GRI-81/0182

MARINE BIOMASS PROGRAM

ANNUAL REPORT
(JANUARY-DECEMBER 1982)

Gas Research Institute
8600 West Bryn Mawr Avenue
Chicago, Illinois 60631

GRI-81/0182

MARINE BIOMASS PROGRAM

ANNUAL REPORT

(January-December 1982)

Prepared by

A.N. Tompkins
General Electric
Advanced Energy Programs Department
P.O. Box 527
501 Allendale Road
King of Prussia, Pa. 19406

For

GAS RESEARCH INSTITUTE

Contract No. 5081-323-0452

GRI Project Manager
Dr. Kimon Bird
Biomass Department
March 1983

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. GRI-81/0182	2.	3. Recipient's Accession No. 81-0182

4. Title and Subtitle

MARINE BIOMASS PROGRAM
ANNUAL REPORT 1982

5. Report Date March 1983

6.

7. Author(s)

A.N. Tompkins

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

General Electric Company
Advanced Energy Programs Department
P.O. Box 527
King of Prussia, Pennsylvania 19406

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C) GRI 5081-323-0452

(G)

12. Sponsoring Organization Name and Address

Gas Research Institute
8600 West Bryn Mawr Avenue
Chicago, Illinois 60631

13. Type of Report & Period Covered

Annual Report
January 1982-December 1982

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report provides the details of the research and development activities performed on the Marine Biomass Program by the General Electric Company and its team of associates for the Gas Research Institute. The work performed during this period was, for the most part, a continuation of the research program started in 1981. The primary objective of this project at the start of work in January 1982 was to obtain harvestable yield data at the Goleta Nearshore Test Facility and at the Catalina Test Facility.

In support of this objective, a significant body of data was derived from both test facilities. This included: Evaluation of the growth capabilities of individual plants with subsequent identification and selection of high yielding plants; insight into the relationship between kelp productivity, water temperature, solar radiation and nutrition; successful demonstration of planting techniques that can be developed into high rate planting systems; determination of effects of pulse versus continuous fertilization of kelp; and critical preliminary data on the effect of nutritional history on tissue levels of the highly biodegradable kelp constituent mannitol. The data base was incorporated into a comprehensive system specification which served as a base line for an independent economic analysis.

17. Document Analysis a. Descriptors

Marine Biomass, Nearshore Test Farm, Kelp Farming, Substitute Natural Gas, Kelp Biology Hemidome Concept, Kelp Genetics, Macrocystis pyrifera, Anaerobic Digestion

b. Identifiers/Open-Ended Terms

Methane from Marine Biomass, Nearshore Kelp Farm, Anaerobic Digestion of Kelp, Kelp Farming System Analysis

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release Unlimited	Unclassified	442
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18) *See Instructions on Reverse*

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

GRI DISCLAIMER

LEGAL NOTICE This report was prepared by General Electric Company as an account of work sponsored by the Gas Research Institute (GRI). Neither GRI, members of GRI, nor any person acting on behalf of either:

a. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

b. Assumes any liability with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

1 RESEARCH SUMMARY

1. RESEARCH SUMMARY

Title	Biomass Annual Report 1982
Contractor	General Electric Company Advanced Energy Programs Department GRI Contract Number: 5081-323-0452
Principal Investigator	A.N. Tompkins Biomass Program Manager
Report Period	January-December 1982 Annual Report
Objective	To obtain measurements of harvestable yield from adult kelp plants under natural as well as artificially induced environmental conditions and to utilize this data to determine the commercial feasibility of producing methane from a nearshore kelp farm.
Technical Perspective	Kelp yield data from nearshore test facilities, together with associated data for economic analysis, would allow GRI to assess the potential of methane from marine biomass against other biomass projects and subsequently to determine whether there was merit in continuing with the investigation of the overall marine biomass concept.
Results	Kelp yield data obtained from four harvests at the Goleta nearshore test facility determined that a harvestable kelp yield of 15 dry ash free tons per acre per year may be achievable in a commercial production system. Individual plants were shown to be capable of producing harvestable yields which can be projected to three times the average 15 ton yield, thereby indicating the possibility of significantly lowering gas production costs. It was also determined that kelp plants can be reliably established and maintained on nearshore substrates and that continuous year-round fertilization of cultivated kelp was shown not to be required to support the sustained harvestable yield. As a result of the 1982 studies, the Gas Research Institute was also provided with a credible bottom line cost for the production of methane from kelp obtained in nearshore commercial cultivation systems. Data from the Goleta Test Facility was used as a key input to a separately funded detailed economic analysis of a marine biomass production and conversion system.

Technical Approach

In order to provide information upon which to assess methane potential from marine biomass, two nearshore test facilities (Catalina and Goleta) were put into operation early in 1982. From these facilities, kelp biology and production data were acquired which enabled the determination of sustained kelp yield for marine farm systems. The resultant data was used as a basis for a detailed system and economic analysis of nearshore, coastal scenarios for commercial production of methane from kelp.

At Catalina and Goleta, emphasis was placed on the direct measurements of growth rates, planting densities, harvest yields, and mortality of Macrocystis, as well as on the influences on these related to nutrient supply and uptake, contaminants, competitors and plant structure. The estimates of potential yields of marine farms were developed from the data collected. Laboratory and farm studies and collection of information on planting technology were also pursued as adjunct data sources.

In the laboratory, efforts were concentrated on the maintenance and screening of bacterial cultures for the development of improved inocula to maximize acetate production and conversion of kelp to methane. Studies of microbial interactions in kelp bioconversion through development of binary and multiple organism food chains were also pursued.

Effort was expended during 1982 toward developing a model for an "least cost system" which produces methane from Macrocystis cultivated in nearshore coastal farms. Kelp biological/engineering requirements were defined from available literature. Candidate system and subsystem concepts, functions and functional relationships were defined in order to identify the complete system requirements. Potential ocean and land sites suitable for substitute natural gas (SNG) production systems were identified based on the biological requirements of kelp, engineering requirement of the hardware, competing uses for the area, and environmental/permitting requirements.

Project Implications

The 1982 Marine Biomass Program achieved a number of major successes. Quantitative kelp yields were documented for the first time, and new concepts on cultivation techniques (for testing in the 1983 program) were inferred from the outcome of the experiments. Equally important, there are strong indications that the yields could be increased through genetic selection of superior growing kelp plants.

Critical growth and carbon allocation experiments are now providing an idea of carbon utilization and fate in kelp. Incorporating these data into a kelp growth model, as well as obtaining additional carbon allocation data will ultimately permit selection of kelp morphologies for increased harvest yields.

Research into microbial conversion of kelp to volatile fatty acids, the substrates of the methanogenic phase, determined key controlling steps in kelp conversion. The several phases in breakdown of complex kelp tissues to volatile fatty acids will lead to better control of these reactions and enhanced bioconversion of kelp in multiphase digesters.

The system and economic analysis conducted by General Electric, associated with a multifaceted examination of chemical co- and by-products indicates that early commercialization of kelp to methane systems could proceed through development of an integrated low-cost gas supply and chemical by-product industry, followed by a more intensive methane-oriented expansion as other investors are attracted.

1.1 OVERALL PROJECT OBJECTIVE

The overall objective of the GRI Marine Biomass Project is to define integrated processes, including feedstock production, harvesting, and conversion, to produce methane from seaweed in nearshore systems that are cost-competitive on a commerical basis with other alternative sources of energy. The technical, economic and energy requirements of a prototype commercial production system are to be determined so that the feasibility of producing cost-competitive methane from nearshore marine biomass farms can be fully established.

1.2 LIST OF 1982 PUBLICATIONS

California Institute of Technology

Anderson, L.M., J.S. Kuwabara, and W.J. North. Effects of copper, zinc, iron, and manganese on growth of Macrocystis gametophytes and sporophytes. Proc. So. Calif. Acad. Sci. In press.

Arnold, K.E., and S.L. Manley. Carbon allocation in Macrocystis: I. Intrinsic metabolic variability. In preparation.

Barcelona, M.J., L.C. Cummings, S.H. Lieberman, H.S. Fastenau, and W.J. North. 1982. Marine farming the coastal zone: chemical and hydrographic considerations. CalCOFI Rpt., Vol. XXIII, 180-187.

Gerard, V.A. 1982. Growth and utilization of internal nitrogen reserves by the giant kelp Macrocystis pyrifera in a low-nitrogen environment. Mar. Biol. 66, 27-35.

Gerard, V.A. 1982. In situ rates of nitrate uptake by giant kelp, Macrocystis pyrifera (L.) C. Agardh: tissue differences, environmental effects, and predictions of nitrogen-limited growth. J. Exp. Mar. Biol. Ecol. 62, 211-224.

Gerard, V.A. 1982. In situ water motion and nutrient uptake by the giant kelp Macrocystis pyrifera. Mar. Biol. 69, 51-54.

Gerard, V., and W. North. 1981. Kelp growth on an ocean farm in relation to fertilizing. Proc. Inter. Seaweed Symp. 10, 581-586.

Gerard, V., P. Delaney, E. Excobar-Briones, J. Farley, F. Jara, M. Krausse, G. Pechter, G. Pittenger, T. Stebbins, M. Wright, and A. Yourke. Effects of harvesting on growth of giant kelp, Macrocystis pyrifera (Phaeophyta; Laminariales). Submitted to Phycologia.

Gerard, V.A., and H. Kirkman. Ecological observations on a unique, branching form of Macrocystis pyrifera (L.) C. Agardh in New Zealand. Submitted to Bot. Mar.

Gerard, V.A., and W.J. North. Measuring growth, production, and yield of the giant kelp, Macrocystis pyrifera. Submitted to Proc. Inter. Seaweed Symp. 11

Kuwabara, J.S. 1981. Gametophytic growth by Macrocystis pyrifera (Phaeophyta) in response to various iron and zinc concentrations. J. Phycol. 17, 417-419.

Manley, S.L. 1981. Iron uptake and translocation by Macrocystis pyrifera. Plant Physiol. 68, 914-918.

Manley, S.L. 1983. Composition of sieve tube sap from Macrocystis pyrifera (Phaeophyta) with emphasis on the inorganic constituents. J. Phycol. 19, 118-121.

Manley, S.L. Micronutrient uptake and translocation by Macrocystis pyrifera (Phaeophyta). In press J. Phycol.

Manley, S.L. Physiological basis of kelp growth. In press Proc. Symp. on Effects of Waste Disposal on Kelp Communities. SIO 1-83.

Manley, S.L., V.A. Gerard, L.M. Anderson, J.S. Kuwabara, and W.J. North. 1982. Environmental considerations involved in farming Macrocystis. Proc. 1981 Intl. Gas Res. Conf., Govt. Insts. Inc., Rockville, MD, 693-698.

Manley, S., and W. North. 1981. Micronutrient uptake by juvenile Macrocystis pyrifera (L.) C. Ag. Proc. Inter. Seaweed Symp. 10 467-472.

Manley, S.L., and North, W.J. Phosphorus and the growth of juvenile Macrocystis pyrifera (Phaeophyta) sporophytes. Submitted to J. Phycol.

North, W.J. 1981. Biomass production in oceanic settings - a progress report. Proc. 8th Ocean Energy Conf., Mar. Tech. Soc., Washington, DC, Vol. 1, 249-252.

North, W.J. Enhancement and rehabilitation of kelp beds. Submitted to Proc. Symp. on Restor., Rehabil., and Enhance. of Nat. Veg. in Coastal States USA.

North, W.J. The sea urchin problem. In press Proc. Symp. on Effects of Waste Disposal on Kelp Communities. SIO 1-83

North, W.J. Separating the effects of temperature and nutrients. In press Proc. Symp. on Effects of Waste Disposal on Kelp Communities. SIO 1-83.

North, W.J. Culturing and utilization of large brown seaweeds (kelps). Submitted to Proc. Oceans '83 Conf. 8-83.

North, W., V. Gerard, and J. Kuwabara. 1982. Farming Macrocystis at coastal and oceanic sites. In Synthetic and Degradative Processes in Marine Macrophytes, L.M. Srivastava (ed.), Walter de Gruyter, Berlin, 247-264.

North, W., V. Gerard, and R. McPeak. 1981. Experimental fertilizing of coastal Macrocystis beds. Proc. Inter. Seaweed Symp. 10, 613-618.

North, W.J., and R.C. Zimmerman. Influences of macronutrients and water temperatures on summertime survival of Macrocystis canopies. Submitted to Proc. Inter. Seaweed Symp. 11.

Wilson, K.C., and W.J. North. Restoration and management of kelp beds in southern California. In press Proc. World Mariculture Soc.

Neushul Mariculture, Incorporated

Harger, B.W.W. and M. Neushul, 1982. Macroalgal Mariculture. In: A. San Pietro (ed.). Biosaline Resources. Plenum Publishing: New York. pp. 393-404.

Neushul, M., B.W.W. Harger and G.A. Grosseau, 1982. Studies of biomass yield from a near-shore macroalgal test farm. Preprints of the intl. Gas Res. Conf. (in press).

Scott, J. and M. Neushul, 1982. Ultrastructure of Macroalgae: Introduction and Bibliography, In: Rosowaki, J.R. and B.C. Parker (eds.) Selected Papers in Phycology, II. Phycological Soc. of America: Lawrence, Kansas. pp. 191-201.

Neushul, M., 1982. The Kelp beds of Southern California. Ocean Studies Symposium of the California Coastal Commission.

TABLE OF CONTENTS

Section		Page
	GRI Disclaimer	i
1	RESEARCH SUMMARY	iii
	1.1 Overall Project Objective	vii
	1.2 List of 1982 Publications	ix
2	SUMMARY OF ALL WORK PREVIOUSLY PERFORMED	2-1
3	SPECIFIC OBJECTIVES OF CURRENT YEAR	3-1
	EXPERIMENTAL RESEARCH	
4	WORK TASKS FOR CURRENT YEAR	4-1
	4.1 Evaluation, Operation, and Maintenance of Experimental Marine Farm Systems	4-1
	4.2 Biological Studies	4-2
	4.3 Kelp Biomass Conversion Studies	4-5
	4.4 Systems Analysis	4-6
	4.5 Engineering Support	4-7
5	1982 WORK PERFORMED BY TASK	5.1-1
	5.1 Kelp Digestion Biology	5.1-1
	5.1.1 Microbial Studies	5.1-1
	5.1.2 Mannitol Dehydrogenance Activity of Microbial Isolates	5.1-9
	5.1.3 Microbial Examination of Kelp "Shot-Hole" Disease	5.1-12
	5.2 Catalina Kelp Cultivation Biology	5.2-1
	5.2.1 Yield and Growth Studies at Catalina Test Farm	5.2-1
	5.3 Goleta Kelp Cultivation Biology	5.3-1
	5.3.1 Density, Fertilization and Yield Studies	5.3-1
	5.3.2 Genetics and Plant Characterization	5.3-14
	5.3.3 Environmental Monitoring	5.3-15
	5.3.4 Foreign Technology Assessment	5.3-21
APPENDIX A		
	Appendix A-1. Tables for Experimental Results	A1-1
	Appendix A-2. Goleta Environmental Data	A2-1
	Appendix A-3. Hemidome Engineering Support	A3-1
	5.4 Nearshore System Analysis	5.4-1
	5.4.1 Ground Rules and Constraints	5.4-2
	5.4.2 Kelp Biological and Engineering Data Base Definition	5.4-3
	5.4.3 Site Study and Environmental Conditions	5.4-20
	5.4.4 System Concept Definitions	5.4-26
	5.4.5 System Functional Requirements and Specification Document	5.4-60
	5.5 By-Product/Co-Product of Methane Production from Kelp	5.5-1
	5.5.1 Introduction	5.5-1
	5.5.2 Background and Scope	5.5-3

TABLE OF CONTENTS (Cont)

Section		Page
	5.5.3 Screening of Potential By-Products and Co-Products	5.5-7
	5.5.4 Technical Processes and Economic Analysis	5.5-21
	5.5.5 Capital and Operating Cost Estimates	5.5-40
	5.5.6 Economic Analysis	5.5-58
	5.5.7 Recommendations	5.5-74
APPENDIX B		
	Appendix B. Laboratory Tests on L-Fraction Sample Preparation and Characterization	B-1
	5.6 Lost Test Farm	5.6-1
	5.6.1 Background	5.6-1
	5.6.2 Technical Analyses in Support of Claim	5.6-3
ACHIEVEMENTS, PROBLEMS AND CONCLUSIONS		
6	MAJOR ACHIEVEMENTS	6-1
7	MAJOR TECHNICAL PROBLEMS	7-1
8	CONCLUSIONS	8-1
9	WORK PLAN FOR 1983	9-1
	9.1 Yield and Biological Studies - California Institute of Technology	9-1
	9.2 Kelp Biomass Production - Neushul Mariculture Incorporated	9-2

LIST OF ILLUSTRATIONS

Figure		Page
5.1-1	Growth of Alginolytic Cytophaga as Indicated by Increased Culture O.D. on Mixed Substrates Algin Grown Inoculum	5.1-3
5.1-2	Growth of Alginolytic Cytophaga as Indicated by Increased Culture on Mixed Substrates. Inoculum was Pregrown on Mannitol Based Medium	5.1-4
5.1-3	Consumption of Mannitol and Algin by a Cytophaga sp. Growing on Kelp (Macrocystic Pyrifera)	5.1-7
5.2-1	Catalina Test Farm - General Layout and Mooring Arrangement	A3-2
5.2-2	CTF Hydraulic System Schematic Diagram	A3-3
5.2-3	Inlet/Discharge Pump Modification	A3-6
5.2-4	Pig Design for Biofoul Cleaning Operation	A3-10
5.2-5	Original Bag Configuration and Interface with Distribution Nozzle After Head Loss	A3-12
5.2-6	Bag Bottom Section Repair with Modified Port Design	A3-14
5.2-7	Screen Configurtions on Discharge Pump	A3-18
5.2-8	Screen Configurations on Intake Pumps	A3-19
5.2-9	Additional Gravity Drain Hose Installation	A3-21
5.2-10	Extended Inlet and Final Intake Screen Configuration	A3-22
5.2-11	Annular Flow Sensor Installation	A3-26
5.2-12	CTF Daily Checklist	A3-27
5.2-13	CTF Weekly Checklist	A3-28
5.2-14	Chart of the Eastern Portion of the Catalina Isthmus Region, Showing Relation of the Hemidome Installation to the Surrounding Geographical Locations Mentioned in the Text. The Control Kelp Bed on the North Side of Intake Point was Utilized for the First Experimental Series	5.2-6
5.2-15	Chart of Big Fisherman Cove with Details of the Hemidome Installation and (Below) a Cross-sectional View of the Hemidome. Control Plants were those Utilized During the Second Experimental Series	5.2-22
5.2-16	Plot of Holdfast Depth Versus N-Content of Various Types of Blades Sampled on November 15 and December 6, 1982, From Several of the Ex-Hemidome Plants moored at Various Depths in Big Fisherman Cove. Only Canopy Tissues Showed a Fairly Defined Relation to Holdfast Depth	5.2-27
5.2-17	Prosphate (Pi) Uptake Rate Versus Temperature Pi = 1.8 μM	5.2-31
5.2-18	The Effect of Tissue Type, Light, and Certain Inhibitors on Phosphate Uptake. All Light Experiments at Light Intensity of 1.3×10^4 ergs cm^{-2} sec^{-1}. [Pi] = 1.4 μM. DCMU = 3-(3,4-dichlorophenyl)-1,1-dimethyl urea (50 μM). As = Arsenate (1 μM). V = Vanadate (1 μM). Brackets Indicate 95% Confidence Interval (n = 6)	5.2-31
5.2-19	Phosphate Uptake Rate Versus External Pi Concentration = Best Fit From V Versus v/S Regression (r = 0.959)	5.2-32
5.2-20	Pi Tissue Content Versus Exposure Time. After Punching Discs for Uptake Experiments, the Entire Juvenile Blade was Extracted and Analyzed for Pi. = Blades in Constant 2.5 μM Pi Seawater. x = Blades in Low Pi Seawater (t = 0, [Pi] = 0.6 μM; t = 7, [Pi] = 0.02 μM)	5.2-33

LIST OF ILLUSTRATIONS (Cont)

Figure		Page
5.2-21	Pi Uptake Rate Versus Time. Uptake Determined at 1.5 μM Pi and 1.3 x 10^4 ergs cm^{-2} sec^{-1}. Brackets indicate 95% Confidence Interval (n = 6). · = Blades in 2.5 μM Pi Seawater x = Blades in Low Pi Seawater (0.06 to 0.02 μM Pi)	5.2-33
5.2-22	Photosynthetic Time Course Linearity on Mature Blade Plugs. Different Symbols Represent Different Plugs	5.2-42
5.2-23	Net Photosynthesis (O_2-Evolution) as a Function of Temperature.	5.2-43
5.2-24	The Effects of Wounding in Net PS and DR in Mature Blade Plugs. T Represents Number of Hours From Collecting the Blade	5.2-46
5.2-25	Profiles of Net PS (O_2-evolution) in Different-Aged Blades	5.2-49
5.2-26	Profiles of DR (O_2-uptake) in Different-Aged Blades	5.2-50
5.2-27	Profiles of Light Carbon Fixation in Different-Aged Blades	5.2-51
5.2-28	Profiles of Dark Carbon Fixation in Different-Aged Blades	5.2-52
5.2-29	Net PS and DR in Apical Scimitar, Sporophyll, Stipe, and Holdfast Tissues (Terminal Haptera)	5.2-53
5.2-30	LCF and DCF in Holdfast and Stipe Tissue	5.2-55
5.2.31	Frond Profiles of Net PS as a Function of Blade Age (Number)	5.2-57
5.2-32	Frond Profile of Net PS as a Function of Blade Age (Number)	5.2-58
5.2-33	Size Distributions of Fronds Tagged on Experimental M. Pyrifera Plants in the Three Plots During Two Intervals	5.2-65
5.2-34	Size Distributions of Parent Fronds with Intact Apical Blades (Meristematic or Terminal) and Newly Formed Initials on Experimental M. Pyrifera Plants in the Three Plots	5.2-67
5.2-35	Log-Transformed Elongation Rates (R_L) for Frond Initials on Experimental M. Pyrifera Plants in the Three Plots $R_L = \frac{\ln L_t - \ln L_o}{t}$ Where L_o is Length (cm) at Time = 0, L_t is Length at Time = t, and t is Time (Days)	5.2-68
5.2-36	Organic Contents ($\bar{x} \pm 1$ SD, n = 3) of Mature Laminae From Fronds of Various Length on Experimental M. Pyrifera Plants Before Transplanting and in the Three Plots 1 Month After Transplanting	5.2-69
5.3-1	Gravel-Bag Plant Anchor Design With Plant Attached	5.3-3
5.3-2	General Experimental Planting Arrangement	5.3-4
5.3-3	Changes in Macrocystis Number as a Function of Planting Density	5.3-6
5.3-4	Plant Wet Weight Increase	5.3-7
5.3-5	Projected Yield for Four Seasons and Three Planting Densities	5.3-9
5.3-6	Harvested Yield From Six Selected High Yielding Plants Compared to the Average Yield of Low Density Plants for Four Seasonal Harvests	5.3-11
5.3-7	Death Rate at the End of Four Seasonal Harvest at Three Planting Densities	5.3-12
5.3-8	Surface Irradiance in Goleta from 1968 to 1977 (Above, Plotted Superimposed) and in 1982 (Below). The Surface Irradiance in 1982 Followed a Pattern Similar to that of Prior Years (1968 to 1977 Plot From Harger 1979)	5.3-16
5.3-9	Irradiance Reduction by High and Medium Density Plantings, June 15, 1982 ("Pre-Harvest")	5.3-18

LIST OF ILLUSTRATIONS (Cont)

Figure		Page
5.3-10	Irradiance Reduction by Medium and High Density Plantings, August 4, 1982 (Post-Harvest")	5.3-19
5.3-11	Seasonal Variation of Solar Irradiance, Surface Nitrate Concentration, Natural Kelp Bed Harvesting Rate and Individual Plant Production Rate (for Center Plants Only) for Plants Planted at Low Density (0.0625 Plants/m2), Medium Density (0.2500 Plants/m2) and High Density (1.0000 Plants/m2)	5.3-22
5.4-1	Projected Yields for Four Seasonal Harvests of Plants Planted at Three Densities	5.4-6
5.4-2	Farm Nutrient Model	5.4-8
5.4-3	Commercial Fertilizer Requirements	5.4-9
5.4-4	Resistance of Macrocystis angustifolia Holdfasts to Tearout by Horizontal Forces	5.4-13
5.4-5	Methane Yield Versus Retention Time	5.4-16
5.4-6	Temperature/Inoculum Study Results	5.4-17
5.4-7	Batch Settling of Digester Effluent	5.4-19
5.4-8	Mainland Southern California Natural Kelp Beds	5.4-21
5.4-9	Potential Acreage of Sourthern California Costal Area	5.4-24
5.4-10	Nearshore System Functional Requirements	5.4-27
5.4-11	System Concept	5.4-28
5.4-12	Baseline Planting Subsystem Concept (Natural Beds)	5.4-33
5.4-13	Farm Substrate Concepts (Water Depth 25 to 60 Feet/ 60 to 80 Feet)	5.4-36
5.4-14	Anchor-Cable Substrate System Concept	5.4-37
5.4-15	Kelp Dynamics Effects on Anchor Sizing	5.4-39
5.4-16	Deep Farm Substrate Concept (Water Depth 80-100 Ft.)	5.4-42
5.4-17	Baseline Harvest/Transport Concept	5.4-47
5.4-18	Process Flow Diagram for Gas Production Subsystem	5.4-51
5.4-19	Gas Cost Results	5.4-59
5.5-1	Scenario for Relative Comparison of Kelp Products	5.5-10
5.5-2	Scenarios for Production of By-Products and Co-Products	5.5-22
5.5-3	Process Schematic for Production of Gas and By-Products	5.5-23
5.5-4	Process Schematic for Production of Co-Products From Raw Kelp	5.5-29
5.5-5	Process Schematic for Production of Gas, By-Products and Co-Products	5.5-37
5.5-6	Estimated Daily Production of Various Products in Scenario 1	5.5-41
5.5-7	Estimated Daily Production of Various Products in Scenario 2	5.5-42
5.5-8	By-Products/Co-Product Net Revenues Versus Gas Cost Reduction	5.5-66
5.5-9	Gas Production System Capacity Versus Gas Cost	5.5-67
5.5-10	Effect of Product Portfolio Selection on Gas Costs and Investment Criteria (L-Fraction at $1/lb)	5.5-71
5.5-11	Effect of L-Fraction Value on Gas Costs and Pretax Profits (at $3/lb of L-Fraction, Net Gas Cost is Zero)	5.5-73
5.6-1	Single Leg Mooring System	5.6-6
5.6-2	Tension Vs. Mooring Leg Position with a 150.000 lb Force at the Mech Buoy	5.6-10

LIST OF ILLUSTRATIONS (Cont)

Figure		Page
5.6-3	Mooring Leg Shape with a 150,000 lb Force at the Mech Buoy	5.6-11
5.6-4	Load in Catenary Line Versus Time	5.6-13
5.6-5	Ship Weight Versus Peak Catenary Load	5.6-14

LIST OF TABLES

Table		Page
5.1-1	Effect of Growth Substrate on Presence of Specific Polymer-Degrading Enzymes in Cytophoga Strains	5.1-8
5.1.2-1	Morphological Characteristics of Kelp Digester Isolates	5.1-10
5.1.2-2	Mannitol Dehydrogenases of Mannitol Utilizing Isolates	5.1-11
5.1-3	Comparison of Macrocystic Harvests	5.1-12
5.1-4	Characteristics of Kelp Bacterial Isolates	5.1-15
5.1.5	ATP (Nanograms/Liter)	5.1-21
5.2-1	Catalina Test Farm Operating and Maintenance Procedure Table of Contents	A3-29
5.2-2	Major Hemidome Events	5.2-3
5.2-3	Environmental Data Summaries From Continuously Monitoring Sensors in the Hemidome. Insolation Values Represent Maximum and Minimum for Each Day Between Approximately 0900 and 1600 Hours Unless Specified Otherwise Under Remarks. ΔO_2 Values Represent Daily Integrated Differences Between an Outflowing Water Sensor (Nos. 2 and 3) and the Single Inflowing Water Sensor. All Dates Represent 1982	A1-1
5.2-4	Daily Integrated Insolation in MilliEinsteins/cm^2 Recorded at the Instrument Shed on the Hemidome in Big Fisherman Cove, Catalina Island, From May to December, 1982	A1-7
5.2-5	Concentrations of Macronutrients Measured for Water Samples for the Hemidome and Surroundings During 1982	A1-8
5.2-6	Mean Standard Growth Rates (Percent Daily Elongation Normalized to a One m Frond Length) and Associated Parameters Determined for the Indicated Time Spans Among Macrocystis Transplants in the Hemidome and the Nearby Controls. G = Mean Standard Growth Rate, n = No. of Fronds in Sample, σ = Standard Deviation, UCI = Upper 95% Confidence Interval, LCI = Lower 95% Confidence Interval, ESG = No. of Abnormally Slow-Growing Fronds (Not Excluded in Computing G). All Dates Were 1982. Data Represent the First Experimental Series	5.2-7
5.2-7	Mean Standard Growth Rates (Percent Daily Elongation Normalized to a One m Frond Length) and Associated Parameters Determined for the Indicated Time Span Among Macrocystis Transplants in the Hemidome and the Nearby Controls. G = Mean Standard Growth Rate, n = No. of Fronds in Sample, σ = Standard Deviation, UCI = Upper 95% Confidence Interval, LCI = Lower 95% Confidence Interval, ESG = No. of Abnormally Slow-Growing Fronds (Not Excluded in Computing G). All Dates were 1982. Data Represent the Second Experimental Series	5.2-8
5.2-8	Total Stipes Displayed by 51 Macrocystis Transplants in the Hemidome at the Indicated Dates and by 10 Control Plants Nearby at Intake Point or in Big Fisherman Cove. All Dates are 1982	5.2-9

LIST OF TABLES (Cont)

Table		Page
5.2-9	Analyses of Tissue N (Percent Dry Wt) During 1982 Among Macrocystis Blades in the Hemidome and Control Populations. Values Represent Means and Standard Deviations, From Analyses of 5-6 Blades (Hemidome) or 2-3 Blades (Controls) Except When Only a Single Blade was Available (No Standard Deviation Given). Frequency of Pulse Fertilizing in the Hemidome was Reduced After September 21, 1982	5.2-10
5.2-10	Changes in Mannitol Content (Percent Dry Wt) During 1982 Among Macrocystis Blades in the Hemidome and Control Populations. Values Represent Means and Standard Deviations, From Analyses of 5-6 Blades (Hemidome) or 2-3 Blades (Controls) Except When Only a Single Blade was Available (No Standard Deviation Given)	5.2-12
5.2-11	Mean Standard Growth Rates, G (Percent Daily Elongation Normalized to A One-Meter Frond Length), From Two Groups of Adult Macrocystis Plants as Indicated. ESG Fronds Were Omitted in Computing Means. All Dates are 1982. N = No. of Fronds used in Computing Mean G, σ = Standard Deviation, UCI = Upper 95% Confidence Interval, LCI = Lower Confidence Interval	5.2-21
5.2-12	Standard Growth Rates, G (Percent Daily Elongation Normalized to a Frond Length of One Meter), Measured Among Eight of the Adult Macrocystis Ex-Hemidome Transplants Moored at the Depths Shown (Bottom Depth of 17.7 m). ESG Designates an "Extremely Slow Growing" Frond, Considered as Abnormal. Dates are 1982	5.2-23
5.2-13	Ranges of Temperatures in Degress Celsius Obtained From Minimax Thermometers Positioned Just Outside the Hemidome on 19 November 1982 at Two Depths. All Dates Represent 1982	5.2-25
5.2-14	Analyses of Tissue N (Percent Dry Wt) Among Macrocystis From the Transplants Formerly in the Hemidome (Moored Just Outside on October 29, 19820 and From Control Plants and Naturally Attached Plants Nearby in Big Fisherman Cove. Values Represent Means + Standard Deviations, and (Sample Sizes). All Dates are 1982.	5.2-26
5.2-15	Numbers of Small Fronds (i.e., 50 cm or Shorter) per Plant for the Ten Hemidome Transplants Relocated From the Hemidome Interior to Central Big Fisherman Cove on October 29, 1982. Plants 11, 17, and 24 Lost Most or all of the Upper Foliage During Relocation. All Survey Dates Represent 1982	5.2-28
5.2-16	Chemical Composition of Sieve Tube Sap From Macrocystis Pyrifera. Data IN Mg ml^{-1}	5.2-37
5.2-17	Determination of Photosynthetic Quotients From Different Blade Tissues in Macrocystis Pyrifera	5.2-45
5.2-18	The Effects of Wounding and Preincubation on Photosynthetic Performance of Mature Plugs in Macrocystis Pyrifera	5.2-47
5.2-19	A Comparison of Light and Dark Carbon Fixation in Macrocystis Pyrifera	5.2-56
5.2-20	Net Photosynthesis/Respiration Ratios for Various Thallus Parts of Macrocystis Pyrifera	5.2-60

LIST OF TABLES (Cont)

Table		Page
5.2-21	A Comparison of Photosynthetic Rates in Macrocystis Pyrifera	5.2-60
5.2-21A	Macrocystis Productivity Estimate Derived from PS&R for 1 Hour Maximum Summer Irradiance and Darkness	5.2-62
5.3-1	The Increase in Wet Weight Production Due to Fertilization	5.3-10
5.3-2	First Harvest Yield Data Tables	A1-12
5.3-3	Second Harvest Yield Data Tables	A1-21
5.3-4	Third Harvest Yield Data Tables	A1-28
5.3-5	Fourth Harvest Yield Data Tables	A1-32
5.3-6	Fifth Harvest Yield Data Tables	A1-36
5.3-7	Highest Yielding Plants in the First Through the Fifth Harvests	A1-40
5.3-8	Highest Yielding Plants in the First Harvest	A1-41
5.4-1	Assumed Yield and Planting Density Values for System Concept Point Design	5.4-5
5.4-2	Point Conception Area Survey - Plant Data Summary	5.4-12
5.4-3	Methane Yield Range	5.4-15
5.4-4	Summary of GE Baseline System Concept	5.4-31
5.4-5	Harvest/Transport Subsystem Elements	5.4-46
5.4-6	Reactor Process Specification	5.4-49
5.4-7	Summary Characteristics of Processing Plant Elements	5.4-52
5.4-8	Candidate By-Products and Co-Products	5.4-53
5.4-9	Baseline System Capital Costs	5.4-55
5.4-10	Baseline Annual Operating and Maintenance Costs	5.4-56
5.4-11	Baseline Systems Energy Budget	5.4-57
5.4-12	Gas Cost Sensitivity	5.4-60
5.4-13	Contents of System Functional Requirements and Specification Document	5.4-62
5.5-1	Summary of By-Products/Co-Products Impact on Gas Cost	5.5-2
5.5-2	Potential By-Product and Co-Product Chemicals	5.5-5
5.5-3	Technical Screening of Co-Products and By-Products	5.5-8
5.5-4	Potential for Co-Products From Raw Kelp	5.5-11
5.5-5	Potential Production of and Gross Revenues From Various Co-Products	5.5-12
5.5-6	Potential Gross Revenues From Gas and By-Products	5.5-14
5.5-7	Potential Gross Revenues From Various by-Products and Co-Products	5.5-15
5.5-8	Iodine Data Summary	5.5-16
5.5-9	Algin Data Summary	5.5-17
5.5-10	Potash Data Summary	5.5-18
5.5-11	Carbon Dioxide Data Summary	5.5-19
5.5-12	Mannitol Data Summary	5.5-20
5.5-13	Recovery Efficiencies of Various Products	5.5-39
5.5-14	Algin Recovery-Capital Cost Estimate	5.5-43
5.5-15	Mannitol Recovery-Capital Cost Estimate	5.5-45
5.5-16	Fucoidan Recovery-Capital Cost Estimate	5.5-46
5.5-17	Iodine Recovery Production-Cost Estimate	5.5-47
5.5-18	Liquid Carbon Dioxide-Production Cost Estimate	5.5-48
5.5-19	L-Fraction and Bacterial Protein-Product Cost Estimate	5.5-49

LIST OF TABLES (Cont)

Table		Page
5.5-20	Potash Recovery-Capital Cost Estimate	5.5-51
5.5-21	Process Equipment-Installed Cost Summary	5.5-52
5.5-22	Summary of Daily Operating Requirements - Scenario 1	5.5-53
5.5-23	Summary of Daily Operating Requirements - Scenario 2	5.5-54
5.5-24	Comparative Investment Ratios for Scenario 2	5.5-56
5.5-25	Estimate of Total Capital Investment	5.5-57
5.5-26	Summary of Annual Plant Operating Costs	5.5-60
5.5-27	Unit Price and Rate Data	5.5-61
5.5-28	Estimate Annual Production and Sales Revenues	5.5-62
5.5-29	Profitability Evaluation of By-Products/Co-Products	5.5-63
5.5-30	Effect on Gas Cost	5.5-65
5.5-31	Sensitivity of Gas Cost to L-Fraction Recovery Cost	5.5-69
5.5-32	Effect of Product Portfolio Selection System Economics and Gas Costs	5.5-70
5.6-1	Summary of Swivel Capability	5.6-4
5.6-2	Static Mooring Analysis	5.6-7
5.6-3	Water Velocity Versus Depth	5.6-17
5.6-4	Load and Cable Tension Results	5.6-19

2 SUMMARY OF ALL WORK PREVIOUSLY PERFORMED

2 SUMMARY OF ALL WORK PREVIOUSLY PERFORMED

The thrust of the work performed on the Marine Biomass Program since 1976 has been the acquisition of biological and engineering data that was critical to making an accurate determination of the technical and economic feasibility of the commercial production of Methane from Kelp. The following sections summarize the previous work directed towards validation of the basic concepts involved in the engineering of marine farm systems (Ocean Engineering); the growth and nutrition of Macrocystis (Biological Studies); and the conversion of Macrocystis to methane (Bioconversion).

The objective of the Ocean Engineering work which commenced in 1978 was to provide an open-ocean test structure suitable for the controlled cultivation of Macrocystis. This off-shore test farm (OSTF) was not intended as a miniature version of a commercial farm but rather was designed to enable the biological experiment team to gather the requisite data for determining the growth, yield and nutritional requirements of kelp.

The farm configuration, selected after an extensive series of computer analyses and model testing, was designed to initially support approximately 100 adult Macrocystis plants on a substrate suspended approximately 50 feet below the surface. The test farm also had the capability of providing upwelled water from a depth of 1500 feet through a two foot diameter polyethylene pipe.

The test farm was positioned in approximately 2000 feet of water by a three point catenary mooring system approximately 4.5 miles off Laguna Beach in Southern California.

Although successfully deployed and planted, the OSTF proved incompatible with the adult Macrocystis plants. Heaving of the structure combined with ambient current resulted in entanglement and abrasion of the plants.

Although the primary objective of obtaining harvestable yield data was not met, experience with the OSTF indicated that kelp could survive, reproduce and grow in the open ocean when artificially fertilized with upwelled nutrient-rich seawater.

Biological studies involving kelp growth investigations and nutritional requirements were performed at the California Institute of Technology (CIT) under the leadership of Dr. Wheeler J. North, Professor, Environmental Sciences. The objective of this work was to determine the nutritional requirements of Macrocystis and to provide data on the physiological requirements for optimizing kelp growth in an open ocean cultivation system. Through extensive laboratory and field observations, Dr. North established a set of biological criteria which must be met in order to achieve commercially acceptable yields. Laboratory work also indicated that a mixture of deep and surface water should provide the near optimal media for fertilizing plants in oceanic farms.

Research at CIT also led to the development of techniques for transplanting healthy adult Macrocystis plants directly from natural beds into the OSTF, as well as experimental techniques for the controlled evaluation of kelp growth, yield, recruitment and health conditions for the open ocean experiment.

By May 1981, engineering and biological data indicated that the offshore test facility could not be adequately shielded against ocean currents and surface motions. As a result of this evaluation, the kelp biological tasks were reviewed and redirected toward the development of the nearshore test farms for the acquisition of yield data.

The research in bioconversion prior to 1982 concentrated in three major areas: Pretreatment/Post-treatment; Inoculum Development; and Anaerobic Process Development.

Pretreatment/Post-treatment studies were conducted at the Western Regional Research Center, Albany, California. These efforts were directed toward the definition and evaluation of mechanical and chemical pretreatment/post-treatment process steps which would increase the microbial digestibility of kelp. Mechanical pretreatment studies centered on the development of least capital and least energy intensive methods to increase surface areas and cell rupture. Baseline processes and process equipment were evaluated and a material balance for the selected process was developed. Particle size reduction was examined using pilot scale and commercial scale equipment. Grinding mechanisms were studied and demonstrations of grinding using pilot scale equipment indicated that hammer-mill grinding was the least energy-intensive method for the range of particle sizes of interest.

Additional studies resulted in an assessment of the potential use of digester solid effluent as an animal feed supplement. Study data indicated that the effluent has a crude protein content of about 37% and has good potential as an animal feed supplement.

Inoculum development research work over the past several years has led to the identification of the specific enzyme requirements for the degradation of major constituents of kelp as well as the optimum pH values for maximum enzymatic degradation of certain major constituents. This research has also resulted in successful development of microorganism enrichments which can produce methane from the major constituents; algin, cellulose, mannitol, and fucoidan. Temperature studies using enriched anaerobic cultures of marine microorganisms indicated that such inocula can be incubated at ambient temperatures rather than at the mesophilic range of 35^{o}C without sacrificing reaction rates. The impact of this data, once satisfactorily verified, would be a reduction in processing system costs and energy requirements.

Anaerobic digestion systems development progressed towards the goal of maximizing methane yields which represent approximately 75% of that which is theoretically attainable, and which on the average exceeds those of any other known biomass. It was established that Macrocystis is degradable in a saline culture, can be fed directly to digesters in its undiluted state, and can effectively be converted to methane without the addition of supplementary nutrients. Results from this research suggests that still lower digester retention times and increased yields can be expected as a result of this microbial work.

While experimentation over the past years has answered several critical questions concerning the concept of marine farming as a renewable energy source, it has also raised additional considerations. The variation of harvest yield as a function of crop density, harvest frequency and upwelled water application is a critical factor that must be understood.

Ongoing biological research and innovative engineering development will focus on these and other considerations. The primary task will be the determination of the productive capacity and the sustained yields that may be obtained during the controlled cultivation of kelp.

3 SPECIFIC OBJECTIVES OF CURRENT YEAR

3 SPECIFIC OBJECTIVES OF CURRENT YEAR

During the current year, the objectives GRI intends to meet are; (1) to determine if macroalgal feedstock can be obtained in sufficient quantity and yield to demonstrate a strong economic future of ocean farm systems; (2) to confirm that ocean farms can provide net energy gains; and (3) to determine that macroalgae can be harvested and converted to methane at costs competitive with other alternate sources of energy. The primary concepts to be investigated in the marine farming area are the growing of kelp on bottom or near bottom attachment systems in nearshore waters utilizing natural and artificial nutrients.

Previous work has shown that controlled cultivation of macroalgae is feasible and that methane can be derived from marine biomass feedstock. Such work has also indicated that kelp can be grown in the open ocean when fertilized by artificially upwelled deep ocean waters and in nearshore waters fertilized with chemicals, and that kelp can be readily converted into methane gas. Commercial industries are in place that harvest and utilize this natural coastal kelp for the production of high value chemicals. However, it has not been shown that open ocean or nearshore cultivation of kelp can be accomplished in such a way as to allow methane to be generated at costs that are competitive with other alternate methods of methane production.

Further research for the Gas Research Institute continued the investigation of practical marine farm systems for producing methane from kelp. Emphasis was placed on (1) continuation of biological and kelp growth experiments that have been initiated in the two nearshore test farms (Catalina and Goleta); (2) continued but limited investigation of inocula capable of enhancing methane production; (3) monitoring the quality of kelp grown on the nearshore test farms in terms of its methane potential; and (4) detailed systems and economic analyses of nearshore, coastal scenarios for commercial production of methane from kelp.

EXPERIMENTAL RESEARCH

4 WORK TASKS FOR CURRENT YEAR

4 WORK TASKS FOR CURRENT YEAR

4.1 EVALUATION, OPERATION, AND MAINTENANCE OF EXPERIMENTAL MARINE FARM SYSTEMS

4.1.1 OBJECTIVE

Operate and maintain the nearshore experimental test facilities, (Catalina and Goleta), from which continued acquisition of kelp biology and production data in the marine environment will enable the determination of sustained kelp yield for marine farm systems.

4.1.2 APPROACH

a. Startup and Operation of Farm Systems

1. Objective: Evaluate, checkout, startup, and operate the Catalina Test Farm (CTF) and the Goleta Test Farm (GTF) to enable the conduct of experiments on kelp growth and biology.

2. Activities

(a) Catalina Test Farm (CTF)

- Evaluate and complete the checkout of the installed facility.
- Test the performance of the nutrient distribution system and adjust as appropriate to provide the desired distribution and circulation.
- Maintain the CTF. This shall include routine maintenance of the supply and discharge pumps as well as the navigation equipments; regular inspection of the CTF hardware, and normal repairs as well as damage repairs; establishing a critical spares inventory; and maintenance of the on-board data acquisition system.
- Operate the CTF. This shall include providing consumables such as electricity, fertilizers, and land-based laboratory support needs necessary for conduct of the kelp growth and biology experiments.
- Monitor the natural environment around the CTF to assure operational conformance to the issued permits and licenses.

(b) Goleta Test Farm (GTF)

- Evaluate and complete the check of the installed facility and supporting equipments and vessels.
- Maintain the GTF. This shall include routine maintenance and regular inspection of the GTF hardware and supporting equipments and vessels; normal repairs as well as damage repairs of the farm structures and equipments; and establishing a critical spares inventory.

- Operate the GTF. This shall include providing consumables such as; fuel, electricity and fertilizer, as well as the costs associated with facility rentals and leases.

b. Demobilization of the Off-Shore Test Farm

1. Objective: Demobilize the remains of the Off-Shore Test Platform (OSTF) that was installed in 1978 and determine the probable cause of the loss of the test structure for the purposes of recovering the insured value of the system.

2. Activities:

- Remove, by salvaging and/or sinking, the remnants of the OSTP still in place.
- Conduct a detailed failure analyses of the recovered test structure mooring cables to determine the most probable cause of failure.
- Conduct a series of tensile tests on the remaining cables to assess their residual strength at the time the test structure was lost.
- Document and present the known facts, both quantitative and qualitative, to the insurance underwriters and represent GRI's interests in pursuing the recovery of the insured value of the OSTP.

4.2 BIOLOGICAL STUDIES

4.2.1 OBJECTIVE

To determine the potential yield of Macrocystis cultivated under ocean conditions.

The most crucial factor affecting the potential of the marine farm concept is yield. This, in turn, is affected by the kelp growth rates obtained at specific planting densities, as well as rates of natural or systems induced mortality. Thus, those elements of marine farm systems which significantly impact upon plant performance are central concerns of this program. In addition to direct measurements of growth rates, planting densities, harvest yields, and mortality, it will be necessary to conduct intensive evaluations of influences related to nutrient supply and uptake, contaminants and competitors, and structure. Actual determination of potential yields of marine farms will be developed from data being collected at the Catalina and Goleta Test Farms. Laboratory and farm studies and a collection of information on planting technology will be pursued in the present phase of the project as an adjunct data source addressing those influences on plant yield listed above.

The activities to be conducted during 1982 are described in the following paragraphs:

4.2.2 APPROACH

a. Laboratory Studies

1. Objectives

- To obtain the information necessary to assure the complete nutrition of kelp.
- To learn how best to produce kelp tissues with the chemical composition most likely to maximize the value of kelp feed-stock for anaerobic digestion.
- To support the conduct of the Nearshore Test Farms experiments by providing information on the cultivation needs of Macrocystis.

2. Purpose: To provide the information required to better assess the needs and application of kelp growth in energy farms.

3. Activities: The following activities shall be continued:

(a) Genetics and Propagation Methodology

Existing strains of gametophytes shall be maintained.

(b) Aquil Experiments

- Experiments on the growth of Macrocystis gametophytes and sporophyte juveniles in a completely defined artificial medium shall be continued.
- The studies of optimal concentrations of nitrogen, phosphorous, iron, manganese, iodine, copper, molybdenum, cobalt, and zinc shall be continued for gametophytes and juvenile sporophytes.
- Evaluations shall continue of the suitability of the various chemical forms of these elements to determine speciation and chelation requirements.
- Analyses shall be continued of the uptake rates of the above listed micronutrients.

b. Yield and Growth Studies on Nearshore Test Farms

1. Objective: To obtain biomass growth and harvestable yield data from adult Macrocystis plants in marine environments under controlled and/or measured nutrient/light conditions.

2. Purpose: To provide improved data for prediction and evaluation of marine kelp farm growth potentials for application to and update of system and economic models of methane from marine biomass concepts.

3. Activities: Two activities shall be initiated:

- Biological and growth experiments will be conducted on the enclosed Catalina Test Farm (CTF) to determine the growth and harvestable yield performance of adult Macrocystis plants under varying controlled test conditions. Adult Macrocystis plants will be selected from natural beds and transplanted to the enclosure. Automated and/or manual measurements will be made of required parameters on a regular basis to ascertain and verify the growth/environmental conditions within the enclosure during each growth phase of the experiment. As a minimum, the following data will be recorded:

  - Observed plant motion
  - Nutrient levels
  - Water temperature vs time
  - Light levels vs time
  - Standing crop density
  - Standing crop sample composition
  - Harvested biomass quantity
  - Harvested sample composition
  - Growth vs time
    - Frond length/number
    - Frond initiation rate
  - Plant damage due to abrasion/motion, etc. if any
  - Plant damage due to grazers, etc.
  - Survey of other flora/fauna in enclosure
  - O_2 levels
  - pH
  - Total fronds/plant

- A similar set of experiments will be conducted on the Goleta Test Farm. In this case, no containment enclosure will be employed so that only limited control of nutrient levels will be possible. Artificial nutrients will be applied directly to the canopy. Adequacy of application will be measured by chemical analysis of the plant tissue. The Goleta Test Farm data will provide the same type of growth/harvestable yield information as with the CTF, except that no enclosure interaction will be present. Several

large test plots will be run simultaneously at various plant densities. Many of the same test parameters and data measurements as used in the CTF studies will be employed for these experiments. The combined data from the CTF and GTF will provide a new and significant body of data on growth potential of mature plants in an ocean environment under controlled and monitored nutrient conditions.

4.3 KELP BIOMASS CONVERSION STUDIES

4.3.1 OBJECTIVE

To research, develop, and demonstrate efficient processing and conversion technologies with the potential for producing commercial methane gas, and by-products from macroalgal feedstock.

During 1982, the efforts will be concentrated on continuing the research into improved inocula assessing the methane potential of kelp grown under controlled conditions in the nearshore test farms.

4.3.2 APPROACH

a. The Research and Development of Basic Inocula for the Anaerobic Digestion of Kelp to Methane

1. Objective: To develop inocula capable of increasing the rates of biological/chemical reactions leading to methane generation and gas yield.

2. Purpose: To provide the basic biological materials required in the anaerobic digestion of kelp feedstock.

3. Activities: The following activities shall be continued:

- o Baseline bacterial cultures shall be maintained for use in the startup of new digesters and all subsequent studies.
- o Experimental studies on the ultimate digestibility of kelp including the use of specially developed inocula for the recalcitrant fraction will be continued.
- o Studies of microbial interactions in kelp bioconversion through development of binary and multiple organism food chains will be continued.

b. Assessment of Compositional Analyses of Kelp Grown at the Nearshore Test Farms

1. Objective: To determine the quality of Macrocystis grown under controlled conditions at the Near Shore Test Farms.

2. Activities: The following activities shall be initiated.

- Using previously developed analytical procedures, perform compositional analysis on samples of kelp grown under controlled conditions from the Catalina and Goleta Test Farms.
- Determine the theoretical gas yield from the compositional data of each sample.
- Perform biomethanation evaluation of each sample of kelp using previously developed bioassay techniques.
- Evaluate feedstocks from Catalina and Goleta under laboratory controlled, continuous baseline steady-state anaerobic digestion conditions.

4.4 SYSTEMS ANALYSIS

4.4.1 OBJECTIVES

- To provide and apply a technique for evaluating marine farm project systems performance on a continuing basis.
- To develop and apply a tool for decision making, including program paths and timing for both economic and energy balances.
- To provide credible concepts and defensible costs associated with the production of methane from Macrocystis grown on nearshore marine farms.

4.4.2 PURPOSES

- To provide and apply the methodology required to synthesize and evaluate total marine farm project systems from all component subsystems, groups, and elements, giving value measures to the benefits to be derived from technical advances in the various subsystem technologies.
- To assess the cost benefit of a renewable methane supply that is generated from ocean cultivation of Macrocystis.

4.4.3 APPROACH

The approach to be used in 1982 toward the stated objectives will be the analyses of nearshore marine farm systems.

Energy, mass flow, and economic models capable of simulating the performance of nearshore marine farm systems will be developed.

4.4.4 ACTIVITIES

The following activities will comprise the effort in 1982 toward developing a model for a least cost system which produces gas from Macrocystis cultivated in nearshore coastal farms.

- The kelp biological/engineering requirements will be defined from available literature and by analysis of existing data interpreted in terms of the needs of the system and subsystem designs and tradeoffs to be performed.

- Candidate system and subsystem concepts, functions, and functional relationships will be defined in order to identify the end-to-end system for more detailed design evaluation and costing. A top-down system functional block diagram will be developed to the level required to visualize hardware. The functional interfaces between the various functions and related subsystems will be defined, and various options will be detailed to meet the end-to-end and lower level functional requirement.

- Potential Southern California ocean and land sites suitable for the SNG production system(s) will be identified and described. Recommended siting locations will consider such things as the biological requirements of the kelp, the engineering requirement of the ocean and land hardware, the competing uses for the area from commercial, military, recreational and residential viewpoints, and the environmental/permitting requirements.

- Subsystem hardware design concepts will be developed to accomplish the identified functional requirements. Sufficient design information will be developed to permit engineering cost estimates, energy requirement and tradeoffs of subsystem candidate. The most promising candidate design concepts for each subsystem will be selected, and all subsystem hardware performance and interface requirements will be defined. An overall "Systems Performance/Design Requirements Specification" will be developed from the above details.

- With the "Systems Specification" as defined above, a third party GRI contractor will define the detailed engineering and cost model of the least cost gas production system. GE will provide support to this third party contractor.

4.5 ENGINEERING SUPPORT

4.5.1 OBJECTIVE

To maintain and continue to foster the technical engineering expertise needed for the development of marine farm systems.

4.5.2 PURPOSES

- To ensure systematic integrated cost-effective development of the program.

- To make available the necessary expertise as a form of checks and balances in the overall program effort.

- To make available the specific expertise needed to assure uninterrupted conduct of the Nearshore Test Farm experiments.

4.5.3 ACTIVITIES

Specific activities for which support shall be needed include the following:

- Project engineering whereby interrelated tasks undertaken by the various program subscontractors are conducted in a manner to insure timely, integrated and cost-effective performance.

- Field engineering for support and monitoring of ocean engineering related to the operation and maintenance of the experimental marine farm systems.

- Systems engineering whereby the data developed from the near-shore test farm experiments are analyzed and utilized in the models developed for the commercial gas production scenarios.

5 1982 WORK PERFORMED BY TASKS

5.1 KELP DIGESTION BIOLOGY

5 1982 WORK PERFORMED BY TASKS

The following sections describe the experimental work expended during the course of this contract - the 12 month period beginning January 1, 1982 and ending December 31, 1982. To provide clarity to the reader, each major section listed below is presented as an individual section of work.

5.1 Kelp Digestion Biology
5.2 Catalina Kelp Cultivation Biology
5.3 Goleta Kelp Cultivation Biology
5.4 System Analysis
5.5 Co-Products/By-products
5.6 Lost Farm Activities

5.1 KELP DIGESTION BIOLOGY

5.1.1 MICROBIAL STUDIES

The efforts described in this Section are a continuation of previous studies concerned with the microbiological and biochemical events in the anaerobic digestion of marine algae to methane. In particular, these studies have focused upon the biodegradation of the major constituents, algin and mannitol, and have resulted in the isolation, characterization, and identification of the predominant microbial species responsible for these activities. These findings, besides being detailed here, have been submitted for publication (Title: Isolation and partial characterization of alginate - and mannitol - utilizing bacteria from a methanogenic kelp (Macrocystis pyrifera) digester) in Applied and Environmental Microbiology.

Additional studies have shown that selected isolates show a great metabolic diversity and are able to degrade a wide variety of macroalgal constituents from kelp including laminarin, fucoidan and cellulose. The particular enzyme activities and the mechanisms which control each of these activities are beginning to be defined. Each isolate has been characterized as to its specific mannitol dehydrogenase enzyme and co-factor requirements, and this data will be utilized to study various digestion factors which may affect rate limiting reactions in reactors.

Kelp quality studies were also conducted as an adjunct to the kelp growth and nutrition studies. These included compositional analyses of major component materials and comparative gasification assessments of various kelp harvests.

This segment also includes a detailed report describing some microbiological studies associated with efforts to elucidate the cause of the "shot-hole" disease syndrome - a warm weather related condition resulting in a peppered or "shot-hole' appearance of the near surface kelp blades - and includes some recommendations for future studies in kelp pathology.

5.1.1.1 Growth of Cytophaga on Mixed Substrates

Previous studies had shown that the alginolytic Cytophaga strains that had been isolated from kelp digesters were also capable of utilizing mannitol, another major component of Macrocystis. However, while algin and mannitol are rapidly consumed individually, it was necessary to determine what, if any, interactive effects occur when both substrates are present simultaneously as found in the kelp digester system.

As can be seen in Figure 5.1-1, simultaneous utilization of algin and mannitol occurs when cells are pre-grown on algin. There is sufficient alginase carryover with the inoculum to provide initial growth substrate and further enzyme synthesis. No induction period is needed for alginase production. There is no apparent effect of algin or its breakdown products on mannitol utilization, and mannitol is consumed more rapidly as it is probably assimilated directly and does not depend on extracellular enzymatic activities as with algin degradation.

In contrast, if cells are pre-grown on mannitol (no detectable alginase activity), no evidence of algin degradation occurs until the mannitol is completely consumed as shown in Figure 5.1-2. At this point, algin consumption is initiated and a secondary growth phase takes place (Diauxie Growth). These data suggest that mannitol (or its breakdown products) may interfere in some manner with algin-lyase production/release. This remains to be determined.

5.1.1.2 Growth of Bacterial Isolates on Kelp

Previous studies on the ability of Cytophaga species to degrade the various constituents of kelp have been performed in defined medium containing pure compounds (i.e. sodium alginate, mannitol, etc.). It has been shown for instance, that essentially 100 percent of pure algin is rapidly degraded by these bacteria as are many other components. In order to fully evaluate the role of these microorganisms in the kelp to methane food chain, it is necessary to determine how these bacteria utilize the natural substrate.

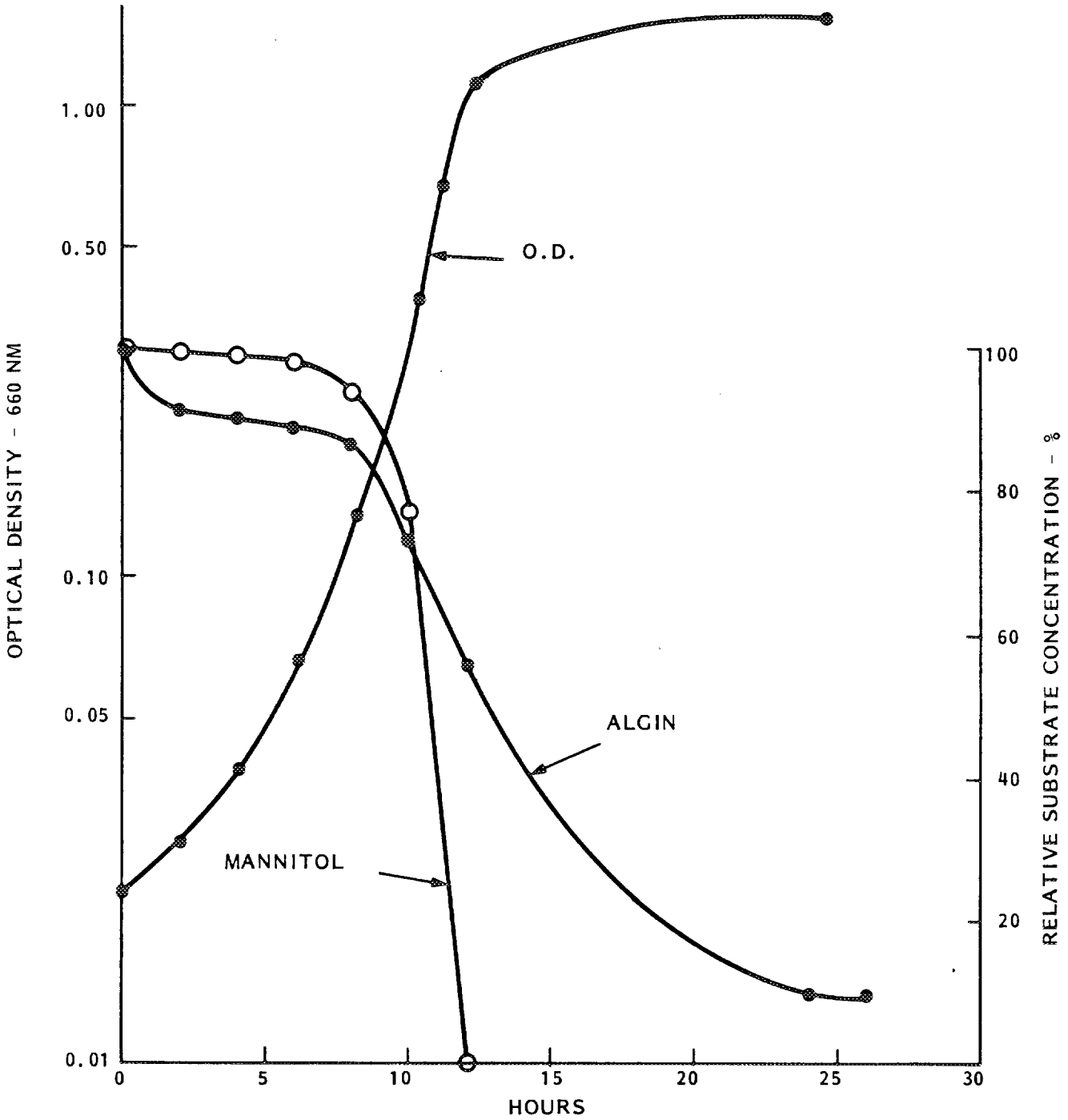


Figure 5.1-1. Growth of Alginolytic Cytophaga as Indicated by Increased Culture O.D. on Mixed Substrates Algin Grown Inoculum

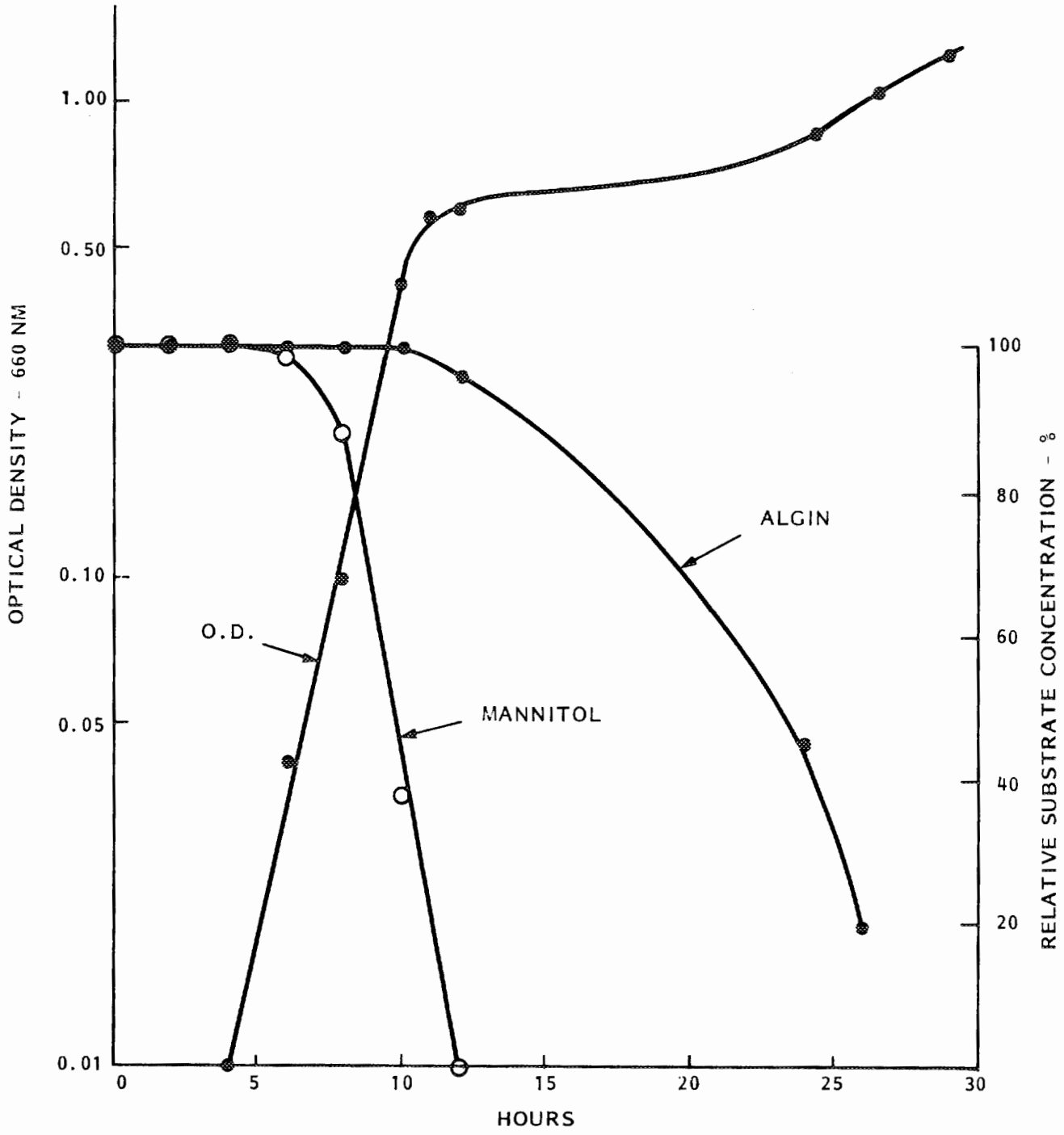


Figure 5.1-2. Growth of Alginolytic Cytophaga as Indicated by Increased Culture O.D. on Mixed Substrates Inoculum was Pregrown on Mannitol Based Medium

Studies were first conducted to determine whether kelp would support the growth of the Cytophaga species. A medium was prepared by combining basal medium (Mah et al,) and a known weight of raw kelp (Macrocystis pyrifera, Lot 53-1) in serum bottles using standard anaerobic techniques and a nitrogen atmosphere. The medium was sterilized by autoclaving. It is recognized that this procedure induces some changes in the kelp, but alternative sterilization techniques were not available.

After inoculation and incubation, microscopic observations indicated growth of all Cytophaga strains (39-1, 12 and 15) to be extremely prolific, with individual cells appearing to be very healthy. In fact, these cultures appear denser than any previously grown. In addition, an obvious change in the quantity and texture of the kelp substrate was noted; the kelp particles were coalesced in the presence of the microorganisms in contrast to individual rapidly settling particles in control media. These cultures have been harvested and will be analyzed for metabolic products.

Similar observations were made with the mannitol-utilizing isolates. All isolates grew, but coagulation of the kelp particles occurred with only two strains, MTL-2 and MTL-8. The kelp particles in the other cultures remained dispersed. Furthermore, microscopic observations of most cultures revealed what may be kelp-bacterium associations, especially in the case of MTL-3. Cells of this strain were observed to attach in tremendous numbers to some, but not all, kelp particles in such a way as to resemble a "fur coat" of cells. It is not clear at present why some particles and not others were involved. Although these isolates may utilize some minor kelp components other than mannitol, it is known that they do not utilize algin, fucoidan or laminarin.

In order to study the degradation (utilization) of the various components of the kelp substrate during the growth of the bacterial species, it was necessary to develop methods for the small-scale analysis of these components. This was accomplished by modifying and combining some existing techniques as follows. The contents of serum bottles, i.e. 20 ml volume containing 0.2 to 0.6 gm (dry weight) of kelp, were transferred to 50 ml centrifuge tubes. The bottles were thoroughly washed with 20 ml 0.4 N H_2SO_4, and this wash fluid was added to the contents of the centrifuge tubes. After standing at room temperature overnight, the tubes were centrifuged at 15000 RPM for 10 minutes. The supernatants were transferred to volumetric flasks, the pellets resuspended in 10 ml 0.2 N H_2SO_4 and recentrifuged. The supernatant was combined with the previous supernatant and the

volume brought to 50 ml by the addition of 0.2 N H_2SO_4. This supernatant fraction was then analyzed for mannitol by the HPLC method described in previous reports and for fucoidan by the method of Dische and Shettles (1948).

The pellet from the second centrifugation was resuspended in 15 ml, 3 percent Na_2CO_3, heated at 55°C for two hours to solubilize the algin fraction. After centrifugation, (15000 RPM, 10 minutes) the supernatant was saved and the pellet re-extracted once with 15 ml, 1.5 percent Na_2CO_3 and once with 15 ml deionized water. The supernatant fractions were combined and quantitatively brought to a 50 ml volume. This solution was then analyzed for algin by the Orcinol Reagent method of Dische (1953).

Utilizing these techniques, the consumption of algin and mannitol by Cytophaga sp number 15 growing on kelp was examined. Figure 5.1-3 depicts the results of these experiments. Each point represents the average of three replicate samples. Mannitol (initial concentration of 3.2 g/l) was completely consumed during these tests. Algin (2.5 gm/l) in contrast appears to be only partially degraded. Approximately 40 percent was rapidly degraded within the first 24 hours of incubation. Degradation at a much slower rate followed over the next 48 hours. In all, about 60 percent was degraded in 72 hours. No degradation of fucoidan was evident in these experiments though fucoidanase activity had been demonstrated previously in cells grown on fucoidan. Several factors may be operating to account for these findings; repression of enzyme synthesis, depression of enzyme activity by uncontrolled pH changes in batch culture, inaccessibility of algin within kelp particles to alginase enzymes, overabundance of substrate, etc. These effects remain to be investigated. It should be noted, however, that these results are similar to that obtained when the Cytophaga are grown on mixed, pure substrates as shown previously (see Figure 5.1-2). This suggests that other components in the kelp substrate do not significantly effect the mechanisms governing the consumption of these major materials.

5.1.1.3 Preliminary Studies on Effect of Growth Substrate on Polymer Degrading Enzymes in Cytophaga Species

Previous studies undertaken during this program have shown that alginase activity in the algin degrading Cytophaga isolates is inducible, rather than constitutive, as evidenced by absence of activity when these strains are grown in the absence of algin (i.e. grown on mannitol). These studies have also shown that these Cytophaga species are able to degrade the glucose polymer, laminarin and the sulfated fucose polymer, fucoidan. It was of interest therefore to determine

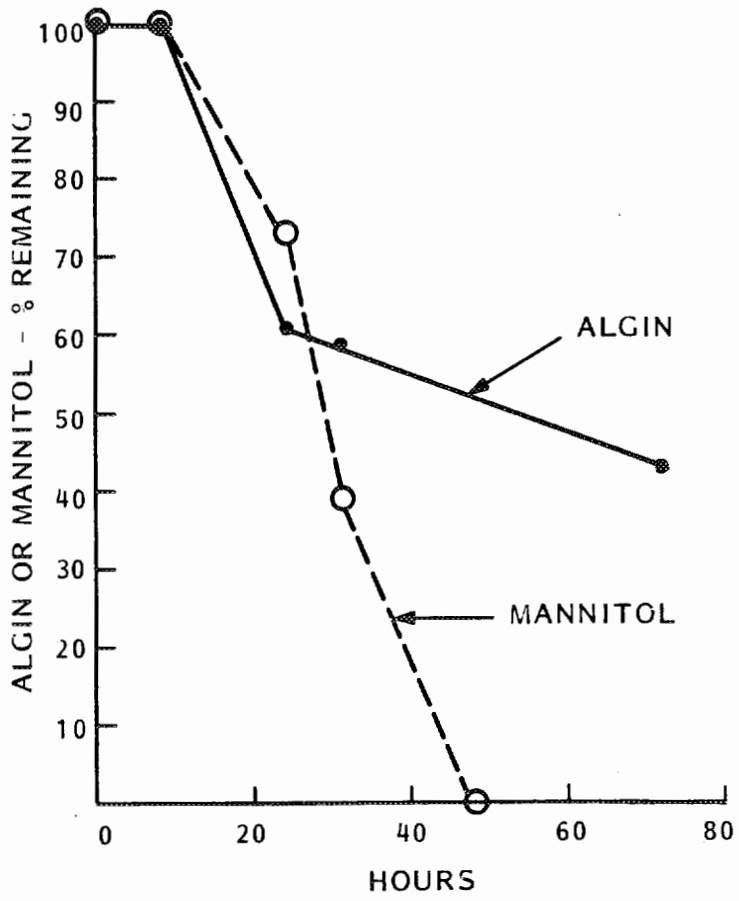


Figure 5.1-3. Consumption of Mannitol and Algin by a Cytophaga sp. Growing on Kelp (Macrocystis pyrifera)

whether these latter enzymes activities were under similar control. Cultures were grown in algin, mannitol, laminarin and fucoidan and the resulting culture supernatants tested with respect to activity against the various polymers using the DNS reducing sugar assay (Miller, 1959). In general, fucoidanase activity appeared to be rather low in comparison to alginase and laminarinase activities, but this may reflect present assay conditions/procedures. It is planned to use the more specific cysteine-sulfuric acid method (Dische and Shettles, 1948) in future studies.

The results of these preliminary studies are presented in Table 5.1-1. As can be seen, the data is very clear for cells grown on glucose, algin or mannitol. Alginase, laminarinase and fucoidanase are inducible enzymes. For cultures grown on laminarin or fucoidan, however, the data is not as clear cut, and it appears at first glance that laminarin may induce fucoidanase activity and some alginase activity and that fucoidan may induce some laminarinase and alginase activity. Three explanations for this phenomena are possible: 1) an intermediate in the breakdown of laminarin or fucoidan can also act as an enzyme inducer, 2) both the laminarin and fucoidan can also act as enzyme inducers, or 3) both the laminarin and fucoidan preparations are impure and contain sufficient quantities of other polymers present to cause induction of other enzyme activities. The latter is probable in view of the results with algin and mannitol, but this remains to be verified. It also becomes necessary to determine the activities of each of the specific enzymes when all substrates are present simultaneously (i.e. as in kelp), as this will provide a more quantitative measure of these organisms role in the total digestion process.

TABLE 5.1-1. EFFECT OF GROWTH SUBSTRATE ON PRESENCE OF SPECIFIC POLYMER-DEGRADING ENZYMES IN CYTOPHAGA STRAINS

	+/- Enzyme Activity			
	Activity			
Growth Compound	Algin'ase	Mannitol'ase	Laminarin'ase	Fucoidan'ase
Glucose	-	-	NT	NT
Algin	+	NT	-	-
Mannitol	-	+	-	-
Laminarin	±	NT	+	+
Fucoidan	±	NT	±	+

NT = Not Tested
\+ = Strong Activity
\- = No or very little low activity
± = Some Activity

5.1.2 MANNITOL DEHYDROGENASE ACTIVITY OF MICROBIAL ISOLATES

Upon completion of the isolation/characterization studies of the algin-utilizing and mannitol-utilizing isolates, studies were begun to determine the identity and regulation involved in the major enzymes of mannitol metabolism.

Experimentally, isolates M1, M2, M3, M8, A12, A15, and A39 (Table 5.1.2-1) were grown in mannitol media (0.2 percent mannitol) until mid-stationary phase was reached (as determined by Optical Density readings). Cells were harvested by centrifugation washed with 0.02 M sodium/potassium phosphate buffer (pH 6.8) containing 10^{-2} M 2-mercaptoethanol. The cell pellet was resuspended in the same buffer and the cells broken by sonication. Cell debris and unbroken cells were removed by centrifugation and the supernatant used for subsequent mannitol dehydrogenase assays. Reactants for enzyme assay were: 0.2 M TRIS-HCl buffer (pH 8.5) containing 5 x 10^{-2}M 2-mercaptoethanol, 5 x 10^{-4} M cofactor (either NAD^+ or $NADP^+$), substrate (either 10^{-2} mannitol or 3.3 x 10^{-3} M mannitol-1-phosphate). Enzyme activity was measured by determining the rate in increase in optical density at 340 nM. Protein was determined by the method of Lowry et al (1951).

Table 5.1-2 presents a summary of the activities obtained with each of the isolates tested. Isolates M1, M2, and M8 possessed mannitol-1-phosphate dehydrogenase as the first enzyme of mannitol metabolism whereas M3, A12, A15, and A39 had mannitol dehydrogenase. Each of these enzymes was active with NAD^+ but not with $NADP^+$as a cofactor. The presence of mannitol-1-phosphate dehydrogenase in some isolates suggests that in these strains the mannitol was phosphorylated during transport into the cells, probably by a PEP-phosphotransferase system found in many other anaerobic bacteria. The absence of this enzyme in the other strains indicates that mannitol was not phosphorylated during transport into these bacteria.

In addition to these experiments, the mannitol isolates were also grown on glucose as a substrate prior to testing for mannitol-dehydrogenase activity. In these tests, neither mannitol-1-phosphate dehydrogenase nor mannitol dehydrogenase were produced indicting that these enzyme activities are regulated by induction. Future experiments on this subject are expected to include a more detailed study of enzyme induction, including induction effects in the mannitol-utilizing alginate isolates and effects of phloroglucinol, volatile fatty acids and other kelp digester related factors on enzyme production. This data is essential to

TABLE 5.1.2-1. CHARACTERISTICS OF KELP DIGESTER ISOLATES

Characteristic[a]	Isolates										
	A39	A12	A15	M1	M2	M3	M6	M8	T4	T5	T7
Cell morphology	rod	rod	rod	coccoid rod	rod	rod	coccoid rod	rod	rod	rod	rod
Cell size (μm)	0.35-0.55 by 5-8.5	0.35-0.55 by 5-8.5	0.35-0.55 by 5-8.5	1.0 by 1.5-2.5	0.7-1.5 by 3.5-9	0.7 by 2.5-5.0	1.0 by 1.5-2.5	0.7 by 3.5-6.0	0.7 by 2.0-3.5	0.7 by 2.0-3.5	1.0 by 3.5-8.0
Gram reaction	-	-	-	+	V	-	+	-	-	-	+
Spores	-	-	-	-	-	-	-	-	-	-	+
Motility	ND	ND	ND	-	-	+	-	+	+	+	+
Flagellation	ND	ND	ND	ND	ND	P	ND	MS	MS	MS	P
Colony diameter (mm)[b]	ND	ND	ND	0.5	1.5	0.5	0.5	1.0	0.25	0.25	1.5

[a]Symbols are +, positive; -, negative; V, -gram-variable; ND, not determined; P, pertirichous flagella; and MS, monotrichous, subpolar flagellum

[b]Average colony diameter observed on MTY medium after incubation for 1 to 3 days (3 to 4 weeks for isolates T4 and T5) at 37°C. Other colony characteristics were as described in the text.

Characteristic[c]	Isolates										
	A39	A12	A15	M1	M2	M3	M6	M8	T4	T5	T7
Growth in presence of:											
No salt	-	-	-	+	-	+	+	-	-	-	+
3% NaCl	+	+	+	+	+	+	+	+	+	+	+
3% KCl	-	-	-	+	-	+	+	±	-	-	+
3% NaCl + 3% KCl	+	+	-	+	-	+	+	+	+	+	+
Ethanol/acid production[d]	APs	Aps	Aps	EaLf	Ealf	as	EaLf	Eaf	eapibiv	eapibiv	eapibbivic
H_2 production	-	-	-	-	+	+	-	+	+	+	+
NH_3 production	-	-	-	-	-	-	-	-	+	+	+
Pyruvate utilization	-	-	-	-	-	-	-	-	+	+	+
Starch hydrolysis	+	+	+	-	-	-	-	-	-	-	-
Meat digestion	-	-	-	-	-	-	-	-	-	-	+
Indole production	-	-	-	-	-	-	-	-	-	-	+
Catalase formation	ND	ND	ND	-	-	-	-	-	-	-	-
Pigment production	+	+	+	-	-	-	-	-	-	-	-
Aerobic growth	+	+	+	+	-	-	+	-	-	-	-

[c]Symbols are +, positive; -, negative; ND, not determined. None of the isolates produced acetylmethylcarbinol, but all produced CO_2.

[d]Acid and ethanol end-products were determined for alginate, mannitol, and tryptone isolates grown on TY medium containing alginate, mannitol, and no substrate additions, respectively. Products are e, ethanol; a, acetate; p, propionate; b, butyrate; ib, isobutyrate; iv, isovalerate; ic, isocaproate; l, lactate; s, succinate; f, formate. Capital letters indicate acids produced in amounts of 5 mM or greater small letters indicate amounts less than 5 mM.

understanding the kelp digestion process and helping overcome potential process instability.

TABLE 5.1.2-2. MANNITOL DEHYDROGENASES OF MANNITOL UTILIZING ISOLATES

	Isolate	NAD+ Linked Mannitol Dehydrogenase	
		Mannitol	Mannitol-1-Phosphate
Mannitol Isolates	M1	-	+
	M2	-	+
	M3	+	-
	M8	-	+
Algin Isolates	39-1	+	-
	#12	+	-
	#12	+	-

5.1.2.1 Degradation of Cellulose by Alginate-Utilizing Isolates

Whereas previous studies found that none of the three (3) Cytophaga strains exhibited any noticeable growth response with insoluble cellulose sources (microcrystalline cellulose or Avicel and Whatman number 1 filter paper), it now has been determined that they do possess cellulolytic activity against soluble cellulose (carboxymethylcellulose). This finding thus extends the range of known macroalgal component materials that these microorganisms can successfully degrade, further emphasizing their importance in the overall degradative process. Further tests will determine this cellulase activity against native cellulose in kelp.

The mannitol-utilizing isolates M1, M2, M3 and M8 and the tryptone-utilizing isolates T4, T5, and T7 were also tested for their ability to use soluble cellulose and were found to be negative.

Kelp Evaluation Studies - These studies were undertaken in order to provide a data base for use in correlating growth performance experiments with compositional changes and potential gasification of cultivated Macrocystis pyrifera.

Macrocystis samples were provided by personnel at the California Institute of Technology and Neushul Mariculture Inc. and shipped to this laboratory packed in ice. Upon receipt, the samples were frozen (-20°C) and then ground for one minute in a food processor (General Electric). After thoroughly mixing, subsamples were taken for proximate analysis, algin and mannitol analyses and for comparative biogasification potential using the Bioassay technique (60 Day).

Algin was determined by the method of Cameron et al (1948) and mannitol by the in-house developed HPLC technique.

Table 5.1-3 presents the results of these studies. A sample from Kelp Lot 53-1 assayed in parallel is shown for comparison.

TABLE 5.1-3. COMPARISON OF MACROCYSTIS HARVESTS

Lot #	Source	% DW	% VS	% NA Alginate	% Mannitol	SCF CH_4/lb VS
82-1	CIT, 6/14/82	11.70	62.45	18.70	10.83	4.43
82-2	CIT, 6/16/82	8.87	53.50	17.80	6.50	4.42
82-3	NMI, 7/1/82	11.55	58.22	20.80	6.56	4.49
82-4	NMI, 7/20/82	12.61	64.44	19.00	22.42	4.70
53-1	WRRC, 10/22/80	12.74	60.96	14.70	17.24	4.65

Because of the limited number of samples provided to this laboratory, it is difficult to make any definitive statements as to their worth as digestion feedstocks. Based upon past experience, however, it would appear that the characteristics of lot 82-4 closely approximated that of lot 53-1, and most certainly would have given similarly high sustained yields of methane under steady-state digester conditions. A striking difference was noted in mannitol concentrations in NMI lots 82-3 and 82-4 and according to Dr. Harger, this reflects the difference in cultivation strategies with 82-3 being fertilized and 82-4 acting as a control. In general, samples from CIT, in particular 82-2, visually appeared to be of a paler and less healthy condition than those from NMI

5.1.3 MICROBIAL EXAMINATION OF KELP "SHOT HOLE" DISEASE

Due to the reappearance of the "shot-hole" disease syndrome in the Macrocystis plants within the Catalina hemidome test facility, and the previously propounded theory of bacterial involvement, an on-site visit was requested of the GE Laboratory personnel to make a preliminary, experimental investigation into the possible microbiological causes/relationships for this syndrome. This section details these limited studies, provides generalized observations and makes recommendations for future efforts.

The study was divided into three basic areas: One, attempts at isolation of bacterial strains from "infected" tissues; two, basic characterization of these strains and three, a generalized assessment of biomass loading in the hemidome environment through measurement of ATP levels.

5.1.3.1 Microbiological Studies

Culture Media - The media used for initial isolation contained the following per liter: yeast extract, 0.1 g; tryptone, 0.5 g; $(NH_4)_2 SO_4$, 0.2 g; 0.2 M sodium phosphate buffer, pH 7.2, 50 ml (final concentration, 0.01 M); agar, 20 g, and either glucose or mannitol at a final concentration of 0.2 percent, wt/vol. The media were prepared with seawater, and the final pH adjusted to 7.2 with NaOH.

A kelp extract medium was also tried for isolation. Diseased kelp from the hemidome was ground to a fine consistency in a blender and employed in the medium as a composite source of all kelp organic materials. This medium (pH 7.6) contained: yeast extract, 0.1 g; tryptone, 0.5 g; kelp extract, 50 ml (final concentration, 5 percent, vol/vol); agar, 20 g; and seawater, 950 ml.

The following medium was used for culture transfers, stock culture maintenance, and characterization studies: yeast extract, 0.1 g; tryptone, 0.5 g; NH_4Cl, 1.0 g; K_2HPO_4, 0.2 g; agar, 20 g; glucose or mannitol at a final concentration of 0.2 percent wt/vol; and Instant Ocean, 1 liter. The Instant Ocean is an inorganic, bicarbonate buffered substitute for seawater. The pH of the medium was 7.0.

Isolation of Bacteria - Diseased kelp samples and water from the hemidome, and healthy kelp from Inlet Point were employed in a variety of methods to isolate bacteria. The types of isolation media used are described in the previous section. The following is an outline of the sample sources and isolation methods used.

Code	Sample	Isolation Method
A	Diseased Kelp[a]	Aseptically grind kelp in sterile seawater in mortar and pestle or blender; streak the slurry
B	Diseased Kelp[a]	Aseptically cut kelp pieces and place pieces on agar surface.
C	Diseased Kelp[a]	As in B, but use the pieces in an agar pour plate.

Code	Sample	Isolation Method
D	Diseased Kelp[a]	As in B, but simply rub piece over agar surface.
E	Hemidome Seawater	Streak on agar plates.
F	Healthy Kelp from Intake Point	As in A

[a] All parts of diseased kelp blades were used in the study including areas showing holes, holes in progress of being made, non-hole areas, discolored blotchy areas.

Isolation plates were incubated aerobically for 24-72 hours at 20°C, followed by picking of growth types and streaking on new plates until pure cultures were attained. Isolates were then placed on agar slants.

The Isolates - All isolations began at Catalina Island, but some of the original isolation plates were brought back to Valley Forge where the isolation process was continued. Those isolates obtained in pure culture at Valley Forge were given the prefix V. Those completed at Catalina received the prefix C. All characterization work was done at Valley Forge. Table 5.1-4 lists data on all of the kelp isolates, including isolation method and source, growth appearance, cell morphology, motility, gram reaction, and growth at 4°C and 35°C. Based on this data, the isolates were grouped as described further on.

Several characteristics which were studied are not included in Table 5.1-4 since the results were essentially the same for all isolates. All isolates grew at room temperature (20-24°C), most within 24-48 hours. In addition, all isolates grew on agar media containing yeast extract and tryptone with or without mannitol or glucose. The data in Table 5.4-1 were obtained on isolates grown on mannitol-containing agar media.

Microscopic observation of bacteria required the suspension of growth from an agar plate in a buffered salt solution (Instant Ocean) on a slide. Under these conditions, the cells remained viable and motile. Resuspension in distilled water caused loss of viability, lysis, and loss of motility.

The isolates were transferred twice weekly onto new agar plates, and fresh cultures were used for all characterization studies. Agar slant stock cultures are stored at 4°C.

TABLE 5.1-4. CHARACTERISTICS OF KELP BACTERIAL ISOLATES

Isolate[c]	Initial Isolation Method/Source[a]	Appearance of Growth[b]	Cell Morphology	Observed Motility	Gram Reaction	Growth at 4°C Within 8 Days	Growth at 35°C Within 24 Hrs.
V1	D	S	Oval rods, pleomorphism	+	-	-	+
V2	D	C	Short rods	+	-	+	-
V3	D	S	Oval rods, pleomorphism	+	-	-	+
V4	A	C	Oval rods	+	-	-	-
V5	A	C	Oval rods	+	-	-	-
V6	A	C	Short to medium rods, pleomorphism	-	-	+	-
V7	A	C	Short to medium rods, pleomorphism	-	-	-	-
V8	A	C	Short to medium rods, pleomorphism	-	-	-	-
V9	A	C	Short to medium rods, pleomorphism	-	-	+	-
V10	A	C	Medium rods	+	-	-	+
V11	A	S	Oval rods, pleomorphism	+	-	-	+
V12	B	C,Y	Tiny rods or coccobacilli	+	-	+	+
V13	B	S	Oval rods, pleomorphism	+	-	-	+
V14	B	S	Oval rods, pleomorphism	+	-	-	+
V15	B	S	Oval rods, pleomorphism	+	-	-	+

TABLE 5.1-4. CHARACTERISTICS OF KELP BACTERIAL ISOLATES (Cont)

Isolate[c]	Initial Isolation Method/Source[a]	Appearance of Growth[b]	Cell Morphology	Observed Motility	Gram Reaction	Growth at 4°C Within 8 Days	Growth at 35°C Within 24 Hrs.
V16	B	S	Oval rods, pleomorphism	+	-	-	+
V17	B	C	Small rods	+	-	-	+
V18	B	S	Oval rods, pleomorphism	+	-	-	+
V19	B	C	Pleomorphic sacks, blobs, ovals, circles	+	-	-	+
V20	B	C	Pleomorphic sacks, blobs, ovals, circles	+	-	-	+
V21	B	S	Oval rods, pleomorphism	+	-	-	+
V22	D	C	Cocci or coccobacilli	+	-	-	+
V24	D	C	Short to medium rods, pleomorphism	-	-	+	-
V25	D	C	Small curved rods	+	-	+	-
C1	A	C	Medium to large rods	+	-	+	-
C2	A	C	Medium to large rods	+	-	+	-
C3	A	C	Medium rods	+	-	-	+
C4	B	S	Oval rods, pleomorphism	+	-	-	+
C5	C	C	Short rods	+	-	-	+
C6	D	C	Short to medium rods, pleomorphism	-	-	+	-

TABLE 5.1-4. CHARACTERISTICS OF KELP BACTERIAL ISOLATES (Cont)

Isolate[c]	Initial Isolation Method/Source[a]	Appearance of Growth[b]	Cell Morphology	Observed Motility	Gram Reaction	Growth at 4°C Within 8 Days	Growth at 35°C Within 24 Hrs.
C7	D	C	Short to medium rods, pleomorphism	-	-	+	-
C9	A	C,Y,V	Short to medium, thin rods	-	-	+	-
C10	A	C	Cocci or coccobacilli	+	+	+	+
C11	A	C,sV	Medium rods	+	-	+	-
C12	B	C	Short rods or coccobacilli	+	-	+	+
C13	B	C	Short to medium, curved rods, pleomorphism	+	-	-	-
C14	B	S	Oval rods, pleomorphism	+	-	-	+
C15	A	C,Y	Short to medium rods	+	-	+	-
C16	E	C,sV	Medium rods	+	-	+	-
C17	F	S	Oval rods, pleomorphism	+	-	-	+
C18	F	S	Oval rods, pleomorphism	+	-	-	+

[a] See isolation methods section for details.

[b] S, spreading growth (growth occurs as a mass with motile veils emanating from it); C, colonial growth; Y, yellow pigment; V, viscous growth; sV, slightly viscous growth mainly observed in older cultures. Except for the yellow-pigmented strains, the color of growth of the other isolates ranged from almost clear to various shades of gray and/or white. Except for the one consistently viscous strain,C9, the growth consistency of the other isolates was soft or butyrous.

[c] Isolates V23 and C8 failed to grow on initial transfers after isolation and could not be recovered.

Although the 41 bacterial isolates have been divided into eight groups, there appears to be about 20 different types of bacteria represented in the collection. Some characteristics of the isolates have been determined, but obviously additional study would be required in order to link any of the isolates to the cause of "shot-hole" disease.

One such study would be exposure of healthy kelp plants to one or more bacterial isolates under laboratory-controlled, kelp growth conditions similar to those which occurred in the hemidome (i.e. elevated temperature and nitrogen levels) with appropriate controls. At present, however, it would be difficult to make a single choice of the many bacterial types available for inclusion in this type of study.

Another study which would be very useful is an analysis of the "normal" bacterial flora of healthy kelp plants. Only two isolates (both the same) were obtained from healthy kelp, but not much work was done in this area. It is expected that a variety of bacterial types would also be found on healthy kelp. From a comparison of the bacterial floras of both healthy and diseased kelp, the choice of potential pathogens would be narrowed. However, under opportunistic conditions, even a member of the "normal" flora of a healthy organism can cause a disease.

5.1.3.2 Grouping of Kelp Isolates

The groups are based on growth appearance, gram reaction, growth at $4^{o}C$ and $35^{o}C$, and motility. The isolates within each group are often different except for the above unifying characteristics. In the cases where intragroup similarities do exist, parentheses are used to indicate this.

Group I - Spreading Growth - 13 Isolates

Isolates (V1, V3, V11, V13, V14, V15, V16, V18, V21, C4, C14, C17, C18)

Note: All of the spreading isolates appear to be similar except for occasional, minor differences. All are motile, grow at $35^{o}C$ within 24 hours, fail to grow at $4^{o}C$, and are gram-negative.

Group II - Colonial Growth - 28 Isolates

a. Gram-positive - 1 Isolate

Isolate C10 - motile, grows at $4^{o}C$ within 8 days, and at $35^{o}C$ within 24 hours.

b. Gram-negative - 27 Isolates

1. Growth at 4°C, within 8 days - 15 Isolates

(a) Growth at 35°C within 24 hours - 2 Isolates

(1) Motile - Isolates V12, C12

(2) Non-Motile - None

(b) No growth at 35°C within 24 hours - 13 Isolates

(1) Motile - Isolates V2, V25, (C1,C2), C11,C15,C16

(2) Non-Motile - Isolates C9, (V6, V9, V24, C6, C7)

2. No growth at 4°C within 8 days - 12 Isolates

(a) Growth at 35°C within 24 hours - 7 Isolates

(1) Motile - Isolates V10, V17, V22, (V19, V20), (C3,C5)

(2) Non-Motile - None

(b) No growth at 35°C within 24 hours - 5 Isolates

(1) Motile - Isolates C13, (V4, V5)

(2) Non-Motile - Isolates (V7,V8)

5.1.3.3 ATP Analysis of Bacteria/Biological Populations in and around Big Fisherman's Cove

Background - The ubiquity and functional significance of Adenosine Triphosphate (ATP) in metabolism allows its assay to be an excellent monitor of the amount of biologically active material within a given specimen. Because it was established that the firefly/Luciferase reaction - where light is produced by an enzymatic reaction - is specific for ATP, many investigators use this reaction as a time saving indicator of the amount of bacteria or biological mass present.

