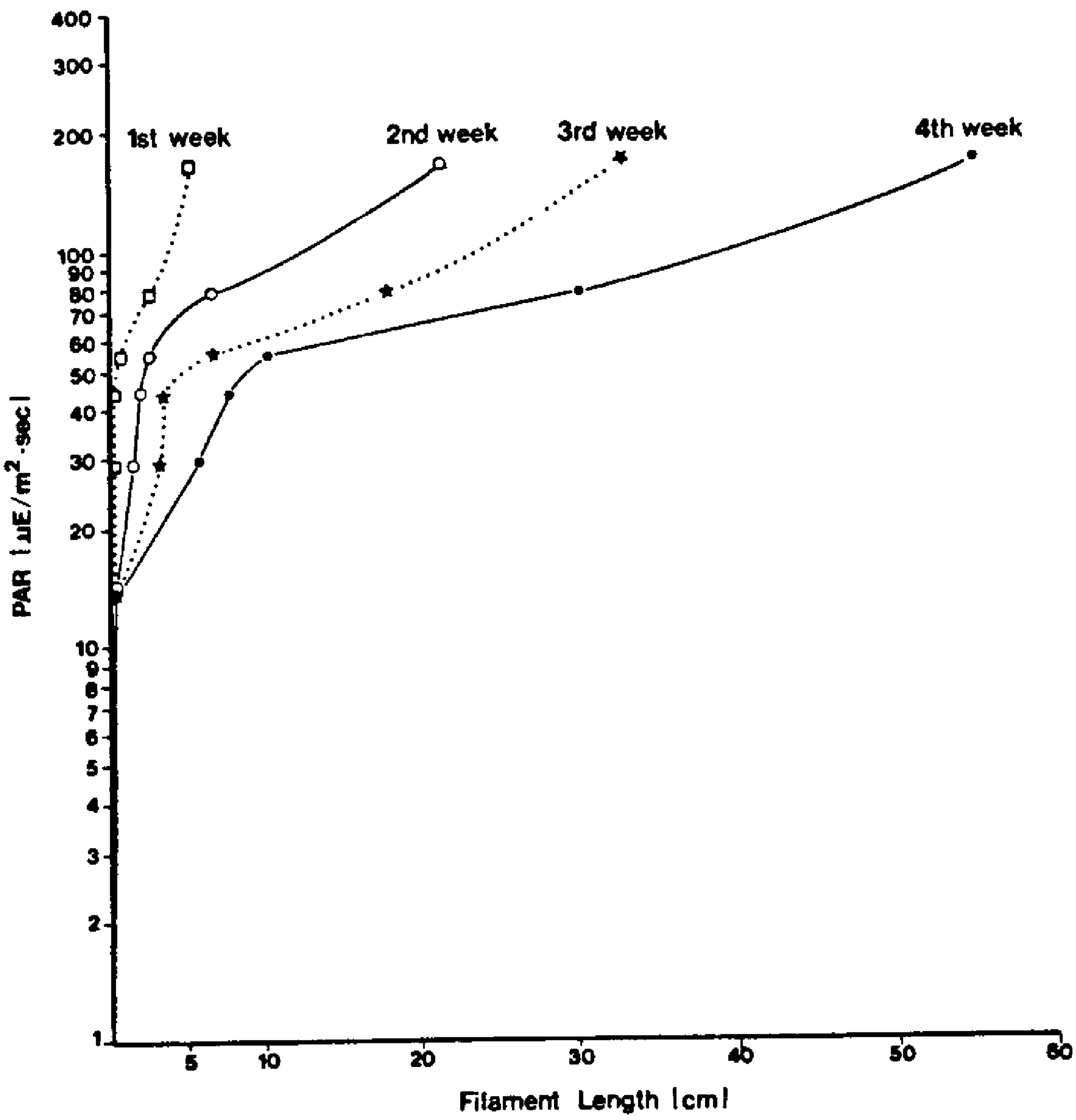


Figure 22. Cladophora Light Gradient Experiment, Filament Length Increase at the Various Light Levels (Lorenz 1981).

lake environment, resulting in less than optimal conditions, which affects net production. For these reasons, 50 $uEm^{-2}sec^{-1}$, the value approaching the upper limit of the light gradient minimal growth regime of 30 to 55 $uEm^{-2}sec^{-1}$ (Fig. 22), was chosen as the minimal PAR capable of supporting growth in the natural environment (Lorenz 1981). This value compares well with the minimal light values associated with Cladophora colonization found in the lake during the surveys by this investigation.

To test the theory that 50 $uEm^{-2}sec^{-1}$ is the limiting PAR in the lake environment, we developed a light model to predict the maximum depth of Cladophora colonization based on this value. This theoretical maximum depth of colonization was then compared to the actual field observed depth.

It has been shown:

$$1. \quad I_z = I_o \, e^{-kz},$$

where I_z is PAR at depth z, I_o is incident PAR, k is the light extinction coefficient; a composite of absorption by particles of suspended in the water and dissolved compounds, e is the base of natural logarithms; approximately 2.72, and z is water depth. Site specific k values were calculated from light profiles collected at each site.

k may be calculated by rewriting Equation 1 as:

$$2.\quad k \quad \frac{\ln I_o - \ln I_z}{z}$$

where k is the site specific calculated value, I_z is 50 $uEm^{-2}sec^{-1}$; the hypothesized minimum light value for growth, I_o is incident light, and ln is the natural logarithms for these numbers. Once the light extinction coefficient is known the depth at which 50 $uEm^{-2}sec^{-1}$ will occur can be calculated. An average incident light (I_o) value of 2000 $uEm^{-2}sec^{-1}$ (LiCor 1980) was used in all calculations to eliminate the variability between sites sampled at different times of the day and under different weather conditions. The actual average field incident PAR at South Bass and Stony Point from May through July was 2009 $uEm^{-2}sec^{-1}$ (Lorenz 1981).

Thus Equation 2 may be solved for z:

$$3.\quad z = \frac{\ln 2000 - \ln 50}{\text{site specific } k},$$

where z represents the depth at which PAR will be 50 $uEm^{-2}sec^{-1}$.

The maximum observed depth of Cladophora colonization at the survey sites was compared to the predicted depth from the model. If 50 $uEm^{-2}sec^{-1}$ is the minimum light level of PAR capable of supporting Cladophora colonization, the calculated depth from Equation 3 should be similar to the field observed depth. Comparison of these two values indicates that they are indeed similar (Table 9). A linear regression was plotted for the observed versus predicted depth of growth for all three years of the field surveys and a mean r value of 0.90 was calculated (Fig. 23).

This model may be expanded to other systems where light attenuation is the limiting factor to the vertical distribution of Cladophora. Model calculations with data from Harbour Beach, Lake Huron, (Auer et al. 1982) predicted the deepest depth of Cladophora colonization to be 2.5 m, which compares to the estimated deepest colonization of 3 m (Canale and Auer 1982).

Primary Productivity

Field Productivity. Productivity for the above discussion was defined by the increase in filament length or the amount of standing crop. To complement this work primary productivty experiments were conducted in the field and laboratory to determine carbon fixation rates. An integrated field and laboratory approach was utilized to determine if the minimal light regime of 30 to 55 $uEm^{-2}sec^{-1}$ correlated with actual photosynthetic rates.