Test Procedure - Water samples were taken daily at the following three locations in and around Big Fisherman's Cove, Catalina Island during the time span August 4 - August 11: (1) Inside the hemidome at the depth of approximately one foot; (2) shoreside of the hemidome, approximately 10 feet inshore; (3) at inlet point near the mouth of the Cove. The samples were transferred immediately to the laboratory, filtered through 0.22 millipore filters to remove seawater, and assayed for Adenosine Triphosphate.

Results - Numbers in Table 5.1-5 represent nanograms of Adenosine Triphosphate per liter of seawater as recorded on a LKB - Wallac Luminometer 1250. Early attempts to corrolate ATP with number of bacteria (the ATP content of an average bacterium is about 2.5×10^{-10} g per organism) were discarded when microscopic examination showed the presence in the samples of equally large quantities of non-bacterial organisms.

What the numbers clearly show, however, is that there is a large difference in ATP levels within the secluded hemidome and restricted cove as compared to Intake Point where fresh seawater is constantly cleansing the natural kelp beds, and that these differences reflect the relatively high nutrient levels in these environments.

5.1.3.4 General Observations

- "Shot-holes" are generally well developed, regularly shaped lesions ranging to no more than 5-6 mm in diameter. Microscopically, there does not appear to be much tissue damage beyond the edge of the hole, as if they had stopped enlarging (healed ?). In some ways, the holes are reminiscent of viral lesions in terrestrial plants.

- Microscopically, no evidence of fungal hyphae was noted nor did there appear to be other flora or fauna directly associated with the holes (i.e. epiphytes).

- When cut tissue was placed on or in agar plates and observed after incubation, a large amount of bacterial growth was associated with cut edges, but little or none (in some cases) was associated with the "holes". Of course, this may reflect the media/conditions employed.

- Upon incubation of tissues, further decay or the appearance of new holes was not evident.

5.1.3.5 Summary and Recommendations

A preliminary study of bacterial species associated with Macrocystis tissue displaying "shot-hole" disease symptoms has resulted in the isolation of a total of 41 bacterial cultures. Although these cultures can be divided into 8 groups, there appears to be about 20 different types of bacteria represented by this collection. While some characteristics of these isolates have been determined, it is not possible at this stage to show any cause/effect relationship to "shot-hole" disease nor to determine if these are different from those found associated with "healthy" tissues. In fact, it is entirely feasible that this disease is not of bacterial origin, but rather viral in nature or even an auto-response to the adverse environmental conditions. The isolates do provide, however, a catalogue

TABLE 5.1-5. ATP (NANOGRAMS/LITER)

	Date 8/4	8/5	8/6	8/9	8/10	8/11
Hemidome	30	16	20	28	20	22
Nearshore	19	15	19	17	17	18
Intake Pt.	5	5	5	3	2	5

of strains for future reference and possible re-infection studies, the latter being an essential task in defining this kelp abnormality.

On the basis of the destructive nature of this syndrome on Macrocystis and its subsequent effect on yield and probably gasification, it is highly recommended that an effort be undertaken to reproduce the disease in the laboratory where it can be studied more closely. The a priori assumption that this is a result of the imposition of an adverse (or unusual) growth condition should be verified. Along these lines then, several approaches are suggested.

- Imposition of environmental stress conditions without deliberate attempts to add a causative agent(s). This means growing kelp tissues under conditions of high temperatures and high nutrients. If "shot-hole" disease occurs, this becomes an excellent model with which to study cause/effect relationships.

- The transmissible nature of the disease could be studied by challenging "healthy" tissues with extracts from "diseased" tissues. Extracts here are meant to include ground tissues as well as filtered (i.e. 022 μ) extracts to separate bacterial/fungal attack from viral induced effects.

There are, of course, several other areas which should be pursued especially now that intensive farming of a new crop is envisioned.

- A definition of the "normal" microbial associations should be undertaken. This should include, yeast, fungi as well as viruses. What has been done in the past in this area is extremely limited.

- A better knowledge of "shot-hole" pathology should be attained through a comparative cytological examination of healthy and diseased tissues. This should include histological techniques.

- Other pathological conditions should be explored - (Black Rot, Tumors, Basal Blade Syndrome, etc.) and the "disease state" microbial flora defined.

- An evaluation of kelp's natural defense mechanisms should also be made.

References

Lowry, D.H., N.J. Rosebrough, A.L. Farr and R.J. Randell. 1951. Protein measurement with the Folin phenol reagent. J. Biol. Chem. 193: 265-275.

Weissbach, A. and J. Hurwitz. 1959. The formation of 2-keto-3-deoxyheptanoic acid in extracts of Escherichia coli. J. Biol. Chem. 234: 705-709.

Dische, Z. and L.B. Shettles. 1948. A specific color reaction of methylpentose and a spectrophotometric micromethod for their determination. J. Biol. Chem. 175: 595-603.

Miller, G.L. 1959. Use of dinitrosalicylic acid reagent for determination of reducing sugars. Anal. Chem. 31: 426-428.

Cameron, M.C., A.G. Ross and E.G.V. Percival. 1948. Methods for the routine estimation of mannitol, alginic acid and combined fucose in seaweeds. J. Soc. Ind. Chem. 67: 161-164.

5.2 CATALINA KELP CULTIVATION BIOLOGY

5.2 CATALINA KELP CULTIVATION BIOLOGY

5.2.1 YIELD AND GROWTH STUDIES AT CATALINA TEST FARM

The Catalina Test Facility (Hemidome) was a floating, flexible structure which was moored in approximately 60 feet of water in Big Fisherman's Cove, Catalina. The dome shaped structure was 50 feet in diameter and 45 feet deep. The Hemidome could accommodate up to 50 adult kelp plants.

As the test plants were isolated from the surrounding environment, this facility could be used for observation of plant response to controlled nutrient environments. Surface water obtained at a depth of 14 feet was pumped through the system. Nitrate and phosphate salts were added to the throughput stream in order to provide a defined nutrient environment.

The objectives of this work included determinations of growth rate, harvestable canopy, frond initiation and photosynthetic rates.

Physiological measurements performed by CIT include determination of phosphorus uptake rates, photosynthetic capacity as a function of tissue age, type and location and observations of relationships between biomass density, depth, organic content, parent frond size and frond initiation rate.

Detailed descriptions of the experimental observations, methodologies and results from the CIT tasks are presented in this section.

5.2.1.1 Environmental Monitoring

The environmental monitoring effort at CIT involved extensive measurements of light intensity, water temperature, dissolved oxygen (DO), pH, dissolved macronutrients, water flow into the Hemidome, studies of the discharged effluent, and routine monitoring of the mechanical condition of the Hemidome. Vertical profiles of light intensity, water temperature, DO, and pH every 3 m from the surface to 12 m depths were taken, usually several times per week, by an activity referred to as "daily monitoring", to distinguish it from another major data-gathering activity, "continuous monitoring". Continuous monitoring was accomplished by fixed sensors located within or next to the Hemidome. Outputs from the sensors were stored on tape by a data logger on the Hemidome. Taped data were transferred to a computer which presented the information as printouts. Parameters measured by the continuous monitoring system included light intensity at half hour intervals, water temperature half-hourly (inflowing and outflowing water as well as bottom water in the Hemidome), and half-hourly DO values (input

pipe and two output ports). Computer processing provided daily integrated values for light and for DO from the continuously monitoring system.

Results from the environmental monitoring program were influenced to some degree by events happening within the Hemidome experiment (Table 5.2-2). For example, depth of the intake pipes was lengthened on August 11, 1982, to provide cooler water to our transplants in the Hemidome. Consequently, characteristics of water entering the Hemidome resembled outside water at 12-13 m depths after August 11, whereas the comparison should be drawn to 3 m depths before that date.

Temperature, DO, and insolation data from the continuous monitoring system have been summarized by citing daily ranges (temperature and insolation) or net daily production (DO) in order to provide an overview of seasonal changes in these parameters (Table 5.2-3 in Appendix A). DO data were not collected after June 20. Installation of two additional outflow ports caused an oscillatory tipping of the Hemidome that exposed the oxygen sensors periodically to bubbles, producing erroneous data.

Light falling on the Hemidome each day was integrated from the half-hourly data sheets by computer (Table 5.2-4 in Appendix A). Light measurements arising from the daily monitoring program have not been included because of the quality of data available from the continuous monitoring system. Illumination readings from daily monitoring are often difficult to interpret due to shading by kelp fronds and canopies. The remaining parameters from the daily monitoring studies are useful because they describe background physiochemical conditions in the control areas and also because they supply valuable information concerning vertical distributions of the characteristics measured.

The temperature ranges from daily monitoring of the Hemidome parameters complement those obtained from our continuous monitoring. Effects on Hemidome water temperatures from extending the lengths of the intake pipes are readily discernable by comparing Hemidome values with surface values from Big Fisherman's Cove (BFC) before and after installation of the pipe extensions on August 11. Values for DO and pH suggested that background levels were usually more important as determinants of conditions within the Hemidome than physiological factors such as photosynthesis of the kelp. Thus, pH readings for all locations during spring and fall rarely exceeded 8.3 whereas during the summer they rarely fell below 8.3. Macronutrient analyses typically yielded low values for background waters, especially the surface and near-surface layers (Table 5.2-5 in Appendix A).

TABLE 5.2-2. MAJOR HEMIDOME EVENTS

Date	Event
Dec '81-Jan '82	Major components of Hemidome installed at Catalina
1/12/82	4 adult Macrocystis transplanted to Hemidome for testing flow characteristics
1/22/82	Input nozzles installed
2/12/82	Daily monitoring initiated
2/23/82	Hemidome discharge monitoring initiated
2/23/82	Studies of Hemidome flow characteristics began
Mar '82	Juvenile Macrocystis appeared, Hemidome intake pipe
4/6/82	Continuously monitoring record began
4/15/82	First Macrocystis yield study began, transplanting completed
May '82	Damage from disease in basal regions of transplants becoming significant
6/14-14/82	Transplants harvested
June '82	2 additional outlet ports installed, Senorita fish introduced to control encrustations on kelp blades
6/24/82	Transplants removed from Hemidome and discarded
7/7/82	Next set of transplants installed in Hemidome
7/20/82	Extensive diseases noted on bases of some plants
7/26/82	GE microbiological study initiated
8/11/82	Depth of intake lowered from 3 m to 13 m
9/20/82	Depth of thermocline descended significantly
10/27/82	Large tear in Hemidome bag discovered
10/29/82	Bag removed for repairs, most of transplants discarded
12/7/82	Bag repairs completed and bag reinstalled

Values from Hemidome waters generally correlated with the somewhat complex schedules of fertilizing employed (see below). These environmental data will be presented during discussions that follow in the section regarding Hemidome Operations.

Studies of the discharged Hemidome effluent included 12 intensive surveys that attempted to detect diluted effluent at selected locations and monthly water collections from 19 m depths over the discharge diffusers for analyses of oil and grease, turbidity, settleable solids, pH, and macronutrients. The 12 intensive surveys, using fluorescent dye, or added nutrients, attempt to detect discharged effluent and were conducted on February 23 and 26; March 9, 11, 19, 22, and 25; May 6 and 13; June 3; and July 15 and 29. Diluted effluent may have been detected on two occasions (4 ppb at 15 m depth at Bird Rock on 2/26/82 and 3 ppb at 15 m depth at Isthmus Reef on 2/23/82), but it is more likely that these values arose from unfamiliarity with, or incorrect usage, of equipment during these two first surveys.

Effluent from the discharge pipe of the Hemidome facility sometimes reached depths less than 18 m, at least at two of the four areas of sensitivity (Bird Rock and Isthmus Reef). Transport of the effluent to these sites was not simply dependent on tidal currents. Tidal conditions during the studies on February 23 and March 9 were similar; dye was detected at Isthmus Reef on February 23 but not on March 9. Tidal conditions were similar during studies conducted on February 26 and March 11; dye was detected at Bird Rock on February 26 but not on March 11. Transport to shallow depths probably depended on the thermocline depth which is often greater than 18 m (R. Zimmerman, personal communication).

Effluent that reached depths less than 18 m at the areas of sensitivity showed dye concentrations diluted 500-1000X the initial release concentration. Thus, an initial effluent concentration of 15 M NO_3^- would be diluted to 0.02-0.03 M NO_3^- at the areas of sensitivity (potential nutrient-limited macroalgal sites). Such low concentration enhancement would centainly have no measurable effect on macroalgal growth, especially if it occurred infrequently.

5.2.1.2 Hemidome Operations

Two experimental series were attempted within the Hemidome during 1982 (see Table 5.2-2). The first operation began with a set of 51 Macrocystis transplants installed April 12 to April 15. The second experimental series began with a second group of 51 transplants which were moved into the Hemidome from July 1 to July 7. Both experiments included 10 control transplants moored nearby at Intake

Point or within Big Fisherman's Cove (Figure 5.2-14). The test plants in the Hemidome became seriously affected by disease (referred to later as the "shot-hole" disease), leading to lesions and tissue sloughing especially in the lower portions of the frond bundles and the sporophylls, basal meristems, basal branches, and holdfasts. The disease problem was considered to result from encouragement of microorganisms resulting from elevated nutrients and water temperatures as well as from trapping and continual recirculation of sloughed and decaying tissues in the bottom of the bag. The disease effect caused us to discard the first set of transplants after they were harvested June 14-15, hoping that the impact could be reduced by changes in the fertilizing schedule and by extending lengths of the intake pipes so as to draw in cool water from below the thermocline. These changes were believed to produce some benefits, but severe effects from disease still developed.

The primary objective of the Hemidome experimentation was to measure productivity and yield on a group of adult transplants held under carefully controlled and monitored conditions. The primary methodology for assessing productivity was to measure growth rates of various size fronds continuously, as well as changes in frond numbers and frond size distributions. This information was converted to changes in biomass by means of separately-determined frond length to weight relationships. Frond elongation rates tended to be in the middle-to-lower range of what is considered normal, with means from test plants occasionally significantly different from controls during the first experimental series (Table 5.2-6) and usually exceeding controls during the second experimental series (Table 5.2-7). Total frond numbers declined steadily during both experimental series (Table 5.2-8). These reductions resulted from the combined effects of losses of fronds as stipe rot caused severance in the basal branching system and a lack of senile frond replacement by juvenile fronds. A slowdown in production of juvenile fronds resulted from losses of basal meristems due to tissue sloughing. Analyses of N-contents of kelp blades indicated that plants in the Hemidome had adequate supplies of macronutrients at all times and maintained relatively low concentrations of mannitol (Tables 5.2-9 and 5.2-10). By contrast, control plants often displayed N-contents suggesting growth limitation by this element and elevated mannitol levels.

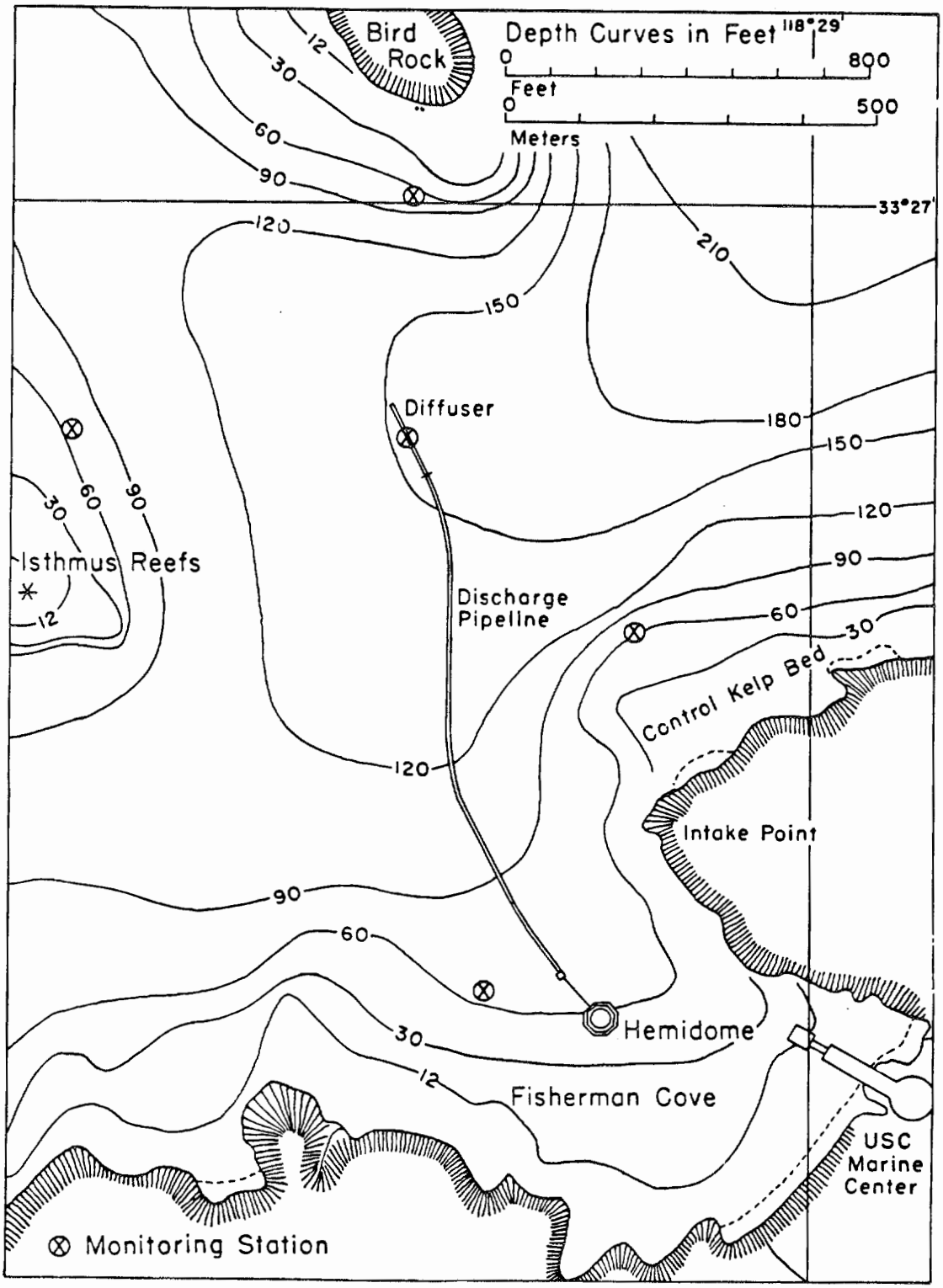


Figure 5.2-14. Chart of the Eastern Portion of the Catalina Isthmus Region, Showing Relation of the Hemidome Installation to the Surrounding Geographical Locations Mentioned in the Text. The Control Kelp Bed on the North Side of Intake Point was Utilized for the First Experimental Series

TABLE 5.2-6. MEAN STANDARD GROWTH RATES (PERCENT DAILY ELONGATION NORMALIZED TO A ONE m FROND LENGTH) AND ASSOCIATED PARAMETERS DETERMINED FOR THE INDICATED TIME SPANS AMONG MACROCYSTIS TRANSPLANTS IN THE HEMIDOME AND THE NEARBY CONTROLS. $\bar{G}$ = MEAN STANDARD GROWTH RATE, n = NO. OF FRONDS IN SAMPLE, σ = STANDARD DEVIATION, UCI = UPPER 95% CONFIDENCE INTERVAL, LCI = LOWER 95% CONFIDENCE INTERVAL, ESG = NO. OF ABNORMALLY SLOW-GROWING FRONDS (NOT EXCLUDED IN COMPUTING $\bar{G}$). ALL DATES WERE 1982. DATA REPRESENT THE FIRST EXPERIMENTAL SERIES

	Measurement period											
Parameter	Feb 25 Mar 8	Mar 23-29	Mar 30 Apr 5	Apr 20-26	Apr 28 May 3	May 4-10	May 11-17	May 18-24	May 25 June 1	June 2-7	June 7-17	June 17-23
	— Pretransplanting —			Hemidome plants								
$\bar{G}$	6.9	6.6	6.9	6.7	7.1	6.0	6.5	7.0	6.1	6.3	6.7	7.1
n	15	26	27	50	30	30	51	23	44	27	19	26
σ	0.8	0.8	1.3	1.4	1.4	0.9	1.7	0.9	1.6	0.9	1.0	1.5
UCI	7.3	6.9	7.4	7.1	7.6	6.3	6.9	7.4	6.6	6.7	7.2	7.7
LCI	6.5	6.3	6.4	6.3	6.6	5.7	6.1	6.6	5.6	5.9	6.2	6.5
ESG	0	0	0	2	0	1	3	0	5	0	0	1

	Measurement period								
Parameter	Apr 21-27	Apr 28 May 3	May 4-10	May 10-17	May 17-24	May 24 June 1	June 1-7	June 7-17	June 17-23
	Control plants								
$\bar{G}$	6.2	5.7	6.1	5.9	5.6	7.4	6.2	7.4	8.7
n	28	29	30	30	30	28	29	17	21
σ	1.0	1.0	1.3	0.8	0.8	1.6	1.2	1.1	1.3
UCI	6.6	6.1	6.6	6.2	5.9	8.0	6.7	8.0	9.3
LCI	5.8	5.3	5.6	5.6	5.3	6.8	5.7	6.8	8.1
ESG	0	1	1	0	1	1	0	0	0

TABLE 5.2-7. MEAN STANDARD GROWTH RATES (PERCENT DAILY ELONGATION NORMALIZED TO A ONE m FROND LENGTH) AND ASSOCIATED PARAMETERS DETERMINED FOR THE INDICATED TIME SPANS AMONG MACROCYSTIS TRANSPLANTS IN THE HEMIDOME AND THE NEARBY CONTROLS. $\overline{G}$ = MEAN STANDARD GROWTH RATE, n = NO. OF FRONDS IN SAMPLE, σ = STANDARD DEVIATION, UCI = UPPER 95% CONFIDENCE INTERVAL, LCI = LOWER 95% CONFIDENCE INTERVAL, ESG = NO. OF ABNORMALLY SLOW-GROWING FRONDS (NOT EXCLUDED IN COMPUTING $\overline{G}$). ALL DATES WERE 1982. DATA REPRESENT THE SECOND EXPERIMENTAL SERIES

	Measurement period														
Parameter	July 12-19	July 20-26	July 27 Aug 2	Aug 3-9	Aug 10-16	Aug 17-23	Aug 24-30	Aug 31 Sept 7	Sept 8-13	Sept 14-20	Sept 20-27	Sept 28 Oct 4	Oct 4-11	Oct 12-18	Oct 18-25
Hemidome plants															
$\overline{G}$	5.2	6.2	4.3	4.3	5.6	6.2	5.7	5.7	6.1	5.9	6.0	4.5	5.0	5.0	5.0
n	30	30	29	26	29	50	29	30	27	33	28	26	26	26	25
σ	0.84	0.47	1.54	1.27	1.01	1.41	1.28	2.25	1.52	1.54	1.26	1.57	0.99	2.02	1.26
UCI	5.5	6.4	5.8	4.8	6.0	6.5	6.1	6.5	6.7	6.8	6.5	5.1	5.4	5.8	5.5
LCI	4.9	6.0	2.8	3.8	5.2	5.9	5.2	4.9	5.5	5.0	5.5	3.9	4.6	4.2	4.5
ESG	2	0	8	6	2	0	2	3	3	3	1	4	2	4	4
Control plants															
$\overline{G}$	4.0	4.2	3.2	3.2	2.8	2.7	3.3	2.1	2.7	3.6	3.0	2.7	1.8	2.7	1.1
n	30	33	30	33	33	33	28	24	22	29	25	19	21	23	17
σ	1.27	0.83	1.32	1.25	1.41	1.51	1.20	1.63	1.25	1.13	1.35	1.04	1.42	1.09	1.10
UCI	4.5	4.5	3.7	3.6	3.3	3.2	3.8	2.8	3.3	4.0	3.6	3.2	2.4	3.2	1.7
LCI	3.5	3.9	2.7	2.8	2.3	2.2	2.8	1.4	2.1	3.2	2.4	2.2	1.2	2.2	0.5
ESG	12	10	19	25	26	27	20	23	21	17	20	18	14	15	17

TABLE 5.2-8. TOTAL STIPES DISPLAYED BY 51 MACROCYSTIS TRANSPLANTS IN THE HEMIDOME AT THE INDICATED DATES AND BY 10 CONTROL PLANTS NEARBY AT INTAKE POINT OR IN BIG FISHERMAN COVE. ALL DATES ARE 1982.

Date	4/12-14	5/13	6/8	7/9	7/22	8/5	8/19	9/2	9/16	9/30	10/14
	First experimental series			Second experimental series							
Hemi-dome fronds	1655	1476	1170	1815	1765	1564	1366	1312	1110	928*	810**
Control fronds	385	360	381	351	328	336	359	285	315	258	220

*One plant lost (broken holdfast), one plant dead.

**Two plants lost, two plants dead.

TABLE 5.2-9. ANALYSES OF TISSUE N (PERCENT DRY WT) DURING 1982 AMONG MACROCYSTIS BLADES IN THE HEMIDOME AND CONTROL POPULATIONS. VALUES REPRESENT MEANS AND STANDARD DEVIATIONS, FROM ANALYSES OF 5-6 BLADES (HEMIDOME) OR 2-3 BLADES (CONTROLS) EXCEPT WHEN ONLY A SINGLE BLADE WAS AVAILABLE (NO STANDARD DEVIATION GIVEN). FREQUENCY OF PULSE FERTILIZING IN THE HEMIDOME WAS REDUCED AFTER SEPTEMBER 21, 1982

		% N content				% N content			
Date	Blade type:	Canopy	Subcanopy	Basal	Juvenile frond	Canopy	Subcanopy	Basal	Juvenile frond
		FIRST EXPERIMENTAL SERIES							
		Hemidome				Control			
April 8		1.2±0.2	1.4±0.2	1.4±0.15	2.0±0.2	--	--	--	--
April 26		--	1.8±0.5	1.4±0.2	2.1±0.3	--	1.9±0.3	1.5±0.05	2.3±0.1
May 11		2.9±0.4	2.5±0.5	1.7±0.1	3.2±0.6	1.1±0.03	1.1±0.1	1.2±0.1	2.0±0.7
May 25		3.3±0.7	3.3±0.4	2.1±0.1	4.0±0.6	0.7±0.1	1.0±0.1	1.1±0.1	1.3±0.2
June 8		1.9±0.5	2.6±0.3	1.8±0.2	3.0±0.9	0.7±0.1	0.8±0.2	1.0±0.1	1.3±0.4
June 14-15		1.9±0.4	--	--	--	0.8±0.04	--	--	--
June 21		--	2.3±0.3*	2.1±0.4*	2.4±0.3	--	0.6±0.1*	1.0±0.1*	1.4±0.4

*Samples from fronds that had been harvested.

TABLE 5.2-9. ANALYSES OF TISSUE N (PERCENT DRY WT) DURING 1982 AMONG MACROCYSTIS BLADES IN THE HEMIDOME AND CONTROL POPULATIONS. VALUES REPRESENT MEANS AND STANDARD DEVIATIONS, FROM ANALYSES OF 5-6 BLADES (HEMIDOME) OR 2-3 BLADES (CONTROLS) EXCEPT WHEN ONLY A SINGLE BLADE WAS AVAILABLE (NO STANDARD DEVIATION GIVEN). FREQUENCY OF PULSE FERTILIZING IN THE HEMIDOME WAS REDUCED AFTER SEPTEMBER 21, 1982 (Cont)

Date	Blade type:	% N content				% N content			
		Canopy	Subcanopy	Basal	Juvenile frond	Canopy	Subcanopy	Basal	Juvenile frond
					SECOND EXPERIMENTAL SERIES				
			Hemidome				Control		
July 13		--	1.92±0.32*	1.82±0.23*	1.68±0.16	--	1.82±0.12*	1.39±0.25*	1.40±0.03
July 27		1.34±0.27	1.92±0.14	1.83±0.18	1.97±0.16	0.83±0.17	1.33±0.26	1.18±0.24	1.23±0.12
Aug 10		2.07±0.40	1.80±0.31	1.75±0.25	2.14±0.43	0.48±0.07	0.72±0.06	0.67±0.08	0.73±0.14
Aug 24		2.80±0.29	2.43±0.46	2.37±0.41	2.98±0.60	0.30±0.12	0.60±0.08	0.57	0.79±0.19
Sept 8		3.05±0.44	2.77±0.28	--	3.31±0.60	0.41±0.09	0.48±0.19	0.45	0.71±0.20
Sept 21		3.46±0.25	3.0±0.49	--	3.14±0.46	--	0.53±0.09	--	0.58±0.10
Oct 5		2.01±0.39	2.23±0.34	--	2.50±0.57	0.73±0.24	0.68±0.05	--	0.75±0.28
Oct 20		1.80±0.14	2.08±0.14	--	2.44±0.41	--	--	--	0.71±0.30

*Represents blades sampled from fronds that had been harvested.

TABLE 5.2-10. CHANGES IN MANNITOL CONTENT (PERCENT DRY WT) DURING 1982 AMONG MACROCYSTIS BLADES IN THE HEMIDOME AND CONTROL POPULATIONS. VALUES REPRESENT MEANS AND STANDARD DEVIATIONS, FROM ANALYSES OF 5-6 BLADES (HEMIDOME) OR 2-3 BLADES (CONTROLS) EXCEPT WHEN ONLY A SINGLE BLADE WAS AVAILABLE (NO STANDARD DEVIATION GIVEN).

Date	Blade type:	% Mannitol content				% Mannitol content			
		Canopy	Subcanopy	Basal	Juvenile frond	Canopy	Subcanopy	Basal	Juvenile frond
		FIRST EXPERIMENTAL SERIES							
		Hemidome				Control			
April 8		15.2±6.9	6.9±3.1	6.3±3.2	3.3±0.7	--	--	--	--
April 26		--	4.6±2.1	4.2±1.4	3.8±0.7	--	6.7±5.5	8.4±6.9	3.4±0.2
May 11		11.2±6.5	3.1±0.8	2.3±0.5	2.4±0.1	12.1±2.1	10.4±0.7	4.2±0.5	4.2±0.7
May 25		8.0±6.8	5.7±4.8	2.7±0.6	2.7±0.8	7.4±3.6	14.4±5.6	6.4±0.6	4.0±0.8
June 8		18.2±9.4	9.4±4.6	5.5±1.4	4.4±1.2	27.9±5.0	16.2±6.1	7.3±3.0	5.0±1.4
June 14-15		14.1±8.2	--	--	--	26.5±5.4	--	--	--
June 21		--	4.0±1.4*	5.0±3.3*	2.6±0.3	--	26.2±3.6*	5.2±0.1*	3.1±1.2

*Samples from fronds that had been harvested.

TABLE 5.2-10. CHANGES IN MANNITOL CONTENT (PERCENT DRY WT) DURING 1982 AMONG MACROCYSTIS BLADES IN THE HEMIDOME AND CONTROL POPULATIONS. VALUES REPRESENT MEANS AND STANDARD DEVIATIONS, FROM ANALYSES OF 5-6 BLADES (HEMIDOME) OR 2-3 BLADES (CONTROLS) EXCEPT WHEN ONLY A SINGLE BLADE WAS AVAILABLE (NO STANDARD DEVIATION GIVEN). (Cont)

Date	Blade type:	% Mannitol content				% Mannitol content			
		Canopy	Subcanopy	Basal	Juvenile frond	Canopy	Subcanopy	Basal	Juvenile frond
		SECOND EXPERIMENTAL SERIES							
		Hemidome				Control			
July 13		--	8.4±2.9*	4.6±1.1*	7.9±2.6	--	12.9±5.5*	8.8±4.6*	18.3±2.4
July 27	Uncut fronds	20.1±9.3	7.5±4.0	4.3±0.7	4.6±1.3	31.6±8.3	27.5±6.3	16.9±4.6	24.3±2.1
	Harvested fronds	--	5.5±1.6	3.5±0.6	--	--	17.9±8.8	14.0±10.7	--
Aug 10		16.75±7.4	6.1±3.7	3.7±0.6	5.0±2.1	30.7±0.3	29.8±19.2	22.3±7.2	37.5±7.2
Aug 24		11.75±4.2	7.8±6.5	4.7±1.9	10.4±5.5	35.9±6.4	33.6±7.5	30.6	32.2±5.3
Sept 8		6.8±5.4	2.7±1.0	--	2.5±0.4	36.4±5.5	25.1±15.7	22.0	35.8±6.0
Sept 21		8.8±2.7	5.0±0.9	--	4.8±1.8	--	32.6±1.3	--	34.6±2.6

*Represents blades sampled from fronds that had been harvested.

During the first experimental series, 41 kelp plants were transplanted from nearby Isthmus Reef into the Hemidome. The remaining 10 were collected from Laguna Beach on the mainland (ca. 60 km from Big Fisherman's Cove). Observations of tissue sloughing and frond growth rates indicated that the mainland plants might have fared slightly better than their Catalina counterparts. In planning for the second experimental series, it was decided to include a higher proportion of plants from the mainland, hoping thereby to reduce susceptibility to the disease problem. Thirty-one adult Macrocystis were collected from near Bunker Point, Palos Verdes, as a part of the second transplanting. Palos Verdes is a strong upwelling area, and Bunker Point lies downstream from a major sewage discharge at Palos Verdes. It was conjectured that these plants might have developed resistance to any microorganisms whose growth is stimulated by high levels of macronutrients.The second transplanting also included 10 plants from Laguna Beach on the mainland and 10 from Isthmus Reef at Catalina Island. The 10 control plants for the first experimental series had been situated in a natural kelp bed at Intake Point, a fairly exposed location. Strong currents here periodically pulled canopies of the control and the natural plants well beneath the surface. Thus, it appeared that these controls were experiencing an environment fundamentally different from conditions in the Hemidome. A nearby protected site would be more appropriate. Thus, the northeastern border of Big Fisherman's Cove was chosen as a suitable control site for the second experimental series. A small fringing kelp bed occurred on the steeply descending rocky wall of the cover here. Ten control plants from Isthmus Reef were moored along the outside edge of this natural bed in the cove. Water depth was about 18 m at this point. The holdfasts of the controls were to be at nine m depths (the depth of holdfasts in the Hemidome). Consequently,the controls were moored on buoys tethered about 9 m above the bottom. A further row of plants was placed offshore from the controls so that the control plants would not constitute the edge of the overall kelp stand at the site.

Water temperatures inside the Hemidome were approximately 18^{o}C at the beginning of the second experimental series, rising to 19^{o}C during the second week of July and extending up beyond 20^{o}C during the third week. Observations on natural kelp beds reported in the literature indicated that 20^{o}C was about the maximal level tolerated by kelp canopies. Water temperatures rose to 21^{o}C during the last week in July and exceeded 22^{o}C for short periods during early August. Extensions of the intake pipes on August 11 reduced Hemdidome water temperatures one-to-two degrees below ambient.

Fertilizing methodology was also altered during the second experimental series to reduce the likelihood of stimulating growth by pathogenic microorganisms from artificially high levels of nutrients. The objective of fertilizing during the first experimental series had been to create continuous concentrations of 15 μM nitrate and 1 μM phosphate in Hemidome waters. Fertilizing was discontinued from May 25 to June 9 in order to determine possibilities for ameliorating the effects of the disease problem. It appeared subjectively that progression of the disease may have been reduced by stopping fertilization. Hence, for the second experimental series, two alternate fertilizing schemes were tested: supplying macronutrients continuously at low concentrations (objective - 3 μM nitrate, 0.3 μM phosphate), and pulsing periodically at high concentrations (15 μM nitrate, 1 μM phosphate). The latter method appeared to be the most successful. N-contents of the test plants rose steadily throughout the summer (see Table 5.2-9). Tissue-P paralleled tissue-N fairly closely.

Transplants were examined in the Hemidome on July 20, and early evidences of disease and deterioration occurring among basal blades of many plants were noted. Weekly studies were then initiated to document the progression of symptoms in detail and to detect whether attempted palliative measures were yielding any results. Drs. John Forro and Anthony Cacciapuoti, General Electric Company microbiologists arrived July 26 to assist in defining any causative organisms that might be responsible for the observed lesions developing among the kelp tissues. They succeeded in obtaining numerous isolates from kelp lesions but were unable to determine which organisms (if any) might be principal plant pathogens.

Primary symptoms observed in the Hemidome transplants appeared in greatest intensity within the lower two-to-three meters of the plants - from the holdfast upward well into the stipe bundles. Lesions appeared in blade tissues within this lower region. Tissue coloration changed in some cases. Sizes and shapes of lesions varied from round holes 1 or 2 mm in diameter to irregularly-shaped areas of discoloration or tissue loss several cm across. The small roundish hole gave the appearance of penetration by a "BB" or shot. When many holes occurred together, the condition became known as "shot-hole disease" or SHD. SHD became prevalent during the first experimental series in May-June. SHD also occurred during the second experimental series but did not predominate as it had previously. As lesions proliferated, tissues weakened and fell off, adding to a large accumulation of litter near the bottom of the bag. Water circulation within the bag kept much of the small algal fragments in suspension, particularly in the

region of the plant bases. Prevalence of disease symptoms in the basal portions of the plants (contrasting with the normal pattern of summertime deterioration among adult Macrocystis which occurs in the canopy and other near-surface portions of plants) suggested that the circulating drift fragments may have served as an inoculum enhancing infection of the basal tissues of transplants by pathogens.

Stipe and hapteral tissues also began displaying lesions and discolored patches. These afflictions frequently led to severance of the stipe or breaking off of holdfast sections, allowing fronds to drift up to the surface where they were collected and discarded. This process was partially responsible for declines in frond numbers (see Table 5.2-8).

Grazing and encrusting organisms also caused difficulties. A small amphipod, Jassa falcata, constructed arenaceous tubes that covered considerable portions of blade surfaces and may have created focal points for colonization by microscopic pathogens. Encrustations by Jassa are rarely seen in natural kelp beds. It was reasoned that some predator, possibly a fish species, might control Jassa in nature. A small fish, the senorita (Oxyjulis californica) was introduced into the Hemidome in June to determine if it could control Jassa. Some senoritas were noted picking at Jassa tubes, but they were unable to eliminate the kelp encrustation in the Hemidome altogether.

Small urchins were apparently recruited from the plankton onto holdfasts in the Hemidome and caused some grazing damage. Most of these were removed before their feeding activities constituted a serious problem. Dove snails (Mitrella carinata) also recruited onto many of the fronds. Although individual snails are only a few mm long as adults, they can cause substantial grazing damage when a large population developes. Snail grazing was believed to be a significant factor in tissue losses incurred during the second experimental series.

Sedimentation was noted on a large proportion of the blade population at all times (subcanopy to basal blades, rarely in the canopy). This may have arisen from a lack of scrubbing action by wave surge inside the Hemidome. Sedimentation may have encouraged development of pathogens underneath.

In contrast to extensive tissue losses incurred in basal portions of the test plants, canopy tissues fared well and suffered primarily from normal senescent processes. Fairly dense canopies developed during both experimental series. Canopy thinning occurred during September and October 1982, probably because senescing fronds were not adequately replaced by developing juvenile fronds. The

juveniles were being destroyed as a result of the disease processes occurring in the basal regions.

The unusual disease problem impacted the productivity and yield determinations during the two experimental series and forced us to abandon hope of obtaining any valid data for these parameters. Several indications and conclusions emerged which provide a basis for further investigation if it should ever become desirable.

No basis was found for concluding that the disease problem arose from a unique causative agent possibly associated with the special circumstances under which the test plants were being cultured. All the various types of lesions, discolorations, and other afflictions noted among the test plants were also observed in natural kelp beds at Catalina and the mainland during summer 1982.

The unique aspect of our disease problem was its prevalence among the lower portions of our test plants. Similar disease symptoms, when they occur in natural kelp beds, tended to focus in the upper portions of plants or were spread throughout the water column.

Warm water temperatures probably enhanced the disease problem. Some test plants improved remarkably immediately after the intake pipes were extended down to 12-13 m depths.

Pulsed nutrient inputs may have been less stimulating to the disease(s) than continuous fertilizing at low concentrations of macronutrients.

Constantly recirculating algal debris may have enhanced the disease(s) in some way.

One final set of observations during the second experimental series is worth mentioning; namely, comparisons between test plants in the Hemidome and the control and naturally attached plants in Big Fisherman's Cove. Test plants in the Hemidome maintained their canopies in fair to good condition throughout the summer and fall 1982. Canopies of the control and naturally attached plants began deteriorating in July and were almost non-existent by early August. Lack of canopy continued for the remainder of August and for the first half of September.

A temperature of 20^{o}C had previously been considered as the uppermost temperature tolerated by adult Macrocystis. Our temperature data indicated that surface temperatures hovered close to or above 20^{o}C through October while

temperature at 12 m depths fell below 19.0°C only for one sampling day, October 10. Thus, the period after September 22 was characterized by an upper layer of water from the surface to at least 12 m depths of almost uniform temperature, usually in the rather narrow range of 19.0°C to 20.5°C. In other words, the thermocline appears to have been situated below the level of the holdfasts of our control transplants in Big Fisherman's Cove. During this period, the lower portions of many of the control plants deteriorated, and quantitative data such as frond counts and growth rates indicated that these plants were stressed (see Table 5.2-6 and Table 5.2-7). Transplants in the Hemidome also showed stress symptoms, but the severity was less than that of the controls and may in part have been caused by an enclosure effect. It is believed that deterioration among our controls was primarily a nutritional problem arising from descent of the thermocline after about September 22 and a lack of upwelling. The stress symptoms observed (tissue paling, sloughing, black rot, lesions, buoyancy loss) mimicked many of the signs commonly noted among deteriorating kelp canopies during warm summers. It is worth noting that commencing about mid-September, the natural kelp bed in Big Fisherman's Cove (beginning about 10 feet inshore from the controls) displayed good canopy formation and a healthy appearance. These healthy plants were attached to the bottom at depths well below those of our controls (i.e., 40-50 feet deep, Figure 5.2-14). There were some naturally attached plants whose holdfasts were at depths comparable to the holdfasts of our controls (i.e., 26 to 30 ft deep). These shallowest natural plants were intermediate in appearance between the deeply-attached natural plants and our controls. Their upper foliage had disappeared so that tops lay about 10 ft below the surface. They displayed pale blades, particularly near their tops. The bases, however, appeared healthy with good coloration and minimal sloughing.

These data suggest that some upwelling occurred during August and early September, benefitting plants in the natural bed, the controls, and the Hemidome. Sometime around September 20, 1982, depth of the thermocline increased so that none of these plant groups received much exposure to nutrient-rich subthermocline water. Surface temperatures in the cove declined slightly after the first week in September to approximately 20°C. The deeply-attached natural plants benefitted considerably from the upwelling in August-September and were able to produce and sustain a canopy from mid-September onwards, aided by the gentle decline in surface temperature. Possibly recycled nutrients in the bottom waters of the bed also contributed to their well-being. This hypothesis is substantiated by the

continuing healthy appearance of the basal portions of the shallowest naturally attached plants. These plants, however, did not benefit as much from the August-September upwelling as the nearby deeply attached plants because of the vertical gradient of nutrients in an upwelling event. Hence, the shallowest plants were not able to form and sustain a canopy. The control plants, some 20 to 30 ft off the bottom, received no benefit from recycled nitrogen in the near-bottom water. Hence, they displayed symptoms of nutritional deficiency throughout their lengths shortly after the thermocline descended around September 20. The Hemidome plants never suffered from nutritional deficiency, and any tissue degradation was presumably caused by enclosure effects and grazing damage. The evidence sustains previous conclusions (based primarily on observational data) that 20°C is tolerated by adult Macrocystis tissues. There is an important caveat, however, which is that plants must be well-nourished to survive in 20°C water.

After the Hemidome bag tore, the loss of head pressure inside the bag prevented the walls from maintaining their inflated configuration. Buoyancy from the transplants and their moorings caused the bottom of the bag to rise so that most of the plant tissues became relocated at or near the water surface. Many blades were pushed out of the water and suffered from desiccation and related exposure damage. It was decided to discard all but ten of the plants, pending repair of the bag and initiation of the next experiment. The ten retained transplants were moored at depths from 9 to 18 m on the umbilical cord bringing electrical power from the shore to the Hemidome. It was desirable to observe whether these plants would change in terms of growth and composition as a result of returning to open water after four months of enclosure. It was also desirable to know if it were possible to set up an experiment duplicating the situation described above where control plants deteriorated, while nearby naturally attached plants survived, presumably due to differences in availability of recycled nitrogen. The ex-Hemidome plants moored at higher levels on the umbilical cord should, like our controls, receive much less recycled N than plants moored close to the bottom. Hopefully, any differences would be reflected in growth rates and tissue composition. This small study lasted from October 29 to December 20, 1982.

All ten plants displayed good coloration when first examined on November 1, 1982. Seven of the ten bore evidences of significant tissue damage from exposure to air

and/or desiccation. One plant (Number 11) had become "decapitated" (all the longer fronds were cut) during removal from the bag. Another (Number 17) lost all but two long fronds and even these were badly damaged. Three plants (Numbers 2, 17, and 24) shed their long fronds over the next two weeks. Lesions and grazing damage present while plants were in the Hemidome were noted subsequently. The grazing by urchins and snails became negligible outside the bag, although a few opaleye perch were noted occasionally munching on blades. The storm that tore the bag in late October also dislodged attached algae throughout the cove. Drifting algal fragments littered the bottom near the Hemidome, and amounts increased as other storms swept through the area, particularly a very violent storm at the end of November. The drift may have stimulated microbial growth near the bottom. Three of the ten test plants were moored close to the bottom (Numbers 11, 15, and 17). These three plants suffered greatly from disease symptoms closely resembling the lesions, etc., noted among plants in the Hemidome, and their appearance deteriorated throughout the seven-week experiment. The remaining seven plants remained healthy but changed in various ways.

Elongation rates among the ex-Hemidome plants were at the low end of the range of normality, and there were always high proportions of ESG (extremely slow growing) fronds within the sample population (Table 5.2-11). Mean growth rates were usually not significantly different, however, from a control population which consisted of plants in the kelp bed along the north-east edge of the cove (see Figure 5.2-15). Examination of the distribution of growth rates in the ex-Hemidome plants showed that individuals moored at depths of 13 m or less, however, rarely yielded growth rates above the ESG category (Table 5.2-12). Most of the non-ESG rates came from the transplants moored between depths of 13 and 16.4 m.

Counts of fronds whose growth increased or decreased or remained unchanged between measurement periods indicated that the latter half of November was a poor growth period, with the great majority of fronds showing declining growth rates (bottom three lines in Table 5.2-12). Early December, however, was a more favorable growth period, with few declining growth rates and a large majority of increasing growths. Declining growth rates were evident in an overwhelming majority of the samples during the final measurement period. Mean growth rates among the naturally attached plants declined significantly during the final measurement period, but otherwise, trended upward throughout the study (see Table 5.2-11). Water temperatures in Big Fisherman's Cove declined from ca. 19^{o}C to

TABLE 5.2-11. MEAN STANDARD GROWTH RATES, $\overline{G}$ (PERCENT DAILY ELONGATION NORMALIZED TO A ONE-METER FROND LENGTH), FROM TWO GROUPS OF ADULT MACROCYSTIS PLANTS AS INDICATED. ESG FRONDS WERE OMITTED IN COMPUTING MEANS. ALL DATES ARE 1982. N = NO. OF FRONDS USED IN COMPUTING MEAN G, σ = STANDARD DEVIATION, UCI = UPPER 95% CONFIDENCE INTERVAL, LCI = LOWER CONFIDENCE INTERVAL

	Measurement period					
Parameter	Nov 8-15	Nov 15-22	Nov 22-29	Nov 29-Dec 6	Dec 6-13	Dec 13-20
			Ex-Hemidome plants			
$\overline{G}$	5.8	5.7	4.6	4.8	5.3	4.6
N	10	10	6	9	10	3
σ	1.03	1.35	0.43	0.61	1.00	0.62
UCI	6.5	6.6	5.1	5.3	6.0	6.1
LCI	5.0	4.7	4.2	4.4	4.6	3.1
No. of ESG	14	14	18	15	12	11
% Growth increasing	--	29	17	83	77	0
			Naturally attached plants			
$\overline{G}$	6.3	6.6	6.6	6.8	7.0	5.6
N	29	27	27	15	15	7
σ	1.27	1.18	0.91	0.56	0.59	0.47
UCI	6.8	7.0	7.0	7.1	7.3	6.0
LCI	5.8	6.1	6.3	6.5	6.6	5.2
No. of ESG	1	0	0	0	0	2

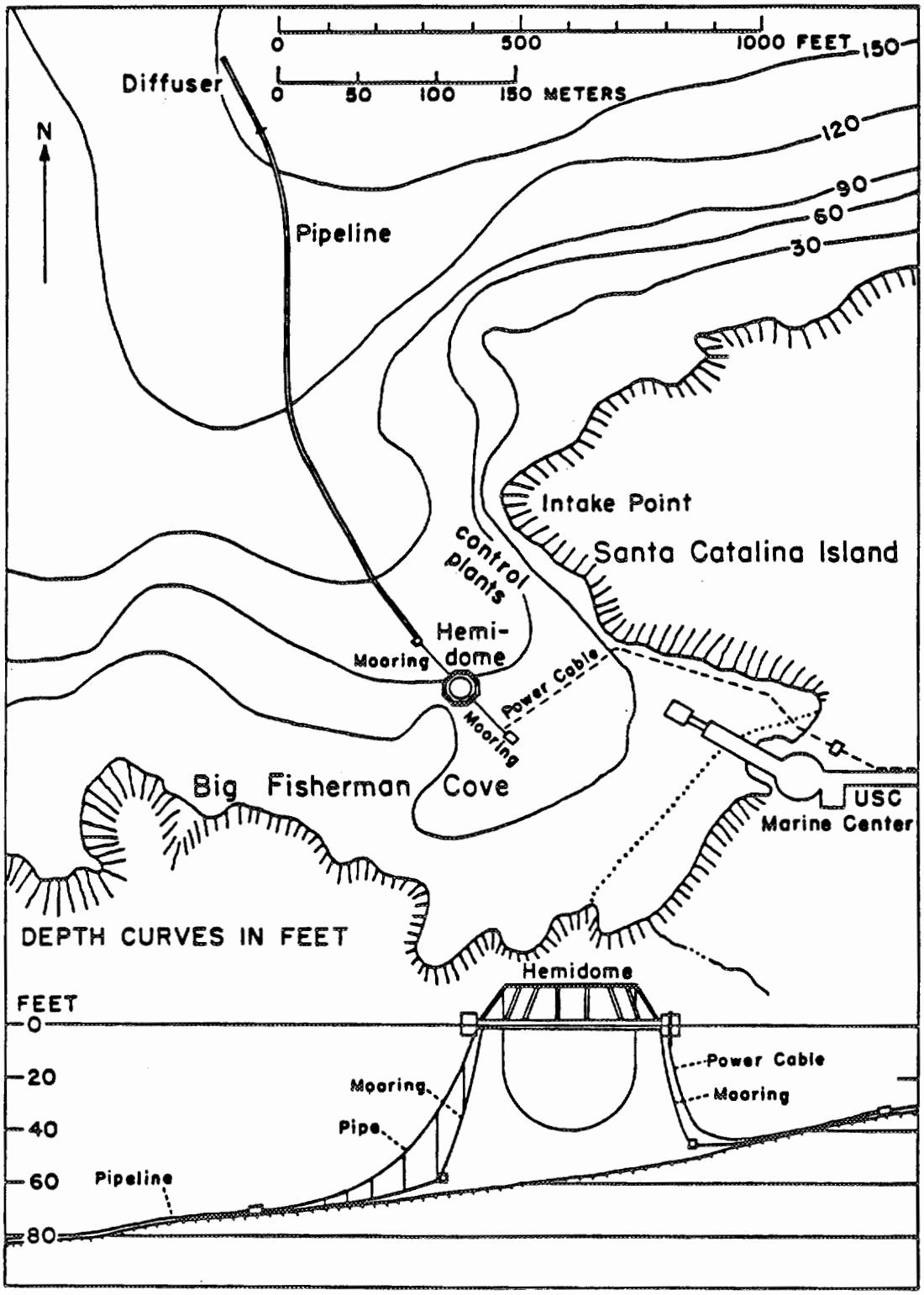


Figure 5.2-15. Chart of Big Fisherman Cove with Details of the Hemidome Installation and (Below) a Cross-sectional View of the Hemidome. Control Plants were those Utilized During the Second Experimental Series

TABLE 5.2-12. STANDARD GROWTH RATES, $\bar{G}$ (PERCENT DAILY ELONGATION NORMALIZED TO A FROND LENGTH OF ONE METER), MEASURED AMONG EIGHT OF THE ADULT *MACROCYSTIS* EX-HEMIDOME TRANSPLANTS MOORED AT THE DEPTHS SHOWN (BOTTOM DEPTH OF 17.7 m). ESG DESIGNATES AN "EXTREMELY SLOW GROWING" FROND, CONSIDERED AS ABNORMAL. DATES ARE 1982.

Plant no.	Holdfast depth, m	Frond no.	Measurement period: Nov 8-15		Nov 15-22		Nov 22-29		Nov 29-Dec 6		Dec 6-13		Dec 13-20	
			ESG	Normal	ESG	Normal	ESG	Normal	ESG	Normal	ESG	Normal	ESG	Normal
2	9.7	1	0		0		0		2.4		0		-	
		12	0.9		0.1		0		1.1		1.1		0	
		28	2.0		0.7		0		0.9		2.1		0	
44	10.1	11	3.8		3.0		3.1			4.1		4.4	3.1	
		2	3.8		2.7		1.5			4.7	2.8		-	
		17	2.7		2.1		2.6		2.8		3.0		2.0	
19	11.6	6	0.4		0		0		0.3		0		0	
		26	2.3		2.2		1.7		2.7		3.2		1.7	
		27	0.5		0		1.7		1.2		1.4		0	
38	12.8	10	3.9			4.5	3.3			4.2		5.1	3.4	
		29	3.0		1.5		2.8		2.1		2.6		1.8	
		30		4.9		4.2	2.9		3.8			4.0	1.1	
39	14.6	8		6.3		6.9		4.4		4.6		5.3		4.1
		19		6.3		6.5		5.0		4.3	3.8		0	
		21		6.9		6.7		4.3		4.9		5.4		4.4
42	14.6	13	3.7			4.1	1.6		2.0		2.7		2.0	
		18		5.9		7.1		4.6		5.4		6.7	0	
		20		7.7		7.2		5.3		5.9		6.8		5.3
24	16.4	14		4.7		4.0	2.3		2.7			4.8	3.5	
		16		4.8	3.7		1.9		3.1			4.1	3.1	
		24		5.3	3.8		1.6		2.2		2.5		1.4	
15	17.7	5	0		0		0		0		0		0	
		7		4.8		5.4		4.2		5.3		6.0	3.8	
		9	1.7		2.9		1.2		1.3		-		-	
No. growth increasing					7		4		20		17		0	
No. growth unchanged					2		3		1		2		2	
No. growth decreasing					15		17		3		3		19	

ca. 18°C during November (Table 5.2-13). Temperatures below 18°C became common following the end of November, possibly due to mixing of surface and deep water during the 20-year storm of November 30 to December 1. The dramatic rise in percent of fronds showing increased growth rates during the November 29 to December 6 period (Table 5.2-11) suggests a strong stimulatory effect as a result of this storm. Possibly stirring up of bottom water increased availability of recycled nutrients to all the ex-Hemidome plants, without causing disease problems associated with the mass of decaying algal litter on the bottom.

Analyses of N-contents of blade tissues from the ex-Hemidome and naturally attached plants did not reveal any significant changes between the samplings of November 15 and December 6 (Table 5.2-14). The analyses did indicate that N-contents from both groups were so low that reserves were probably lacking. Frond growth may have been N-limited. Under such conditions, growth rapidly dilutes any assimilated nitrogen so that reserves do not build up and N-contents remain fairly constant. Mean tissue-N for the former controls indicated severe depletion of macronutrients. A plot of N-content for each individual sample against holdfast depth for the plant which yielded the sample showed a direct correlation between N-content and depth for canopy samples but poorer degrees of correlation for subcanopy tissues and juvenile fronds (Figure 5.2-16). Except for one subcanopy and two juvenile frond samples, none of the N-content values indicated presence of nutrient reserves, therefore the data probably reflected factors other than distance above the bottom (and availability of recycled N). For example, juvenile fronds on the highest plant, number 2 at a holdfast depth of 9.7 m, were probably experiencing C-limited growth because this plant had lost all its long fronds.

One important change was observed among the ex-Hemidome plants following their removal from the bag. Numbers of small fronds (less than 50 cm long) increased substantially during November 1982 on all plants. By the end of the month, the total number of small fronds present was more than fourfold greater than the tally from the final week of the intact Hemidome. (Table 5.2-15). Even plant 11, which became "decapitated" during relocation from the Hemidome and also lost most of its small fronds from exposure damage, managed to regenerate the complement present before the catastrophic events of October 29. The findings recorded in Table 5.2-15 suggest existence of a depressing effect by the Hemidome environment on abilities of plants to maintain their complements of fronds. By the end of our observations on the ex-Hemidome plants, numbers of small fronds were in a modestly

TABLE 5.2-13. RANGES OF TEMPERATURES IN DEGREES CELSIUS OBTAINED FROM MINI-MAX THERMOMETERS POSITIONED JUST OUTSIDE THE HEMIDOME ON 19 NOVEMBER 1982 AT TWO DEPTHS. ALL DATES REPRESENT 1982

Date	Minimum temp. °C	Maximum temp. °C
	0.7 m depth	
24 Nov	15	19
29 Nov	18	18
5 Dec	14	18
13 Dec	14	17
20 Dec	15	17
	13.1 m depth	
24 Nov	18.5*	18
29 Nov	15*	19
5 Dec	16*	17
13 Dec	16*	17
20 Dec	17*	17

*Minimum recordings for the deep thermometer may be erroneous.

TABLE 5.2-14. ANALYSES OF TISSUE N (PERCENT DRY WT) AMONG MACROCYSTIS FROM THE TRANSPLANTS FORMERLY IN THE HEMIDOME (MOORED JUST OUTSIDE ON OCTOBER 29, 1982) AND FROM CONTROL PLANTS AND NATURALLY ATTACHED PLANTS NEARBY IN BIG FISHERMAN COVE. VALUES REPRESENT MEANS ± STANDARD DEVIATIONS, AND (SAMPLE SIZES). ALL DATES ARE 1982.

	% N content			
Date	Canopy	Subcanopy	Basal	Juvenile
		EX-HEMIDOME		
Nov 15		1.12±0.45(2)		1.46±0.69(3)
Dec 6	0.71±0.12(5)	0.76±0.15(5)		0.98±0.18(9)
		FORMER CONTROLS		
Nov 15		0.47±0.16(3)		0.70±0.15(4)
		NATURALLY ATTACHED		
Nov 15		0.98±0.24(3)		1.07±0.30(3)
Dec 6	1.20±0.23(5)	0.90±0.27(5)	0.84±0.33(5)	1.21±0.40(5)

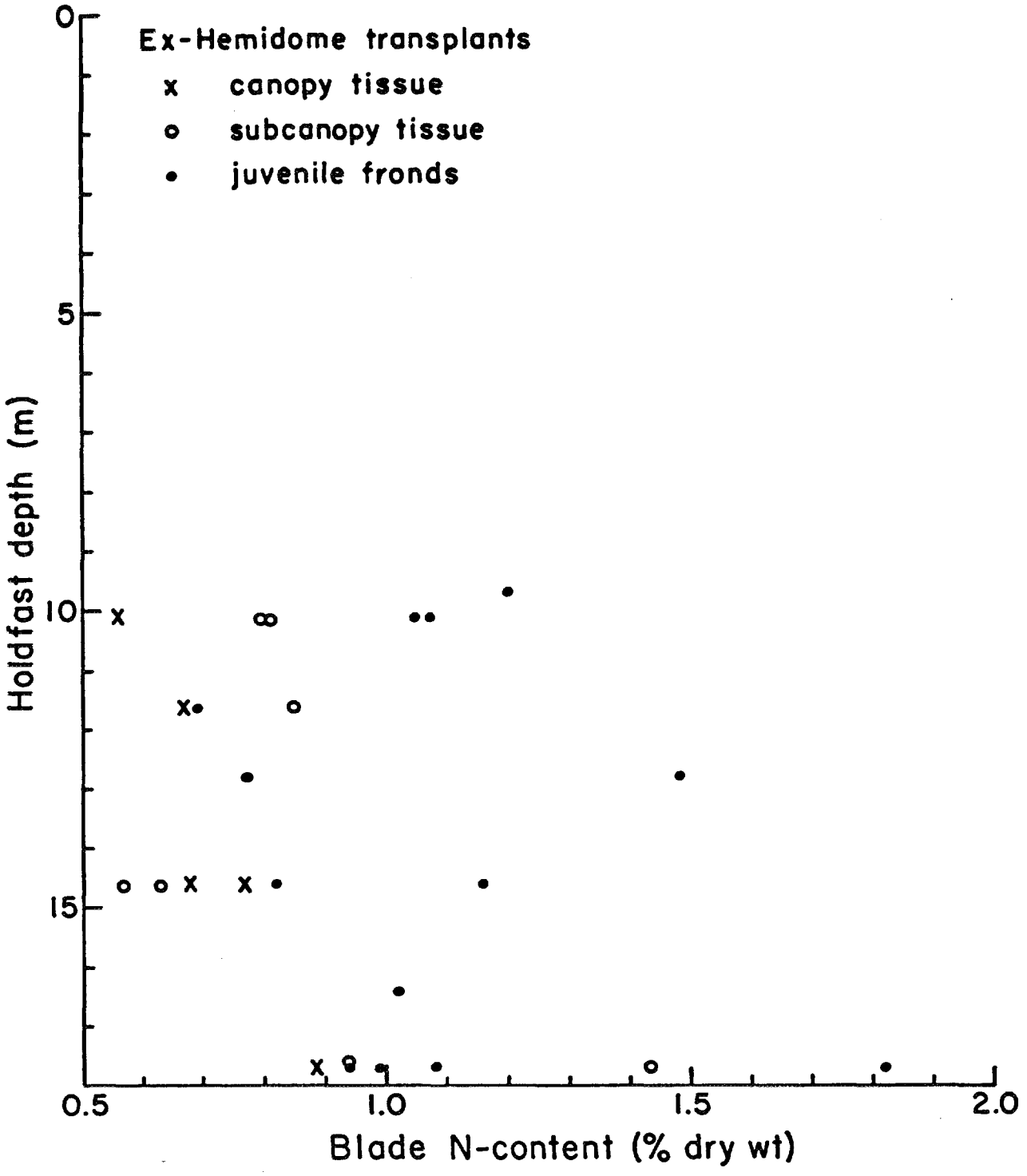


Figure 5.2-16. Plot of Holdfast Depth Versus N-Content of Various Types of Blades Sampled on November 15 and December 6, 1982, From Several of the Ex-Hemidome Plants moored at Various Depths in Big Fisherman Cove. Only Canopy Tissues Showed a Fairly Defined Relation to Holdfast Depth

TABLE 5.2-15. NUMBERS OF SMALL FRONDS (I.E., 50 cm OR SHORTER) PER PLANT FOR THE TEN HEMIDOME TRANSPLANTS RELOCATED FROM THE HEMIDOME INTERIOR TO CENTRAL BIG FISHERMAN COVE ON OCTOBER 29, 1982. PLANTS 11, 17, AND 24 LOST MOST OR ALL OF THE UPPER FOLIAGE DURING RELOCATION. ALL SURVEY DATES REPRESENT 1982

Plant no.	Sep 27	Oct 4	Oct 11	Oct 18	Oct 25	Nov 1	Nov 8	Nov 15	Nov 23	Nov 29	Dec 6	Dec 13	Dec 20
2	-	6	8	7	5	7	7	16	33	30	36	31	27
11	2	3	6	8	6	1	6	5	8	8	5	4	1
15	8	7	6	6	4	6	15	20	22	25	26	27	22
17	1	5	5	7	6	5	12	11	15	17	13	9	8
19	4	4	6	6	8	4	9	21	19	28	18	15	16
24	5	5	4	6	7	8	-	9	15	15	13	11	15
38	3	6	5	7	6	8	9	18	16	20	24	21	15
39	2	4	6	7	4	8	11	32	21	30	26	20	21
42	5	6	5	7	5	9	9	21	20	37	29	27	23
44	4	6	5	7	4	6	13	16	20	35	24	25	21
Total	34+	52	56	68	55	64	91+	169	189	235	214	190	184
					plants relocated to open water								

declining trend. As noted above, growth rate data indicated poor conditions for both the ex-Hemidome and the naturally attached plants during the final week of the study (see Table 5.2-11). Specific causes for reduced growth and declining totals of small fronds were not identified.

Summarizing the study of the ex-Hemidome plants, relocation apparently reduced disease and grazing problems among those individuals moored a meter or more off the bottom. Numbers of small fronds increased substantially, suggesting release from some adverse factors(s) affecting frond initiation in the Hemidome. Growth rates of juvenile fronds, however, were moderately low, and tissue analyses indicated growth was probably N-limited. Similar analyses of nearby naturally attached plants also suggested presence of N-limited growth, although mean growth rates among these latter plants was sometimes significantly higher than mean values from the ex-Hemidome group. Existence of N-limited growth interfered with the attempt to assess availability of recycled N to the ex-Hemidome plants by analyzing N-content as a function of holdfast depth. Indications of a depth-related influence on growth rates were noted, however, in that most fronds among the shallow-moored plants fell into the ESG category while most of the non-ESG fronds occurred among the deeply moored plants. Although all ex-Hemidome plants experienced N-limited growth, limitation was apparently most severe among the shallow-moored individuals. Even these severely limited plants, however, displayed a burst in production of small fronds.

5.2.1.3 Physiological Studies

Laboratory and field investigations in support of the hemidome experiment as well as program objectives of a broader scope - including studies of phosphate uptake, sieve tube exudate, photosynthesis, and factors affecting frond initiation rate - were conducted during this report period. Work performed in each of these areas is reported herein:

Phosphate Uptake by Macrocystis - Of the two macronutrients which can be potentially growth limiting at ambient concentrations (nitrogen as ammonia and nitrate, and phosphorus as phosphate) phosphate has been the least studied of the two. Initial findings of phosphate (Pi) uptake by adult sporophyte tissue are facilitated by use of the radioisotope P-32. Six parameters of Pi uptake are discussed: (1) temperature, (2) tissue type, (3) light/dark, (4) inhibitors, (5) external Pi concentration, (6) tissue (internal) Pi concentration. Uptake periods were for five minutes utilizing tissue discs taken from the same distance from the

blade base. Uptake was linear with time to at least 12 minutes. Less than 7 percent of the label taken up was in the free space; therefore, washes were usually not performed.

Temperature (Figure 5.2-17). Pi uptake maximum was 24^{o} C which is near the photosynthetic maximum of 20-25^{o} C (Clendenning). The temperature used for the remaining experiments was 15^{o} C.

Tissue Type (Figure 5.2-18). Mature blade tissue takes up Pi at a rate 20 percent greater than juvenile blade tissue and 45 percent greater than apical scimitar tissue.

Light/Dark (Figure 5.2-18). Light enhances juvenile tissue Pi uptake to a greater extent (20 percent increase) than it enhances mature tissue Pi uptake (10 percent increase).

Inhibitors (Figure 5.2-18). Arsenate is a competitive inhibitor of Pi uptake in algae, hence, Pi uptake rate declined in its presence. Arsenate is concentrated in Macrocystis tissue over ambient concentrations of 50 nM. Vanadate is a known Pi analog, competitively inhibiting various enzymes including Na^{+}, K^{+}-ATPase. Its inhibition of Pi uptake may be direct competitive inhibition or by inhibiting the formation of ATP. DCMU, an inhibitor of photosynthetic Hill reaction inhibited Pi uptake which implies that the ATP produced from cyclic phosphorylation does not support the high influx of Pi.

External Pi Concentration (Figure 5.2-19). Pi uptake follows saturation kinetics, with K_S = 3.51 μM and V_{max} = 5.3 nmoles $cm^{-2}hr^{1}$.

Tissue (Internal) Pi Concentration (Figures 5.2-20 and 5.2-21). Juvenile blades from the same frond were placed in two aquaria both containing 15 μM NO_3. One aquarium contained 2.5 μM Pi; the other began at 0.06 μM and fell to 0.02 μM by the end of the experiment (7 days). At zero, three and seven days, two blades were removed from both tanks. All blades were placed in stirred seawater (0.04 μM Pi) to remove free space Pi. One blade from each tank was sent out for total tissue P analysis. Six discs were punched from the remaining blades and placed in bubble culture for 10 mins (0.04 μM Pi). The remainder of the tissue was extracted and analyzed for Pi (98 percent Pi removed).

The tissue Pi concentration decreased with time (growth dilution) in tissue exposed to low external Pi concentrations. Their uptake capacity (at 1.6 μM), however, increased with time. The opposite results were obtained with those

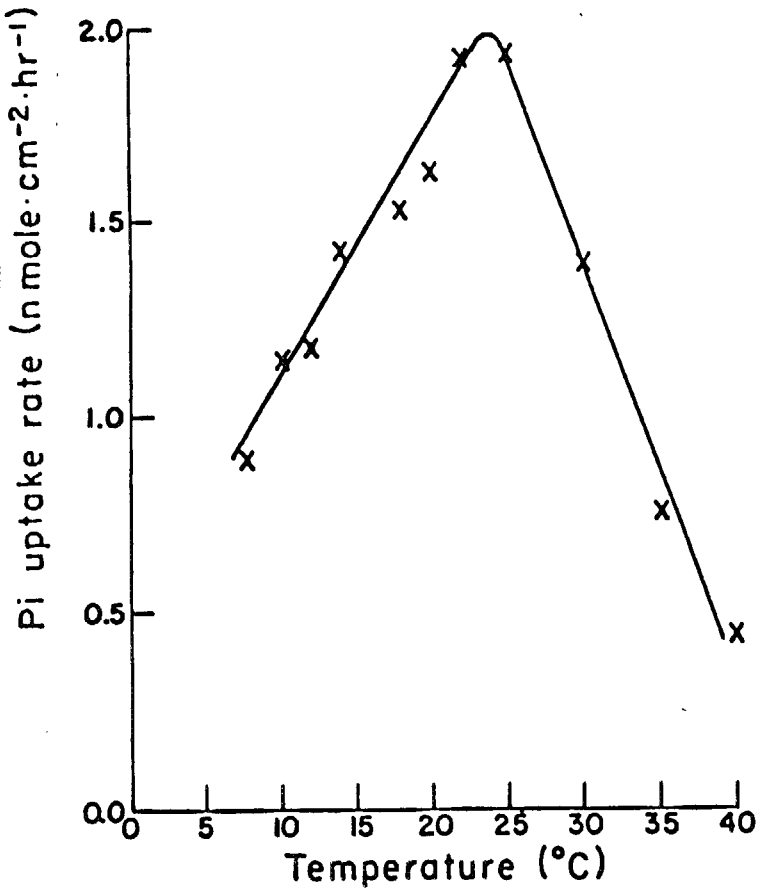


Figure 5.2-17. Prosphate (Pi) Uptake Rate Versus Temperature [Pi] = 1.8 μM

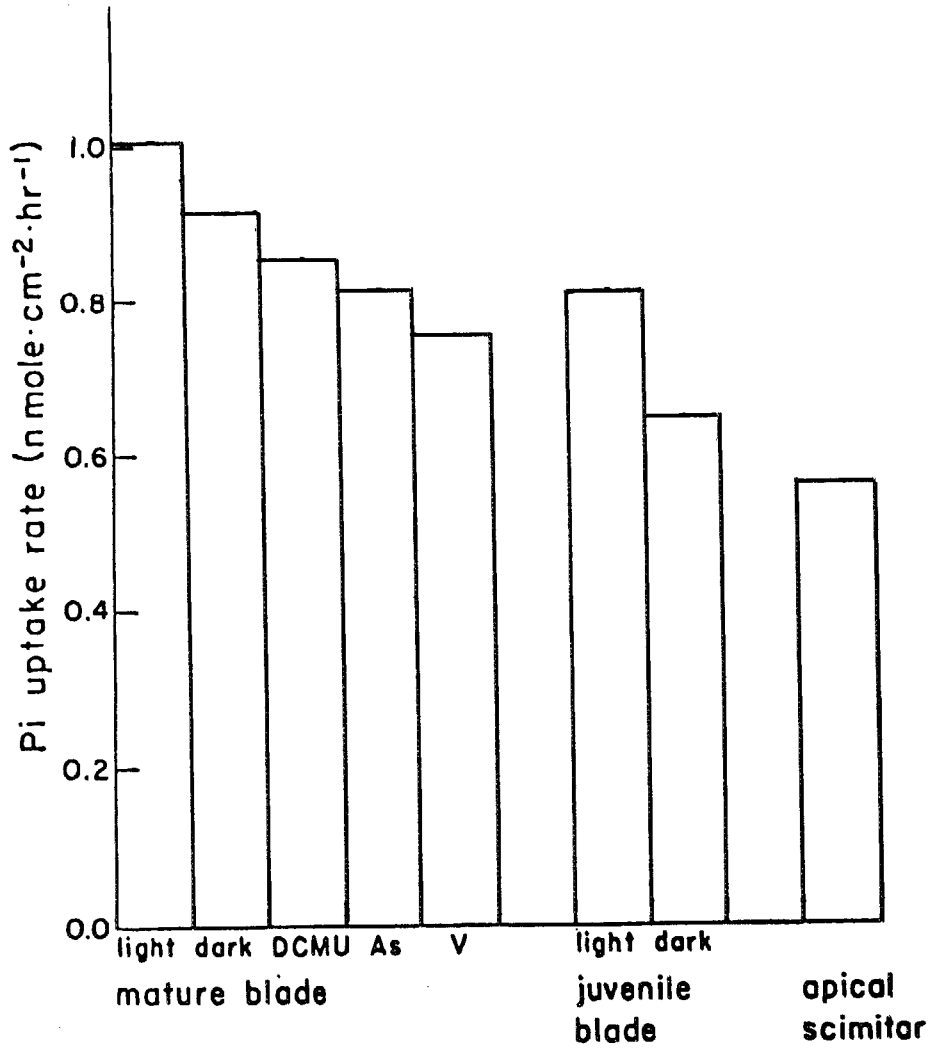


Figure 5.2-18. The Effect of Tissue Type, Light, and Certain Inhibitors on Phosphate Uptake. All Light Experiments at Light Intensity of 1.3 x 10^4 ergs cm^{-2} sec^{-1}. [Pi] = 1.4 μM. DCMU = 3-(3,4-dichlorophenyl)-1,1-dimethyl urea (50 μM). As = Arsenate (1 μM). V = Vanadate (1 μM). Brackets Indicate 95% Confidence Interval (n = 6)

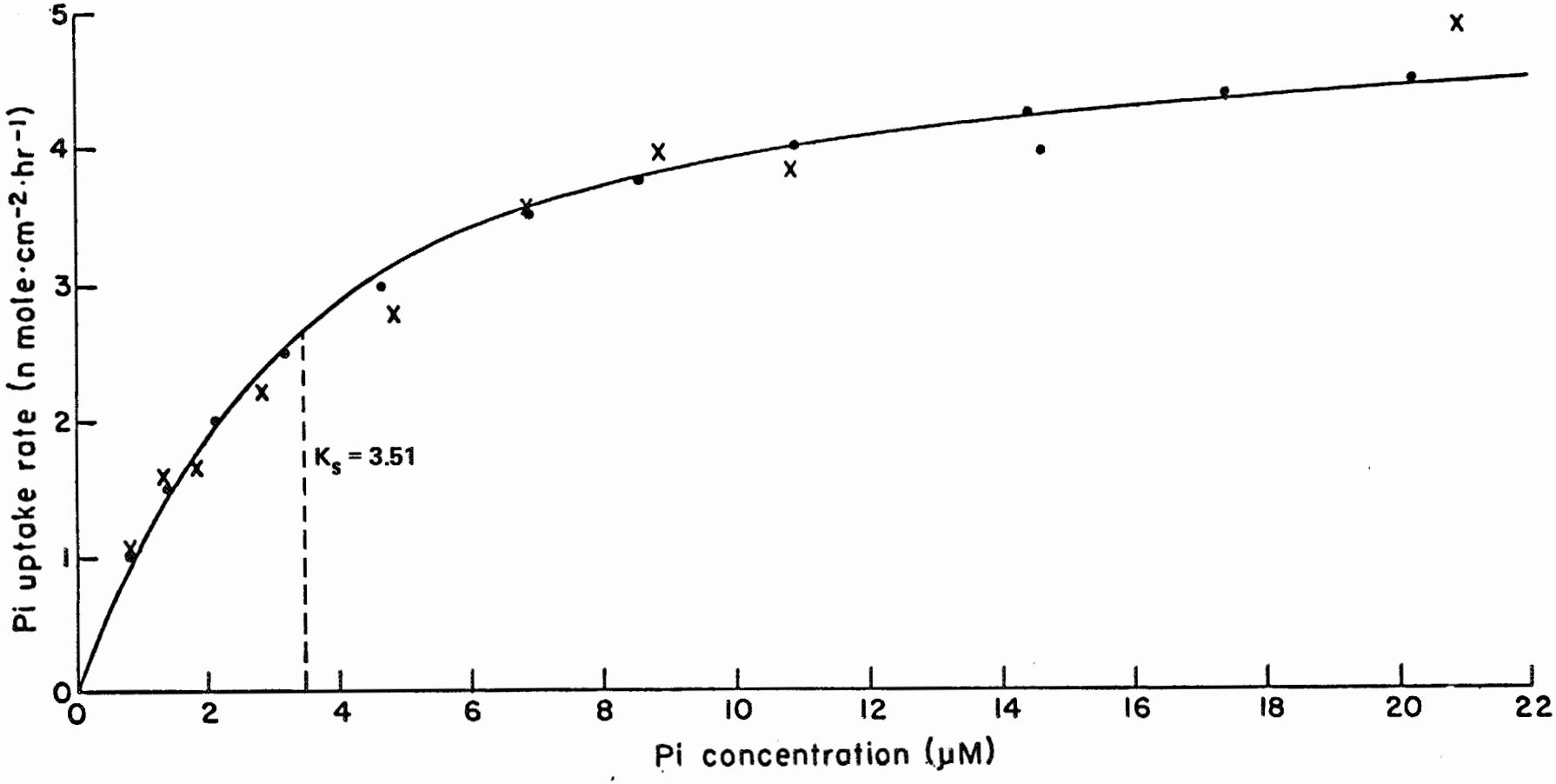


Figure 5.2-19. Phosphate Uptake Rate Versus External Pi Concentration = Best fit From V Versus v/S Regression (r = 0.959)

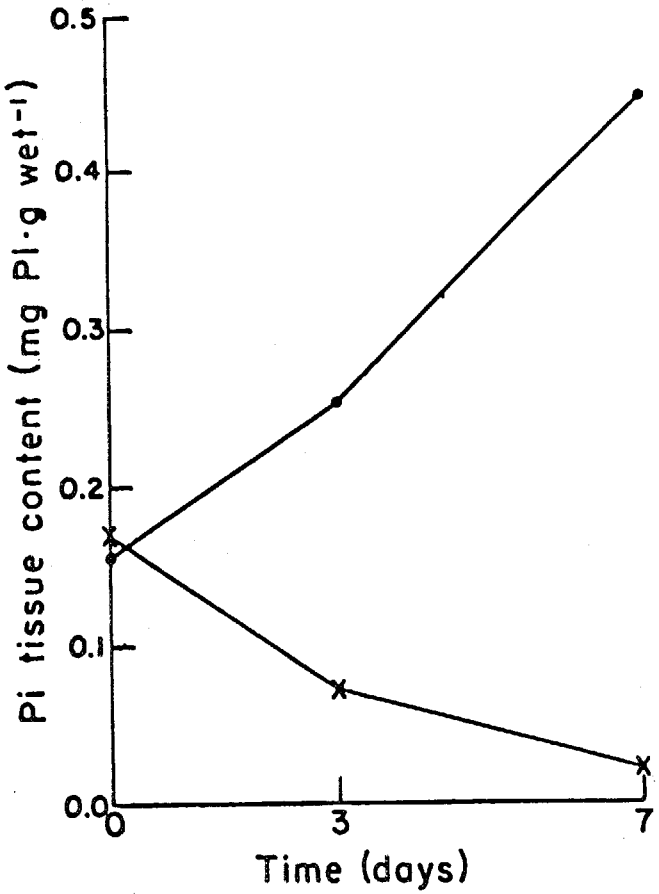


Figure 5.2-20. Pi Tissue Content Versus Exposure Time. After Punching Discs for Uptake Experiments, the Entire Juvenile Blade was Extracted and Analyzed for Pi. • = Blades in Constant 2.5 μM Pi Seawater. x = Blades in Low Pi Seawater (t = 0, [Pi] = 0.6 μM; t = 7, [Pi] = 0.02 μM)

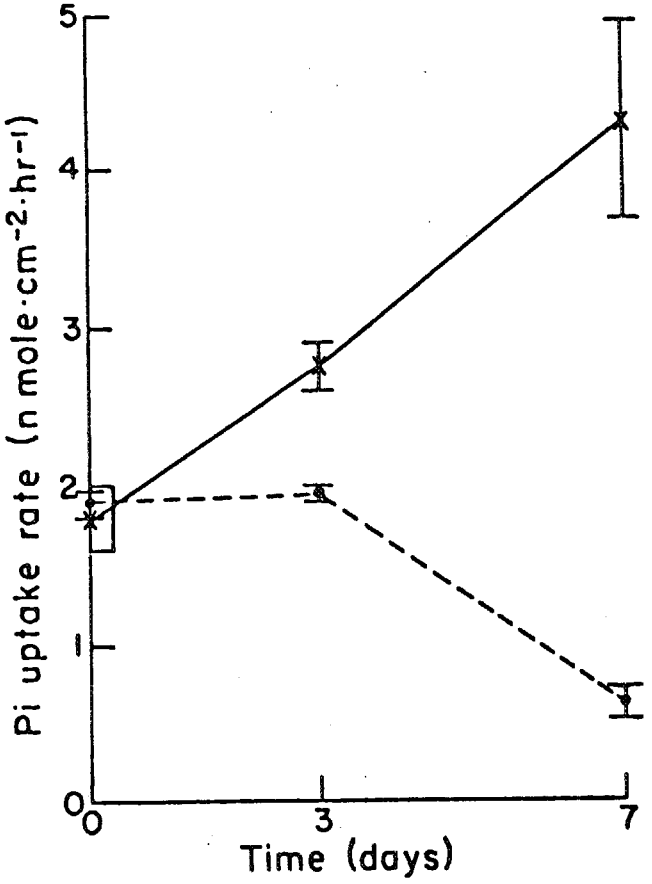


Figure 5.2-21. Pi Uptake Rate Versus Time. Uptake Determined at 1.5 μM Pi and 1.3 x 10^4 ergs cm^{-2} sec^{-1}. Brackets indicate 95% Confidence Interval (n = 6). • = Blades in 2.5 μM Pi Seawater. x = Blades in Low Pi Seawater (0.06 to 0.02 μM Pi)

blades exposed to a high external Pi concentration; increase in internal Pi concentration, and decrease in uptake capacity.

The change in the uptake rates may be due to a change in Pi carriers per unit area or a change in the kinetic properties of the carrier (inhibition and activation). The second mechanism is considered more likely since it is a short-term response. Data analysis yields a Ki (dissociation constant of the implied carrier-inhibitor complex) of 0.09 mg Pi-g wet $^{-1}$. Assuming the response is due to a noncompetitive inhibition (K_m constant, V_{max} lowered) due to internal Pi, an internal Pi concentration equal to Ki yields a 50 percent inhibition over maximum uptake obtainable at all external Pi concentrations. This type of inhibition for Pi uptake has been reported for unicellular algae, bacteria, and fungi. Whether the inhibition is caused by the direct action of internal Pi on the carrier or by a phosphate-containing intermediate is not known. A Dixon plot, 1/v versus inhibitor concentration (internal Pi) yielded a high correlation coefficient ($r = +0.87$).

The condition of the plant tissue, as represented by Pi content, has an effect on the kinetics of Pi uptake. This may explain the wide variability initially encountered from experiments performed in this laboratory.

Previous experiments with juvenile sporophytes have shown that growth is saturating (under specified conditions) at approximately 0.2 percent P (dry weight bases). Adult plants probably also have a growth saturating internal concentration. The activation/inhibition of Pi uptake by internal Pi (directly or indirectly) is a means by which the plant attempts to maintain a growth optimal internal P concentration. Phosphate uptake requires energy (active transport), and it would be energetically unfavorable for the plant to accumulate a large excess of P in its tissue and to do so at a maximum rate. This is not meant to suggest that the adult plant does not have a phosphorus storage capacity. Whatever that capacity is, the plant would not need to devote as much energy to Pi uptake as compared to a "P-starved" state. A complete understanding of nutrient uptake and assimilation must be viewed in context with the growing adult plant in which nutrient sinks are supplied via translocation from source tissue. Phosphorus concentration was measured in the sieve tube sap (STS) at 0.84-0.97 mg ml^{-1} with 15 to 42 percent at Pi.

The regulation of Pi uptake by internal Pi content further supports the fertilization strategy of short-term pulse application in order to optimize fertilization efficiency.

Studies on Composition of Sieve Tube Sap - Mannitol and free amino acids are the major constituents of sieve tube sap (STS) from Macrocystis (Schmitz and Srivastava 1979a, Parker 1966). The major inorganic constituents identified have been K, Na, and I (Parker 1966), with the later addition of Mg (Schmitz and Srivastava 1979a), B, Ca, and trace amounts of 17 additional elements (Manley 1981). None of the inorganic analyses to date have included those anions which are commonly found in the phloem of higher plants, notably PO_4^{3-}, Cl^-, SO_4^{2-}, and HCO_3^- (Ziegler 1975), although short-term labeling of Macrocystis STS identified 12 percent of the ^{32}P present as PO_4^{3-} (Schmitz and Srivastava 1979b). These facts suggest that the inorganic fraction of STS may be larger than previously determined. Knowledge of the inorganic and organic content is necessary for the understanding of the translocation process and nutrient assimilation in Macrocystis. The following data give a more complete analysis of the inorganic content of STS from Macrocystis pyrifera.

Three mature sporophytes of Macrocystis pyrifera (L.) C. Ag. (18-23 fronds per plant) were collected from Cameo Shores, California. Each adult plant was submerged on a sunny day in Newport Harbor with holdfast placed on a dock. The exposed portion of fronds (1 m) were wrapped in wet towels to prevent desiccation. All of the fronds were cut directly above the holdfast. After the cut ends were rinsed with deionized water, the first few drops of STS were discarded, and STS (6-10 mL) was collected (4-5 h) with Pasteur pipettes. Flow was maintained by periodically cutting 2 cm from the stipe. STS was kept at 5°C and then stored frozen (-60°C). Samples number 1, 2, and 3 correspond to STS from plants one, two, and three. Analyses for total inorganic carbon and pH were performed within 1 hour of collection prior to freezing.

The following methods were used for the chemical analysis of STS: Mannitol was determined by the method of Cameron et al. (1948); total amino acid content (leucine standard) by the method of Moore and Stein (1954); trichloracetic acid precipitated protein by the method of Lowry et al. (1951); I^-, Br^-, Cl^-, and NH_3 by potentiometric titrations with known additions utilizing specific ion and ammonia electrodes (Orion Research 1970); Na, K, Ca, Mg, As, B, and P by ICP emission spectroscopy (ICPES); total inorganic carbon, as CO_2, by modified Van Slyke method (Frings et al. 1973); and pH with hydrogen ion electrode.

Inorganic phosphate (Pi) was determined by a modified method of Fiske and SubbaRow (1925): 2 mL of STS previously diluted 1:100 and 1:1000 was added to 1 mL acid molybdate solution (Sigma Chemical Co.) and mixed prior to the addition of 250 μL of Fiske and SubbaRow Solution (Sigma). After 10 minutes, the absorbance was read to 660 nm. This assay is selective for Pi (Stanton 1968). In order to determine, however, if hydrolysis of organic phosphate esters occurred during the analysis, solutions of ATP and glucose-6-phosphate (at concentrations equivalent in total P to STS total P) were similarly analyzed. Negligible color formation occurred.

Analysis for nitrate and sulfate was performed on sample #3 only. Nitrate was determined with a Technicon Auto-Analyzer II based on the method of Strickland and Parsons (1972) (Vetter Research, Costa Mesa, CA). A blank with the same concentration of mannitol and amino acids (as aspartate) and the same ionic strength (with KCl) as STS was prepared and similarly analyzed. The high content of organic matter necessitated diluting the samples thirty-fold for nitrate analysis. Sulfate was determined by the nephelometric method of Toennies and Bakay (1953). STS was turbid, especially after freezing, due to precipitated protein. This was removed by centrifugation; a control, however, was used to account for any remaining turbidity.

Two measurements were made for each analysis on samples number one and two except the single ICPES analysis on sample number two. Six and three replicates were used for the sulfate and nitrate analyses, respectively, on sample number three. Dry weights were determined on measured volumes of STS oven-dried at 105^{o}C.

Analysis accounted for 97.3-107 percent of the STS dry weight, limited by accuracy of the dry weight measurements (Table 5.2-16). Previous studies accounted for 94 percent (Schmitz and Srivastava 1979a) and 48 percent (Parker 1966) of the dry weight. Organic composition of the STS determined in this study was similar to that described by Schmitz and Srivastava (1979a).

The method of mannitol determination (periodic acid oxidation) will not distinguish between mannitol and other low molecular weight carbohydrates. Parker (1966) did not detect any other carbohydrates. The ^{14}C-labeling studies revealed, in addition to mannitol, hexose di-and monophosphates (Schmitz and Srivastava 1979a,b) which are present in concentrations too low to significantly affect the mannitol determination.

TABLE 5.2-16. CHEMICAL COMPOSITION OF SIEVE TUBE SAP FROM *MACROCYSTIS PYRIFERA*. DATA IN Mg ml^{-1}

	Sample 1	Sample 2	Seawater[a]
	pH = 7.02	pH = 7.25	pH = 8.0
Mannitol	92.6-96.9	120-122	--
Amino acids	21.1	21.5-26.0	--
Protein	1.34-1.36	1.74-2.00	--
Ca	0.048-0.054	0.020	0.412
Mg	0.150-0.165	0.062	1.29
K	8.50-9.54	7.48	0.380
Na	1.73-1.95	0.986	10.77
B	0.248-0.276	0.352	0.004
As	0.020-0.032	0.018	3.7×10^{-6}
Cl^-	9.67-11.1	8.26-8.30	18.8
Br^-	1.28-1.60	1.32-1.35	0.067
I^-	0.529-0.535	0.592	1.3×10^{-5}
NH_4^+	not detected	not detected	$\leq 1.4 \times 10^{-5}$
NO_3^- [c]	0.0021 ± 0.0021 ($p = 0.05$)		$\leq 6.2 \times 10^{-4}$ [b]
SO_4^{2-} [c]	not detected		0.905
Total CO_2	0.266-0.275	0.248-0.255	0.028
Total P	0.842-0.972	0.600	--
as P_i	0.254-0.275	0.154-0.163	$\leq 1.4 \times 10^{-4}$ [b]
organic	0.567(58%)-0.718(85%)	0.437(73%)-0.446(74%)	--
Dry weight (sum)	138.3-145.9	163.2-170.0	--
Dry weight (determined)	141.5-142.1	158.8-159.1	--
Yield	97.3%-103%	103%-107%	--

[a] From Brewer (1975). [b] Maximum nearshore, S. Calif. (Jackson 1977). [c] Analysis performed on sample #3 (pH=7.24, mannitol=126mg/ml); for SO_4^{2-}, n=6; for NO_3^-, n=3.

The inorganic fraction constituted 17 percent and 12 percent of the dry weight of STS samples numbers one and two respectively. Cation concentrations were similar to previously reported values. The Mg^{2+} concentration was similar to that reported by Manley (1981) but an order of magnitude lower than that reported by Schmitz and Srivastava (1979a). Cations represented between 5 to 8 percent of the STS dry weight. Inorganic anions (including inorganic C as bicarbonate) constituted between 6 to 9 percent of the STS dry weight. The major anion (and inorganic ion) of the STS was Cl^-. Chloride is a major inorganic ion of osmosis regulation in Ecklonia (Kirst and Bisson 1979) and may have a similar function in Macrocystis. The other two halogens, present and measured as I^- and Br^-, were concentrated 4 x 10^4 and 20 times respectively in the STS over their ambient concentration. Their function remains unknown. The concentration of I is more than double that found by Parker (1966). The elements B and As may be present as the anions borate and arsenate, although some of the As may be present as arseno-sugars as found in the kelp Ecklonia radiata (Edmonds and Francesconi 1981). Borate readily complexes with sugars and hexitols, regulates carbohydrate metabolism, and may be involved in the translocation process of higher plants (Ziegler 1975). A similar function may occur in Macrocystis.

Sulfate was not detected, the limit of detection being 1.5 ppm. Sulfur is translocated primarily in methionine (Schmitz and Srivastava 1979a). The inorganic carbon (C_i) concentration measured in the STS was an order of magnitude greater than in seawater. This high concentration, however, may have been due to the respiratory activity of the sieve tube cells or the covered portion of stipe tissue. The major species of C_i at the pH of STS is bicarbonate.

A significant amount of inorganic phosphate (P_i) was present in the STS. The ATP concentration in Macrocystis integrifolia STS has been measured at 1.18 mg mL^{-1} decreasing 67 percent upon standing at room temperature for 30 minutes. (Schmitz and Srivastava 1974). The STS Pi concentration determined in this study may, therefore, be slightly larger than found in vivo, although fractions were not allowed to stand at temperature greater than 5^oC. Organically bound P was equal to the difference between total P (determined by ICPES) and Pi (determined chemically) concentrations. Most of the P, approximately 72 percent, was organically bound, which was consistent with the finding that 88 percent of the p^{32} incorporated into the STS after a four hour exposure was organically bound (Schmitz and Srivastava 1979b).

Nitrogen is translocated primarily as amino acids. Ammonium was not detected (measured at pH 11 as NH_3) in the STS but may be present below the detection limit (2 ppm). Nitrate was detected in the STS. The results, however, were variable and thus the mean was of questionable accuracy. Tissue nitrate levels of less than 15 mol g^{-1} wet weight have been measured in Macrocystis (Gerard 1982) and up to 150 mol g^{-1} wet weight in Laminaria (Chapman and Craigie 1977). Macrocystis and other Laminariales are probably capable of nitrate translocation.

The reported concentrations of STS solutes should be interpreted as being static. The use of certain STS solutes, such as nitrate, phosphate, and the organic constituents, by the rapidly growing apical region of a frond could result in a lower solute level in STS obtained from the apex as compared to that obtained from the frond base as it flows directly from the source regions. If certain solutes are slowly accumulated in the STS during the life of a plant, then their concentration in STS from juvenile plants should be lower than in mature plants.