The intent of the field experiments was to investigate productivity rates at various light intensities at depth with emphasis on the values at the one percent incident light level. This depth is defined as the compensation depth where no net primary production occurs (Sumich 1980).

TABLE 9

COMPARISON OF OBSERVED WESTERN LAKE ERIE
DEPTH OF CLADOPHORA GROWTH (m) WITH PREDICTED GROWTH DEPTHS
BASED ON A 50 $\mu E m^{-2} sec^{-1}$ LIGHT LIMITING REGIME
1981-1983

SITE	Predicted Depth (m) 1981	1982	1983	Maximum Observed Depth (m) 1981	1982	1983
South Bass	3.3	3.8	4.0	3.0	3.0	3.2
Gull Island Shoal	4.7	4.1	3.9	3.2	2.5	3.6
Catawba	—	1.8	1.7	—	1.8	1.5
Marblehead	2.3	1.7	2.2	2.5	1.6	2.0
West Sister	—	5.1	4.1	—	3.5	3.8
Kelleys	4.1	4.7	4.0	4.5	4.0	4.0
East Sister	5.0	3.1	2.5	4.5	3.5	2.5
Stony Point	1.9	1.5	—	1.5	1.7	1.5
Middle Ground Shoal	7.7	5.2	5.0	4.8	4.3	4.5
Chickenolee	5.4	3.3	3.5	6.0	5.0	3.3
Colchester	6.1	7.1	7.1	7.0	7.0	6.1
North Bass	5.1	5.8	3.8	4.5	4.5	3.2
Middle Sister	—	—	2.4	—	—	2.5
Hen	—	—	3.6	—	—	3.3

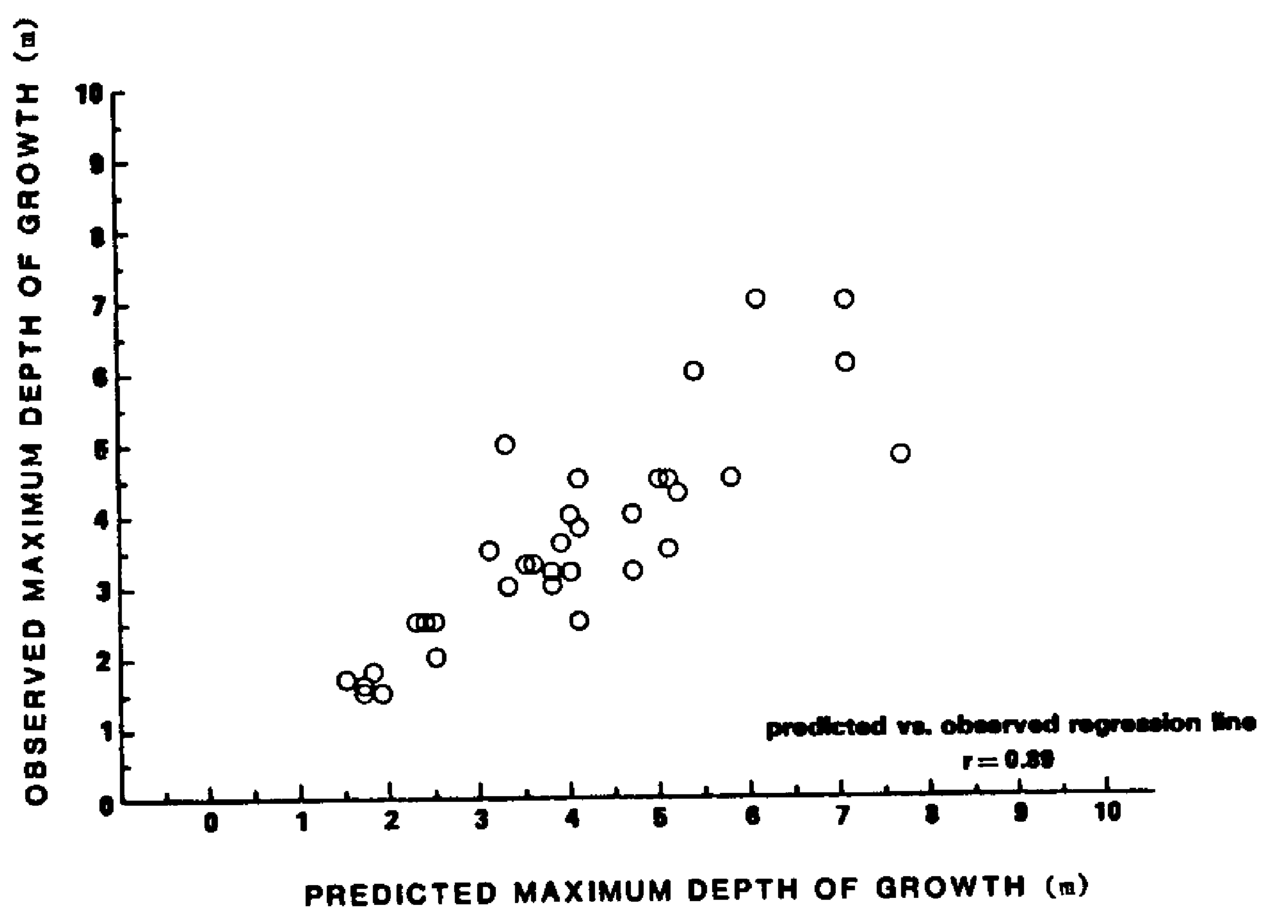


Figure 23. Predicted Maximum Depth of Cladophora Colonization vs. Observed Maximum Depth of Colonization, Western Lake Erie Survey Sites, 1981-1983.

A general photosynthetic curve is depicted below which indicates the zones of productivity (Fig. 24). The photosynthetic rate in the field at the compenstion depth for both experiments was 0.13 mg C g dry $wt^{-1}h^{-1}$. This value, which is 16X smaller than the mean productivity value at 2 m, was recorded at light intensities of 30 $uEm^{-2}sec^{-1}$ for the experiments. This minimal photosynthetic value correlates well with Lorenz's (1981) and Graham's et al. (1982) laboratory results at this limiting light level, and is within the range of field productivity values reported by Adams and Stone (1982) for a Lake Michigan sample of Cladophora.

Laboratory productivity. To verify the field data, laboratory productivity experiments were performed at various light intensities to elucidate the minimum light requirements for Cladophora net primary production. At a light level of 35 $uEm^{-2}sec^{-1}$ and water temperatures of 15°C, net photosynthetic rates increased dramatically and remained relatively constant through 70 $uEm^{-2}sec^{-1}$, the highest light level obtained in the gradient (Fig. 3). These results correlate with Graham et al. (1982) who reported 35 $uEm^{-2}sec^{-1}$ as the minimal PAR necessary for positive net photosynthesis and recorded relatively consistent results for gross and net photosynthesis and respiration at light levels ranging from 35 to 300 $uEm^{-2}sec^{-1}$.