Although the translocation of C^{14} labeled and P^{32} labeled STS constituents occurs at similar velocities in intact and cut fronds of M. integrifolia (Schmitz and Srivastava 1979b), the mobility of the other constituents is unknown. In the present study, the fronds were removed from basal meristems which are considered sinks (Lobban 1978) and the STS was collected while flowing from the cut stipes. It is, therefore, tempting to infer that the constituents were mobile; however, the creation of an artificial sink (the cut end of the stipe) may have influenced the mobility of the various elements. The radioisotopes introduced as $^{32}PO_4^{3-}$, ^{86}Rb (K analogue), and $^{35}SO_4^{2-}$ to the thallus of Laminaria (which contains sieve elements) displayed, as detected by autoradiography, long-distance transport while $^{45}Ca^{2+}$ and $^{36}Cl^-$ were nonmobile (Floc'h and Penot 1976, 1980). Also, the elements K, Na, Mg, P, S, and Cl of higher plant phloem sap were described as mobile while Ca and B were nonmobile (Ziegler 1975).

Macrocystis STS differs in composition from higher plant phloem sap in that it contains high concentrations of iodide, bicarbonate, amino acids, and mannitol

TABLE 5.2-21A. MACROCYSTIS PRODUCTIVITY ESTIMATE DERIVED FROM PS AND R AND 1 HOUR MAXIMUM SUMMER IRRADIANCE AND DARKNESS

I. Weight Distribution Estimate[1]

Tissue type	Canopy 39.6 kg fronds >9 m (12 m avg) #=12		Below canopy 19.3 kg canopy fronds to 9 m #=12		Subcanopy 1-9 m (7 m avg) #=17		Subcanopy <1 m #=19		Total		Holdfast 35 kg
stipe	10 kg	26%	5 kg	26%	3.5 kg	18%	0.58 kg	3%	9.1 kg	47%	
immature laminae	7.2 kg	18%	0		0.69 kg	4%	0.39 kg	2%	1.2 kg	6%	
mature "	22 kg	56%	4.3 kg	22%	1.9 kg	10%	--		6.2 kg	32%	
senescent "	0	0	2.0 kg	10%	0.91 kg	4%	--		2.9 kg	15%	

II. Net Productivity

	Fresh wt (kg)	% dry wt	Dry wt (kg)	Quantum irradiance ($uE \cdot m^{-2} \cdot sec^{-1}$)	% PS	PS ($mgC \cdot g dry^{-1} \cdot hr^{-1}$)	R	Carbon assimilation (g C) 1 hr light		1 hr dark	
Canopy											
stipe	10	11	1.1	2000	100%	0.45	0.10	0.5	2.8%	0.11	2%
immature	7.2	9.7	0.70			4.5	1.0	3.2	18%	0.70	15%
mature	22	13	2.9			3.5	0.65	10.2	57%	1.9	42%
senescent	0	12	0			2	0.5	--			
Below canopy											
stipe	9.1	11	0.10	200	10%	0.45	0.1	.045	0.2%	.010	2%
immature	1.2	9.7	0.12			4.5	1.0	.53	2.9%	.012	3%
mature	6.2	13	0.81			3.5	0.65	2.8	16%	.53	11%
senescent	2.9	12	0.35			2	0.5	0.7	3.9%	.18	4%
Holdfast	35	16	5.6	10	0.5%	0	-0.1	0.2	-.56	1.12	24%
							Total		17.0	4.56	

[1] Derived from weight distribution presented in Parsons Report, morphometric data of North (1971)

rarely limiting to small frond growth (Gerard 1982) and plant hormones have not yet been demonstrated to affect kelp growth (Buggeln 1976; Hart 1982). The research described herein is designed to examine effects of factors influencing translocation on frond initiation rates. Experimental variables include parent frond size and condition, irradiance, substrate depth, and biomass density. Relative differences in organic content of lamina tissues are used as an indicator of translocational source strength. Manipulation of translocational sources and sinks provides a direct test of the hypothesized relationship between translocation and basal meristem activity. Results and conclusions presented herein are based on small sample sizes and are strictly preliminary.

Twenty adult Macrocystis pyrifera were transplanted on 30 September 1982 from a naturally occurring population at nine to eleven meters depth, Intake Point, Santa Catalina Island, to three experimental plots also at Intake Point. The plots were located at two depths and planted at two biomass densities. Five experimental plants made up the nine-meter low density plot with approximately 0.3 plant/m^2. Eleven experimental plants were transplanted to the nine-meter high density plot, surrounded by other adult plants to give one plant/m^2. Four experimental plants were moved into a natural kelp stand to form the 15 meter high density plot, also with one plant/m^2. All fronds on experimental plants were counted on 11 October and 6 December. Experimental plants were not harvested, but canopy tissues of plants adjacent to the nine-meter low density plot were removed on 30 September and 15 November to minimize shading.

On 1 to 5 and 18 and 19 October, 198 fronds with intact apical meristems were tagged on the experimental plants. The length of each frond was measured, and each basal meristem was categorized as undivided (U), having a single split (1S), or having a frond initial less than 100 cm long (I). Initials were identifiable when three to four cm long but were sometimes confused with basal meristems undergoing a secondary division. In time, the latter were recognized and categorized as an uninitiated two-split stage (2S). Basal meristem status on all tagged fronds was rechecked at two-week intervals through 20 December. When a newly formed frond initial was identified, the length and apical condition (intact apical meristem, intact terminal blade, or broken apex) of the parent frond were recorded. The length of each frond initial was measured at two-week intervals until it exceeded 100 cm.

Translocational sources and sinks were manipulated on fronds with intact apical meristems and undivided or single-split basal meristems. On 22-23

November, fronds on plants in the nine-meter high-density plot were randomly subjected to one of three treatments. No tissues were removed from control fronds; the apical 1 meter, a translocational sink, was removed from some fronds; and translocational source laminae occurring two meters from the apex to one meter above the base were removed from other fronds. Basal meristem status was rechecked at two-week intervals.

Organic contents of translocational source blades (Lobban 1978) indicated relative differences in source strength for fronds of various lengths. Mature laminae were collected two meters from the apical meristem, cleaned of epiphytes, and dried for 24 hours at 60°C. Organic content was determined as percent ash-free dry weight (percent AFDW): dried samples were weighed, ashed for 24 hours at 550°C, reweighed, and the percent AFDW was calculated as the percentage of dry weight lost during ashing.

Minimum and maximum temperatures at nine and 15 meter depths were recorded at weekly intervals from min-max thermometers located at Intake Point. Subsurface light levels were determined using a Biospherical Irradiance Meter.

The mean size of the twenty experimental M. pyrifera was 34.3 fronds/plant (SD = 8.1) on 11 October. Frond density, therefore, was 10 fronds/m^2 in the low-density plot and 34 fronds/m^2 in the two high-density plots. Mean size of the eleven plants in the nine-meter high-density plot did not change significantly between 11 October and 6 December (35.7 $\pm$ 9.2 and 33.1 $\pm$ 10.8 respectively). Some plants in the other two plots were damaged by a storm on 30 November, so changes in mean plant size for those treatments did not necessarily reflect frond initiation rate.

Fronds tagged on 1 to 5 October were generally longer than fronds tagged on 18 and 19 October (Figure 5.2-33). The earlier group also had an extra growing period of 13 to 18 days after tagging and so were substantially older and larger than the later group. Original size distributions of both frond groups were similar for plants in the three experimental plots.

Between 18 October and 23 November, fronds with basal meristems that were originally uninitiated showed differences in initiation rate between the three experimental plots. Only 8 percent of the nine-meter low-density fronds retained undivided meristems during this period as compared to 25 percent of the nine-meters high-density fronds and 40 percent of the 15-meter high-density fronds (n = 26, 74, and 25 respectively). Parent frond size at the time of frond

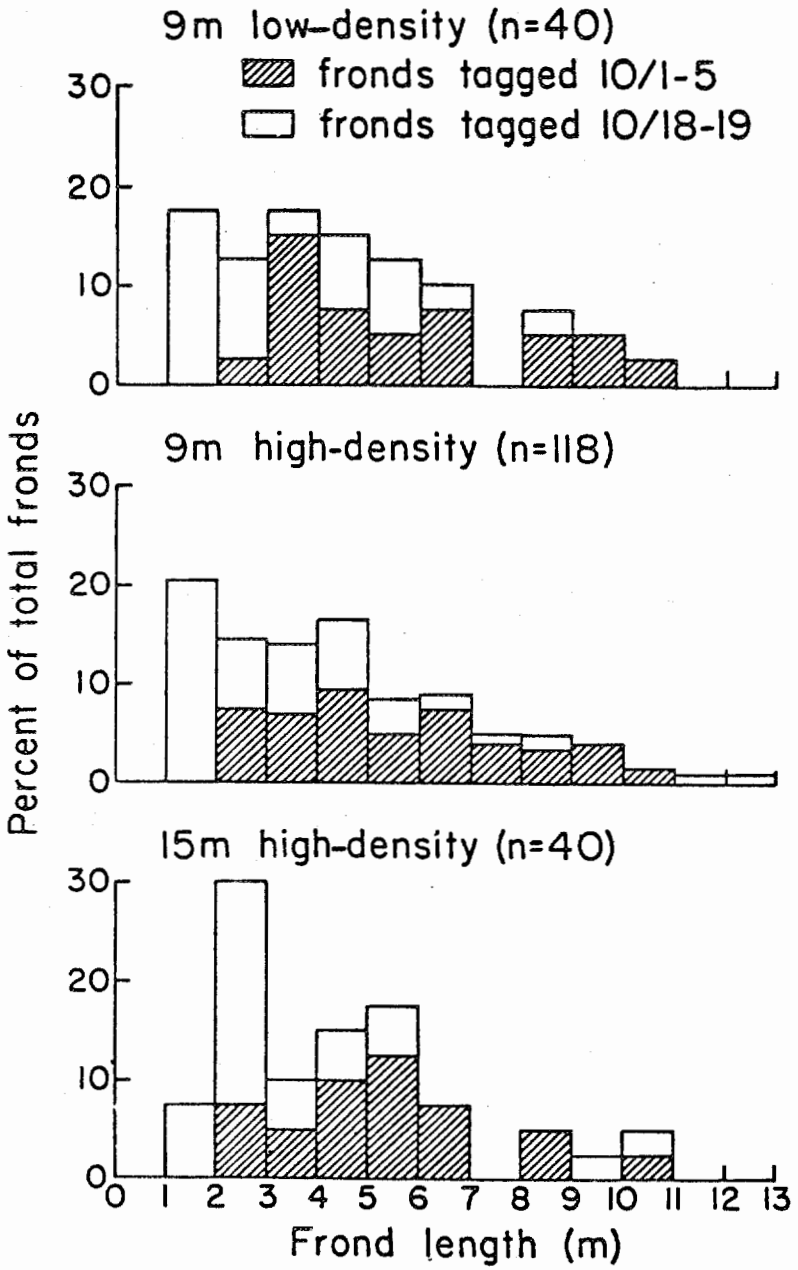


Figure 5.2-33. Size Distributions of Fronds Tagged on Experimental M. Pyrifera Plants in the Three Plots During Two Intervals

initiation also showed differences between the three plots. Although size ranged widely in all three groups of plants, parent fronds were generally smallest in the nine-meter low density plot and largest in the 15 meter high-density plot (Figure 5.2-34).

Altogether, 17 percent of the basal meristems on all 198 tagged fronds were broken, damaged by grazing, or showed abnormal development between 18 October and 23 November. This proportion was similar for the three plots. All frond initials that were formed prior to 18 October remained intact through 22 November ($n = 37$). Probability of damage or abnormal development seemed higher for undivided or single-split meristems than for frond initials or small fronds. The log-transformed elongation rates were low for frond initials less than 20 to 25 cm long but relatively constant for larger initials (Figure 5.2-35). Rates were similar for experimental plants in the three plots.

Organic contents of mature laminae generally increased with increasing frond length (i.e., with decreasing distance from the surface) in all experimental plants, both before transplanting and in the three plots one month after transplanting (Figure 5.2-36). Organic contents for fronds of similar length varied between the three plots: nine-meter low-density plants had the highest, and 15 meter high-density plants had the lowest values.

Eleven of the 63 manipulated fronds formed new frond initials between 22 November and 20 December. The basal meristems of those fronds had already undergone primary division prior to manipulation. Only five of the fronds maintained intact apical blades (meristematic or terminal) during the observation period, and this sample size was too small for statistical analysis. A larger sample size and longer observation period are necessary to directly examine effects of translocation on frond initiation rate.

Despite the small sample sizes and preliminary nature of the data presented in this report, some effects of the experimental variables on frond initiation rate are evident.

Both depth and biomass density appear to influence basal meristem activity in Macrocystis pyrifera. Of the two high-density plots used in this study, experimental plants in the shallow plot had higher frond initiation rates than plants in the deep plot. Comparing the two shallow plots, plants in the low-density plot showed higher frond initiation rates than plants in the high-density plot. This result supports the surmise that differences in frond

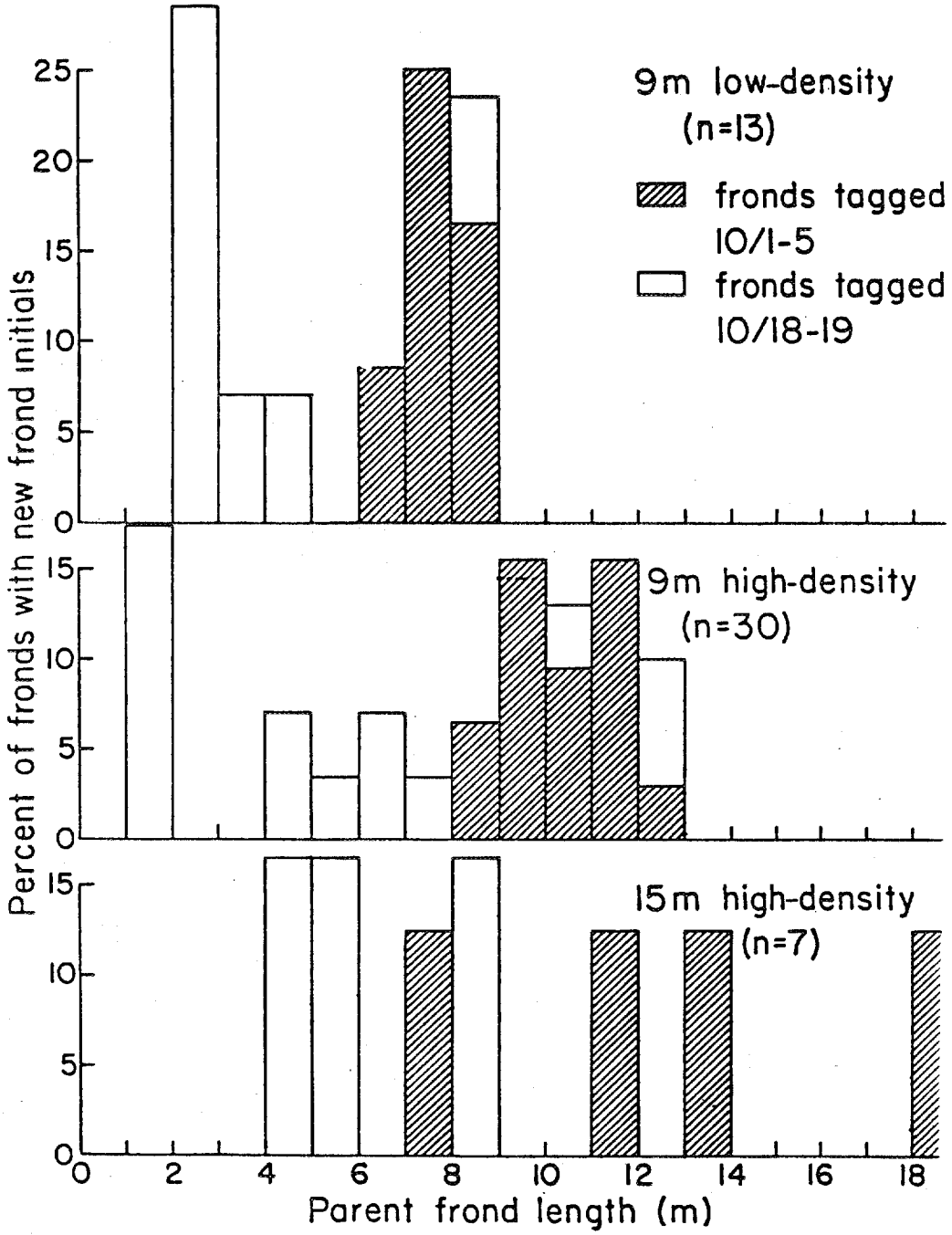


Figure 5.2-34. Size Distributions of Parent Fronds with Intact Apical Blades (Meristematic or Terminal) and Newly Formed Initials on Experimental M. Pyrifera Plants in the Three Plots

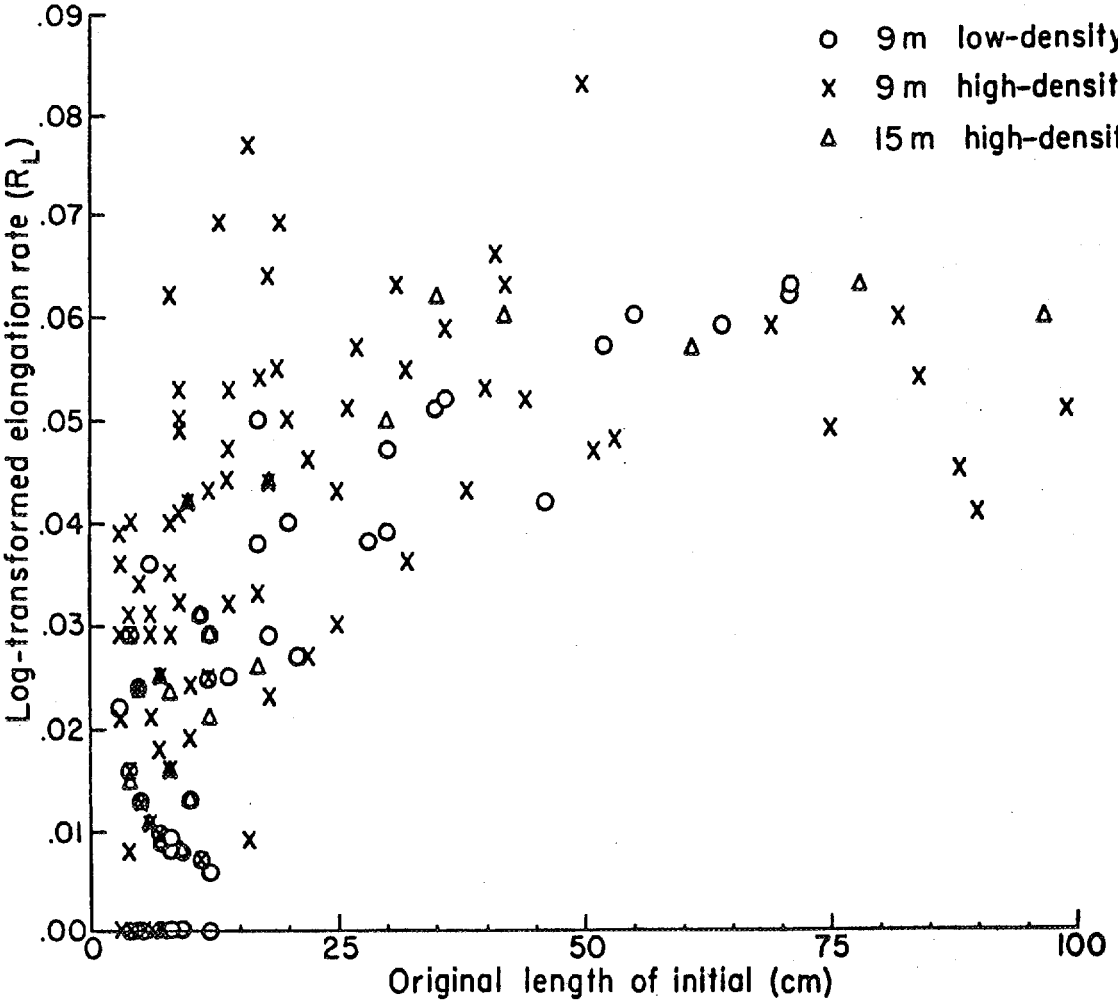


Figure 5.2-35. Log-Transformed Elongation Rates (R_L) for Frond Initials on Experimental M. Pyrifera Plants in the Three Plots

$$R_L = \frac{\ln L_t - \ln L_o}{t}$$

Where L_o is Length (cm) at Time = 0, L_t is Length at Time = t, and t is Time (Days)

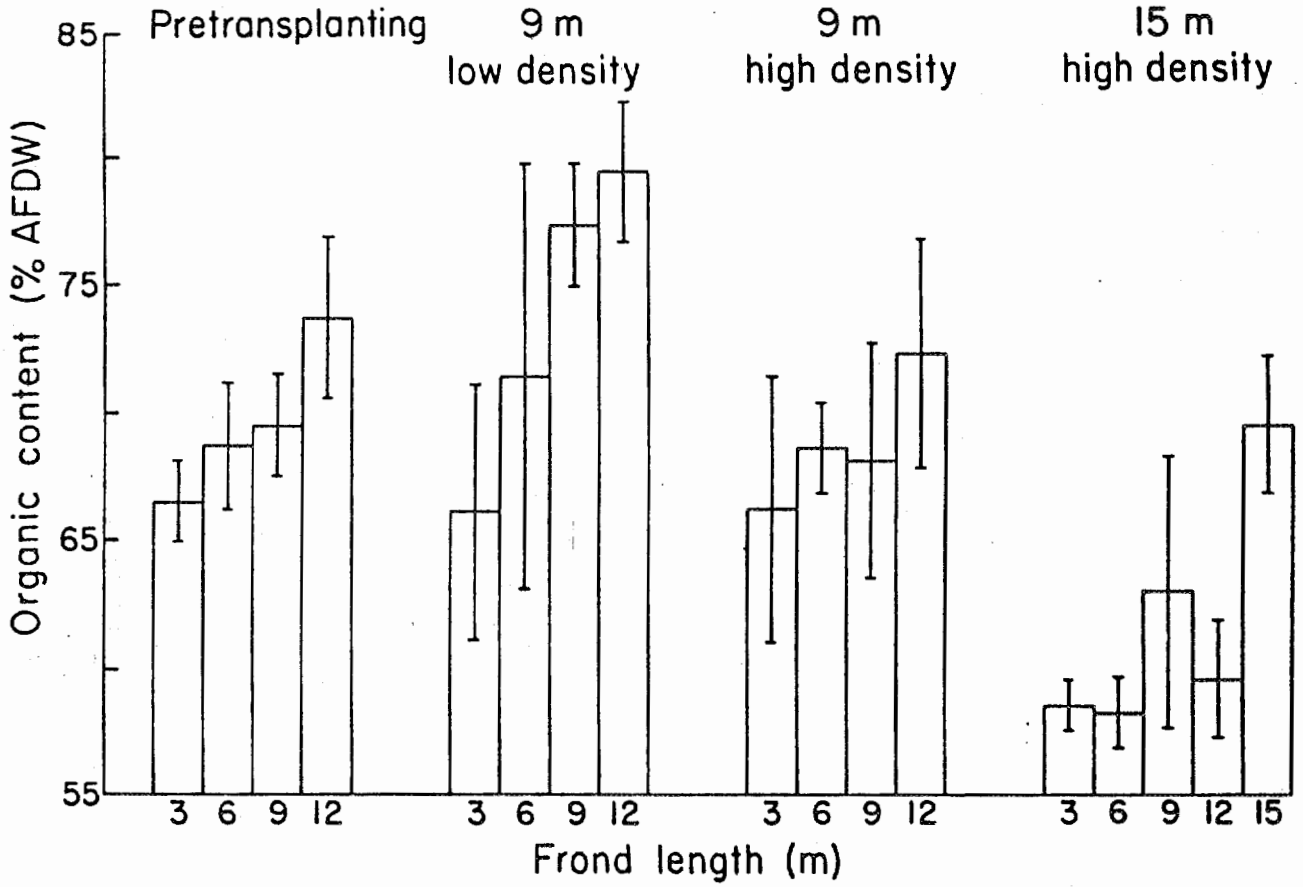


Figure 5.2-36. Organic Contents ($\bar{x}$ + 1 SD, n = 3) of Mature Laminae From Fronds of Various Length on Experimental *M. Pyrifera* Plants Before Transplanting and in the Three Plots 1 Month After Transplanting

initiation rate were at least partly responsible for observed plant size increases in low-density plots and decreases in high-density plots of Macrocystis pyrifera at Santa Barbara (Neushul and Harger, personal communication).

The trend of increasing parent frond size with increasing biomass density and depth (Figure 5.2-34) may account for the rate differences between plots. Tagged fronds on plants in all three plots had similar size distributions at the beginning of the study (Figure 5.2-33). If increased biomass density and depth delayed basal meristem activity until parent fronds were longer, this delay could have resulted in the observed decreases in frond initiation rate.

Organic contents of mature laminae may provide an index of translocational source strength for Macrocystis pyrifera fronds. Accumulation of solutes, primarily mannitol, in source tissues gives rise to the osmotic pressure gradients that drive translocation (Schmitz and Srivastava, 1979, 1980). Differences in organic content of Macrocystis pyrifera laminae largely reflect differences in mannitol content (Gerard, et al. submitted). Therefore, mature laminae with high organic content are probably stronger translocational sources than similar tissues with low organic content. Increasing organic contents of mature laminae from fronds of increasing size support this hypothesized relationship. During growth, Macrocystis pyrifera fronds add tissues nearer the surface which photosynthesize at higher light levels and at higher rates than deeper tissues (Sargent and Lantrip, 1952; Towle and Pearse, 1973). As frond length increases, mature laminae become photosynthetically self-supporting, then accumulate photosynthates, begin acropetal translocation, and finally begin basipetal translocation (Lobban, 1978). Basal meristem activity may well be stimulated when basipetal translocation exceeds some threshold level.

Biomass density and depth probably influence translocation by affecting subsurface light levels. Self-shading is enhanced at increased biomass density. Lower light levels and, therefore, photosynthetic rates probably result in reduced translocation, as evidenced by lower organic contents of mature laminae from the nine-meter high-density plot than in comparable tissues from the nine-meter low-density plot (Figure 5.2-36). By the same reasoning, fronds growing at deeper depths probably have reduced translocation in comparison to fronds of similar size at shallow depth. Lower organic contents of mature laminae in the 15 meter high density treatment than in the nine-meter high-density treatment (Figure 5.2-36) seem to substantiate this depth effect. If basal meristem activity depends on

supply of translocated photosynthates, reduced basipetal translocation due to increased biomass density or depth could delay frond initiation until parent frond size and translocational source strength increase sufficiently. Thus, translocational regulation of basal meristem activity could account for the differences in parent frond size and frond initiation rate between experimental plants in the three plots.

Rate of frond initiation by Macrocystis pyrifera at a density of 34 fronds/m^2 and nine-meter depth was sufficient to maintain constant plant size over a two month period. This result contrasts the marked reduction in plant size noted in two experimental plots of Macrocystis angustifolia at 25 fronds/m^2 and seven meter depth at Santa Barbara and attributed to low frond initiation rate (Neushul and Harger, personal communication). This apparent contradiction may be explained by site-specific differences in environmental conditions. The leeward coast of Santa Catalina Island has generally low turbidity and high subsurface light levels; the Santa Barbara coast is characterized by high turbidity and low subsurface light levels. If basal meristem activity depends on translocation of photosynthates, turbidity probably affects frond initiation rate in a similar manner to biomass density and depth.

The observed relationships between biomass density, depth, organic content of mature laminae, parent frond size, and frond initiation rate provide indirect support for the hypothesis that basal meristem activity is regulated by translocation. Manipulation of translocational sources and sinks would provide a direct test of the hypothesis but requires a large sample size for statistical comparison of frond initiation parameters. This work is now planned for Spring 1983 when frond initiation rates should be relatively high (Zimmerman, personal communication). Effects of biomass density, depth, and other experimental variables may be examined further at that time. In addition, observations on synchrony of frond initiation and occurrence of simple versus multiple-division meristems will also be continued.

REFERENCES

1. Anonymous. 1970. Gran's plots and other schemes. Orion Research Newsletter, Vol. 2, #11 & 12:49-56.

2. Arnold, K.E., 1980. Ph.D. Thesis, University of California, Irvine, 149 pp.

3. Brewer, P.G. 1975. Micronutrients in seawater. In Riley, J.P. & Skirrow, G. Eds. Chemical Oceanography, 2nd ed., Vol. 1, Academic Press, London, 415-91.

4. Buggeln, R.G., 1976. Auxin, an endogenous regulator of growth in algae. J. Phycol. 12:355-358.

5. Cameron, M.C., Ross, A.G. & Percival, E.G.V. 1948. Methods for the routine estimation of mannitol, alginic acid, and combined fucose in seaweeds. J. Soc. Chem. Ind. (Lond.) 67:161-4.

6. Chapman, A.R.O. & Craigie, J.S. 1977. Seasonal growth in Laminaria longicruris: relations with dissolved inorganic nutrients and internal reserves of nitrogen. Mar Biol (Berl.) 40:197-205

7. Clendenning, K.A., 1971. Nova Hedwigia, 32: 169-188.

8. Dromgoole, F.I., 1978a. Aquatic Botany, 4: 11-22.

9. Dromgoole, F.I., 1978b. Aquatic Botany, 4: 281-297.

10. Edmonds, J.S. & Francesconi, K.A. 1980. Arseno-sugars from brown kelp (Ecklonia radiata) as intermediates in cycling of arsenic in a marine ecosystem. Nature (Lond.) 289:602-4.

11. Fiske, C.H. & SubbaRow, Y. 1925. The colorimetric determination of phosphorus. J. Biol. Chem. 66:375-400.

12. Floc'h, J.Y. & Penot, M. 1976. Etude comparative du transport a longue distance de differents radioelements dans le thalle de Laminaria digitata (Linne) Lamouroux. C.R. Acad. Sc. Paris (Series D) 289:989-92.

13. Floc'h, J.Y. & Penot, M. 1980. Variation de la composition minerale et transport a longue distance au cours de la croissance de la lame chez Laminaria hyperborea (Gunn) Fosl. Z. Pfanzenphysiol. 96.S.:377-85.

14. Frings, C.S., Neri, B.P. & Hulsey,. G. 1973. Evaluation of Harleco carbon dioxide apparatus, comparison with Natelson microgasmeter and SMA 6/60 methods for determining serum bicarbonate (carbon dioxide). Clin. Chem. 19:1227.

15. Gerard, V.A. 1976. Some aspects of material dynamics and energy flow in a kelp forest in Monterey Bay, California. Ph.D. Thesis, Univ. Calif. Santa Cruz, 173 p.

16. Gerard, V.A. 1982. Growth and utilization of internal nitrogen reserves by the giant kelp Macrocystis pyrifera in a low nitrogen environment. Mar. Biol. 66:27-35.

17. Gerard, V.A./, & 10 coauthors. Effects of harvesting on growth of giant kelp Macrocystis pyrifera (Phaeophyta, Laminariales). Submitted to Phycologia.

18. Hart, L.C. 1982. Auxins as plant growth regulators in the marine alga Pelagophycus porra (Leman) Setchell (Phaeophyta, Laminariales). Ph.D. Thesis, Univ. Southern Calif., 271 p.

19. Iverson, R.L. et al. 1976. Limnology Oceanography, 21: 756-758.

20. Jackson, G.A. 1977. Nutrients and production of giant kelp, Macrocystis pyrifera, off southern California. Limnol. Oceanogr. 22: 979-95.

21. King, R.J. and W. Schramm, 1976. Marine Biology 37: 215-222.

22. Kirst, G.O. & Bisson, M.A. 1979. Regulation of turgor in marine algae: ions and low molecular-weight organic compounds. Aust. J. Plant. Physiol. 6:539-56.

23. Kremer, B.P., 1981. Phycologia, 20: 242-250.

24. Littler, M.L., 1979. Aquatic Botany, 7: 21-34.

25. Lobban, C.S. 1978. Translocation of ^{14}C in Macrocystis pyrifera (Giant Kelp). Plant Physiol. 61:585-9.

26. Lobban, C.S., 1974, Limnology and Oceanography, 19: 356-356.

27. Lowry, O.H., Rosebrough, N.J., Farr, A.L. & Randall, R.J. 1951. Protein measurement with the Folen phenol reagent. J. Biol. Chem. 193:265-75.

28. Manley, S.L. 1981. Iron uptake and translocation by Macrocystis pyrifera. Plant Physiol. 68:914-8.

29. Manley, S.L., 1981. Plant Physiology, 68: 914-918.

30. Moore, S. & Stein, W.H. 1948. Photometric ninhydrin method for use in the chromatography of amino acids. J. Biol. Chem. 176:367-88.

39. North, W.J. 1971. Introduction and background. Beih.z.Nova Hedwig. 32: 1-97

40. Parker, B.C. 1966. Translocation in Macrocystis. III. Composition of sieve tube exudate and identification of the major C^{14} - labeled products. J. Phycol. 2:38-41.

41. Sargent, M.C., & L.W. Lantrip. 1952. Photosynthesis, growth, and translocation in giant kelp. Amer. J. Bot. 39:99-107.

42. Schmitz, K., & L.M. Srivastava. 1979. Long distance transport in Macrocystis integrifolia. I. Translocation of ^{14}C-labeled assimilates. Plant Physiol. 63:995-1002.

43. Schmitz, K., & L.M. Srivastava. 1980. Long distance transport in Macrocystis integrifolia. III. Movement of THO. Plant Physiol. 66:66-69.

44. Schmitz, K. & Srivastava, L.M. 1974. The enzymatic incorporation of ^{32}P into ATP and other organic compounds by sieve-tube sap of Macrocystis integrifolia Bory. Planta (Berl.) 116:85-9.

45. Schmitz, K. & Srivastava, L.M. 1979a. Long distance transport in Macrocystis integrifolia. I. Translocation of ^{14}C-labeled assimilates. Plant Physiol. 63:995-1002.

46. Schmitz, K. & Srivastava, L.M. 1979b. Long distance transport in Macrocystis integrifolia. II. Tracer experiments with ^{14}C and ^{32}P. Plant Physiol. 63:1003-9.

47. Stanton, M.G. 1968. Colorimetric determination of inorganic phosphate in the presence of biological material and adenosine triphosphate. Anal. Biochem. 22:27.

48. Strickland, J.D.H., 1960. Fisheries Research Board of Canada, Bulletin 122: 1-172.

49. Strickland, J.D.H. and T. Parsons, 1972. Bulletin Fisheries Research Board of Canada, 167: 1-310.

50. Strickland, J.D.H. & Parsons, T.R. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Board Can. 167:71-89

51. Toennies, G. & Bakay, B. 1953. Photonephelometric microdetermination of sulfate and organic sulfur. Anal. Chem. 25:160-5.

52. Towle, D.W., & J.S. Pearse. 1973. Production of the giant kelp Macrocystis, estimated by in situ incorporation of ^{14}C in polyethylene bags. Limnol. Oceanogr. 18:155-159.

53. Wassman, E.R. and J. Ramus, 1973. Marine Biology, 21: 289-297.

54. Willenbrink, J. et al., 1979. Canadian Journal of Botany, 57: 890-897.

55. Ziegler, H. 1975. Nature of transported substances. In Zimmerman, M.H. & Milburn, J.A. Eds. Transport in Plant I. Phloem Transport, Springer-Verlag, Berlin, 59-100.

5.3 GOLETA KELP CULTIVATION BIOLOGY

5.3 GOLETA KELP CULTIVATION BIOLOGY

The 1982 effort at the Goleta Test Facility (GTF) was a continuation of the work that was initiated in April 1981 by Neushul Mariculture Incorporated (NMI). The major objective of the GTF was to determine sustainable harvest yield as a function of crop density and fertilization.

The GTF consisted of two, one-half acre test plots each containing approximately 350 adult Macrocystis plants. One plot was fertilized while plants on the second were exposed to naturally ambient nutrients only. On each test plot, the plants were grouped into three planting (biomass) densities. These were 0.0625 plant/square meter (low density), 0.25 plant/sq. m. (medium), and 1.0 plant/sq. m. (high). These densities compare to 1 plant every 16, 4, and 1 square meters, respectively. The plants were hand-harvested at three month intervals, thereby producing data for a full growing season. In addition to the yield task, NMI performed work in the areas of plant genetic selection and characterization, environmental monitoring and the assessment of foreign kelp growth technology.

The following sections discuss the experimental observations, results and conclusions.

5.3.1 DENSITY, FERTILIZATION AND YIELD STUDIES

5.3.1.1 Planting

The purpose of the yield study was to determine the yields that could be obtained from a large sample of mature plants grown under defined and maintained planting densities. Major goals were to determine if the frond growth and initiation rates remained high and how the plants would respond to quarterly harvests and nutrient fertilization.

Planting the farm was accomplished by collecting 722 mature Macrocystis angustifolia plants from the inshore area of bed # 28 near Ellwood, California. Each plant was cut loose from the sea floor with a pruning saw and harvested at approximately one meter below mean tide level. This pre-planting harvest made it easier to transport the plants to the farm and established an initial "starting point" for all the plants. The plants were placed in nylon-mesh bags and taken to the surface where both the plant and holdfast were weighed and plastic tags were affixed. They were then transported by boat to the farm. Once at the farm, the holdfasts were placed into the tops of gravel-filled mesh bags. The mouth of each bag was closed above the

holdfast, around the base of the primary basal branches. These bags were then allowed to sink to the sea floor and were tied to one-half inch chain and rope lines, which were laid out to make a planting grid with rope-chain intercept points serving as sites for each plant. The farm consisted of two one-half acre plots which were in turn divided into five sections. There were two low-density sections each with 0.0625 plant per square meter on a four-meter grid, two medium-density sections with 0.250 plant per square meter on a two-meter grid, and one high-density section with one plant per square meter on a one meter grid. Each plot was in about 23 feet (7m) of water and oriented perpendicularly to the prevailing swell. Of the total 722 plants, 72 of these were extensively studied "sample plants". These plants had each frond tagged with a plastic tag on a quarterly basis and the growth of individual fronds was followed. Of the remaining 650 plants, six were used as "handling" controls for the sample plants, these being measured underwater to avoid handling damage. Figure 5.3-1 shows the attachment detail for an individual plant. Figure 5.3-2 indicates the general planting arrangement on one of the test plots.

5.3.1.2 Cultivation, Harvesting and Measurement

Cultivation, harvesting, and measurement were an extension of the 1981 work and were continued through 1982 along with the other tasks discussed below. Three experiments were run simultaneously. These were:

Density-yield
Fertilization-yield
Frond-production

In the density-yield experiment, various areas of both plots were harvested on a quarterly basis at one meter below the mean low tide level. For each plant, the number of fronds at one meter above the holdfast and at the harvest point were counted. The canopy was then cut off and placed in a mesh bag by a diver and taken to a boat where it was allowed to drip until all the excess water was removed. The bags were then weighed to the nearest 0.5 kilogram. Any of the plants that were lost or that had died during the quarter were recorded as such and were replaced at the end of the harvest. Plants that were living but that had no fronds reaching the harvest depth, were recorded as plants with no canopy but were not replaced.

The fertilization-yield experiment involved repeated applications of fertilizer. One of the two half-acre plots was fertilized four to five days a

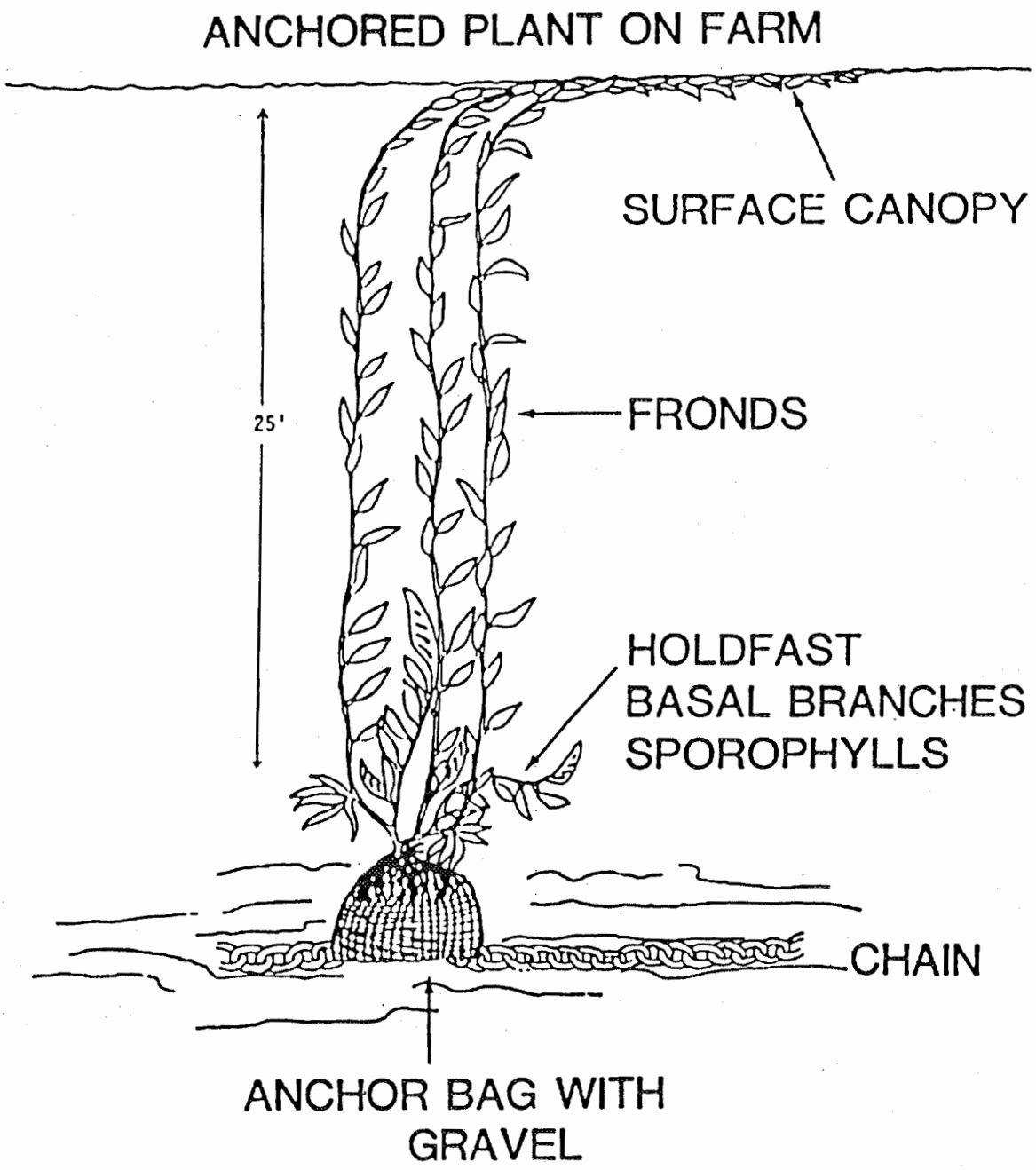


Figure 5.3-1. Gravel-Bag Plant Anchor Design with Plant Attached

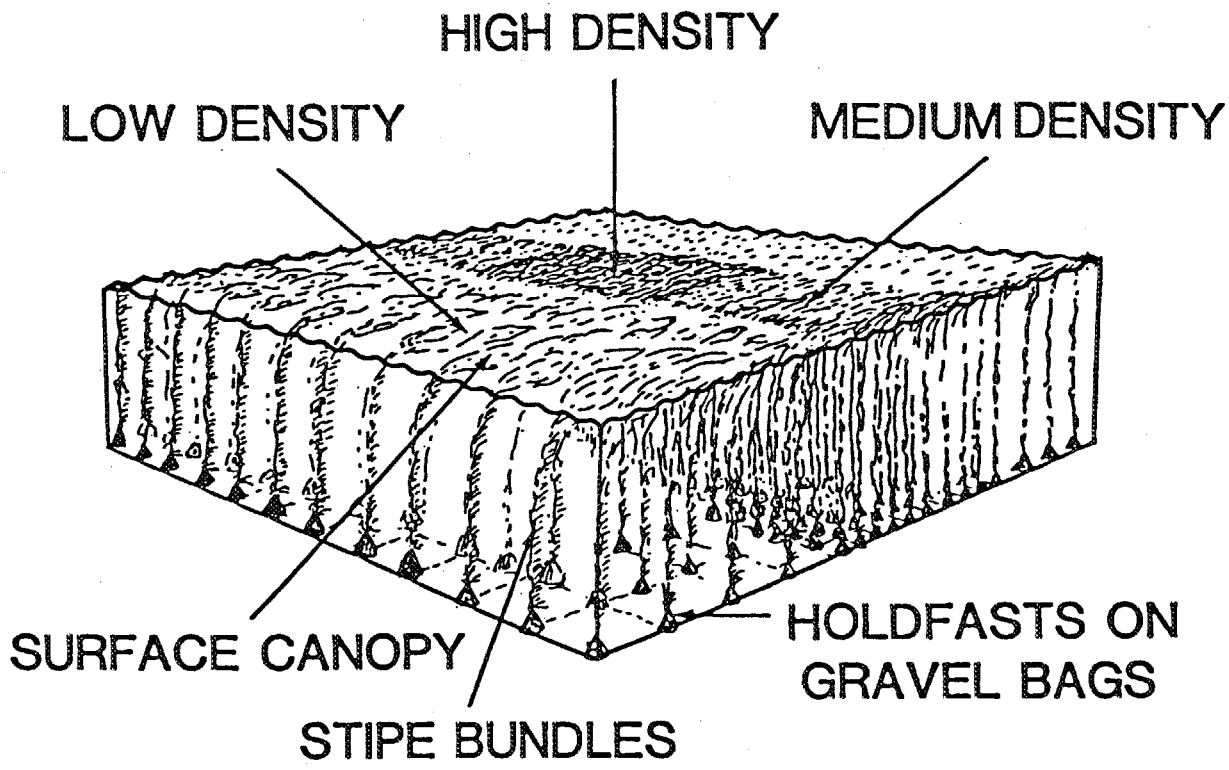


Figure 5.3-2. General Experimental Planting Arrangement

week depending on the weather, while the other acted as a control and received no fertilizer. The fertilization was performed by dissolving solid ammonium sulfate in sea water and applying it at a rate of 37.8 grams per square meter. A fertilizer boat was used to apply nutrients through a spray gun directly onto the kelp canopy.

The frond-production experiment utilized sample plants which were randomly chosen from the test plant population. At three month intervals, the sample plants were removed from the water, taken aboard a boat, and spread out on a marked table. The fronds were individually identified and tagged at the base with a numbered plastic tag. The fronds were then measured to the nearest 10cm; those that were longer than the harvest length (1 m below mean low tide) were individually harvested and weighed. When all of the fronds were tagged and measured, the plants were returned to their respective locations. The anchoring system for the sample plants used in the frond-production experiment was somewhat different from that used for the population plants. While mesh bags were used, these contained floats and were tied to the farm grid so that they could be easily and repeatedly removed and replaced. Later, the floats were discarded and the plants were planted directly in gravel-filled bags and removed periodically for processing. Since these plants received extensive handling, and it was not certain what the effect of repeated dislodgements and handling would be, six plants from one of the medium density areas were chosen to function as controls. These plants were treated in a way similar to the sample plants except that they were removed from the water; the canopy was harvested at the same time as the normal population plants. Each frond of the controls was carefully disentangled from the rest of the plant and then measured by stringing it out on the sea floor next to a plastic measuring tape.

5.3.1.3 Cultivated Kelp Bed Yield and Stability

The results of the Macrocystis yield study show quite clearly that there is a pronounced effect of plant crowding (Figure 5.3-3). If the edge plants are disregarded and only the center ones evaluated, one can see that the number of fronds produced per plant increased for plants at low density, remained about the same for plants at medium density, and decreased from 25 to around 10 fronds total for plants at the highest planting density. The effect of density is also evident when the production of tissue by individual plants is considered. Here again the production of low density plants was higher than that of medium and high density plants (Figure 5.3-4).

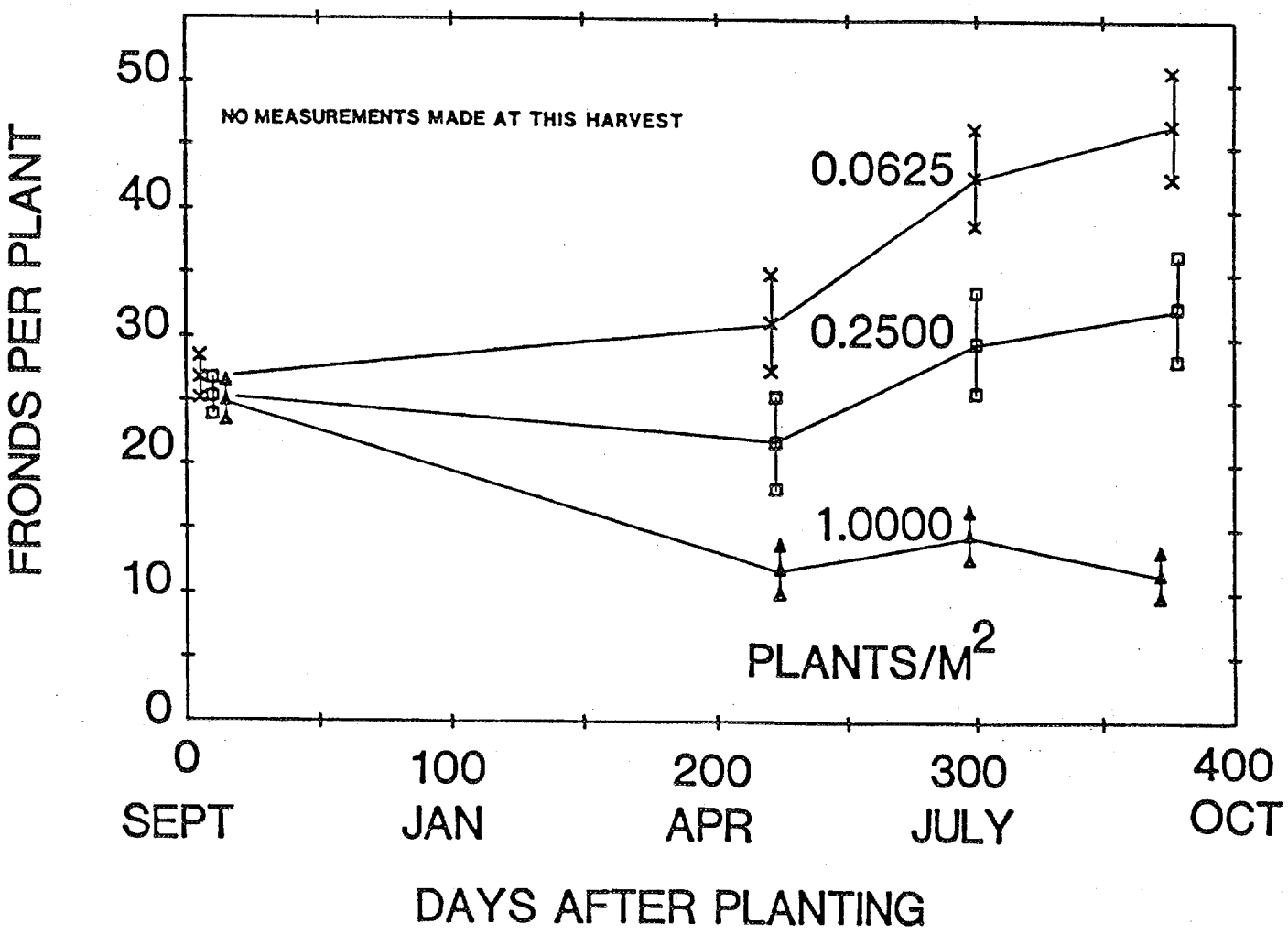


Figure 5.3-3. Changes in Macrocystis Number as a Function of Planting Density

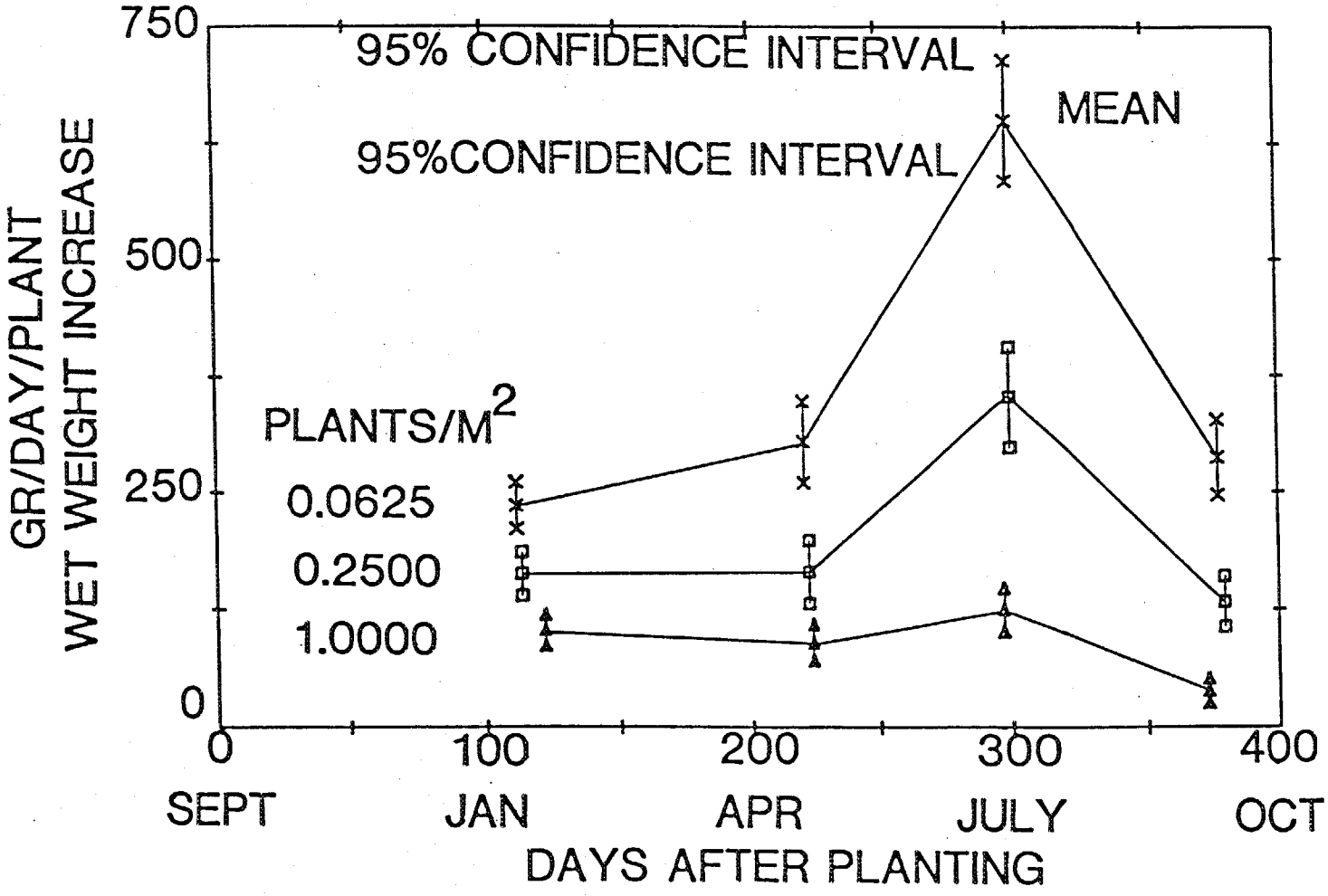


Figure 5.3-4. Plant Wet Weight Increase

The projected yield from four seasonal harvests at three planting densities in dry ash-free tons per acre per year, ranged from a high of around 15 DAFT/AY for high-density plantings to 2 to 3 for low-density plantings (Figure 5.3-5). The higher number is similar to what had been projected from the 1981 data (Neushul, Harger and Woessner 1981) while the lower number is similar to estimates from natural kelp beds.

The results of the planting, cultivating and harvesting tasks show that there is a major seasonal difference in yield, with the Spring harvest in June being the highest at all densities. There is significant upwelling of nutrient-rich water in early Spring. The lowest harvests were in late summer when nutrient levels had been low for several months while temperatures and light levels were high. It was found that fertilization was effective only during this "nutrient drought" period of the year (Table 5.3-1). At low densities, fertilization had no significant effect, but at medium density, yield was doubled and at high density, quadrupled.

During the course of the yield studies, it was observed that some individual plants consistently produced significantly more biomass than the average population. Six of these plants were selected for further study. Their production is compared in Figure 5.3-6 to the population average in the low density (highest individual plant growth average) plot. Spores from these plants were collected for future study with the objective of attempting to produce populations of adults with similar high-yield characteristics.

An additional striking relationship was observed during the course of the study in the apparent effect of planting density on plant mortality. The low and medium plantings had similar mortality rates, approximately 4.5 percent, over the study. The high density group, however, averaged 16 percent mortality with a peak of 26 percent occurring during the winter (lowest light level) period. The plant mortality data is summarized in Figure 5.3-7. Detailed growth rate, yield and mortality are listed as follows:

First Harvest	Table 5.3-2 - (A-U) (Appendix A)
Second Harvest	Table 5.3-3 - (A-N) (Appendix A)
Third Harvest	Table 5.3-4 - (A-I) (Appendix A)
Fourth Harvest	Table 5.3-5 - (A-I) (Appendix A)
Fifth Harvest	Table 5.3-6 - (A-I) (Appendix A)

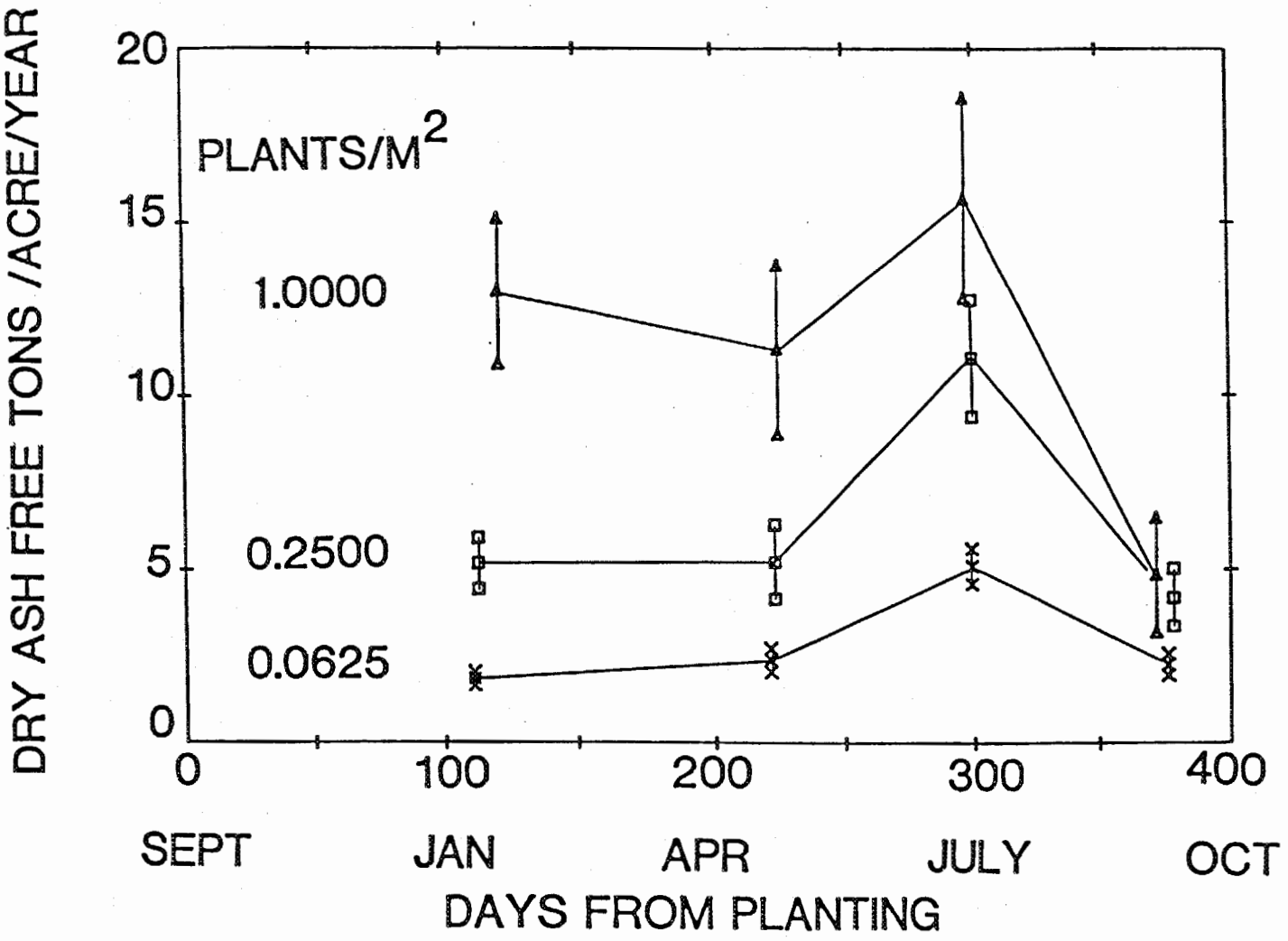


Figure 5.3-5. Projected Yield for Four Seasons and Three Planting Densities

TABLE 5.3-1. THE INCREASE IN WET WEIGHT PRODUCTION DUE TO FERTILIZATION

The information used here is the individual plant production for center plants only. It is in grams per day.

First Harvest (December 1981-January 1982)

Density	Fertilization	Mean	Std. Dev.	n	t	p
Low	Unfertilized	254.91	174.63	78		
	Fertilized	217.81	143.10	80	1.46	0.150
Medium	Unfertilized	192.25	136.84	63		
	Fertilized	134.98	120.86	62	2.48	0.014
High	Unfertilized	115.49	104.25	67		
	Fertilized	91.99	92.42	68	1.39	0.171

Second Harvest (March-April 1982)

Density	Fertilization	Mean	Std. Dev.	n	t	p
Low	Unfertilized	297.99	300.30	78		
	Fertilized	310.38	254.26	78	0.28	>0.200
Medium	Unfertilized	168.40	200.66	61		
	Fertilized	162.60	185.93	63	0.17	>0.200
High	Unfertilized	84.28	113.18	66		
	Fertilized	96.05	116.50	67	0.59	>0.200

Third Harvest (June-July 1982)

Density	Fertilization	Mean	Std. Dev.	n	t	p
Low	Unfertilized	658.80	436.79	84		
	Fertilized	640.25	417.30	83	0.28	>0.200
Medium	Unfertilized	327.98	279.18	63		
	Fertilized	375.96	338.24	65	0.87	>0.200
High	Unfertilized	134.92	137.54	73		
	Fertilized	115.04	145.98	72	0.84	>0.200

Fourth Harvest (September 1982)

Density	Fertilization	Mean	Std. Dev.	n	t	p
Low	Unfertilized	249.54	278.71	86		
	Fertilized	323.96	254.87	86	1.83	0.071
Medium	Unfertilized	87.03	115.57	65		
	Fertilized	179.48	175.55	65	3.55	<0.001
High	Unfertilized	15.92	31.61	73		
	Fertilized	61.11	105.89	73	3.49	<0.001

Fifth Harvest (December 1982)

Density	Fertilization	Mean	Std. Dev.	n	t	p
Low	Unfertilized	170.00	186.77	85		
	Fertilized	121.04	159.61	86	1.84	0.068
Medium	Unfertilized	124.58	111.12	65		
	Fertilized	153.00	152.43	65	1.21	>0.200
High	Unfertilized	43.39	59.69	73		
	Fertilized	37.08	66.96	73	0.60	>0.200

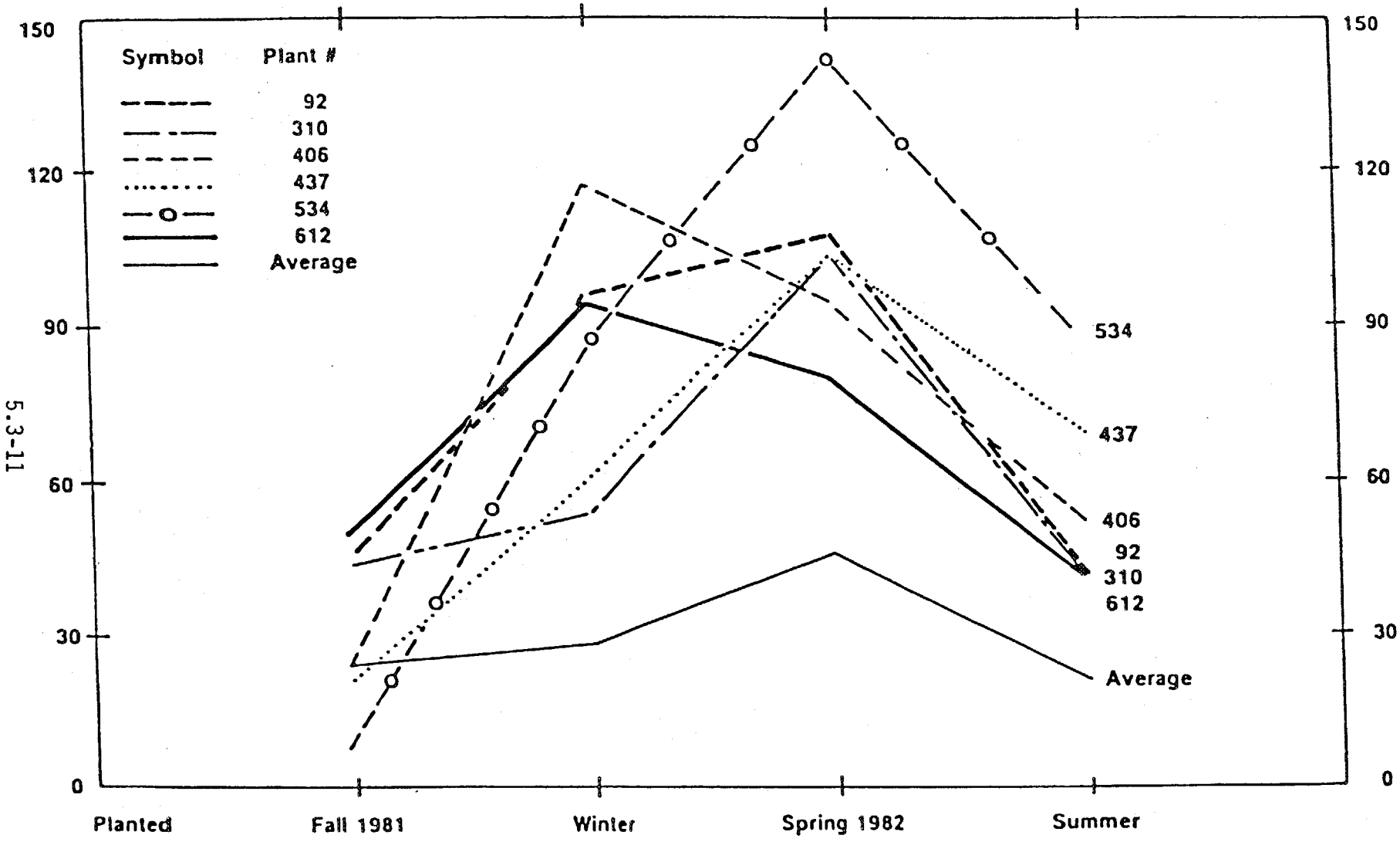


Figure 5.3-6. Harvested Yield from Six Selected High Yielding Plants Compared to the Average Yield of Low Density Plants for Four Seasonal Harvests

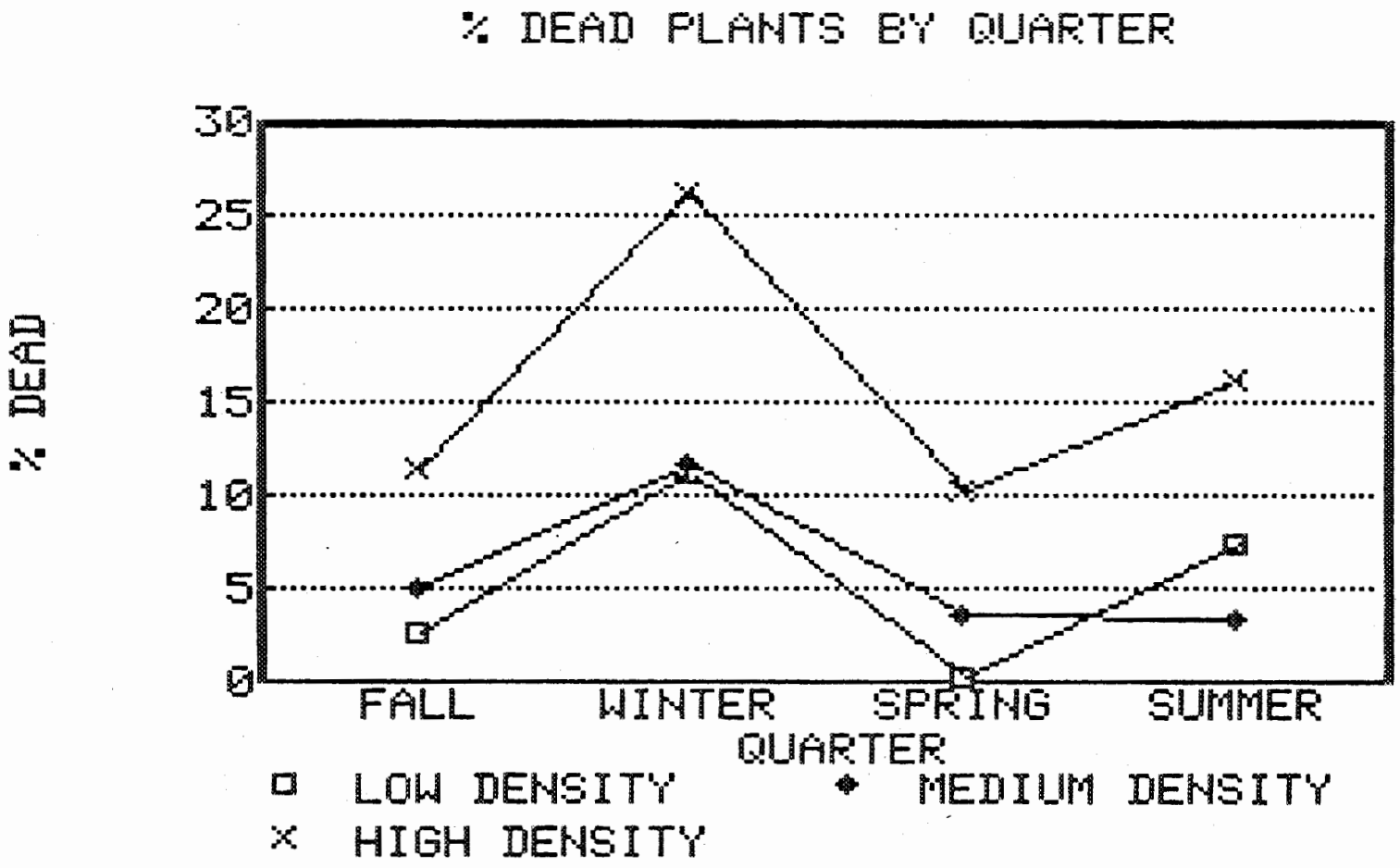


Figure 5.3-7. Death Rate at the End of Four Seasonal Harvests at Three Planting Densities

SUMMARY

The nearshore planting of twelve tons of Macrocystis returned a harvestable yield of fifty-five tons during the 12 month observation period and sixty-one tons from the time of initial planting in October 1981.

Measurements of frond-production and biomass yield from individual plants show that planting density has an effect on the giant kelp, reducing individual plant frond production and plant yield as density increases. The data indicate that farms with one plant per square meter will produce large amounts of biomass per acre, but may not sustain this yield, since the individual plants do not produce new fronds rapidly and become smaller. In contrast, both the intermediate and low-density plants increased in size, even when harvested quarterly.

If it is assumed that no fronds were lost, and all fronds that were produced were eventually harvested, a projected frond production rate can be calculated. The low-density plants had an average of 6.5 fronds harvested per month with a net increase of 1.7 fronds per month. Their total gross production was 8.2 fronds per month. The medium-density plants had an average of 4.8 fronds harvested per month with a net increase of 0.6 frond per month. Their total growth production was 5.4 fronds per month. The high-density plants had an average of 2.0 fronds harvested per month with a net decrease of 1.1 fronds per month. Their total gross production was 0.9 frond per month. These rates all fall within the range reported by Gerard (1976) for natural kelp beds in Central California. The average wet weight production per day of individual plants was found to be 0.63 percent, 0.69 percent, 1.3 percent and 0.73 percent for the fall, winter, spring and summer harvest respectively. The average whole-plant growth per day for the entire year was calculated to be 0.71 percent.

The test farm is at least as stable as natural kelp beds, showing similar patterns of plant growth and loss. The plants on the test farm appear to respond to fertilization during the low-nutrient, high-irradiance months of late summer, with the medium-density yield being doubled and the high-density yield being quadrupled.

High mortality in the high-density plot is thought to be due to the effects of shading. Future research arising from this consideration will have the objective of increasing average light to densely planted tissue through row planting and higher frequency of harvesting. If a planting and/or harvesting strategy could be developed to reduce shading in the crop, higher yields and lower mortality might be possible with dense plantings.

Preliminary fertilization efforts indicate that plants with a developed surface canopy can be spray-fertilized from the sea surface, but that widely scattered plants at low-density are not as effectively fertilized. This is probably due to the fact that the heavier surface canopy in the denser plots confines water than can be enriched by fertilization and not washed out and diluted.

Increased yield might also be achieved by selecting and propagating the highest-yielding plants.

5.3.2 GENETICS AND PLANT CHARACTERIZATION

5.3.2.1 Gametophytic and Sporophytic Seedstock

During 1982, gametophytic and sporophytic seed-stock was maintained in the laboratory and in the field. NMI maintained 468 kelp gametophyte cultures through 1982 with no losses. Of these, 115 are duplicates of monoclonal (single-spore derived) cultures initiated at the University of California at Santa Barbara (UCSB) in 1975.

In collaboration with the UCSB marine botany group, bacteria-free kelp gametophytes were produced. These were obtained from one of the high-yield kelp plants identified in 1982.

5.3.2.2 Characterization of Seedstock

By mid-summer 1982, only five of the genetically-defined plants that were outplanted in 1980 and 1981 remained. These were still on the original float-bags attached to chains on the bottom. The plants were detached, taken to the Ellwood Pier greenhouse, analyzed in detail, and replanted on sea-floor gravel bags. Of particular interest was the observation that the remaining Macrocystis pyrifera plant was much more robust and showed less sloughing than any of the Macrocystis angustifolia plants under study. It is clear that maintaining the rapidly growing and changing sporophytic phase of the kelp life history requires much cultivation and monitoring work, particularly when the plants reach a large size (Table 5.3-7 Appendix A).

It is likely that one will not obtain maximum yields from a farm by planting randomly-selected wild plants. It should be possible to select for longevity (which would be a function of holdfast development and resistance to decay) or high yield. The hand harvesting and stipe counts made for individual plants on the test farm have shown that some plants have consistently produced more fronds and more material than the others. Selection of high-yield plants is an obvious

first step in the domestication of giant kelp as a biomass producer. Tables 5.3-7 and 5.3-8 (Appendix A) give detailed data for the high yielding individual plants observed during the course of the study.

5.3.3 ENVIRONMENTAL MONITORING

The atmospheric and oceanographic climatological conditions at the farm were monitored. In general, the year was a relatively calm one, with a normal pattern of light, temperature and nutrient availability. In view of the interesting results of planting density and fertilizer application experiments, it became obvious that light availability and shading, both self-shading and between-plant shading, were likely to be significant factors influencing yield. Consequently, an effort was made to document the light climate in the kelp farm. By determining the photosynthetic efficiency of a kelp crop grown under a defined set of environmental cultivation conditions, and developing an understanding of the factors which influence and limit photosynthetic efficiency in crop systems, we attempted to analyze the yield variations and to suggest possible improvements in kelp farming practices.

The light climate of the Goleta Test Farm was determined both by measurements of light at the sea surface and underwater. Average solar radiation levels were determined from continuously recorded pyranometer readings at the University of California, Santa Barbara. These readings showed 1982 light to follow a seasonal pattern similar to prior years (see Figure 5.3-8). Underwater light profile transects on the farm were taken before and after each harvest using a Li-Cor underwater quantum flux sensor. Surface irradiance was measured at the same time that underwater measurements were being made. This was done with a Li-Cor LI-190SB quantum sensor (with a cosine collector). The Li-Cor meters measure photosynthetic photon flux density (PPFD) in the waveband used by plants for photosynthesis (400 to 700 nm).

Light within the kelp farm was measured along transects through the farm from outside the planting area, through the crop and out the other side, covering a distance of 72 meters. These transects ran through low, medium, and high density plantings. Irradiance readings were taken along the transects 0.5m above the bottom at 2 meter intervals and at the base of each plant. After every fifth reading, a reading of the surface irradiance was made by a tender on a boat outside of the farm. Diver and boat readings were coordinated by using a Helle underwater communications system, allowing the boat operator and diver to talk to

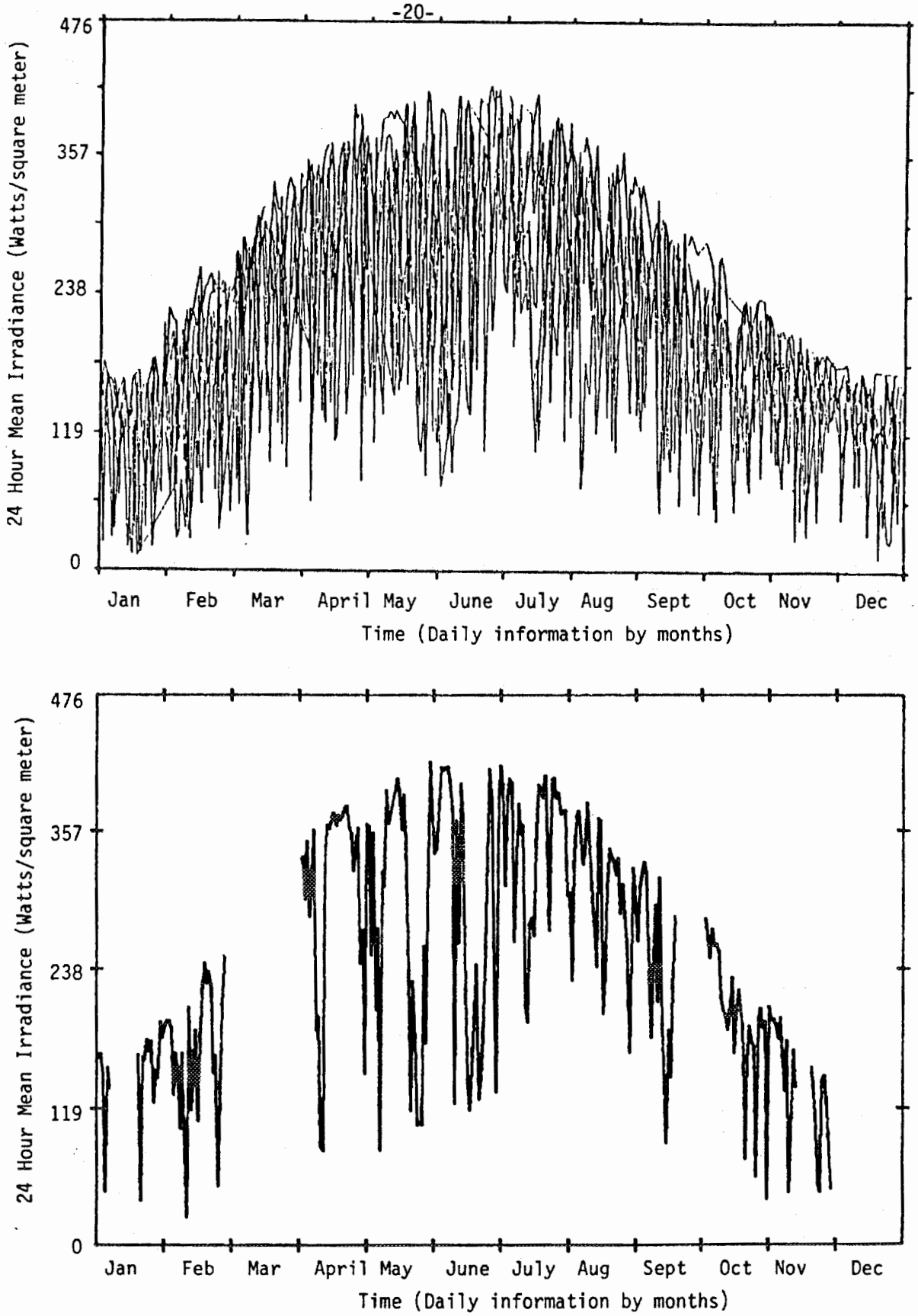


Figure 5.3-8. Surface Irradiance in Goleta from 1968 to 1977 (Above, Plotted Superimposed) and in 1982 (Below). The Surface Irradiance in 1982 Followed a Pattern Similar to that of Prior Years (1968 to 1977 Plot from Harger 1979).

one another. Horizontal and vertical secchi disc readings were taken at the surface, 4 meters, and the bottom before and after each transect run. All the transect measurements were made between 10 a.m. and 2 p.m. to reduce the effects of early-morning and late afternoon low sun angles (which produce increased reflection) on subsurface irradiance levels. Light climate measurements along the transects were expressed as a percentage of surface light.

The light "envelope" around individual plants was studied by making four short linear transects out from the holdfast center, along compass headings. North, South, East and West transects were run for each plant, and light was measured at 5cm intervals across the holdfast and then at 10cm intervals along the bottom moving away from the plant.

The light climate was significantly altered both by planting density and by harvesting. Little affect was seen within the low density plot. Pre-harvest irradiance levels at the bottom, outside of the farm, averaged 11.2 percent of surface reading. Irradiance within the low-density plot averaged 5.2 percent of the surface irradiance. Post-harvest irradiance levels outside of the farm averaged 7.6 percent. Post-harvest irradiance inside the low density plot averaged 4.6 percent. Dramatic reductions in irradiance occurred in the medium and high density plots. Before harvest irradiance levels averaged 7.1 percent outside the farm. Irradiance dropped to 1.02 percent in the medium-density plot and to 0.12 percent in the high density plot. After harvesting, irradiance outside the farm averaged 9.2 percent. Medium density plot irradiance increased to 4.1 percent and high-density plot irradiance increased to 0.8 percent. Figures 5.3-9 and 5.3-10 show irradiance levels in the high and medium density plots, pre and post harvest.

Irradiance reduction attributable to self-shading by individual plants is greatest at the holdfast, within the clump of fertile blades and frond initials. Average irradiance levels were 0.65 percent of surface irradiance outside the two plant holdfasts that were studied. Irradiance outside the holdfast rapidly increased to normal sea-floor levels. The zone of severe irradiance reduction appears to extend approximately 1.0 to 2.0 meters from the center of the holdfast in all directions. Thus, one would anticipate severe light reduction in a high-density planting where the plants were one meter apart, which is what is seen in the transacts run through the high-density plantings.

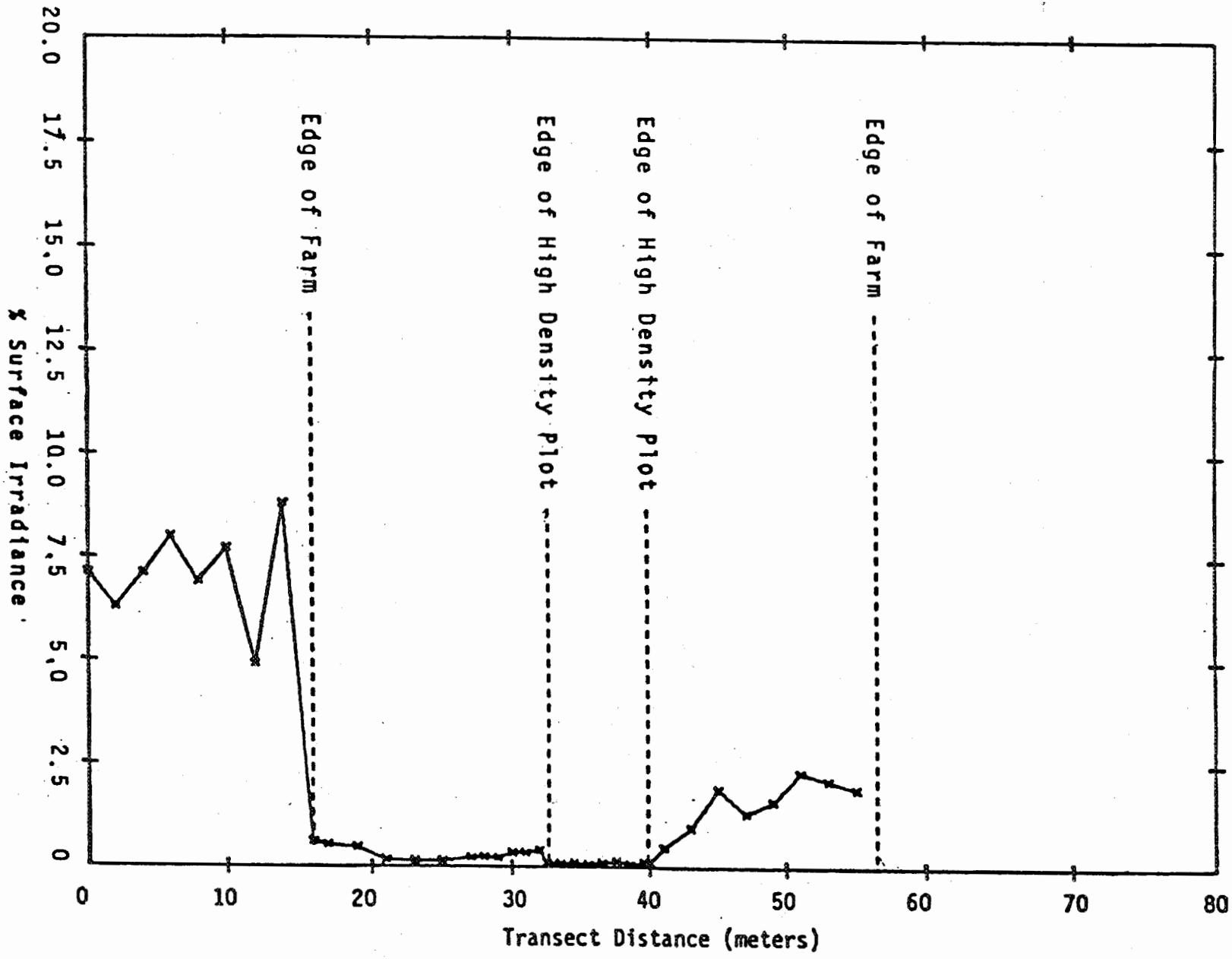


Figure 5.3-9. Irradiance Reduction by High and Medium Density Plantings, June 15, 1982 ("Pre-harvest")

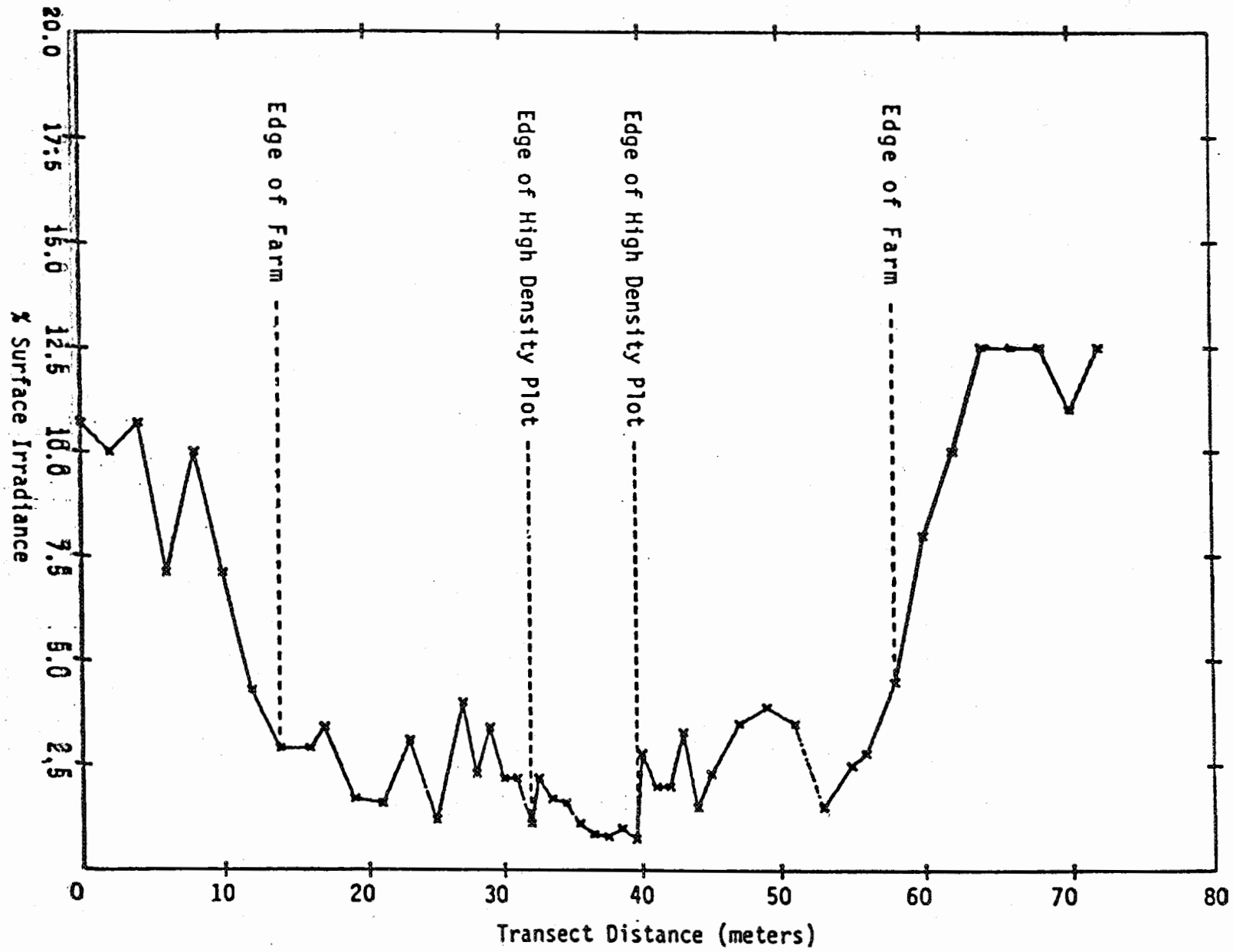


Figure 5.3-10. Irradiance Reduction by Medium and High Density Plantings, August 4, 1982 ("Post-harvest")

Light climate appears to be an important factor in determining harvest yields for kelp crops, particularly if other potentially limiting factors such as nutrients can be supplied during cultivation. The kelp plant has a number of morphological characteristics which increase its ability to gather light. For example, it has spiralling blades on the fronds near the base that have an effect like that produced by leaf phyllotaxy in land plants, while the same fronds produce bilaterally arranged blades, layered and spaced with a shingling-effect nearer the surface. This offsetting of blades no doubt contributes to more effective light harvesting. The surface corrugations on the blades may have an important hydrodynamic function, but also contribute to blade stiffness which controls the degree to which the blades remain horizontal in the water. These and other features serve to optimize blade orientation to incident light.

Light is always limiting during some part of the day in dense crop stands. Biomass production can be increased by increasing crop light interception and by reducing wasteful respiration. The 1982 yield results support this reasoning. Yields and presumably areal photosynthetic efficiency per unit area of sea surface were both highest for the dense planting treatment. Dense row planting might reduce the amount of solar radiation which is now lost to open spaces in the crop canopy. Optimal light utilization by a crop occurs when the incoming light is distributed as evenly as possible over the largest possible leaf area. This reduces the fraction of leaves exposed to irradiances below compensation or above saturation levels and minimizes respiratory losses. Maximum yields also require that the leaf area index of the crop be optimized. Harvest depth and frequency may well effect the size of the photosynthetic units in the blades. If the crop is cut back too deeply or too often, the leaf area index would be reduced below its optimum and solar energy would be "wasted". If, however, enough canopy can be removed to eliminate the shading of new and subsurface fronds without areal lowering photosynthetic efficiency significantly, then yield should be enhanced. Proper orientation of the farm rows may increase the interception of light by the crop.

Changes in light quality within the kelp canopy are still poorly understood. Light within the canopy may be enriched in the non-photosynthetically active regions due to differential transmission by the blades. The test results also indicate that dense kelp beds reduce lateral transmission within the farm plot which may in turn reduce day length in the lower parts of stand. Strip harvesting of alternate rows at different times could improve light climate while avoiding dramatic reductions in the size of the crop. Frequent harvesting may also reduce

mortality by decreasing drag forces and tangling which contribute to plant loss particularly during storm periods.

In order to calculate the areal photosynthetic efficiency of the Goleta Test Farm test plants, one would have to convert the weights of the material harvested to energy equivalents and compare this harvested energy with the amount of whole spectrum solar energy incident on the farm (1 acre surface). Based on kelp energy content of 1.7×10^7 BTU per DAFT of kelp, an incoming solar flux of 2.3×10^{10} BTU per acre, and harvested biomass yields ranging from 2.88 DAFT/A-Y in the low-density plots to 11.21 DAFT/A-Y in the high-density plots, areal photosynthetic efficiency under the test conditions was estimated to be in the range of 0.2 to 0.8 percent.

Plant production both in natural kelp beds and in the cultivated bed, appears to track variations in solar irradiance rather than nutrient concentrations (Figure 5.3-11).

5.3.3.1 Temperature and Nutrients in 1982

Lowered water temperatures and elevated nitrate concentrations were coincidental in 1982, natural enrichment occurring in late March and again in May. Current speeds at the GTF rarely exceeded 8 cm/sec. Vertical visibility was generally lower during the January to April period and higher in summer, following the usual seasonal pattern (Appendix A).

5.3.4 FOREIGN TECHNOLOGY ASSESSMENT

Professor X.G. Fei of the Institute of Oceanology, Quingdao, China continued his work on the effects of light on kelp growth and development at UCSB. Professor Fei also participated in the SUNY, Stony Brook marine farming workshop, and in addition, spent two months working directly with the New York program to produce seedstock and to help with planting. Professor C.K. Tseng from the Peoples Republic of China visited the Goleta facility on August 21 and August 23.

NMI maintained contacts with the Japanese Marine Biomass Program through formal and informal meetings and discussions with a number of Japanese marine scientists.