The experiment was also conducted at 26°C and productivity increased considerably at values of 35 $uEm^{-2}sec^{-1}$ and greater. Graham et al. (1982) reported at 25°C net positive photosynthesis

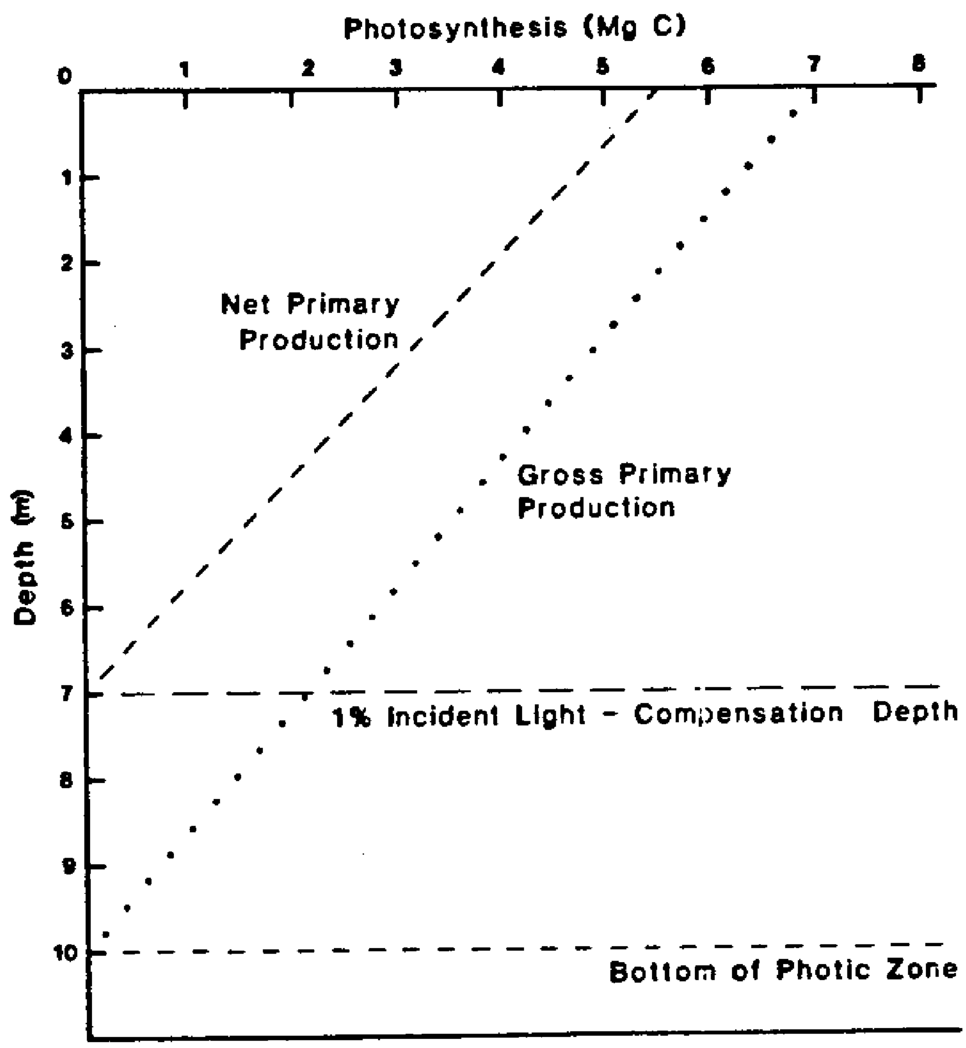


Figure 24. Primary Production Photosynthetic Curves.

occurred at 75 $uEm^{-2}sec^{-1}$. At 70 $uEm^{-2}sec^{-1}$ in the gradient experiment a marked change in slope occurred for the productivity curve (Fig. 20).

Water Quality Indicator

Phosphorus has been identified as a limiting nutrient for algal productivity in Lake Erie (Hartley and Potos 1971). For the past ten years the mean concentration of total phosphorus has been 43 ug/l (Herdendorf 1983). Thomas (1975) suggested that *Cladophora* starts to become a nuisance at total phosphorus concentrations of 15 ug/l. Herdendorf (1983) indicated that the decline in phosphorus loadings to the lake can not be translated to a similar decline in concentrations or quantities of total phosphorus measured within the lake. No significant change in western basin total phosphorus concentrations has occurred for the past twelve years. This can be partially explained by phosphorus releases from the sediment through wave suspension and anoxic regeneration (Herdendorf 1983). If improvements are to show up in the lake they should be detected first in western Lake Erie where the largest decrease in loadings has occurred. If these decreased concentrations are great enough a reduction in *Cladophora* biomass may occur, which would help assess management strategies.

Recent works (Neil and Jackson 1982, Millner et al. 1982, Lorenz and Herdendorf 1982) indicate that *Cladophora* growth may show considerable variation across the lake due to the differing physical and chemical characteristics of the three major sub-basins. The surveys have been done too few years to provide the necessary biomass data for investigators to determine if Cladophora may be used as an indicator of water quality. Since decreased loadings of phosphorus into the Great Lakes to limit algae growth has been a major objective for water quality managers, the assessment of present and future changes in distribution and abundance of Cladophora is necessary. This information will enable investigators to determine the usefulness of Cladophora as an indicator organism of the effectiveness of nutrient abatement and management strategies.

Calculations by Canale and Auer (1982) suggest that the eastern basin and to lesser extent the central basin of Lake Erie Cladophora populations may be sensitive to reduction in lakewide phosphorus levels. Western basin calculations indicate that due to the high degree of nutrient enrichment, Cladophora is likely to persist. Thus, the indicator concept does not have much utility in western Lake Erie, but has been successfully demonstrated in Lake Huron where soluble reactive phosphorus levels are often below detection limits (Canale and Auer 1982).

As evident from the literature and the data contained herein, nutrients are not limiting Cladophora colonization in western Lake Erie. Light attenuation is the dominant factor. Thus, the increase in the turbidity of the western basin over the past century which has contributed to the decline of aquatic vascular plants (Stuckey 1971), may also decrease the vertical colonization of Cladophora. If, in the future the clarity of the water increases, the quantity of Cladophora may increase due to greater vertical colonization.

CONCLUSIONS

1. The greatest limiting factor to Cladophora colonization in western Lake Erie is the availability of substrate.

2. Cladophora is present throughout the western basin and is generally found wherever suitable natural or artificial substrate is available. Only three percent of the lake bottom in western Lake Erie provides adequate substrate for attachment with the largest populations of this alga located in the Island Region, where six percent of this area contains suitable substrate for colonization.

3. Peak standing crop and seasonal distribution vary from year-to-year, depending on environmental conditions. These parameters include water clarity, temperatures, nutrients, and water levels.

4. The vertical distribution of Cladophora is limited by light attenuation at depth. Photosynthetically active radiation below approximately 50 $uEm^{-2}sec^{-1}$ was determined to limit colonization.

5. The depth to which Cladophora was found on the island shelves and reefs varies with location. Depth of colonization is greater in the northern portion of the basin. Correspondingly, Secchi disk transparencies are greater and the extinction coefficients of light are smaller at the northern sites.

6. Growth of *Cladophora* in the infralittoral zone exhibits a bimodal pattern. Growth is generally observable from April to July, with death occurring until October when an autumn pulse becomes present at cooler lake temperatures. The greatest vertical distribution occurs with the first pulse. Splash zone *Cladophora* was present the entire growing season, even at high water temperatures.

7. Nutrients are not limiting *Cladophora* colonization in western Lake Erie, as evident by the high lake water and tissue nutrient concentrations of phosphorus.

8. A long baseline data set is necessary if *Cladophora* is to be used as indicator of water quality. In areas where nutrient concentrations are low, such as the upper Great Lakes and the eastern basin of Lake Erie, *Cladophora* may be used as an indicator of nutrient sources. An increase in the vertical colonization of *Cladophora* may indicate an increase in water transparency.