In May, Dr. Neushul was invited to give a seminar in Ensenada, Mexico, by the Sea Grant/Mexico program. In August, a television crew from Japan visited and made a trip from Santa Barbara to the Goleta Test Facility. They also visited the pier, greenhouse, and laboratory facilities where they added to their video-taped

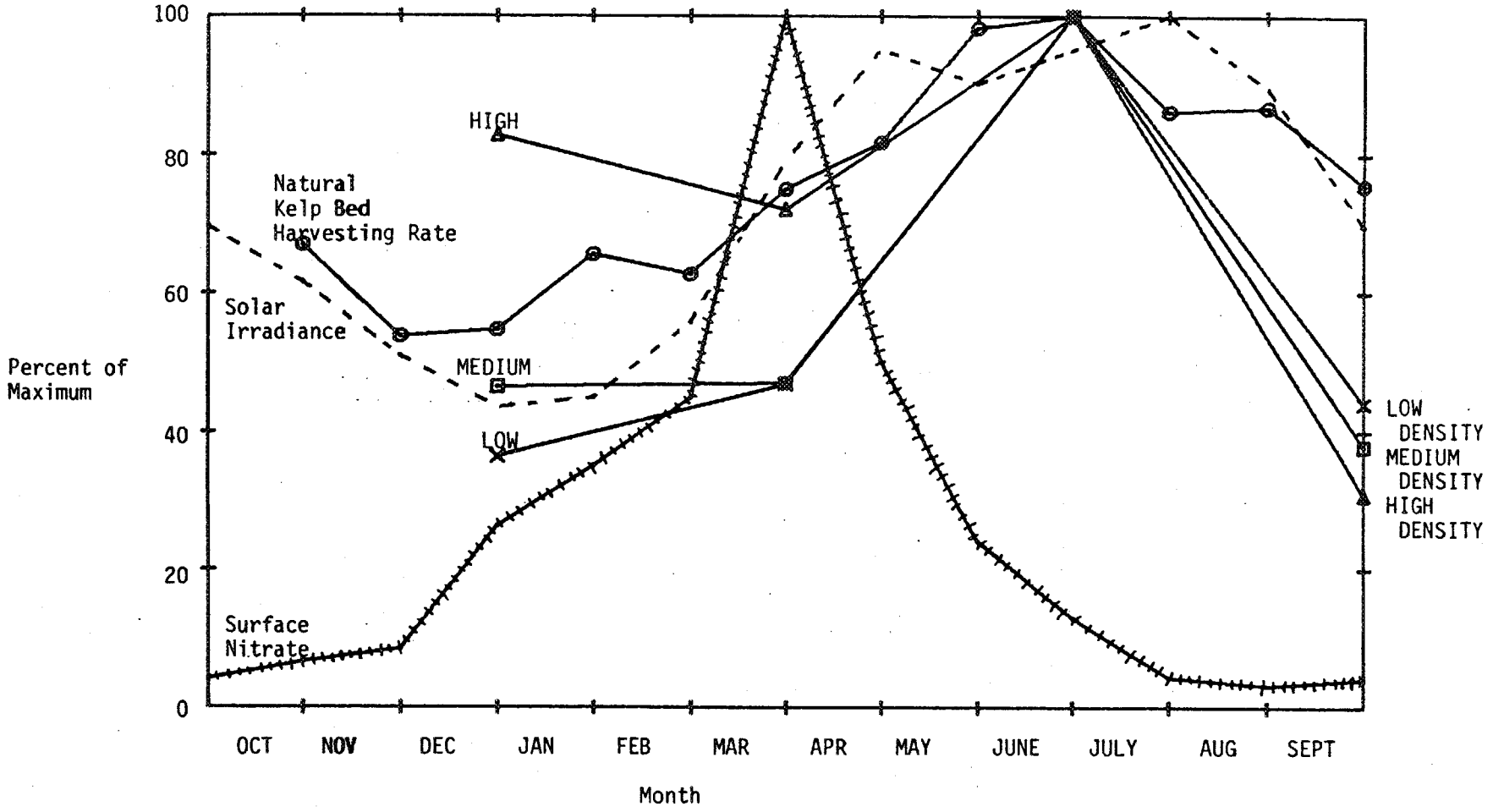


Figure 5.3-11. Seasonal Variation of Solar Irradiance, Surface Nitrate Concentration, Natural Kelp Bed Harvesting Rate and Individual Plant Production Rate (for Center Plants Only) for Plants Planted at Low Density (0.0625 plants/m^2), Medium Density (0.2500 plants/m^2) and High Density (1.0000 plants/m^2)

footage. A program dealing with marine biomass farming was subsequently given for Japanese television. In November and December, NMI had visits from Dr. Amos Richmond of the University of the Negev, Israel, and Nagahisa Uki of the Tohoku Regional Fisheries Research Laboratory in Shiogama, Japan. All of these visitors provided NMI with valuable information on marine biomass programs and uses in other parts of the world.

APPENDIX A

A-1 Tables for Experimental Results

Tables 5.2-3, 5.2-4, 5.2-5, 5.3-2, 5.3-3, 5.3-4, 5.3-5, 5.3-6, 5.3-7 and 5.3-8

A-2 Goleta Environmental Data

A-3 Hemidome Engineering Support

APPENDIX A-1

TABLES FOR EXPERIMENTAL RESULTS

TABLE 5.2-3. ENVIRONMENTAL DATA SUMMARIES FROM CONTINUOUSLY MONITORING SENSORS IN THE HEMIDOME. INSOLATION VALUES REPRESENT MAXIMUM AND MINIMUM FOR EACH DAY BETWEEN APPROXIMATELY 0900 AND 1600 HOURS UNLESS SPECIFIED OTHERWISE UNDER REMARKS. ΔO_2 VALUES REPRESENT DAILY INTEGRATED DIFFERENCES BETWEEN AN OUTFLOWING WATER SENSOR (NOS. 2 AND 3) AND THE SINGLE INFLOWING WATER SENSOR. ALL DATES REPRESENT 1982.

Date		Inflow Temp. °C Min.	Inflow Temp. °C Max.	Outflow Temp. °C Min.	Outflow Temp. °C Max.	ΔO_2 gm 2-1	ΔO_2 gm 3-1	Insolation nE/cm^{2}sec Max.	Insolation nE/cm^{2}sec Min.	Remarks
Apr	15	15.9	18.1	14.0	15.0	--	--	499	242	Insolation record began at 1330 hr
	16	14.6	15.9	13.4	14.3	--	--	525	227	
	17	13.3	14.5	13.5	15.8	--	--	600	186	
	18	13.0	14.8	14.3	14.9	--	--	508	317	
	19	13.0	14.1	14.4	15.9	--	--	490	250	
	20	12.8	13.5	14.5	15.9	--	--	510	245	
	21	13.0	15.6	14.7	15.9	--	--	534	247	
	22	12.5	13.9	14.0	15.4	--	--	523	246	
	23	11.5	13.1	13.9	15.5	--	--	504	323	
	24	11.9	13.5	14.2	15.5	--	--	511	250	
	25	12.0	13.3	14.5	15.3	--	--	545	145	
	26	12.9	14.2	15.0	15.5	--	--	584	177	
	27	12.4	14.7	14.9	16.0	--	--	510	120	
	28	12.2	13.3	15.2	15.9	--	--	552	93	Inflow temperature to 1330 hr
	29	--	--	15.6	16.3	--	--	574	115	
	30	--	--	16.2	16.4	-724.1	-1929.3	--	--	Outflow temperature began at 1728 hr
May	1	--	--	16.3	16.8	-503.1	-2064.2	610	104	
	2	--	--	16.4	16.9	-1159.6	-2809.3	655	92	
	3	--	--	16.5	17.1	-2092.1	-3750.8	572	58	
	4	--	--	17.0	17.2	-3765.9	-5181.1	373	59	
	6	--	--	17.0	20.9	-25288.0	-25020.7	701	90	
	7	--	--	16.5	17.4	-32748.6	-32988.4	675	74	
	8	--	--	16.5	17.0	-11168.0	-11697.4	569	59	
	10-11	--	--	16.4	17.0	--	1105.9	353	--	Began at 1500 hr
	12	14.0	18.2	16.7	17.1	--	1350.0	346	--	Began at 1500 hr
	13	14.4	18.2	16.3	17.1	--	841.8	571	179	
	14	14.3	17.2	16.4	16.9	--	530.5	512	128	
	15	14.8	18.5	16.1	17.2	--	29135.1	518	353	
	16	14.9	19.0	16.6	17.4	--	53170.6	514	357	

TABLE 5.2-3. ENVIRONMENTAL DATA SUMMARIES FROM CONTINUOUSLY MONITORING SENSORS IN THE HEMIDOME. INSOLATION VALUES REPRESENT MAXIMUM AND MINIMUM FOR EACH DAY BETWEEN APPROXIMATELY 0900 AND 1600 HOURS UNLESS SPECIFIED OTHERWISE UNDER REMARKS. ΔO_2 VALUES REPRESENT DAILY INTEGRATED DIFFERENCES BETWEEN AN OUTFLOWING WATER SENSOR (NOS. 2 AND 3) AND THE SINGLE INFLOWING WATER SENSOR. ALL DATES REPRESENT 1982. (Cont)

Date		Inflow Temp. °C Min.	Inflow Temp. °C Max.	Outflow Temp. °C Min.	Outflow Temp. °C Max.	ΔO_2 gm 2-1	ΔO_2 gm 3-1	Insolation nE/cm^{2}sec Max.	Insolation nE/cm^{2}sec Min.	Remarks
May	17	15.5	19.2	17.0	17.8	18047.2	8621.6	518	351	
	18	15.0	17.7	17.2	17.6	23441.5	11029.4	540	161	
	19	13.8	17.9	17.3	18.0	19521.8	10043.3	590	356	
	20	15.5	17.8	17.4	17.7	--	--	181	79	
	21	17.3	17.6	17.2	17.5	--	--	131	46	
	22	16.9	17.1	17.1	17.2	--	--	183	64	
	23	16.7	17.4	16.9	17.3	--	--	537	291	
	24	16.4	16.8	16.8	17.1	--	--	107	54	
	25	16.5	16.8	16.8	16.8	1595.9	2394.5	189	91	
	26	16.3	16.7	16.6	16.8	2759.2	3968.0	215	50	Insolation maximum at 1526 = 235 hr
	27	16.1	16.5	16.4	16.6	3077.2	4276.2	235	55	
	28	16.3	17.8	16.4	17.6	4068.1	4474.9	653	222	
	29	16.2	17.4	17.1	17.4	3324.7	2527.6	315	67	
	30	17.2	17.9	17.3	18.0	2885.3	1067.0	551	386	
	31	17.6	18.0	17.8	18.1	1341.0	316.1	577	139	
June	1	17.5	18.0	17.7	18.3	3943.7	4736.5	527	409	
	2	17.4	17.8	17.7	17.9	3159.8	2722.3	257	87	Insolation maximum at 1526 = 330 hr
	3	17.2	26.0	17.7	27.1	3833.9	-2830.2	528	380	
	4	17.4	21.1	17.7	20.2	-3.6	-1.3	553	142	
	5	17.2	18.2	17.9	18.1	469.3	161.0	581	149	
	6	17.1	18.2	17.7	18.1	53.7	-1488.3	523	147	
	7	17.4	18.0	17.6	18.0	-243.4	-1640.6	--	--	Began at 1552 hr
	8	17.0	18.8	17.5	17.8	-1354.0	-2113.6	652	185	
	9	16.4	18.0	17.4	18.1	-2430.4	-2934.0	543	244	
	10	17.0	17.9	17.6	18.0	-555.1	-832.5	642	195	
	11	17.3	27.1	17.6	25.8	--	--	613	140	
	12	17.1	17.7	17.6	17.9	--	--	449	52	
	13	17.0	17.7	17.4	17.8	--	--	613	178	
	14	17.2	17.7	17.3	17.6	--	--	497	32	
	15	17.0	17.4	17.4	17.6	2197.6	1063.9	305	87	Stopped at 1858 hr
	16	15.8	17.0	16.3	17.1	2811.9	-1387.3	232	162	Began at 1256 hr
	17	16.9	17.3	17.1	17.3	3909.9	716.5	413	69	
	18	16.6	17.1	17.1	17.3	3966.7	1915.8	363	53	
	19	16.4	17.0	16.9	17.1	4709.9	3807.2	150	47	
	20	16.9	17.4	17.1	17.4	4468.0	3650.1	145	24	

TABLE 5.2-3. ENVIRONMENTAL DATA SUMMARIES FROM CONTINUOUSLY MONITORING SENSORS IN THE HEMIDOME. INSOLATION VALUES REPRESENT MAXIMUM AND MINIMUM FOR EACH DAY BETWEEN APPROXIMATELY 0900 AND 1600 HOURS UNLESS SPECIFIED OTHERWISE UNDER REMARKS. ΔO_2 VALUES REPRESENT DAILY INTEGRATED DIFFERENCES BETWEEN AN OUTFLOWING WATER SENSOR (NOS. 2 AND 3) AND THE SINGLE INFLOWING WATER SENSOR. ALL DATES REPRESENT 1982. (Cont)

	Inflow Temp. °C		Outflow Temp. °C		Insolation nE/cm^{2}sec		
Date	Min.	Max.	Min.	Max.	Max.	Min.	Remarks
June 21	16.6	17.3	17.2	17.3	150	48	
22	14.9	17.0	16.7	17.1	281	148	Began at 1130 hr
23	13.9	16.6	16.1	16.9	219	93	
24	14.9	16.8	16.2	16.7	663	42	Insolation maximum atypical, 284 average maximum
25	15.8	17.4	16.7	17.6	617	177	
26	16.0	17.6	17.0	17.8	523	215	
27	15.1	17.6	17.1	17.6	704	149	
28	16.2	17.1	16.8	17.6	617	167	
29	15.7	17.1	17.0	17.6	775	62	
30	16.9	17.8	17.1	18.3	704	188	
July 1	16.4	18.3	17.7	18.8	521	169	
2	15.8	18.3	17.2	18.6	555	214	
3	16.2	17.7	17.5	17.8	305	6	Record ended at 1022 hr
4	17.9	18.8	18.5	19.0	542	297	Record began at 1052 hr
5	17.5	18.7	18.3	18.9	590	110	
6	17.8	19.1	18.4	19.2	540	111	
7	17.8	19.3	19.0	19.5	627	121	
8	18.2	19.2	18.9	19.4	525	133	
9	17.7	19.1	18.8	19.2	521	234	
10	18.4	19.8	18.7	19.5	519	296	
11	18.9	19.7	19.3	19.8	527	210	
12	18.6	19.8	19.3	19.8	529	115	
13	18.9	20.0	19.5	19.9	651	151	
14	19.0	20.2	19.5	20.1	591	166	
15	18.6	19.7	19.2	19.9	598	117	
16	19.0	19.6	19.2	19.7	650	71	
17	18.8	20.3	19.6	20.0	582	180	
18	19.6	20.4	19.9	20.4	541	179	
19	19.1	19.9	19.6	20.1	525	237	
20	18.8	20.3	19.3	20.1	512	299	
21	17.2	19.9	18.8	20.0	508	279	
22	15.5	19.3	17.8	19.4	500	271	
23	17.3	20.1	18.5	19.7	665	224	
24	16.5	19.8	19.4	19.8	508	192	
25	19.3	20.5	19.5	20.3	493	276	

TABLE 5.2-3. ENVIRONMENTAL DATA SUMMARIES FROM CONTINUOUSLY MONITORING SENSORS IN THE HEMIDOME. INSOLATION VALUES REPRESENT MAXIMUM AND MINIMUM FOR EACH DAY BETWEEN APPROXIMATELY 0900 AND 1600 HOURS UNLESS SPECIFIED OTHERWISE UNDER REMARKS. ΔO_2 VALUES REPRESENT DAILY INTEGRATED DIFFERENCES BETWEEN AN OUTFLOWING WATER SENSOR (NOS. 2 AND 3) AND THE SINGLE INFLOWING WATER SENSOR. ALL DATES REPRESENT 1982. (Cont)

	Inflow Temp. °C		Outflow Temp. °C		Insolation nE/cm^{2}sec		
Date	Min.	Max.	Min.	Max.	Max.	Min.	Remarks
July 26	19.8	20.7	20.1	20.7	498	233	
27	20.0	20.8	20.4	21.0	504	237	
28	20.5	21.3	20.6	21.4	511	243	
29	20.6	21.6	21.1	21.6	492	254	
30	21.1	22.0	21.3	21.9	492	252	
31	21.4	22.0	21.6	22.6	552	210	
Aug 1	20.7	22.2	21.8	22.2	602	85	
2	20.9	22.1	21.5	22.1	637	99	
3	21.3	22.1	21.6	22.1	515	226	
4	21.1	22.4	21.8	22.8	515	237	
5	20.7	21.8	21.5	22.1	495	194	Gap in record from 0700 to 1300 hr
6	19.9	21.4	21.0	21.7	498	154	
7	20.7	21.3	21.0	21.3	509	259	
8	20.6	21.5	21.0	21.5	501	134	
9	20.8	21.6	21.0	21.5	504	234	Gap in record from 0900 to 1300 hr
10	20.2	21.8	21.0	21.9	499	251	Record began at 0927 hr
11	20.0	21.3	18.7	21.2	607	143	Intake pipes extended to ca. 15 m depth
12	20.2	20.9	18.0	20.8	638	86	
13	20.4	21.0	19.1	20.6	652	103	
14	20.4	21.4	18.5	20.4	537	153	
15	20.7	21.3	17.9	20.1	502	42	
16	20.5	21.4	18.2	21.0	545	108	
17	20.8	21.7	18.6	21.3	550	249	
18	20.6	21.4	18.2	20.1	609	106	
19	20.5	21.4	18.2	20.5	473	231	
20	19.9	21.2	18.3	20.6	482	234	
21	20.1	20.9	18.0	20.7	465	216	Gap from 0557 to 0947 hr
22	19.4	20.7	17.8	20.7	500	203	
23	19.1	20.4	17.2	20.5	582	98	
24	19.4	19.7	17.9	18.5	--	73	Record stopped at 0847 hr
25	19.1	20.1	17.8	20.1	502	187	Record began at 0805 hr
26	19.1	20.5	18.3	19.8	455	161	
27	19.9	20.7	18.2	19.7	552	200	
28	20.1	20.9	19.1	20.1	574	80	
29	20.6	21.4	19.1	20.6	574	197	

TABLE 5.2-3. ENVIRONMENTAL DATA SUMMARIES FROM CONTINUOUSLY MONITORING SENSORS IN THE HEMIDOME. INSOLATION VALUES REPRESENT MAXIMUM AND MINIMUM FOR EACH DAY BETWEEN APPROXIMATELY 0900 AND 1600 HOURS UNLESS SPECIFIED OTHERWISE UNDER REMARKS. ΔO_2 VALUES REPRESENT DAILY INTEGRATED DIFFERENCES BETWEEN AN OUTFLOWING WATER SENSOR (NOS. 2 AND 3) AND THE SINGLE INFLOWING WATER SENSOR. ALL DATES REPRESENT 1982. (Cont)

Date	Inflow Temp. °C Min.	Inflow Temp. °C Max.	Outflow Temp. °C Min.	Outflow Temp. °C Max.	Insolation nE/cm^2sec Max.	Insolation nE/cm^2sec Min.	Remarks
Aug 31	20.3	21.2	18.4	20.3	533	101	Record stopped 0812, began 1012 hr
Sept 1	20.1	20.9	18.2	20.0	523	105	
2	19.0	21.0	18.6	21.1	470	59	
3	20.3	21.5	19.1	21.1	518	63	Gap in record from 0541 to 0847 hr
4	20.8	22.1	19.1	20.7	471	43	
5	18.8	21.4	18.9	19.9	478	49	
6	19.2	21.2	18.7	20.1	475	45	
7	20.1	21.1	19.6	20.2	494	50	Gap in record after 2017 hr
8	19.9	21.2	18.6	19.8	122	26	Gap in record from midnight to 0859 hr
9	20.0	21.1	17.6	19.7	533	72	
10	19.1	20.8	17.7	19.8	274	41	Temperatures erroneous from 1059 to 1359 (read up to 35°)
11	17.8	20.3	17.8	18.9	491	77	
12	19.9	20.7	18.2	19.5	549	51	
13	20.2	20.5	18.9	20.6	458	106	Gap in record from 0814 to 1426 hr
14	20.3	20.5	18.7	20.5	482	45	
15	17.7	20.4	18.1	18.9	633	27	
16	19.6	20.0	18.7	20.0	549	39	Gap in record from 0826 to 1020 hr
17	19.3	20.0	18.6	19.8	517	28	
18	19.6	20.3	18.5	20.1	554	45	
19	19.7	20.1	18.7	20.0	519	38	
20	16.9	20.3	18.5	18.8	460	37	Gap in record from 0620 to 0844 hr
21	16.9	20.1	17.9	20.4	455	39	Gap in record after 1814 hr
22	19.3	20.3	19.5	20.4	460	40	Gap in record from midnight to 1204 hr
23	19.8	20.2	18.9	19.5	541	95	Gap in record from 1104 to 1327 hr
24	18.6	20.2	18.6	20.7	508	56	
25	18.4	20.0	18.4	20.2	246	22	
26	18.5	20.2	18.4	20.2	580	47	
27	19.9	20.2	19.9	20.3	491	46	Gap in record after 1815 and from 0727 to 1015 hr
28	19.3	19.8	19.0	19.6	380	53	Gap in record from midnight to 0825 and after 0955 except for 1024 and 1801 hr
29	19.6	19.4	19.3	19.8	559	66	Gap in record from midnight to 0924 and 1224 to 1350 hr
30	19.6	19.8	19.4	20.4	422	51	Gap in record from 1155 to 1518 and from 0750 to 1155 hr
Oct 1	19.1	19.9	19.6	20.4	420	39	Gap in record from 0518 to 0751 hr
2	19.0	20.0	19.6	20.4	433	38	

TABLE 5.2-3. ENVIRONMENTAL DATA SUMMARIES FROM CONTINUOUSLY MONITORING SENSORS IN THE HEMIDOME. INSOLATION VALUES REPRESENT MAXIMUM AND MINIMUM FOR EACH DAY BETWEEN APPROXIMATELY 0900 AND 1600 HOURS UNLESS SPECIFIED OTHERWISE UNDER REMARKS. ΔO_2 VALUES REPRESENT DAILY INTEGRATED DIFFERENCES BETWEEN AN OUTFLOWING WATER SENSOR (NOS. 2 AND 3) AND THE SINGLE INFLOWING WATER SENSOR. ALL DATES REPRESENT 1982. (Cont)

	Inflow Temp. °C		Outflow Temp. °C		Insolation nE/cm^{2}sec		
Date	Min.	Max.	Min.	Max.	Max.	Min.	Remarks
Oct 3	19.3	19.8	19.6	20.2	504	41	Gap in record after 1821
5	18.0	18.8	18.8	19.3	414	272	Record began 0806, ended 1137
14	19.5	20.1	19.3	19.9	347	41	Record began at 1329
15	19.5	19.8	19.4	19.7	433	39	
16	19.4	19.8	19.5	19.7	379	43	Record ended at 1529
17	19.1	19.8	19.1	19.6	400	32	Record began 0937, ended 2137
18	19.3	19.8	19.0	19.6	390	33	Record began at 0807
19	19.6	19.8	19.5	19.8	397	34	Record ended at 2037

TABLE 5.2-4. DAILY INTEGRATED INSOLATION IN MILLIEINSTEINS/cm^2 RECORDED AT THE INSTRUMENT SHED ON THE HEMIDOME IN BIG FISHERMAN COVE, CATALINA ISLAND, FROM MAY TO DECEMBER, 1982

Day	Month							
	May	June	July	August	September	October	November	December
1		15.577	15.315	8.077	11.907	10.098	7.793	1.822
2		7.045	14.365	9.953	12.474	10.619	8.497	5.085
3		15.577	4.528	13.945	12.060	10.332	8.173	5.459
4		13.088	15.153	14.304	12.479	0.000	7.189	5.767
5		14.451	14.595	13.452	12.685	10.568	6.221	6.018
6		14.409	15.152	13.194	12.514	11.255	5.267	5.812
7		12.105	13.401	14.326	11.419	11.078	4.329	2.630
8		15.322	14.550	14.266	3.123	10.903	3.397	3.167
9		15.429	14.544	14.132	6.845	10.728	2.490	1.782
10		13.496	15.131	13.566	4.233	10.555	4.635	5.239
11		11.425	15.018	8.330	9.326	10.383	7.135	5.198
12		6.246	13.815	8.443	8.852	10.213	6.274	5.655
13	11.995	15.121	14.763	9.333	9.422	10.044	5.143	
14	8.056	6.773	13.852	13.111	3.722	9.229	7.077	
15	14.473	5.221	12.866	12.570	5.683	8.142	7.162	
16	14.623	10.259	11.103	11.288	3.787	9.227	3.449	
17	14.251	4.705	13.809	14.028	5.349	9.093	6.465	
18	7.948	5.452	13.605	12.601	9.175	8.653	4.753	
19	14.561	3.299	15.248	13.076	10.102	7.861	6.795	
20	4.180	2.613	14.921	13.317	11.595	7.318	5.470	
21	2.581	2.564	14.597	11.678	11.541	7.682	4.215	
22	4.520	6.258	14.257	13.065	11.107	8.039	1.701	
23	11.205	4.594	13.142	9.500	9.364	8.372	2.077	
24	2.653	5.552	13.242	3.448	6.323	8.718	2.444	
25	3.873	13.805	13.750	9.974	4.277	6.261	2.807	
26	3.851	15.389	14.232	12.136	7.568	3.848	3.166	
27	3.455	12.861	14.307	12.259	9.755	7.670	3.521	
28	15.043	13.069	14.650	8.975	2.822	8.266	3.873	
29	5.907	7.868	13.862	11.475	6.989	6.103	3.649	
30	15.811	13.426	13.857	12.882	10.144	2.872	1.997	
31	9.835		13.324	11.655		6.395		

TABLE 5.2-5. CONCENTRATIONS OF MACRONUTRIENTS MEASURED FOR WATER SAMPLES FOR THE HEMIDOME AND SURROUNDINGS DURING 1982

Date (depth, m)		Hemidome			Hemidome Intake			Intake Pt.		
		μM NO_3	μM PO_4	μM NH_4	μM NO_3	μM PO_4	μM NH_4	μM NO_3	μM PO_4	μM NH_4
Feb 12	(0)	0.4	0.3	<0.1						
	(3)				0.8	0.4	<0.1			
	(9)	0.3	0.4	<0.1						
Mar 9	(0)	0.2	0.3							
	(3)				0.1	0.4				
	(9)	0.1	0.3							
Mar 11	(0)	9.6,9.6, 9.2						0.25		
	(3)				0.25					
	(9)	9.3,9.3, 9.3						2.36		
Mar 19	(0)	<0.1	0.27					0.4	0.25	
	(3)				<0.1	0.25				
	(9)	0.1	0.27					<0.1	0.22	
Mar 25	(0)	9.7	0.58	<0.1				0.6	0.56	<0.1
	(3)				0.1	0.29	<0.1			
	(9)	9.7	0.54	<0.1				1.2	0.35	<0.1
Mar 31	(0)	10.8-11.4	0.97-1.07	<0.1				0.6	0.41	<0.1
	(3)				0.8	0.32	<0.1			
	(9)	10.7	1.01	<0.1				0.6	0.34	<0.1
April 5	(0)	11.1-11.2	1.0-1.1					1.02	0.29	
	(3)				0.3	0.24				
	(9)	9.1-11.3	0.95-1.1					0.2	0.16	
April 19	(0)	<0.1	0.19					0.2	0.23	
	(3)				<0.1	0.17				
	(9)	<0.1	0.15					<0.1	0.17	
April 21	(0)	<0.1	0.21					<0.1	0.17	
	(3)				<0.1	0.17				
	(9)	<0.1	0.21					5.5	0.71	
April 23	(0)	<0.1	0.27					0.2	0.31	
	(3)				0.2	0.25				
	(9)	<0.1	0.31					0.5	0.31	
April 26	(0)	<0.1	0.33					<0.1	0.21	
	(3)				<0.1	0.30				
	(9)	<0.1	0.27					0.2	0.25	
April 29	(0)	9.4	1.04	<0.1				<0.1	0.34	<0.1
	(3)				0.1	0.39	<0.1			
	(9)	9.5	1.05	<0.1				<0.1	0.30	<0.1
May 3	(0)	0.3	0.38					0.2	0.34	
	(3)				0.1	0.22				
	(9)	0.3	0.36					0.6	0.38	

TABLE 5.2-5. CONCENTRATIONS OF MACRONUTRIENTS MEASURED FOR WATER SAMPLES FOR THE HEMIDOME AND SURROUNDINGS DURING 1982 (Cont)

Date (depth, m)	Hemidome			Hemidome Intake			Intake Pt.		
	µM NO_3	µM PO_4	µM NH_4	µM NO_3	µM PO_4	µM NH_4	µM NO_3	µM PO_4	µM NH_4
May 6 (0)	13.2	0.88					0.2	0.35	
(3)				<0.1	0.39				
(9)	13.8	0.89					<0.1	0.36	
May 13 (0)	12.1	1.02					<0.1	0.37	
(3)				1.1	0.33				
(9)	12.7	1.16					0.2	0.32	
May 17-18 (0)	13.1	0.78	<0.01				0.2	0.23	<0.01
(3)				<0.1	0.25	<0.01			
(9)	13.4	0.83	0.14				0.2	0.28	0.14
May 21 (0)	11.2	0.70					0.5	0.24	
(3)				0.6	0.35				
(9)	11.6	0.75					0.3	0.16	
May 24 (0)	11.9	0.83					0.5	0.70	
(3)				1.1	0.36				
(9)	12.0	0.84					1.2	0.36	
May 28 (0)	0.5	0.24					0.3	0.25	
(3)				0.4	0.22				
(9)	0.6	0.31					0.5	0.31	
June 1 (0)	0.3	0.241					0.3	0.30	
(3)				0.7	0.26				
(9)	0.3	0.27					0.3	0.24	
June 3 (0)	0.4	0.29					0.3	0.30	
(3)				0.6	0.35				
(9)	0.4	0.36					0.9	0.36	
June 7 (0)	0.3	0.87					0.4	0.28	
(3)				0.3	0.27				
(9)	0.4	0.32					1.1	0.31	
June 9 (0)	0.4	0.24					0.4	0.31	
(3)				0.3	0.28				
(9)	0.4	0.29					3.1	0.53	
June 17 (0)	2.2	0.48					0.3	0.31	
(3)				0.3	0.28				
(9)	1.9	0.48					0.3	0.34	
June 21 (0)	3.1	0.58					0.9	0.23	
(3)				1.8	0.35				
(9)	3.3	0.61					3.9	0.50	
June 23 (0)	4.2	0.58					0.8	0.25	
(3)				1.3	0.40				
(9)	3.8	0.60					1.4	0.72	
July 13 (0)	0.2	0.38		2.3	0.87				
(3)				2.3	0.87				
(12)				0.3	0.31				
July 15 (0)	0.7	0.36							
(3)				0.2	0.17				
(12)				0.2	0.18				
July 19 (0)	0.6	0.39							
(3)				0.3	0.33				
(12)				1.3	0.83				

TABLE 5.2-5. CONCENTRATIONS OF MACRONUTRIENTS MEASURED FOR WATER SAMPLES FOR THE HEMIDOME AND SURROUNDINGS DURING 1982 (Cont)

Date (depth, m)	Hemidome			Hemidome Intake			Intake Pt.		
	µM NO_3	µM PO_4	µM NH_4	µM NO_3	µM PO_4	µM NH_4	µM NO_3	µM PO_4	µM NH_4
July 20 (0)	1.4	0.35							
(3)				0.2	0.35				
(12)				1.2	0.79				
July 22 (0)	4.8	0.78							
(3)				0.9	0.42				
(12)				2.5	0.54				
July 21 (0)	3.8	0.64							
(3)				0.2	0.14				
(12)				0.3	0.15				
July 27 (0)	0.4	0.3							
(3)				0.3	0.15				
(12)				0.3	0.21				
July 29 (0)	1.7	0.37	0.23						
(3)				0.5	0.26	<0.01			
(12)				0.4	0.20	<0.01			
Aug 2 (0)	0.2	0.31							
(3)				10.4	0.91				
(12)	0.2	0.32							
Aug 3 (0)	17.6	1.6							
(3)				0.1	0.31				
(12)							0.4	0.25	
Aug 9 (0)	25.4	2.4							
(3)				0.4	0.24				
(12)				0.7	0.28				
Aug 10 (0)	1.5	0.44							
(3)				0.3	0.18				
(12)				0.4	0.4				
Aug 12 (3)				0.2	0.26	0.18			
(12)				0.3	0.36	0.25			
Aug 16 (3)				0.4	0.24				
(12)				0.3	0.23				
Aug 18 (3)				0.3	0.16				
(12)				0.2	0.14				
Aug 20 (3)				0.2	0.24				
(12)				1.2	0.48				
Aug 22 (3)				0.4	0.30				
(12)				0.8	0.36				
Aug 25 (3)				0.4	0.26				
(12)				1.1	0.29				
Aug 27 (3)				0.2	0.22				
(12)				0.5	0.25				
Aug 29 (3)				0.2	0.17				
(12)				0.2	0.34				
Sept 1 (3)				0.2	0.28				
(12)				0.2	0.23				
Sept 3 (3)				0.2	0.30				
(12)				0.2	0.29				

TABLE 5.2-5. CONCENTRATIONS OF MACRONUTRIENTS MEASURED FOR WATER SAMPLES FOR THE HEMIDOME AND SURROUNDINGS DURING 1982 (Cont)

Date (depth, m)	Hemidome			Hemidome Intake			Intake Pt.		
	µM NO_3	µM PO_4	µM NH_4	µM NO_3	µM PO_4	µM NH_4	µM NO_3	µM PO_4	µM NH_4
Sept 5 (3)				0.2	0.32				
(12)				0.3	0.34				
Sept 9 (3)				0.3	0.33				
(12)				0.3	0.33				
Sept 11 (3)				0.3	0.34				
(12)				0.4	0.36				
Sept 12 (3)				0.5	0.24				
(12)				0.6	0.23				

TABLE 5.3-2. FIRST HARVEST YIELD DATA TABLES

(September/October through December/January 1981)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
A. EXPERIMENT PARAMETERS, ASSUMPTIONS, CALCULATIONS & CONSTANTS			
Individual Plants / sq. M	0.0625	0.2500	1.0000
Square Meters / Ind. Plant	16	4	1
Distance Between Centers (M)	4	2	1
Plants / Acre (4,046.9 sq M)	252.9	1,011.7	4,046.9

Assumption:	Dry Wt	/ Wet Wt	= 12.36%	(literature mean)
Assumption:	Dry Ash-Free Wt	/ Dry Wt	= 62.39%	(literature mean)
Calculation:	Dry Ash-Free Wt	/ Wet Wt	= 7.71%	
Constant:	Kg	/ Short Ton	= 907.18	

Conversion from gm production / day / plant to Dry Ash-Free Wt / Acre / Year
Assuming growth is the same in each quarter of the year

Low Density =	0.0078
Medium Density =	0.0314
High Density =	0.1255

Conversion from gm production / day / plant to Dry Ash-Free Wt / Acre / Year
Assuming growth is proportional to solar irradiance
(Winter = 185.20, Spring = 288.80, Summer = 266.83, Fall = 160.70 W / sq. M)

Low Density =	0.0109
Medium Density =	0.0440
High Density =	0.1760

B. FRONDS PER PLANT (@ 1M from the bottom)			
Center-Unfertilized	26.28(80) 9.58	25.53(64) 8.29	25.46(67) 9.61
Edge -Unfertilized	26.38(40) 9.92	25.14(36) 8.31	22.68(38) 6.60
Sample-Unfertilized	24.75(12) 8.04	24.67(12) 8.47	20.17(12) 6.74
Total -Unfertilized	26.17(132) 9.50	25.31(112) 8.25	24.02(117) 8.60
Center-Fertilized	27.39(80)12.00	25.10(62) 8.44	24.58(69) 9.14
Edge -Fertilized	26.35(40) 9.25	27.51(37) 8.86	25.53(36) 8.23
Sample-Fertilized	21.25(12) 9.18	22.58(12) 7.08	22.33(12) 5.92
Total -Fertilized	26.52(132)11.06	25.63(111) 8.52	24.64(117) 8.57
Total Center	26.83(160)10.84	25.32(126) 8.33	25.01(136) 9.35
Total Edge	26.36(80) 9.53	26.34(73) 8.62	24.07(74) 7.52
Total Sample	23.00(24) 8.62	23.63(24) 7.71	21.25(24) 5.24
Total	26.34(264)10.29	25.47(223) 8.37	24.33(234) 8.57

TABLE 5.3-2. FIRST HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
C. FROND DENSITY (@ 1M from the bottom) Fronds / Sq M			
Total -Unfertilized	1.64	6.33	24.02
Total -Fertilized	1.66	6.41	24.64
Total	1.65	6.37	24.33
D. BEGINNING HOLDFAST WET WEIGHT (kg)			
Center-Unfertilized	2.44(79) 1.70	2.45(64) 1.90	2.32(67) 1.36
Edge -Unfertilized	2.59(40) 1.35	2.55(36) 1.44	2.04(38) 1.49
Sample-Unfertilized	1.44(12) 0.78	1.46(12) 0.65	1.29(12) 0.73
Total -Unfertilized	2.39(131) 1.56	2.37(112) 1.69	2.12(117) 1.38
Center-Fertilized	2.64(80) 1.46	2.60(63) 1.34	2.32(69) 1.46
Edge -Fertilized	2.59(40) 1.05	2.42(37) 1.22	2.67(36) 1.50
Sample-Fertilized	1.38(12) 1.21	1.49(12) 1.05	1.51(12) 0.69
Total -Fertilized	2.51(132) 1.36	2.42(112) 1.30	2.34(117) 1.44
Total Center	2.54(159) 1.58	2.52(127) 1.64	2.32(136) 1.41
Total Edge	2.59(80) 1.20	2.48(73) 1.32	2.34(74) 1.52
Total Sample	1.41(24) 1.41	1.48(24) 0.86	1.40(24) 0.70
Total	2.45(263) 1.47	2.40(224) 1.50	2.23(234) 1.41
E. BEGINNING SUBSURFACE FRONDS WET WEIGHT (kg)			
Center-Unfertilized	15.58(80) 6.84	14.90(64) 5.94	13.56(67) 5.86
Edge -Unfertilized	13.58(40) 5.80	15.83(36) 5.58	13.43(38) 6.01
Sample-Unfertilized	13.04(12) 4.84	12.92(12) 6.37	13.21(12) 5.26
Total -Unfertilized	14.75(132) 6.43	14.99(112) 5.88	13.48(117) 5.81
Center-Fertilized	13.52(80) 7.03	14.80(63) 6.59	13.15(69) 7.50
Edge -Fertilized	16.88(40) 7.38	14.31(37) 4.83	14.64(36) 5.97
Sample-Fertilized	14.75(12) 6.04	16.21(12) 5.21	10.67(12) 2.88
Total -Fertilized	14.65(132) 7.17	14.79(112) 5.90	13.35(117) 6.76
Total Center	14.55(160) 7.00	14.85(127) 6.25	13.35(136) 6.72
Total Edge	15.23(80) 6.80	15.06(73) 5.24	14.02(74) 5.98
Total Sample	13.90(24) 5.42	14.56(24) 5.94	11.94(24) 4.35
Total	14.70(264) 6.80	14.89(224) 5.88	13.42(234) 6.29

TABLE 5.3-2. FIRST HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
F. BEGINNING WET WEIGHT OF HOLDFAST AND SUBSURFACE FRONDS (kg)			
Center-Unfertilized	18.02(80) 7.98	17.34(64) 7.11	15.88(67) 6.56
Edge -Unfertilized	16.17(40) 6.73	18.38(36) 6.56	15.47(38) 6.90
Sample-Unfertilized	14.48(12) 5.43	14.38(12) 6.61	14.50(12) 5.75
Total -Unfertilized	17.14(132) 7.47	17.36(112) 6.92	15.61(117) 6.56
Center-Fertilized	16.16(80) 7.96	17.40(63) 7.50	15.47(69) 8.26
Edge -Fertilized	19.47(40) 7.93	16.73(37) 4.87	17.31(36) 6.82
Sample-Fertilized	16.13(12) 6.69	17.70(12) 5.94	12.18(12) 3.00
Total -Fertilized	17.16(132) 7.94	17.21(112) 6.54	15.70(117) 7.55
Total Center	17.09(160) 8.00	17.37(127) 7.28	15.67(136) 7.45
Total Edge	17.82(80) 7.49	17.55(73) 5.79	16.36(74) 6.88
Total Sample	15.30(24) 6.01	16.04(24) 6.38	13.34(24) 4.64
Total	17.15(264) 7.69	17.29(224) 6.72	15.65(234) 7.06
G. BEGINNING BIOMASS DENSITY (Wet kg / Sq M)			
Total -Unfertilized	1.07	4.34	15.61
Total -Fertilized	1.07	4.30	15.70
Total	1.07	4.32	15.65
H. WET WEIGHT OF HARVESTED MATERIAL PER PLANT (kg)			
Center-Unfertilized	28.17(78)20.11	21.01(63)14.51	13.81(67)12.14
Edge -Unfertilized	19.92(39)13.90	16.92(36)11.26	15.08(38)14.95
Sample-Unfertilized	16.65(12) 7.09	8.32(12) 7.34	8.54(12) 7.48
Total -Unfertilized	24.60(129)18.04	18.31(111)13.42	13.68(117)12.80
Center-Fertilized	24.37(80)16.93	15.74(62)14.25	11.32(68)11.76
Edge -Fertilized	19.69(40)17.37	19.47(37)15.50	17.61(35)13.67
Sample-Fertilized	14.37(12)11.83	8.90(12) 7.81	9.68(12) 5.07
Total -Fertilized	22.04(132)16.88	16.24(111)14.38	13.06(115)12.20
Total Center	26.25(158)18.61	18.40(125)14.57	12.55(135)11.97
Total Edge	19.80(79)15.65	18.21(73)13.54	16.29(73)14.31
Total Sample	15.51(24) 9.61	8.61(24) 7.42	9.11(24) 6.27
Total	23.31(261)17.48	17.28(222)13.92	13.37(232)12.48

TABLE 5.3-2. FIRST HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

I. TIME BETWEEN HARVESTS (days)

	Low Density	Medium Density	High Density
Center-Unfertilized	111.66(79)13.45	110.55(62) 7.79	121.91(67) 8.53
Edge -Unfertilized	116.21(39)13.78	110.29(35) 8.21	115.58(38) 7.90
Sample-Unfertilized	90.25(12) 6.97	88.08(12) 9.37	89.67(12)10.73
Total -Unfertilized	111.05(130)14.76	107.99(109)10.67	116.55(117)12.80
Center-Fertilized	111.65(80)12.06	116.14(63) 7.21	121.62(68)10.74
Edge -Fertilized	116.35(40)18.57	122.08(37)10.91	116.49(35)11.54
Sample-Fertilized	95.08(12) 6.13	88.00(12)11.22	90.58(12) 8.18
Total -Fertilized	111.57(132)15.02	115.09(112)13.28	116.82(115)14.15
Total Center	111.65(159)12.73	113.37(125) 7.98	121.76(135) 9.67
Total Edge	116.28(79)16.28	116.35(72)11.31	116.01(73) 9.76
Total Sample	92.67(24) 6.88	88.04(24)10.11	90.13(24) 9.35
Total	111.31(262)14.86	111.59(221)12.55	116.68(232)13.46

J. PROPORTION OF PLANTS THAT DIED AND PROPORTION OF PLANTS THAT DID PRODUCE HARVESTABLE CANOPY (Beginning Number / % Dead / % Producing Harvestable Canopy

Center-Unfertilized	78 / 2.6 / 94.9	63 / 5.0 / 93.7	67 / 11.9 / 85.1
Edge -Unfertilized	39 / 2.6 / 97.4	36 / 11.1 / 88.9	38 / 10.5 / 84.2
Sample-Unfertilized	12 / 0.0 / 100.0	12 / 0.0 / 83.3	12 / 0.0 / 75.0
Total -Unfertilized	129 / 2.3 / 96.1	111 / 6.3 / 90.2	117 / 10.3 / 83.8
Center-Fertilized	80 / 2.5 / 93.8	62 / 4.8 / 88.7	68 / 19.1 / 75.0
Edge -Fertilized	40 / 5.0 / 90.0	37 / 2.7 / 86.5	35 / 5.7 / 82.9
Sample-Fertilized	12 / 0.0 / 100.0	12 / 0.0 / 91.7	12 / 0.0 / 100.0
Total -Fertilized	132 / 3.0 / 93.2	111 / 3.6 / 88.3	115 / 13.0 / 80.0
Total Center	158 / 2.5 / 94.3	125 / 4.8 / 91.2	135 / 15.6 / 80.0
Total Edge	79 / 3.8 / 93.7	73 / 6.8 / 87.7	73 / 8.2 / 83.6
Total Sample	24 / 0.0 / 100.0	24 / 0.0 / 87.5	24 / 0.0 / 87.5
Total	261 / 2.7 / 94.6	222 / 5.0 / 89.6	232 / 11.6 / 81.9

TABLE 5.3-2. FIRST HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

K. AVERAGE WET WEIGHT PRODUCTION PER PLANT (gm / Day)
Including All Plants

	Low Density	Medium Density	High Density
Center-Unfertilized	254.91(78)174.63	192.25(63)136.84	115.49(67)104.25
Edge -Unfertilized	175.96(39)121.73	155.72(36)105.37	132.56(38)133.65
Sample-Unfertilized	184.11(12) 74.34	97.56(12) 85.51	98.40(12) 83.64
Total -Unfertilized	224.46(129)157.02	170.16(111)125.46	119.28(117)112.50
Center-Fertilized	217.81(80)143.10	134.98(62)120.86	91.99(68) 92.42
Edge -Fertilized	176.16(40)156.24	158.23(37)124.44	155.59(35)122.35
Sample-Fertilized	151.03(12)122.28	102.47(12) 91.16	108.79(12) 58.79
Total -Fertilized	199.12(132)146.49	139.21(111)119.49	113.10(115)103.15
Total Center	236.13(158)160.02	163.84(125)131.82	103.65(135) 98.80
Total Edge	176.06(79)139.38	156.99(73)114.64	143.60(73)127.99
Total Sample	167.57(24)100.40	100.01(24) 86.48	103.59(24) 70.90
Total	211.64(261)152.02	154.69(222)123.22	116.22(232)107.77

L. BIOMASS YIELD (Wet gm / Sq M / Day)

Total -Unfertilized	14.03	42.54	119.28
Total -Fertilized	12.45	34.80	113.10
Total	13.23	38.67	116.22

M. BIOMASS YIELD (Wet kg / Sq M / Year)
Assuming growth is the same in each quarter of the year

Total -Unfertilized	5.12	15.53	43.54
Total -Fertilized	4.54	12.70	41.28
Total	4.83	14.11	42.42

N. BIOMASS YIELD (Wet kg / Sq M / Year)
Assuming growth is proportional to solar irradiance
(Winter = 185.20, Spring = 288.80, Summer = 266.83, Fall = 160.70 W / sq. M)

Total -Unfertilized	7.18	21.77	61.04
Total -Fertilized	6.37	17.81	57.88
Total	6.77	19.79	59.48

TABLE 5.3-2. FIRST HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

O. Average Wet Weight Procuction Per Plant (gm / Day)
Including Only Those Plants that Produced Harvestable Canopy

	Low Density	Medium Density	High Density
Center-Unfertilized	269.69(74)168.57	205.28(59)131.51	135.75(57)100.05
Edge -Unfertilized	180.59(38)119.83	175.18(32) 94.95	157.41(32)131.45
Sample-Unfertilized	184.11(12) 74.34	117.07(10) 79.99	131.20(9) 69.12
Total -Unfertilized	233.51(124)153.38	187.01(101)118.88	142.41(98)108.66
Center-Fertilized	232.33(75)135.80	152.16(55)117.64	122.65(51) 87.23
Edge -Fertilized	195.74(36)152.52	182.95(32)115.39	187.78(29)109.17
Sample-Fertilized	151.03(12)122.28	111.79(11) 89.42	108.79(12) 58.79
Total -Fertilized	213.69(132)141.08	157.68(98)115.11	141.37(92) 96.37
Total Center	250.39(149)153.52	179.65(114)127.29	129.57(108) 94.00
Total Edge	187.96(74)135.98	179.07(64)104.89	171.85(61)121.34
Total Sample	167.57(24)100.40	114.30(21) 82.97	118.39(21) 62.78
Total	223.64(247)147.42	172.57(199)117.67	141.91(232)102.62

P. MAXIMUM WET WEIGHT GROWTH BY ANY PLANT IN THE TREATMENT
(gm / Day)

Center-Unfertilized	779.02	587.45	398.89
Edge -Unfertilized	416.53	366.69	506.93
Sample-Unfertilized	261.99	244.51	229.15
Total -Unfertilized	779.02	587.45	506.93
Center-Fertilized	794.32	530.55	334.05
Edge -Fertilized	663.28	497.10	426.72
Sample-Fertilized	381.99	362.27	203.33
Total -Fertilized	794.32	530.55	426.72
Total Center	794.32	587.45	398.89
Total Edge	663.28	497.10	506.93
Total Sample	381.99	362.27	229.15
Total	794.32	587.45	506.93

TABLE 5.3-2. FIRST HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

Q. PROJECTED YIELD (Dry Ash-Free Tons / Acre / Year)
Based on the Above Assumptions and that growth is the same each quarter of the year 365 x per Day Production Rate

	Low Density	Medium Density	High Density
Data for All Plants			
Total -Unfertilized	1.75	5.34	14.97
Total -Fertilized	1.55	4.37	14.19
Total	1.65	4.85	14.59
Data for Those Plants that Produced Harvestable Canopy			
Total -Unfertilized	1.82	5.87	17.87
Total -Fertilized	1.67	4.95	17.74
Total	1.74	5.42	17.81
Data for The Plant in the Treatment with Maximum Growth			
Total -Unfertilized	6.07	18.45	63.62
Total -Fertilized	6.20	16.66	53.55
Total	6.20	18.45	63.62

R. PROJECTED YIELD (Dry Ash-Free Tons / Acre / Year)
Based on the Above Assumptions and that growth is proportional to solar irradiance (17.83% in Fall)

Data for All Plants			
Total -Unfertilized	2.45	7.49	20.99
Total -Fertilized	2.17	6.13	19.91
Total	2.31	6.81	20.45
Data for Those Plants that Produced Harvestable Canopy			
Total -Unfertilized	2.55	8.23	25.06
Total -Fertilized	2.33	6.94	24.88
Total	2.44	7.59	24.98
Data for The Plant in the Treatment with Maximum Growth			
Total -Unfertilized	8.49	25.85	89.22
Total -Fertilized	8.66	23.34	75.10
Total	8.66	25.85	89.22

TABLE 5.3-2. FIRST HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

S. AVERAGE GROWTH RATE BASED ON BEGINNING TOTAL PLANT WEIGHT AND HARVEST WEIGHT (Exponential, % / Day)

	Low Density	Medium Density	High Density
Center-Unfertilized	0.816(80)0.441	0.679(64)0.380	0.452(67)0.302
Edge -Unfertilized	0.665(40)0.392	0.596(36)0.362	0.537(38)0.394
Sample-Unfertilized	0.852(12)0.296	0.558(12)0.431	0.487(12)0.347
Total -Unfertilized	0.773(132)0.419	0.639(112)0.379	0.483(117)0.338
Center-Fertilized	0.809(80)0.396	0.522(63)0.392	0.415(69)0.377
Edge -Fertilized	0.591(40)0.430	0.568(37)0.337	0.559(36)0.380
Sample-Fertilized	0.654(12)0.360	0.459(12)0.260	0.639(12)0.272
Total -Fertilized	0.729(132)0.413	0.530(112)0.361	0.482(117)0.375
Total Center	0.812(160)0.418	0.601(127)0.392	0.433(136)0.342
Total Edge	0.628(80)0.410	0.582(73)0.347	0.548(74)0.385
Total Sample	0.753(24)0.338	0.508(24)0.351	0.563(24)0.315
Total	0.751(264)0.416	0.585(224)0.373	0.483(234)0.357

T. AVERAGE GROWTH RATE BASED ON BEGINNING SUBSURFACE FRONDS WEIGHT AND HARVEST WEIGHT (Exponential, % / Day)

Center-Unfertilized	0.888(80)0.477	0.743(64)0.410	0.504(67)0.326
Edge -Unfertilized	0.747(40)0.430	0.656(36)0.391	0.584(38)0.419
Sample-Unfertilized	0.916(12)0.320	0.612(12)0.462	0.520(12)0.369
Total -Unfertilized	0.848(132)0.453	0.701(112)0.409	0.532(117)0.362
Center-Fertilized	0.908(80)0.432	0.580(63)0.422	0.462(69)0.408
Edge -Fertilized	0.656(40)0.473	0.642(37)0.379	0.620(36)0.405
Sample-Fertilized	0.694(12)0.383	0.489(12)0.272	0.708(12)0.293
Total -Fertilized	0.812(132)0.454	0.591(112)0.394	0.536(117)0.405
Total Center	0.898(160)0.454	0.662(127)0.422	0.483(136)0.369
Total Edge	0.701(80)0.451	0.649(73)0.382	0.601(74)0.410
Total Sample	0.805(24)0.363	0.550(24)0.376	0.614(24)0.339
Total	0.830(264)0.453	0.646(224)0.405	0.534(234)0.383

TABLE 5.3-2. FIRST HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

U. MAXIMUM GROWTH RATE BY ANY PLANT IN THE TREATMENT
Growth Rate Based on Beginning Subsurface Fronds Weight and Harvest Weight (Exponential, % / Day)

	Low Density	Medium Density	High Density
Center-Unfertilized	1.932	1.673	1.118
Edge -Unfertilized	1.820	1.325	1.588
Sample-Unfertilized	1.622	1.231	0.920
Total -Unfertilized	1.932	1.673	1.588
Center-Fertilized	1.731	1.442	1.631
Edge -Fertilized	1.624	1.234	1.544
Sample-Fertilized	1.363	1.039	1.108
Total -Fertilized	1.731	1.442	1.631
Total Center	1.932	1.673	1.631
Total Edge	1.820	1.325	1.588
Total Sample	1.622	1.231	1.108
Total	1.932	1.673	1.631

TABLE 5.3-3. SECOND HARVEST YIELD DATA TABLES

(December/January through March/April 1982)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
A. EXPERIMENT PARAMETERS, ASSUMPTIONS, CALCULATIONS & CONSTANTS			
Individual Plants / sq. M	0.0625	0.2500	1.0000
Square Meters / Ind. Plant	16	4	1
Distance Between Centers (M)	4	2	1
Plants / Acre (4,046.9 sq M)	252.9	1,011.7	4,046.9

Assumption:	Dry Wt	/ Wet Wt	= 12.36%	(literature mean)
Assumption:	Dry Ash-Free Wt	/ Dry Wt	= 62.39%	(literature mean)
Calculation:	Dry Ash-Free Wt	/ Wet Wt	= 7.71%	
Constant:	Kg	/ Short Ton	= 907.18	

Conversion from gm production / day / plant to Dry Ash-Free Wt / Acre / Year
Assuming growth is the same in each quarter of the year

Low Density =	0.0078
Medium Density =	0.0314
High Density =	0.1255

Conversion from gm production / day / plant to Dry Ash-Free Wt / Acre / Year
Assuming growth is proportional to solar irradiance
(Winter = 185.20, Spring = 288.80, Summer = 266.83, Fall = 160.70 W / sq. M)

	Winter	Spring	Summer	Fall
Low Density =	0.0095	0.0061	0.0066	0.0109
Medium Density =	0.0382	0.0245	0.0265	0.0440
High Density =	0.1527	0.0979	0.1060	0.1760

B. TIME BETWEEN HARVESTS (days)			
Center-Unfertilized	112.51(76)11.02	114.28(60)11.48	105.12(67) 8.53
Edge -Unfertilized	113.14(37)10.98	110.89(35)13.25	106.24(38) 9.58
Sample-Unfertilized	98.50(12) 5.81	96.08(12)14.70	105.58(12)13.85
Total -Unfertilized	111.35(125)11.37	111.13(107)13.54	105.53(117) 9.44
Center-Fertilized	106.08(77) 7.99	104.14(57) 8.31	98.93(57) 9.57
Edge -Fertilized	106.39(36) 8.39	102.09(35)10.43	103.29(21) 9.45
Sample-Fertilized	101.58(12) 5.63	99.25(12) 7.37	111.58(12) 2.23
Total -Fertilized	105.74(125) 7.91	102.88(104) 9.05	101.63(90) 9.85
Total Center	109.27(153)10.11	109.34(117)11.24	102.27(124) 9.51
Total Edge	109.81(73)10.21	106.49(70)12.64	105.19(59) 9.55
Total Sample	100.04(24) 5.81	97.67(24)11.49	108.58(24)10.17
Total	108.54(250)10.17	107.07(211)12.24	103.84(207) 9.79

TABLE 5.3-3. SECOND HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
C. WET WEIGHT OF HARVESTED MATERIAL PER PLANT (kg)			
Center-Unfertilized	32.90(80)33.84	18.70(62)22.62	9.08(66)12.36
Edge -Unfertilized	16.82(40)19.56	14.14(36)16.92	10.74(38)12.77
Sample-Unfertilized	12.35(12) 7.07	3.72(12) 5.24	3.89(12) 7.42
Total -Unfertilized	26.16(132)29.69	15.84(110)20.07	9.09(116)12.16
Center-Fertilized	33.15(79)26.90	16.97(63)19.69	9.44(67)11.60
Edge -Fertilized	22.49(40)22.69	21.52(37)21.97	13.26(34)20.63
Sample-Fertilized	22.82(12)25.31	10.16(12)14.27	5.79(12) 8.90
Total -Fertilized	28.95(131)28.95	17.75(112)20.11	10.20(113)14.75
Total Center	33.03(159)30.49	17.46(125)21.12	9.26(133)11.94
Total Edge	19.66(80)21.24	17.88(73)19.86	11.93(72)16.86
Total Sample	17.59(24)19.06	6.94(24)11.02	4.84(24) 8.08
Total	27.55(263)27.84	16.67(222)20.07	9.64(229)13.48
D. FRONDS PER PLANT (@ 1M from the bottom at the end of the experimental growth period)			
Center-Unfertilized	31.56(80)26.78	22.91(64)20.40	12.45(67)12.15
Edge -Unfertilized	20.90(40)14.89	21.56(36)19.02	14.74(38)13.70
Sample-Unfertilized	27.75(12)16.06	11.17(12)10.03	10.58(12)13.98
Total -Unfertilized	27.28(132)23.31	21.21(112)19.31	13.00(117)12.81
Center-Fertilized	30.80(80)21.49	20.60(63)21.40	11.38(69)10.40
Edge -Fertilized	26.65(40)22.87	24.49(37)16.18	15.29(35)18.57
Sample-Fertilized	33.08(12)17.85	18.00(12)17.32	12.00(12)12.81
Total -Fertilized	29.75(132)21.58	21.61(112)19.37	12.62(116)13.59
Total Center	31.18(160)24.20	21.76(127)20.85	11.90(136)11.27
Total Edge	23.78(80)19.39	23.04(73)17.60	15.00(73)16.10
Total Sample	30.42(24)16.82	14.58(24)14.28	11.29(24)13.14
Total	28.87(264)22.43	21.41(224)19.30	12.81(233)13.18
E. FROND DENSITY (@ 1M from the bottom at the end of the experimental growth period) (September Frond Densities shown in parentheses) Fronds / Sq M			
Total -Unfertilized	1.71 (1.64)	5.30 (6.33)	13.00 (24.02)
Total -Fertilized	1.86 (1.66)	5.40 (6.41)	12.62 (24.64)
Total	1.80 (1.65)	5.35 (6.37)	12.81 (24.33)

TABLE 5.3-3. SECOND HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
F. FRONDS HARVESTED PER PLANT (fronds)			
Center-Unfertilized	14.64(80)13.14	10.38(64)10.52	5.81(67) 6.75
Edge -Unfertilized	9.28(40) 8.40	7.86(36) 7.78	7.16(38) 6.91
Sample-Unfertilized	10.83(12) 7.96	4.08(12) 5.28	4.42(12) 6.68
Total -Unfertilized	12.67(132)11.69	8.89(112) 9.42	6.10(117) 6.79
Center-Fertilized	17.69(80)13.92	11.46(63)13.73	6.23(69) 6.63
Edge -Fertilized	14.93(40)16.34	13.27(37)10.31	8.60(35)11.26
Sample-Fertilized	10.90(10) 3.48	8.25(12)10.31	6.08(12) 7.74
Total -Fertilized	16.32(130)14.30	11.71(112)12.34	6.93(116) 8.39
Total Center	16.16(160)13.58	10.91(127)12.18	6.02(136) 6.67
Total Edge	12.10(80)13.22	10.60(73) 9.49	7.85(73) 9.22
Total Sample	10.86(22) 6.20	6.17(24) 8.29	5.25(24) 7.12
Total	14.48(262)13.15	10.30(224)11.05	6.52(233) 7.62
G. WET WEIGHT HARVESTED PER FROND (kg)			
Center-Unfertilized	1.87(80) 1.18	1.32(62) 0.96	1.03(66) 1.06
Edge -Unfertilized	1.66(40) 1.09	1.34(36) 0.94	1.09(38) 1.05
Sample-Unfertilized	1.10(12) 0.42	0.52(12) 0.49	0.49(12) 0.50
Total -Unfertilized	1.74(132) 1.12	1.24(110) 0.94	0.99(116) 1.02
Center-Fertilized	1.67(79) 0.85	1.25(63) 0.86	1.07(67) 1.19
Edge -Fertilized	1.20(40) 0.87	1.40(37) 1.03	0.84(34) 0.84
Sample-Fertilized	1.22(10) 0.35	0.89(12) 0.54	0.62(12) 0.53
Total -Fertilized	1.49(129) 0.85	1.26(112) 0.90	0.95(113) 1.05
Total Center	1.77(159) 1.03	1.29(125) 0.91	1.05(133) 1.13
Total Edge	1.43(80) 1.01	1.37(73) 0.98	0.97(72) 0.96
Total Sample	1.15(22) 0.38	0.70(24) 0.54	0.56(24) 0.50
Total	1.61(261) 1.00	1.25(222) 1.25	0.97(229) 1.03

TABLE 5.3-3. SECOND HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
H. PROPORTION OF PLANTS THAT DIED AND PROPORTION OF PLANTS THAT DID PRODUCE HARVESTABLE CANOPY (Beginning Number / % Dead / % Producing Harvestable Canopy			
Center-Unfertilized	80 / 11.3 / 85.0	62 / 9.7 / 80.6	66 / 24.2 / 68.2
Edge -Unfertilized	40 / 7.5 / 87.5	36 / 5.6 / 86.1	38 / 21.1 / 71.1
Sample-Unfertilized	12 / 8.3 / 100.0	12 / 25.0 / 58.3	12 / 41.7 / 58.3
Total -Unfertilized	132 / 9.8 / 91.7	110 / 10.0 / 80.0	116 / 25.0 / 68.1
Center-Fertilized	79 / 11.4 / 86.4	63 / 17.5 / 81.0	67 / 22.4 / 67.2
Edge -Fertilized	40 / 20.0 / 80.0	37 / 5.4 / 91.9	34 / 41.2 / 55.9
Sample-Fertilized	12 / 0.0 / 100.0	12 / 16.7 / 83.3	12 / 16.7 / 83.3
Total -Fertilized	131 / 13.0 / 87.0	112 / 13.4 / 84.8	113 / 27.4 / 65.5
Total Center	159 / 11.3 / 86.8	125 / 13.6 / 80.8	133 / 23.3 / 67.7
Total Edge	80 / 13.8 / 83.8	73 / 5.5 / 89.0	72 / 30.6 / 63.9
Total Sample	24 / 4.2 / 95.8	24 / 20.8 / 70.8	24 / 29.2 / 70.8
Total	263 / 11.4 / 86.7	222 / 11.7 / 82.4	229 / 26.2 / 66.8
I. AVERAGE WET WEIGHT PRODUCTION PER PLANT (gm / Day) Including All Plants			
Center-Unfertilized	297.99(78)300.30	168.40(61)200.66	84.28(66)113.18
Edge -Unfertilized	157.10(38)190.34	119.83(35)145.70	102.14(38)120.28
Sample-Unfertilized	126.47(12) 80.09	41.49(12) 57.33	36.31(12) 66.72
Total -Unfertilized	240.08(128)266.69	138.56(108)177.03	85.17(116)112.54
Center-Fertilized	310.38(78)254.26	162.60(63)185.93	96.05(67)116.50
Edge -Fertilized	210.37(39)206.21	205.18(37)199.05	116.54(33)181.98
Sample-Fertilized	224.63(12)250.00	105.50(12)150.51	52.48(12) 81.02
Total -Fertilized	272.17(129)243.21	170.55(112)187.87	97.42(112)136.36
Total Center	304.18(156)277.40	165.47(124)192.55	90.21(133)114.58
Total Edge	184.08(77)199.04	163.69(72)179.17	108.84(71)151.12
Total Sample	175.54(24)188.34	73.49(24)116.08	44.40(24) 73.05
Total	256.19(257)255.18	154.85(220)182.92	91.19(228)124.69
J. BIOMASS YIELD (Wet gm / Sq M / Day) (December Numbers in Parentheses)			
Total -Unfertilized	15.01 (14.03)	34.64 (42.54)	85.17 (119.28)
Total -Fertilized	17.01 (12.45)	42.64 (34.80)	97.42 (113.10)
Total	16.01 (13.23)	38.71 (38.67)	91.19 (116.22)

TABLE 5.3-3. SECOND HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
K. BIOMASS YIELD (Wet kg / Sq M / Year) Assuming growth is the same in each quarter of the year (December Numbers in Parentheses)			
Total -Unfertilized	5.48 (5.12)	12.64 (15.53)	31.09 (43.54)
Total -Fertilized	6.21 (4.54)	15.56 (12.70)	35.56 (41.28)
Total	5.84 (4.83)	14.13 (14.11)	33.28 (42.42)
L. BIOMASS YIELD (Wet kg / Sq M / Year) Assuming growth is proportional to solar irradiance (Winter = 185.20, Spring = 288.80, Summer = 266.83, Fall = 160.70 W / sq. M) (December Numbers in Parentheses)			
Total -Unfertilized	6.67 (7.18)	15.38 (21.77)	37.84 (61.04)
Total -Fertilized	7.56 (6.37)	18.94 (17.81)	43.28 (57.88)
Total	7.11 (6.77)	17.20 (19.79)	40.50 (59.48)
M. AVERAGE WET WEIGHT PRODUCTION PER PLANT (gm / Day) Including Only Those Plants that Produced Harvestable Canopy			
Center-Unfertilized	352.17(66)295.72	209.64(49)203.73	123.61(45)118.11
Edge -Unfertilized	180.91(33)193.52	139.80(30)148.32	143.76(27)119.91
Sample-Unfertilized	137.95(11) 72.88	71.12(7) 59.73	62.25(7) 79.23
Total -Unfertilized	279.37(110)267.95	174.00(86)182.24	125.06(79)116.71
Center-Fertilized	350.87(69)242.47	200.86(51)187.15	143.01(45)116.14
Edge -Fertilized	264.66(31)197.52	223.29(34)197.63	213.66(18)200.91
Sample-Fertilized	224.63(12)250.00	126.60(10)157.22	62.98(10) 85.38
Total -Fertilized	313.48(112)234.83	201.07(95)188.36	149.47(73)144.15
Total Center	351.50(135)268.81	205.17(100)194.51	133.31(90)116.88
Total Edge	221.47(64)198.44	184.15(64)179.86	171.72(45)159.03
Total Sample	183.17(23)188.74	103.75(17)126.63	62.68(17) 80.34
Total	296.58(222)251.79	188.21(181)185.46	136.78(152)130.75

TABLE 5.3-3. SECOND HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
N. MAXIMUM WET WEIGHT GROWTH BY ANY PLANT IN THE TREATMENT (gm / Day)			
Center-Unfertilized	1,526.77	1,042.04	414.29
Edge -Unfertilized	841.55	515.00	492.00
Sample-Unfertilized	245.65	174.32	239.23
Total -Unfertilized	1,526.77	1,042.04	492.00
Center-Fertilized	1,033.54	901.21	415.37
Edge -Fertilized	761.06	829.02	850.35
Sample-Fertilized	935.29	533.05	261.91
Total -Fertilized	1,033.54	901.21	850.35
Total Center	1,526.77	1,042.04	415.37
Total Edge	841.55	829.02	850.35
Total Sample	935.29	533.05	261.91
Total	1,526.77	1,042.04	850.35

O. PROJECTED YIELD (Dry Ash-Free Tons / Acre / Year)
Based on the Above Assumptions and that growth is the same each quarter of the year 365 x per Day Production Rate (December Numbers in Parentheses)

Data for All Plants			
Total -Unfertilized	1.87 (1.75)	4.35 (5.34)	10.69 (14.97)
Total -Fertilized	2.12 (1.55)	5.36 (4.37)	12.23 (14.19)
Total	2.00 (1.65)	4.86 (4.85)	11.44 (14.59)
Data for Those Plants that Produced Harvestable Canopy			
Total -Unfertilized	2.18 (1.82)	5.46 (5.87)	15.70 (17.87)
Total -Fertilized	2.45 (1.67)	6.31 (4.95)	18.76 (17.74)
Total	2.31 (1.74)	5.91 (5.42)	17.17 (17.81)
Data for The Plant in the Treatment with Maximum Growth			
Total -Unfertilized	11.91 (6.07)	32.72 (18.45)	61.75 (63.62)
Total -Fertilized	8.06 (6.20)	28.30 (16.66)	106.72 (53.55)
Total	11.91 (6.20)	32.72 (18.45)	106.72 (63.62)

TABLE 5.3-3. SECOND HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

P. PROJECTED YIELD (Dry Ash-Free Tons / Acre / Year)
Based on the Above Assumptions and that growth is proportional to solar irradiance (20.54% in Winter, 32.03% in Spring, 29.60% in Summer and 17.83% in Fall) (December Numbers in Parentheses)

	Low Density	Medium Density	High Density
Data for All Plants			
Total -Unfertilized	2.28 (2.45)	5.29 (7.49)	13.01 (20.99)
Total -Fertilized	2.59 (2.17)	6.52 (6.13)	14.88 (19.91)
Total	2.43 (2.31)	5.92 (6.81)	13.92 (20.45)
Data for Those Plants that Produced Harvestable Canopy			
Total -Unfertilized	2.65 (2.55)	6.65 (8.23)	19.10 (25.06)
Total -Fertilized	2.98 (2.33)	7.68 (6.94)	22.82 (24.88)
Total	2.82 (2.44)	7.19 (7.59)	20.89 (24.98)
Data for The Plant in the Treatment with Maximum Growth			
Total -Unfertilized	14.50 (8.49)	39.81 (25.85)	75.13 (89.22)
Total -Fertilized	9.82 (8.66)	34.43 (23.34)	129.85 (75.10)
Total	14.50 (8.66)	39.81 (25.85)	129.85 (89.22)

TABLE 5.3-4. THIRD HARVEST YIELD DATA TABLES
(March/April through June/July 1982)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
A. EXPERIMENT PARAMETERS, ASSUMPTIONS, CALCULATIONS & CONSTANTS			
Individual Plants / sq. M	0.0625	0.2500	1.0000
Square Meters / Ind. Plant	16	4	1
Distance Between Centers (M)	4	2	1
Plants / Acre (4,046.9 sq M)	252.9	1,011.7	4,046.9

Assumption:	Dry Wt	/ Wet Wt	= 12.36%	(literature mean)
Assumption:	Dry Ash-Free Wt	/ Dry Wt	= 62.39%	(literature mean)
Calculation:	Dry Ash-Free Wt	/ Wet Wt	= 7.71%	
Constant:	Kg	/ Short Ton	= 907.18	

Conversion from gm production / day / plant to Dry Ash-Free Wt / Acre / Year
Assuming growth is the same in each quarter of the year

Low Density =	0.0078
Medium Density =	0.0314
High Density =	0.1255

Conversion from gm production / day / plant to Dry Ash-Free Wt / Acre / Year
Assuming growth is proportional to solar irradiance
(Winter = 185.20, Spring = 288.80, Summer = 266.83, Fall = 160.70 W / sq. M)

	Winter	Spring	Summer	Fall
Low Density =	0.0095	0.0061	0.0066	0.0109
Medium Density =	0.0382	0.0245	0.0265	0.0440
High Density =	0.1527	0.0979	0.1060	0.1760

B. TIME BETWEEN HARVESTS (days)			
Center-Unfertilized	82.08(85)12.16	81.57(63) 7.00	77.04(73)10.05
Edge -Unfertilized	82.95(39)10.17	82.37(38)11.63	77.30(40) 8.54
Total -Unfertilized	82.35(124)11.54	82.23(101) 9.62	77.65(113)10.20
Center-Fertilized	73.16(80) 5.27	72.77(65)11.39	68.74(73) 9.50
Edge -Fertilized	76.02(41)12.96	73.58(40)11.05	66.32(37)11.64
Total -Fertilized	74.37(121) 9.07	73.35(106)11.51	67.93(110)10.28
Total Center	77.76(165)10.44	77.10(128)10.43	72.89(146)10.60
Total Edge	79.40(80)12.12	77.86(78)12.10	72.03(77)11.49
Total	78.39(245)11.11	77.70(206)11.50	72.90(223)11.32

TABLE 5.3-4. THIRD HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
C. WET WEIGHT OF HARVESTED MATERIAL PER PLANT (kg)			
Center-Unfertilized	54.41(85)36.13	26.51(65)23.38	11.48(73)12.23
Edge -Unfertilized	31.98(41)22.93	33.68(39)30.78	14.29(40)14.46
Total -Unfertilized	47.11(126)34.02	28.97(104)26.46	12.26(113)13.06
Center-Fertilized	49.91(80)30.95	25.69(65)23.17	7.81(72) 9.52
Edge -Fertilized	41.20(43)31.65	30.98(40)22.28	20.23(40)16.34
Total -Fertilized	46.48(123)31.50	27.54(105)22.83	12.24(112)13.69
Total Center	52.23(165)33.69	26.10(130)23.19	9.66(145)11.08
Total Edge	36.70(84)27.96	32.31(79)26.67	17.27(80)15.62
Total	46.80(249)32.73	28.25(209)24.65	12.25(225)13.34
D. FRONDS PER PLANT (@ 1M from the bottom at the end of the experimental growth period)			
Center-Unfertilized	44.66(86)26.29	30.72(65)23.59	15.47(73)12.10
Edge -Unfertilized	32.02(41)20.31	31.92(39)22.56	20.80(40)16.31
Total -Unfertilized	40.58(127)25.14	30.97(104)23.08	17.15(113)13.87
Center-Fertilized	41.91(81)23.93	28.55(65)22.45	13.68(72)10.40
Edge -Fertilized	39.93(43)25.07	34.60(40)21.30	24.30(40)17.48
Total -Fertilized	40.90(124)24.43	30.82(105)22.01	17.47(112)14.24
Total Center	43.33(167)25.13	29.64(130)22.96	14.58(145)11.29
Total Edge	36.07(84)36.07	33.28(79)21.83	22.55(80)16.88
Total	40.74(251)24.74	30.90(211)22.50	17.31(227)14.02
E. FROND DENSITY (@ 1M from the bottom at the end of the experimental growth period) Fronds / Sq M (September / March / June)			
Total -Unfertilized	1.64/ 1.71/ 2.54	6.33/ 5.30/ 7.74	24.02/ 13.00/ 17.15
Total -Fertilized	1.66/ 1.86/ 2.56	6.41/ 5.40/ 7.71	24.64/ 12.62/ 17.47
Total	1.65/ 1.80/ 2.55	6.37/ 5.35/ 7.73	24.33/ 12.81/ 17.31

TABLE 5.3-4. THIRD HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
F. FRONDS HARVESTED PER PLANT (fronds)			
Center-Unfertilized	22.90(86)15.59	14.91(65)12.42	7.49(73) 6.21
Edge -Unfertilized	14.46(41)10.03	16.74(39)13.61	9.43(40) 8.56
Total -Unfertilized	20.17(127)14.55	15.49(104)12.83	8.04(113) 7.16
Center-Fertilized	24.15(81)16.67	16.45(65)14.45	5.97(71) 6.09
Edge -Fertilized	21.91(43)15.94	18.08(40)13.40	12.44(39) 8.59
Total -Fertilized	23.18(124)16.46	16.96(105)13.99	8.26(110) 7.69
Total Center	23.50(167)16.09	15.68(130)13.44	6.74(144) 6.17
Total Edge	18.27(84)13.82	17.42(79)13.43	10.91(79) 8.65
Total	21.67(251)15.57	16.23(209)13.41	8.15(223) 7.41
G. WET WEIGHT HARVESTED PER FROND (kg) Only for those plants producing harvestable canopy			
Center-Unfertilized	2.41(84) 0.66	1.88(60) 1.33	1.54(59) 0.78
Edge -Unfertilized	2.28(39) 0.80	1.98(36) 0.95	1.56(29) 0.56
Total -Unfertilized	2.37(123) 0.71	1.91(96) 1.19	1.53(88) 0.72
Center-Fertilized	2.13(76) 0.60	1.73(63) 1.06	1.17(55) 0.60
Edge -Fertilized	1.95(41) 0.80	1.74(38) 0.54	1.53(35) 0.52
Total -Fertilized	2.07(117) 0.68	1.73(101) 0.89	1.31(90) 0.60
Total Center	2.28(160) 0.65	1.80(123) 1.19	1.36(114) 0.72
Total Edge	2.11(80) 0.81	1.85(74) 0.77	1.55(64) 0.54
Total	2.22(240) 0.71	1.82(197) 1.05	1.42(178) 0.67

TABLE 5.3-4. THIRD HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
H. AVERAGE WET WEIGHT PRODUCTION PER PLANT (gm / Day) Including All Plants			
Center-Unfertilized	668.81(84)441.07	334.68(63)282.39	149.96(73)157.69
Edge -Unfertilized	397.66(40)282.86	390.32(38)339.29	186.87(40)185.48
Total -Unfertilized	581.34(124)415.75	352.54(101)304.65	160.21(113)168.03
Center-Fertilized	679.41(79)414.75	365.18(65)320.58	120.40(72)148.02
Edge -Fertilized	558.32(43)429.62	414.35(40)287.07	308.33(38)246.17
Total -Fertilized	631.56(122)424.45	381.21(105)307.56	185.32(110)207.12
Total Center	673.95(163)427.23	350.17(128)301.59	135.28(145)153.15
Total Edge	480.89(83)372.98	402.65(78)311.77	246.04(78)224.23
Total	606.35(246)420.00	367.15(206)305.74	172.49(225)188.16
I. PROJECTED YIELD (Dry Ash-Free Tons / Acre / Year) Based on the Above Assumptions and that growth is the same each quarter of the year 365 x per Day Production Rate (December / March / June)			
Data for All Plants			
Total -Unfertilized	1.75/ 1.87/ 4.53	5.34/ 4.35/11.07	14.97/ 10.69/20.11
Total -Fertilized	1.55/ 2.12/ 4.93	4.37/ 5.36/ 9.66	14.19/ 12.23/23.26
Total	1.65/ 2.00/ 4.73	4.85/ 4.86/11.53	14.59/ 11.44/23.61

TABLE 5.3-5. FOURTH HARVEST YIELD DATA TABLES

(June/July through September 1982)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
A. EXPERIMENT PARAMETERS, ASSUMPTIONS, CALCULATIONS & CONSTANTS			
Individual Plants / sq. M	0.0625	0.2500	1.0000
Square Meters / Ind. Plant	16	4	1
Distance Between Centers (M)	4	2	1
Plants / Acre (4,046.9 sq M)	252.9	1,011.7	4,046.9

Assumption:	Dry Wt	/ Wet Wt	= 12.36%	(literature mean)
Assumption:	Dry Ash-Free Wt	/ Dry Wt	= 62.39%	(literature mean)
Calculation:	Dry Ash-Free Wt	/ Wet Wt	= 7.71%	
Constant:	Kg	/ Short Ton	= 907.18	

Conversion from gm production / day / plant to Dry Ash-Free Wt / Acre / Year
Assuming growth is the same in each quarter of the year

Low Density =	0.0078
Medium Density =	0.0314
High Density =	0.1255

Conversion from gm production / day / plant to Dry Ash-Free Wt / Acre / Year
Assuming growth is proportional to solar irradiance
(Winter = 185.20, Spring = 288.80, Summer = 266.83, Fall = 160.70 W / sq. M)

	Winter	Spring	Summer	Fall
Low Density =	0.0095	0.0061	0.0066	0.0109
Medium Density =	0.0382	0.0245	0.0265	0.0440
High Density =	0.1527	0.0979	0.1060	0.1760

B. TIME BETWEEN HARVESTS (days)

Center-Unfertilized	75.79(86) 2.90	76.75(65) 3.38	76.04(73) 3.82
Edge -Unfertilized	75.44(41) 2.64	77.26(39) 3.02	75.05(40) 5.42
Sample-Unfertilized	83.25(4) 0.50	76.50(4)13.67	76.75(4)13.18
Total -Unfertilized	75.91(131) 3.06	76.93(108) 3.92	75.73(117) 4.86
Center-Fertilized	79.43(86) 6.31	80.88(65) 4.23	74.92(73) 8.72
Edge -Fertilized	79.33(40) 5.95	81.15(40) 4.98	76.08(40) 7.90
Sample-Fertilized	83.75(4) 0.96	82.25(4) 4.86	83.50(4) 3.00
Total -Fertilized	79.70(130) 6.13	81.03(109) 4.51	75.61(117) 8.42
Total Center	77.61(172) 5.22	78.82(130) 4.34	75.48(146) 6.73
Total Edge	77.36(81) 4.96	79.23(79) 4.55	75.56(80) 6.75
Total Sample	83.50(8) 0.76	79.38(8) 9.98	80.13(8) 9.55
Total	77.71(261) 5.16	78.99(217) 4.69	75.67(234) 6.86

TABLE 5.3-5. FOURTH HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
C. WET WEIGHT OF HARVESTED MATERIAL PER PLANT (kg)			
Center-Unfertilized	18.85(86)20.86	6.69(66) 8.84	1.14(73) 2.16
Edge -Unfertilized	12.67(42)13.55	11.05(42)12.38	3.68(40) 5.42
Sample-Unfertilized	11.61(4) 7.32	0.93(4) 1.31	0.00(4) 0.00
Total -Unfertilized	16.66(132)18.71	8.12(112)10.43	1.97(117) 3.79
Center-Fertilized	26.28(86)20.78	14.53(66)14.17	4.16(73) 6.65
Edge -Fertilized	20.48(42)19.31	20.00(42)14.62	10.20(40)11.49
Sample-Fertilized	8.09(4) 3.71	1.94(4) 0.68	0.91(4) 1.05
Total -Fertilized	23.89(132)20.30	16.13(112)14.52	6.11(117) 9.00
Total Center	22.57(172)21.09	10.61(132)12.40	2.65(146) 5.15
Total Edge	16.57(84)17.04	15.52(84)14.19	6.94(80) 9.51
Total Sample	9.85(8) 5.69	1.44(8) 1.11	0.46(8) 0.84
Total	20.27(264)19.82	12.12(224)13.24	4.04(234) 7.19
D. FRONDS PER PLANT (@ 1M from the bottom at the end of the experimental growth period)			
Center-Unfertilized	46.00(86)29.22	29.11(65)21.12	10.86(73)10.01
Edge -Unfertilized	34.00(42)23.02	32.81(42)24.65	20.33(40)16.31
Sample-Unfertilized	46.25(4)17.75	15.75(4) 5.91	2.25(4) 1.71
Total -Unfertilized	42.19(132)27.54	30.03(111)22.31	13.80(117)13.28
Center-Fertilized	47.51(86)27.43	35.56(66)26.57	12.10(73)11.90
Edge -Fertilized	50.24(42)30.56	46.10(42)24.03	27.78(40)21.55
Sample-Fertilized	40.50(4)14.53	24.75(4)14.64	6.75(4) 2.75
Total -Fertilized	48.17(132)28.08	39.13(112)25.80	17.27(117)17.41
Total Center	46.76(172)28.26	32.36(131)24.15	11.48(146)10.98
Total Edge	42.12(84)28.10	39.45(84)25.10	24.05(80)19.36
Total Sample	43.38(8)15.32	20.25(8)11.40	4.50(8) 3.21
Total	45.18(264)27.92	34.60(223)24.50	15.54(234)15.55
E. FROND DENSITY (@ 1M from the bottom at the end of the experimental growth period) (September / March / June / September)			
Fronds / Sq M			
Total -Unfertilized	1.6/1.7/2.5/2.6	6.3/5.3/7.7/7.5	24.0/13.0/17.3/13.3
Total -Fertilized	1.7/1.9/2.6/3.0	6.4/5.4/7.7/9.8	24.6/12.6/17.6/17.4
Total	1.7/1.8/2.5/2.8	6.4/5.4/7.7/8.7	24.3/12.8/17.4/15.6

TABLE 5.3-5. FOURTH HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
F. FRONDS HARVESTED PER PLANT (fronds)			
Center-Unfertilized	19.41(86)18.25	10.55(66)11.60	2.14(73) 4.10
Edge -Unfertilized	11.98(42)10.95	13.07(42)12.90	5.30(40) 6.68
Sample-Unfertilized	17.25(4) 8.34	1.75(4) 1.71	0.00(4) 0.00
Total -Unfertilized	16.98(132)16.34	11.18(112)12.06	3.15(117) 5.29
Center-Fertilized	21.60(86)14.98	15.35(66)13.53	4.79(73) 6.46
Edge -Fertilized	23.83(42)19.98	18.74(42)11.03	12.35(40)12.44
Sample-Fertilized	12.75(4) 3.40	6.50(4) 1.00	2.75(4) 2.22
Total -Fertilized	22.05(132)16.57	16.30(112)12.58	7.31(117) 9.57
Total Center	20.51(172)16.68	12.95(132)12.79	3.47(146) 5.55
Total Edge	17.90(84)17.09	15.90(84)12.26	8.83(80)10.53
Total Sample	15.00(8) 6.37	4.13(8) 2.85	1.38(8) 2.07
Total	19.51(264)16.62	13.74(224)12.56	5.23(234) 7.99
G. WET WEIGHT HARVESTED PER FROND (kg) Only for those plants producing harvestable canopy			
Center-Unfertilized	0.93(73) 0.38	0.60(46) 0.26	0.92(29) 1.28
Edge -Unfertilized	1.03(34) 0.42	0.89(34) 0.46	0.69(24) 0.36
Sample-Unfertilized	0.66(4) 0.17	0.45(3) 0.25	0.00(0) 0.00
Total -Unfertilized	0.95(111) 0.39	0.71(83) 0.38	0.82(53) 0.98
Center-Fertilized	1.40(78) 1.91	0.89(63) 0.40	0.79(40) 0.40
Edge -Fertilized	0.90(40) 0.47	1.03(41) 0.42	0.88(33) 0.39
Sample-Fertilized	0.63(4) 0.22	0.30(4) 0.12	1.71(3) 2.25
Total -Fertilized	1.21(122) 1.57	0.92(108) 0.42	0.86(76) 0.56
Total Center	1.17(151) 1.41	0.77(109) 0.37	0.85(69) 0.88
Total Edge	0.96(74) 0.45	0.96(75) 0.44	0.80(57) 0.39
Total Sample	0.65(8) 0.18	0.37(7) 0.19	1.71(3) 2.25
Total	1.09(233) 1.17	0.83(191) 0.42	0.85(129) 0.76

TABLE 5.3-5. FOURTH HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
H. AVERAGE WET WEIGHT PRODUCTION PER PLANT (gm / Day) Including All Plants			
Center-Unfertilized	249.54(86)278.70	87.03(65)115.57	15.92(73) 31.61
Edge -Unfertilized	168.30(41)184.73	146.08(40)163.30	48.97(40) 70.55
Sample-Unfertilized	139.55(4) 88.39	11.80(4) 15.53	0.00(4) 0.00
Total -Unfertilized	220.76(131)251.17	105.94(109)136.72	26.67(117) 50.62
Center-Fertilized	323.96(86)254.87	179.48(65)175.55	61.11(73)105.89
Edge -Fertilized	249.70(40)228.95	249.79(40)171.78	134.45(40)147.46
Sample-Fertilized	96.87(4) 45.14	23.56(4) 7.60	11.05(4) 12.60
Total -Fertilized	294.12(130)247.20	199.56(109)176.76	84.48(117)125.16
Total Center	286.75(172)268.87	133.25(130)155.14	38.52(146) 81.10
Total Edge	208.50(81)210.46	197.93(80)174.51	91.71(80)122.64
Total Sample	118.21(8) 68.86	17.68(8) 12.95	5.52(8) 10.14
Total	257.30(261)251.42	152.75(218)164.48	55.57(234) 99.56

I. PROJECTED YIELD (Dry Ash-Free Tons / Acre / Year) Based on the Above Assumptions and that growth is the same each quarter of the year 365 x per Day Production Rate (December / March / June / September)

Data for Center Plants (Excluding Edge and Sample Plants) (Including Dead Plants and Plants that did not produce harvestable canopy)

Total -Unfertilized	2.1/2.3/5.1/1.7	6.5/5.3/10.3/3.3	17.0/10.6/16.9/ 3.3
Total -Fertilized	1.8/2.4/5.0/2.3	4.8/5.1/11.8/6.3	15.4/12.1/14.4/10.6
Total	2.0/2.4/5.1/2.0	5.6/5.2/11.1/4.8	16.3/11.3/15.7/ 7.0

TABLE 5.3-6. FIFTH HARVEST YIELD DATA TABLES

(October through December 1982)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
A. EXPERIMENT PARAMETERS, ASSUMPTIONS, CALCULATIONS & CONSTANTS			
Individual Plants / sq. M	0.0625	0.2500	1.0000
Square Meters / Ind. Plant	16	4	1
Distance Between Centers (M)	4	2	1
Plants / Acre (4,046.9 sq M)	252.9	1,011.7	4,046.9

Assumption: Dry Wt / Wet Wt = 12.36% (literature mean)
Assumption: Dry Ash-Free Wt / Dry Wt = 62.39% (literature mean)
Calculation: Dry Ash-Free Wt / Wet Wt = 7.71%
Constant: Kg / Short Ton = 907.18

Conversion from gm production / day / plant to Dry Ash-Free Wt / Acre / Year
Assuming growth is the same in each quarter of the year

Low Density =	0.0078
Medium Density =	0.0314
High Density =	0.1255

Conversion from gm production / day / plant to Dry Ash-Free Wt / Acre / Year
Assuming growth is proportional to solar irradiance
(Winter = 185.20, Spring = 288.80, Summer = 266.83, Fall = 160.70 W / sq. M)

	Winter	Spring	Summer	Fall
Low Density =	0.0095	0.0061	0.0066	0.0109
Medium Density =	0.0382	0.0245	0.0265	0.0440
High Density =	0.1527	0.0979	0.1060	0.1760

B. TIME BETWEEN HARVESTS (days)

Center-Unfertilized	72.34(86) 4.49	70.88(66) 2.79	69.55(73) 4.25
Edge -Unfertilized	72.43(42) 4.89	71.29(42) 2.49	69.55(40) 4.32
Sample-Unfertilized	77.25(4) 1.50	67.25(4)18.86	36.00(4) 0.00
Total -Unfertilized	72.52(132) 4.62	70.90(112) 4.12	68.40(117) 7.41
Center-Fertilized	79.05(86) 4.80	79.56(66) 2.21	78.56(73) 6.36
Edge -Fertilized	79.57(42) 4.19	79.62(42) 2.34	80.90(40) 2.95
Sample-Fertilized	76.50(4) 1.00	75.50(4) 0.58	76.00(4) 0.00
Total -Fertilized	79.14(132) 4.55	79.44(112) 2.34	79.27(117) 5.45
Total Center	75.69(172) 5.72	75.22(132) 5.03	74.05(146) 7.04
Total Edge	76.00(84) 5.78	75.45(84) 4.83	75.23(80) 6.79
Total Sample	76.88(8) 1.25	71.38(8)13.11	56.00(8)21.38
Total	75.83(264) 5.65	75.17(224) 5.43	73.84(234) 8.47

TABLE 5.3-6. FIFTH HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
C. WET WEIGHT OF HARVESTED MATERIAL PER PLANT (kg)			
Center-Unfertilized	12.45(85)13.60	8.76(65) 7.81	2.91(73) 4.04
Edge -Unfertilized	7.05(42) 8.76	10.68(42)10.60	6.31(40) 6.05
Sample-Unfertilized	4.69(4) 4.18	0.68(4) 1.23	1.47(4) 1.53
Total -Unfertilized	10.48(131)12.30	9.20(111) 9.00	4.02(117) 5.03
Center-Fertilized	9.67(86)12.87	12.12(65)12.03	2.72(73) 4.75
Edge -Fertilized	5.85(42)10.25	14.57(42)14.98	7.48(40) 7.62
Sample-Fertilized	4.46(4) 3.94	4.66(4) 3.82	0.13(4) 0.15
Total -Fertilized	8.30(132)12.01	12.78(111)13.12	4.26(117) 6.26
Total Center	11.05(171)13.27	10.44(130)10.24	2.82(146) 4.39
Total Edge	6.45(84) 9.49	12.63(84)13.05	6.89(80) 6.86
Total Sample	4.58(8) 3.76	2.67(8) 3.38	0.80(8) 1.23
Total	9.38(263)12.19	10.99(222)11.37	4.14(234) 5.67
D. FRONDS PER PLANT (@ 1M from the bottom at the end of the experimental growth period)			
Center-Unfertilized	32.86(86)31.78	27.85(66)21.29	10.66(73)11.93
Edge -Unfertilized	23.57(42)24.91	30.71(42)25.92	20.13(40)15.62
Sample-Unfertilized	37.50(4)19.42	15.25(4)11.64	12.50(4) 5.00
Total -Unfertilized	30.05(132)29.64	28.47(112)22.93	13.96(117)13.82
Center-Fertilized	23.76(86)27.38	28.44(66)23.64	6.90(73) 9.42
Edge -Fertilized	17.19(42)26.22	33.86(42)29.27	17.28(40)15.25
Sample-Fertilized	25.50(4) 8.66	27.25(4)23.06	1.75(4) 2.87
Total -Fertilized	21.72(132)26.70	30.43(112)25.80	10.27(117)12.65
Total Center	28.31(172)29.92	28.14(132)22.41	8.78(146)10.88
Total Edge	20.38(84)25.62	32.29(84)27.53	18.70(80)15.40
Total Sample	31.50(8)15.33	21.25(8)18.09	7.13(8) 6.88
Total	25.88(264)28.46	29.45(224)24.37	12.12(234)13.35

E. FROND DENSITY (@ 1M from the bottom at the end of the experimental growth period)
Fronds / Sq M
(September / March / June / September / December)

Total-Unfert.	1.6/1.7/2.5/2.6/1.9	6.3/5.3/7.7/7.5/7.1	24.0/13.0/17.3/13.3/14.0
Total-Fert.	1.7/1.9/2.6/3.0/1.4	6.4/5.4/7.7/9.8/7.6	24.6/12.6/17.6/17.4/10.3
Total	1.7/1.8/2.5/2.8/1.6	6.4/5.4/7.7/8.7/7.4	24.3/12.8/17.4/15.6/12.1

TABLE 5.3-6. FIFTH HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
F. FRONDS HARVESTED PER PLANT (fronds)			
Center-Unfertilized	18.58(86)19.18	15.12(66)12.24	5.44(73) 7.42
Edge -Unfertilized	11.24(41)12.53	17.14(42)15.19	10.55(40) 9.88
Sample-Unfertilized	17.00(4)11.58	4.25(4) 6.65	4.75(4) 3.30
Total -Unfertilized	16.24(131)17.42	15.49(112)13.41	7.16(117) 8.56
Center-Fertilized	12.84(86)16.02	16.15(66)14.25	3.97(73) 5.85
Edge -Fertilized	9.00(42)15.25	18.95(42)18.13	10.23(40) 9.31
Sample-Fertilized	11.50(4) 7.51	13.50(4)10.72	1.00(4) 1.41
Total -Fertilized	11.58(132)15.61	17.11(112)15.67	6.01(117) 7.75
Total Center	15.71(172)17.85	15.64(132)13.24	4.71(146) 6.70
Total Edge	10.11(83)13.93	18.05(84)16.65	10.39(80) 9.54
Total Sample	14.25(8) 9.50	8.88(8) 9.63	2.88(8) 3.09
Total	13.90(263)16.67	16.30(224)14.58	6.59(234) 8.17
G. WET WEIGHT HARVESTED PER FROND (kg) Only for those plants producing harvestable canopy			
Center-Unfertilized	0.66(58) 0.22	0.58(55) 0.20	0.59(47) 0.26
Edge -Unfertilized	0.59(26) 0.20	0.61(32) 0.27	0.83(31) 1.20
Sample-Unfertilized	0.26(4) 0.09	3.52(2) 4.73	0.65(4) 0.71
Total -Unfertilized	0.62(88) 0.23	0.66(89) 0.70	0.68(82) 0.78
Center-Fertilized	0.73(48) 0.22	0.71(57) 0.22	0.64(37) 0.32
Edge -Fertilized	1.12(18) 1.45	0.77(28) 0.30	0.73(33) 0.31
Sample-Fertilized	0.35(4) 0.11	0.33(4) 0.09	3.57(2) 4.61
Total -Fertilized	0.80(70) 0.77	0.72(89) 0.26	0.76(72) 0.79
Total Center	0.69(106) 0.22	0.65(112) 0.22	0.61(84) 0.29
Total Edge	0.81(44) 0.96	0.69(60) 0.29	0.78(57) 0.39
Total Sample	0.30(8) 0.11	1.40(6) 2.68	1.62(6) 2.62
Total	0.70(158) 0.55	0.69(178) 0.53	0.72(154) 0.78

TABLE 5.3-6. FIFTH HARVEST YIELD DATA TABLES (Cont)

Shown in these tables are: Mean (Sample Number) Standard Deviation

	Low Density	Medium Density	High Density
H. AVERAGE WET WEIGHT PRODUCTION PER PLANT (gm / Day) Including All Plants			
Center-Unfertilized	170.00(85)186.77	124.58(65)111.12	43.39(73) 59.69
Edge -Unfertilized	95.74(42)116.82	150.10(42)149.53	90.81(40) 86.09
Sample-Unfertilized	61.16(4) 55.25	16.86(4) 31.93	40.74(4) 42.38
Total -Unfertilized	142.87(131)168.28	130.35(111)127.21	59.51(117) 72.55
Center-Fertilized	121.04(86)159.61	153.00(65)152.43	37.08(73) 66.96
Edge -Fertilized	72.85(42)125.77	183.99(42)191.46	92.11(40) 93.82
Sample-Fertilized	58.56(4) 51.98	61.67(4) 50.18	1.69(4) 2.04
Total -Fertilized	103.81(132)148.69	161.44(111)166.88	54.69(117) 80.73
Total Center	145.37(171)174.86	138.79(130)133.63	40.24(146) 63.29
Total Edge	84.29(84)121.19	167.05(84)171.59	91.46(80) 89.47
Total Sample	59.86(8) 49.68	39.26(8) 45.71	21.22(8) 34.74
Total	123.26(263)159.65	145.89(222)148.86	57.10(234) 76.62

I. PROJECTED YIELD (Dry Ash-Free Tons / Acre / Year)
Based on the Above Assumptions and that growth is the same each quarter of the year 365 x per Day Production Rate (December / March / June / September / December)

Data for Center Plants (Excluding Edge and Sample Plants)
(Including Dead Plants and Plants that did not produce harvestable canopy)

Total-Unfert.	2.1/2.3/5.1/1.7/1.3	6.5/5.3/10.3/3.3/3.9	17.0/10.6/16.9/ 3.3/5.4
Total-Fert.	1.8/2.4/5.0/2.3/0.9	4.8/5.1/11.8/6.3/4.8	15.4/12.1/14.4/10.6/4.7
Total	2.0/2.4/5.1/2.0/1.1	5.6/5.2/11.1/4.8/4.4	16.3/11.3/15.7/ 7.0/5.1

TABLE 5.3-7. HIGHEST YIELDING PLANTS IN THE FIRST THROUGH THE FIFTH HARVESTS

A. PLOT 1 Fertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	409	271.6	437	300.5	658	179.5	79	346.9	406	324.8
2	610	265.4	166	261.3	291	154.4	159	342.5	92	311.5
3	408	246.8	94	206.1	330	137.5	78	297.0	216	272.8
4	399	195.3	420	188.7	834	136.0	249	246.1	570	252.8
5	517	188.9	23	182.2	670	117.3	101	219.0	404	251.7
6	378	162.9	300	159.0	490	114.2	100	212.6	310	244.1
7	73	115.1	523	158.9	206	89.9	389	186.9	414	219.0
8	525	113.3	97	146.0	81	89.2	183	180.1	438	216.8
9	676	106.8	436	129.0	494	82.8	98	151.1	397	209.5
10	44	62.0	445	127.9	928	78.5	80	135.5	413	208.0
11	922	57.5	95	126.2	554	76.7	240	129.7	536	202.3
12	402	48.2	433	121.5	844	64.5	687	128.4	312	196.4
13	639	45.4	219	96.5	385	61.6	686	118.6	405	186.4
14	5	40.6	447	95.2	669	59.2	252	102.6	501	186.3
15	929	39.5	444	81.1	662	57.2	684	90.8	439	184.3

B. PLOT 2 Unfertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	546	451.9	325	273.4	628	187.4	174	284.6	284	412.2
2	504	378.4	324	167.4	647	140.9	188	275.0	459	269.2
3	322	378.1	230	155.0	548	112.3	189	263.9	458	263.9
4	716	374.6	606	154.1	665	107.1	177	233.7	601	260.4
5	505	294.9	229	132.8	644	101.3	258	182.0	600	251.2
6	364	284.4	542	128.0	348	101.2	296	174.7	426	238.5
7	26	227.9	681	126.6	336	96.5	718	153.1	584	214.6
8	714	205.5	786	119.0	593	94.8	362	136.7	287	201.6
9	747	160.6	603	117.5	522	93.5	277	123.2	202	199.2
10	356	150.8	178	106.9	509	89.1	261	113.0	244	187.8
11	11	146.3	231	90.7	351	88.5	375	106.8	423	187.2
12	547	123.6	856	82.5	630	80.8	361	106.2	462	178.7
13	588	106.3	559	82.0	800	76.5	138	97.4	585	161.4
14	33	91.3	790	81.9	511	75.1	360	90.2	566	155.5
15	545	86.5	604	75.8	512	67.2	260	88.0	425	137.8

TABLE 5.3-8. HIGHEST YIELDING PLANTS IN THE FIRST HARVEST

A. PLOT 1 Fertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	451	99.2	447	56.2	330	49.5	159	63.1	216	58.0
2	448	82.9	94	47.2	291	44.8	79	61.6	579	51.7
3	456	58.4	329	40.3	615	44.8	78	42.5	405	44.9
4	400	53.9	166	39.3	144	42.5	99	39.0	92	44.9
5	453	48.9	300	38.0	272	42.0	686	38.1	310	42.6
6	612	48.9	526	38.0	265	40.3	238	36.2	570	41.3
7	515	47.1	445	35.8	83	35.7	101	35.0	312	40.4
8	109	44.8	420	35.7	84	35.7	389	34.9	308	35.8
9	382	44.8	436	33.5	386	33.5	98	34.0	90	35.8
10	640	44.8	151	30.4	699	33.5	53	30.4	35	35.5
11	610	42.5	523	28.9	574	33.1	183	30.4	88	34.9
12	675	42.0	524	26.7	87	31.2	390	28.5	309	34.5
13	409	40.3	633	24.9	206	29.0	685	27.6	404	33.5
14	622	40.3	332	22.2	143	28.9	155	27.2	581	33.5
15	611	38.9	95	22.2	616	28.9	100	26.7	441	32.6

B. PLOT 2 Unfertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	322	102.8	325	46.2	628	57.7	188	55.8	583	59.0
2	504	76.6	542	44.8	509	46.6	719	54.0	423	53.6
3	546	76.1	606	38.1	593	46.6	189	48.1	342	48.0
4	505	67.5	181	36.7	522	42.0	138	47.2	461	47.2
5	650	58.4	323	33.0	518	41.5	361	39.0	116	45.8
6	364	56.2	538	32.2	548	40.4	260	38.5	458	45.5
7	506	53.9	604	31.3	209	38.0	261	38.5	460	44.9
8	223	49.4	324	30.8	169	36.7	258	38.1	287	44.9
9	716	48.9	561	29.9	511	36.6	142	37.6	284	43.5
10	321	47.1	690	26.7	336	35.7	296	35.8	459	41.7
11	547	46.6	231	25.5	551	33.5	346	35.3	584	40.4
12	224	44.8	541	24.0	532	31.3	141	31.7	424	39.7
13	226	44.8	232	22.5	558	31.3	191	31.3	601	38.1
14	366	44.8	178	21.3	128	31.2	358	31.3	602	37.2
15	594	44.3	605	20.8	337	31.2	567	31.3	696	37.2

TABLE 5.3-8. HIGHEST YIELDING PLANTS IN THE FIRST HARVEST (Cont)

C. PLOT 1 Fertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	612	93.7	437	60.2	574	97.7	159	96.4	406	116.7
2	408	90.2	94	53.4	613	51.5	79	92.8	92	95.5
3	610	87.8	23	50.6	658	47.1	78	72.9	22	95.4
4	453	70.7	445	42.5	670	44.8	101	66.5	534	86.0
5	399	70.2	421	39.3	372	44.3	100	53.8	216	70.2
6	448	69.8	332	35.0	291	37.6	249	51.1	394	69.8
7	409	68.8	433	34.8	265	35.7	80	49.5	405	67.4
8	381	53.4	166	34.5	330	33.5	389	47.5	416	66.5
9	513	47.1	97	32.6	764	31.2	392	47.0	308	62.0
10	410	44.8	436	27.5	257	28.9	99	45.7	407	62.0
11	517	44.8	444	22.1	494	28.9	687	44.3	535	60.1
12	611	44.8	151	19.0	51	28.8	98	38.0	395	57.9
13	762	41.2	95	18.5	144	26.7	686	38.0	397	57.9
14	378	40.3	219	18.5	767	26.7	240	37.1	310	53.4
15	642	40.3	419	17.0	774	26.7	183	35.2	582	50.7

D. PLOT 2 Unfertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	716	167.5	538	109.5	628	52.0	174	106.5	342	174.0
2	322	118.0	323	98.0	647	51.0	188	97.0	284	139.5
3	504	110.5	325	73.5	552	47.5	718	94.5	359	112.5
4	546	110.0	786	59.5	872	45.5	189	94.0	601	99.5
5	714	108.0	561	58.5	43	37.5	177	84.0	458	94.5
6	505	99.5	230	54.0	665	34.5	345	79.5	459	88.5
7	651	99.5	681	53.5	169	32.5	721	77.5	427	84.5
8	26	98.5	606	52.0	335	29.5	258	55.5	600	78.5
9	738	89.0	229	51.5	348	29.5	175	54.5	426	76.5
10	506	85.0	324	47.5	664	29.5	296	52.5	287	75.0
11	226	74.0	470	45.5	800	29.5	192	44.5	202	73.5
12	782	69.5	327	45.0	887	29.5	277	39.5	462	71.5
13	356	69.0	603	44.5	548	28.5	362	37.5	566	71.5
14	363	69.0	542	39.5	881	26.5	259	34.5	201	69.5
15	355	67.0	178	37.5	334	24.5	261	34.5	602	66.0

TABLE 5.3-8. HIGHEST YIELDING PLANTS IN THE FIRST HARVEST (Cont)

E. PLOT 1 Fertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	449	104.5	166	109.5	834	67.0	159	99.5	534	142.0
2	408	98.5	437	103.5	658	53.0	249	79.5	404	113.0
3	451	93.5	420	87.5	574	44.5	78	74.0	569	111.0
4	762	83.5	23	69.5	253	41.0	392	67.0	582	107.5
5	612	78.5	300	61.5	613	39.0	79	66.5	92	107.0
6	399	77.0	332	50.5	577	38.5	183	59.5	310	103.5
7	517	74.5	810	49.5	144	37.5	389	57.5	413	103.5
8	381	74.0	94	48.5	490	37.5	100	52.0	406	94.0
9	409	73.5	97	48.5	670	36.5	101	51.5	535	93.5
10	398	72.5	95	44.5	767	35.5	98	51.0	216	92.5
11	453	69.0	523	44.5	291	35.0	184	49.5	536	89.0
12	760	69.0	436	44.0	206	30.5	207	47.5	394	86.5
13	410	67.5	433	41.0	237	30.5	240	44.5	89	79.0
14	610	66.0	302	39.5	330	29.5	388	42.0	407	74.0
15	378	63.5	807	37.5	844	27.5	250	37.5	537	74.0

F. PLOT 2 Unfertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	716	167.5	538	109.5	628	52.0	174	106.5	342	174.0
2	322	118.0	323	98.0	647	51.0	188	97.0	284	139.5
3	504	110.5	325	73.5	552	47.5	718	94.5	359	112.5
4	546	110.0	786	59.5	872	45.5	189	94.0	601	99.5
5	714	108.0	561	58.5	43	37.5	177	84.0	458	94.5
6	505	99.5	230	54.0	665	34.5	345	79.5	459	88.5
7	651	99.5	681	53.5	169	32.5	721	77.5	427	84.5
8	26	98.5	606	52.0	335	29.5	258	55.5	600	78.5
9	738	89.0	229	51.5	348	29.5	175	54.5	426	76.5
10	506	85.0	324	47.5	664	29.5	296	52.5	287	75.0
11	226	74.0	470	45.5	800	29.5	192	44.5	202	73.5
12	782	69.5	327	45.0	887	29.5	277	39.5	462	71.5
13	356	69.0	603	44.5	548	28.5	362	37.5	566	71.5
14	363	69.0	542	39.5	881	26.5	259	34.5	201	69.5
15	355	67.0	178	37.5	334	24.5	261	34.5	602	66.0

TABLE 5.3-8. HIGHEST YIELDING PLANTS IN THE FIRST HARVEST (Cont)

G. PLOT 1 Fertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	762	62.0	437	68.5	577	45.5	79	69.0	534	88.5
2	409	53.5	166	47.5	834	44.5	78	51.5	414	82.0
3	610	49.5	523	39.5	658	38.5	159	49.0	407	79.0
4	28	44.5	420	35.5	928	31.5	249	47.5	535	74.0
5	642	44.0	302	34.5	144	29.5	100	44.5	569	71.0
6	612	39.5	23	32.5	253	24.5	99	39.5	438	69.5
7	760	39.0	806	31.5	291	24.5	388	39.5	570	64.0
8	517	38.5	809	31.5	613	18.5	101	34.5	537	55.5
9	611	36.5	300	29.5	670	18.5	392	33.5	308	54.5
10	619	35.5	332	28.5	844	18.5	184	28.0	312	54.0
11	676	34.5	808	26.5	919	17.5	183	26.5	89	53.5
12	745	32.5	94	25.5	851	16.5	684	26.5	582	51.5
13	750	32.5	219	24.5	330	14.5	80	25.5	406	51.0
14	449	29.0	97	22.5	930	14.5	389	25.5	441	50.0
15	456	27.5	93	21.5	494	13.5	207	23.5	580	48.0

H. PLOT 2 Unfertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	546	109.5	538	45.5	647	24.5	174	54.5	284	90.0
2	226	53.0	323	35.5	879	15.5	188	37.5	359	64.5
3	651	50.0	470	27.0	335	14.5	177	36.5	459	59.0
4	322	49.0	856	26.5	800	12.0	189	32.5	426	47.5
5	504	49.0	911	25.5	628	10.5	258	22.5	458	47.5
6	364	43.5	324	25.0	942	10.5	261	17.5	584	46.0
7	366	42.5	230	21.5	665	9.5	296	17.5	861	42.5
8	590	40.5	786	21.5	548	9.0	360	13.5	427	41.5
9	738	40.5	229	17.5	944	8.5	849	13.5	722	39.5
10	784	40.5	606	17.5	630	7.5	345	12.5	585	31.5
11	11	40.0	681	17.5	644	7.5	362	11.5	202	31.0
12	714	34.0	327	14.5	868	6.5	877	11.0	338	27.0
13	26	33.5	178	13.5	869	6.5	277	10.5	859	26.5
14	505	32.5	561	13.5	938	5.5	854	10.5	124	24.5
15	224	31.5	892	13.5	940	5.0	140	8.5	287	24.5

TABLE 5.3-8. HIGHEST YIELDING PLANTS IN THE FIRST HARVEST (Cont)

I. PLOT 1 Fertilized

Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	754	50.0	437	47.5	613	27.5	79	57.0	570	45.0
2	409	35.5	523	37.5	253	24.5	78	56.0	536	40.5
3	408	26.5	809	34.5	834	24.5	249	48.0	406	39.0
4	525	23.5	808	33.5	490	23.5	820	36.5	438	38.5
5	517	22.5	94	31.5	928	20.5	100	35.5	404	37.0
6	378	21.5	166	30.5	844	18.5	159	34.5	818	36.5
7	750	20.5	812	26.5	952	18.5	781	34.5	821	32.5
8	610	19.5	420	24.5	658	16.5	101	31.5	396	30.0
9	745	19.5	23	22.5	950	16.5	183	28.5	20	27.5
10	748	18.5	97	22.5	955	15.5	687	26.5	311	27.5
11	922	17.5	95	19.5	81	14.5	894	26.5	397	27.5
12	760	15.5	901	17.5	848	14.5	897	24.5	501	27.5
13	743	14.5	219	16.5	291	12.5	80	23.5	92	26.5
14	44	13.5	300	16.5	855	11.5	252	23.5	413	25.5
15	399	13.5	763	15.5	330	10.5	684	23.5	816	22.5

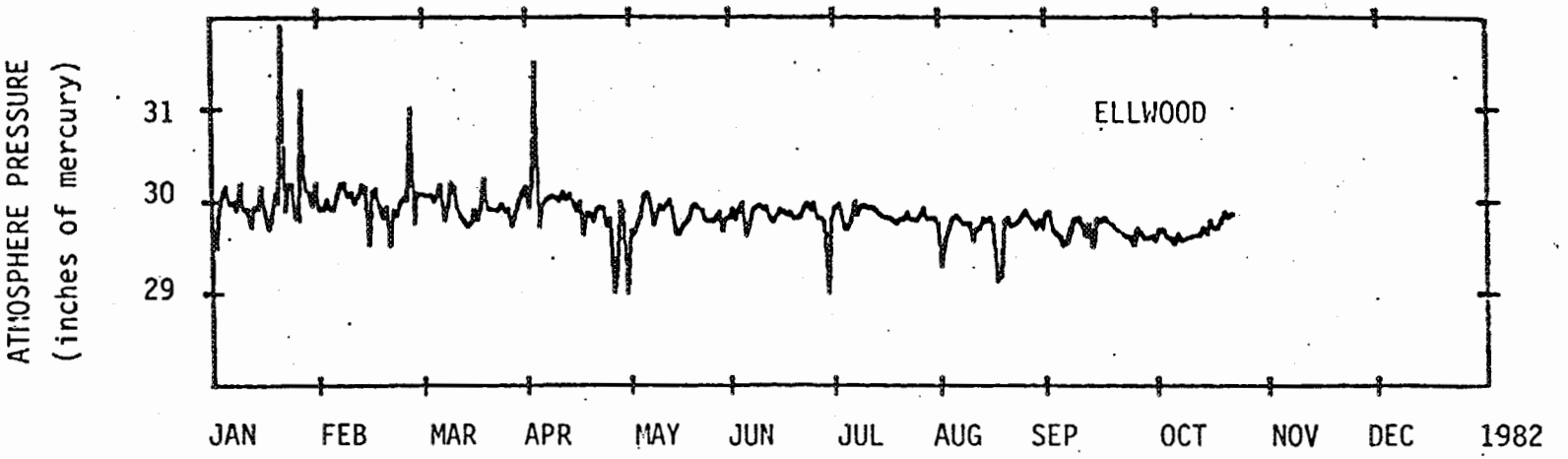
J. PLOT 2 Unfertilized

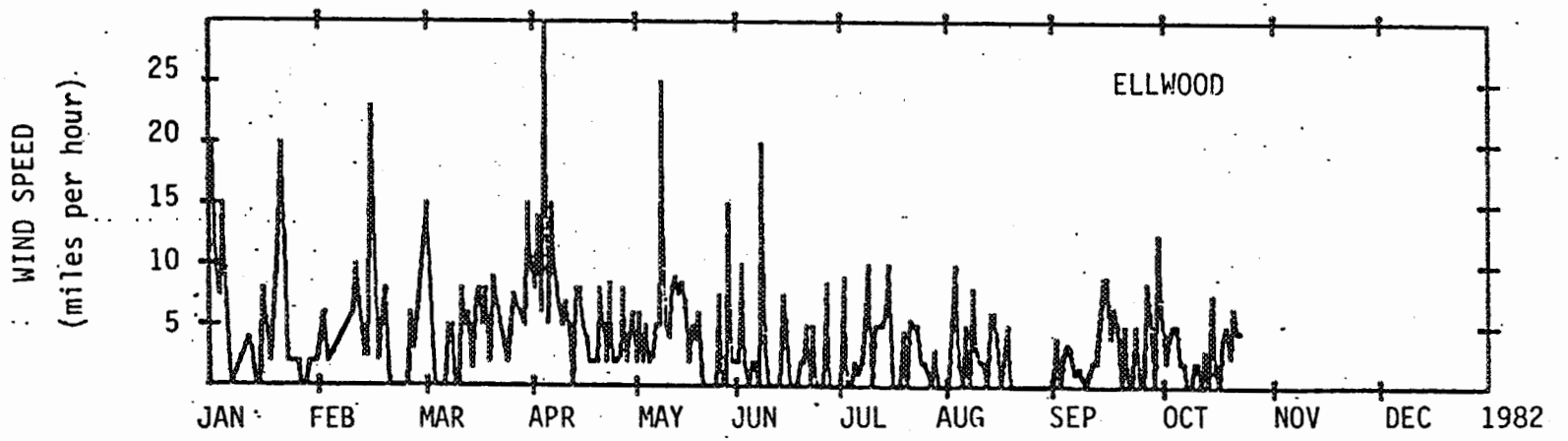
Rank	Section A Low Density Plt #	Prod (kg)	Section B Medium Density Plt #	Prod (kg)	Section C High Density Plt #	Prod (kg)	Section D Medium Density Plt #	Prod (kg)	Section E Low Density Plt #	Prod (kg)
1	546	49.5	325	26.5	866	26.5	174	48.0	284	54.0
2	26	48.5	681	26.5	800	21.5	718	28.5	861	41.5
3	716	43.5	786	26.5	647	17.5	188	24.5	601	34.5
4	505	37.5	852	24.5	628	15.5	189	24.5	458	32.5
5	504	35.5	892	24.5	665	15.5	177	23.5	462	30.5
6	322	34.5	856	23.5	887	15.5	362	22.5	863	27.5
7	714	30.5	974	23.5	351	14.5	375	21.5	338	24.5
8	739	26.5	229	19.5	989	14.5	854	21.5	584	23.5
9	364	25.5	324	17.5	884	12.5	261	20.5	859	23.5
10	547	20.5	606	17.5	908	12.5	296	19.5	425	22.5
11	727	19.5	790	17.5	1001	12.5	849	16.5	585	22.5
12	11	17.5	911	16.5	995	11.5	140	15.5	600	22.5
13	33	15.5	562	13.5	522	10.5	259	15.5	67	21.5
14	225	13.5	178	12.5	879	10.5	975	15.5	287	21.5
15	356	12.5	603	12.5	1010	10.5	273	14.5	459	21.5

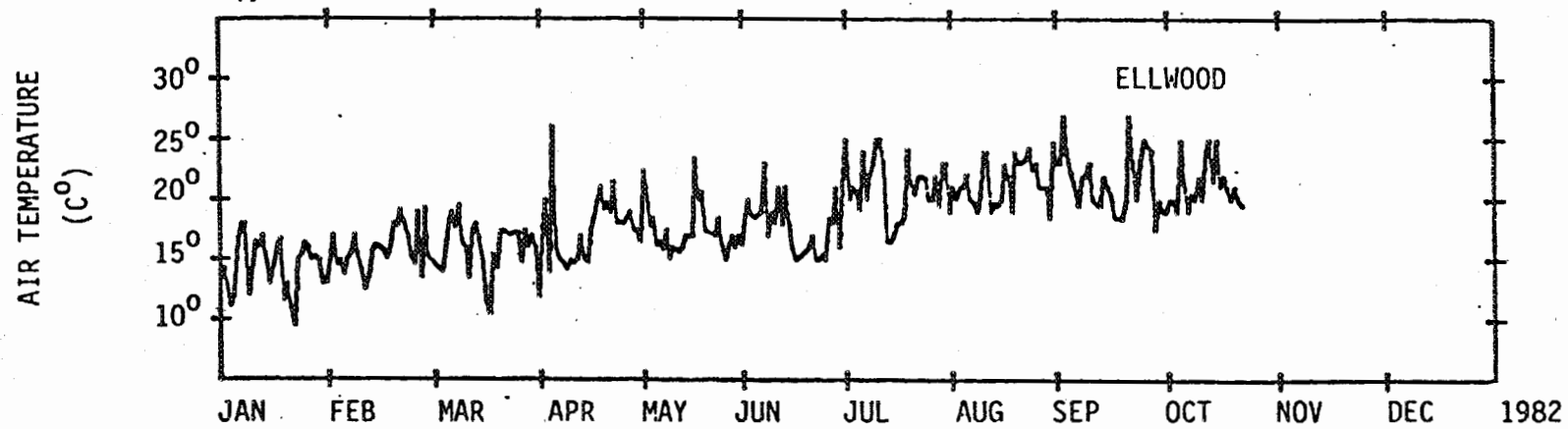
APPENDIX A-2

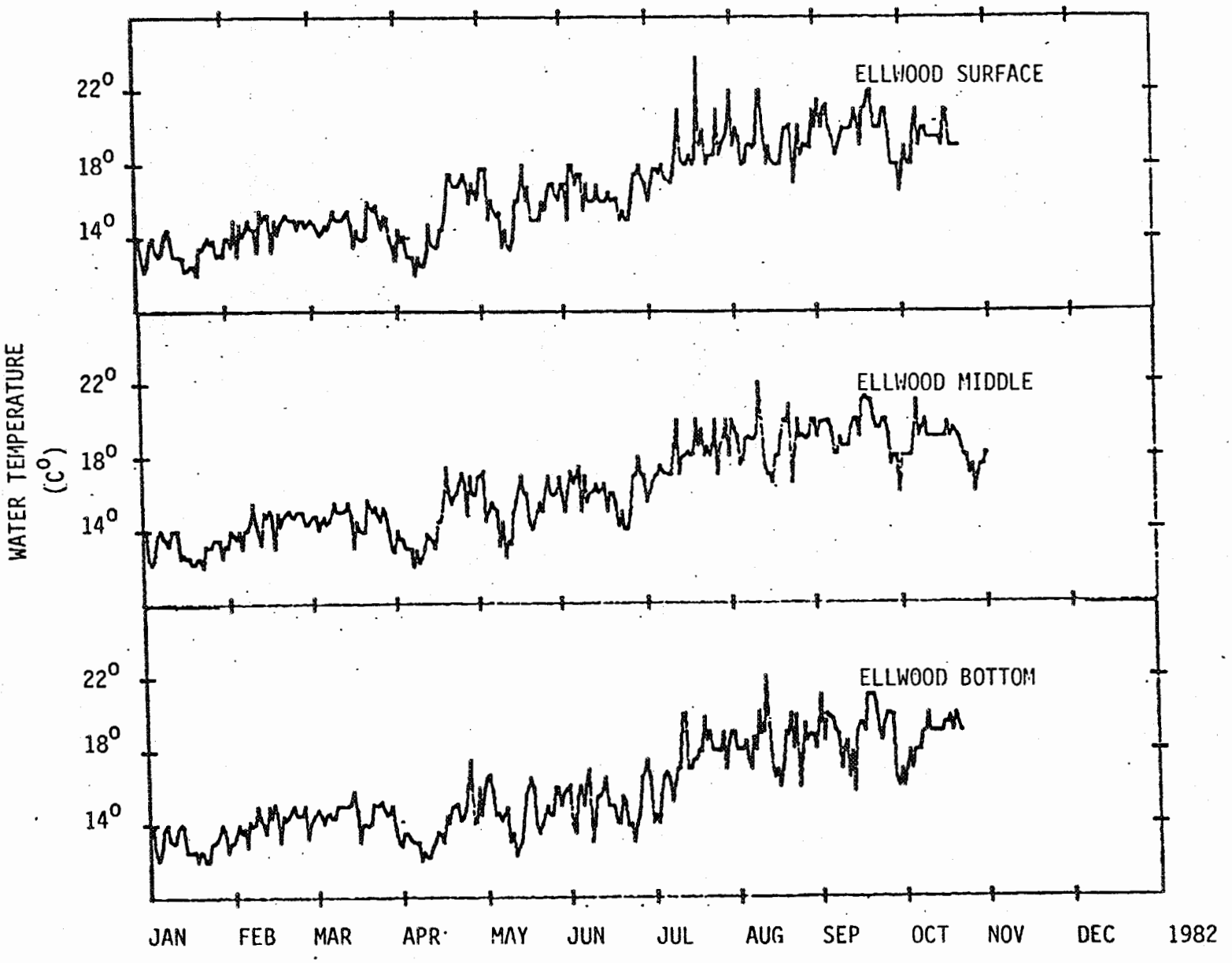
GOLETA ENVIRONMENTAL DATA

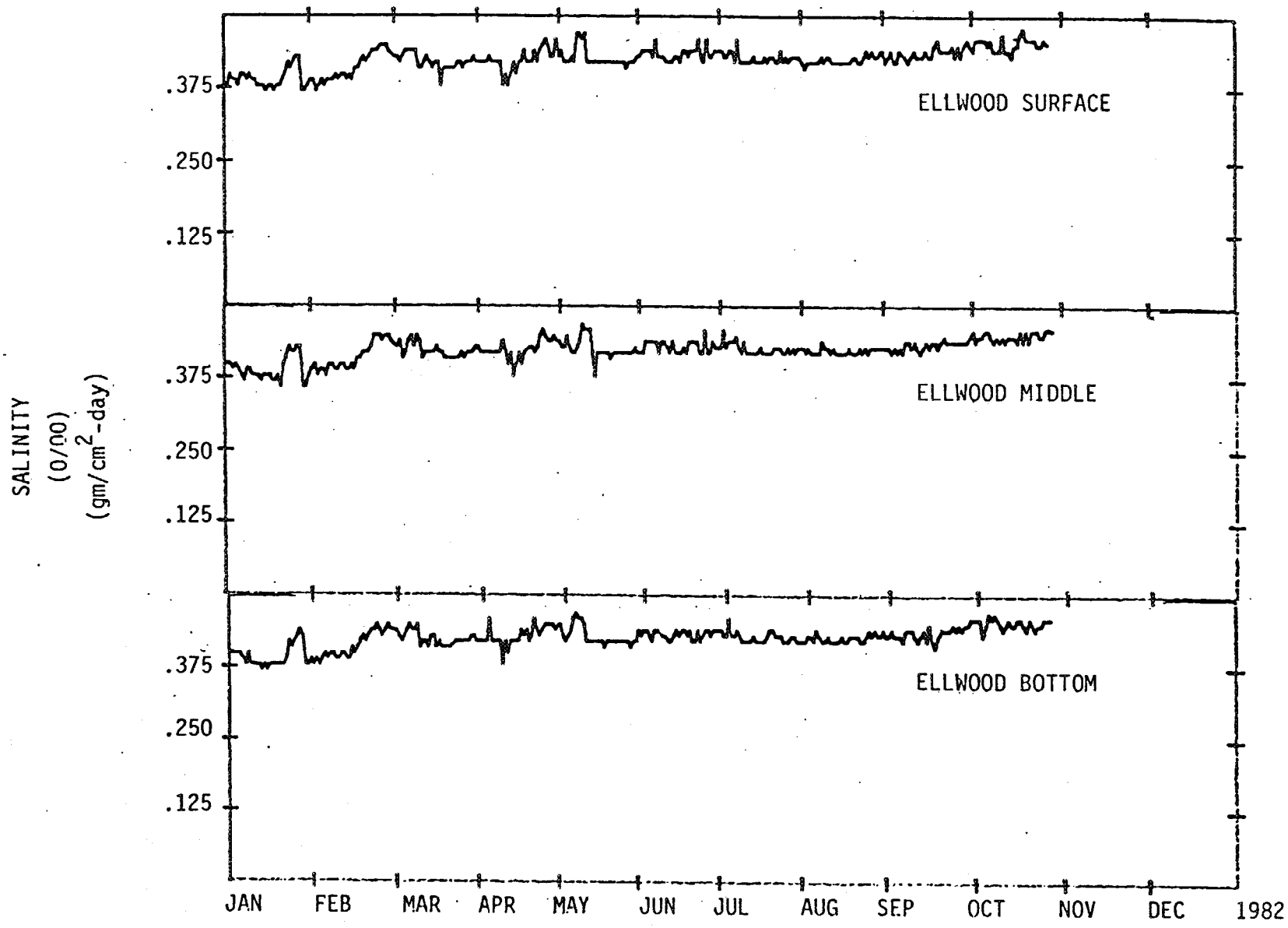
This section contains plots of environmental monitoring measurements collected from January to December 1982. Information was collected on a daily and weekly basis at Ellwood Pier in the close proximity to the planted area. Daily measurements were made of: atmospheric pressure, wind speed, air temperature, water temperature, salinity, current speed and vertical visibility. Daily current speeds were measured at about 1 m depth. Weekly measurements were made of: water temperature, salinity, nitrate concentration, nitrite concentration, ammonium concentration, phosphate concentration, current speed, horizontal visibility and sedimentation rate. Many of the measurements made were taken on the surface, in the middle of the water column at (about 4 m deep) and on the bottom (8 m deep).

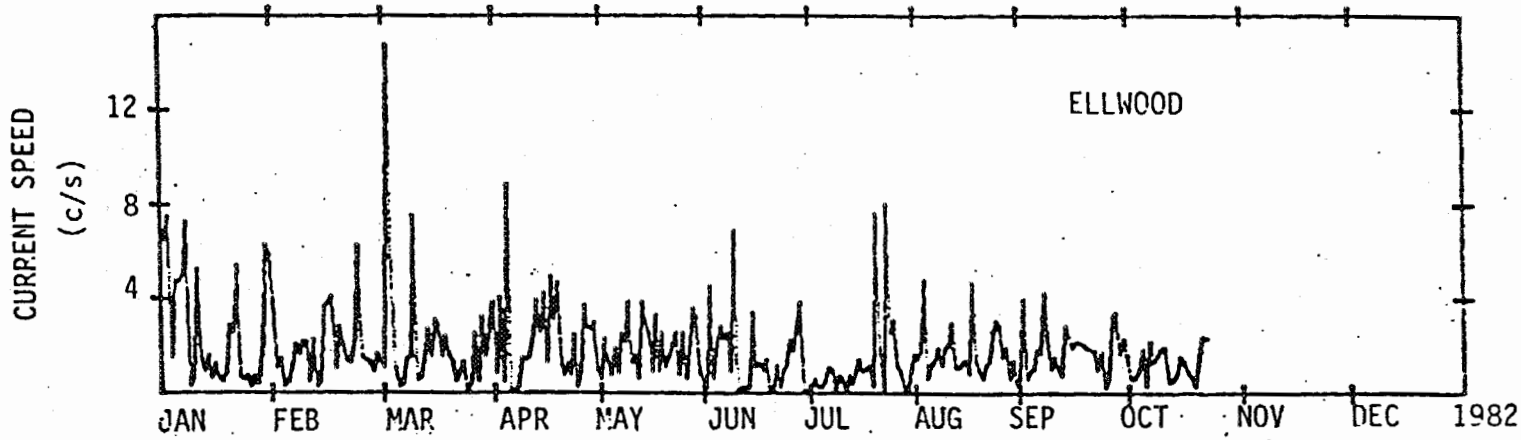

ATMOSPHERE PRESSURE
(inches of mercury)
31
30
29
ELLWOOD
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

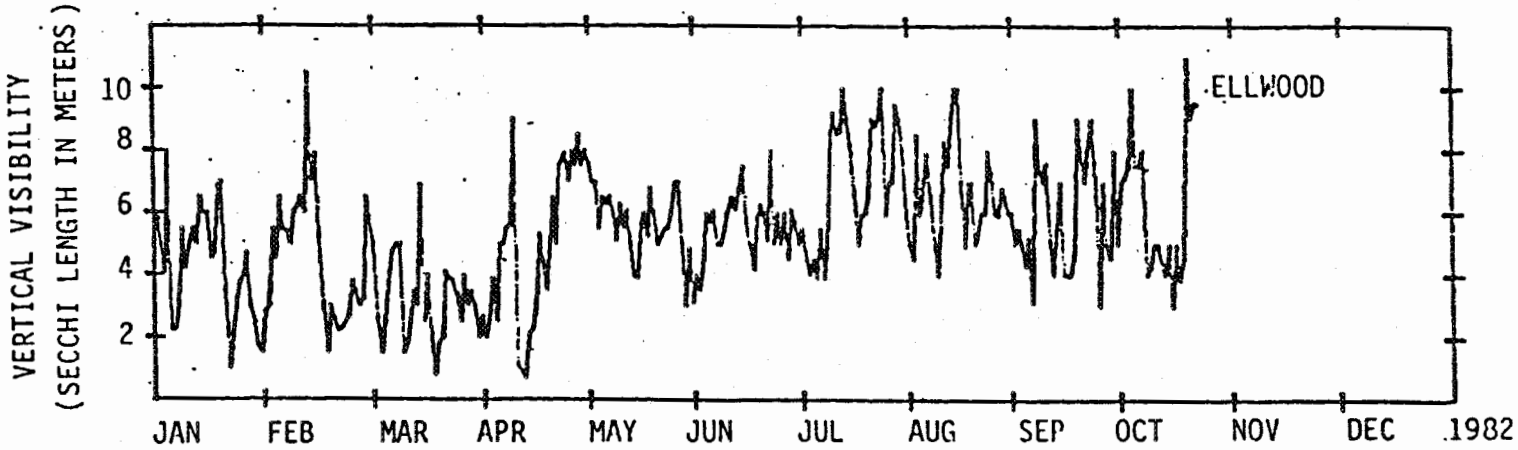

WIND SPEED
(miles per hour)
25
20
15
10
5
ELLWOOD
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

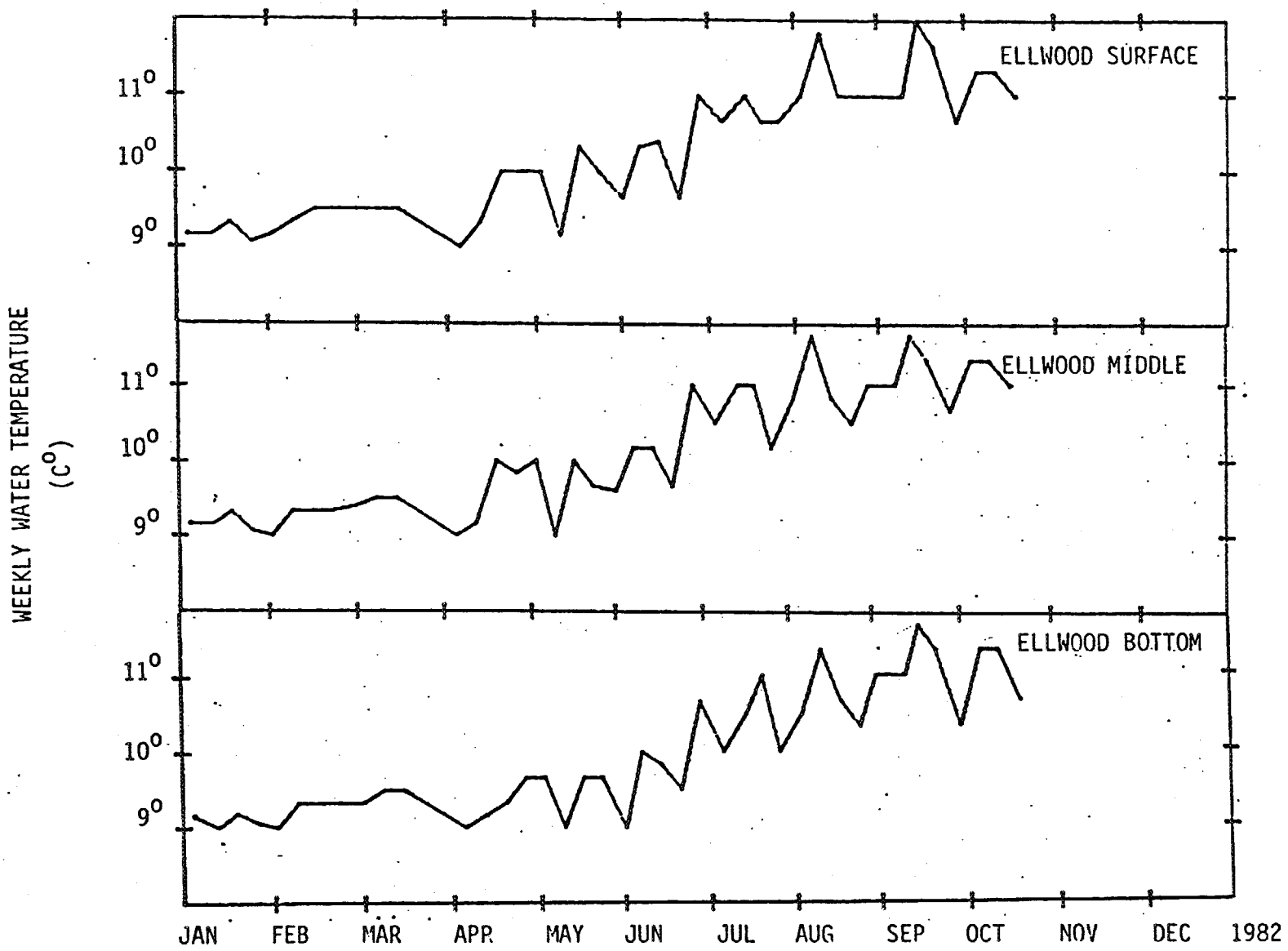

AIR TEMPERATURE
(C°)
30°
25°
20°
15°
10°
ELLWOOD
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

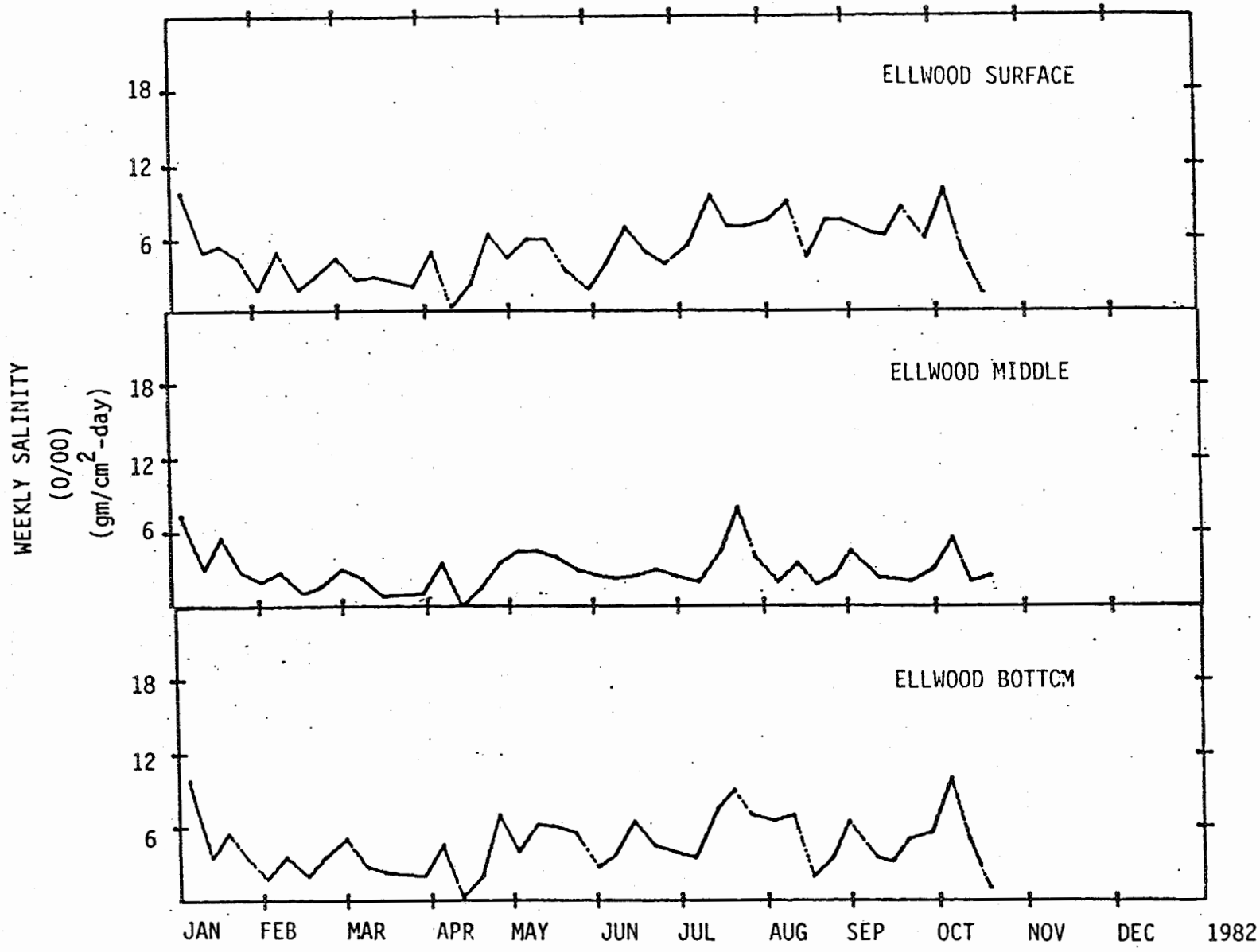

ELLWOOD SURFACE
ELLWOOD MIDDLE
ELLWOOD BOTTOM
WATER TEMPERATURE (C°)
22°
18°
14°
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

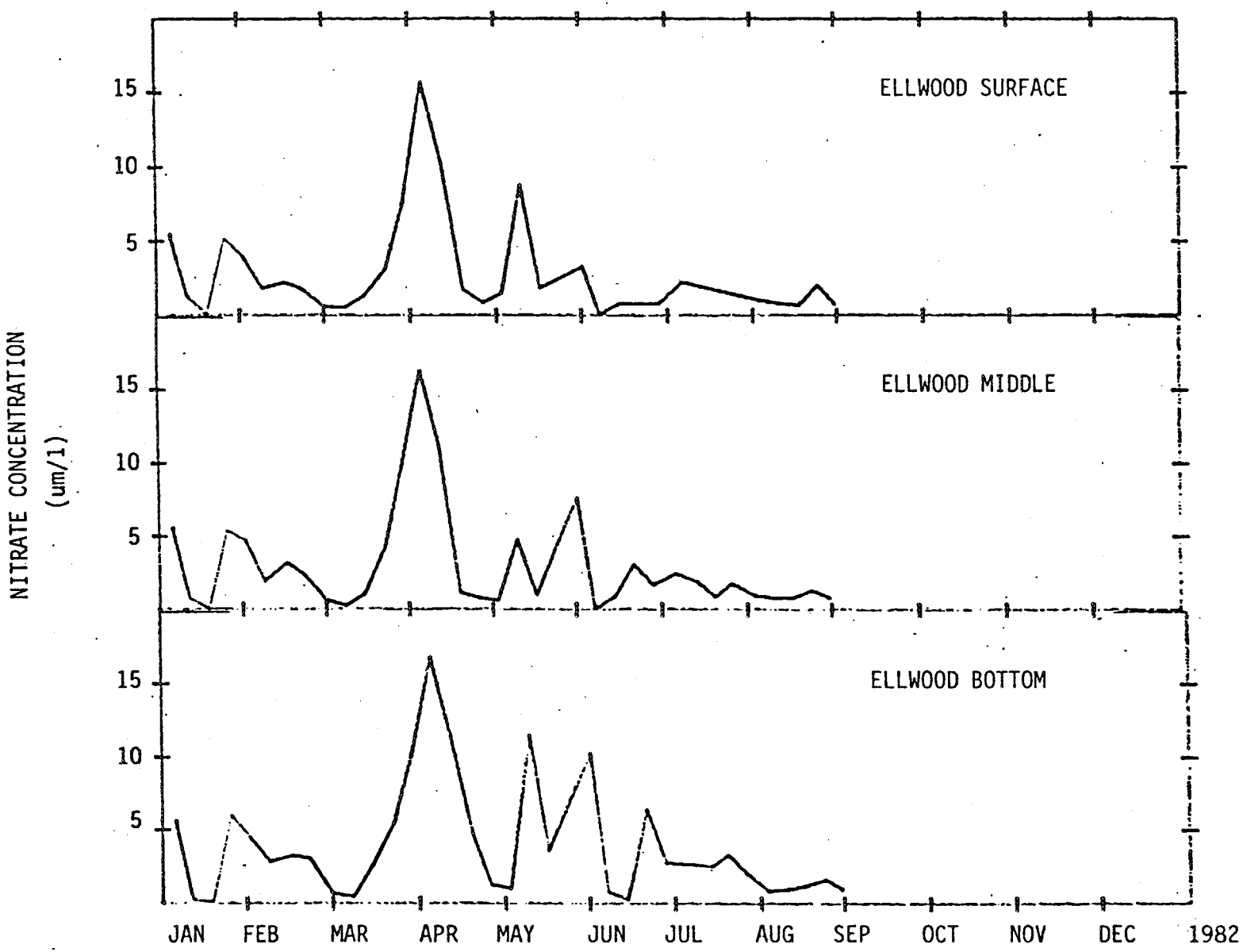

SALINITY
(0/00)
(gm/cm^2-day)
.375
.250
.125
ELLWOOD SURFACE
ELLWOOD MIDDLE
ELLWOOD BOTTOM
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

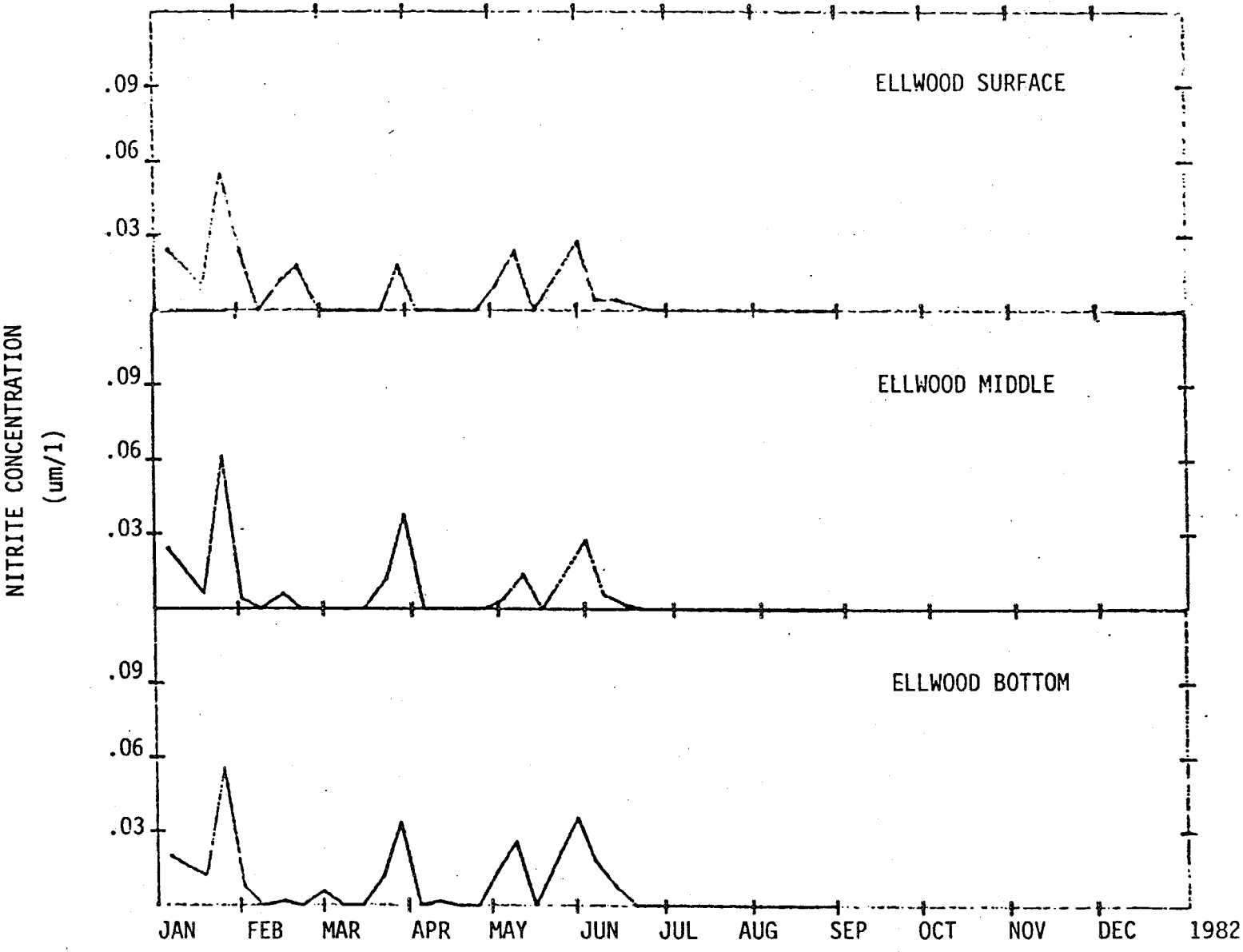

CURRENT SPEED
(c/s)
12
8
4
ELLWOOD
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

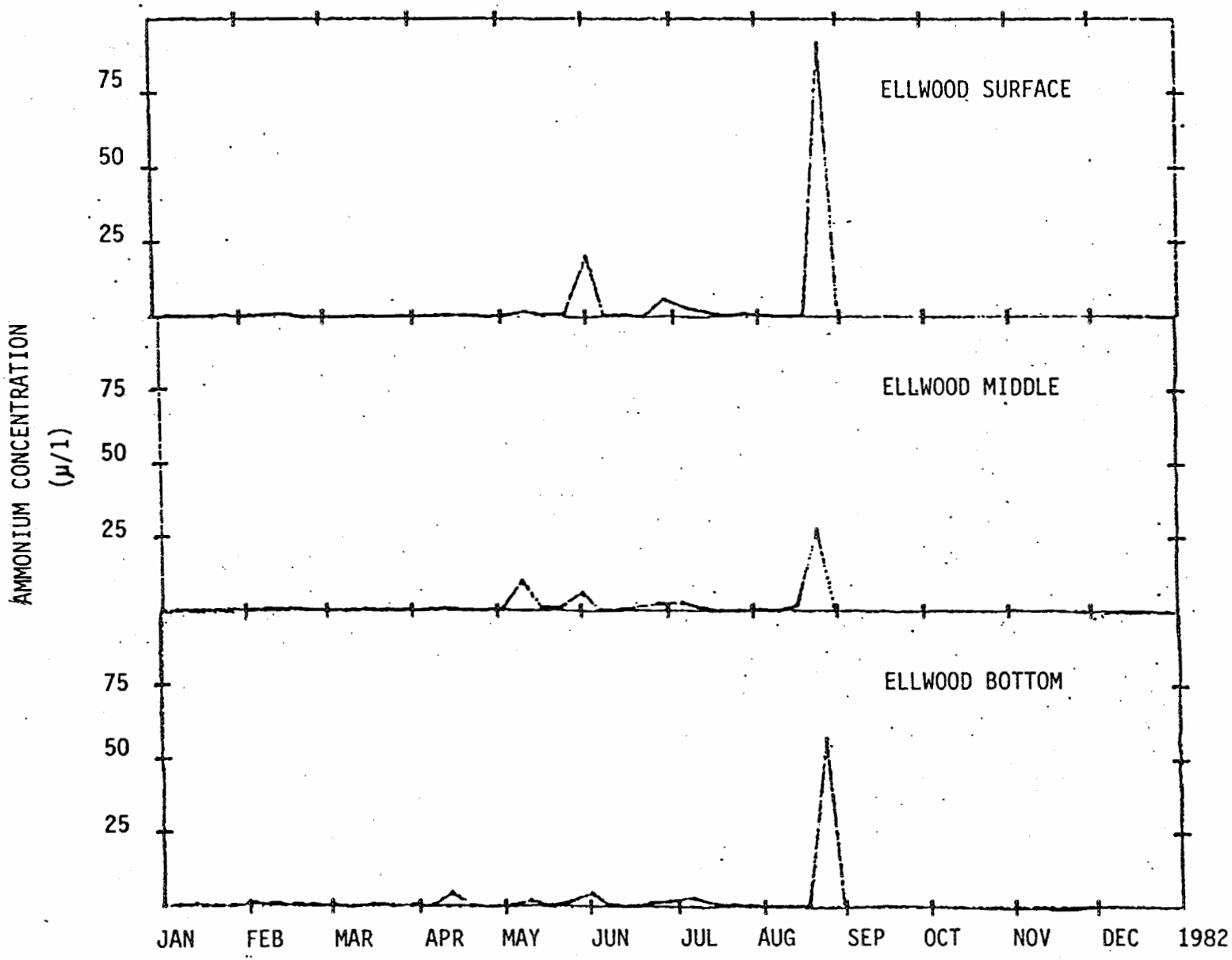

VERTICAL VISIBILITY
(SECCHI LENGTH IN METERS)
10
8
6
4
2
ELLWOOD
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

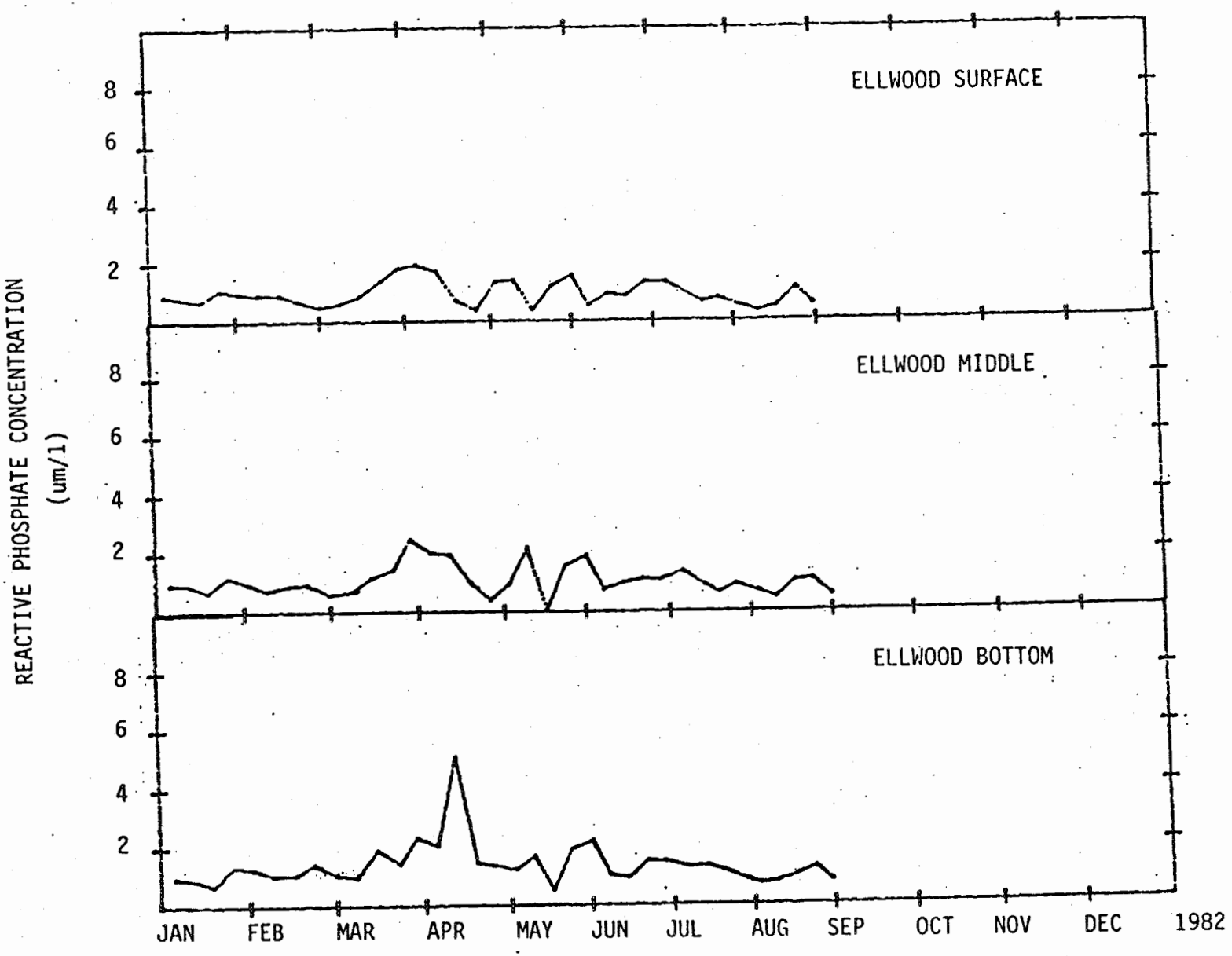

ELLWOOD SURFACE
ELLWOOD MIDDLE
ELLWOOD BOTTOM
WEEKLY WATER TEMPERATURE (C°)
11°
10°
9°
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

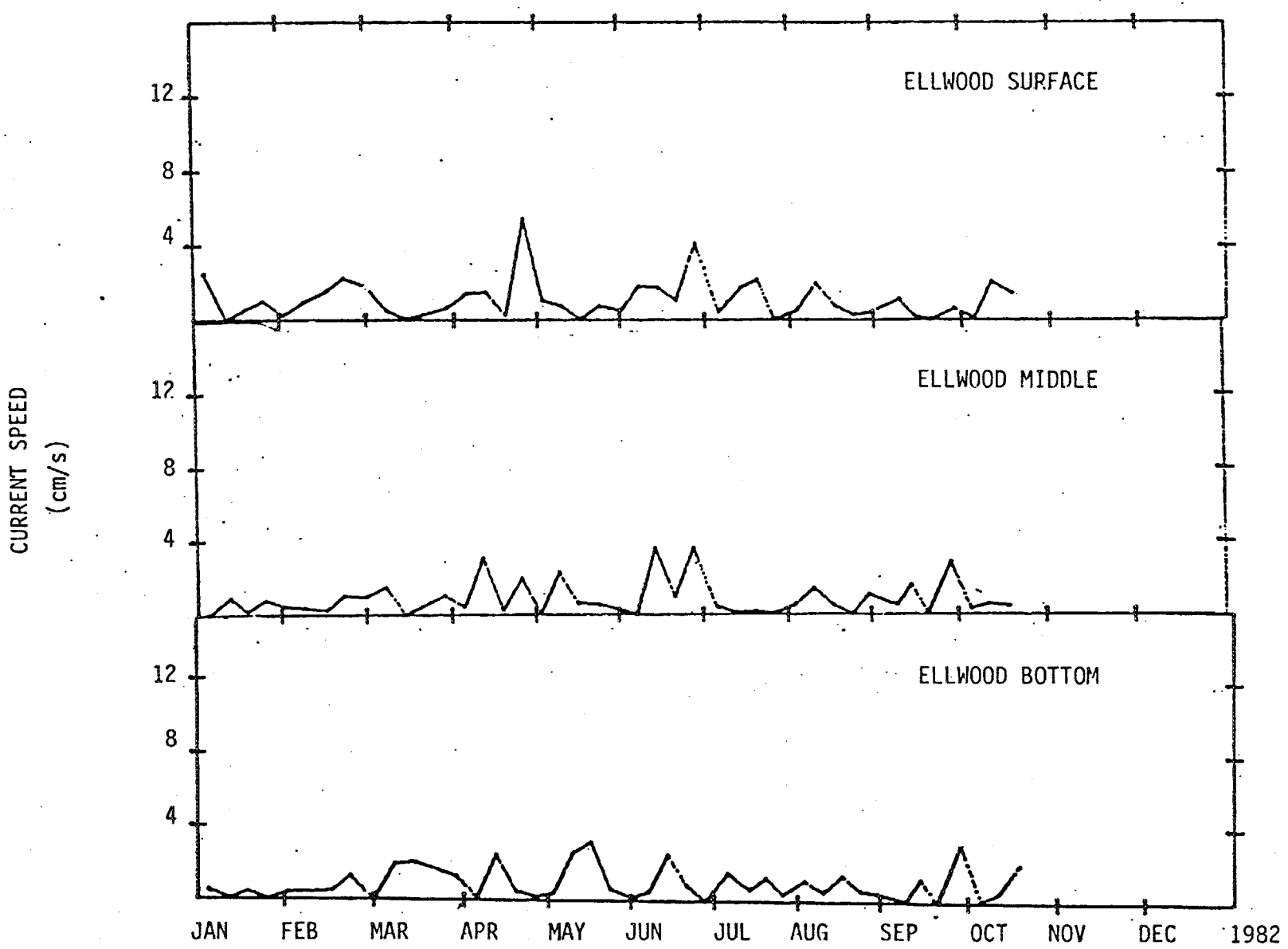

ELLWOOD SURFACE
ELLWOOD MIDDLE
ELLWOOD BOTTOM
WEEKLY SALINITY
(0/00)
(gm/cm^2-day)
18
12
6
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

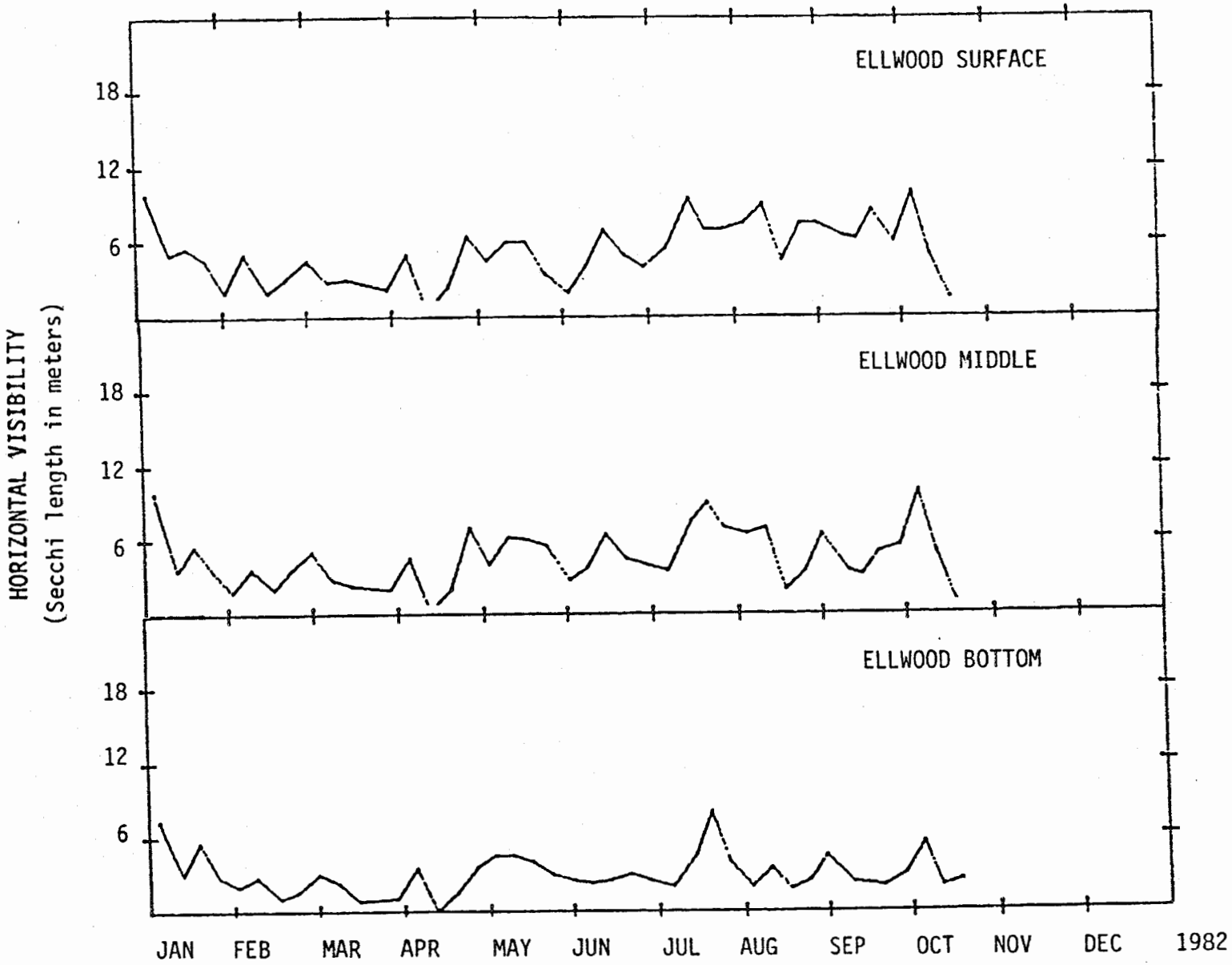

ELLWOOD SURFACE
ELLWOOD MIDDLE
ELLWOOD BOTTOM
NITRATE CONCENTRATION
(um/1)
15
10
5
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

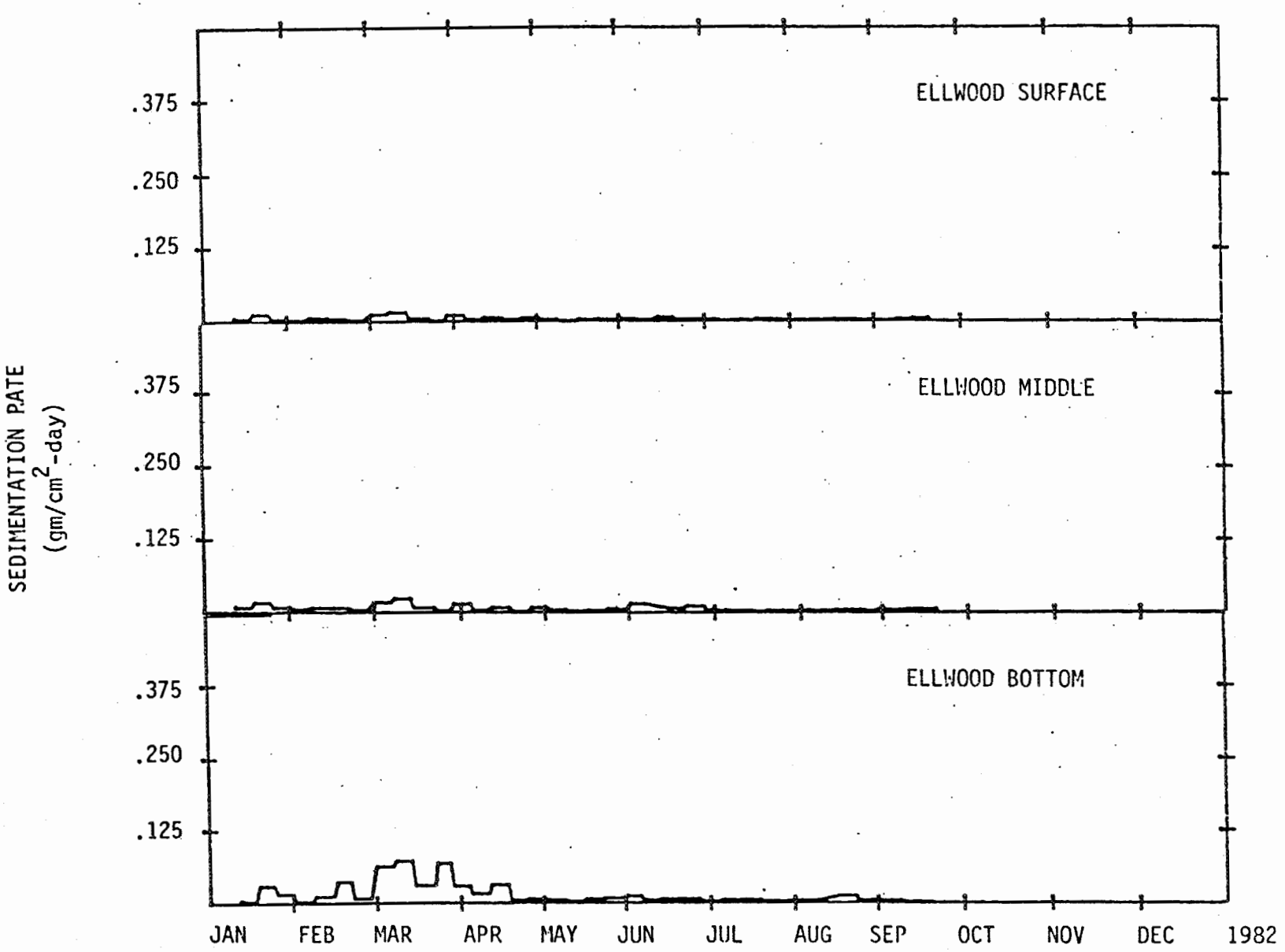

ELLWOOD SURFACE
ELLWOOD MIDDLE
ELLWOOD BOTTOM
NITRITE CONCENTRATION
(um/1)
.09
.06
.03
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982


AMMONIUM CONCENTRATION (μ/1)
75
50
25
ELLWOOD SURFACE
75
50
25
ELLWOOD MIDDLE
75
50
25
ELLWOOD BOTTOM
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982


ELLWOOD SURFACE
ELLWOOD MIDDLE
ELLWOOD BOTTOM
REACTIVE PHOSPHATE CONCENTRATION (um/1)
8
6
4
2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982


ELLWOOD SURFACE
ELLWOOD MIDDLE
ELLWOOD BOTTOM
CURRENT SPEED (cm/s)
12
8
4
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982


ELLWOOD SURFACE
ELLWOOD MIDDLE
ELLWOOD BOTTOM
HORIZONTAL VISIBILITY
(Secchi length in meters)
18
12
6
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982


ELLWOOD SURFACE
ELLWOOD MIDDLE
ELLWOOD BOTTOM
.375
.250
.125
SEDIMENTATION RATE
(gm/cm2-day)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1982

APPENDIX A-3

HEMIDOME ENGINEERING SUPPORT

APPENDIX A-3

HEMIDOME ENGINEERING SUPPORT

The Catalina Test Farm was installed at Big Fisherman's Cove, Santa Catalina Island off the coast of Southern California during the December 1981-January 1982 time period. A sketch of the general arrangement and layout of the facility after initial installation is presented in Figure 5.2-1. Installation had been completed and facility checkout, calibration and operation initiated by mid January 1982. Kelp growth experiments were planned to start after an initial six week period to complete operational checkouts and the required leaching of the new bag material.

Engineering support efforts during 1982 were directed primarily at developing reliable operating and maintenance procedures, accomplishing facility calibrations and checkouts, and incorporating design and procedural modifications as required to improve the operational performance, reliability, or experimental viability of the facility.

This Appendix describes the 1982 work and accomplishments in these efforts.

Facility Checkout, Performance and Diagnostic Analyses

Pump Operation and Performance - The hydraulic system was designed for a maximum seawater flow rate of 2400 gpm. Three inlet pumps supply seawater to the hemidome bag. Nutrients are added to the incoming seawater before inputting to the bag. A gravity drain system carries water from the bag to the sump tank, and three discharge pumps transport the nutrient rich seawater from the sump tank to the end of the 1200 foot outfall. The hydraulic system is diagrammatically represented in Figure 5.2-2. The main stainless steel flow pumps, Grundfos Model SP120-1, are single stage centrifugals directly coupled to a 3600 rpm submersible motor and are capable of 800 gpm at a head of 40 feet.

During the initial system checkout in January 1982, the total flow rate capability of the inlet pumps was greater than 2500 gpm. The flow rate of the discharge pumps cannot be directly measured since there is no flow instrumentation in this subsystem. The overall maximum system flow rate at equilibrium, i.e., inlet flow equal to discharge flow was 2150 gpm rather than the design maximum flow rate of 2400 gpm, due to restrictions in the gravity feed subsystem.

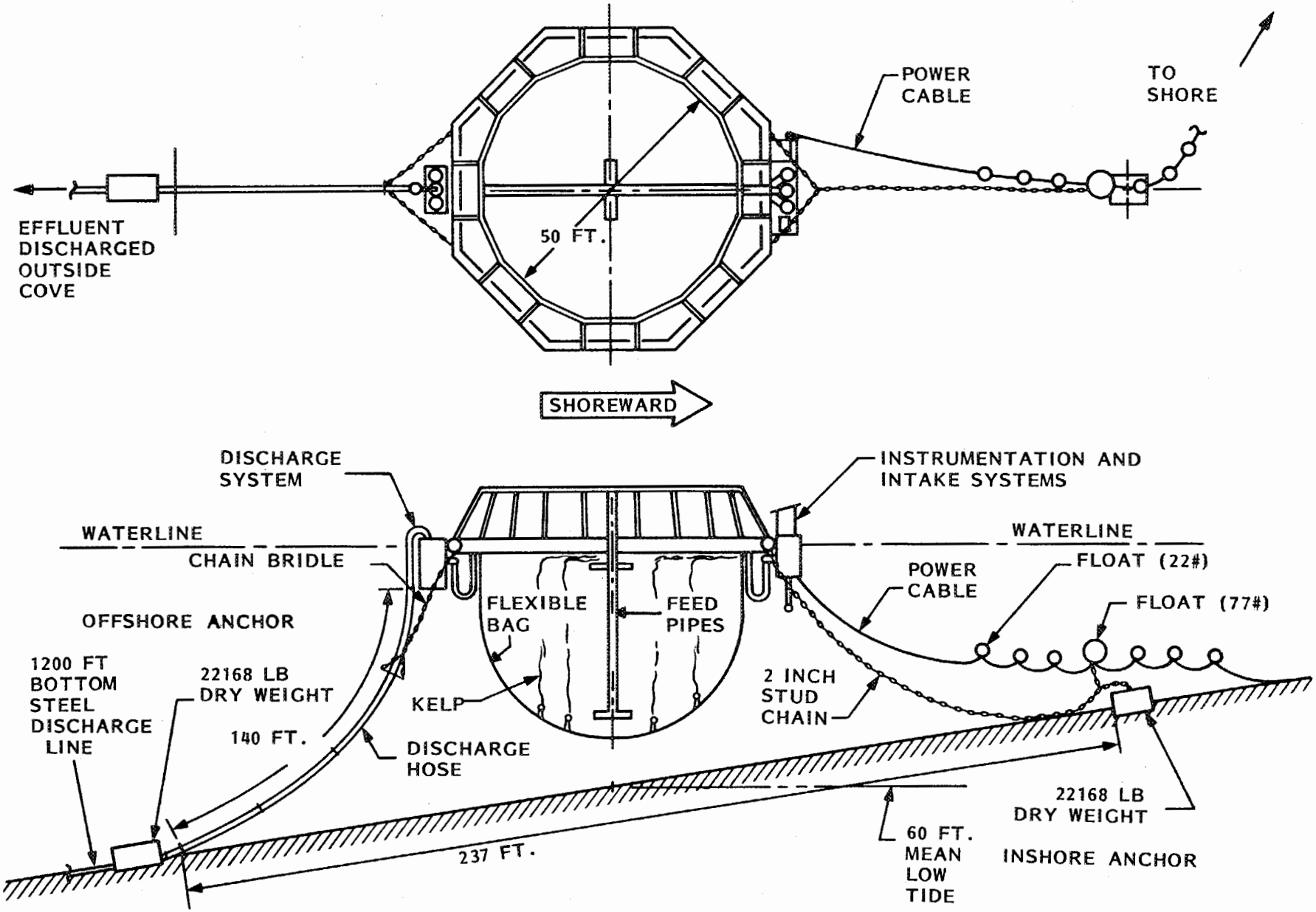


Figure 5.2-1. Catalina Test Farm - General Layout and Mooring Arrangement

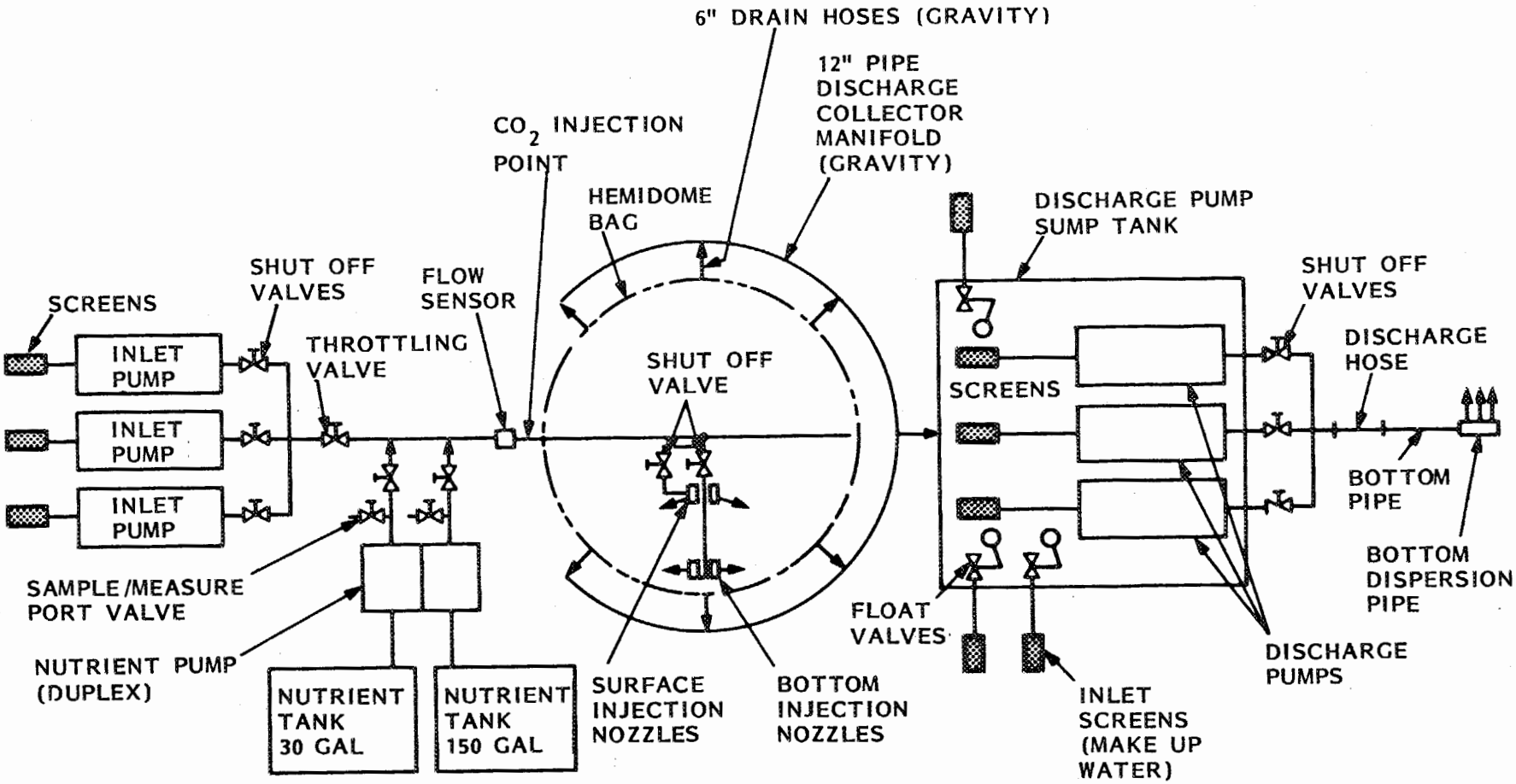


Figure 5.2-2. CTF Hydraulic System Schematic Diagram

On February 9, 1982, discharge pump number 2 tripped the motor starter overload. Diagnostic testing showed an insulation-resistance failure in the wires within the 42 inch diameter ring. Attempts to pull the wires and a 1/2 inch nylon lead rope out of a plastic conduit were unsuccessful, indicating that the wires had fused together within the conduit which is buried within the foamed 42 inch diameter main flotation ring. A subsequent analysis of the failure showed that the Ohmic heating in the wire was low, but with the wire buried in 42 inch of foam sufficient heat was built up to cause failure of the electrical insulation on the power cables. New metal conduit was installed above the 42 inch flotation ring, and new wires for the three discharge pumps were routed through. The pumps were restarted on February 20th with no problems. The maximum system flow rate was 2125 gpm at equilibrium. Again, the reduced maximum flow rate was due to the restrictions in the gravity drain system.

A flow test of the inlet pumps on June 23rd showed that their performance had degraded about 20 percent. Biofouling on the internal screen wrapped around the pump inlet (inside the 10 in diameter casing) was suspected. Number 3 discharge pump was pulled on July 27th revealing that 70-75 percent of the internal screen was covered with biofouling organisms. After removing the screen, cleaning the pump casing, and reinstalling the pump, an increase in performance was noted. The system flow rate increased from 1525 gpm to 1775 gpm, and the pressure drop through the discharge pipe increased to 19.5 psig from 17.5 psig also indicating a higher flow. As a result, the remaining five pumps were removed and cleaned during the week of August 3rd. All pumps had significant biofouling; about 75 percent of the internal screen area was covered with growth. In addition, significant fouling was found inside the intake end of the 10 inch casings for the inlet pumps, resulting in further flow path restriction on these pumps.

On August 4th, discharge pump number 1 failed. The measured motor current was 12 amps versus 19 amps normal, indicating that the motor had lost the major portion of its load. The failed pump had 4780 hours operating time prior to its failure. The spare pump was installed in its place. A failure analysis of the pump at the vendor plant showed the following:

a. The pump shaft was broken where it was undercut for the pump/motor coupling. The shaft was made from 316 Stainless Steel, 1 1/4 inch diameter, and the diameter at the undercut was reduced to 3/4 inch.

b. The upper bearing was completely destroyed, and welds on the bearing holder were broken.

c. The high-speed impeller had slipped downward and exhibited excessive wear caused by rubbing against the stationary suction housing due to loss of impeller/housing clearance.

d. The motor shaft was frozen.

During discussions with the manufacturer, the point was brought out that the Net Positive Suction Head requirement, as specified by the manufacturer, had been increased, and the maximum recommended flow rate now was reduced to 750 gpm. This limitation was imposed to prevent cavitation at the rotor tips which would significantly reduce the pump life. The manufacturer did not see any indication that this pump failure was caused by cavitation.

On August 15th, the motor starter overload tripped for number 2 discharge pump. The pump would only run for a short time after resetting/restarting indicating a high current draw. This pump had been the original spare and had 3815 operating hours prior to failure. Inlet number 1 developed a ground fault during the same period.

A failure analysis was conducted at the manufacturer's plant on number 2 discharge pump and number 1 inlet pump. In addition, number 3 discharge pump which was still operating was taken back for evaluation. The rotor, on all three pumps, had slipped downward on the shaft and was interfering with the stationary suction housing. The bottom edge of the rotor elements showed severe wear. The top surfaces of the suction housings had wear grooves caused by the rotor interference. Discharge pump number 3 which was still operational when removed, had a 1/4 inch groove worn into the top of the suction housing caused by the rotor.

Originally, the rotor was held to the shaft only by a split cone with a nut jamming the rotor into the split cone. The nominal clearance from the rotor to the suction housing is 3/8 inch. Figure 5.2-3 illustrates this arrangement. The rotor, split cone and shaft are all stainless steel, which creates a severe problem in obtaining an acceptable friction fit with the jam-nut. The movement of the rotor on the shaft, due to the inadequacy of the original jam-nut design, and its subsequent interference with the suction housing created side loads which destroyed the bearings, as well as the rotor and the housing.

A design fix was developed by GE engineers working in cooperation with Grundfos and was implemented by the manufacturer. The solution was to pin the nut, split cone and shaft with a 1/4 inch diameter stainless steel rod. The hole

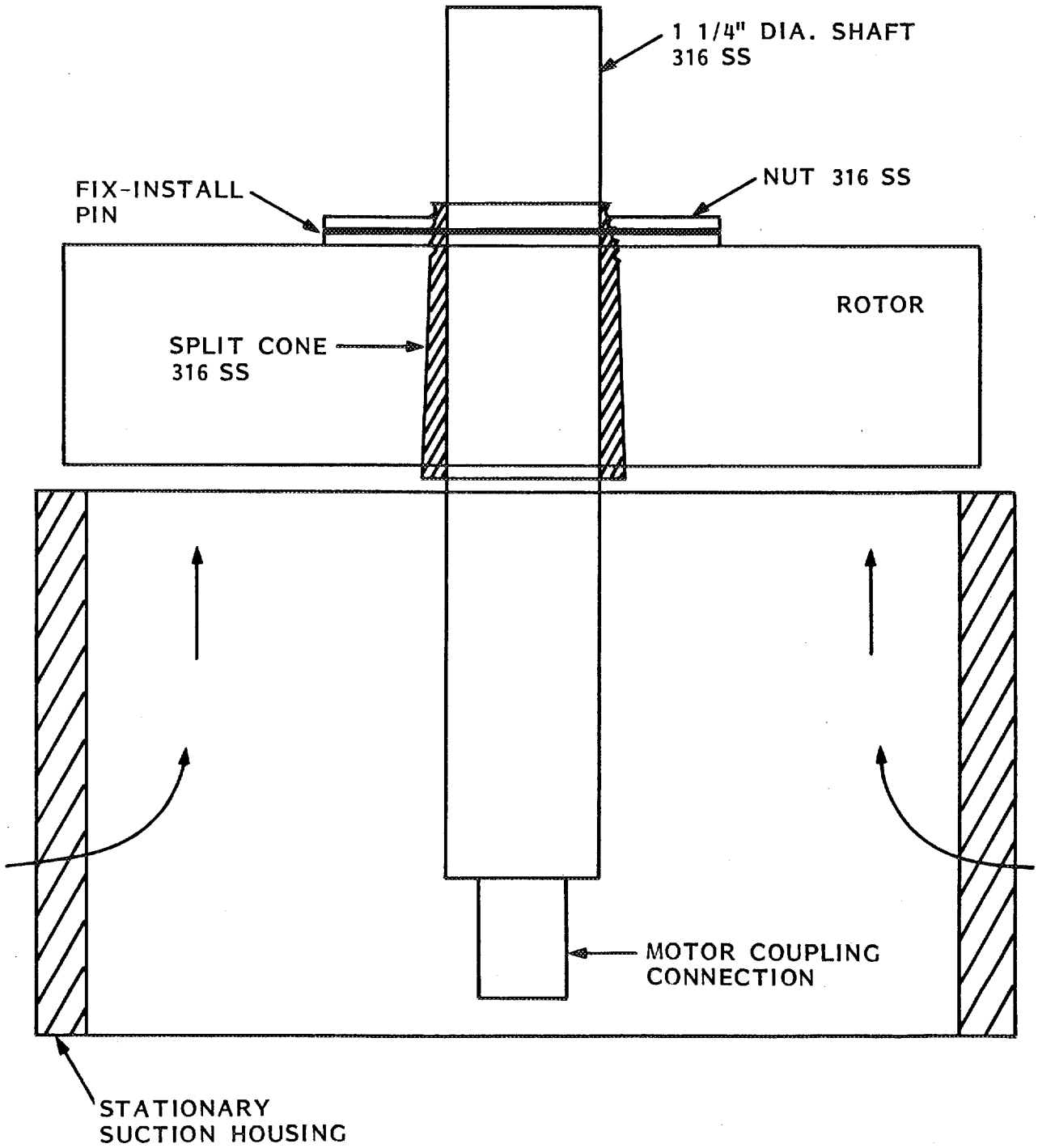


Figure 5.2-3. Inlet/Discharge Pump Modification

for the pin was drilled after the rotor was assembled to the shaft, and the pin was then installed. This arrangement is shown in Figure 5.2-3. All the pumps were rebuilt and modified to incorporate the design fix. The seven pumps which had accumulated extensive operating time were replaced with new pumps and motors. The three pumps with minimal operating time had worn parts replaced and the fix incorporated.

The ground fault on inlet pump number 1 was due to the wire insulation being cut when the pump was reinstalled after cleaning and was not due to any design fault.

In order to maintain flow in the hemidome, only three pumps at a time were refurbished. GE agreed to limit the pump flow rate to 750 gpm by maintaining a back pressure of at least 20 psig. This limited the maximum system flow to 2250 gpm as compared with the initial design value of 2400 gpm. The experimenter agreed that the 150 gpm reduction in system flow rate was acceptable.

The new inlet pumps were installed on September 13th and the discharge pumps on October 7th. After installation of the inlet pumps, several ground faults were again noted. These were traced to manufacturer quality control problems where the underwater cable connector on the motor was not adequately tightened. The pumps were pulled out of their casings, the connectors opened, dried out, and then properly mated and tightened. Thereafter, before installing a new pump, the connector was routinely checked on-site to assure proper connector assembly.

Flow System Biofouling - The original design specification of seven turnovers of seawater per day in the bag resulted in the hydraulic system being designed for a flow rate of 2400 gpm. Later, as a result of the pump manufacturer reducing the pump flow rate specification, the system maximum flow rate was reduced to 2250 gpm giving 6.6 turnovers/day which was acceptable to the experimenter.

When the system was initially activated in January, the combined inlet pump flow rate was greater than 2500 gpm. The flow rate of the discharge pumps as previously mentioned, could not be measured directly due to the lack of flow instrumentation in this subsystem. The maximum system flow rate determined by equalizing inlet with outlet flow, was 2150 gpm rather than the design flow rate of 2400 gpm. Equilibrium was reached when the height of the bag above sea level remained constant for several hours, and was controlled by maximum flow achievable from the discharge system, i.e., gravity drain, discharge pumps and 1200 ft discharge pipe with outlet diffuser.

If the flow rate into the bag is greater than the outflow, the water level differential between the inside of the bag and the outside sea level, i.e., the head, will increase, resulting in increased loads applied to the bungees causing them to stretch until the top edge of the bag is at sea level. When the inlet flow is less than the out flow, the water head will decrease resulting in decreased loads on the bungees causing them to contract, raising the bag until the exit ports are out of the water. When a portion of the exit ports are exposed, the bag outflow will decrease as the flow area is reduced, until an equilibrium flow situation is achieved.

During the early phases of operation, it was found that the discharge pump intake screens were fouling frequently, degrading the system flow. This was due to debris accumulations in the sump tank and in the bag. New improved screens were installed as described in Section 5.2.1.2. The rate of fouling decreased, but the system still did not achieve the predicted 2400 gpm. Data indicated that the restriction was located in the gravity flow subsystem between the bag and the sump tank since the water level difference between the bag and the tank was 2.3 feet instead of the 1.2 feet calculated differential. When comparing the assumptions of the calculations with the actual "as built" condition, it was found that the 6 inch diameter hoses which hydraulically connect the bag to the 12 inch diameter drain manifold had been assumed to have smooth interior surfaces while the installed hoses actually had convoluted interior surfaces. The convoluted interior could increase the pressure drop by up to 1/2 foot. As a result, new hoses with a "hydraulically smooth" interior and heavier wall were ordered. Just before installation of these new hoses, the maximum system equilibrium flow was again measured and had decreased to 1525 gpm. After installing the new hoses and removing considerable marine growth from the fittings, the system flow capability increased to 1950 gpm. The hoses that were removed had small cracks indicating onset of fatigue failures.