PRATICAL APPLICATIONS

The light model developed during this study will provide a first approximation of the areal extent of *Cladophora* colonization due to the impact of increased nutrients, in areas previously nutrient limited. Such as the case of coastal sitings of sewage treatment plants.

In aquatic systems where adequate substrate and nutrients are available, *Cladophora* is difficult to control. The light model is a useful tool which allows managers working in these aquatic environments to exploit the light limitations of *Cladophora*. Water intakes have been clogged by *Cladophora* in Lakes Michigan and Erie (Poston and Gamet 1964). If intakes are designed for placement below the predicted depth of growth, intake fouling may be eliminated. The presence of larval fish in *Cladophora* beds suggest that they may be using the beds as a refuge and/or food source because many invertebrates and epiphytes colonize the alga (Lowe 1982). Based on light data, artificial reefs constructed for fish attraction, could be placed at depths appropriate for *Cladophora* colonization, thus increasing the productivity of the reef.

RECOMMENDATIONS

FOR FUTURE RESEARCH AND APPLICATIONS

1. Long-term placement of structures at a depth to promote or limit the growth of Cladophora to validate the light model.

2. Determine the eulittoral Cladophora mechanism for constant growth throughout the growing season.

3. Investigate areas with different degrees of water quality to determine if Cladophora may be used as an indicator organism for many systems.

4. Investigate the capability of Cladophora to bioaccumulate pesticides, PCB'S, radioactive substances, metals and other contaminants to determine if the alga may be used as an indicator of industrial and domestic pollutants.

5. Monitor beach biomass accumulations of Cladophora and determine current transport patterns of the alga.

6. Develop a quick and economical Cladophora surveillance program throughout the Great Lakes to evaluate the effectiveness of nutrient abatement programs by the increase or decrease of Cladophora biomass.

7. Determine if _Cladophora_ has any economical or commercial value, such as fertilizer for nutrient poor soil, pharmaceuticals, and food stuffs.

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APPENDICIES

APPENDIX A

Equations for tissue nutrient calculations

APPENDIX B

Equation for primary productivity calculations

APPENDIX C1-C5

C1 - *Cladophora* sampling dates
C2 - *Cladophora* biomass data
C3 - *Cladophora* physical and meteorological data
C4 - *Cladophora* water nutrient data
C5 - *Cladophora* tissue nutrients

APPENDIX A

EQUATIONS FOR TISSUE NUTRIENT CALCULATIONS

TOTAL TISSUE PHOSPHORUS:

$$TTP = \frac{(\text{liters in sample})\ (\text{mgP/l of sample})}{\text{mg DW } 64^{o}\text{C of } \underline{\text{Cladophora}} \text{ in sample}} \times 100 = \text{mgP/100mg } \underline{\text{Cladophora}}$$

TOTAL TISSUE CARBON/NITROGEN:

$$TTN = \frac{\text{ugN}}{\text{ug DW } 64^{o}\text{C of } \underline{\text{Cladophora}}} \times 100 = \text{ugN/100ug } \underline{\text{Cladophora}}$$

APPENDIX B

EQUATION FOR PRIMARY PRODUCTIVITY CALCULATIONS

$$P = \frac{r}{R} \times C \times f \times v \times \frac{1}{wt} \times \frac{1}{time}$$

P = Productivity

r = CPM alga + CPM filters + CPM filter rinsate = Total photosynthate released as radiolabeled stable organic carbon during photosynthesis

R = Total available radioactive carbon in counts per minute

C = Total available stable inorganic carbon in mg/l

f = Isotope correction factor

v = volume (.331) in incubation bottle

wt = weight of tissue analyzed (g)

time = duration of incubation (h)

Productivity units = mg C g dry $wt^{-1}h^{-1}$

APPENDIX C-1

CLADOPHORA SAMPLING DATES
1981-1982

Month/ Day	Julian Date	Site	Year	Comment
April 13	103	CS1 and CS2	81	Begin sampling
May 5	125	CS-1	81	Sampling
May 6	126	CS-2	81	Sampling
May 18	138	CS-1	81	Sampling
May 20	140	CS-2	81	Sampling
May 31	151	CS-2	81	Sampling
June 9	160	CS-1	81	Sampling
June 2	173	CS-2	81	Sampling
June 26	176	CS-1	81	Sampling
July 7	188	CS-1	81	Sampling
July 8	189	CS-2	81	Sampling
July 21	202	CS-2	81	Sampling
July 23	204	CS-1	81	Sampling
August 5	217	CS-2	81	Sampling
August 6	218	CS-1	81	Sampling
August 19	231	CS-2	81	Sampling
September 2	245	CS-2	81	Sampling
September 17	260	CS-2	81	Sampling
October 3	276	CS-2	81	Sampling
October 4	277	CS-1	81	Sampling
October 15	288	CS-2	81	Sampling
October 21	294	CS-1	81	Sampling
October 29	302	CS-2	81	Sampling
October 30	303	CS-1	81	Sampling
November 12	316	CS-2	81	Sampling
November 13	317	CS-1	81	End sampling
January 5	05	CS-2	82	Visual observations along shore
January 15	15	CS-2	82	Visual observations and collections through ice
February 15	46	CS-2	82	Visual observations along shore
March 15	74	CS-2	82	Visual observations and collections through ice
May 19	139	CS-2	82	Begin sampling
June 7	158	CS-2	82	Sampling
June 22	173	CS-2	82	Sampling
July 6	187	CS-2	82	Sampling
July 20	201	CS-2	82	Sampling
August 5	216	CS-2	82	Sampling
August 19	230	CS-2	82	Sampling
September 1	243	CS-2	82	Visual observations
September 15	258	CS-2	82	Sampling
October 23	296	CS-2	82	End sampling
December 17	352	CS-2	82	Visual observations

APPENDIX C-2

CLADOPHORA BIOMASS DATA
SOUTH BASS ISLAND, OHIO
1981

Date	Depth (m)	Coverage (%)	Filament Length (cm) Mean	Filament Length (cm) Max	Biomass per .25m² (g) Wet	Dry 64°C	Dry 104°C	Ash	Ash-free	Bio-vol.
103	0.5	0	NO CLADOPHORA PRESENT							
	1.0	0								
	2.0	0								
	3.0	0								
126	0.5	65	9.0	12.0	24.18	6.09	4.24	3.88	0.36	100
	1.0	55	7.0	9.0	27.26	5.53	5.16	4.10	1.06	145
	2.0	40	0.5	1.0	5.2	1.19	1.08	0.79	0.29	35
	3.0	T	—	—	—	—	—	—	—	—
140	0.5	80	13.0	20.0	50.15	12.68	7.13	3.80	3.33	165
	1.0	80	13.0	17.0	55.18	13.95	8.52	4.24	4.27	180
	2.0	40	7.0	10.0	24.62	4.26	4.13	1.67	2.46	35
	3.0	T	—	—	—	—	—	—	—	—
151	0.5	85	15.0	20.0	146.24	19.79	18.47	7.62	10.85	211
	1.0	85	15.0	20.0	192.22	33.26	30.41	15.82	14.59	255
	2.0	95	20.0	28.0	318.56	49.41	42.94	8.72	34.22	410
	3.0	T	—	—	—	—	—	—	—	—
173	0.5	90	25.0	30.0	138.26	33.21	30.41	14.62	15.79	159
	1.0	100	25.0	30.0	128.71	28.87	27.27	13.15	14.12	134
	2.0	100	35.0	50.0	148.55	29.20	27.48	12.80	14.68	143
	3.0	T	—	—	—	—	—	—	—	—
189	0.5	80	20.0	35.0	137.32	18.59	17.23	5.50	11.73	170
	1.0	80	15.0	30.0	109.31	23.70	22.64	13.80	8.84	140
	2.0	85	15.0	25.0	91.86	19.91	19.47	8.19	11.28	140
	3.0	T	—	—	—	—	—	—	—	—
202	0.5	20	3.0	5.0	6.95	2.29	2.15	1.37	0.78	30
	1.0	40	12.0	15.0	17.61	5.68	5.45	3.74	1.71	50
	2.0	80	8.0	12.0	58.26	13.45	12.85	10.25	2.60	90
	3.0	T	—	—	—	—	—	—	—	—
218	0.5	T	—	—	1.0	1.0	1.0	—	—	—
	1.0	T	—	—	1.0	1.0	1.0	—	—	—
	2.0	T	—	—	1.0	1.0	1.0	—	—	—
	3.0	0	—	—	—	—	—	—	—	—

APPENDIX C-2 CONTINUED

CLADOPHORA BIOMASS DATA
SOUTH BASS ISLAND, OHIO
1981

Date	Depth (m)	Coverage (%)	Filament Length (cm) Mean	Max	Biomass per .25m² (g) Wet	Dry 64°C	Dry 104°C	Ash	Ash-free	Bio-vol.
231	0.5	T	—	—	Brown	—	Holdfast	—	—	—
	1.0	T	—	—	Brown	—	Holdfast	—	—	—
	2.0	T	—	—	Brown	—	Holdfast	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
245	0.5	T	—	—	Brown	—	Holdfast	—	—	—
	1.0	T	—	—	Brown	—	Holdfast	—	—	—
	2.0	T	—	—	Brown	—	Holdfast	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
260	0.5	T	—	—	Brown	—	Holdfast	—	—	—
	1.0	T	—	—	Brown	—	Holdfast	—	—	—
	2.0	T	—	—	Brown	—	Holdfast	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
276	0.5	20	3.0	4.0	2.51	0.68	0.67	0.51	0.16	5
	1.0	T	—	—	Brown	—	Holdfast	—	—	—
	2.0	T	—	—	Brown	—	Holdfast	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
288	0.5	20	3.0	5.0	6.32	1.33	1.29	0.68	0.61	5
	1.0	T	—	—	Brown	—	Holdfast	—	—	—
	2.0	T	—	—	Brown	—	Holdfast	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
302	0.5	40	5.0	6.0	77.18	11.15	9.40	3.55	5.85	10
	1.0	T	—	—	Brown	—	Holdfast	—	—	—
	2.0	T	—	—	Brown	—	Holdfast	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
316	0.5	40	5.0	6.0	SAME AS PREVIOUS RECORD					
	1.0	T	—	—	Brown	—	Holdfast	—	—	—
	2.0	T	—	—	Brown	—	Holdfast	—	—	—
	3.0	0	—	—	—	—	—	—	—	—

APPENDIX C-2 CONTINUED

CLADOPHORA BIOMASS DATA
SOUTH BASS ISLAND, OHIO
1982

Date	Depth (m)	Cover-age (%)	Filament Length (cm) Mean	Max	Biomass per .25m^2 (g) Wet	Dry 64°C	Dry 104°C	Ash	Ash-free	Bio-vol.
139	0.5	40	3.5	6.0	TRACE AMOUNTS - BIOMASS NOT COLLECTED					
	1.0	30	2.5	5.0						
	2.0	30	2.0	2.5						
	3.0	T								
158	0.5	70	15.0	25.5	116.5	11.83	11.08	3.38	7.70	—
	1.0	55	10.0	15.0	87.75	12.22	11.83	6.65	5.18	—
	2.0	45	7.0	10.0	11.00	3.09	3.05	2.34	0.71	—
	3.0	T	—	—	—	—	—	—	—	—
173	0.5	70	15.0	30.0	100.79	16.21	15.09	5.74	9.35	—
	1.0	70	10.0	20.0	108.64	18.02	16.83	7.64	9.19	—
	2.0	50	7.0	15.0	20.24	7.44	7.16	6.31	0.85	—
	3.0	T	—	—	—	—	—	—	—	—
187	0.5	80	30.0	75.0	227.6	21.94	21.29	5.87	115.42	—
	1.0	T	--	---	TRACE AMOUNTS - BIOMASS NOT COLLECTED					
	2.0	T								
	3.0	T								
201	0.5	T	OLD DEAD HOLDFASTS		TRACE AMOUNTS - BIOMASS NOT COLLECTED					
	1.0	T								
	2.0	T								
	3.0	T								
216	0.5	T	OLD DEAD HOLDFASTS		TRACE AMOUNTS - BIOMASS NOT COLLECTED					
	1.0	T								
	2.0	T								
	3.0	T								
230	0.5	0	VERY FEW HOLDFASTS PRESENT		TETRASPORA PRESENT - BIOMASS NOT COLLECTED					
	1.0	0								
	2.0	0								
	3.0	0								
243	0.5	0	VERY FEW HOLDFASTS PRESENT		BIOMASS NOT COLLECTED					
	1.0	0								
	2.0	0								
	3.0	0								
258	0.5	T	1-2		TRACE AMOUNTS - BIOMASS NOT COLLECTED					
	1.0	T								
	2.0	T								
	3.0	T								
296	0.5	85	12.0	15.0	54.98	7.61	7.12	2.55	4.57	—
	1.0	T	—	—	—	—	—	—	—	—
	2.0	T	—	—	—	—	—	—	—	—
	3.0	T	—	—	—	—	—	—	—	—
352	0.5	70	10.0	25.0	BIOMASS NOT COLLECTED					
	1.0	T	—	—	—	—	—	—	—	—
	2.0	T	—	—	—	—	—	—	—	—
	3.0	T	—	—	—	—	—	—	—	—