Additional troubleshooting indicated that the gravity subsystem was still limiting and that the primary restriction was caused by marine growth in the 12 inch diameter manifold which not only reduced the flow area but also resulted in a rough internal pipe surface further increasing the pressure drop and reducing flow. A modification to install additional gravity drain capacity directly into the sump tank and bypassing the 12 inch manifold was initiated. It was recognized that the system had to be cleaned, but the additional capacity would extend the period between cleanings and add margin to the system capability.

Shortly after this modification was implemented (see Section 5.2.1.2), the major pump problem as previously described became evident. Just prior to installing the rebuilt pumps, the entire gravity system including the 12 inch drain pipe was completely cleaned. The 12 inch pipe was cleaned with a "pig" pulled through in both directions. The "pig" consisted of two steel hoops welded together at right angles with a cable attached to each end of one hoop while the other hoop is free to clean the pipe. A sketch of this tool is shown in Figure 5.2-4. The "pig" was pulled by a 1/2 inch steel cable through pulleys attached to each end of the drain pipe and additional pulleys attached to the stanchion on which the capstan was mounted. The capstan was hydraulically powered and contained a throttling valve at the input to the hydraulic motor to control the speed of the capstan and, therefore, the cleaning rate. The "pig" was first pulled through with its inside diameter open, i.e., as an open hoop. Thereafter, the top and bottom quarters were closed with steel plate and the pig was pulled through several times. The debris of marine growth removed by the "pig" was pushed out the end of the drain pipe and the hose fittings ahead of the pig. The "pig" was then closed off about 90 percent with steel plate and again pulled through several times. The first time through in this configuration, large quantities of debris were pushed out to the point that the diver reported almost zero visibility. During the final pass, less than a handful of debris was removed.

After the system was cleaned and the rebuilt pumps were installed, the system met its revised maximum flow rate requirement of 2250 gpm with ease.

Flow Meter Performance - During the October 1982 system checkout, after the new discharge pumps had been installed, it was found that the orifice plate used for inlet flow measurements had fouled resulting in erroneous flow data. The fouling was due to some biological growth around the orifice plate area but was primarily caused by debris from the inlet system cleaning being trapped in front of the plate. The pump flow rates were checked by an alternative diagnostic technique using volumetric rates as measured in the sump tank and the hemidome bag. The flow rates measured in this manner were close to the vendor curves verifying that the system flow was 2250 gpm at a back pressure of 20 psig. The orifice flow meter was removed for replacement with another flow sensor type as described in Section 5.2.1.2.

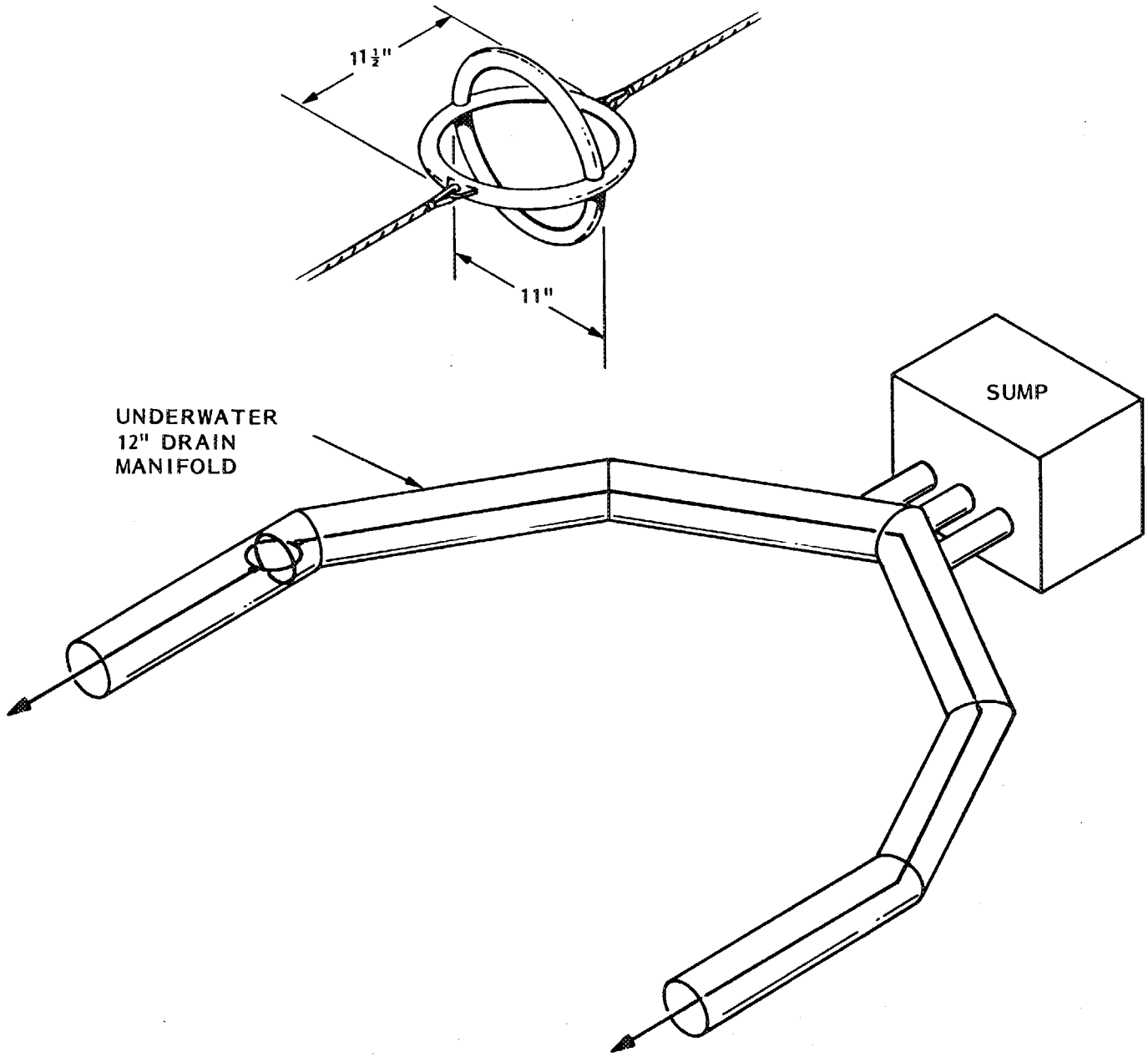


Figure 5.2-4. Pig Design for Biofoul Cleaning Operation

Bag Integrity - On October 25th, a 20 inch tear extending in a semicircle around the bottom cleanout flange was found and repaired. The repair subsequently failed during heavy seas and with the flow out of the tear, the water head inside the bag was lost. Without the weight of the head in the bag, the buoyancy of the holdfast buoys and the test plants caused the bottom of the bag to rise until interference with the nutrient distribution nozzles, caused an additional six foot tear and damage to adjacent areas. (See Figure 5.2-5)

Examination of the initial 20 inch tear area showed that the material surrounding the cleanout port had fatigued. Material away from this flange assembly did not show evidence of fatigue but was stiffer than when originally deployed. A sample of this material was tested by the vendor and showed no change in tensile strength, and only a 10 percent reduction in tear strength.

The fatigue in the vicinity of the cleanout port was probably caused by the heavy, stiff flange-ring assembly (see Figure 5.2-5). Due to the dynamics of the bag, circumferential waves are sometimes generated in the material in an upper section of the bag and propagated downward toward the bottom of the bag. Since the flange-ring assembly at the cleanout port is considerably stiffer than the bag material itself, the assembly will not react to the deflection, and the energy is reflected and absorbed by the surrounding material. Also, divers have observed that under certain conditions, the flange assembly swings due to sea surface wave action, and the material surrounding the assembly must support the added loads associated with this motion.

Due to the extent and nature of the tear, it was decided that the bag should be removed and transported to a vendor ashore for repairs. It was also planned to modify the cleanout port design to alleviate the material fatigue problem.

Following are the steps which were used to remove the bag:

a. Prior to removing the bag, all the plants, the holdfast buoys and the nutrient distribution downcomer pipe assembly were removed.

b. A section of the bag was disconnected from the support ring so that it could be dragged under the stub of the downcomer.

c. The bag was "reefed" pushing out as much water as possible.

d. The remainder of the bag was disconnected and towed to the pier, bottom first.

e. Utilizing the crane on the pier, the bag was lifted up section-by-section and folded on the deck of the workboat for transport back to the mainland.

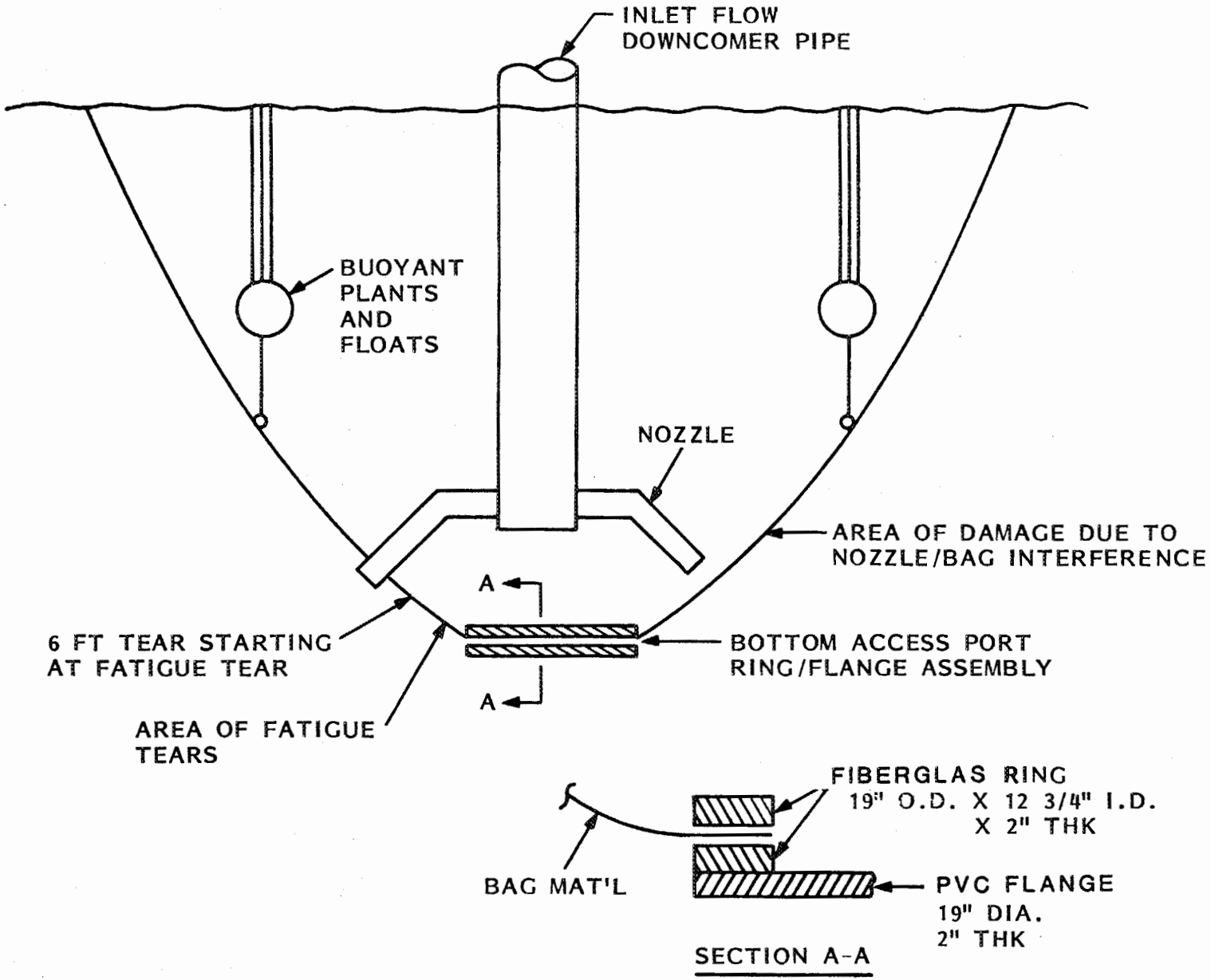


Figure 5.2-5. Original Bag Configuration and Interface with Distribution Nozzle After Head Loss

The damaged bottom of the bag, a 16 foot diameter section, was removed. The redesign of the cleanout flange utilized a flap of bag material held in position by Velcro and "D" rings. See Figure 5.2-6. This assembly is only slightly stiffer than the surrounding area. Therefore, the previous fatigue problems are not anticipated.

A new 16 foot diameter replacement bottom section, incorporating the redesigned cleanout flange, was fabricated. A 12 inch overlap with the existing cut lower edge of the original bag was employed for bonding the new bottom to the old upper bag. The new bottom was bonded to the existing bag using Shelter-Rite's adhesive PM107 with a PM92 catalyst, after the mating surfaces had been cleaned and wiped down with Methyl Ethyl Ketone.

Prior to implementing the actual repair, bonded samples were made utilizing pieces of old and new material using the above adhesive and Stabond U148. These samples were tested at the factory and were subjected to strip-tensile, adhesive-peel, and accelerated aging tests. The samples tested were 1 inch wide and had a 6 inch bonded overlap versus the 12 inch overlap planned for the repair. For both adhesives, the test failure occurred in the base material rather than in the bonded joint, in both the strip tensile and adhesive peel tests. During accelerated aging tests, the samples were soaked for 12 days in 160°F water and then subjected to strip-tensile and adhesion-peel. The PM107/PM92 adhesive system proved to be superior after both adhesive samples had been subjected to accelerated aging. Shelter-Rite adds a moisture retardant to their adhesive for improved underwater performance.

After the bag was repaired, it was folded with the rim on top and an eight string bridle attached to the grommets. In addition, four grommets 90° apart were color-coded and their hanger locations noted. On the CTF, the downcomer was lashed up to the top 10 inch pipe, and the bag was deployed using a technique similar to that employed for the original deployment. The bridle was used to pull the bag off the work boat, across the ring and into the middle of the CTF. Ropes were then attached to the color-coded grommets and slung over the 8 inch support ring above their respective hangers. These ropes were used to position the bag and "unreef" it. The position of the bag was verified by the relationship between the 8 inch diameter drains and the sump tank. The bag was then manually raised, section-by-section, and the 62 bungees tied to the bag. The downcomer was not installed until the bag had been inflated to assure clearance between the bag and

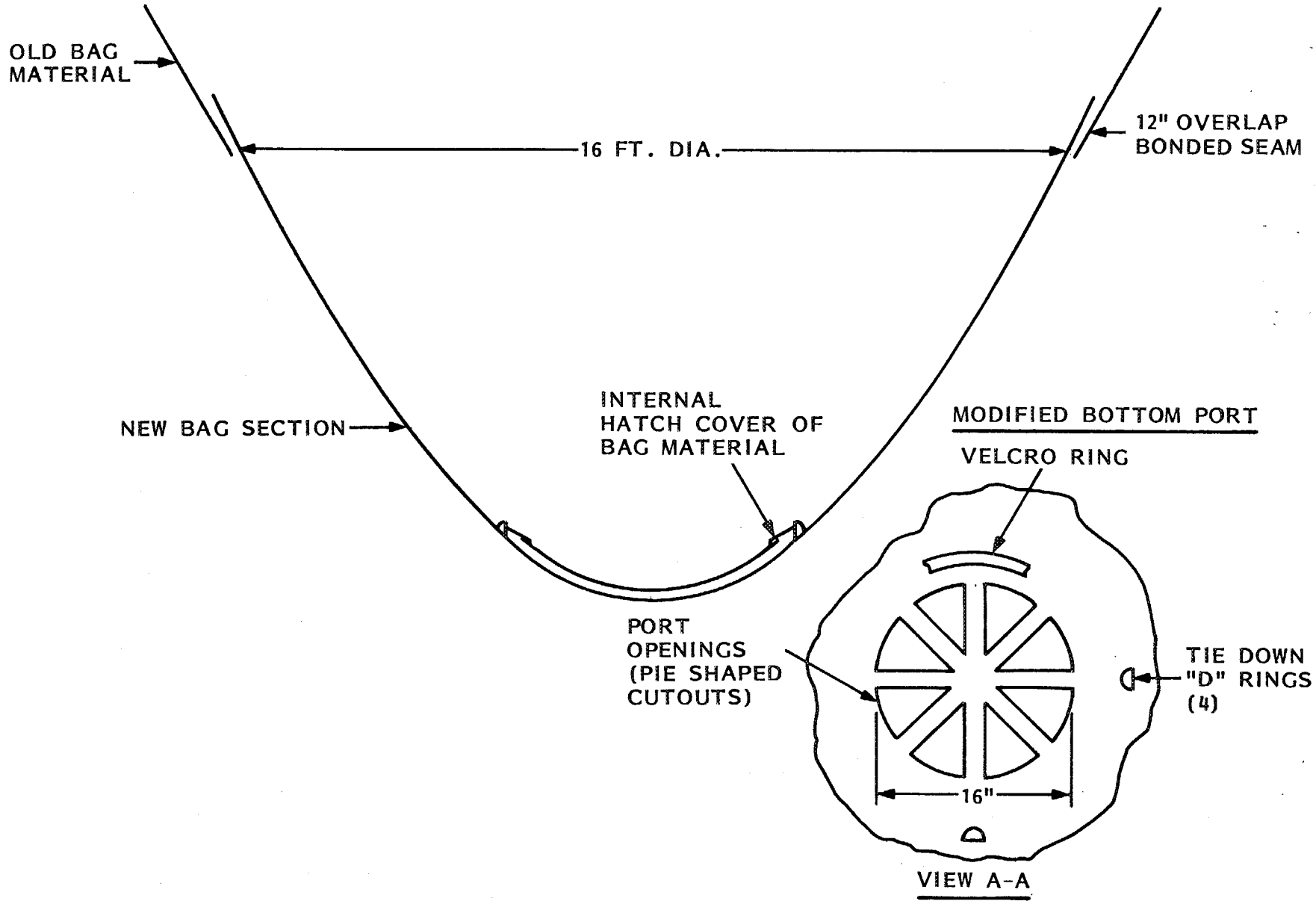


Figure 5.2-6. Bag Bottom Section Repair with Modified Port Design

downcomer. After the installation was completed, several flow rate tests on the hydraulic system verified that no degradation had occurred, and the system met its revised design flow rate.

Inshore Anchor Movement - During a weekly check of the mooring system in January 1982, it was found that the inshore anchor had been overturned and dragged to seaward. The anchor was lying on the mooring chain where the chain originally had been attached to the top of the anchor. The inshore anchor is a concrete block 7 feet x 7 feet x 3 feet weighing 15,000 pounds in water. The original distance between anchors was checked after installation and found to be 237 feet. The separation distance as defined in the design specification is 238 $\pm$ 3 feet. The measured distance between anchors after the movement was 221 feet. The depth of both anchors at their original locations was checked, and it was found that the original inshore anchor location was 5 feet deeper than indicated on the original survey. During the period just prior to the anchor movement, tides were significantly higher than normal and rough seas were reported. An analysis indicated that these sea conditions, combined with the five foot anchor depth discrepancy probably caused the observed anchor movement.

Additional analyses were conducted to assess potential problems associated with the inshore anchor remaining at its new location. The results indicated that the mooring geometry in the new configuration was acceptable since, although the anchor spacing was reduced, the inshore anchor depth had increased and the free length of chain had decreased (approximately 4 feet of chain was permanently trapped under the anchor) so that anticipated motion and loads were similar to those predicted for the original geometry.

A careful diver examination of the inshore electrical cable (floated off the inshore anchor chain) after anchor movement also indicated no damage to the cable and no additional potential for fouling or damage with the new anchor position.

The decision was made to leave the system in its new configuration with no further adjustments to anchor locations or chain lengths, etc. The inshore anchor block remained in its new position through the end of 1982.

Hardware and Facility Modifications

As operating experience was gained, it was found necessary to modify portions of the CTF. These modifications, in most cases, required Engineering sketches, parts fabrication by a vendor and installation by the CTF operating crew or a

subcontractor with on-site engineering support. Following is a description of the major modifications with a brief explanation of the reasons for modification, the design tradeoffs, and the final configuration.

Bag Outlet Screens and Bumpers - In order to protect the gravity drain system from the accumulated debris in the bag, a nylon net screen was placed in front of each outlet port. These screens, 17 feet x 13 feet in size, were attached to flaps on the bag. Due to the flexibility of the bag and the screens, they could not be stretched taut across the bag quadrant. As a result, when the screen in the area of the outlet port became slightly fouled, the water flow pushed the screen into the port partially blocking it, causing a higher pressure drop in the gravity drain system. A short pipe nipple and a 6 inch tee were installed in each of the original outlet ports to restrain the net. The two openings at the ends of the tees served as unobstructed exit ports.

A further simplification and improvement in the entire bag outlet flow screen system was implemented late in 1982 as part of the bag repair/modification activity discussed in Section 5.2.1.1. The large original screens were discarded in favor of several smaller, frame-supported screen assemblies which were hung from the upper lip of the bag, each covering only a single outlet port. This design significantly reduced the difficulty in removing growth and debris from the screen surfaces and outlet port hardware so that more frequent and effective cleaning was possible. The new design of the screens also eliminated the need for the net-bumper tees on the 6 inch outlets so that maintenance of these ports was further simplified.

Discharge Pump Intake Screens - Even though the screens in the bag contained most of the debris, enough small pieces of kelp were passed to rapidly clog the discharge pump intake screens in the sump tank. Therefore, it became necessary to clean the pump screens several times each week. This required that a diver descend into the sump tank and manually clean out the accumulated debris. The original screen configuration covered the end of the 10 inch pipe casing as shown in Figure 5.2-7, which restricted inlet area to that of the pipe cross section. The new screens were constructed from a 16 inch diameter cylinder 12 inch long, which extended from the bottom of the sump tank to the bottom of the 10 inch casing. The screen area was thereby increased by greater than a factor of four.

The new screens can readily be removed for cleaning outside of the sump tank. It was also found that the new screens only required cleaning once a week - a great improvement over the old method.

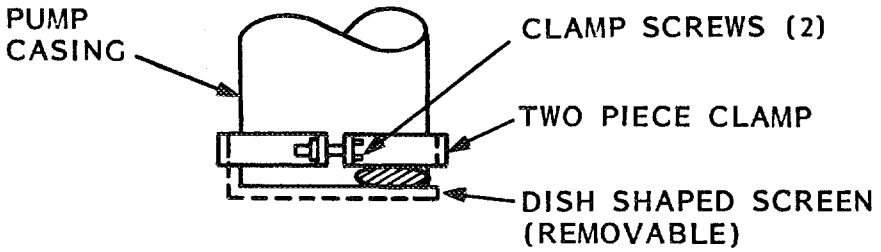
Inlet Pump Intake Screens - The inlet pump intake screens were damaged shortly after the CTF was put into the water at Big Fisherman's Cove when a large school of small squid was attracted by the light on the instrumentation shed and was forced against the screens by the intake water velocity and pressure drop. New screens were designed to be more rigid with increased area and were capable of being readily removed for cleaning topside. The area was increased by almost a factor of three, and the screens could be removed by the diver pulling two pins. The screen was attached to the 10 inch casing by four retaining pins and designed as an inverted "vee" with the top and sides blocked with sheet metal. See Figure 5.2-8 for the old and modified configurations. It should be noted that these screens were further modified and improved as part of the inlet depth redesign discussed in a later paragraph.

Additional Gravity Drain Hoses - A series of tests (see Section 5.2.1.1) were conducted to determine why the maximum system flow rate did not meet the original design predictions. Results indicated that flow restrictions in the gravity drain system were higher than anticipated. It was recommended that additional capacity be added to the gravity drain system both to improve existing performance and to provide additional margin to compensate for potential biofouling within the piping.

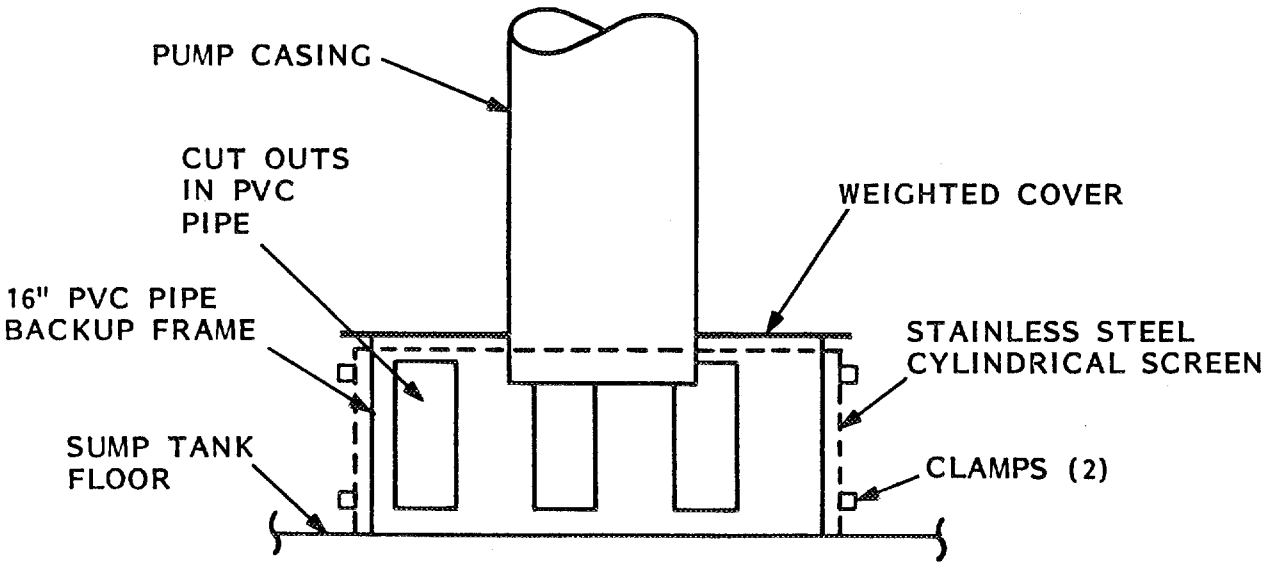
Several candidate concepts were traded-off to increase the flow potential of the gravity system. The following concepts were evaluated:

a. Add two additional 8 inch ports
b. Add two additional 6 inch ports
c. Incorporate an Ejector/Syphon
d. Add a Pump - Bag to Sump

Of these candidates, the addition of two 6 inch ports was the least costly, but only provided a flow rate increase of 730 gpm, while for only a small additional cost, two 8 inch ports would provide a 1300 gpm flow increase with a one foot water level differential between the bag and sump tank. The latter solution was selected since the additional capacity provided a reasonable margin (theoretically 50 percent) for degradation due to biofouling of the gravity drain subsystem and would permit significant reduction in cleaning requirements of the system. Solutions c and d were felt to be too complex and/or expensive.

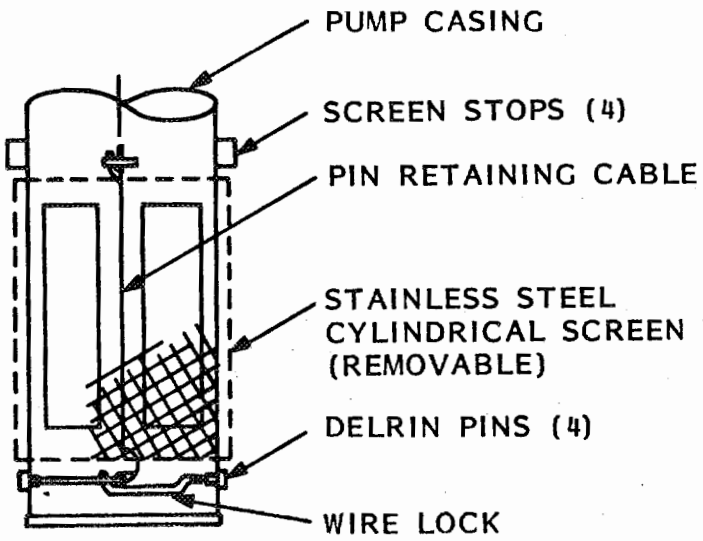


(a) ORIGINAL CONFIGURATION AS DEPLOYED (1981)

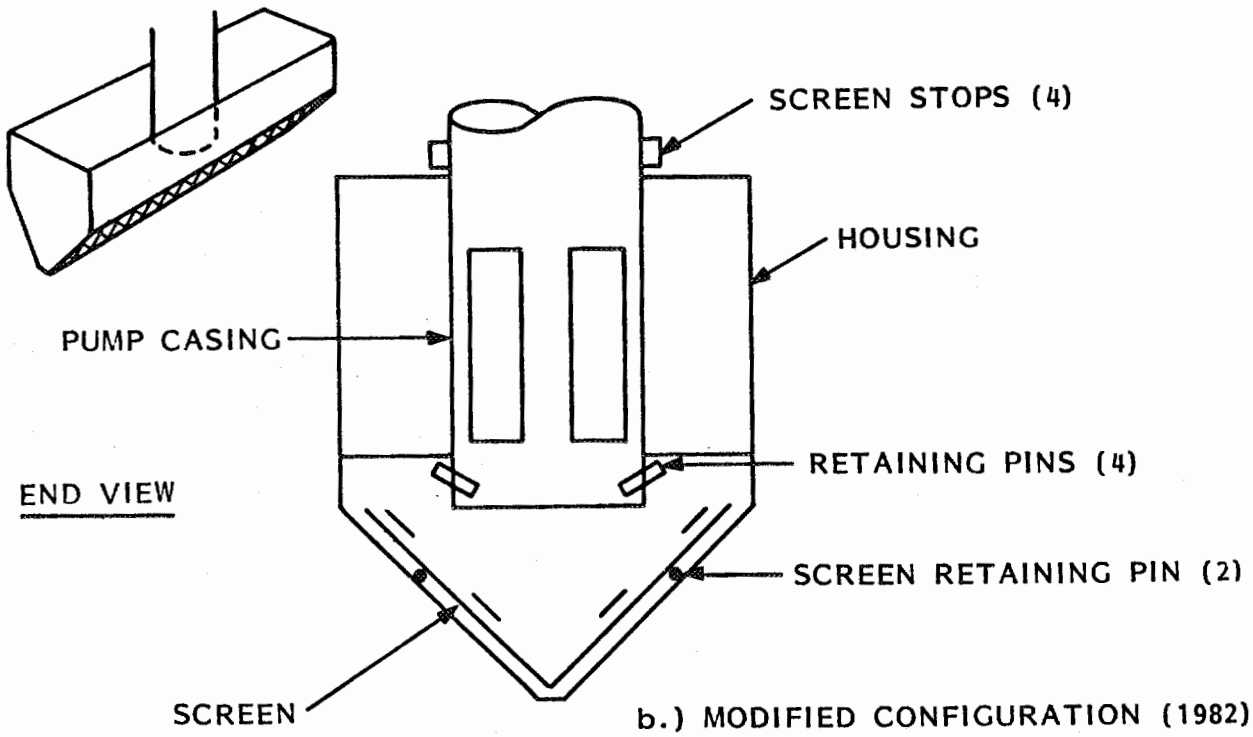


(b) MODIFIED CONFIGURATION (1982)

Figure 5.2-7. Screen Configuration on Discharge Pumps



a.) ORIGINAL CONFIGURATION AS DEPLOYED (1981)



b.) MODIFIED CONFIGURATION (1982)

(NOTE: SCREEN IS TWO RECTANGULAR SURFACES - TOTAL AREA = 3.7 SQ. FT. PER PUMP)

Figure 5.2-8. Screen Configuration on Intake Pumps

The additional drains go directly from the bag to the sump tank bypassing the 12 inch drain manifold which is more sensitive to biofouling because of low flow velocity and is difficult to clean on a frequent basis. Previous experience had shown that the surface and sub-surface inlet nozzles could be adjusted to provide great flexibility in bag flow patterns. Therefore, the effect on the flow in the bag due to addition of two large, new exit ports close together could be compensated by adjustment of the inlet flow patterns.

Two 8 inch diameter holes were cut in the upper 30 inches of the bag, and a 25 inch diameter doubler was bonded to both sides of the bag to reinforce the cutout area as shown in Figure 5.2-9. Two flanges were bolted together through the bag. Each flange face had a phonographic finish, and as a result a good friction interference with the bag was achieved thereby helping to carry the load uniformly around the cutout area. Two 8 inch holes were cut underwater into the bottom of the sump tank. They were reinforced with steel plate doublers. A deflector was required in the sump tank as the flow coming through these openings interfered with the floats which actuated the sea valves. With this modification installed, the system met the design flow rate of 2400 gpm. The flow-limiting subsystem became the discharge pumps and bottom pipe rather than the gravity system.

Extended Inlets - A water temperature of 20°C or higher has a negative impact on the kelp growth and health. During the summer, the water temperature at the inlet pump intakes (12 feet below the surface) reached 20°C and higher. The intakes were therefore extended to 50 feet depth (see Figure 5.2-10) which at most times was below the thermocline with the water temperature at 17°C or cooler. Polyethylene pipe 10 inches in diameter was used to extend the inlet casing. The pressure drop at 800 gpm was calculated to be less than 1 inch of water and thus would have no effect on the pump performance. The intake screens were again redesigned since the existing units weighed 90 pounds each, which would have resulted in excessive cantilever loads if installed on the bottom of the extension. The new screen assemblies were fabricated from polyethylene with steel screen which resulted in sufficient negative buoyancy to balance the positive buoyancy of the polyethylene pipe. The bottom ends of the original casings were also modified to mate with the new extensions. A stress analysis of the entire modified inlet casing design was conducted to verify that all structural elements had sufficient design margin to support the extended inlets.

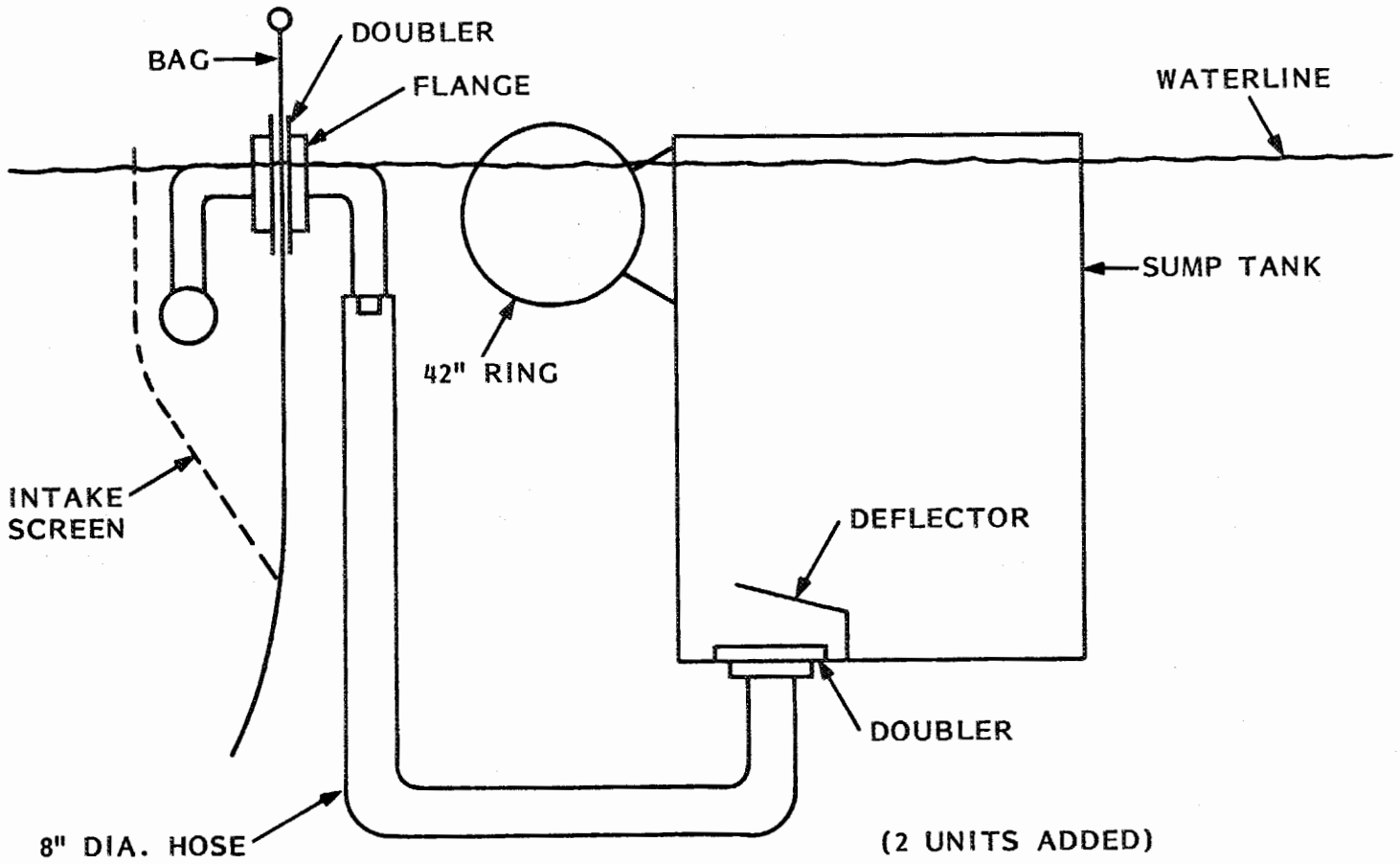


Figure 5.2-9. Additional Gravity Drain Hose Installation

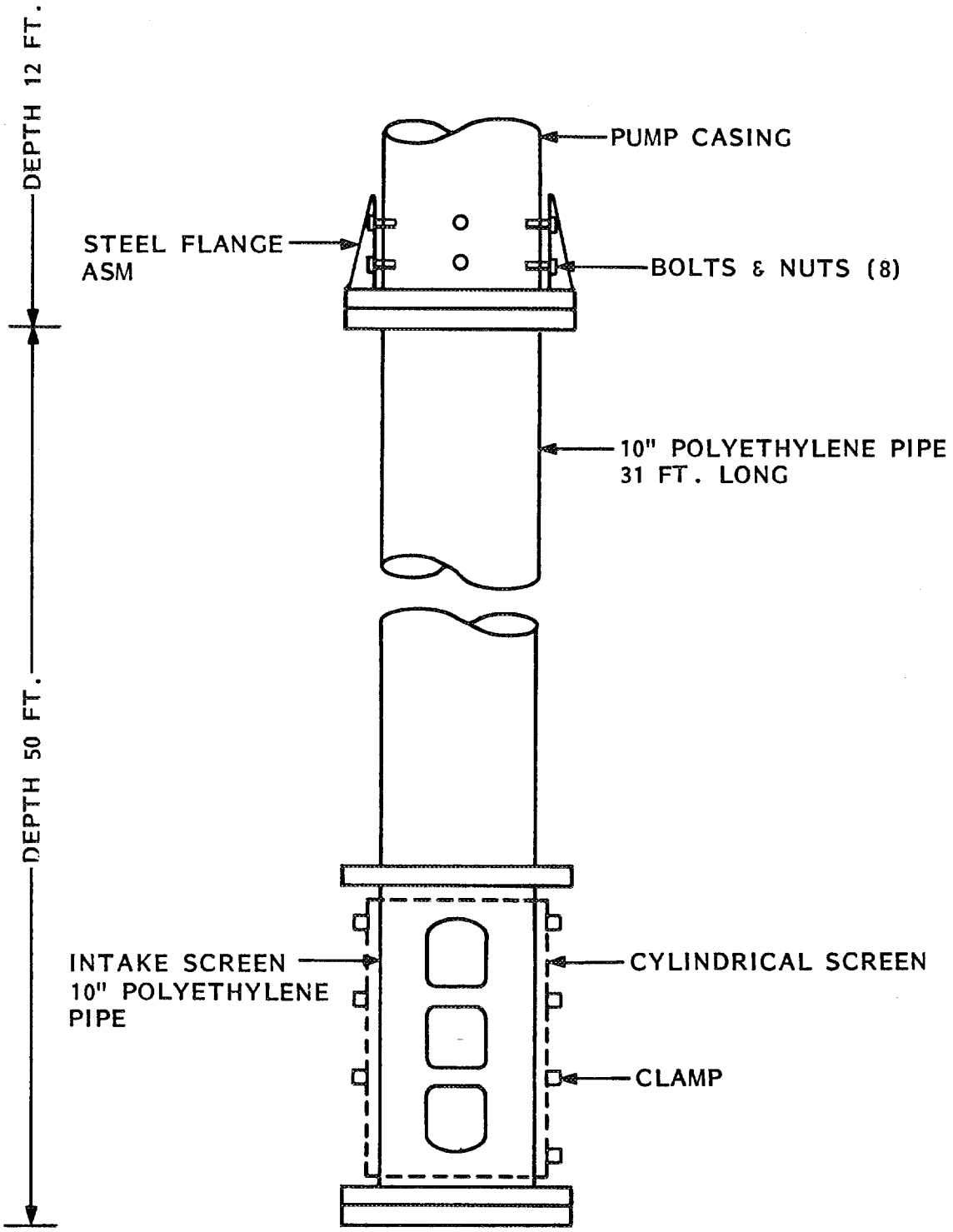


Figure 5.2-10. Extended Inlet and Final Intake Screen Configuration

Originally, the extensions were to be utilized during the summer only (calm seas), and therefore PVC flange interfaces which were easy to install, were employed to attach the steel casings to the polyethylene pipes. After installation and successful operation, the experimenter requested that the inlet extensions remain on throughout the experiment. This required changing to steel flanges since the PVC units had insufficient strength to reliably survive the loads generated by storms anticipated during the late fall, winter, and early spring. The steel flanges were installed at the beginning of October 1982.

Flow Instrumentation - As discussed elsewhere in this Section, 5.2.1.1, the orifice plate employed for flow measurement in the inlet system was found to have fouled resulting in erroneous flow data. The severe fouling was due primarily to growth and accumulation of debris in the flow stagnation areas immediately upstream and downstream of the orifice plate. Frequent cleaning to prevent this condition was impractical because of the plate's location clamped between two 10" pipe flanges in the main inlet water line. Therefore, alternative methods of measuring the flow were evaluated:

a. Annubar - A device which measures and averages the dynamic head at four points in the pipe.

b. Pilot Tube - Measures the dynamic head at one point in the pipe. The operator must traverse the pipe and calculate the average.

c. Flow Totalizer - This would require extensive rework of the 10 inch feed pipe.

d. Ultrasonic Flow Meter - Used by the Navy for seawater flow measurements in submarines but costs in the range of $8,000.

e. Volumetric Tests - Require operator to conduct volumetric tests to determine pump flow rates approximately once a week.

f. Knot Meter with Paddlewheel Transducer - This device would measure the flow only at one point in the pipe and would not be capable of transversing it. The error for this device is in the range of ± 10 percent.

From these candidates, the Annubar was selected as the best solution for the following reasons:

a. It would provide the data required by the experimenter.
b. It can be easily installed initially and then be easily removed for cleaning and maintenance without stopping the flow.
c. Its output can readily be made compatible with the data logger.
d. Its cost of approximately $2,000 was reasonable.

The Annubar, Figure 5.2-11 is installed through a 1-1/4 inch - 1/2 inch pipe coupling which is welded into the 10 inch feed pipe, seven pipe diameters downstream from the 45^{0} elbow on the inlet platform. The location is near the location of the original orifice plate and, in both cases, was selected to assure that the flow disturbance caused by the elbow has a negligible effect on the instrument reading.

Operating & Maintenance Procedures

In an effort to standardize the operation and maintenance of the Catalina Test Farm, operating and maintenance procedures and checklists were developed. These procedures and checklists were then followed and updated as required during the course of the year. The system operating procedures detailed the steps to hydraulically balance the system with the cautions to be observed in order to protect the equipment. This procedure was updated when the pump manufacturer limited the flow rate and increased the Net Positive Suction Head requirement.

A procedure was developed to reactivate the CTF after a shore power shutdown. The procedure was required to prevent large power surges when reactivating the system.

A daily checklist was developed to assure that the operator monitored all critical parameters. This data also served as a log of the CTF operation. A copy of the latest daily check list is shown in Figure 5.2-12. The weekly checklist was also developed to monitor the physical condition of the hardware. A sample of this is shown in Figure 5.2-13.

An Operating & Maintenance Procedure Manual was generated and structured to provide detailed information on the operation, maintenance and test procedures of the system and its major components. The contents of the Manual are outlined in Table 5.2-1. The CTF Operating & Maintenance Procedure Manual was issued as Reference GE-BIO-1851.

1982 Year End CTF Status Summary

By mid-December 1982, all major problems identified with operation of the facility during the year had been corrected:

a. Pumps modified for reliable performance at operational conditions.

b. Flow system modified to improve system margins and revised maximum system flow rate of 2250 gpm demonstrated.

c. Cleaning and maintenance procedures developed and demonstrated to be effective.

d. Major bag repair successfully completed and enclosure back to operational status.

e. All major subsystems/components at operational status so that the new biological experiments could be initiated in early 1983.

Several minor non-critical tasks remained to be implemented, but plans were developed and work was planned for completion in early 1983 during the period required for leaching of the new bag material and installation of new test plants.

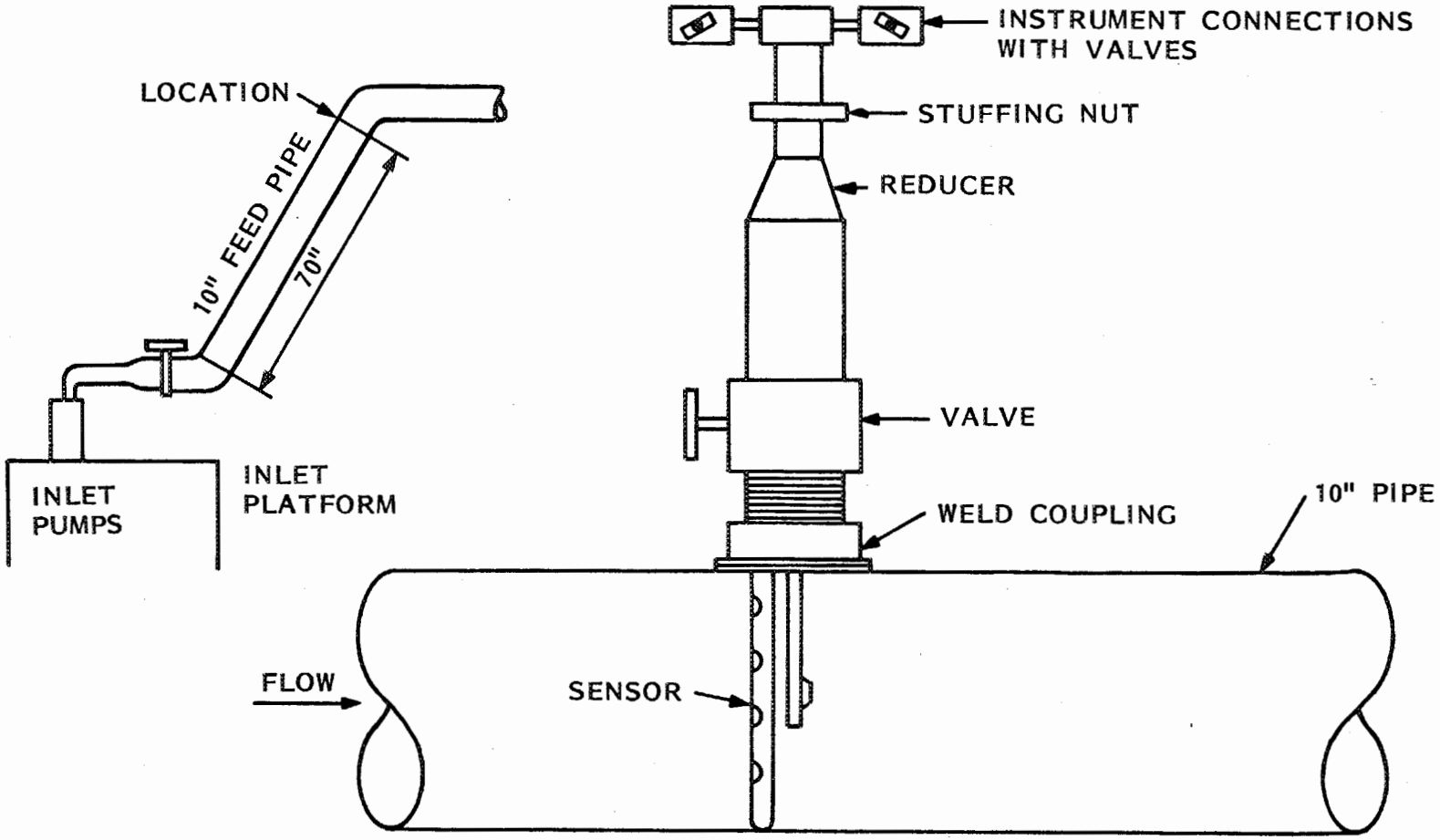


Figure 5.2-11. Annubar Flow Sensor Installation

Date_____

C.T.F. DAILY CHECK LIST

			SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THRUSDAY	FRIDAY	SATURDAY
SEA STATE									
SHORE BEARINGS									
ON SHORE METER READING									
WATER LEVEL IN BAG (INCHES FROM TOP)									
FLOW RATE %	GPM	A.M.							
%	GPM	P.M.							
PUMPS IN OPERATION		Intake 1							
		Intake 2							
		Intake 3							
		Discharge 1							
		Discharge 2							
		Discharge 3							
		Nutrient							
P PSI									
STATIC FEED PIPE PRESSURE									
SUMP TANK LEVEL (INCHES)									
BAG CONDITION									
BUNGEE CORD									
GRAVITY DISCHARGE SYSTEM									
DATA LOGGER									
GROUND FAULT SYSTEM									

COMMENTS:

Figure 5.2-12. CTF Daily Checklist

		F.W. # __	F.W. # __	F.W. # __	F.W. # __	F.W. # __
SURFACE:						
	PYRANOMETER					
	OIL LEVEL IN NUTRIENT PUMP					
	INSTRUMENTATION SHED INSULATION					
	HARDWARE: CLEATS					
	DECKING					
	ETC.					
SUB SURFACE:						
IN BAG:	TEARS					
	LOOSE "D" RINGS					
	SCREENS					
	INJECTORS					
	BOTTOM FLANGE					
OUTSIDE BAG:	MOORINGS					
	ELECTRICAL CABLES					
	INTAKE SCREENS					
	ZINCS 8					
	BAG					
	BOTTOM FLANGE					
	DISCHARGE HOSE					
	GRAVITY DISCHARGE HOSES					
SUMP TANK						

Figure 5.2-13. CTF Weekly Checklist

TABLE 5.2-1. CATALINA TEST FARM OPERATING AND MAINTENANCE PROCEDURE

TABLE OF CONTENTS

List of Figures
List of Tables

1.0 GENERAL
1.1 Reference Documents
1.1.1 Specifications and Instructions
1.1.2 Drawings and Design Documentation
1.2 Operating Equipment Description
1.2.1 Pumping System
1.2.2 Float Valves
1.2.3 Electrical System
1.2.4 Instrumentation
1.2.5 Mooring System

2.0 OPERATING PROCEDURE
2.1 General
2.2 Inlet and Discharge Pump Start-up
2.3 Nutrient Pumps
2.3.1 Nutrient Pump Operation and Flow Adjustment
2.4 Flow Measuring
2.5 Pumping System Start-up and Flow Balancing
2.6 Electrical Ground Faults
2.7 Float Valve Adjustment
2.8 Diver Access Platform
2.9 Druehl Experiment Interfaces
2.10 Underwater Inspection
2.11 Inspection and Reports - Daily/Weekly

3.0 SYSTEM MAINTENANCE AND TEST
3.1 Inlet/Discharge Pump Removal and Replacement Procedures
3.1.1 Material Required
3.1.2 Pump Removal/Installation
3.1.3 Pump Performance Test
3.2 Biofouling Cleaning Procedure
3.2.1 Inlet Pumps
3.2.2 Inlet Flow Distribution Nozzles
3.2.3 Gravity Drains
3.2.4 Discharge System
3.3 Flow Meter
3.4 Navigation Lights

4.0 COMPONENT SPECIFICATIONS AND MANUALS

5.4 NEARSHORE SYSTEMS ANALYSIS

5.4 NEARSHORE SYSTEM ANALYSIS

The overall system study task for 1982 was part of a continuing effort to evaluate the commercialization feasibility of various kelp-to-methane system approaches. This year the task was directed toward development of smaller, nearshore farm concepts with potential for commercial development over a shorter time period and with lower risk than did the offshore concepts addressed in earlier system studies. The present study incorporated information and guidelines developed from past experience of the commercial kelp harvesting industry and new data on farm and gas yield as they become available from 1982 kelp yield experiments and digester development research, respectively. This new study also considered the economic potential associated with chemical by-products and co-products which had not been considered in previous studies. The preliminary results in the by-products area obtained during initial studies indicated sufficient advantages to warrant expansion into a more detailed study which is described in Section 5.5.

The 1982 GE system study task was part of a broader study which included a detailed system costing and economics evaluation accomplished by The Ralph M. Parsons Company employing technical inputs from the GE study results. The primary output of this GE task was a System Functional Requirements and Specification document (Reference 5.4-1) which was issued in July 1982 and updated in October and November 1982. The broad purpose of this document for use by R.M. Parsons was four-fold:

- Define the objectives, ground rules and constraints for the system economic study.
- Summarize biological and engineering data available, identify ranges of uncertainty, and define, where possible, most probable values of technical parameters required for the overall study.
- Identify overall system requirements, subsystem functional and interface requirements.
- Define a GE recommended system concept on the basis of preliminary system/subsystem tradeoffs.

The subtasks described in the following sections were performed in order to generate the information required for the Requirements/Specification document.

5.4.1 GROUND RULES AND CONSTRAINTS

In order to assure that useful and meaningful results could be obtained during the time period available for the overall study, it was necessary to establish constraints and ground rules limiting the variability and range of selectable study parameters such that the scope of the study would fit the planned schedule. In addition, it was decided early in the study to limit candidate technical approaches to those concepts which were considered to be "state-of-the-art" within present technology in order to enhance credibility and confidence in the final cost and economic results to the maximum extent possible. It was decided to make maximum use of available information on kelp growth and harvesting as gained over the past 70 years of comercial harvesting of nearshore California kelp beds for production of chemicals. In addition, in order to take maximum advantage of past Marine Biomass Program results, experience and data, the species and geographical locations were further restricted to those plants and areas selected and studied by program personnel in prior years. These criteria led to the selection of Macrocystis pyrifera or Macrocystis angustifolia for farming in nearshore beds off the mainland of southern California. This selection is also consistent with available process data since a significant body of data exists on gasification of this feedstock.

No minimum or maximum plant production capacity or farm size was specified, but the overall study objective was to trade off various concepts, sizes, etc. to minimize unit cost of energy produced within the other constraints.

The effects of potential non-energy by-product revenue on gas cost and potential environmental impact considerations were to be addressed in a preliminary way during this phase of the study, only to identify those areas which should be subjected to further investigation or which might cause unusual or inordinate environmental problems.

The following items summarize the final study ground rules:

a. Farm sites limited to mainland coastal area of California between Point Conception and the Mexican border.

b. The water depth ranges from 25-200 feet MLLW.

c. Feedstock restricted to Macrocystis pyrifera or Macrocystis angustifolia.

d. Sensitivity to technology will be evaluated by considering both "baseline" and "advanced" system concepts. All materials and technical concepts incorporated in "baseline" system concepts will employ "state-of-the-art" technology. "Advanced" concepts will use advanced technology but will be identified as such.

e. The primary criterion of system merit will be the unit cost of production of the methane in constant dollars, using present value methods as described to GRI.

f. Exploitation of co-products and by-products derived from the gas process effluent will be considered to the extent that potential additional revenue can be obtained to reduce gas cost.

g. The scope and significance of required environmental impact evaluation and permit applications for operation of the total system in California will be considered, keeping in mind that an actual system deployment would not occur until after the year 2000. Comparison of the magnitude and extent of the present concepts with comparable civil or industrial projects of recent experience will be made.

h. The energy consumed in appropriate user components of the system operations can be diverted from the product methane stream with attendant downward adjustment of net output of product. An alternative is to purchase all energy from the market, and preserve the total produced methane for distribution. Net energy produced will be evaluated.

5.4.2 KELP BIOLOGICAL AND ENGINEERING DATA BASE DEFINITION

Available data were researched and reviewed to determine the extent and level of confidence of existing data, the ranges of uncertainty and most probable values for various important parameters, and to identify those areas where new data were required and/or would be generated from the ongoing experiments described in other sections of this report. Information was primarily required in three major areas:

- Kelp Growth Biological Parameters
- Kelp Physical Properties
- Kelp Feedstock Processing and Gasification Data

Ocean environmental data are also required to interface with farm analyses and be employed with the kelp data. Nearshore site and environmental data for both ocean and land locations are very site specific and are discussed in Section 5.4.3 where site selection study results are presented.

5.4.2.1 Kelp Growth Biological Parameters

A review of the biological data base was conducted with the support of kelp biologists from CIT and NMI. The data reviewed comprised primarily data acquired over the years from biological surveys and studies of natural beds and laboratory

studies supplemented with limited data available from commercial kelp harvest experience. Of particular interest was the limited data available on growth, productivity and yield of Macrocystis. New and significant data became available from the Catalina and Goleta harvest yield experiments during the year. Data base definitions were updated continually as more harvest data were acquired and analyzed. Biological parameters of primary interest and the potential range of the parameter based on available data are:

Holdfast Depth	25-60 Feet
Water Temperature	9-20^{o}C
Insolation	As along the So. California Coast
Life Cycle (spore to first harvest)	22-32 Months
Nutrient Requirements	From natural upwelling events or as per simple N-balance model
Harvestable Yield	5-45 DAFT/Acre Yr.

Additional detail, definition of the parameters, and the rationale for selection of the specified values are presented in Reference 5.4-2 which comprises the biologists' input to the data base evaluation. In general, the values of the parameters noted above are based on observations of conditions for the occurrence of kelp in the natural beds along the southern California coast in combination with biologists' laboratory and field test experience.

In the ideal case, a kelp growth/harvest model would be available to predict growth and yield parameters for various conditions. The present state-of-the-art does not permit such a model, however, so that for purposes of this study, simplifying assumptions and empirical data were employed. The yield range noted above is based on optimistic commercial harvest experience with natural beds for the low end. The high end of the range is based on projections of recent but limited data obtained from the NMI test farm for plants with exceptionally high measured productivity and consideration of results of preliminary measurements and modelling of Macrocystis nitrogen uptake rates at CIT. Annual yield was assumed to be independent of harvesting schedule since, as noted above, no validated growth/harvest model exists.

A "most probable" yield value was selected for development of a "baseline" system concept during the early stages of the study. It became obvious also that yield values, planting density, and plant size were all closely interrelated when considering potential harvest yields and design concepts. The following table

indicates the initial "Baseline" values used in early system concept studies and tradeoffs. The value was based primarily on natural bed harvest history and early results from the NMI farm where plants from natural beds were transplanted to closer spacing and cultured and harvested systemtically. Updated "state-of-the-art" and "advanced" concept values based on the expanding NMI farm data base which were utilized by The R.M. Parsons Company in their final economic analysis are also shown in Table 5.4-1.

TABLE 5.4-1. ASSUMED YIELD AND PLANTING DENSITY VALUES FOR SYSTEM CONCEPT POINT DESIGNS

	GE Baseline	State-of-the-Art	Advanced
Areal Yield (DAFT/A-Y)	7.5	15	45
Plant Density (Plants/A)	1000	400	1000
Plant Spacing (Feet)	6.5	10	6.5

A discussion of the NMI data and the rationale for selecting specific yield values for "state-of-the-art" and "advanced" concepts are presented in Reference 5.4-3. Figure 5.4-1 shows a summary of the NMI projected yield data for the Goleta Test Farm. Data are shown for the three planting densities, for the "average" and "highest producing" plants for each of several harvests. The early "baseline" value was based on a minor improvement over the "average" plant yield for a medium density farm. The "state-of-the-art" yield is based on the assumption that the existing NMI "high producer" plants, which originally came from natural beds, can be reproduced on a commercial scale with a minimum of genetics work and will maintain their high producer capability at slightly closer spacing (i.e., 10 ft. as opposed to the NMI farm value of 13 feet). The "advanced" yield value is based on the assumption that genetics research and farm/harvest optimization studies over the next phases of the program will result in significant yield increases (e.g., 40 percent) over those presently obtained with the "high producer" plants at the 1000 plants/acre density. Note that although very high yield values can be projected from the high density (400 plants/acre) spacing, the mortality rates experienced were unacceptable so that it was felt that system concepts employing these very high planting densities and projected yields were not realistic for the present study. Mortality rate at lower densities was much lower but requires further verification to establish acceptability.

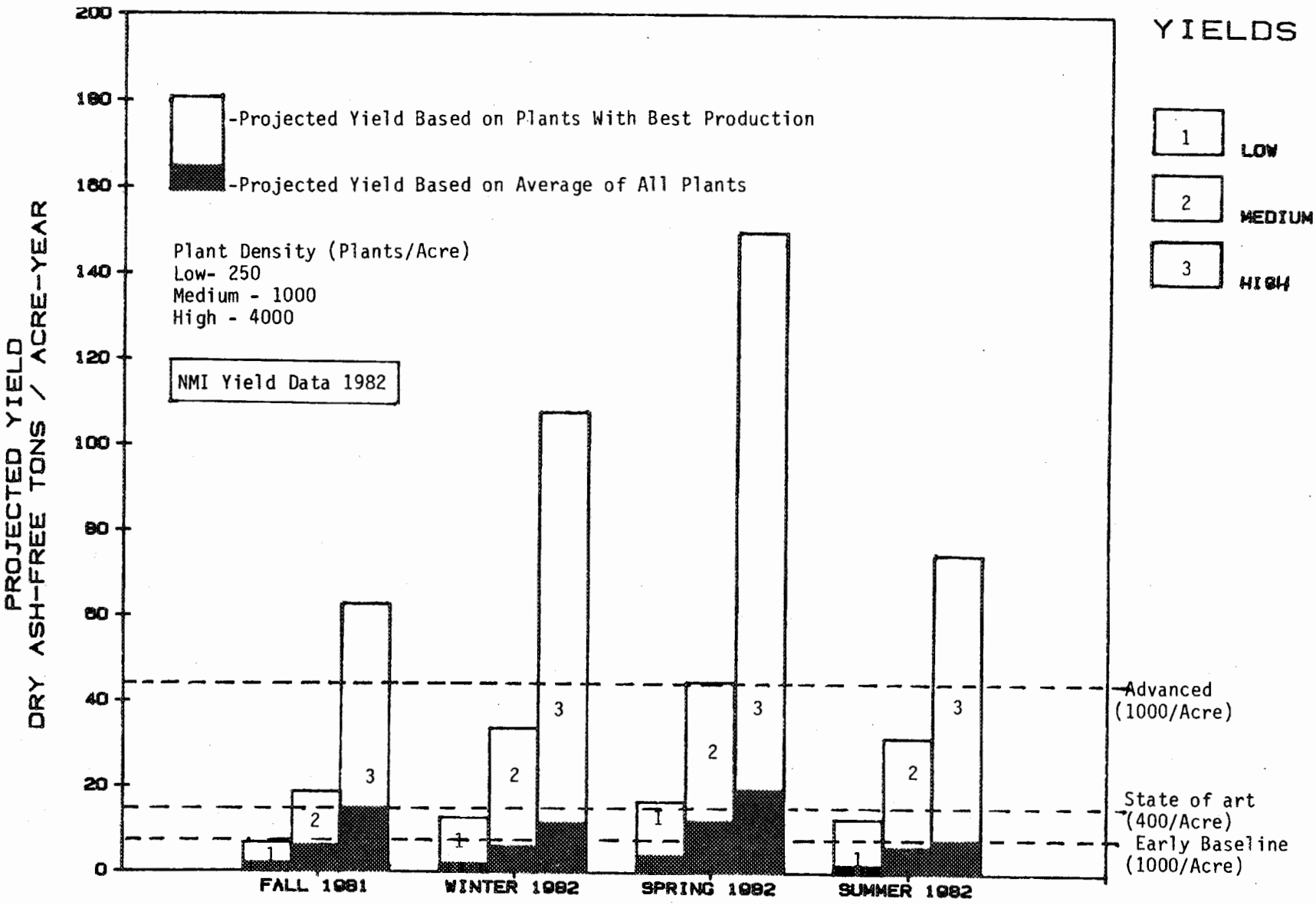


Figure 5.4-1. Projected Yields for Four Seasonal Harvests of Plants Planted at Three Densities

Since no comprehensive fertilization model presently exists to determine nutrient requirements and optimize fertilizing techniques for large nearshore kelp beds, a simple "black box" model was developed for this study. Figure 5.4-2 shows schematically the sources and sinks for nutrients in a kelp bed. It is assumed that natural upwelling events, when they occur, provide sufficient nutrients and that no additional nutrient is required during those periods. When upwelling ceases, however, nutrients, primarily nitrogen, may be required to prevent nutrient-limitation of biomass production. It was assumed that the natural environment would always provide adequate supplies of other macro- and micro-nutrients. The box in Figure 5.4-2 represents the farm boundaries through which the various mechanisms transport nutrients into and out of the farm volume. A detailed model which includes all transfer mechanisms is not only beyond the scope of this study but also beyond the state-of-the-art at this time so that the nutrient requirements were determined by a simple balance between the nitrogen removed in the harvested material (calculated from the assumed harvestable yield and kelp composition) and the nitrogen provided by digester effluent and/or chemical fertilizers put back into the "farm box" by the fertlizing subsystem described later. The large farm area and low internal water velocity conditions were assumed to prevent loss of nutrients from the farm volume by hydrodynamic processes before the plants are able to take up all the nutrient. Similarly, lost and sloughed material was assumed to be recycled within the farm volume, and nitrogen losses by other biological mechanisms were assumed negligible. These assumptions are felt to be realistic in a nearshore shallow-water farm, where the ocean bottom provides an essentially impervious boundary which did not exist in earlier studies of offshore deepwater farms.

Using this simple model, the curves of Figure 5.4-3 were generated to determine chemical fertilizer requirements for various conditions of annual upwelling duration. The values shown are for an annual harvested yield of 100,000 DAFT/Yr and assume that in periods of no natural upwelling, the nitrogen in both the digester effluent (all of which is returned to the farm) and purchased commercial fertilizer is available to the plants. Overall "fertilizing efficiencies" η and β have been included for the commercial fertilizer and digester effluent respectively, to account for the fact that, in actuality, the nitrogen is not totally available to the plants. Although no detailed analyses are available to quantify η, evaluation of gross fertilizing efficiencies obtained by Chinese commercial kelp farmers, Laminaria farms and limited CIT experience

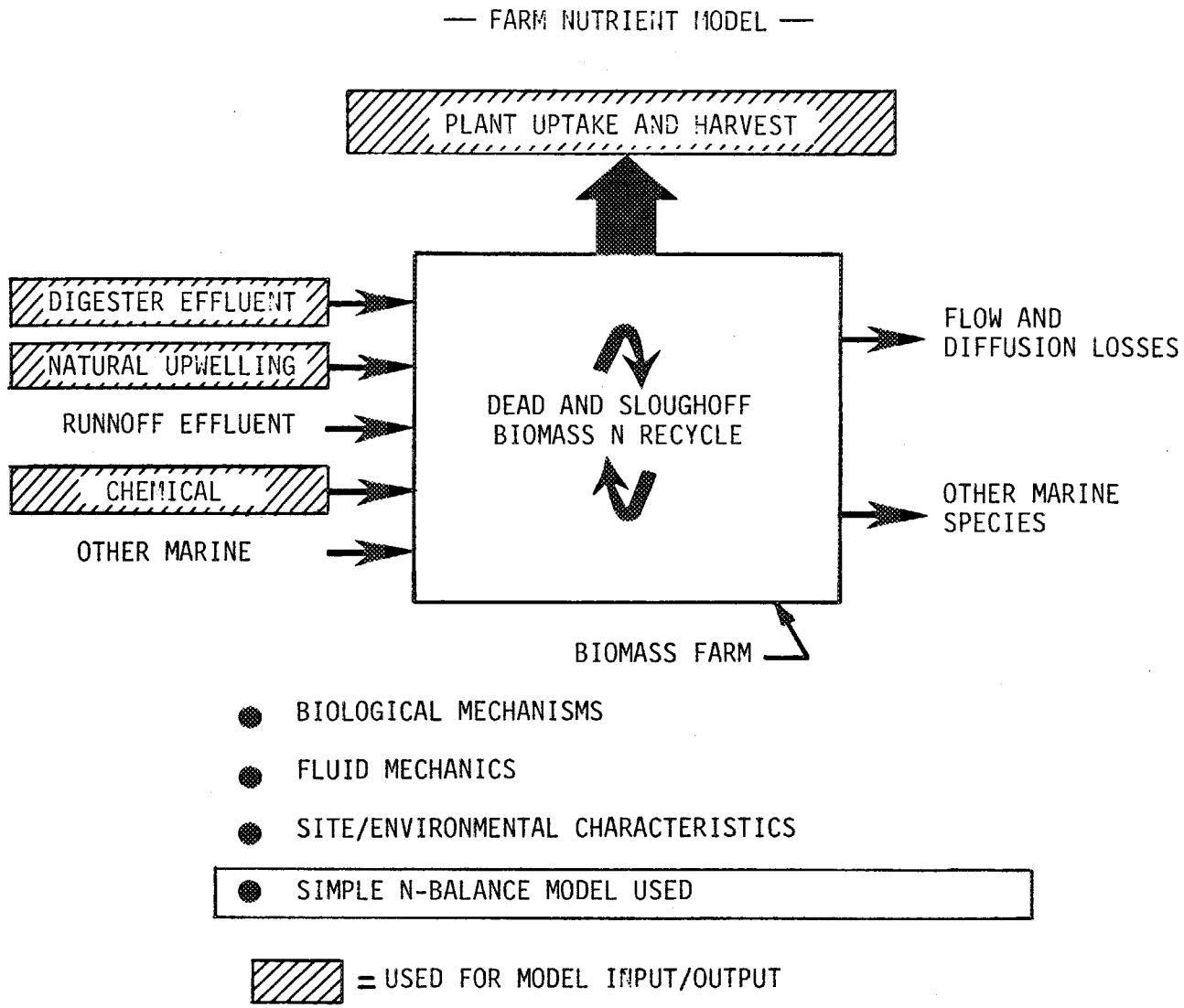


Figure 5.4-2. Farm Nutrient Model

ASSUMPTIONS:
- ALL DIGESTER EFFLUENTS AND COMMERCIAL FERTILIER ARE SPREAD IN THE FARM IN NON-UPWELLING PERIODS
- 1.8% N CONTENT IN KELP
- 100,000 DAFT/YR

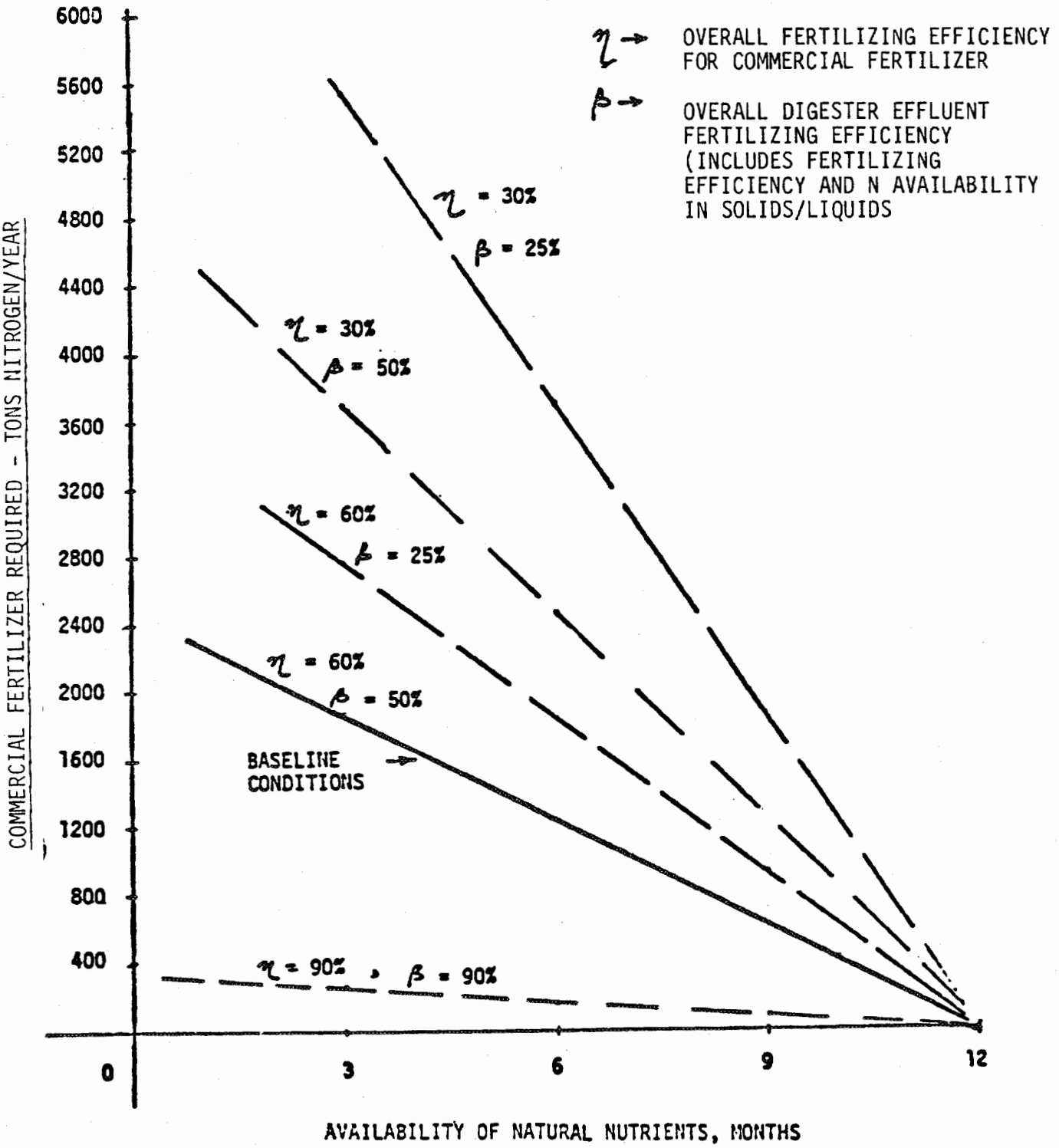


Figure 5.4-3. Commercial Fertilizer Requirements

with Macrocystis natural bed experiments indicate that η = 60 percent is a reasonable baseline value. Similarly, limited evaluation of composition and form of nitrogen in digester effluent suggests a baseline value of 50% for the parameter β. Other values are presented parametrically on the curve to indicate the effect of these efficiencies on fertilizer requirements. Fertilizer requirements for other annual yields and values of kelp nitrogen content (other than the assumed 1.8 percent) are linearly related to the quantities in Figure 5.4-3.

Data availability and requirements were also developed for growth of juvenile plants for initial planting and startup of the farm. The techniques and requirements were defined based on a significant body of experience in this area gained in culturing Macrocystis under laboratory and natural environmental conditions by CIT, NMI and other kelp biologists.

5.4.2.2 Kelp Physical Properties

The kelp physical properties of primary importance to ocean farm siting and concept definition are:

- Plant Size
- Plant Buoyancy
- Plant Drag
- Plant Dynamic Characteristics
- Allowable Relative Water Velocity
- Stipe Strength
- Holdfast Holddown Requirements

These parameters, used in combination with environmental information on water current velocities, wave conditions (such as height, period, orbital velocities, etc.), ocean bottom composition and bottom topography, are employed to specify the design requirements for the farm substrate structural elements which must hold the crop in place and protect it during the design life of the farm.

The buoyancy and hydrodynamic drag properties were determined as a function of plant size (in total frond-feet) by ocean tests conducted earlier in the Marine Biomass Program as part of the ongoing kelp characterization effort. Plant size data were correlated with plant spacing and yield data from the Goleta yield experiment so that the drag and buoyancy characteristics for plants under varying yield and farm density conditions could be estimated to determine loads on farm structures. Information on stipe strength and allowable water velocity were summarized from data available to the kelp biologists.

No reliable data were identified for definition of plant dynamic characteristics, although qualitative observations from divers indicated that dynamics might reduce actual hydrodynamic loads significantly below those predicted using quasi-steady hydrodynamic analyses. A simple dynamics model was developed for load estimation purposes in development of substrate concepts which corroborated that significant drag-load reductions would result from the kelp's inability to follow the wave dynamics. This preliminary model study is described in Reference 5.4-4 which also discusses substrate design concepts. Experiment requirements and preliminary ocean test plans were developed to verify and further investigate kelp dynamics effects.

In the case of holdfast holddown requirements, it was assumed that for Macrocystis pyrifera which would be employed for all off-bottom substrates (water depth greater than 60 feet) and for on-bottom cases with rubble or rocky bottom characteristics, the holdfast would provide no anchoring capability of its own and 100 percent of plant drag, and buoyancy forces would have to be resisted by the farm substrate system of anchors and cables. In the case of Macrocystis angustifolia, however, it was anticipated that the holdfast itself would provide a significant portion of the required holddown force either through its own weight or through adhesion to the bottom (sand or other bottom materials where it occurs naturally) by various mechanisms. Since no quantitative data were available, and since the substrate and total system projected cost could be significantly reduced if anchor sizing could be reduced, a preliminary ocean test operation, Reference 5.4-5, was conducted to obtain data on tearout resistance of Macrocystis angustifolia holdfasts under various bottom conditions and for a range of plant sizes. The results of these measurements are summarized in Table 5.4-2 and Figure 5.4-4. The data indicate that for mature plants greater than about 100 total frond feet in size, the holdfasts alone were capable of resisting the predicted loads due to 20 feet, 20 second storm waves. Although this data sample is small and requires considerable expansion to develop adequate statistical confidence, it is noted that of the total number of plants tested, only a single test sample did not meet this criteria over the three different bottom types investigated. These data resulted in a significant reduction in anchor weight requirements and system cost for on-bottom substrates employing Macrocystis angustifolia as defined in Reference 5.4-3. Anchor weights can be reduced to the 5-20 pound wet-weight range since the plant itself provides a large part of the required resistance to tearout by storm waves. Further research is required to expand the data base in this important area for both Macrocystis angustifolia and for Macrocystis pyrifera also.

TABLE 5.4-2. POINT CONCEPTION AREA SURVEY–PLANT DATA SUMMARY

DATE	TEST PLANT NO.	SITE	BOTTOM DEPTH (FT)	BOTTOM TYPE	NUMBER FRONDS	SIZE (FROND FT)	Holdfast Data						TEAROUT FORCE(LB.)
							LENGTH (IN.)	WIDTH (IN.)	AREA (FT^2)	HEIGHT (IN.)	AIR WT. (LB.)	WATER WT. (LB.)	
9/21	1+	L.Cojo(D)**	50	clay	36	~700	36	30	7.5	9	88	33	>220
9/22	1	L.Cojo(S)	40	Sed/ Clay	18	389	29	25	5	8	33	7	40
	2	"	38	"	25	412	24	24	4	7	-	-	20-75
	3	"	40	"	36	660*	40	44	12	9	-	-	>220
	4	"	38	"	7	111	16	16	1.8	4.5	5	0.5	10
	5	"	40	"	22	436	22	24	4	8	18	2	30
	6	"	40	"	30	550*	34	34	8	9	-	-	>220
	7	L.Cojo(S)	40	Sed/ Clay	37	680*	32	32	7	9	-	-	>220
9/23	1	Gaviota	40	Sand	11	277	17	16	1.9	6.5	10	3	50
	2	"	40	"	10	226	12	12	1	3	1	~0	110
	3	"	42	"	9	203	22	24	3.7	7	9	3	60
	4	"	40	"	35	690	32	30	6.7	18	70	15	209
	5	Gaviota	40	Sand	15	350*	13	20	1.8	-	-	-	75-176
	6	L.Cojo(D)	50	Clay	18	415	18	13	1.6	7	3.25	0.5	77
	7	"	50	"	9	220*	9	6	0.4	4	-	-	106
	8	L.Cojo(D)	50	Clay	13	335	14	14	1.4	7	10	3	77

+ Plant size and force are diver estimates for this test.

* Plant size estimated from stipe count at holdfast and average frond length data.

** L.Cojo (D) indicates the deeper outer bed at Little Cojo. (S) indicates the shallower inner bed at Little Cojo.

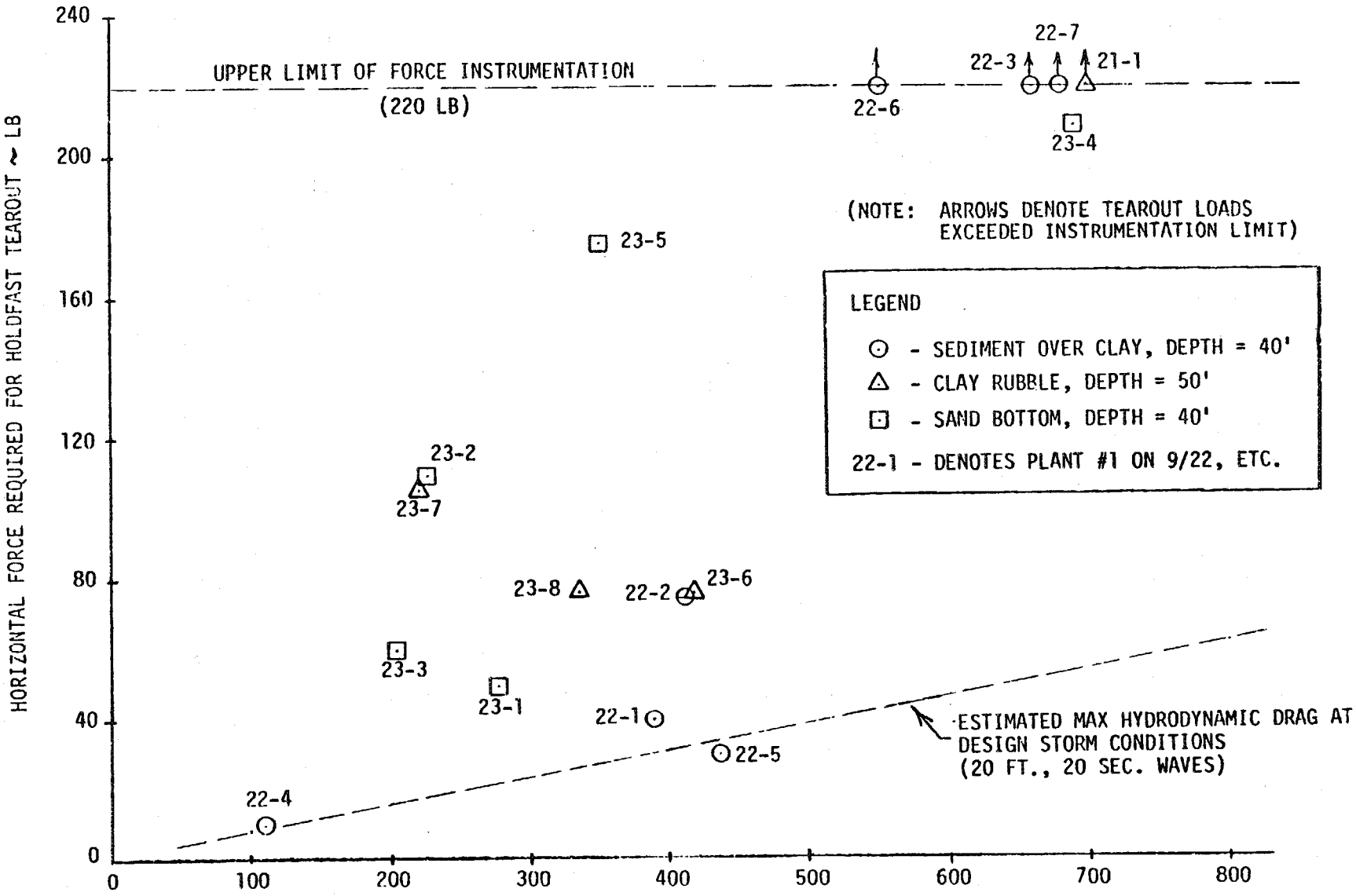


Figure 5.4-4. Resistance of Macrocystis angustifolia Holdfasts to Tearout by Horizontal Forces

5.4.2.3 Kelp Processing/Gasification Properties

A relatively large data base exists to define the range of variability and average values, where meaningful, for kelp chemical composition, physical composition and gasification properties. Kelp biologists surveyed the available data on a large number of samples and summarized the information to provide the required information on kelp composition as documented in References 5.4-1 and 5.4-2. Physical property data required for transport and process subsystem studies were available from previous work done on the program by U.S.D.A. and IGT to determine parameters such as densities of chopped kelp, chopping energy requirements, packing densities and storage characteristics. These data were verified, where possible, with experience of the commercial kelp processing industry. One area of uncertainty developed in ascertaining the viscosity for pumping estimates of chopped undiluted kelp, since this is the preferred feedstock transport mode after the kelp is harvested. Because of the non-Newtonian nature of the material, standard viscometers were not able to provide valid measurements in several laboratory test attempts. Although this does not appear to be a critical parameter, future investigations in the process area should incorporate viscosity or pumping-energy measurements at a larger scale.

The major parameters of concern in evaluation and studies of gasification processes are gas yield data, process temperatures, and process hydraulic characteristics and retention times. A significant body of bench-scale data exists for all these parameters, but the absence of larger scale, i.e., approaching pilot scale, reactor data results in need for added conservatism in engineering concept and economic studies. The available data were reviewed in cooperation with IGT and experts from The R.M. Parsons Company and a mutually acceptable data base defined for the process system studies.

Anaerobic digestion was selected over thermal gasification on the basis of extensive previous studies which indicated that the latter approach was unacceptable primarily due to the high moisture content of the kelp feedstock. Data for anaerobic gasification of a number of kelp lots, for both ambient and mesophilic process temperatures, for several laboratory reactor configurations, for diluted and undiluted kelp and for a variation in kelp feedstock partical size, were evaluated and reviewed. Data on various kelp lots presented in Table 5.4-3, combined with the data of Figures 5.4-5 and 5.4-6 provide the basis for selecting the range of gas yields to be considered in the system study:

TABLE 5.4-3. METHANE YIELD RANGE

Lot 53, Undiluted Feed; Measured Yield in USR = 6.2 SCF/lb VS

Lot 53, Diluted Feed; Measured Yield in STR = 5.2 SCF/lb VS

Yield Adjustment Factor = $\frac{6.2}{5.2}$ = 1.2

Lot No.	Methane Yield Measured in STR* Using Diluted Kelp SCF/lb VS	Expected Methane Yield with Undiluted Kelp in USR SCF/lb VS	Comment
26	4.2	5.04	
37	4.5	5.40	
44	3.5	4.2	
54	4.4	5.28	
59	4.6	5.52	
53	5.2	6.20	Basis for Adjustment

* 12-15 Days Retention Time

BASELINE METHANE YIELD RANGE = 5.0-6.2 SCF/LB VS ADDED

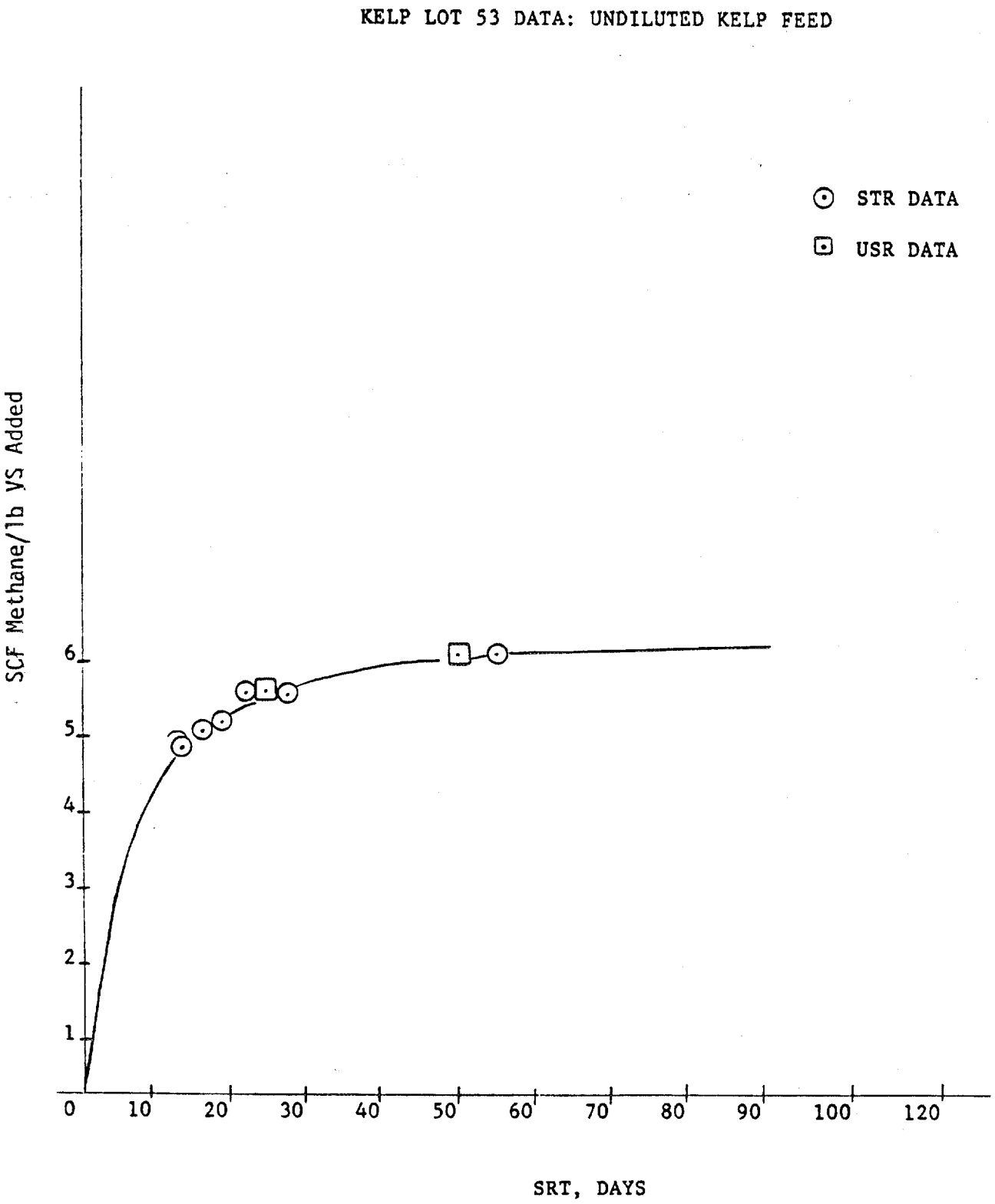


Figure 5.4-5. Methane Yield Versus Retention Time

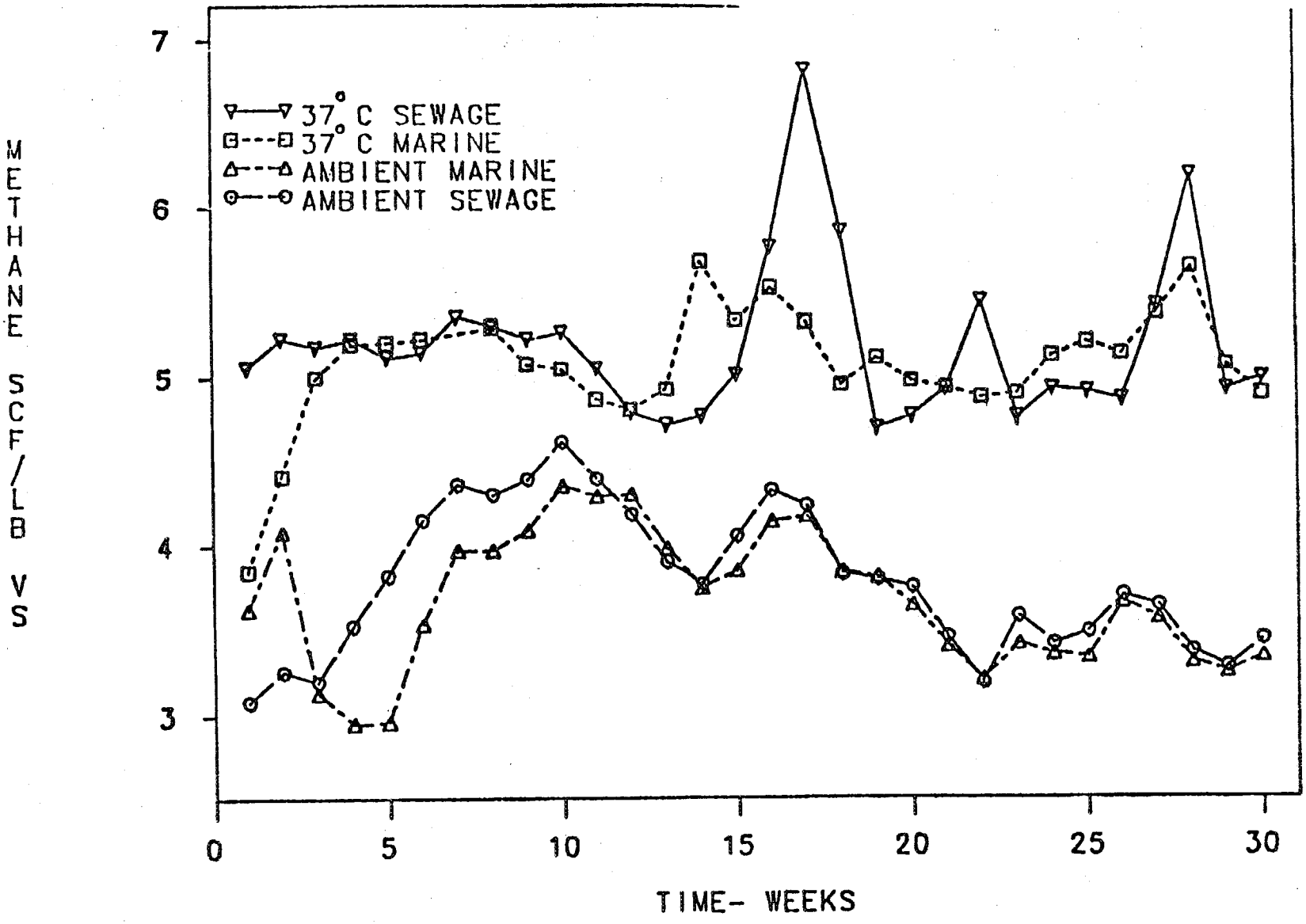


Figure 5.4-6. Temperature/Inoculum Study Results

Methane Yield = 5.0 - 6.2 SCF/LB VS Added

Process Temperature = Mesophilic (33-38°C)

Figure 5.4-5 was developed, Reference 5.4-6, to shown that results from stirred tank and upflow Solids Reactors could be correlated to a common curve using the solids retention time (SRT) as the common parameter of significance. The data of Table 5.4-3 indicate that the yield range noted above is obtained from STR data obtained from diluted kelp at shorter retention time when a correction factor is applied to account for the different flow conditions in the USR and the differences in yield between the diluted and undiluted kelp cases. Figure 5.4-6 shows that significant reductions in yield result if the process is run at ambient temperature. Results from earlier digestion system trade-off studies indicated that more energy is lost in lower gas yield operating the reactor at ambient temperature than is required to heat the feedstock and operate at mesophylic conditions.