APPENDIX C-2 CONTINUED

CLADOPHORA BIOMASS DATA
STONY POINT, MICHIGAN
1981

			Filament Length (cm)		Biomass per .25m^2 (g)					
Date	Depth (m)	Cover-age (%)	Mean	Max	Wet	Dry 64°C	Dry 104°C	Ash	Ash-free	Bio-vol.
103	0.5	0	NO CLADOPHORA PRESENT							
	1.0	0								
	2.0	0								
	3.0	0								
125	0.5	75	8.0	12.0	58.04	23.10	22.83	18.56	4.27	240
	1.0	65	6.0	10.0	58.60	13.20	13.00	6.63	6.37	77
	2.0	0	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
138	0.5	75	10.0	14.5	88.26	16.00	15.47	8.12	7.35	279
	1.0	75	10.0	16.0	85.54	15.86	15.50	7.56	7.94	294
	2.0	T	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
160	0.5	100	25.0	30.0	147.55	28.24	24.00	12.13	—	190
	1.0	85	25.0	30.0	268.67	87.75	85.93	—	—	325
	2.0	T	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
176	0.5	100	20.0	30.0	133.45	22.04	21.22	10.46	10.76	160
	1.0	90	15.0	20.0	52.00	9.58	9.17	4.96	4.21	75
	2.0	T	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
188	0.5	65	20.0	30.0	53.53	9.93	9.67	2.43	7.24	60
	1.0	20	15.0	20.0	23.48	5.21	5.13	2.90	2.23	35
	2.0	T	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
204	0.5	T	—	—	T	T	T	Brown	Holdfast	—
	1.0	40	1.0	3.0	T	T	T	—	—	—
	2.0	0	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
218	0.5	T	—	—	T	T	T	Brown	Holdfast	—
	1.0	T	—	—	T	T	T	—	—	—
	2.0	0	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
277	0.5	T	—	—	T	T	T	Brown	Holdfast	—
	1.0	T	—	—	T	T	T	—	—	—
	2.0	0	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
294	0.5	T	—	—	T	—	—	Brown	Holdfast	—
	1.0	T	—	—	T	—	—	—	—	—
	2.0	0	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
303	0.5	10	3.0	5.0	4.0	4.0	4.0	—	—	7
	1.0	5	3.0	5.0	3.0	3.0	3.0	—	—	5
	2.0	0	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—
317	0.5	10	4.0	6.0	4.0	4.0	4.0	—	—	10
	1.0	10	3.0	5.0	3.0	3.0	3.0	—	—	7
	2.0	0	—	—	—	—	—	—	—	—
	3.0	0	—	—	—	—	—	—	—	—

APPENDIX C-3

<u>CLADOPHORA</u> PHYSICAL AND METEOROLOGICAL DATA
SOUTH BASS ISLAND, OHIO
1982

Date	Depth (m)	Temperature Surface	Temperature Bottom	Secchi (m)	Waves (ft)	Weather Clouds (%)	Weather Air Temp. (°C)
139	0.5	—	—	—	1.0-2.0	70.00	7.2
	1.0	18.00	17.5	B			
	2.0	18.00	17.5	1.75			
	3.0	17.50	17.0	1.75			
158	0.5	19.00	19.0	—	1.0-2.0	40.00	18.3
	1.0	19.00	19.0	0.60			
	2.0	18.00	18.0	0.79			
	3.0	18.00	18.0	1.30			
173	0.5	20.00	20.0	—			
	1.0	20.00	20.0	B	0	25.00	18.3
	2.0	19.50	19.5	1.32			
	3.0	20.00	20.0	1.36			
187	0.5	23.00	22.7	—			
	1.0	23.00	22.5	B	0-1.0	30.00	28.9
	2.0	23.00	22.8	1.20			
	3.0	23.00	22.8	1.10			
201	0.5	24.40	24.4	—			
	1.0	24.40	24.4	B	0.5-1.0	0	29.4
	2.0	24.20	24.1	1.21			
	3.0	23.90	23.9	1.22			
216	0.5	24.40	24.4	—			
	1.0	24.40	24.4	B	0-1.0	95.00	29.4
	2.0	24.40	24.4	B			
	3.0	24.40	24.4	1.30			
230	0.5	23.30	23.3	—			
	1.0	23.30	23.3	B	0-1.0	10.00	23.3
	2.0	23.30	23.0	1.08			
	3.0	23.30	23.0	1.30			
258	0.5	22.00	22.0	—			
	1.0	22.00	22.0	1.00	0-1.0	10.00	21.1
	2.0	21.00	22.0	1.21			
	3.0	21.00	22.0	1.08			
296	0.5	11.00	11.7	—			
	1.0	11.00	11.2	0.80	1.0-2.0	60.00	9.0
	2.0	11.50	11.5	0.90			
	3.0	11.50	11.5	1.00			
352		6.00					

APPENDIX C-3 CONTINUED

CLADOPHORA PHYSICAL AND METEOROLOGICAL DATA
SOUTH BASS ISLAND, OHIO
1981

Date	Depth (m)	Temperature Surface	Temperature Bottom	Secchi (m)	Suspended Solids (mg/l) Total	Suspended Solids (mg/l) Volatile	Waves (ft)
127	0.5	13.20	13.2				
	1.0	13.20	13.0	0.90			
	2.0	12.20	13.0	1.05	10.30	2.10	1.0
	3.0	13.00	13.0	1.15			
140	0.5	15.00	15.0	BO*			
	1.0	15.00	14.5	BO*			
	2.0	15.00	14.5	1.55	9.71	3.75	0
	3.0						
151	0.5	16.00	16.5				
	1.0	16.00	16.2	1.20			
	2.0	16.00	16.0	16.00	6.78	2.00	2.0-3.0
	3.0	16.00	16.0	1.70			
173	0.5	21.00	21.0				
	1.0	21.00	21.0	1.32			
	2.0	21.00	21.0	1.30	9.06	2.68	0
	3.0	21.00	21.0	1.28			
189	0.5	25.00	25.0	BO*			
	1.0	25.00	25.0	BO*			
	2.0	25.00	25.0	BO*			0.5
	3.0	24.20	24.0	BO*			
202	0.5	24.50	24.4				
	1.0	24.50	24.3	1.35			
	2.0	24.50	24.0	1.70	4.29	1.94	0.5
	3.0	24.00	24.0	1.85			
218	0.5	24.50	24.5				
	1.0	24.50	24.5	1.40			
	2.0	24.00	24.5	1.58	7.20	3.31	1.0
	3.0	24.00	24.0	1.60			
231	0.5	22.50	22.5				
	1.0	22.50	22.5	0.63			
	2.0	22.50	22.5	0.85	13.70	2.76	1.0-3.0
	3.0	22.50	21.5	0.97			

APPENDIX C-3 CONTINUED

CLADOPHORA PHYSICAL AND METEOROLOGICAL DATA
SOUTH BASS ISLAND, OHIO
1981

Date	Depth (m)	Temperature Surface	Temperature Bottom	Secchi (m)	Suspended Solids (mg/l) Total	Suspended Solids (mg/l) Volatile	Waves (ft)
245	0.5	23.50	23.5				
	1.0	23.50	23.5				
	2.0	23.50	23.5		9.05	2.88	1.0
	3.0	23.50	23.5				
260	0.5	21.50	21.5				
	1.0	21.50	21.0	0.62			
	2.0	21.00	21.0	0.83	10.05	2.00	2.0
	3.0	21.00	20.5	0.95			
276	0.5	14.10	14.1				
	1.0	14.10	14.1				
	2.0	14.10	14.2		11.64	4.78	
	3.0	14.50	14.3				
288	0.5	14.00	14.0				
	1.0	14.00	13.5	0.38			
	2.0	13.35	13.8	0.67	12.56	2.68	0-1.0
	3.0	13.50	13.5	0.78			
302	0.5	10.50	10.5				
	1.0	10.50	10.5	0.07			
	2.0	10.50	10.5	0.13	26.85	2.73	2.0-3.0
	3.0	10.50	10.5	0.20			
316	0.5	8.50	8.5				
	1.0	8.50	8.5	0.45			
	2.0	8.50	8.5	0.67	17.10	2.86	1.0-3.0
	3.0	9.50	8.5	0.60			

APPENDIX C-3 CONTINUED

CLADOPHORA PHYSICAL AND METEOROLOGICAL DATA
STONY POINT, MICHIGAN
1981

Date	Depth (m)	Temperature Surface	Temperature Bottom	Secchi (m)	Suspended Solids (mg/l) Total	Suspended Solids (mg/l) Volatile	Waves (ft)
103	0.5	10.50	10.5				
	1.0	10.50	10.5				
	2.0	10.50	10.5	0.30			1.0-3.0
	3.0	10.50	10.5	0.30			
125	0.5	15.50	15.5				
	1.0	14.90	14.8	0.90			
	2.0	14.50	14.0	0.85	10.28	3.00	0
	3.0	14.50	14.1	0.90			
138	0.5	14.00	14.0				
	1.0	14.00	14.0	0.15			
	2.0	14.00	13.35	0.20	41.43	9.40	2.0-3.0
	3.0	14.00	13.5	0.31			
160	0.5	21.00	21.5				
	1.0	21.00	21.0	0.50			
	2.0	21.00	20.5	1.20	27.02	4.36	1.0-2.0
	3.0	21.00	20.5	1.50			
176	0.5	23.00	22.5				
	1.0	22.50	22.5	0.45			
	2.0	22.50	22.0	0.50	26.08	3.84	0.5
	3.0	22.50	22.0	0.50			
188	0.5	25.00	25.0	BO*			
	1.0	25.00	25.0	BO*			
	2.0	25.00	25.0	BO*	2.75	1.60	0.5
	3.0	24.20	24.0	BO*			
204	0.5	23.50	23.5				
	1.0	23.50	23.5	0.40			
	2.0	24.00	24.0	0.80	14.90	5.92	1.0
	3.0	24.00	23.5	1.03			
218	0.5	18.50	18.5				
	1.0	18.50	18.5	0.50			
	2.0	19.00	18.5	0.70	22.73	6.03	1.0
	3.0	19.00	18.5	0.85			
277	0.5	12.80	12.8				
	1.0	12.80	12.8	0.30			
	2.0	12.80	12.5	0.46	25.58	5.16	1.0-2.0
	3.0	13.00	12.8	0.57			
294	0.5	10.50	10.5				
	1.0	10.50	10.5	0.10			
	2.0	10.50	10.5	0.30	145.00	15.40	3.0-4.0
	3.0	10.50	10.5	0.50			
303	0.5	10.00	9.8				
	1.0	9.50	10.0				
	2.0	10.00	10.0		64.85	6.70	1.0-2.0
	3.0	10.00	10.0				
317	0.5	8.50	8.5				
	1.0	8.50	8.5				
	2.0	8.50	8.5		2.17	6.23	0-1.0
	3.0	8.50	8.0				

APPENDIX C-4

CLADOPHORA WATER NUTRIENT DATA
SOUTH BASS ISLAND, OHIO
1982

Date	Depth (m)	SRP (ppb)	TFP (ppb)	TP (ppb)
139	0.5			
	1.0	64.0	58.18	83.03
	2.0	2.2	15.33	21.88
	3.0	2.0	3.08	25.43
158	0.5	8.7	19.73	36.37
	1.0	2.6	7.48	28.70
	2.0	7.0	10.29	24.50
	3.0	4.4	10.00	24.60
173	0.5	—	34.13	78.54
	1.0	—	28.98	45.44
	2.0	—	15.90	37.68
	3.0	—	15.80	63.49
187	0.5	4.9	9.35	27.86
	1.0	4.0	9.10	27.96
	2.0	2.6	7.57	22.44
	3.0	3.0	7.76	21.32
201	0.5	2.4	7.67	28.05
	1.0	2.7	7.39	39.08
	2.0	3.7	16.92	35.44
	3.0		20.57	31.80
216	0.5	2.5	7.57	31.79
	1.0	2.6	9.44	31.79
	2.0	2.7	5.80	34.60
	3.0	2.7	6.54	34.41
230	0.5	8.8	5.61	35.53
	1.0	2.0	6.08	33.38
	2.0	2.7	5.80	40.11
	3.0	3.4	8.23	44.13
258	0.5	—	10.28	33.66
	1.0	—	9.44	33.75
	2.0	—	10.28	33.66
	3.0	—	11.69	33.94
296	0.5	1.5	11.13	26.93
	1.0	5.5	14.50	35.62
	2.0	3.7	14.02	38.62
	3.0	7.8	14.96	39.08

APPENDIX C-4 CONTINUED

CLADOPHORA WATER NUTRIENT DATA
SOUTH BASS ISLAND, OHIO
1981

Date	Depth (m)	SRP (ppb)	TFP (ppb)	TP (ppb)	NH_4 (ppb)	NO_2-NO_3 (ppm)
103	0.5					
	1.0	2.2	5.1	32.2	7.0	0.550
	2.0	1.2	4.1	38.2	2.1	0.550
	3.0	1.8	6.5	29.0	13.0	0.555
126	0.5	2.0			1.0	0.519
	2.0	2.1	4.0	13.4	3.0	0.568
	3.0	2.0	4.0	14.3	4.4	0.580
135	0.5	1.5	23.4	23.4	1.0	0.446
	1.0	2.0	24.8	24.8	5.2	0.442
	2.0	1.8	22.9	22.9	1.8	0.439
	3.0	2.8	27.1	27.1	3.5	0.448
140	0.5		4.6	15.3		
	1.0		4.0	14.7		
	2.0		4.1	14.3		
	3.0		5.0	16.8		
151	0.5		3.2	27.1		0.416
	1.0		3.4	22.4		0.430
	2.0		3.6	17.3		0.445
	3.0		5.8	14.8		0.529
174	0.5	6.4	12.0	24.4		
	1.0	6.7	10.7	27.5		
	2.0	4.5	8.9	24.3		
	3.0	8.2	15.2	36.3		
189	0.5	5.0	11.3	30.0	51.0	0.484
	1.0	3.9	9.8	27.9	60.9	0.494
	2.0	1.0	8.8	79.0	64.0	0.504
	3.0	7.6	21.6	33.7	187.8	0.520
202	0.5	1.4	5.0	29.9	28.2	0.637
	1.0	1.4	8.3	20.7	30.0	0.639
	2.0	1.3	4.8	16.1	30.0	0.636
	3.0	1.6	10.6	13.5	39.9	0.650

APPENDIX C-4 CONTINUED

CLADOPHORA WATER NUTRIENT DATA
SOUTH BASS ISLAND, OHIO
1981

Date	Depth (m)	SRP (ppb)	TFP (ppb)	TP (ppb)	NH_4 (ppb)	NO_2-NO_3 (ppm)
217	0.5	1.0	4.8	29.9	17.9	0.465
	1.0	0.5	4.9	28.2	15.5	0.472
	2.0	1.4		27.4	19.4	0.471
	3.0	1.5	4.9	27.6	29.6	0.470
231	0.5	0.9	9.3	42.2	3.2	0.592
	1.0	1.0	11.5	43.4	2.6	0.620
	2.0	1.0	10.2	38.6	10.0	0.594
	3.0	0.7	9.0	39.6	16.2	0.600
245	0.5	2.4	5.4	28.3	11.3	0.590
	1.0	2.3	5.9	29.9	2.5	0.424
	2.0	4.4	6.2	27.1	2.0	0.431
	3.0	4.4	12.5	27.0	4.2	0.444
260	0.5		6.9	41.2		
	1.0		6.0	38.4		
	2.0		7.2	41.6		
	3.0		8.8	41.1		
276	0.5	5.0			13.5	0.321
	1.0	4.3			10.8	0.318
	2.0	3.6			25.3	0.329
	3.0	4.9			3.0	0.329
288	0.5	4.3	11.4	35.1	7.2	0.383
	1.0	7.5	12.7	38.5	10.0	0.405
	2.0	6.4	10.7	35.0	3.6	0.416
	3.0	5.1	10.4	41.3	26.0	0.419
302	0.5	4.4	8.4	54.6	3.6	0.393
	1.0	2.6	7.5	63.8	1.0	0.391
	2.0	5.1	6.5	52.0	2.4	0.495
	3.0	4.3	7.4	43.0	3.6	0.390
316	0.5	2.0	3.8	28.7	6.0	0.289
	1.0	2.0	3.2	35.0	1.4	0.291
	2.0	2.6	4.7	33.7	20.8	0.305
	3.0	2.0	3.7	31.1	14.0	0.316