Other parameters critical to processing subsystem designs include those defining properties of the digester effluent and gas produced both chemically and physically. Available data were collected and evaluated from GE, IGT, and USDA digestion research programs. In general, sufficient data were available on gas chemistry, except in the critical case of sulphur content where additional measurements were made during 1982. More detailed sulfur-content data were required for a realistic evaluation and costing of the gas cleanup subsystem.

Effluent properties are required both for estimation of candidate reactor concept performance and for definition and evaluation of the post-processing steps, e.g., effluent disposal, potential by-product processes and environmental impact analyses. A large body of data on effluent chemical composition and physical properties was reviewed and summarized. The data base was, in general, adequate, except more refined data were identified as required in three areas:

- Effluent settling rates for reactor design
- Form of nitrogen compounds for ocean disposal
- Properties of components for by-product studies

GE bench scale data, Figure 5.4-7, on effluent settling rates presently comprise the total source of information in this area. Although these data are adequate for first estimates of reactor design requirements, data scaleup to commercial size digester analyses is questionable. The design and performance of digesters are strongly dependent on solids separation rates and their effects on SRT. The

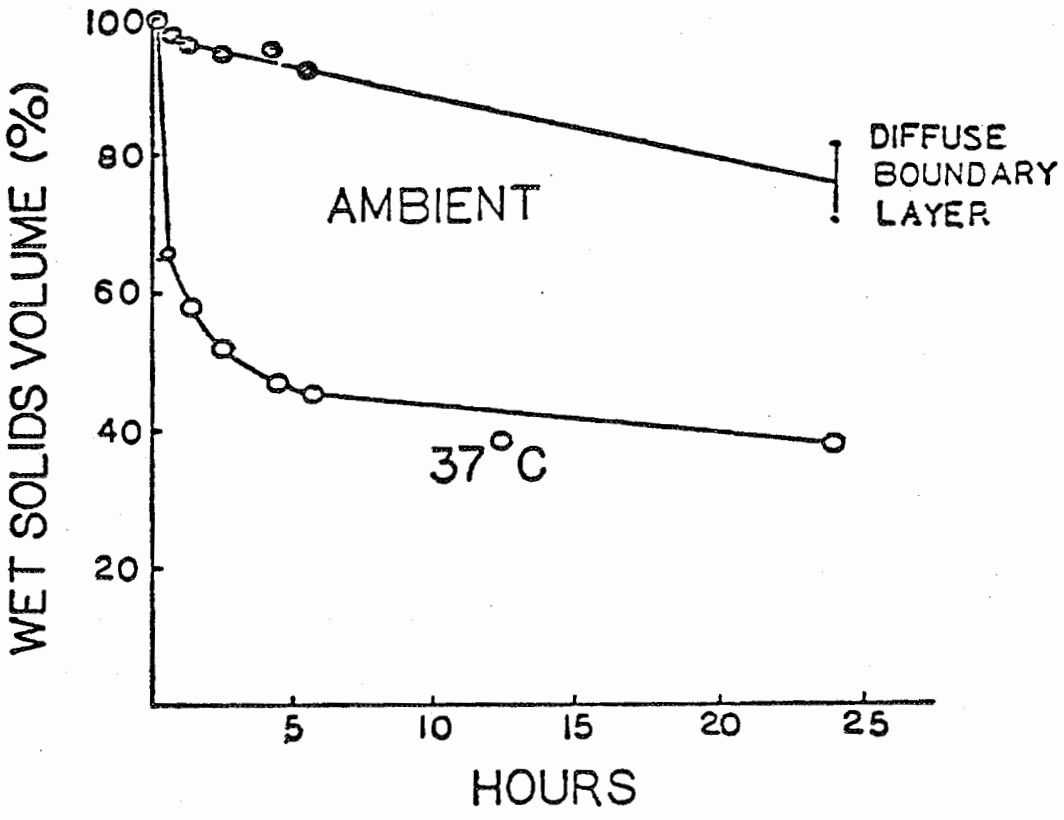


Figure 5.4-7. Batch Settling of Digester Effluent

potential need for effluent recycle systems and/or increased digester volume can have a significant impact on overall system cost. More reliable pilot-scale data on effluent settling and other hydraulic parameters are, therefore, needed. The importance of these parameters is directly linked to the improved gas yields obtained at the high values of SRT.

The digester effluent contains nitrogen compounds which might be available for assimilation by the plants if returned to the farm. The exact form of the nitrogen, e.g., nitrates, nitrites, ammonia, etc., was not known from previous data. Additional testing was conducted by IGT to determine the forms of nitrogen found in the digester effluent and potential changes in these forms which might occur over various storage periods. The results indicated that some of the nitrogen was in the form of dissolved ammonia, a nitrogen form which can be used effectively by the kelp plants as nutrient. IGT also made additional measurements on the sulphur content of the digester product gas. Both the nitrogen and sulfur content results by IGT are documented in Reference 5.4-7.

5.4.3 SITE STUDY AND ENVIRONMENTAL CONDITIONS

Site studies were restricted to those southern California coastal locations identified in the study ground rules, Section 5.4.1. Consistent with the objective of developing system concepts which were, to the maximum extent possible, within the present state-of-the-art, candidate farm sites were constrained to those areas where Macrocystis is frequently found in natural beds. The priority-choice locations are those where natural beds appear to grow consistently and reliably. Figure 5.4-8 shows the approximate distribution of existing natural beds along the California coast from Pt. Conception to the Mexican border. As noted earlier, the depth range of natural kelp beds (Section 5.4.2.1) varies from approximately 25 feet depth on the inner edge to 60 feet depth on the outer edge. As seen in the figure, the largest concentration of natural kelp, approximately 66 percent of existing canopy, is located in the area between Pt. Conception and Santa Barbara; a region which is well protected by the Channel Islands and which gets significant amounts of nutrients from natural upwelling. This area also is that from which the largest commercial harvests have been obtained to date. The kelp population is this region is comprised primarily of Macrocystis angustifolia. The second most prolific kelp production area is located in the southern area between San Clemente and San Diego, an area which again receives considerable amounts of naturally upwelled nutrients but is not as

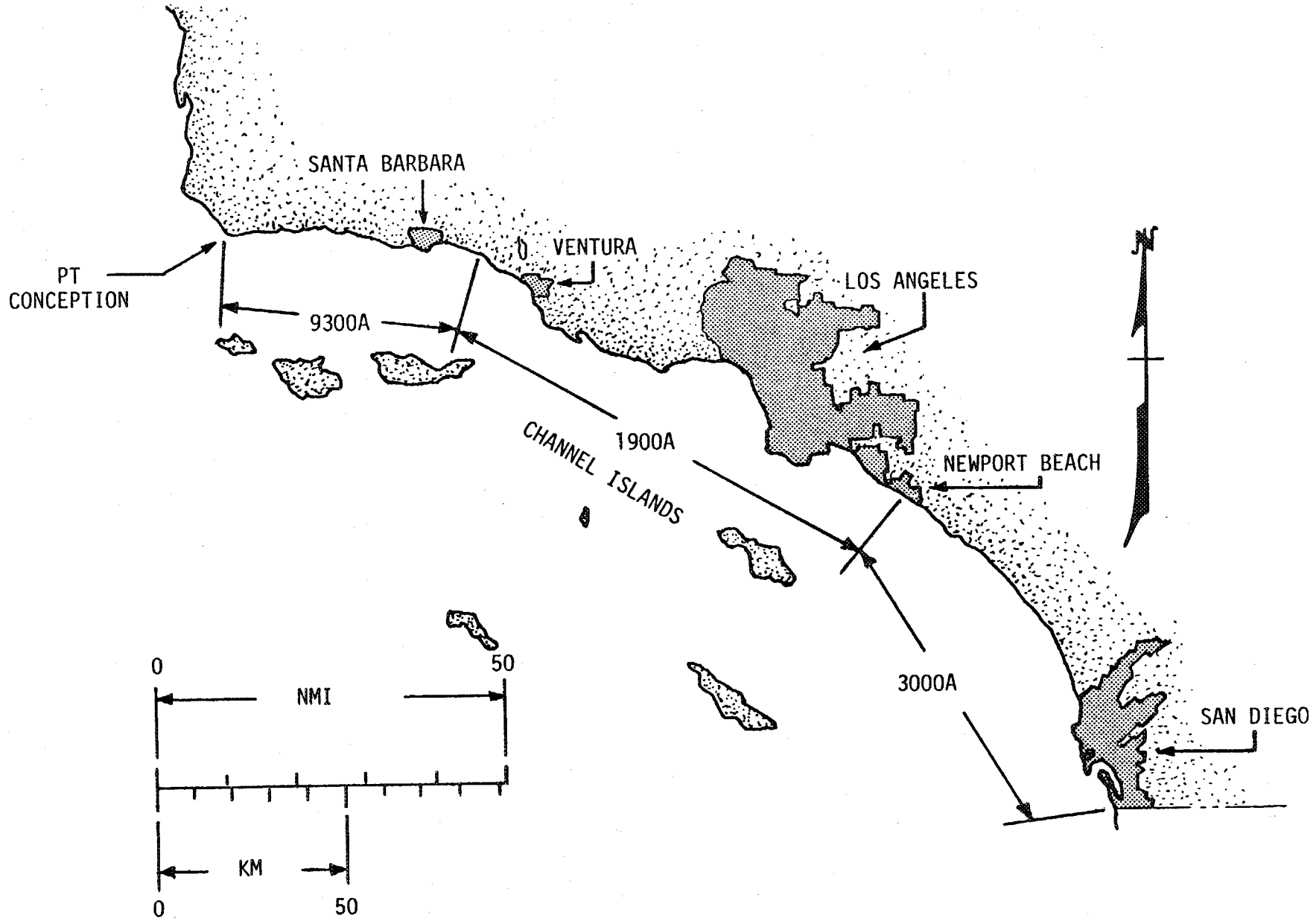


Figure 5.4-8. Mainland Southern California Natural Kelp Beds

well protected from open ocean storms. The area between Santa Barbara and San Clemente is not presently heavily populated with kelp beds although a large natural bed formerly existed off the Los Angeles area at Palos Verdes and, at present, appears to be re-establishing itself. A large area off the Oxnard-Ventura area was found to support very little natural kelp.

The reasons for lack of growth in some areas of the region are not fully understood by biologists, but several potential growth-limiting conditions were identified and were avoided in site selection criteria for the system study. Aside from the obvious reasons of lack of natural nutrients and/or violent mechanical damage due to direct exposure to extreme sea conditions during storms, a potentially prohibitive growth-inhibiting condition may exist in areas where heavy siltation results in high turbidity, reduced light levels at the holdfast and basal sections of the plant, and where the lower parts of plants, particularly young juveniles, could be completely covered by siltation. It is believed that the apparent 60 foot depth limitation on the outer edge of coastal natural beds is due to light penetration limitations, since beds near offshore islands, where water turbidity is much less, are found to grow past the 60 foot depth contour. Siltation problems can occur in areas proximate to large man-made outfalls and natural river outlets. The former, however, will probably not present a problem during the period anticipated for farm deployments due to tightening environmental control requirements and regulations.

On the basis of these considerations, a set of farm site selection guidelines were defined:

a. Kelp presence or previous history of kelp growth.

b. Water depths nearshore 25 to 100 feet where depths greater than 60 feet require off-bottom planting substrate. The 100 foot maximum is somewhat arbitrary and is based primarily on study results which indicate moored substrate cost, at present state-of-the-art, will probably become prohibitive for depths in excess of 100 feet.

c. Frequent occurrence of natural nutrients either from ocean upwelling or runoff if the latter does not create a siltation problem.

d. Sheltered from direct open ocean storm events.

e. Water quality and clarity to be equal to or better than those of average coastal water.

f. Avoid siltation outfalls, either manmade or natural.

g. Locate outside shipping lanes and recreational zones.

h. Potential for shore site access.

Studies were conducted to determine the amount of area potentially available for farm siting. Figure 5.4-9 shows the distribution of total ocean coastal area available in three depth ranges from 25 foot to 100 foot depth. The total area in this depth range along the entire coast from Pt. Conception to the Mexican border is 240,000 acres. Of this area, 14,000 acres out of a total available 100,000 acres in the depth range between 25 feet and 60 feet presently contain kelp beds. Historical records indicate that around 1900 as much as 50,000 acres or 50 percent of this available depth-acceptable area was covered with natural kelp beds. These records indicate that the beds along the northern end of the area of present interest have been quite stable while the beds south of Ventura/Oxnard have tended to be more time-variable and to have decreased in overall area coverage. The three depth ranges in Figure 5.4-9 are associated with different substrate concepts described in Section 5.4.4.3.

Three sites were selected and prioritized for recommendation to The Ralph M. Parsons Company as candidate ocean farm sites. The first two selections were based on criteria listed above and evaluation of available information on the ocean environment. The primary parameter considered was the presence and density of natural kelp beds. The third site was identified as an area of large potential growing area, but one where no significant kelp now exists. It was selected as a location where, should future research permit establishment of kelp beds, large additional farm areas would be available in the proper depth range.

First Choice: Pt. Conception/Santa Barbara Area

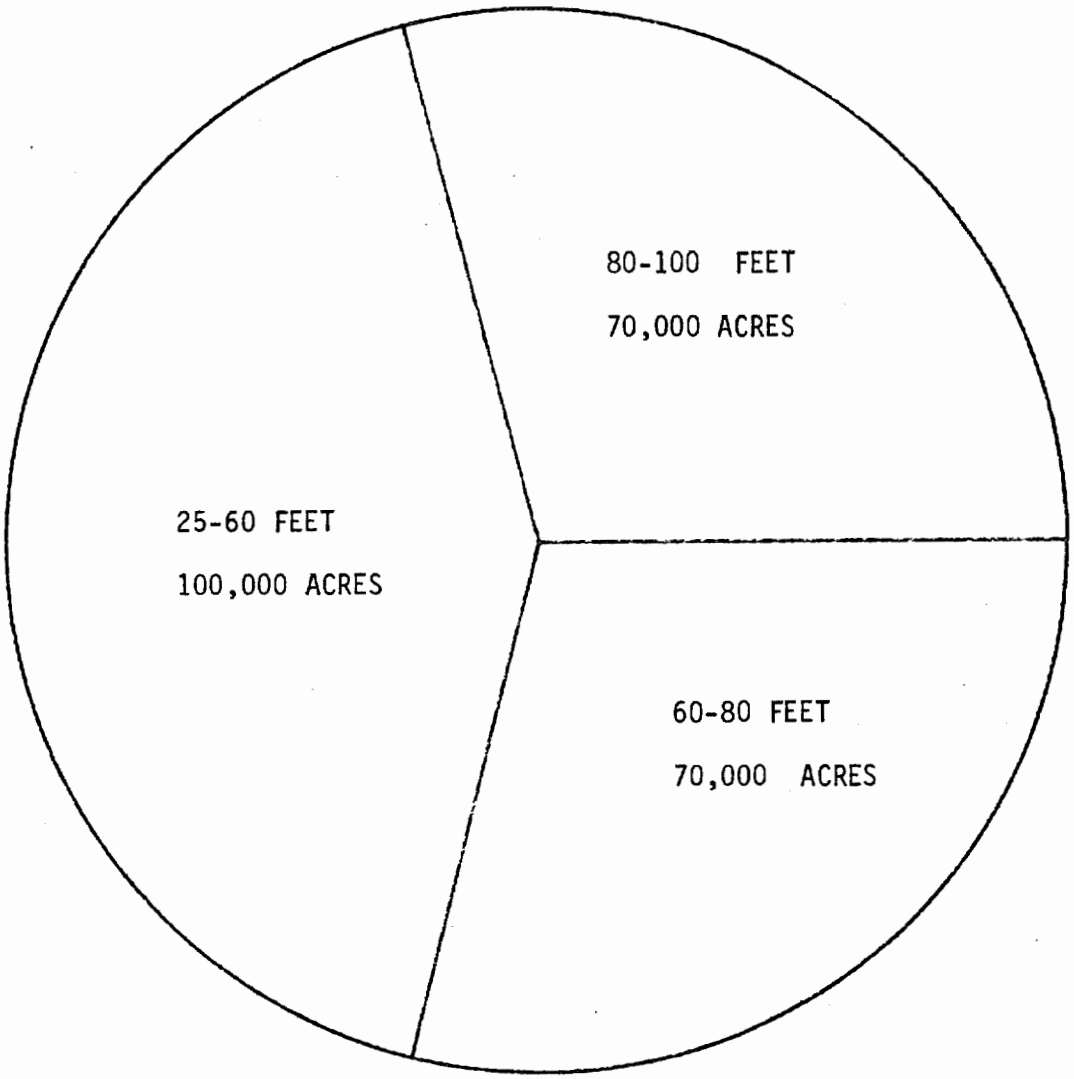
Abundant natural beds with record of large commercial harvest, frequent upwelling with natural nutrients, generally well protected for severe storm activity by Channel Islands.

Second Choice: San Diego County Area

Fairly abundant natural beds with record of good harvest history, frequent upwelling of natural nutrients, only limited protection from offshore islands.

Third Choice: Ventura County Area

No significant kelp presence but large coastal area in depth range of interest. Contingency site if research advances permit effective kelp growth in area.



Total Area 25-100 Ft Depth = 240,000 Acres
Current Kelp Beds = 14,000 Acres
Historical Kelp Beds = 50,000 Acres

Figure 5.4-9. Potential Acreage of Southern California Coastal Area

All of the sites noted would permit relatively easy access to, and land availability for, a shoreside processing plant of the size envisioned for the system concepts of the present study.

A survey of available nearshore oceanographic data was made to establish environmental design requirements for the farm harvest and transport subsystems. Although a large body of data is available for depths greater than 300-600 feet, information for nearshore sites with depths in the range of present interest were not easily available, and in cases where measurements were available, the shallow-water data were extremely site specific since the local shoreline and bottom topography can strongly affect surface wave and current conditions. In the initial studies of 1982, design environmental conditions for shallow conditions were estimated to be approximately the same as for larger depths further offshore. Longshore design maximum currents were conservatively estimated at 2 kts while in lieu of more specific data, maximum design storm wave conditions were estimated to be 20 foot waves with 20 second period. This wave condition would result in a maximum surge velocity of approximately 8.3 fps in the vicinity of the structure and submerged kelp canopy 5 feet off the bottom for average depths of about 40 feet.

Harvesting operations may also be curtailed by sea conditions. Commercial operators have indicated that significant wave heights of 2 feet or greater will prevent safe, effective harvesting of the kelp canopy. Estimates based on sea data available in early 1982 indicated that this limitation would permit a total of 300 days x 10 hrs/day = 3000 hours of annual harvest time for the nearshore farm concepts being considered.

This information in addition to definition of locating of shipping lanes, outfall sites and other pertinent data relative to both ocean and land sites were published in Reference 5.4-1. Toward the latter part of 1982, a new source of more detailed nearshore oceanographic data became available, and the earlier oceanographic information was reviewed and updated in Reference 5.4-8. The new oceanographic data were acquired from various state and federal agencies that collect, reduce and analyze data from a series of nearshore sensors along the entire California coast. Data were also included from two private sources. Data directly applicable to the Pt. Conception first-choice site are included from an environmental impact study at Little Cojo Bay. In this case, several wave conditions were selected from the data. Computer analyses were then conducted to

assess the maximum design water velocities as a function of depth for several cases. The results indicated that the maximum design wave condition for future studies should be updated to waves with 18-20 foot height but periods reduced to 11 seconds. The maximum water velocity at 5 feet off the bottom would be increased from the original 8.3 fps value to 9.5 fps. Maximum conditions at other southern California coastal sites were not updated. The original definition of available harvest time of 3000 hours per year (seas less than 2 feet significant wave height) was confirmed, however, for both the northern region and the second-choice site off San Diego County.

5.4.4 SYSTEM CONCEPT DEFINITIONS

The ground rules, data base and requirements discussed above were employed in preliminary engineering trade-off studies to develop a recommended baseline system concept, subsystem concepts and specifications, and preliminary estimates of system performance and cost. The preliminary concept was updated as new results and information became available over the year and was presented to The Ralph M. Parsons Company as a starting point for their more detailed costing and economic studies.

5.4.4.1 Overall System Concept and Functional Requirements

A system functional block diagram was developed as the first stage in the system concept definition process. Figure 5.4-10 illustrates this procedure where the highest level function, i.e., "Produce Gas from Macrocystis", is identified at the top of the functional block diagram. Each higher level function is then successively broken down into lower level functions and/or operations until the level is reached where the identification of alternative candidate operations or specific equipment is possible. Succeeding levels then represent more detailed definition of subsystem functions, concepts, and components which can then be traded off to develop an optimized overall system concept after candiate subsystem concepts and functions are defined.

The system requirements were evaluated within the ground rules and constraints discussed earlier and a baseline system concept was defined. A system block diagram is shown in Figure 5.4-11 where the various subsystems comprising the overall system are identified. In addition to study ground rules and constraints discussed in Section 5.4.1, it is necessary to specify other system/subsystem parameters either on the basis of the data and requirements discussed in Sections 5.4.2 and 5.4.3 or using some other criteria in order to scope the size (or range

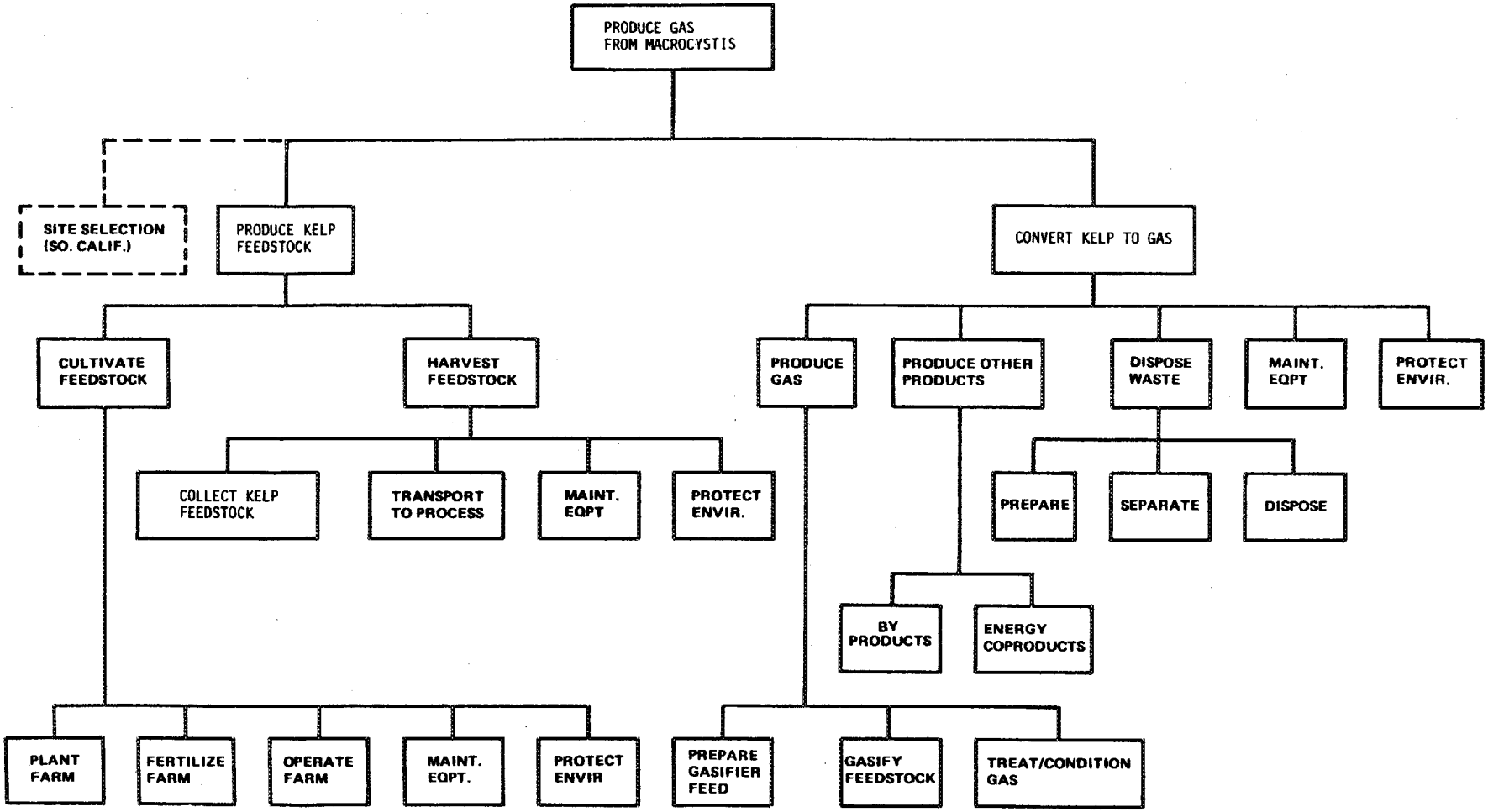


Figure 5.4-10. Nearshore System Functional Requirements

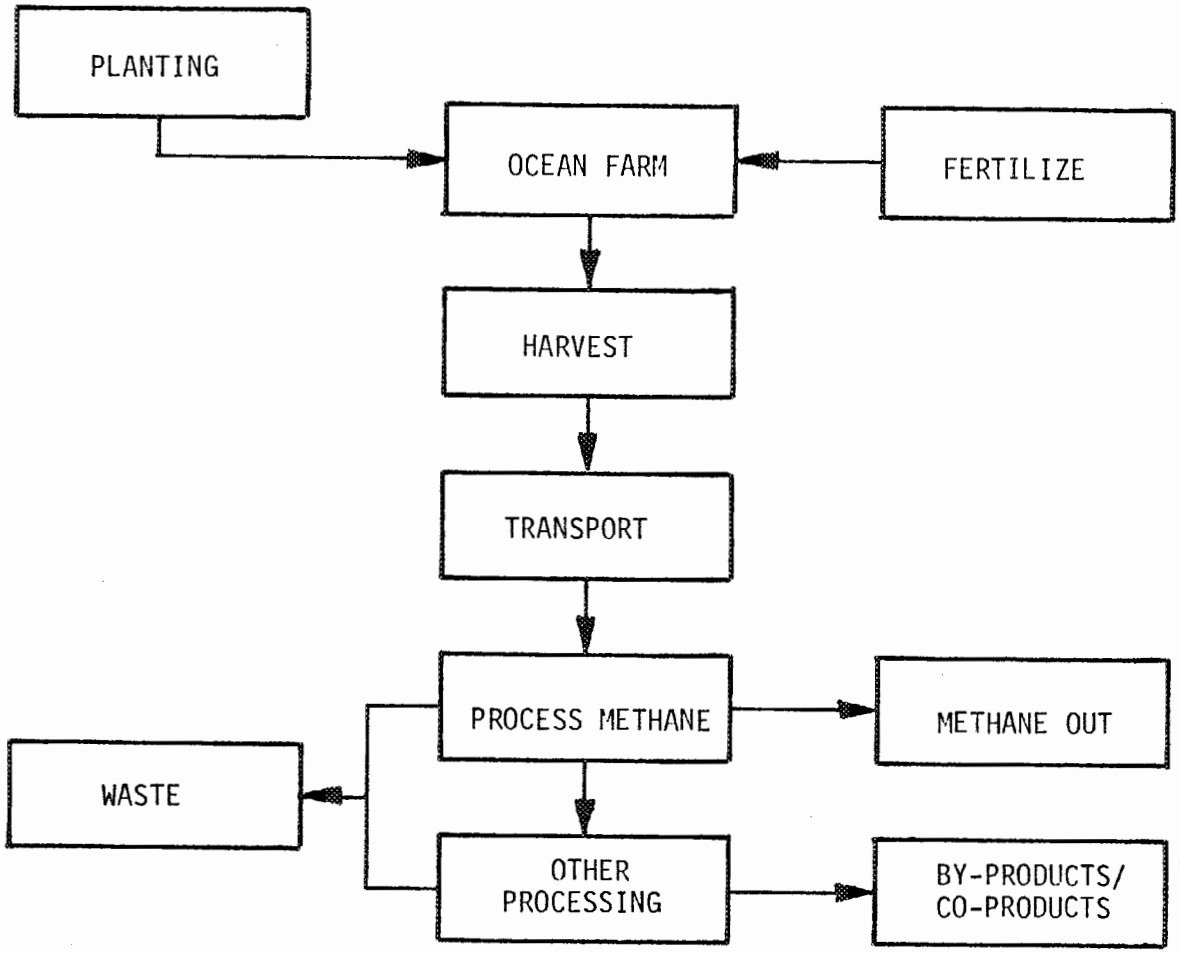


Figure 5.4-11. System Concept

of candiate sizes) of the overall system so that a preliminary point design or baseline can be developed from which sensitivities and comparisons can be made. The remaining parameter which has not been discussed but is crucial in defining and evaluating the baseline concept is the size of the system, either in terms of gas production capacity or alternatively, ocean farm area. Production capacity was selected since this is probably a more meaningful parameter which can be compared with other SNG concepts, market requirements, etc. A baseline gas production capacity of 3 MMCFD was selected for this study somewhat arbitrarily. This size was felt to be sufficiently large to satisfy a reasonable percentage of local demand for a "typical" southern California city yet small enough to require only a reasonably sized ocean farm area. It was intended that the sensitivity studies conducted by The Ralph M. Parsons Company should vary the size of the system roughly from a minimum 0.5 MMCFD up to maximum gas production capacities approaching 15-20 MMCFD in order to determine scale effects and to examine whether gas cost can be minimized within this range of gas capacities.

In order to retain the state-of-the-art system concept approach, the baseline farm was initially assumed to be developed by expanding and increasing the density of an existing natural bed, although the utilization of the genetically defined "high-production" plants described in Section 5.4.2.1 may make it necessary to plant an entire farm. Three system "point designs" were defined for analysis during the year. In general, all three basic system concepts are identical with the differences being caused by different assumed values of farm yield and plant anchoring requirements.

The general concepts and functions of the various subsystems of the baseline system are defined as follows:

a. Planting Subsystem

   Extend Macrocystis natural bed with rope-cultured juveniles to provide initial crop for harvest.

   Maximum advantage should be taken of existing plants in natural bed if possible.

b. Farm Structure Subsystem

   Provide substate at maximum 60 foot depth for plant attachment, and provide devices for crop protecton and maintenance.

c. Fertilization Subsystem

Provide and distribute digester effluent and commercial fertilizer to supplement natural nutrients as required.

d. Harvest/Transport Subsystem

Cut and collect kelp canopy at 1 meter depth and transport/transfer to the gas production subystem.

e. Gas Production Subsytem

Convert Macrocystis feedstock to methane by anaerobic digestion, clean up gas for pipeline input, dispose of effluents by return to farm (harvest/transport boats).

f. By-Product/Co-Product Subsystem

Produce other products compatible with primary system function of SNG production.

The quantitative assumptions and parameters of the initial baseline system concept are summarized in Table 5.4-4 along with the range of parameters to be covered in sensitivity studies where appropriate.

The system parameters defined above were employed in a preliminary GE system engineering and economics study to develop more detailed subsystem descriptions and to estimate capital and operating costs associated with various subsystems and components. These results were then used in an iterative manner, along with new data and information as it became available, to upgrade and improve the concepts which were finally subjected to detailed study by The Ralph M. Parsons Company.

The following sections describe the subsystem concepts developed for the baseline. The functional concepts, interfaces and component definitions were developed over the first six months of 1982 during a series of interactive meetings involving engineers, biologists and systems analysts from all Marine Biomass program organizations including GE, CIT, NMI, IGT and GRI. The quantitative detail of subsystem functional and interface requirements and specifications are defined in detail in Reference 5.4-1 and will not be repeated here. The following discussions will describe the general features of the baseline subsystems and discuss some of the major reasons for selection of the chosen approach.

TABLE 5.4-4. SUMMARY OF GE BASELINE SYSTEM CONCEPT

- Located between Pt. Conception and San Diego

- Enhanced Natural Bed

  Inplanting to increase density
  Periferal planting to expand overall area

- Supplement natural nutrients in non-upwelling periods

  Assume 9 months natural upwelling
  (Range for Sensitivity Studies: 3-12 months of natural upwelling.

- System Gas Production = 3 MMCFD Methane

  (Range for Sensitivity Studies: 0.5-20 MMCFD Methane)

- Crop Yield = 7.5 DAFT/A-Yr

  (Range for Sensitivity Studies: 5-45 DAFT/A-Yr)

- Planting Density = 1000 Plants/Acre

  (Range for Sensitivity Studies: 400-1000 Plants/Acre)

- Gas Yield = 5.5 SCF/LB V.S.

  (Range for Sensitivity Studies: 5.0-6.2 SCF/LB V.S.

- Ocean Farm Area = 13,000 Acres (Consistent with gas yield/farm yield/gas production)

5.4.4.2 Planting Subsystem

The function of this subsystem is to provide the plants for establishment of the new farm as required. Several approaches were considered.

- Transplant adult plants
- Culture new plants in laboratories/nurseries
- Culture new plants in natural beds

Preliminary studies indicated that transplanting of adults was not practical from either cost or availability viewpoints. For example, it may require from 8-10 million new plants to establish a baseline farm of 13,000 acres at a density of 1,000 plants per acre even using an existing bed as a base. The decision was made that the new plants should be juveniles transplanted from culture facilities in natural beds, nursery beds, or nursery facilities. The most cost-effective approach is to transplant cultured juveniles from either nursery beds (genetically defined plants) or natural beds (wild plants). A block diagram showing this concept using natural beds is shown in Figure 5.4-12. The same steps apply to a nursery bed after it has been established except that the initial survey/selection step is not required. In the case of the nursery bed, however, additional initial steps are required to first isolate and cultivate the genetically desirable plants in a laboratory facility and then outplant at appropriate growth stages to establish the mature nursery bed which is then employed to generate the large number of new plants required for the commercial farm. Previous experience in outplanting juveniles to a new area suggests that in order to assure acceptable survivability, the juveniles should not be outplanted to the new farm until they are 2 to 3 feet in length and that survivability from grazing predators is further enhanced if the new juveniles can be deployed in the immediate vicinity of an existing stand of mature kelp. Growth to mature plants acceptable for first harvest is estimated to require up to 30 months after deployment.

Although cultivation in laboratory facilities could be employed for all new plants, it is suggested that a much more cost-effective and technically acceptable approach, as defined in Figure 5.4-12, is to deploy lengths of culture rope in the mature beds (either natural or nursery beds) where the natural reproductive mechanisms of the plant operating in the natural environment result in satisfactory growth of large numbers of juveniles without the need for expensive shore-based growth facilities. It is anticipated that the NMI test farm and similar facilities to be developed in future phases of the program will provide

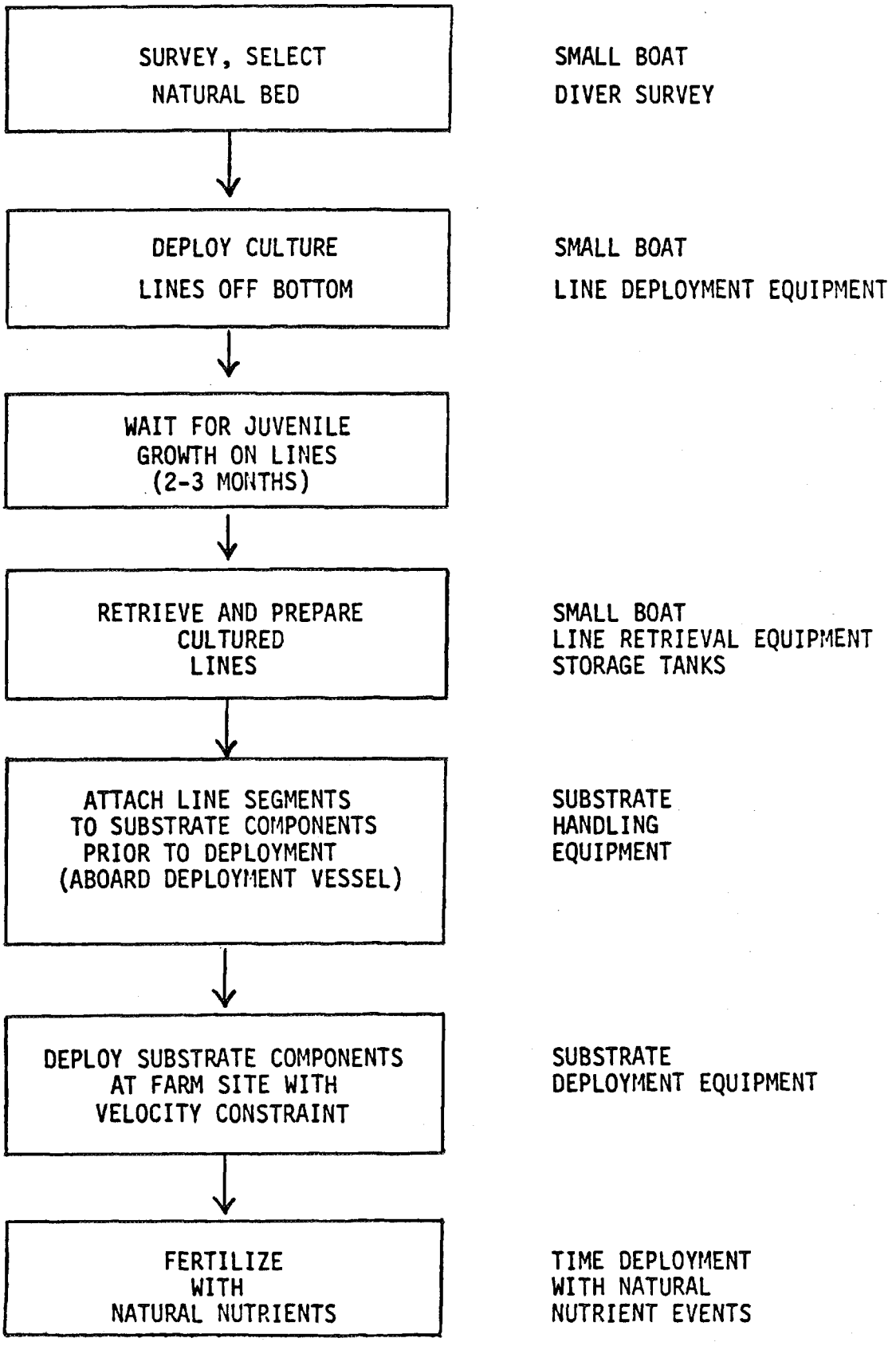


Figure 5.4-12. Baseline Planting Subsystem Concept (Natural Beds)

acceptable culture/nursery beds on a schedule compatible with requirements for a commercial farm planting operation.

After culturing the new plants to the required size, the juvenile-bearing rope segments are cut to appropriate lengths, trimmed to remove all but the healthiest individuals, attached to the substrate components and deployed with the farm structure. Previous experience indicates that the juveniles are sufficiently rugged to survive the required handling and deployment conditions and grow to mature individuals in the natural environment. In this manner, no separate planting operation is required.

The techniques described for initial planting can also be employed for replacement of plants during the operational life of the farm. If severe storm or other damage is sustained which is too extensive to be replaced in a timely manner by natural reproductive processes with in-place plants using the existing farm components as substrate for new replacement plants, additional anchor elements with culture rope segments attached could be deployed.

5.4.4.3 Farm Substrate Subsystem

The substrate subsystem provides the anchors, lines, floats, etc., required to survive and hold the Macrocystis crop in place for the projected 30 year lifetime of the system. The substrate must be compatible with the plants themselves from mechanical, physical, and chemical viewpoints and must also be capable of simple, reliable interfacing with the planting, harvesting, and transport subsystems.

Since the holdfast depth should not exceed 60 feet (for extended periods), the substrate design concept was divided into different configurations for three different water depth ranges between 25 feet minimum and a maximum of 100 feet. Original studies included water depths to 200 feet; however, early results indicated that substrate costs would probably become excessive for any significant farm area to be located deeper than approximately 100 feet. Indeed, from a cost viewpoint, significant engineering creativity and design optimization will be required for the water depths between 80 and 100 feet since costs, even in this range, may be very high.

The three ranges were chosen on the basis of the substrate complexity required to maintain the plants with holdfasts at 60 ft depth or shallower in calm water, and to keep the plants safely in place during worst-case storm conditions. The plant buoyancy and drag characteristics were assumed as defined in Section

5.4.2.2. On the basis of the site studies, Section 5.4.3, the worst case storm design conditions were assumed as:

Waves:

Direction	=	Normal to shoreline
Height	=	20 Feet
Period	=	20 Second
Horizontal Surge Velocity	=	8.5 fps
Vertical Surge Velocity	=	Negligible

Steady Current:

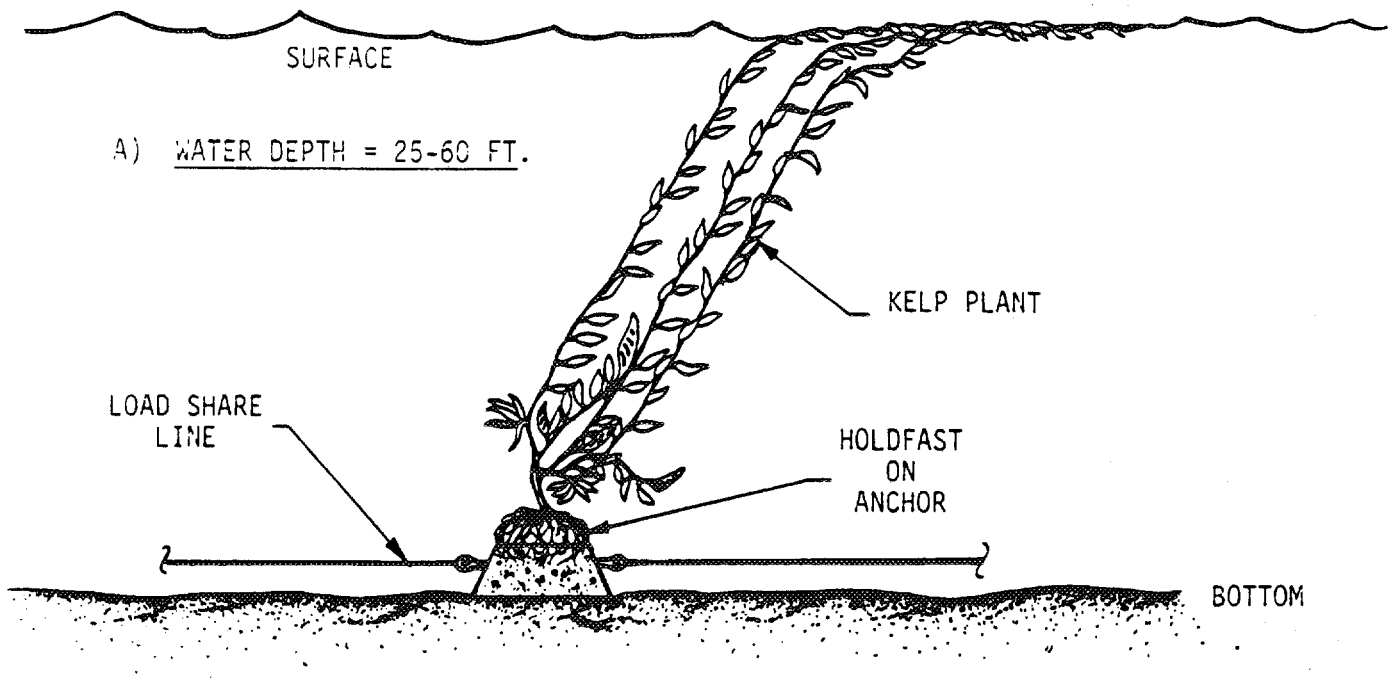
Direction:	=	Parallel to shoreline
Upstream Max. Velocity	=	2.0 kts
Velocity at Upstream Farm Edge	=	1.0 Kts
Vel. Inside Farm	=	0.5 kts

The three substrate/depth concepts are sketched in Figures 5.4-13, 5.4-14, and 5.4-16, and discussed below.

Depth 25 Feet-60 Feet

Plants are attached directly to anchors on the bottom similar to conditions found in natural beds, Figure 5.4-13a. Initial engineering studies assumed single, independent anchors for all plants and also assumed that the anchor would be required to provide all of the required plant restraint force, i.e.; zero natural anchoring capability was assumed for the plant itself. Quasi-steady estimates were employed for maximum drag forces, based on the maximum water velocities.

In general, deadweight anchors were assumed to be the most cost-effective and most universally applicable. The anchor wet weight requirement was defined to be two times the horizontal force component to be held plus the vertical lifting force component (i.e., $W_{wet} = 2\ H + V$). Concrete or stone was assumed to be the least expensive anchor material. Anchor weights in excess of 200 pounds (wet weight)/plant were predicted due primarily to the large forces caused by the wave surge velocities. Extended modelling of wave effects, Reference 5.4-4, led to the concept of employing load sharing lines between individual anchors in the wave propagation direction since different plants located at different phase points in the waveform will be subjected to different surge velocity magnitudes and directions, such that wave-force cancellations between plants will result in significantly reduced anchor weight requirements. This concept is illustrated in



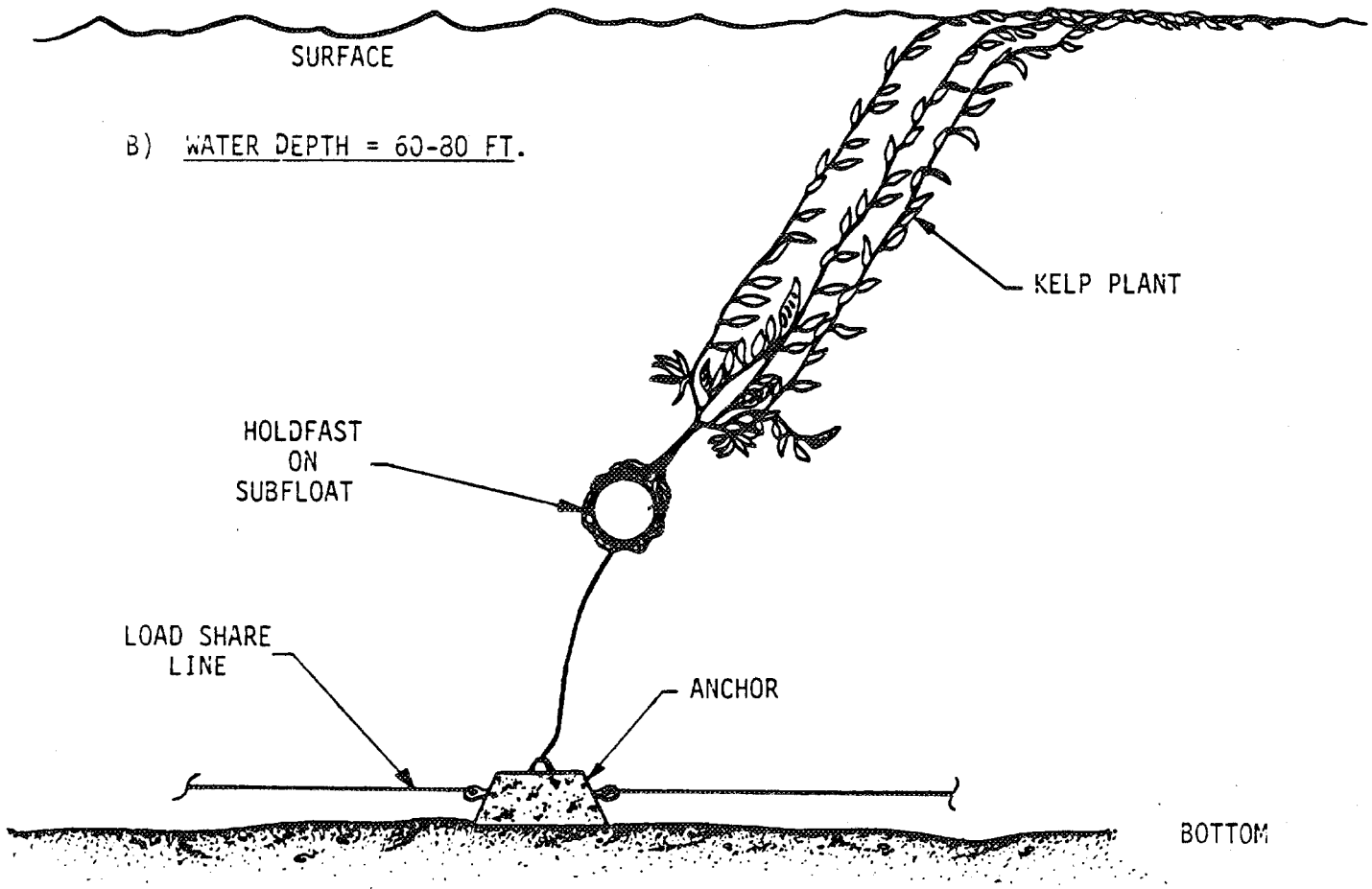


Figure 5.4-13. Farm Substrate Concepts (Water Depth 25 to 60 Feet/60 to 80 Feet)

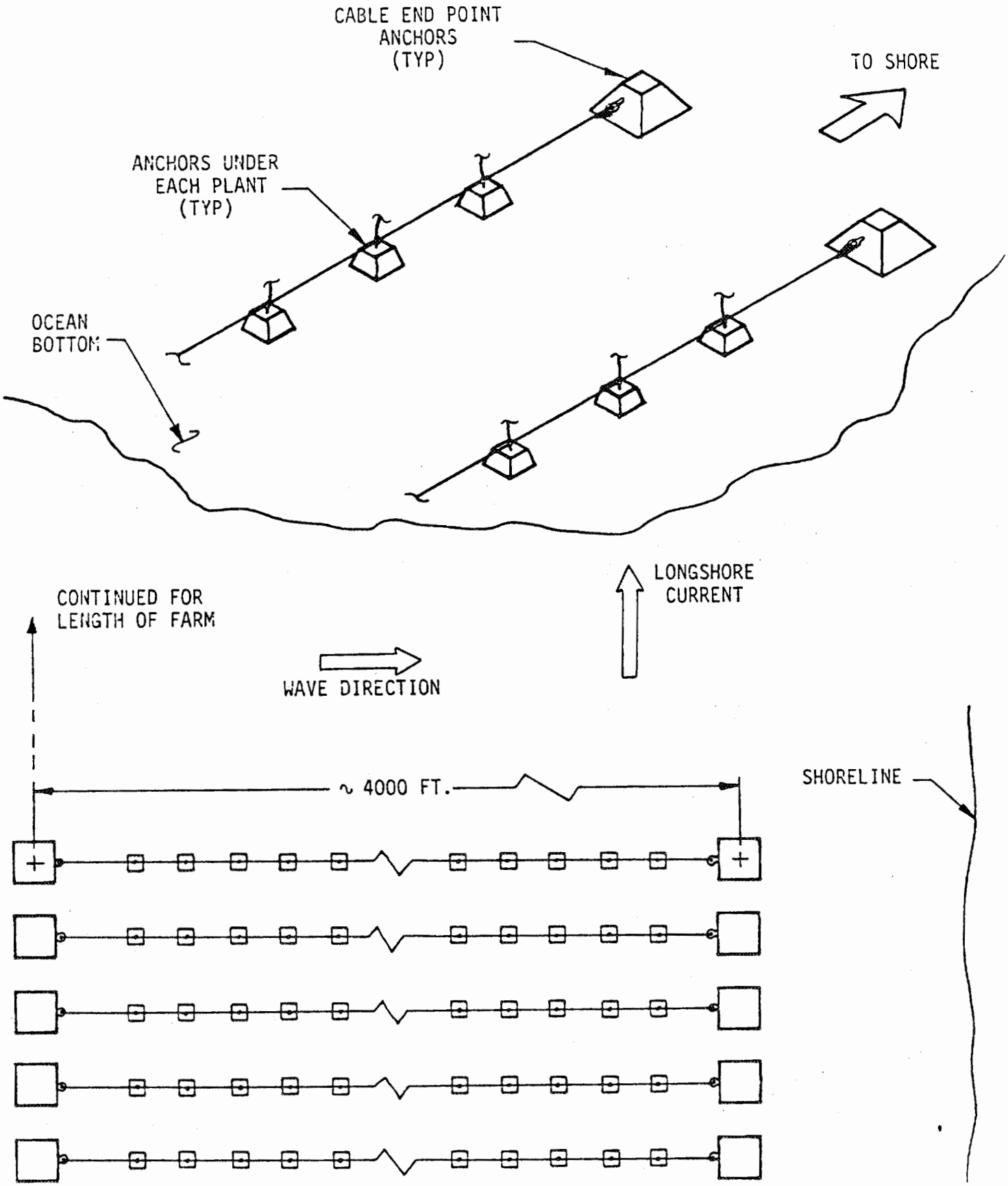


Figure 5.4-14. Anchor-Cable Substrate System Concept

Figure 5.4-14. In addition, this concept permits potentially more efficient utilization of anchor hardware in that large concrete clumps or other anchoring devices can be placed at inshore and offshore ends of each "planting line" to take out the net uncancelled wave forces acting on all the plants along the planting line. In the extreme case, the individual plant anchors would only be required to react the buoyancy and longshore steady current loads which are small compared to wave surge loads. For the GE baseline farm (7.5 DAFT/A-Yr, 1000 plants/acre, 1,500 frond feet plant size) with an assumed farm width normal to the shoreline of approximately 4000 feet (615 plants per planting line), the average total wet anchor weight per plant is approximately 40 pounds, assuming dead-weight clump anchors both for individual plants (16 pounds wet) and for the two wave force anchors (8000 pounds wet) at either end of the planting line.

Additional studies were conducted, Reference 5.4-4 to estimate potential reductions in anchor requirements due to departures from the extremely conservative assumptions of the quasi-steady maximum loads analyses noted above. Since no kelp dynamics analysis techniques are presently available, the kelp plant was modelled as a pendulum driven by buoyancy and hydrodynamic forces to quantitatively estimate reductions in mooring loads due to phase lags between deflections and forces and the probable inability of the kelp plant to follow wave oscillatory motion. The case of individual plant anchors was again assumed so that the anchor is required to react buoyancy, longshore current and wave velocity forces. Results are presented in Figure 5.4-15 as a function of wave height. The upper curve again represents the most conservative quasi-steady maximum load assumption while the lower curve indicates the anchor weight reductions which might actually be allowable due to reduction in anchor loads caused by kelp plant dynamics in the oscillating wave field. Note that dynamics effects alone may bring independent anchor wet weight down to approximately 60 pounds. Further detailed analyses and supporting ocean test data are needed to verify these preliminary dynamics models and loads estimates. Such an analysis/test plan was generated and presented for implementation late in the year.

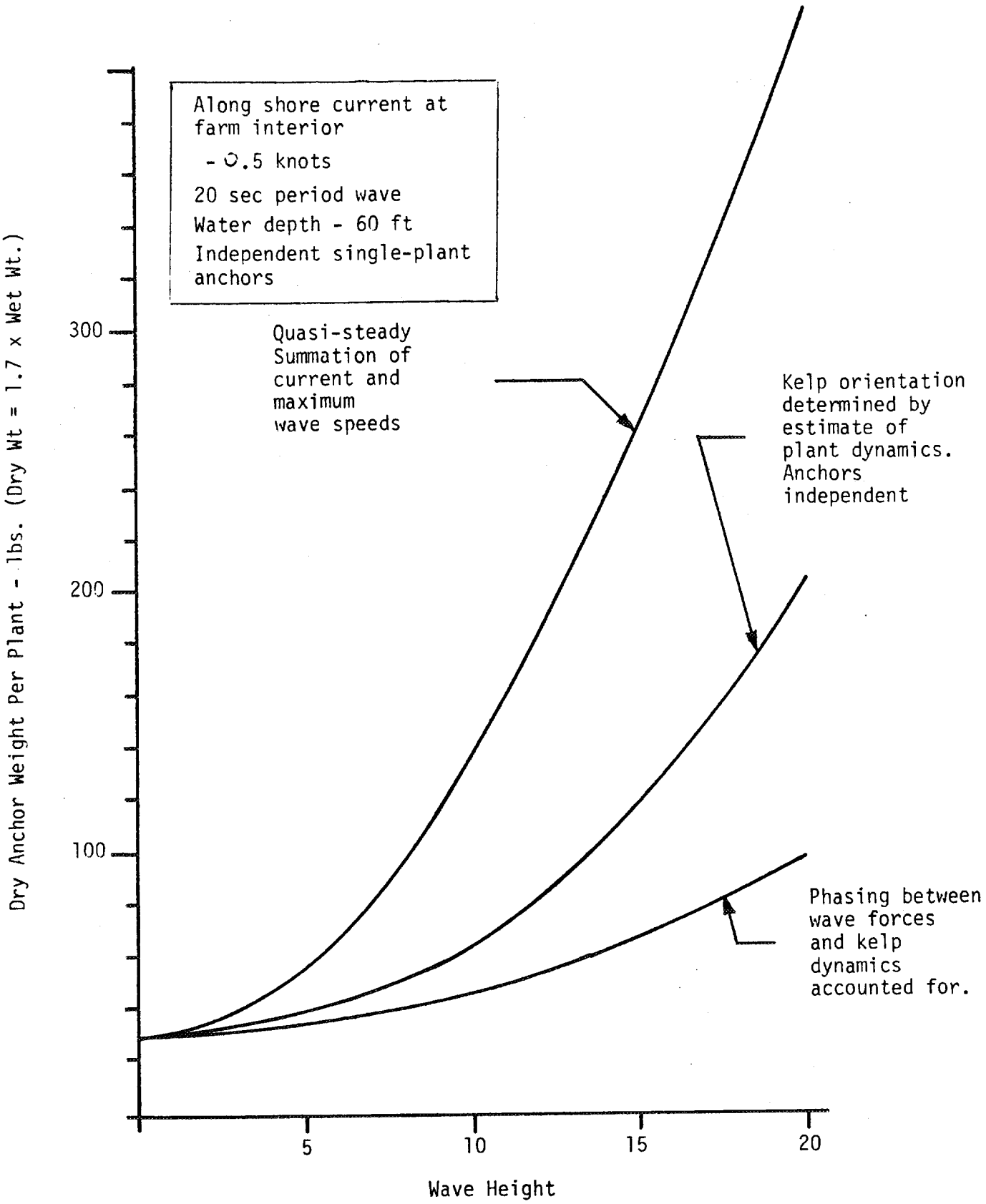


Figure 5.4-15. Kelp Dynamics Effects on Anchor Sizing

It should be noted that the kelp dynamics effects discussed above would also reduce the anchor requirements for the concept employing wave-load sharing along the planting lines. This combined case is significantly more complex than either case taken individually and was not analyzed. In view of kelp dynamics effects, however, it should be possible to reduce average wet anchor weight for the cable-connected anchor system to well below the 40 pounds indicated above which is also the value assumed for the GE baseline system concept.

As already discussed in Section 5.4.2.2 and Reference 5.4-3, further reductions in anchor weight (and cost) for the on-bottom planting concept are possible when the self-anchoring capability of the Macrocystis plant itself is considered. To date, this phenomenon has been quantitatively measured only for the Macrocystis angustifolia variety which can be used for all bottom planting regions in the Santa Barbara - Pt. Conception area. Further investigation is required to determine if angustifolia can be used reliably for bottom-planted farm area in the more southerly coastal regions or if the Macrocystis pyrifera variety is also capable of providing a significant portion of its anchoring requirement. It is presently assumed that all bottom-planted crop can be comprised of Macrocystis angustifolia to take maximum advantage of its demonstrated tearout resistance (Reference 5.4-5). The GE baseline concept recommendation was therefore updated for the final R.M. Parsons Company study to incorporate consideration of the smaller anchoring requirements. The on-bottom anchor requirements for the three recommended cases are:

Case	Wet Anchor Weight	Plant Spacing	Load Share
(1) GE Baseline	40 lb	6.5 ft	Yes
(2) State-of-the-Art	20 lb	10 ft	No
(3) Advanced	5 lb	6.5 ft	No

Depth 60 Feet-80 Feet

In this range, the holdfast must be supported or buoyed up off the bottom to meet the maximum 60 foot holdfast depth requirement of Section 5.4.2.1. Several candidate approaches were considered:

- Tethered submerged buoy/anchor
- Pipes/pilings embedded in bottom
- Pylons standing on bottom

The buoy/anchor concept was chosen primarily on the basis of cost and simplicity of installation. Wave loadings on rigid piling/pylon approaches required incorporation of significant strength and material weight to survive the design conditions with reasonable design margin.

The selected substrate design concept is sketched in Figure 5.4-13b. The concept is similar to the on-bottom case in that each plant is individually tethered from a float/anchor combination as shown in the figure. Loadsharing lines are utilized again to reduce anchor requirements as discussed for the case of the 25 feet - 60 feet depth range. In this case, the anchor weight must be increased sufficiently to negate the buoyancy of the float to which the holdfast is attached and also take out the additional drag of tether and float. The size of the float is designed to provide the net buoyancy required both to support the holdfast wet weight and to prevent tether-to-tether entanglement by restricting the radius of the watch circle of the float to less than the anchor spacing. For the preliminary tradeoff studies, a float with 30 pound net buoyancy was assumed. It was also assumed that only Macrocystis pyrifera will be employed for off-bottom plantings since the large holdfasts of old adult Macrocystis angustifolia would probably require a float too large to be practical from a cost viewpoint. The on-bottom anchor weight reduction possibilities noted earlier for Macrocystis angustifolia are therefore not considered in this case. Potential drag and anchor weight reduction due to dynamics have not been considered for this depth range and could probably again result in significant reductions in anchor weights and substrate costs. The complexities of dynamics modelling of the off-bottom tethered plant requires even further complicated analysis and more sophisticated ocean engineering tests to determine motion characteristics and evaluate potential plant/mooring entanglement problems. A plan to accomplish additional analysis and ocean testing of various off-bottom concepts and parameters was developed and proposed for implementaton in late 1982 and/or early 1983.

Depth 80 Feet-100 Feet (or deeper)

Requirements for plant separation, prevention of entanglement with structure, and reliably maintaining holdfasts at depths of 60 feet or less require a much more complex approach to substrate concepts in this water depth range. Several concepts were considered including configurations incorporating rigid structures, embedded pilings, and flexible grid. A grid concept, Figure 5.4-16 was selected which essentially provides an artificial floor moored above the actual ocean floor

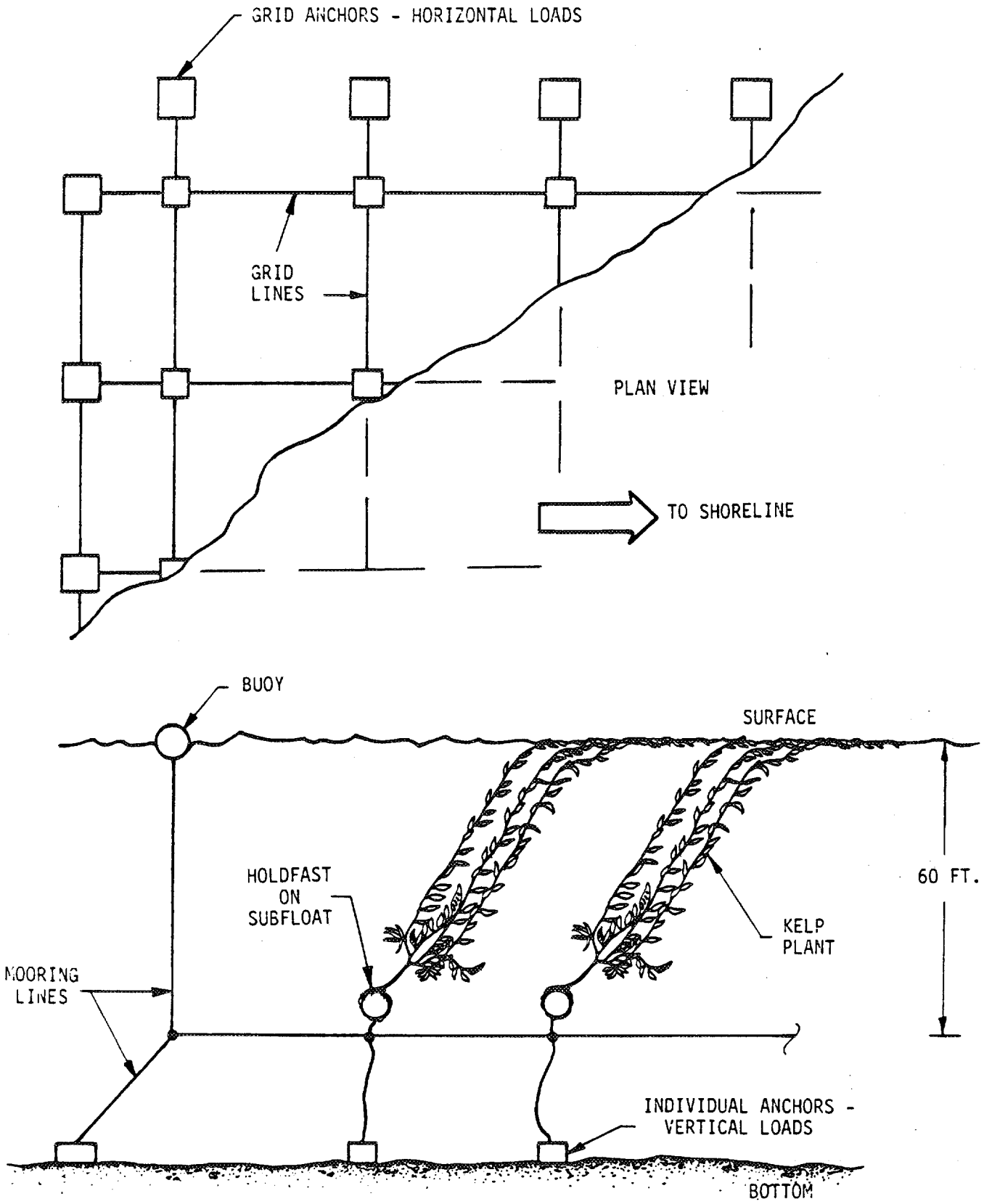


Figure 5.4-16. Deep Farm Substrate Concept (Water Depth 80-100 Feet)

at a depth of 60 feet. The structure is comprised of a 2-D grid stabilized by large anchors and cables in directions both parallel and perpendicular to the shoreline. Small individual clump anchors take out vertical buoyancy loads under each plant-attachment point. All horizontal loads are reacted by the main grid cables and larger peripheral anchors. The individual kelp plants are buoyed up off the cable grid or floats to reduce chances of entanglement with the horizontal members of the cable grid work. Large surface buoys are distributed as required to support the weight of the grid work and to provide the upward forces necessary to limit the dip of the entire structure to acceptable values in design current conditions. Only very limited preliminary analyses were conducted on this concept since early results indicated that without extensive engineering development, analyses and test, which were not compatible with task scope or schedule, conceptual designs employing this approach were too far from the present engineering state-of-the art to fit within the constraints of the present study. In additon, costs estimated from these preliminary studies indicated that substrate costs for this and the other candidate concepts required for water depths greater than about 80 feet would probably be prohibitive on the basis of existing engineering technology. Further development of concepts for these deeper farm areas is deferred for future ocean engineering development tasks.

It should be noted that certain of the types of deep farm substrate concepts which have been rejected above as too costly are employed cost-effectively by the Japanese and Chinese in their commercial seaweed farming operations. The major difficulty with application of their farm concepts to the present kelp-to-methane system study lies in the great difference in the market value of the final product. The oriental farms produce seaweeds for human consumption as food, an extremely high value product when the market value of a ton of kelp sold for food is compared to the market value of a ton of kelp to be converted to SNG and sold with a much lower unit value. The oriental seaweed industry can therefore afford to utilize much more expensive farm substrates than can a commercial SNG production system.

5.4.4.4 Harvest/Transport Subsystem

Initial concept studies indicated that an effective combination of subsystem components could be achieved by providing multifunctional elements to accomplish the functions of harvesting, transportation, fertilizing and digester effluent disposal subsystems. This is feasible since all of these systems, to varying

degree, collect, transport and deliver various types of materials to, from, and within the ocean farm. This section describes the baseline harvest and transport concepts. The further combination with fertilizing and disposal functions is discussed in Section 5.4.4.5 following.

The harvest subsystem must cut the kelp canopy at 1 M depth and collect the material for transfer to the transport subsystem. The transport subsystem carries the harvested material from the farm to the shore terminal with final transfer to the processing plant. In order to achieve high credibility and employ maximum state-of-the-art technology, it was decided to employ the same type of harvest cutting/collecting devices currently in use by the commercial kelp harvesting industry in California. Existing harvesters, however, are multipurpose vessels which in addition to cutting and collecting the feedstock, also transport it to shore terminals located in some cases, more than 100 miles from the harvesting site. The harvest ships therefore also serve the transport function. Current commercial harvesting operations do not incorporate regularly scheduled, frequent harvesting of the well defined, cultivated beds with short transport distances as for the harvest/transport concepts of the present study. Tradeoff studies were conducted for various candidate approaches to individual and combined harvest/transport concepts:

- Multifunction vessels vs simple function vessels
- Harvest whole plant vs canopy only
- Clear harvest vs skip harvest

Although consideration was given to harvest approaches other than cutting the canopy alone, e.g., taking the whole plant or recovering sloughed/broken materials, etc., the baseline was defined as a harvest cut at a depth of 1 M. Other concepts were not felt to employ existing technology while the selected technique is the one employed currently by commercial harvesters.

The selected baseline concept employs single purpose vessels:

- Harvest Cutter Vessel - Remains on farm
- Transport Barge - Collects feedstock from harvester and transports to shore terminal.
- Tugboats - Ferries barges between farm and shore terminal.

The cutter vessels are part of the harvest subsystem only, but the barges serve to collect and transport the harvested material so they can be considered elements of both harvest and transport subsystems. The tugboats are exclusively elements of the transport subsystem and are not required to station-keep the barges during harvest operations. During the period on the farm, the barge is towed and controlled by the cutter vessel. In this manner, each vessel design can be optimized for its most critical mission functions, i.e., low speed cutting for the harvester vessel; high speed transport for the tug boats, and the number of crewmen, and crew costs to perform necessary operations can be minimized. Study results indicated that a return to the multipurpose vessel concept could be favored if the harvest frequency dropped to values of twice annually or less.

After the harvested feedstock is barged to a near-in offshore terminal, it is off-loaded and transported via kelp slurry pipeline to the process plant which is assumed to be located within one mile of the shoreline. The preferred transport method for the kelp after harvest was defined to be slurry pipeline pumping since pipeline and pumping technologies are well developed and can be reliably costed. Based on previous program studies and test results, the baseline concept employs a hammer-mill to chop the harvested kelp fronds on the harvest vessel. No additional water is added since the kelp moisture content is sufficiently high to form a readily pumpable slurry. The chopped feedstock is then pumped into the transfer barge by the harvest vessel and subsequently removed from the barge at the inshore transfer point by pumps at the offshore terminal facility.

The tradeoff study was conducted for the baseline system with 3 MMCFD methane production capacity. For the baseline digester gas yield assumed, this requires a daily kelp harvest/transport capacity of 4000 wet tons/day. It is assumed that the kelp is harvested four times annually based on 1982 NMI test farm experience. The definition of harvest/transport subsystem elements resulting from these preliminary engineering/economics trade-offs are contained in Table 5.4-5.

TABLE 5.4-5. HARVEST/TRANSPORT SUBSYSTEM ELEMENTS

Element	No. Req'd.	Characteristics
Cutter Vessel	4	1.5 Kts, 100 HP, Station Keeps barge, contains kelp chopper, transfer pump.
Transfer Barge	8	450 DWT Capacity, No onboard power
Tow Boat	2	8 Kts, 300 HP, Transfers barges farm to offshore terminal.
Offshore Terminal	1	Located 1/2 mile offshore, pipeline(s) to shore for material transport to/from process plant, contains feedstock transfer pumps.

A schematic diagram of the harvest/transport subsystem elements indicating proposed methods of operation is presented in Figure 5.4-17.

The "skip" harvest technique was selected rather than the "clear" harvest since it was felt that harvest of alternate strips through the farm would enhance light available to the adjacent, unharvested plants thereby resulting in increased biomass productivity and harvest yield. The strip harvest technique also lends itself conveniently to combination of fertilizing and digester effluent disposal functions with the harvest operations as described below.

5.4.4.5 Fertilizer/Digester Effluent Disposal Subsystems

The requirements for fertilization are specified and discussed in Section 5.4.2.1. The baseline approach takes maximum advantage of upwelling of natural nutrients which is assumed to adequately fertilize the farm for nine months of the year. Evaluation of historical data on upwelling events from the Pt. Conception/Santa Barbara coastal area indicates that this is a reasonable assumption for a baseline farm site located in this region. For the remaining three months of the year, nutrients are provided by a combination of purchased chemical fertilizer and digester effluent nitrogen which is transported to the farm and sprayed into the kelp canopy. The amount of chemical fertilizer required depends upon the "fertilizing efficiency" for chemical fertilizer and for digester effluent as discussed in Section 5.4.2.1 where Figure 5.4-3 is provided to define quantities required under various conditions.

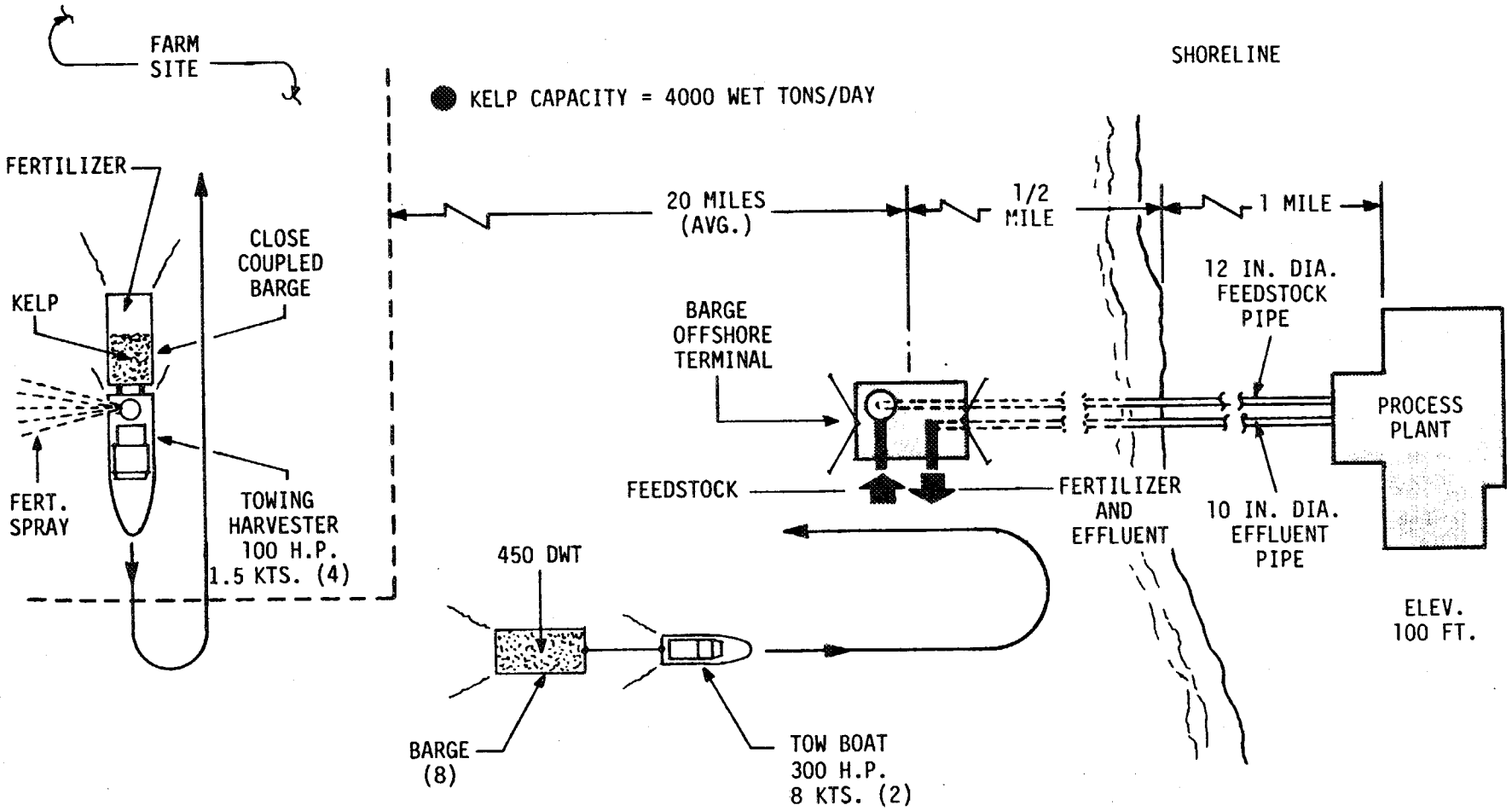


Figure 5.4-17. Baseline Harvest/Transport Concept

The fertilizing subsystem concept combines elements of this subsystem with those of the harvest/transport subsystem. The harvester vessel will be equipped with pumps and spray systems so that the fertilizer, a liquid combination of commercial fertilizer and digester effluent, can be sprayed into adjacent kelp canopy, as required, during the strip harvesting operations. The fertilizer is carried to the farm aboard the compartmented harvest barge and is pumped out as the harvested kelp is loaded into the barge. The fertilizer mixture is prepared ashore at the offshore terminal site and pumped aboard the barges as the harvested kelp is offloaded. Digester effluent (after removal of potential by-product materials) is pumped via pipeline from the process plant site to the barge terminal site.

The digester effluent will be transferred to the farm for ocean disposal during the entire year, even when fertilizing is not required. This technique represents an inexpensive method for disposal of processing plant wastes which might otherwise require additional processing or costs for disposal by other means. It is anticipated that this technique will be environmentally acceptable since no material is returned to the ocean which was not originally harvested from that environment. In addition, the waste will be distributed sufficiently within the farm volume so that no locally significant concentrations of undesirable residues will be permitted to accumulate.

The sketch of Figure 5.4-17 shows the fertilization and effluent disposal functions integrated with the harvest/transport equipment.

5.4.4.6 Gas Production Subsystem

The gas production subsystem incorporates all elements of the system required to generate the primary product, methane, at the conditions specified for input to a gas pipeline. In addition to gas production reactors, then, this subsystem also includes elements for gas cleanup, pressurization if required, and separation or preprocessing of the effluent stream into streams for ocean disposal and for potential input to by-product processes.

The anaerobic digestion process was selected for gasification of the harvested kelp. Based on data discussed in Section 5.4.2.3 and Reference 5.4-1, the parameters summarized in Table 5.4-6 were selected for the reactor process specification. As discussed earlier, these specifications and performance parameters are consistent with available bench-scale data acquired from CSTR and USR testing. The GE baseline reactor was identified as multiple CSTR's with solids recycle since a significant body of engineering data exists to perform

TABLE 5.4-6. REACTOR PROCESS SPECIFICATION

• PROCESS TYPE	ANAEROBIC DIGESTION
• FEEDSTOCK	CHOPPED RAW KELP
• REACTOR TYPE	SERIES CSTR'S WITH SOLIDS RECYCLE CAPABILITY
• TEMPERATURE	MESOPHILIC RANGE, 33-38°C
• SOLIDS RETENTION TIME	50 DAYS
• HYDRAULIC RETENTION TIME	18 DAYS
• ANTICIPATED METHANE YIELD	5.0 TO 6.2 SCF/LB VS

larger scale design studies and costing tradeoffs for this type of reactor using as a basis, cases where other feedstocks were employed. The retention times and gas yields, at least for the bench scale, are compatible with results for either reactor type. The packed-bed reactor was not selected for this preliminary study, since no reliable data were available for reactors of this type operating with kelp or feedstocks similar to chopped kelp.

The elements of the gas production subsystem are shown schematically in the block diagram of Figure 5.4-18. Elements of gas cleanup and potential by-product subsystems are also shown in addition to the interface with fertilizing/effluent disposal subsystem.

Conceptual designs and engineering cost tradeoffs were conducted to define and size system elements and develop preliminary cost estimates for a baseline gas production system with a methane production capability of 3 MMCFD and a kelp feedstock input consistent with the Harvest/Transport Subsystem output of 4000 wet tons per day. Estimates were based on industry-standard cost estimating procedures for concrete tanks and structures, pipelines, pumps and other equipment, and only standard gas cleanup and separation procedures were assumed and costed. A summary of the design characteristics assumed for the major elements of the subsystem is presented in Table 5.4-7.

5.4.4.7 By-Product/Co-Product Preliminary Results

As part of the nearshore system study, an estimate of potential by-product and co-product revenues was made based on the quantity of feedstock required to produce the baseline quantity of 3 MMCFD of methane. Table 5.4-8 summarizes the potential annual production of various candidate products, the total annual revenue possible from each, and the current U.S. market for the product. The total annual revenue from the methane produced at an estimated $10/MMBTU price is included for comparison. The process and marketing costs of the chemical products are not accounted for in the chart and will, of course, reduce the net revenue. It is seen, however, that some of the chemical products have annual revenue potential which might significantly reduce the cost of the methane produced if the by-product/co-product revenue was used to defray cost of gas production. Further evaluation of this potential led to an expanded task in the co-product/by-product area which identified other potential products and processes and which is discussed in detail in Section 5.5.

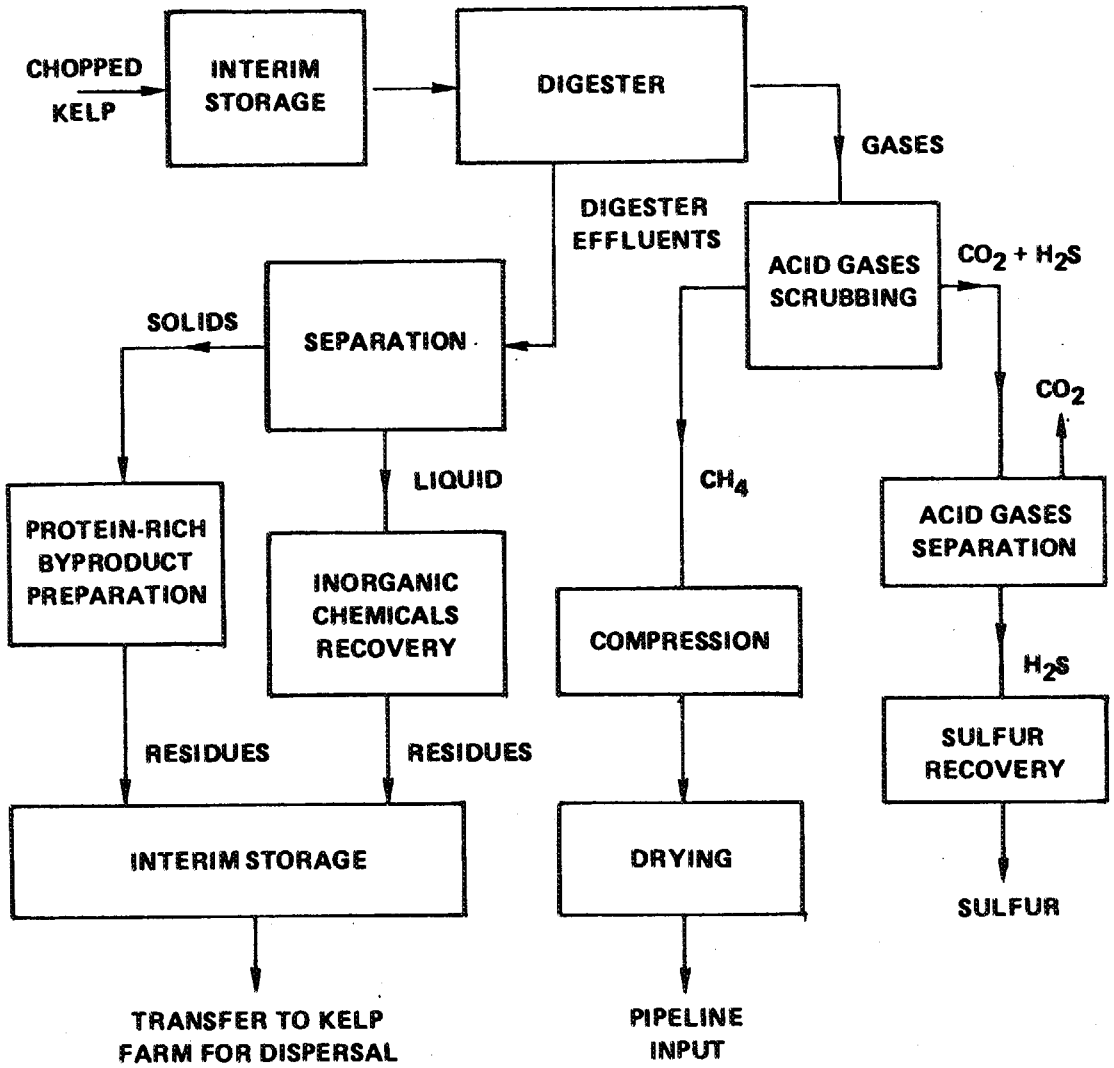


Figure 5.4-18. Process Flow Diagram for Gas Production Subsystem

TABLE 5.4-7. SUMMARY CHARACTERISTICS OF PROCESSING PLANT ELEMENTS

- INCOMING FEEDSTOCK = 4000 T/Day chopped raw kelp slurry

- INCOMING FEEDSTOCK STORAGE
  - Capacity = 3 days' feedstock harvest
  - Volume = 0.4 x 106 cu ft
  - Construction: Covered and lined put

- DIGESTERS
  - 3 CSTR's with solids recycle
  - Combined Volume = 1.75 x 106 Cu Ft
  - Construction: Covered and lined concrete tanks
  - Operating Temperature = 35oC

- GAS SEPARATION SYSTEMS
  - Benfield System
  - Activated hot potassium carbonate absorbent
  - Operating pressure = 75-150 psig
  - Total gas capacity = 6 MMCFD

- GAS COMPRESSION SYSTEMS
  - Atm to 75-150 psig for separation/capacity = 6 MMCFD
  - To psig for methane delivery/capacity = 3 MMCFD

- SULFUR REMOVAL SYSTEMS
  - Stretford Process System
  - Capacity = 300 T/Yr sulfur production

- EFFLUENT STORAGE
  - Capacity = 3 Days' effluent output
  - Volume = 0.4 x 106 Cu Ft
  - Construction: Covered and lined pit

TABLE 5.4-8. CANDIDATE BY-PRODUCTS AND CO-PRODUCTS

- Total Kelp Flow = 100,000 DAFT/YR
- Methane Production = 2.85 MMCFD (Assumes 5% Product Losses)

	Product	Potential Tons/Yr.	U.S. Market, Tons/Yr.	Market Price $/Ton	Potential Revenue MM $/Yr.
1.	Liquid CO_2	45000	2.5 x 106 (1980)	35 (1981)	1.57
2.	KCl	32000	11 x 106 (1979)	80 (1981)	2.56
3.	Protein Feed Supplement	26700	Not Determined	70	1.87
4.	Iodine	400	4500 (1981)	14550 (1981)	5.82
5.	Algin	1300	20000 (1978)	6000 (1981)	7.8
	Methane	22000 (1050 x 106 SCF)			10.5 @ $10/ 1000 SCF

5.4.4.8 Preliminary System Economic Study Results

Preliminary costing and economics estimates were made as part of the GE nearshore system study task. These analyses were done to obtain early estimates of the costs of various subsystems, components, etc., and the potential sensitivity of unit gas costs to variations in design parameters for different parts of the overall system. Preliminary estimates of capital costs, operating costs and unit gas costs were also obtained. Cost and cost-sensitivity information were employed to guide the design concept studies to areas where maximum cost effectiveness could be achieved and to obtain early verification that the overall system concept was capable of producing gas at costs which were within a reasonable range as compared to other sources of SNG. For example, early results employing initial ocean farm substrate concepts indicated that substrate capital costs were excessively high, potentially prohibitive to producing SNG at costs competitive with other approaches. These early conclusions resulted in an intensified effort to develop less costly substrate concepts as discussed in Sections 5.4.2.2 and 5.4.4.3.

The GE baseline concept as described in the preceding sections was employed to develop a complete set of cost and economics results for comparison with The R.M. Parsons Company early results. Tables 5.4-9 and 5.4-10 present the estimated system capital cost breakdown and annual operating and maintenance costs respectively. Costs are in 1982 $.

From Table 5.4-9, approximately one-half of the total 57 MM$ capital cost is associated with the marine farm structure's planting and installation while the remaining half of the capital is needed for the shore-side plant and support elements. Of the total O&M costs in Table 5.4-10, approximately 45 percent is expended on purchase of energy (42 percent for operation of the processing plant, 3 percent for marine fuel). Note also that the total annual operating cost of approximately 10 MM $ is split almost evenly between O&M expenses and capital charges.

The energy budget for the baseline system is presented in Table 5.4-11. Approximately one-third of the amount of energy produced by the system is needed for operations, etc., so that the net energy production is still approximately two-thirds of the gross production.

TABLE 5.4-9. BASELINE SYSTEM CAPITAL COSTS

Subsystem Element	Estimate Millions 1982 $
Substrate	18.1
Planting and Deployment	10.9
Harvesting	3.2
Transportation	4.0
Gas Processing	16.6
Gas Separation & Desulphuring	3.7
Fertilization	0.2
Total	56.7
Annualized Capital Charge @ 8.9%	5.1

TABLE 5.4-10. BASELINE ANNUAL OPERATING AND MAINTENANCE COSTS

Item	Expense, Millions 1982 $
Marine Services and Material	1.51
Plant Services and Material	1.28
Marine Vessel Fuel ($8/MM BTU)	0.17
Plant Process Heat Fuel ($6/MM BTU)	1.10
Plant Electrical Utilities (7¢/kwhr)	1.14
Purchased Fertilizer (200 $/Ton N)	0.14
Total	5.34

TABLE 5.4-11. BASELINE SYSTEM ENERGY BUDGET

GROSS ANNUAL ENERGY PRODUCTION (100% OUTPUT) 1.095×10^{12} BTU

LESS:	
Process Heat	0.183×10^{12} BTU
Electrical Input	0.171
Transportation Fuel	0.021
Fertilizer Energy Content	0.028
NET ANNUAL ENERGY PRODUCTION	0.692×10^{12} BTU
PERCENTAGE OF GROSS ENERGY REQUIRED FOR OPERATIONS	37%
PERCENTAGE NET ENERGY PRODUCTION	63%

Unit gas cost and gas cost sensitivity to farm yield were also calculated for the baseline system. The economic parameters employed in the analysis are those defined by the GRI Economics Group and are identical to those employed in The R.M. Parsons' more detailed economic analyses. Unit gas cost breakdowns for two cases are presented in the bar charts of Figure 5.4-19. The bar on the left shows the contributions to unit cost from the various cost elements for the baseline system with the assumed farm kelp yield of 7.5 DAFT/A-Yr and a gross production of 3 MMCFD. Total unit cost estimated for the baseline is $10.20/MMBTU. The potential sensitivity to farm yield is demonstrated by a similar bar on the right where a total unit gas cost ranging from $6.75/MMBTU-$8.05/MMBTU, is estimated for an assumed "advanced yield" case of 45 DAFT/A-Yr and a gross gas production of 18 MMCFD. Note that in this case, the farm area was kept constant at the baseline size and the capacity of the process plant and supporting subsystems was increased to accommodate the increased feedstock production so that economics of scale were possible in these elements. The dashed segment between the two total unit cost values represents the difference in unit gas cost predicted depending upon whether linear scaling or 0.7 power law scaling is employed to estimate facility cost variation with size or capacity. Engineering experience indicates an actual unit cost which is probably closer to the lower value of $6.75/MMBTU associated with power-law scaling.

It should be noted that similar results would be obtained for a case where reduction of farm size is used to keep gas production at 3 MMCFD with farm yield increased to 45 DAFT/A-Yr. In this case, however, the unit cost would probably be closer to the "linear scaling" value since farm cost decreases would probably scale in that manner.

Table 5.4-12 was generated to demonstrate the comparative sensitivity of gas cost to changes in capital cost versus changes in O&M and purchased energy. Reductions of $1 MM in capital cost result in $0.09/MMBTU reduction in gas cost while a $1 MM reduction in annual operating costs drive gas cost down by $0.96/MMBTU. Changes in operating cost, therefore, have much larger impact on gas cost than do comparable changes in capital cost. Note also that an increase in gas yield from the digestion process translates directly into increased annual gas revenue which is equivalent to a comparable reduction in annual operating cost so that relatively small improvements in digester yield performance can have significant impact on unit gas cost.

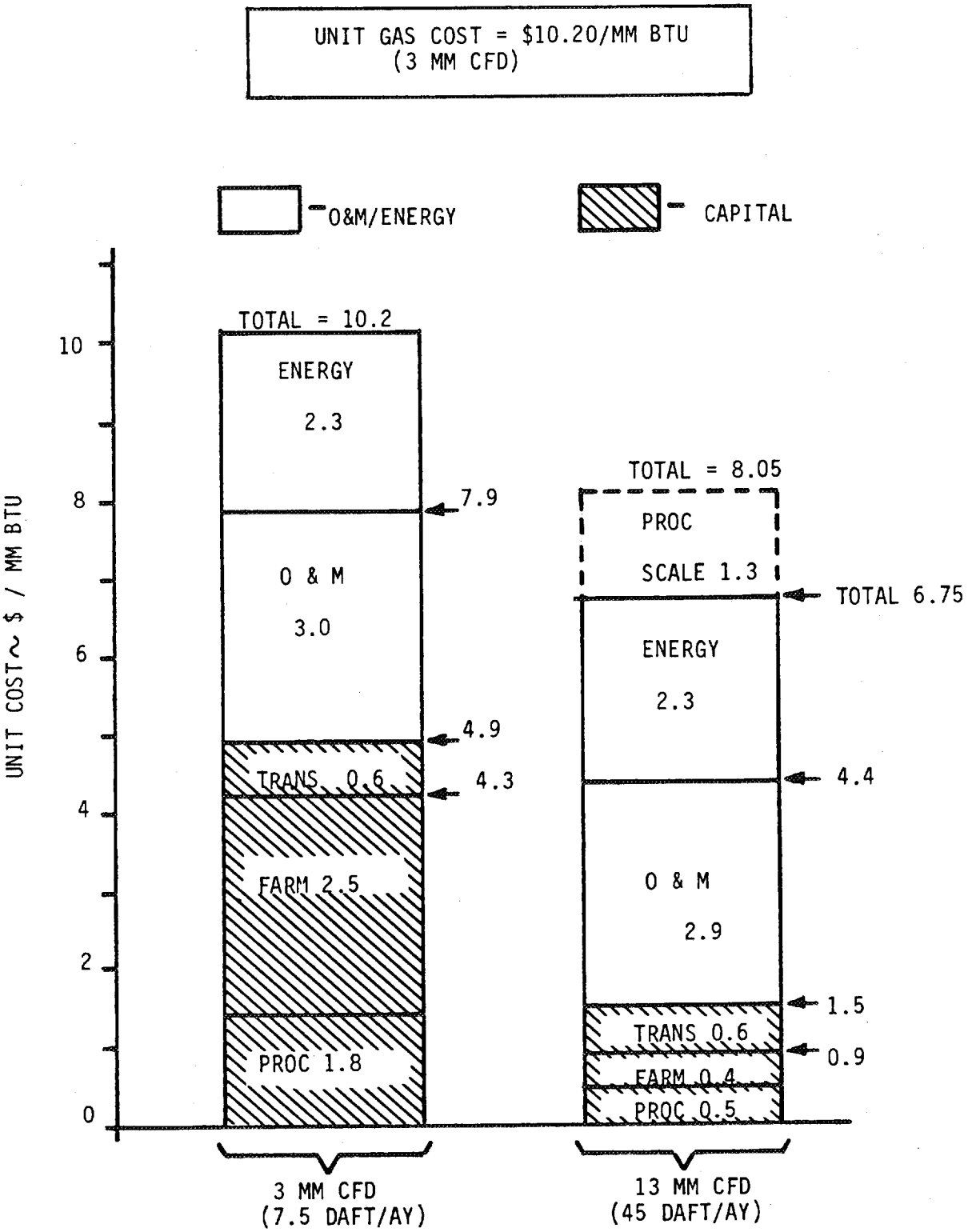


Figure 5.4-19. Gas Cost Results

TABLE 5.4-12. GAS COST SENSITIVITY

Cost Element	Cost Sensitivity ($/MMBTU)/(MM$)	
	3 MMCFD (7.5 DAFT/A-Yr)	18 MMCFD (45 DAFT/A-Yr)
Capital	0.09	0.015
O&M/Energy	0.96	0.16

A brief study was also conducted to assess system senstivity to potential seasonal variations in farm yield due to variations solar insolation and oceanographic conditions. Plant and equipment could be underutilized during low yield periods, or additional farm area might be required. To examine this effect, a sawtooth yield with time functionality was assumed with constant average yield and selected amplitudes for the maximum to minimum range over the annual period. The results indicated that the increase in unit gas cost would be less than 7 percent for a range of seasonal yield of 2. This result was the same if the gas plant was underutilized (annual average 92 percent of capacity) or if required, additional farm area was developed. The seasonality factor is reduced in influence if the kelp harvest is sequenced to allow more crop area to be harvested in the low yield period than in the high yield period. In situ, the mature crop has a life of several months.