APPENDIX C-4 CONTINUED

CLADOPHORA WATER NUTRIENT DATA
STONY POINT, MICHIGAN
1981

Date	Depth (m)	SRP (ppb)	TFP (ppb)	TP (ppb)	NH_4 (ppb)	NO_2-NO_3 (ppm)
103	0.5	12.2	12.2	62.1	320.3	0.459
	1.0	6.6	13.7	83.3	324.0	0.456
	2.0	3.9	10.6	88.8	174.0	0.534
	3.0					
125	0.5	2.1	5.3	30.6	1.5	0.456
	1.0	1.8	6.1	34.5	47.2	0.514
	2.0	2.1	6.9	43.7	155.2	0.530
	3.0					
138	0.5		8.4	116.4		
	1.0		5.0	56.6		
	2.0		4.9	57.5		
	3.0		6.9	98.0		
160	0.5	2.1	10.0	56.6	16.2	0.984
	1.0	3.4	9.8	53.0	28.5	0.910
	2.0	1.3	10.2	53.3	32.9	0.824
	3.0	1.5	12.6	61.1	66.0	0.985
176	0.5	19.4	23.5	93.5	44.9	2.055
	1.0	18.6	24.4	81.7	58.5	2.070
	2.0	20.3	27.1	82.4	69.2	2.320
	3.0	19.5	27.1	78.0	87.7	2.250
188	0.5	1.0	9.9	91.5	90.8	0.295
	1.0	0.8	10.6	54.8	135.0	0.298
	2.0	0.8	7.0	50.0	194.2	0.295
	3.0	0.8	10.2	27.6	200.0	0.300
204	0.5	1.7	8.6	56.6	5.6	0.637
	1.0	1.6	9.8	48.6	6.5	0.639
	2.0	1.1		58.4	8.2	0.636
	3.0	1.3	10.7	50.3	13.1	0.650
218	0.5	0.8	73.0	132.0	1.0	0.269
	1.0	1.4	4.5	58.4	2.4	0.252
	2.0	1.6	10.6	50.1	3.0	0.278
	3.0	1.6	4.2	39.4	3.8	0.283

APPENDIX C-4 CONTINUED

CLADOPHORA WATER NUTRIENT DATA
STONY POINT, MICHIGAN
1981

Date	Depth (m)	SRP (ppb)	TFP (ppb)	TP (ppb)	NH_4 (ppb)	NO_2-NO_3 (ppm)
277	0.5	10.9	8.7	78.7	122.5	0.538
	1.0	5.8	12.0	78.7	125.5	0.509
	2.0	9.2	13.8	72.7	141.8	0.517
	3.0	5.4	8.7	63.9	121.4	0.496
294	0.5	1.8	6.9	202.9	2.9	0.619
	1.0	3.4	8.1	181.7	7.7	0.617
	2.0	2.0	248.0	177.1	8.5	0.623
	3.0	2.9	8.7	173.4	24.1	0.627
303	0.5	29.6	35.4	180.3	82.8	0.824
	1.0	35.8	40.0	172.5	83.0	0.665
	2.0	39.4	43.5	181.2	100.0	0.831
	3.0	39.2	44.3	167.4	100.0	0.625
317	0.5	3.1	4.1	27.1	3.0	0.394
	1.0	1.2	2.9	34.7	2.6	0.401
	2.0	1.1	2.9	28.2	16.3	0.401
	3.0	1.2	2.9	29.4	17.2	0.401

SRP = Soluble reactive phosphorus
TFP = Total filterable phosphorus
TP = Total phosphorus

APPENDIX C-5

CLADOPHORA TISSUE NUTRIENTS
SOUTH BASS ISLAND, OHIO
1982

Date	Depth (m)	TTC%	TTN%
139	S	14.78	0.50
	0.5	8.94	1.12
	1.0	19.61	1.32
	2.0	16.33	1.30
158	S		
	0.5	35.43	4.05
	1.0	27.03	3.3
	2.0	23.50	2.56
173	S	37.54	3.10
	0.5	35.50	2.77
	1.0	30.96	4.25
	2.0	16.91	1.51
187	S	37.53	2.28
	0.5	32.16	2.66
	1.0	19.18	1.37
201	S	8.95	1.92
	0.5	21.50	1.67
230	S	34.64	1.61
296	S	38.78	2.88
	0.5	29.60	4.53
	1.0	35.12	3.56
	2.0	36.18	3.34

APPENDIX C-5 CONTINUED

<u>CLADOPHORA</u> TISSUE NUTRIENTS
SOUTH BASS ISLAND, OHIO
1981

Date	Depth (m)	TTC%	TTN%	TTP%
126	0.5	29.27	2.98	0.104
	1.0	30.44	2.78	0.082
	2.0	29.43	2.46	0.76
140	S	34.10	3.87	0.169
	1.0	33.00	3.44	0.161
	2.0	31.86	3.22	0.095
	3.0	44.73	5.03	0.322
151	S	27.53	2.42	0.063
	0.5	39.41	3.55	0.068
	1.0	32.98	2.27	0.103
	2.0	31.82	2.38	0.082
173	0.5	26.35	2.38	
	1.0	23.64	3.53	0.180
	2.0	29.70	2.96	0.185
	3.0			0.090
189	0.5	30.12	2.95	0.205
	1.0	25.31	3.67	0.204
	2.0	20.42	2.33	0.171
217	S	26.85	1.96	0.60
	0.5	24.00	1.66	0.108
	1.0	9.21	1.13	0.101
	2.0	11.43	1.50	0.194
276	0.5	18.11	2.29	0.259
288	0.5	16.48	1.86	0.216
302	S	35.56	4.35	0.472
	0.5	32.99	3.84	0.426

APPENDIX C-5 CONTINUED

CLADOPHORA TISSUE NUTRIENTS
STONY POINT, MICHIGAN
1981

Date	Depth (m)	TTC%	TTN%	TTP%
125	S	34.84	3.58	
	0.5			0.146
	1.0	34.69	4.58	0.165
138	0.5			0.244
	1.0	32.15	3.83	0.325
160	S	32.70	4.56	0.300
	0.5	31.79	3.68	0.296
	1.0	22.56	3.32	0.263
176	0.5	32.39	3.36	0.351
	1.0	29.94	3.37	0.351
188	0.5			0.166
	1.0	30.67	2.72	0.042
218	S	30.99	2.44	0.108
303	0.5	26.92	3.71	0.391

TTC = Total tissue carbon

TTN = Total tissue nitrogen

TTP = Total tissue phosphorus

S = Splash zone