The GE baseline system study and the cost/economics results discussed above have been presented and published in Reference 5.4-9.

5.4.5 SYSTEM FUNCTIONAL REQUIREMENTS AND SPECIFICATION DOCUMENT

The primary output of the GE nearshore system study is the formal document of Reference 5.4-1. The general content and format of the document are contained in Table 5.4-13, where the Table of Contents, List of Figures, and List of Tables are reproduced from the reference, respectively.

The document was first issued 23 July 1982 after completion of literature searches, data reviews, and formulation of the initial GE recommended system concept. The document was discussed and reviewed with all interested parties at several meetings before and after initial issue. It was updated with Rev. A (10/8/82) and Rev. B (11/17/82) as new data and analysis results became available. The System Functional Requirements and Specification Document along

with its supporting backup data comprises the primary technology base upon which The Ralph M. Parsons system economic study is based.

TABLE 5.4-13. CONTENTS OF SYSTEM FUNCTIONAL REQUIREMENTS AND SPECIFICATION DOCUMENT

TABLE OF CONTENTS

ABBREVIATIONS AND DEFINITIONS

1.0 GENERAL PROVISIONS
- 1.1 Objective and Scope
- 1.2 Introduction
- 1.3 Technical Guidelines
- 1.4 Parametric Accuracy and Precision

2.0 SYSTEM DEFINITION
- 2.1 Objective and Scope
- 2.2 Functional Hierarchy

3.0 SYSTEM PARAMETER INTERACTIONS
- 3.1 Objective and Scope
- 3.2 Summary
- 3.3 System Technical Variables

4.0 KELP CHARACTERISTICS AND PROPERTIES
- 4.1 Objective and Scope
- 4.2 Applicable Documents
- 4.3 Physical Description
- 4.4 Biomass Yield
- 4.5 Life Cycle
- 4.6 Habitat Requirements
- 4.7 Chemical Composition
- 4.8 Nutrient Requirement
- 4.9 Physical Properties

Appendix 4-1

5.0 FARM SITE SELECTION
- 5.1 Objective and Scope
- 5.2 Kelp Occurrence
- 5.3 Site Survey
- 5.4 Land Site
- 5.5 Ocean Terminal

6.0 PLANTING SUBSYSTEM
- 6.1 Objective and Scope
- 6.2 Constraints and Requirements
- 6.3 Applicable Documents
- 6.4 Interface Requirements
- 6.5 General Description and Function
- 6.6 Environmental Requirements

TABLE 5.4-13. CONTENTS OF SYSTEM FUNCTIONAL REQUIREMENTS AND SPECIFICATION DOCUMENT (Cont)

TABLE OF CONTENTS

7.0 FARM STRUCTURE SUBSYSTEM
- 7.1 Objective and Scope
- 7.2 Constraints and Requirements
- 7.3 Applicable Documents
- 7.4 Interface Requirements
- 7.5 General Description and Function
- 7.6 Environmental Requirements

8.0 HARVEST SUBSYSTEM
- 8.1 Objective and Scope
- 8.2 Constraints and Requirements
- 8.3 Applicable Documents
- 8.4 Interface Requirements
- 8.5 General Description and Function
- 8.6 Environmental Requirements

9.0 HARVEST TRANSPORT SUBSYSTEM
- 9.1 Objective and Scope
- 9.2 Constraints and Requirements
- 9.3 Applicable Documents
- 9.4 Interface Requirements
- 9.5 General Description and Function
- 9.6 Environmental Requirements

10.0 GAS PRODUCTION SUBSYSTEM
- 10.1 Objective and Scope
- 10.2 Constraints and Requirements
- 10.3 Applicable Documents
- 10.4 Interface Requirements
- 10.5 General Description and Function
- 10.6 Environmental Requirements

11.0 GAS PRODUCTION SUBSYSTEM
- 11.1 Objective and Scope
- 11.2 Constraints and Requirements
- 11.3 Applicable Documents
- 11.4 Interface Requirements
- 11.5 General Description and Function
- 11.6 Environmental Requirements

TABLE 5.4-13. CONTENTS OF SYSTEM FUNCTIONAL REQUIREMENTS AND SPECIFICATION DOCUMENT (Cont)

TABLE OF CONTENTS

12.0 GAS PRODUCTION SUBSYSTEM
- 12.1 Objective and Scope
- 12.2 Constraints and Requirements
- 12.3 Applicable Documents
- 12.4 Interface Requirements
- 12.5 General Description and Function
- 12.6 Environmental Requirements

13.0 GAS PRODUCTION SUBSYSTEM
- 13.1 Objective and Scope
- 13.2 Constraints and Requirements
- 13.3 Applicable Documents
- 13.4 Interface Requirements
- 13.5 General Description and Function
- 13.6 Environmental Requirements

TABLE 5.4-13. CONTENTS OF SYSTEM FUNCTIONAL REQUIREMENTS AND SPECIFICATION DOCUMENT (Cont)

Figure	Title
2-1	Near Shore System Functional Requirements
2-2	Summary Planting Subsystem Options
2-3	Specific Planting Subsystem Options
2-4	Fertilization Subsystem Options
2-5	Farm Substrate Subsystem Options
3-1	Performance/Subsystem Sensitivity Matrix
4-1	The Southern California Kelp Beds
5-1	Current Kelp Canopy (Acres)
5-2	Southern California Municipal Waste Discharge Sites
5-3	Pacific Coast Sea Lanes
6-1	Baseline Planting Subsystem Concept
6-2	Alternative Planting Subsystem Concept
7-1	Near Bottom Moored
7-2	Suspended Substrate
10-1	Retention of Algin During Storage
10-2	Retention of Mannitol During Storage
10-3	Carbon Dioxide Produced During Air Storage
10-4	Temperature/Inoculum Study
10-5	Methane Yield vs. Retention Time
10-6	USR Methane Yields
10-7	Methane Content in Digester Gas
12-1	A Batch Settling of Digester Effluent
12-2	Candidate By-Products/Co-Products
13-1	Fertilizer Sources and Sinks
13-2	Commercial Fertilizer Requirements

TABLE 5.4-13. CONTENTS OF SYSTEM FUNCTIONAL REQUIREMENTS AND SPECIFICATION DOCUMENT (Cont)

Table	Title
6-1	Planting Subsystem Representative Technical Requirements
10-1	Bioassay Methane Yields of Stored Kelp Samples
10-2	Results of Commercial Scale Grinding of Whole Kelp
10-3	Methane Yield Range
12-1	A Digester Effluent Composition
12-2	Volatile Solids Composition of Solid Effluent
12-3	A Digester Effluent Composition

References

5.4-1 "System Functional Requirements and Specification for a Nearshore Kelp to SNG Production Facility - Preliminary Engineering Study", GE/AEPD Document #GE-B10-1680-B, Nov. 1982.

5.4-2 Kelp Biology Specifications, by A.J. Bryce, GE/AEPD #GE-B10-1442, April 1982.

5.4-3 "Revision of GE System Point Design Concept for the Nearshore System Study Specification" by R.F. Hoppman, GE/AEPD, Document #GE-B10-1751, Oct. 1982.

5.4-4 "Sizing of Kelp Substrate" by Jan Hogan, GE/AEPD, Document #GE-B10-1756, Sept. 1982.

5.4-5 "Measurement of Holdfast Tearout Resistance of Macrocystis angustifolin" by R.F. Hoppman and R. Berthold, GE/AEPD Document #GE-B10-1750, Oct. 1982.

5.4-6 "Significance of Solids Retention Time in Digester System Design" by K. Jain, GE/AEPD, Document #GE-B10-1660, July 1982.

5.4-7 "Kelp Digester Effluent Quality Data" IGT letter, K.F. Fannin to K. Bird, Aug. 13, 1982.

5.4-8 "Summary Report on Waves and Swells of Nearshore California", by J.R. Wrobel, GE/AEPD Document #GE-B10-1810, Jan. 1983.

5.4-9 "A System Concept Evaluation of Commercial Scale Methane Production from Coastal California Kelp" by R. Hoppman, K. Jain, W. Kugler, J. Wrobel, ASME Paper 83-Pet-3, Presented at 6th Annual Energy - Sources Technology Conference and Exhibition, Houston, TX, Feb. 83.

APPENDIX B.
LABORATORY TESTS ON L-FRACTION
SAMPLE PREPARATION AND CHARACTERIZATION

TO: A.N. Tompkins, Program Manager
Biomass Programs

January 26, 1983

FROM: J.R. Forro
Biomass Programs

SUBJECT: Studies on Potential By-Products from Kelp. I. Phloroglucinol Derivatives

As part of an assessment of the possible recovery and utilization of components of Macrocystis pyrifera and/or products of the anaerobic digestion of this seaweed to methane, a preliminary study of the polyphenolic fraction or L-fraction was made.

Previous studies performed on the Marine Biomass Program have shown that Macrocystis contains a lignin-like material fraction when analyzed by the Forage Fiber Analysis method of Goering and Van Soest (1970). Further, this fraction shows the presense of phenolics when tested by specific color reactions, and lastly, this L-fraction appears to be refractory to microbial attack under the anaerobic conditions found in methanogenic digesters to the extent that as much is recovered after passage through the digestion process as went in. Whether any qualitative changes have occurred remains to be investigated.

The presence of phenolic compounds in brown algae has not been widely studied, but Ragan and Craigie (1978) have analyzed polyphloroglucinols in Fucus vesiculosus and their work provided an excellent guide for study of similar materials in other algae.

The following procedures were employed to extract polyphloroglucinols from Macrocystis lot 53-1 and from digester effluent obtained from a 10-liter methanogenic digester being operated on a once-a-week feeding schedule of 0.1 lbs vs/ft^3-week. These procedures are essentially those of Ragan and Craigie (1978).

A. Extraction

Method 1. Methanol Extraction Technique

1. Extraction of chopped raw kelp with cold methanol. Final methanol concentration is 80% (V/V). Shake slowly overnight at 4°C under nitrogen.

2. Filter thru Whatman #1

3. Take Filtrate to dryness on rotary evaporator at 40°C

4. Dissolve residue in dionized water under N_2

5. Filter through Whatman #1

6. Lyophilize Filtrate

7. Resuspend in cold methanol and let stand overnight in freezer

8. Filter through Whatman #42 and wash residue with small volume cold methanol - Combine filtrates

9. Reduce volume of filtrate by evaporation under N_2. Protect from light.

Method 2. H_2SO_4 Extraction Technique

1. Extract 200 gm chopped raw kelp from 400 nl cold 0.2 N H_2SO_4 overnight at 4°C under nitrogen

2. Filter through Whatman #1

3. Neutralize filtrate with 10% NaOH (To pH 7.0)

4. Continue from step #6 above

B. Analysis

The material fractions obtained by both the methanol and H_2SO_4 extraction procedures outlined above were analyzed for phenolics by the following procedures. Pure phloroglucinol was used as a standard.

1. Ultraviolet Absorption at 270 nm.

2. Folin-Denis Reagent (1970) for "Total Phenols"

3. Infrared Absorption

Results

Extraction of kelp or digester effluent with either the methanol or H_2SO_4 procedures resulted in a final fraction that was intensely yellow-orange in color. Dilution of those fractions were necessary prior to assay. Of the two quantitative methods used, the U.V. procedure seemed to be more reliable. The Folin-Denis reagent gave consistently low results, possibly due to the

extinction of the colored product being much greater for phloroglucinol than with higher molecular-weight polyphloroglucinols in the sample. Table 1 presents the results obtained utilizing the U.V. absorption method and compares the amount of polyphenolic obtained from raw kelp and digester effluent by extraction with methanol and H_2SO_4. Methanol appears to be a more efficient extraction solvent than H_2SO_4, and this is similar to the results of Ragan and Craigie (1978).

On the basis of methanol extraction of raw kelp and analysis of this extraction by U.V. absorption and using phloroglucinol as a standard, at least 3.68% of the dry weight is phenolic-like material. Previous studies using the fiber analysis method reported 5.7% of dry weight as L-fraction. It should be pointed out here, however, that extraction efficiency was not of concern in those preliminary experiments and some losses were bound to have occurred.

Infrared absorption studies (see attached) confirm existence of phenolic in these fraction but are not able to identify specific molecules due to the heterogeneous nature of the sample. They do provide clues, however, as to functional groups present.

Samples obtained in these experiments have been forwarded to the General Electric Corporate Research and Development Center for further analysis.

J.R. Forro
Biomass Programs
U-4021 - Bldg. 100 - Ext. 1180

JRF:ldp

Attachment

Copies: Dr. K. Jain

No. GE-BIO-1832

TABLE B-1. POLYPHENOLIC DETERMINATIONS* ON EXTRACTS OF MACROCYSTIS PYRIFERA

	80% MeOH Extraction	0.2 N. H_2SO_4 Extraction
53-1 Raw Kelp	3.68% of Kelp Dry Weight	1.77% of Kelp Dry Weight
Effluent	1.40% of Effluent Dry Weight	0.56% of Effluent Dry Weight

*UV Analysis at 270 nm.

References

Ragan, M.A. and J.S. Craigie. 1978. Phenolic compounds in brown and red algae. In Hellebust, J.A. and J.S. Craigie (Eds). Handbook of Phycological Methods, Physiological and Biochemical Methods. Cambridge Univ. Press, Cambridge.

Horowitz, W. (Ed.). 1970. Official Methods of Analysis of the Association of Official Analytical Chemists, 11th ed. pg. 154, The Association, Washington, D.C.

Goering, H.K. and P.J. Van Soest. 1970. Forage Fiber Analysis (Apparatus, Reagents, Procedures, and Some Applications). Agricultural Research Handbook No. 379. United States Department of Agriculture. Jacket No. 387-598.

TO: DR. K.K. Jain March 30, 1983

FROM: Jim Carnahan

SUBJECT: Analysis of Kelp Extract.

Sample Description.

The sample was received as an amber methanol solution with a trace of white precipitate. The sample volume was approximately 150 ml. The sample was stored under refrigeration until analysis.

Sample Analysis.

The sample was examined by a number of techniques available in this laboratory. Infrared spectroscopy of a film cast from the sample solution directly showed mainly hydroxyl bands. This might be expected in a polar solvent extract of a natural product where sugars and related compounds might be present. The lack of fine structure in the IR spectrum is probably due to a number of related materials with close but not identical IR frequencies. The infrared spectrum is included as Figure 1.

A sample was dried under a stream of nitrogen at room temperature leaving a brown residue which upon further drying on a vacuum line became a vitreous material. The percent solids was calculated by evaporating a weighed amount of the solution and weighing the residue after thorough drying. The sample was found to be 13 % solids. The vitreous solid obtained above was dissolved in deutero-dimethylsulfoxide (DMSO-D6) and filtered to remove a small amount of undissolved white crystalline material. This crystalline material was found to be water soluble and was not further characterized (probably salts).

Proton nuclear magnetic resonance spectroscopy (NMR) was carried out on a portion of the perdeutero-dimethylsulfoxide solution. This is shown as figure 2 . The large broad peak at 4.7 ppm is due to all of the hydroxyl groups in the sample. This may include strongly bound water such as that hydrating carboxylic acid salts. The small peak at 8.1 ppm is indicative of alkyl or alkenyl aldehydes or perhaps formic acid derivatives. The unresolved multiplet at 3.5 ppm is probably due to methylene groups adjacent to a hydroxyl (note the residual peak for methanol) or alkyl ethers. The sharp peak at 3.1 ppm is almost certainly an isolated methyl group

(no adjacent group with protons). The remaining peaks at 1.8 and 1.3 ppm are the result of methyl groups attached to alkyl chains or at highly substituted (i.e. tertiary butyl) centers. The spectra clearly shows the absence of any aromatic rings, the protons of which resonate in the 6.5 to 8.0 ppm region.

The DMSO solution was also analyzed by C-13 NMR on a Varian XL-300 superconducting magnet instrument resulting in the spectrum shown as figure 3. The spectrum is labelled to show the types of carbons found. Note the absence of aromatic carbons but the multiplicity of the carbonyl region with at least 9 types of distinct carbonyl groups. The region represented by ethers and alcohols shows the greatest signal intensity but this signal intensity should not be interpreted as representing proportional amounts of material. A number of experimental problems prevent the integration of signals under the conditions used for this spectrum.

The sample as received was diluted 500:1 with methanol and examined by absorption spectroscopy. The spectrum is shown in Figure 4 and shows a number of absorption bands extending into the visible region. The major band at 223 may be due to unsaturated carbonyl compounds. Longer wavelength absorptions must be due to more conjugated systems and may be a result of chlorophyl degradation products.

Several attempts were made to find a solvent for the dehydrated extract that would be compatible with our gel permeation chromatography system. We do not have the facilities for analysis in polar solvents such as water methanol or DMSO since we normally do not deal with materials of biological origin. Reversed-phase liquid chromatography provided only the information that this was a multi-component system and that all of the material was extremely polar in nature. This is no surprise given the solubility properties of the material.

In order to determine the approximate molecular weight of the material it was analyzed by field adsorption mass spectrometry on a Varian Mat 731. This ionization technique is preferred for biological molecules since they do not char as readily under the conditions used. We were unsuccessful in obtaining any meaningful signal. We also attempted ionization by electron impact and finally by atom bombardment. This latter technique gave signals at every mass unit. There were no outstanding peaks. This result is at odds with some of the NMR data that suggest at best less than 10 major components. We conclude that the system is merely unstable under even the most gentle ionization conditions available to us and forms oligomers or polymers.

The solution you submitted contains no aromatic compounds and thus is substantially free of lignin. The components that are present are suggestive of sugars and sugar degradation products. These have not been characterized further as we are not set up for those types of analysis.

If you have any questions or wish further discussion of this analysis feel free to call me at 8-235-8388.

5.5 BYPRODUCTS/COPRODUCTS RESEARCH

5.5 BY-PRODUCTS/CO-PRODUCTS OF METHANE PRODUCTION FROM KELP

5.5.1 INTRODUCTION

There are several valuable chemicals and products that can be economically recovered as by-products and co-products of methane production. Net revenues from the production of these chemicals can be used for partially or totally offsetting the methane production costs as summarized in Table 5.5-1. It is strongly recommended that research in the by-product and co-product area be initiated and pursued vigorously. A high priority to this task in the overall Marine Biomass evaluation is recommended due to the large anticipated returns.

a. Of more than a dozen chemicals that can be recovered as by-products and co-products, only four or five offer the potential for achieving significant reductions in gas cost. These are iodine, L-fraction, algin, mannitol, and possibly carbon dioxide. All except the L-fraction are commercial products at present. Further, the technical evaluations conducted in this study show that these chemicals can be produced as by-products or co-products of methane production. Laboratory samples of L-fraction have been prepared from raw kelp and from digester effluents. Based on preliminary characterizatons of these samples and discussions with technical researchers in this area, potential applications of L-fraction are suggested to be as a feedstock or a component for making specialty plastics, and adhesives, and timed-release substances such as pharmaceuticals or pesticides. Such applications suggest the L-fraction to be worth $1-2/lb and up to $6-7/lb depending on the particular usage. For purposes of this analysis, L-fraction was valued at $1 and $3 per pound.

b. In one scenario analyzed in this study in which all the kelp from the farm is used for methane production, the recovery of iodine and carbon dioxide from the digester effluents can decrease the gas cost of $13.47/MMBTU by an estimated 16 percent. Recovery of the L-fraction can further decrease the gas cost. With L-fraction valued at $1/lb, the gas cost reduction due to net revenues from by-products is estimated at 30-35 percent. At $3/lb of L-fraction, more net revenues are anticipated from the sale of by-products than needed to completely offset the cost of methane production.

c. In the second scenario, approximately 15 percent of the farm output is devoted to the production of selected chemicals such as algin and mannitol, and the remainder is used for methane production. Net revenues from the production of these chemicals and of iodine and carbon dioxide from digester effluents can

TABLE 5.5-1. SUMMARY OF BY-PRODUCTS/CO-PRODUCTS IMPACT ON GAS COST

SCENARIO 1

- 100% of farm output used for methane production and by-products recovered from digester effluents.
- Baseline Gas Cost = $13.47/MMBTU

By-Products	Est. Gas Cost Reduction
1. Iodine + CO_2	16%
2. Iodine + CO_2 + L-fraction	
(a) L-fraction valued at $1/lb	30-35%
(b) 50% increase in L-fraction recovery costs	10-15%
(c) L-fraction valued at $3/lb at nominal or 50% higher recovery costs	***

SCENARIO 2

- Approximately 85% of the farm output used for methane production and the rest for co-products such as algin and mannitol. By-products recovered from digester effluents.
- Estimated Gas Cost = $15/MMBTU

By-Products and Co-Products	Est. Gas Cost Reduction
1. Algin + Mannitol + Iodine + CO_2	55%
2. Algin + Mannitol + Iodine + CO_2 + L-fraction	
(a) L-fraction valued at $1/lb	65-80%
(b) 50% increase in L-fraction recovery costs	50-65%
(c) L-fraction valued at $3/lb at nominal or 50% higher recovery costs	***

*** NET REVENUES FROM BY-PRODUCTS/CO-PRODUCTS MORE THAN MEET TOTAL COST OF GAS

reduce the gas cost of $15/MMBTU* by an estimated 55-60 percent. With L-fraction included, valued at $1/lb, the gas cost reduction is estimated at 65-80 percent. At $3/lb of L-fraction, as in the first scenario, the by-products and co-products generate more net revenues than needed to pay totally for the cost of methane production.

5.5.2 BACKGROUND AND SCOPE

A detailed system study and economic assessment of commercial production of methane from kelp has been conducted for the Gas Research Institute by The Ralph M. Parsons Company.[1] The Parsons' analysis is based on a system concept of a nearshore farm off the coast of southern California in which kelp is grown and harvested, and transported to a land site for the production of methane gas using an anaerobic digestion process. In the system concept studied, the digester effluents from the digestion process are returned to the kelp farm to supplement the naturally occurring nutrients. The nominal system capacity is 3 million SCFD of pipeline quality gas. This study is adjunct to the Parsons' study and considers the production of by-products** and co-products*** within the framework of the system concept analyzed by Parsons.

The objective of this investigation is to evaluate the technical and economic feasibility of producing inorganic and organic chemicals as by-products or co-products of methane production. These may be produced from the digester effluents, a fraction of the kelp grown in the farm, or both. The results of the study provide an assessment of the effect of an integrated production system (methane + co-products/by-products) on the cost of gas.

Kelp has been used for the past 60 years to produce a variety of organic and inorganic chemicals such as algin, mannitol, potash, and iodine. In each case, however, only one product was made from a given mass of kelp. Some of these chemicals such as potash and iodine can be extracted from either kelp or digester effluents since only the organic constituents of kelp are consumed in the

---

*Estimated increase of $1.53/MMBTU due to reduced gas production system capacity.

**By-product: Chemicals or products recovered in conjunction with the production of methane from the same pound of kelp.

***Co-product: Chemicals or products recovered from a portion of baseline farm kelp used exclusively for chemicals production.

anaerobic digestion gas production process. The anaerobic digestion process also yields carbon dioxide, hydrogen sulfide, and bacterial protein as by-products. From the data on historical kelp usage, knowledge of kelp composition, and the data on the various digestion products, one can identify potential products that could conceivably be recovered as by-products or co-products of gas production from kelp. Table 5.5-2 lists such potential chemicals and products.

Except for fucoidan and the L-fraction, all of the chemicals and products listed in Table 5.5-2 are commercially produced at present. While kelp continues to be the sole source for commercial production of algin at present, the sources for the production of the rest of the chemicals and products are non-kelp based. Cellulosics and plant protein are currently derived from terrestrial biomass sources. Brines from various lakes and underground water throughout the world are primary sources for the production of iodine, bromine, and magnesium. Potash, sodium compounds, and sulfur are primarily produced from mine sources. Limited production of potash and sodium compounds is also based on brine sources. Sources of commercial carbon dioxide include flue gases resulting from the combustion of carbonaceous fuels, synthetic ammonia and hydrogen plants in which methane or other hydrocarbons are converted to carbon dioxide and hydrogen, fermentation processes, lime kiln operations involving thermal degradation of carbonates, and natural carbon dioxide gas wells.

The residual solids from the kelp digestion are rich in protein, and have been estimated to contain over 50 percent protein matter in samples taken from kelp digesters.[2,3] It has also been shown that these protein-rich solids can readily be separated from the total digester effluents using physical separation methods based on sedimentation and centrifugation.[2,3] The bacterial protein product appears to be an economical source for protein supplement for animal and poultry diets based on its composition analyses.[3]

The kelp digestion experiments conducted during the GRI Marine Biomass Program showed the presence of algin in the digester effluents.[2] This algin is termed the by-product algin. It is recoverable and that is the basis for including it in Table 5.5-2. Fucoidan is not available commercially at present, and is used only as a laboratory chemical for scientific purposes, however, the material is considered to have unusual colloidal characteristics which may be of considerable interest in various industries such as cosmetics and pharmaceuticals. Table 5.5-2 includes a product "phenolic compound" as a potential by-product or a co-product.

TABLE 5.5-2. POTENTIAL BY-PRODUCT AND CO-PRODUCT CHEMICALS

	By-Products	Co-Products
Organic	Bacterial Protein Product	Algin
	Phenolic Compound (L-Fraction)	Mannitol
	Algin (Residual from the digestion process)	Fucoidan Cellulosic Compounds
		Plant Protein
		Phenolic Compound (L-Fraction)
Inorganic	Iodine	Iodine
	Potash	Potash
	Magnesium Compounds	Magnesium Compounds
	Bromine	Bromine
	Sodium Compounds	Sodium Compounds
	Sulfur	
	Carbon Dioxide	

The existence of such a fraction in raw kelp and digester liquid effluents has been confirmed during laboratory investigations in the Marine Biomass Program.[2] Small laboratory samples of this material have been isolated and characterized. Based on limited analyses and discussions with experts in the materials evaluation area, it appears that the phenolic compound (L-Fraction) may have applications in areas such as plastics, adhesives, and timed-release dispersants. The sample preparation and characterization techniques used to analyze the L-fraction are discussed in Appendix I. It has been suggested that the L-fraction in kelp biomass may be analogous to the lignin structure in terrestrial biomass as it contains similar phenolic groupings.

It should be noted that a listing in Table 5.5-2 does not necessarily imply technical and/or economic producibility of each chemical, but only that it is present in the feedstock stream. Conceivably, some of those products listed may not be technically producible unless one or more are "sacrificed" during the processing scheme. Indeed, one of the purposes of this study is to determine which ones are technically feasible and are economically most attractive.

A screening of the producibility of by-products and co-products was necessary for several reasons: (1) The number of potential products is too large to permit a reasonable technical and economic investigation of each one; (2) the status of recovery technology in several cases is undefined or non-existent; (3) only those which have the potential for significant economic impact need to be studied. The screening was conducted using available technical and marketing data, and these results are presented in Section 5.5.3. The market data reviewed included current U.S. demand and production, anticipated growth rate of the demand/production, current sources and methods of production, and major applications. Revenue potential was also considered in the screening process.

Detailed process systems designs and cost analyses of the production of selected chemicals from raw kelp and digester effluents are presented in Section 5.5.4. Also included is a discussion of the economic impact on gas cost. In order to develop cost estimates, inputs were obtained from experts who have had extensive experience in developing and operating algin, mannitol, and iodine production systems. Based on these analyses, several research needs are identified and recommendations are made which are included in this report.

5.5.3 SCREENING OF POTENTIAL BY-PRODUCTS AND CO-PRODUCTS

The purpose of the screening process discussed in this chapter was to identify the most technically and economically attractive potential co-products and by-products. Presently available market and technical data were used in the screening process.

5.5.3.1 Technical Screening

The products listed in Table 5.5-2 were evaluated technically for their producibility potential (from kelp or the digestion process effluents) and classified into three categories. The first cateogry includes only those products which, at some time or another, have been produced from kelp at commercial scale. It also includes those which have a high technical probability of being produced from digestion process effluents, (e.g. Iodine, Potash, and Bromine). These chemicals have been and are currently being produced from subsurface brines. The digester effluent liquid fraction is considered essentially a brine, and contains a variety of inorganic materials amenable to existing processing steps that are currently used for the production of these chemicals. Equipment for the production of CO_2 and sulfur from a mixture of gases containing CH_4, CO_2, and H_2S is commercially available. The second category of products includes those which have been produced at pilot scale or laboratory scale. This includes mannitol, fucoidan, L-fraction, bacterial protein, and algin residual from the digestion process. The last category includes those products for which there is no experimental evidence that they can be produced from kelp or digestion effluents but which are present in raw kelp. This includes the cellulosics and plant protein fractions, and the sodium and magnesium compounds.

The results of this screening process are presented in Table 5.5-3. The cellulosics and the protein products were dropped because there is no technical data presently available to evaluate the producibility. Furthermore, they are likely to be at a disadvantage in the marketplace, in terms of competition from established terrestrial biomass sources.

Magnesium and sodium compounds were eliminated from further analysis because there is no technical data readily available to support the potential for their recovery from kelp or digester effluents. While one could conceive of processing techniques, for example, based on fractional crystallization and electrolysis for their recovery, these methods are likely to interfere with the recovery of other inorganics such as iodine which is a high value chemical.

TABLE 5.5-3. TECHNICAL SCREENING OF CO-PRODUCTS AND BY-PRODUCTS

Technical Producibility	Product
1. Commercially produced from kelp,	Algin Potash Iodine Mannitol
or	
High Probability of producibility from digestion effluents/kelp	Iodine (b)* Potash (b) CO_2 (b) Sulfur (b) Bromine (b, c)* Bacterial Protein Product (b)
2. Laboratory/Pilot Plant Data	Mannitol (c) Fucoidan (c) Phenolic Compound (c, b) Algin Residual (b)
3. No data on producibility from kelp or digester effluents	Cellulosics (c) Plant Protein (c) Magnesium Compounds (c, b) Sodium Compounds (c, b)

*(b) - Denotes recovery as a by-product
(c) - Denotes recovery as a co-product

Algin as a by-product from digester effluents is also eliminated from further analysis. Samples of residual algin were recovered from laboratory digester effluents. These samples exhibited significantly lower viscosities than those from fresh kelp. Apparently, as the algin molecule passes through the digestion process, its original polymeric structure changes resulting in loss of viscosity. The application of the residual algin (by-product) would be significantly limited compared to algin recovered from raw kelp.

5.5.3.2 Potential Revenues

Revenue potential was used for evaluating the contribution to the reduction of gas cost by each of the candidate co-products and by-products. Total revenues were used in the initial screening because the range of the gross revenues from various chemicals was very wide such that the ones at the lower end of the revenue range could be justifiably eliminated for purposes of the current study since net revenues cannot exceed total revenues.

For the purposes of this study, two of many possible production scenarios were developed. In the first, gas production is maximized; only residual materials from the anaerobic digestion process are treated for by-products recovery. In the second scenario, approximately 15 percent of the kelp farm output is used exclusively for the production of chemicals and the rest for the production of gas. The revenue screen was developed on the basis of the second system scenario since it is the more comprehensive of the two analyzed in detail in this report. The scenario is depicted in Figure 5.5-1 and includes the recovery of by-products from digester effluents. As the main objective of the system is to produce gas, it is necessary that the bulk of the farm output be used for that purpose. At the same time, the size of the chemicals production facility must approach commercial scale in order to achieve economical viability. Preliminary calculations indicated that using 10 to 20 percent of the farm output kelp for chemical production achieved both objectives. For purposes of this particular scenario, it was assumed that 500 tons/day of raw kelp are used for the production of chemicals which, for the baseline kelp farm, amounts to approximately 15 percent of the total output.

Kelp composition data were used as the basis for estimating the annual production of various co-products from kelp, which when multiplied by the respective current market prices yielded estimates of annual revenues. The bases for these calculations are summarized in Tables 5.5-4 and 5.5-5. Fucoidan is

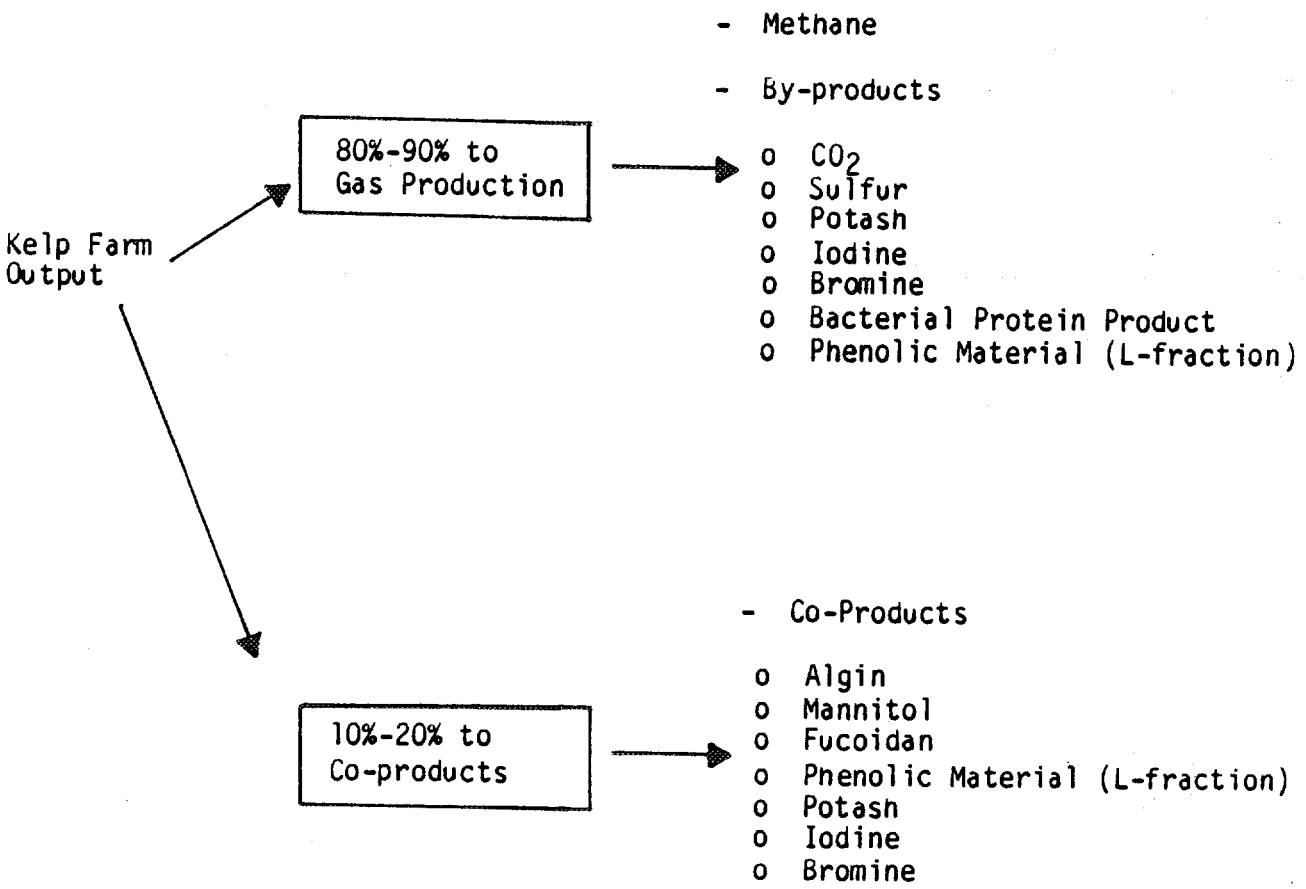


Figure 5.5-1. Scenario for Relative Comparison of Kelp Products

TABLE 5.5-4. POTENTIAL FOR CO-PRODUCTS FROM RAW KELP

Basis

- 500 Wet Tons/Day
- 365 Days/Yr.
  = 182,500 Tons/Yr. of Raw Kelp (RK)
- Raw Kelp Composition

Water	87.5%	1750 lbs/Ton RK
Organics	7.5%	150
Inorganics	5.0%	100

Organics		Composition	Recovery Efficiency*	Annual Production
Algin, % of Total Solids (TS)	17%	42.5 lbs/Ton RK	0.72	2792 Tons/Yr
Mannitol	15%	37.5	0.7	2395
L-Fraction	5%	12.5	0.65	740
Fucoidan	1.5%	3.8	0.60	208
Inorganics				
KCl, % of Total Solids (TS)	26%	65	0.60	3558
Iodine	0.3%	0.7	0.65	42
Bromine	0.1%	0.25	0.65	15

*Discussed in Section III

TABLE 5.5-5. POTENTIAL PRODUCTION OF AND GROSS REVENUES FROM VARIOUS CO-PRODUCTS

BASIS: 500 TONS/DAY OF RK

Product	Market Price, $/Ton	Annual Production, Tons/Yrs.	Potential Revenue $/Yr., Millions
Algin	$ 6000/Ton	2792	16.8
Mannitol	$ 6000	2395	14.37
L-Fraction	$ 2000-6000	740	1.5-4.4
Fucoidan	$ 6000*	208	1.25
Iodine	$14500	42	0.6
Potash	$ 60	3558	0.21
Bromine	$ 1200	15	0.02

*Assumed to be the same value as mannitol

currently available on the market only as a laboratory chemical at approximately $10/gram. However, it is considered to have unique colloidal properties which may be of interest in several applications.[4] For purposes of this analysis, it is valued the same as mannitol. The L-fraction is valued at $1-3/lb depending on its usage whether it is in the materials manufacturing area, for example in specialty plastics, or in controlled timed-release dispersants, for example in pharmaceuticals or pesticides. Algin is valued at $3/lb for comparison purposes; it is realized that its exact value will depend on the particular alginate product, purity, and the intended usage.

Approximately 85 percent of the farm output is devoted to the production of gas and by-products. Potential revenues from gas and by-products production are summarized in Table 5.5-6. In making these calculations, experimental data on gas production and digester effluent composition obtained on the Marine Biomass Program were used. The recovery efficiencies of various products shown in Tables 5.5-4 and 5.5-8 are discussed in Section 5.5.4. The bacterial protein product is valued at $70/ton based on a preliminary study conducted for the Marine Biomass Program in 1978. Lacking any further development on the subject, the same value is used in the analysis although the value in 1982 dollars may have increased substantially. Total revenues from the production of various by-products and co-products are summarized in Table 5.5-7. Methane production is valued at $10/1000 SCF only for comparison purposes. Bromine and sulfur show the lowest potential revenues, being an order of magnitude lower than any of the other contributors, and, therefore, were eliminated from further consideration.

5.5.3.3 Market Data

For several products, market data were collected and reviewed in more detail. The data include the U.S. demand, production, market growth-rate, current production methods and major applications and are summarized in Tables 5.5-8 through 5.5-12 for each of the products. From a review of these data, several significant observations can be made:

a. Other than the phenolic materials and fucoidan, all other products are currently produced commercially and thus have established commercial applications

b. The market is projected to continue to grow for all the products.

c. The U.S demand for potash, iodine, and algin outstrips production and must be met by imports.

TABLE 5.5-6. POTENTIAL GROSS REVENUES FROM GAS AND BY-PRODUCTS

BASIS: 1.15×10^6 Tons of Raw Kelp, Wet Basis

	Recovery Efficiency	Tons/Yr.	$/Ton	$/Yr.
Methane		20139	473 ($10/1000 SCF)	9.5 Millions
Carbon Dioxide	90%	4039	35	1.4
Sulfur	90%	322	120	0.04
L-Fraction	65%	4603	2000-6000	9.2-27.6
Bacterial Protein	80%	11220	70	0.8
Potash	60%	22441	60	1.35
Iodine	65%	288	14500	4.2
Bromine	65%	115	1200	0.1

TABLE 5.5-7. POTENTIAL GROSS REVENUES FROM VARIOUS BY-PRODUCTS AND CO-PRODUCTS

Methane Gas	$ 9.5	Millions/Yr.
Algin	16.8	
Mannitol	14.37	
Fucoidan	1.25	
L-Fraction	10.7-32.0	
Bacterial Protein	0.8	
Carbon Dioxide	1.4	
Potash	1.56	
Iodine	4.8	
Bromine	0.12	
Sulfur	0.04	

TABLE 5.5-8. IODINE DATA SUMMARY[5,6]

CURRENT MARKET	U.S. Demand:	8.7 Million Pounds (1979)
	U.S. Production:	Actual figures not available; Estimated at 25-30% of the demand
	Market Price:	$6.80/lb in 1980 and $7.25/lb in February 1983; crude iodine in drums
	Market Size:	$60 Million (1980), production value
	Growth Rate:	~3.7%, to a demand of ~18 million pounds in year 2000
PRODUCTION FROM BASELINE SYSTEM	300-400 Tons/Yr.	
CURRENT PRODUCTION METHODS & SOURCES	Extraction of subsurface brines; process based on displacement of iodine by chlorine followed by recovery (blow out with air or adsorption on carbon), and purification. Produced from brines in Michigan and Oklahoma.	
MAJOR APPLICATIONS	Used as a catalyst, e.g. in rubber industry; in feeds and food products, pharmaceuticals, heat stabilizer, inks and colorants, sanitary and industrial disinfectants, and photography.	
OTHER COMMENTS	A strategic chemical inventoried for national emergencies in the National Defense Stockpile. First produced in the U.S. from kelp during World War I. About 2/3 of the current demand met by imports, primarily from Japan and some from Chile.	

TABLE 5.5-9. ALGIN DATA SUMMARY[7,8]

CURRENT MARKET	U.S. Demand:	Actual figures not available
	U.S. Production:	7800 Tons (1976)
	Market Price:	$2.50/lb to $6/lb depending on product variety and application
	Market Size:	
	Growth Rate:	5.4% averaged annually from 1950-1970
PRODUCTION FROM BASELINE SYSTEM	2500-3000 tons a year assuming 15% of farm output is devoted to production of chemicals (algin as a co-product of mannitol).	
CURRENT PRODUCTION METHODS & SOURCES	Produced from raw kelp; method based on treating raw kelp with sodium carbonate to dissolve algin and then precipitate and refine it in several steps to desired specifications.	
MAJOR APPLICATIONS	Alginate gums of various viscosities have a variety of applications in the food, pharmaceutical, paper, and textile industries.	
OTHER COMMENTS	Market currently monopolized by Kelco Company. Some concern expressed by knowledgeable sources that China may soon start to export algin heavily and undercut the existing prices. China is reported to have developed significant algin production capacity in recent years.	

TABLE 5.5-10. POTASH DATA SUMMARY[9-12]

CURRENT MARKET	U.S. Demand:	7 Million Tons (K_2O equiv.) in 1979
	U.S. Production:	2 Million Tons K_2O in 1982 2.4 Million Tons K_2O in 1981 3.3 Million Tons K_2O in 1966
	Market Price:	\$110-\$130/Ton of K_2O equivalent in 1982
	Market Size:	\$225 Million, production value in 1982
	Market Growth Rate:	Between 1.5 and 3% for the U.S. market to year 2000
PRODUCTION FROM BASELINE SYSTEM	20,000-30,000 Tons/Year	
CURRENT PRODUCTION METHODS & SOURCES	Shaft and solution mining of potassium salts, (mainly the chloride) and subsequent purification. About 83% of U.S. production is from deposits in Carlsbad, N.M., and the balance from brines and bedded deposits in Utah, and brines in California.	
MAJOR APPLICATIONS:	95% for fertilizer	
OTHER COMMENTS	~25% of U.S. production exported to Latin American countries. Currently about 2/3 of U.S. demand met by import from Canada, the remainder by U.S. production. Higher dependence on imports anticipated in future. Estimated capital requirements for new ventures at about \$300/annual capacity ton of K_2O equivalent (1979-1980). Energy required for production estimated at 6×10^6 BTU/ton of K_2O (1973-1974); natural gas is the major fuel source for 70% of the total energy used.	

TABLE 5.5-11. CARBON DIOXIDE DATA SUMMARY[13,14,15]

CURRENT MARKET	U.S. Demand:	2.5×10^6 Tons in 1982 (Includes solid solid, liquid and gas)
	U.S. Production	
	Market Price:	Very site dependent; $30-50/ton in 1982
	Market Size:	$100 million in 1982
	Growth Rate:	
PRODUCTION FROM BASELINE SYSTEM	40,000-50,000 Tons/Year	
CURRENT PRODUCTION METHODS & SOURCES	Recovered from combustion of carbonaceous fuels, by-product of ammonia synthesis plants and fermentation processes, gas wells, calcination operations. CO_2 concentration in the feed stream varies depending on the source. It is concentrated by absorption - desorption using a variety of available solvents, and then purified to the desired degree which is determined by usage.	
MAJOR APPLICATIONS	About 40% in chemical synthesis (urea, methanol, sodium salicylate, and a variety of inorganic carbonates and bicarbonates); about 35% in enhanced oil recovery; and the rest in beverage carbonation, rapid chilling, refrigerant, and other.	
OTHER COMMENTS	Market price is very site dependent and usage dependent. Processing required and hence costs may vary significantly depending on the intended usage and the source of the raw CO_2.	

TABLE 5.5-12. MANNITOL DATA SUMMARY[16]

CURRENT MARKET	U.S. Demand:
	U.S. Production:
	Market Price: $3/lb in February 1983
	Market Size:
	Growth Rate:
PRODUCTION FROM BASELINE SYSTEM	2000-2500 tons per year based on the assumption that approximately 15% of the kelp farm output is devoted exclusively to its production (as a co-product of algin).
CURRENT PRODUCTON METHODS & SOURDES	Produced as a co-product with sorbitol from invert sugar. Process steps include hydrogenation and crystallization.
MAJOR APPLICATIONS	Sold as a white, crystalline powder or free flowing granules. Principal use in pharmaceutical applications. Used as a base in tablets of vitamins, antacids, aspirin, and other pharmaceuticals sometimes in combination with sucrose or lactose granules.
OTHER COMMENTS	Manufactured in the U.S. by ICI United States, Inc.

d. U.S. dependence on outside sources for iodine, potash, and algin in the future is likely to continue to increase.

e. The co-products and by-products from a baseline kelp farm would improve the U.S. supply, but would not exert a dramatic influence in the marketplace on pricing or affect significantly competitive sources of supply. Fucoidan, which does not have a bulk industrial market, is an unknown factor and cannot be evaluated based on available data.

From the analysis and observations above, production of selected co-products and by-products should have a solid market.

The results of the screening process in this section may be summarized by stating that of the fifteen chemicals and products identified in Table 5.5-2 as potential co-products and by-products, the technical and market data available support eliminating seven of those. Analysis was continued on the remaining eight. These are algin, mannitol, fucoidan, L-fraction, iodine, potash, carbon dioxide, and bacterial protein.

5.5.4 TECHNICAL PROCESSES AND ECONOMIC ANALYSIS

This chapter provides a description of the process systems envisioned for the recovery of the by-products and co-products and provides estimates of capital and operating costs. These costs are then used in an economic analysis to determine the impact on the gas cost. Two different scenarios are considered. In one, all the kelp from a farm (approximately 3700 t/day is used in gas production and only digester effluents are processed for the recovery of by-products. In the second, approximately 15 percent of the farm output is used for the production of co-products and the remainder for the production of gas and by-products. These scenarios are shown in block diagram form in Figure 5.5-2.

5.5.4.1 Process Descriptions

a. Gas and By-Products Production Processes (Scenario 1)

The process scheme is shown in Figure 5.5-3. Raw kelp from the farm is received at the processing site, chopped to approximately 1/4 inch particle size, and fed to digesters. The gases out of the digesters contain carbon dioxide, hydrogen sulfide, and water vapor in addition to methane. This gas stream is processed to separate the acid gases from the methane using a physicochemical absorption system based on the Selexol process. The final steps in methane production include compression and moisture removal steps which are necessary in order to meet gas pipeline quality standards. Hydrogen sulfide released during

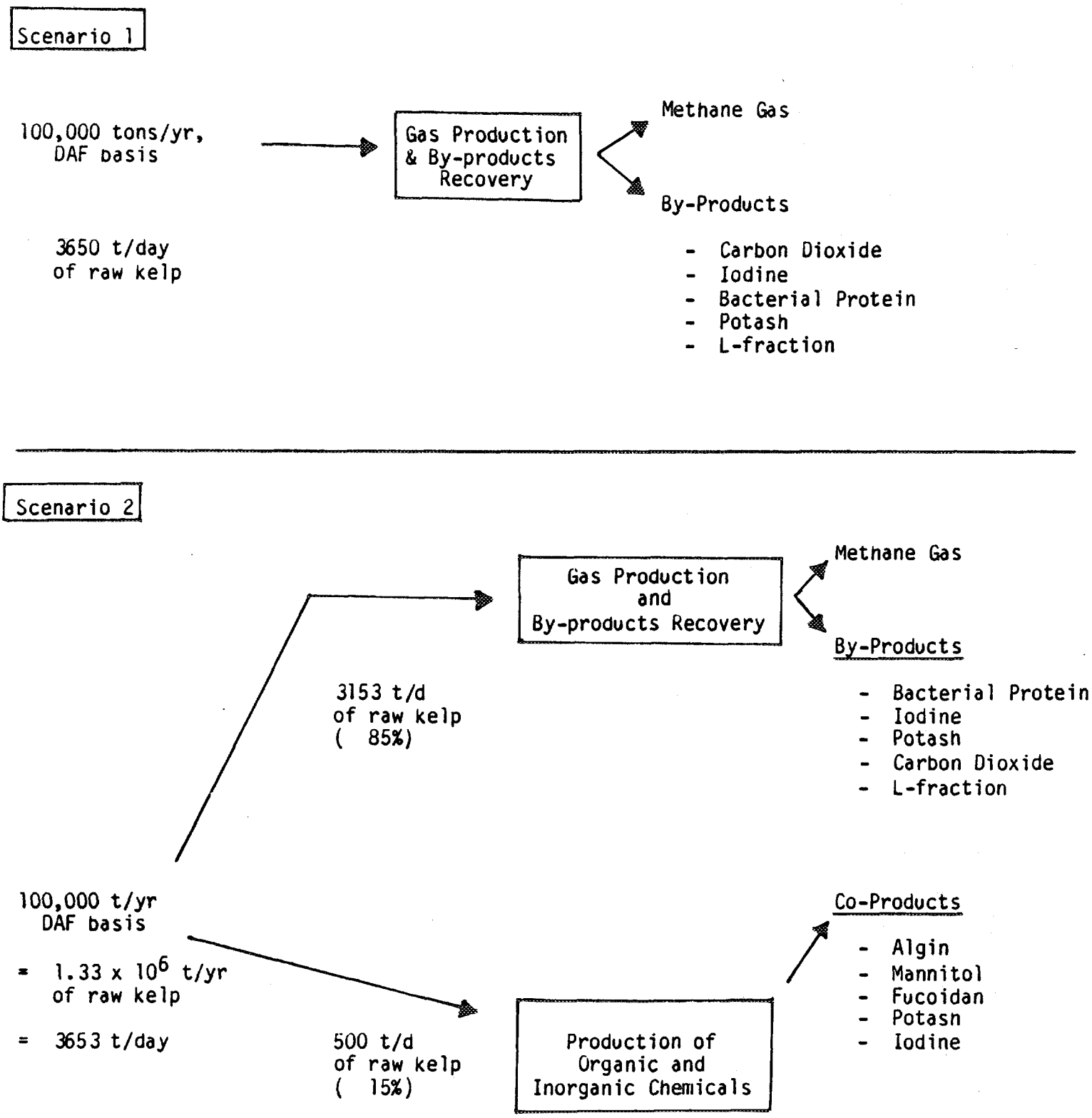


Figure 5.5-2. Scenarios for Production of By-Products and Co-Products

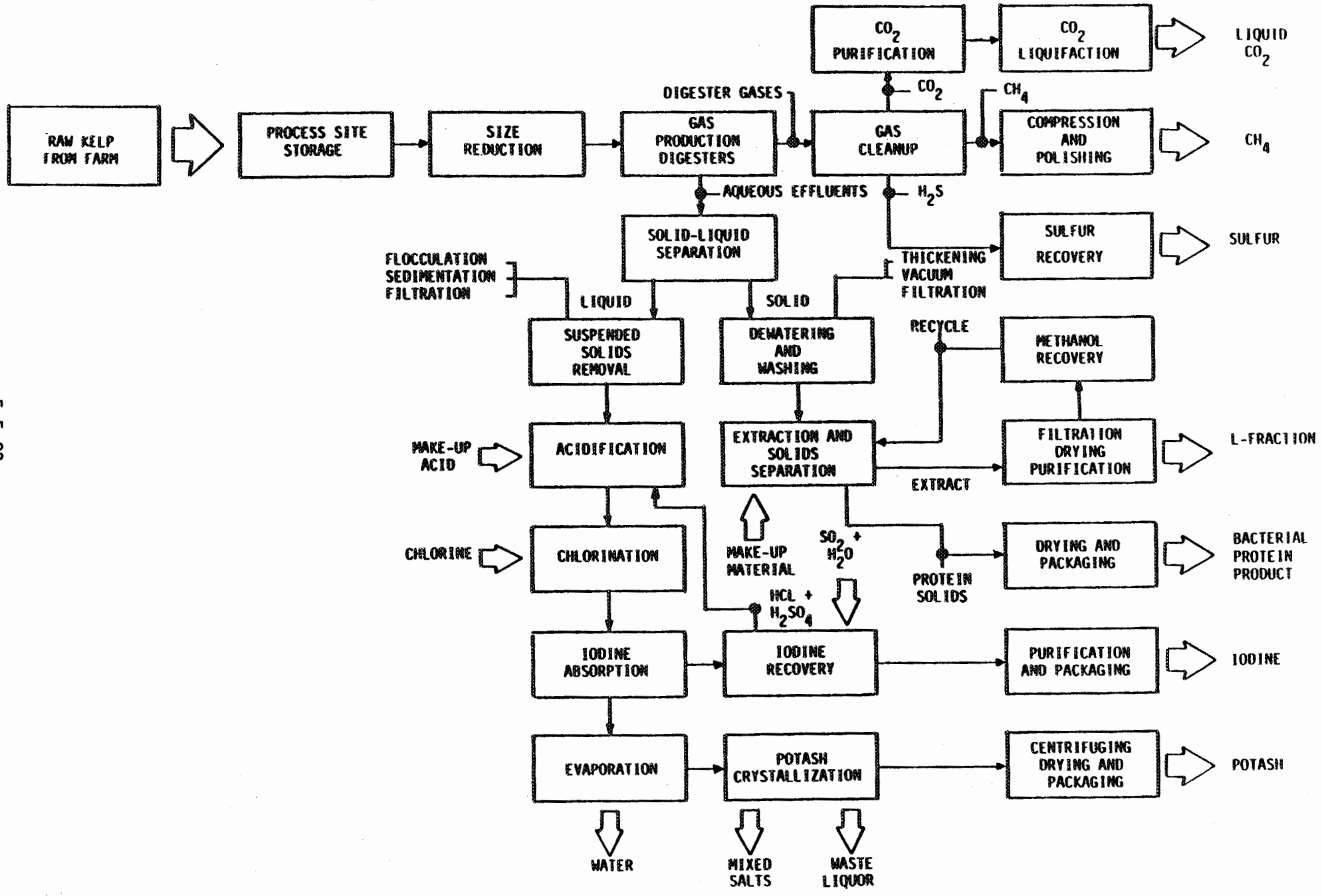


Figure 5.5-3. Process Schematic for Production of Gas and By-Products

the absorbent regeneration in gas cleanup is further processed for the recovery of sulfur using the Stretford process. The processing of hydrogen sulfide to sulfur is required in order to satisfy air pollution control requirements. Other effluents from the gas production process are the aqueous digester effluents containing both solids and liquid, and the carbon dioxide from the gas cleanup process. The steps involved in the gas production portion of the overall process shown in Figure 5.5-3 have been described in detail in the Parsons' report[1] and are only summarized in this report.

1. Bacterial Protein and L-Fraction.

The aqueous digester effluent is separated into a solid and a liquid fraction using a sedimentation tank. The solid fraction is further processed for the recovery of L-fraction and bacterial protein product. The liquid fraction is processed for the recovery of iodine and potash.

Solids from the separation step are concentrated using thickening and vacuum filtration processes. The cake is given a waterwash to reduce the inorganic salts concentration in the protein solids to a level acceptable for its intended use as an animal feed supplement. The L-fraction recovery process, based on methanol extraction of the washed cake,is currently in the early stages of laboratory development. Based on the laboratory procedure used for the recovery of the L-fracton, process steps will most probably include: extraction with 80 percent methanol for several hours; filtration of the extract; and drying. Appendix I describes the results of the laboratory experiments on sample preparation and characterization of the L-fraction. Further purification of the L-fraction may be accomplished by repeating the process sequence. Since the eventual applications of the L-fraction are not specifically defined at present, the recovery process includes only one sequence of steps. The methanol in the extract is recovered in the drying steps and recycled back to the extraction step. The solids or the cake produced from the extract filtration represent the protein-rich product that can be used as an animal feed supplement. Further processing of the protein-rich solids includes drying and packaging of the material. The use of the proteinaceous digester solids as an animal feed supplement is predicated on the early exploratory work done on the Marine Biomass Program.[3]

2. Iodine.

The recoveries of iodine and potash from the liquid stream emanating from the solids sedimentation process are based respectively on existing carbon adsorption

and crystallization processes. The liquid stream must be made free of suspended solids before feeding it to the carbon columns for iodine recovery. This is achieved by chemical flocculation, sedimentation, and sand filtration. The liquid is then acidified with a mixture of sulfuric acid and hydrochloric acids to a pH below 3.0, and chlorinated with chlorine gas at a rate somewhat in excess of the stoichiometric ratio of 0.28 pound of chlorine per pound of iodine to liberate iodine. The acidificaton and chlorination reactions are rapid and can be accomplished using in-line mixing techniques. Iodine is then displaced by chlorine and adsorbed on activated carbon. Once a carbon column is saturated with iodine, it is desorbed using a solution of hydroiodic and sulfuric acids, (HI + H_2SO_4) to which water and sulfur dioxide are added continuously.

$$I_2 \text{ (adsorbed)} + 2\ H_2O + SO_2 \longrightarrow 2\ HI + H_2SO_4$$

A part of the HI-H_2SO_4 mixture is continuously withdrawn and treated with chlorine to precipitate iodine. The HCl and H_2SO_4 mixture is a by-product of the chlorination reaction used in the acidification step. The precipitated iodine is filtered, dried with sulfuric acid, and melted in a kettle under sulfuric acid. The melted iodine is withdrawn, solidified, and packaged.

The carbon adsorption process has been successfully used in both the U.S. and Japan for the recovery of iodine from subsurface brines. It was selected for this application as a result of discussions with the North American Brine Resources Company which is currently involved in the application of this technology in the U.S. for the production of iodine from subsurface brines. The advantages of this technology over others such as those based on air or steam stripping of an iodine containing stream, include: a higher process recovery efficiency, capability to handle a wider range of influent iodine concentrations, lower operating energy requirements, and improved economics at smaller system capacities. From the process chemistry of the iodine recovery process, it can be seen that a significant process cost is incurred by the use of chemicals used in the process. In addition, the concentration of iodine in the feed stream is a significant economic variable because of the requirement to adjust the pH to below 3.0 prior to chlorination. This means that the higher the iodine concentration, the lower the acid cost per unit mass of iodine recovered. For carbon based recovery processes, the economic cutoff is 30-40 ppm of iodine concentration in the feed stream; the concentraton in the kelp brines is expected to be 6 to 15 times higher. Further, in current production processes using subsurface brines, the

energy cost of pumping is a significant fraction of the overall cost. Since no extensive pumping operations are involved in processing kelp brines, significant potential cost advantages may accrue for iodine produced from kelp.

3. Potash.

The aqueous stream leaving the carbon adsorption process can be further processed for the recovery of potash through evaporation and crystallization. However, detailed and clear definition of all the processing steps required to produce potash cannot be generated at present since an accurate and complete composition of the liquid stream downstream of the iodine process is not available. In any case, it is known that the feed stream has a low concentration of KCl, and must be concentrated through evaporation. A multieffect evaporation system is used for this purpose. A pH adjustment of the stream may also be needed prior to evaporation because of the highly acidic nature of the effluent from the iodine carbon column. Following evaporation, supersaturation with respect to the potash may be achieved using equipment such as a crystallizing evaporator or a vacuum crystallizer. The selection of the crystallization equipment will be determined by the composition of the stream. For purposes of this study, a crystallizing evaporator system was selected since at elevated temperatures KCl has a higher solubility than NaCl, the other principal inorganic salt present in the feed. At ambient temperatures, NaCl has a higher solubility than KCl. Following the crystallization process, the crystals are separated through centrifugation, dried, and packed. Recrystallization may be needed to develop a special grade product. For purposes of this study, a commercial grade product is assumed and therefore no additional refining will be assumed. As discussed in the previous section, 95 percent of the potash used in the U.S. is used in fertilizer For such usage, the K_2O content must meet 60 percent (equivalant to 49.8 weight by percent K), and the presence of minor by-products is inconsequential. The potash product from the kelp effluents is intended for the same type of application.

4. Carbon Dioxide.

The carbon dioxide separated from the methane stream will be processed for applications such as refrigeration, beverage carbonation, and rapid chilling but must be purified and liquified for these applications. These applications were selected as being more conservative for economic analysis purposes. The product requirements for food grade CO_2 application are more stringent compared to an application such as enhanced oil recovery. Another major application of carbon

dioxide is in urea manufacture. However, urea manufacturing facilities are generally located next to the ammonia manufacturing facilities from which they can obtain both ammonia and carbon dioxide required for the urea manufacture. Carbon dioxide is a byproduct of ammonia manufacture.

As pointed out in the previous chapter, the economics of CO_2 usage is very site dependent. For purposes of this analysis, it is assumed that the plant siting will allow this usage of CO_2. Since the food processing market, in which liquid CO_2 finds its major use, is highly segmented and is frequently clustered around large urban centers, the CO_2 processing facilities must be strategically located to be economically practical.

Carbon dioxide produced by regeneration of the absorbent medium in the digester gas cleanup process may contain traces of hydrogen sulfide and organics. These must be removed prior to the liquifaction process in order to avoid causing a taste or odor in the product. The CO_2 gas specifications include a purity of 99.9 percent +, moisture content equivalent to -60°F dew point, max 20 ppm volatile noncondensibles, max 5 ppm of heavy condensibles such as compressor oil, max 25 ppm ammonia, max 5 ppm NO_x, max 5 ppm SO_2, and no atypical odor.[15] Purification methods based on scrubbing with potassium permanganate, potassium dichromate, and activated carbon are available and can be used to control the H_2S and organics content in the CO_2 stream.

$$3\ H_2S + 2\ KMnO_4 + 2\ CO_2 \longrightarrow 3\ S + 2\ MnO_2 + 2\ KHCO_3 + 2\ H_2O$$

$$K_2\ Cr_2O_7 + 3\ H_2S + H_2O + 2\ CO_2 \longrightarrow 3\ S + 2\ Cr\ (OH)_3 + 2\ KHCO_3$$

The manganese dioxide, sulfur, and chromium hydroxide appear as precipitates and are discarded. For application of the potassium permanganate or the dichromate scrubbing process, the feed gas may be bubbled through the solution or contacted with the liquid in a packed tower in which the scrubbing solution is constantly recirculated.

The scrubbed CO_2 stream is liquified at a temperature between 31°C (critical point) and -56.6°C (triple point) by compressing it to the corresponding liquefaction pressure and removing the heat of condensation. Near the critical temperature, water may be used for cooling however compression of gas to 75 atmosphere is required. If a refrigerant-cooling system is used to provide cooling to a temperature of -12° to -23°C, compression of gas to 16-24 atmospheres is required. In either process, the basic process steps are

compression, filtration and dehydration to remove moisture and oil, and condensation. The liquified CO_2 can be stored at ambient temperatures in refrigerated insulated tanks.

b. Co-Products Production Processes

The organic and inorganic co-products considered include algin, mannitol, fucoidan, potash, iodine, and the L-fraction. An overall process scheme for the production of these chemicals from raw kelp is shown in Figure 5.5-4.[4] It may be noted that Figure 5.5-4 does not correspond to the second system scenario sketched in Figure 5.5-2 which includes production of gas and by-products. The processes for the referenced scenario are discussed later.

The overall scheme is based on leaching ground raw kelp with hot water which leaches out mannitol, fucoidan, and inorganic salts into the water stream, and reacting the leached kelp with sodium carbonate to solubilize algin which can be separated and further processed to produce algin. The residual solids from the algin digestion process contain the L-fraction and the cellulosic constituents of kelp. The former is recovered by the methanol extraction method described earlier. Recovery of fucoidan from the leachate water is based on its precipitation with isopropyl alcohol (IPA), and following that, mannitol is recovered by evaporation and crystallization. The mother liquor from the mannitol crystallization process contains potash and the iodine, which are recovered using processes as described earlier. The following sections include descriptions of processes for the recovery of algin, mannitol, and fucoidan. Processes for iodine, potash, and L-fraction have been described earlier, and are applicable to the scheme in Figure 5.5-4.

Feedstock Operations. Kelp entering the chemical plant is subjected to a two stage milling operation in which it is reduced first to one inch lengths and finally to 1/4 inch pieces. The milled kelp is moved to a large preservation tank by means of a progressive cavity (Moyno) pump. Here it is immersed for about 16 hours in 0.05 percent formalin solution, following which it is pumped continuously to the leaching system. Preservation of the kelp is necessary in order to prevent any deterioration in quality due to bacterial activity.

Kelp Leaching. This process requires a five-stage countercurrent wash of the kelp using water at 180°F. Approximately one part of water per part of kelp is needed, and water is recirculated in each wash box. Turbine mixers are used in each wash box to maximize leaching of the water soluble chemicals from kelp.

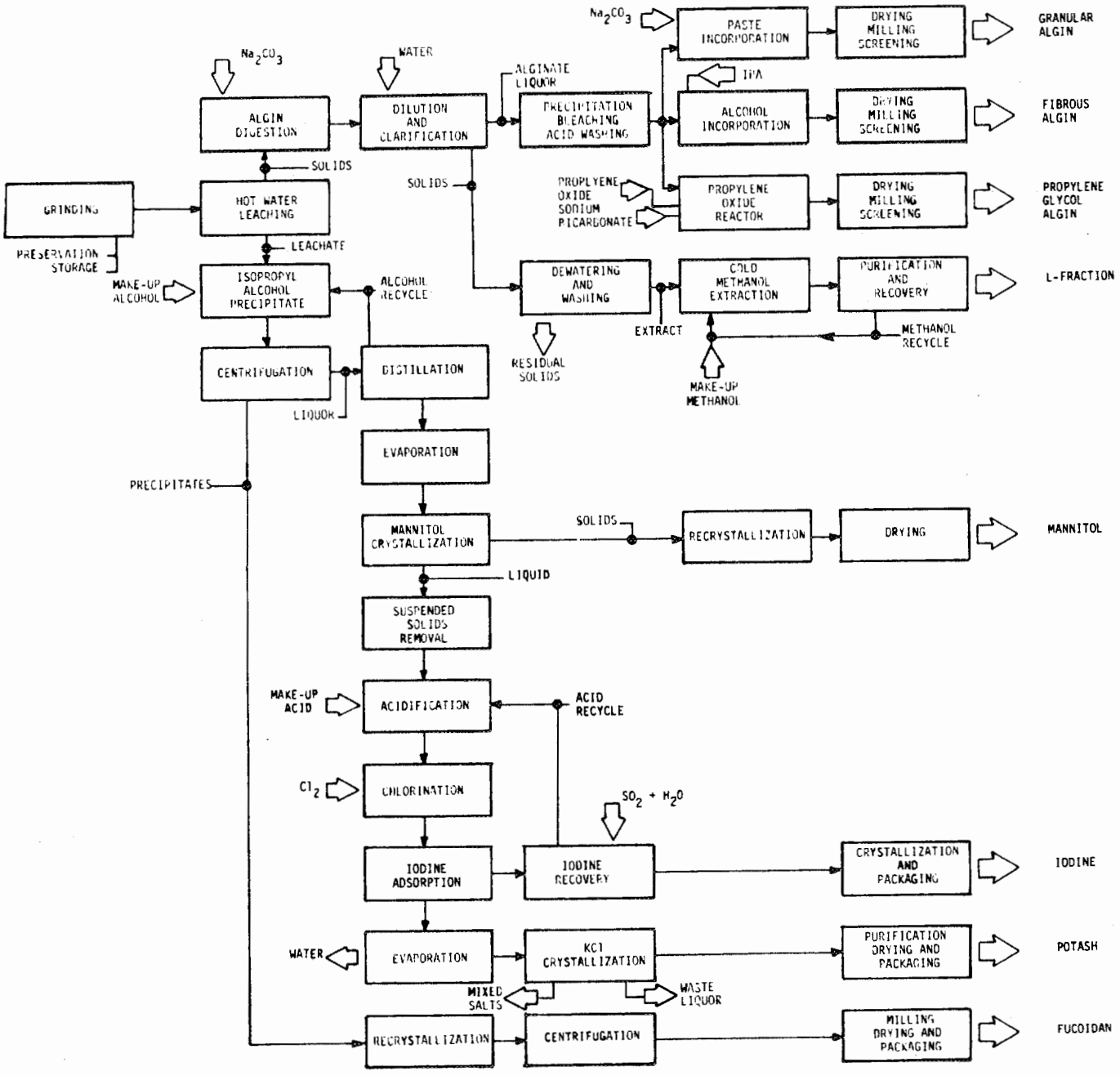


Figure 5.5-4. Process Schematic for Production of Co-Products From Raw Kelp

Separation of water and kelp is carried out using either gravity fed revolving screens or more expensive but cleaner stationary DSM screens. The latter greatly reduce losses of fine kelp particles but require self-priming pumps between stages.

Leach water coming from this system proceeds to a large storage tank which acts as a surge ahead of the fucoidin recovery process. The leached kelp is pumped to the digesters of the algin plant.

1. Fucoidan Recovery.

Fucoidan and mannitol are both recovered from the solution coming from the kelp leaching step.

Separation of fucoidin is relatively easy, as fucoidan is insoluble in 45-50 percent isopropyl alcohol solution. A stringy precipitate is produced which can be readily separated using a basket centrifuge. Dilute alcohol recovered at this stage is recirculated through a still.

Provision is made to re-dissolve and re-precipitate this material to eliminate impurities. After centrifugal separation, the fucoidan fibers are fluffed-up by passage through a milling fan before going to a jacketed rotary vacuum dryer. This permits additional recovery of the solvent remaining in the precipitated colloid. The dried fibers are then finished in a milling and screening system set up ahead of a blending-packaging station.

Large amounts of solvent are required in this process which can be recovered by distillation and recycled. Small amounts of alcohol from the algin line (described later) are also combined with this stream for recovery purposes. Make-up alcohol due to losses is estimated at 0.8 pound per pound of product.

Steam and water requirements at this step for the alcohol recovery are heavy. However, the warm water coming from the condensers on this unit may be used at the dilution step of the algin process. No such energy saving was assumed in the utility estimates included in this report.

It should be pointed out that fucoidan is not available at the present time on U.S. or world markets. A sales or market development program would be required before its full potential is reached. The unusual colloidal properties of the chemical suggest high potential for new uses in a variety of fields, particularly the cosmetics industry.

2. Mannitol Recovery.

The liquor from fucoidan precipitation goes through an evaporation-crystallization process for mannitol recovery. The process was developed at the Kelco Company from work done earlier in Europe. This process was investigated in the Kelco laboratory, and a pilot plant and a full scale plant were also operated for a short time. In the original process, a lime defecation reaction similar to that used in the sugar industry was used to precipitate fucoidan. The lime precipitation proved to be inefficient and difficult to control as fucoidan concentrations in the leach solution changed with season. Colloidal materials escaping this step fouled the heating surfaces of the evaporators and caused complications in mannitol crystallization.

In the proposed scheme, alcohol precipitation is used. Clear solutions are obtained from this process and fucoidan precipitation is complete. Evaporation of this solution is carried out in a submerged tube, forced circulation unit. In the suggested process, this evaporator is large enough to hold a two day supply of concentrated liquor, allowing removal of half its contents without upsetting its operation.

A portion of the concentrate is withdrawn to a vacuum crystallizer once a day. Mannitol separating after a period of evaporative cooling is recovered in a series of basket centrifuges. Part of the mother liquor is recirculated to the crystallizer while approximately one third is bled off to the iodine-potassium chloride plant.

Crude mannitol crystals are re-dissolved in fresh water and re-crystallized in a second, smaller vacuum unit. Basket centrifges are used, as before, to separate the mannitol product while the mother liquor is recirculated to either the secondary or the primary crystallizer.

Crystals recovered as above are dried in a small stainless steel rotary dryer, screened, and milled to meet sales specifications. The latter steps and the packaging process may have to be carried out under "clean room" conditions to meet requirements in certain applications.

3. Algin Recovery.

The algin process shown schematically in Figure 5.5-4 is designed to produce three different types of product. This type of product portfolio is necessary in order to meet the wide range of performance requirements for algin which vary with

the intended use. For example, the granular and the fibrous alginates which are finished at a pH of 7.5 are used under neutral or alkaline conditions, becoming insoluble in acid solutions. Propylene glycol alginates on the other hand possess a finished pH of 4.0 and are designed for use in acid solutions, becoming insoluble under alkaline conditions. Since algin quality may vary from one kelp batch to another depending on a number of variables related to growth conditions, age, and processing conditions, the portfolio approach also allows the producer to meet the particular performance requirements by blending different products.

The algin production process is based on solubilizing it as the sodium salt by adding an alkali to the washed kelp. Dilution of the resulting paste with large amounts of hot water is necesary to facilitate filtration of the alginate liquor. Algin is then recovered from the clarified liquor by precipitation as calcium alginate. After conversion of this material to alginic acid (also water insoluble) by an acid wash, the alginic acid is converted to the soluble products of commerce by reaction in a concentrated paste or in a solid fibrous form with sodium carbonate, potassium carbonate, etc. or with propylene oxide.

The following gives a more detailed description of the various steps in the production process.

Kelp Digestion. A controlled amount of leached kelp is mixed continuously with a metered flow of 5 percent soda ash solution and three parts of water at 190°F. This mixture is pumped to a series of digestion tanks equipped with turbine mixers. Temperature here is held at 190-200°F by means of direct steam introduced tangentially to aid mixing. Sodium carbonate additions are controlled to hold the pH of the mix at 10.0. Circulation pumps are needed to move the gel from one tank to the next controlled by level sensors in the forward tank. Total reaction time is of the order of four hours.

Dilution. The digestion mix coming from the above system is much too concentrated and viscous for clarification and must be diluted to a viscosity of about 20 cps., Brookfield, at a temperature of 180°F. This requires an additional six parts of hot water. Dilution is accomplished in an enclosed tank equipped with a turbine mixer. This entire operation runs continuously at a rate determined by the downstream filters. A large run-down tank is needed to provide surge between these two steps. Suitable temperature and viscosity controls are required for a smooth operation at this station. The water may be heated by direct steam.

Filtration/Centrifugation. Liquor going to the production of granular alginates need not be sparkling clear following clarification since the end products can contain a certain amount of haze. For this reason, it is processed without the use of filter aid using continuous belt, pan filters. Further processing is carried out on a separate precipitation-acid wash line.

Insoluble materials must be completely removed from the raw alginate liquor intended for the manufacture of fibrous or propylene glycol alginates. This is accomplished by using a battery of rotary precoat filters varying in size from 300 to 1000 square feet of filtering area. It is estimated that about 10,000 square feet will be needed to produce the 15,000 pounds of algin. The filtration based separation methods described here are currently in use though centrifugation may be a more cost-effective method of achieving the same objective.

Past experience has demonstrated that regular diatomaceous earth filter aids cannot be used in this service due to extensive cracking of the cake. Fine popped perlite, is used at precoat depths of up to four inches. After sealing, such a precoat is cut off at the rate of 0.005 to 0.007 inch per revolution to maintain a constant flow of clear liquor. The clarified liquor goes to a surge tank at the head of the appropriate acid line.

Precipitation, Bleaching and Washing. Algin is sold in various forms which differ in chemical composition (sodium, potassium, ammonium, propylene glycol alginates), calcium content, viscosity, particle size and color. In some cases, an algin product is blended with other inorganic or organic materials as required to meet specific requirments by a particular customer.

To assist in the output of these various products, the precipitation acid washing station has been divided into three lines - one serving the hazy granular products and the others for the production of more refined products. This permits producing alginic acids of differing viscosities, color and calcium content.

Since the processing of fresh, preserved kelp usually results in algin of a relatively high viscosity, a jacketed rotary reactor is included in the system to permit the breakdown of viscosity where needed by applying heat to the alginic acid. Extensive fiber losses in the acid wash tanks are avoided in this way.

All three acid lines are identical and are described below.

(a) Precipitation: The three precipators consist of 5000 gallon tanks into which calcium chloride brine and clear alginate liquor are introduced at controlled rates under the eye of a propellor agitator. A hard fiber is produced which can be successfully dewatered on a gyratory screen. Detention time in this reactor runs about 20 minutes. The underflow from the screen is discarded.

(b) Bleaching: Fiber separated in the above screen falls into a second identical tank where it is mixed with a small amount of a 10 percent calcium hypochlorite solution. Snow-white fibers are produced which are separated using the gyrating screen with the fiber moving continuously to the acid wash tanks and the effluent liquor going to discharge. A hood and ventilating fan are provided in order to remove small amounts of chlorine that may be liberated here.

(c) Acid Washing: The acid wash system consists of three agitated 5000 gallon tanks. Here the algin meets a countercurrent stream of dilute hydrochloric acid. Alginic acid fiber is moved through this system by suitable pumps. Wash water is separated at each stage by gyratory screens. Muriatic acid is metered into the final wash tank at a rate such that the pH is controlled at a value between 1.5 and 2.0, depending upon the calcium content desired in the alginic acid product.

Alginic acid is discharged from the final gyratory screen into the throat of a horizontal screw press that removes additional water and yields a fibrous product which feels quite dry but still contains in excess of 80 percent moisture. This material is stored in a shallow V shaped bin serving as a surge ahead of the incorporators. Fiber is moved from this bin, by means of a screw conveyor, into a stainless steel milling fan where it is fluffed before being conveyed to the incorporation system for final conversion to saleable products.

In some cases, the alginic acid is diverted to a steam jacketed rotary reactor where sufficient heat is applied to yield the reduced viscosity needed in certain products.

4. Incorporation, Drying and Finishing.

(a) Granular Products. When alginic acid, at 20 percent solids content, is reacted with an alkali such as sodium carbonate, a thick doughy paste results.

The reaction rate under such conditions is slow, requiring 30 to 45 minutes for completion even when using heavy mixing-kneading equipment. Alkali additions are controlled to produce a pH between 6.5 and 7.5 in the mix at the end of this period. If other materials are required in the final product, they are blended in at this time. Fines from the milling-screening step are added just before unloading the mixer to improve the handling properties of the paste.

Before drying, the resulting paste is pelletized or "wormed" by passage through a perforated plate, screw extruder similar to a Hobart meat chopper.

The "worms" from the above step are dried in a fluid bed dryer having a deck area of about 25 square feet. Sufficient hot air is used to cause the individual particles to move around violently. Dehydration is performed at product temperatures between 140° and 150°F. Inlet air temperatures are held at approximately 250°F. A dust removal system is incorporated.

The dried material overflows a dam at the end of the dryer into the fan of an air-veying system which elevates it to a two-deck gyrating screen in which 20 and 80 mesh surfaces are usually used. Oversize material (+ 20 mesh) gravitates to a hammer mill for size reduction before being returned to the screens. The air stream used for conveying the material helps dissipate the heat generated by the milling action and ensures that material viscosity is not lost due to thermal breakdown.

In-specification material (-20 + 80 mesh) is picked up in a second air stream and conveyed to suitable storage bins. Fines (-80 mesh) are returned to the incorporator for mixing with subsequent batches of product.

Three storage bins are provided to hold alginates of different colors, pH or viscosity ranges. Algin is discharged from the bottom of these bins by screw conveyors into an air stream which moves it to the Air Mixer blender. Discharge is scheduled to deliver calculated weights of any desired lot to this unit for blending into saleable material. Mixing is accomplished by a series of short air blasts. Blends of approximately 3000 pounds are made, which after laboratory testing are packed in drums or bags.

(b) Fibrous Alginate. High quality alginate products are produced by reacting alginic acid made from clear sodium alginate liquor with the required amount of alkali in an isopropyl alcohol medium. This is accomplished in an agitated, totally enclosed 2000 gallon tank. Two vessels are needed to permit a batchwise

operation in which one unit is reacting while the other is being unloaded to a screw press. Reaction is carried out using approximately 4000 pounds of alginic acid fiber, an equivalent amount of 10 percent sodium or potassium carbonate solution and sufficient solvent to yield a liquid phase containing approximately 40 percent isopropyl alcohol. The final pH of this mix is adjusted to between 7.5 and 8.0. The reacted mixture is dewatered by passage over a gyratory screen, the underflow being returned to the distillation system, and the fiber to a screw press which raises the solids content to about 40 percent.

Drying, milling, screening, storage and blending of these products are accomplished in a system similar to that for the granular alginate.

(c) Propylene Glycol Alginate. Production of these materials is somewhat more complicated in that the starting alginic acid must be dried to about 40 percent solids and partially neutralized with sodium bicarbonate before reaction with propylene oxide. This is accomplished in a tank reactor system similar to that used for the fibrous alginates, the required amount of alginic acid being added in an isopropyl alcohol medium. Dewatering by a screw press then results in the desired starting material.

These partially neutralized fibers are reacted with a calculated weight of propylene oxide in a pair of jacketed rotary vacuum dryers. Reaction time is about four hours at a maximum temperature of 125^{o}F. Since considerable heat is developed during this reaction, cooling water is needed. The initial gas absorption rate is rapid, and a vacuum develops in the reactor. Completion of the reaction is indicated by return of this pressure to normal. Gas addition is continued until the pH of the reaction mix stabilizes at 4.0

The reacted material is then dried under vacuum using steam heat. The final product is unloaded to a milling-screening-blending system similar to that described earlier.

c. Integrated System Process (Scenario 2)

An overall process for the integrated system for the production of gas, by-products and co-products corresponding to the second scenario is shown in Figure 5.5-5. The liquor from the mannitol crystallization process is combined with the liquid stream of the separated digester effluents, and the two are processed together for the recovery of iodine and potash. Since these organic chemicals are not affected chemically by any of the preceding processing steps in

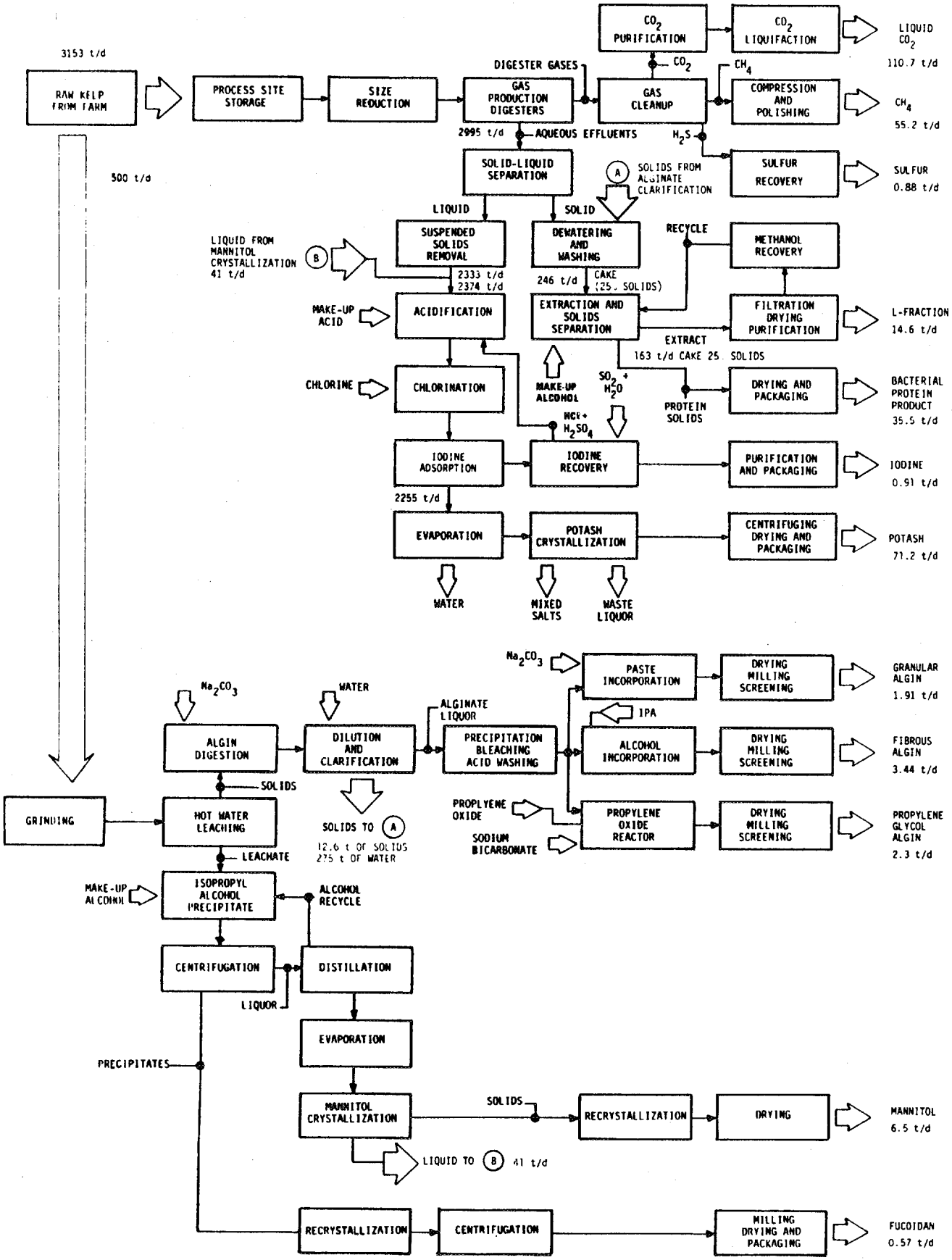


Figure 5.5-5. Process Schematic for Production of Gas, By-Products and Co-Products

either of the two schemes, no adverse effect on the quality of the products recovered or any increased difficulty or complexity in the downstream recovery processes are expected. The same rationale is applied to the solids separated from the alginate liquor and those separated from the digester effluents for the recovery of the L-fraction. It has been shown in experiments conducted on the Marine Biomass Program that the L-fraction does not break down during the anaerobic gasification process.[2] By combining these streams, the capital and operating costs for the overall system can be reduced. The solids separated from the alginate liquor contain, in addition to the L-fraction, kelp carbohydrate fractions such as laminarin and cellulosics. Such components when mixed with the protein-rich solids separated from the digester effluents are not expected to present any problems effecting end product usage as an animal feed supplement.

The obvious reason for combining these streams is to achieve lower capital and operating costs.

5.5.4.2 PROCESS RECOVERY EFFICIENCIES

Recovery efficiencies for each of the various by-products and co-products are listed in Table 5.5-13. The values for L-fraction and fucoidan recovery are more uncertain than the others due to their development status. That is also the reason for selecting their values on the low side compared to most other products. For iodine, algin, and CO_2 products, the recovery values represent direct actual manufacturing experience. Values for the remainder are based on commercial processes in similar applications.

Of the losses in algin manufacture, approximately 15 percent occur in the filtration of the alginate cake (calcium alginate). Additional losses occur in leaching (approximately five percent) caused probably by the loss of very low viscosity components of algin, from the acid lines (approximately five percent), and as dust during the finishing process steps (approximately three percent). Process efficiency in the case of mannitol is based on development experience at Kelco[4]. The recovery of mannitol at 70 percent is considered to be on the conservative side when the isopropyl alcohol precipitation of fucoidan process step is employed.

For the bacterial protein product, the bulk of the losses, (10 to 15 percent), are expected to occur in the various solids separation and concentration steps including sedimentation, thickening and washing. Additional losses occur in the

TABLE 5.5-13. RECOVERY EFFICIENCIES OF VARIOUS PRODUCTS

Product	% Efficiency
Algin	72
Mannitol	70
Fucoidan	60
L-Fraction	65
Bacterial Protein	80
Carbon Dioxide	90
Potash	60
Iodine	65

methanol extract separation, product drying and packaging steps; about two to five percent at each process step. Solids recovery from the alginate liquor filtration is also expected to have losses of 10 to 15 percent during the leaching and alginate clarification processes.

Carbon dioxide losses occur in the separation processes (from methane and hydrogen sulfide), and in purification steps prior to the liquifaction process. The technology of all the processes is commercialized fully, and a 90 percent recovery value is considered within the state-of-the-art.

Major losses of potash and iodine (10 to 20 percent), occur in the separation of the solids from digester effluents. The liquor stream from the mannitol crystallization process also reflects similar losses through the preceding process steps which include; kelp washing, leaching, alcohol precipitation, and mannitol crystallization. Additional losses occur due to the removal of the fine particles in the chemical flocculation process, (5 to 10 percent), and with the liquors from the potash crystallizers. The losses with the liquors cannot be estimated because of the lack of adequate composition data. The values of 60 percent and 65 percent for potash and iodine respectively, however, are considered achievable.

5.5.5 CAPITAL AND OPERATING COST ESTIMATES

In order to develop the capital and operating costs data for the various products, each of the process blocks shown in Figures 5.5-4 or 5.5-5 was defined to the next level of detail. Daily production of various products in the two scenarios were calculated. These are shown, along with major mass flows, in Figures 5.5-6 and 5.5-7. Design parameters were selected for each component process and equipment sizes were calculated. Cost estimates for major pieces of equipment and auxiliaries such as storage vessels, pumps, stirrers, chemicals, storage and feeding, etc., were made using data from a variety of sources including published literature and communications with equipment dealers, manufacturers and chemicals producers.[18-21] Installed costs were estimated using suggested factors in the referenced sources. Costs were then aggregated for each of the major process blocks shown in Figures 5.5-6 and 5.5-7.

The equipment capital cost makeup and major operating requirements for the production of the various chemicals are presented in a tabular format in Tables 5.5-14 through 5.5-23.

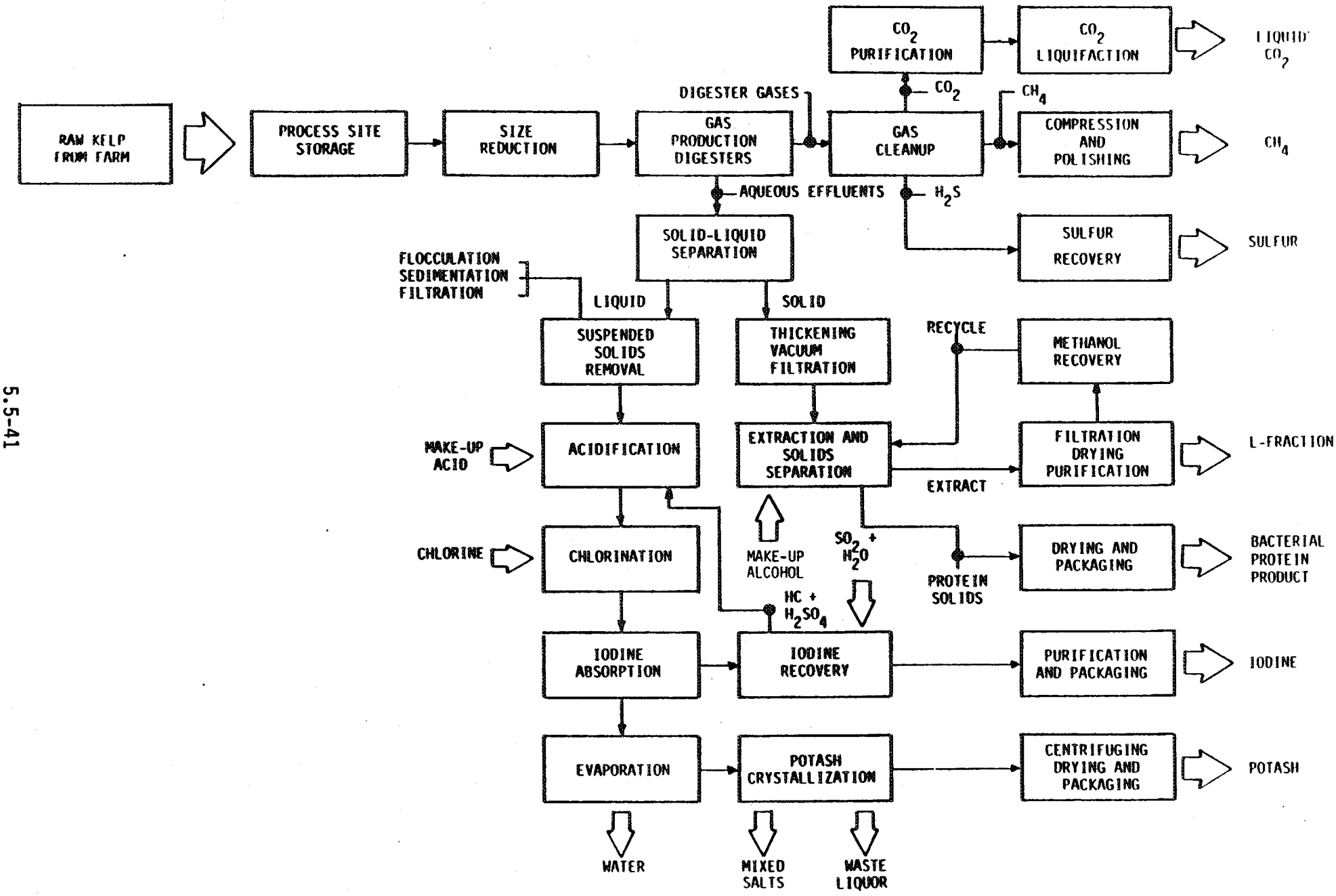


Figure 5.5-6. Estimated Daily Production of Various Products in Scenario 1

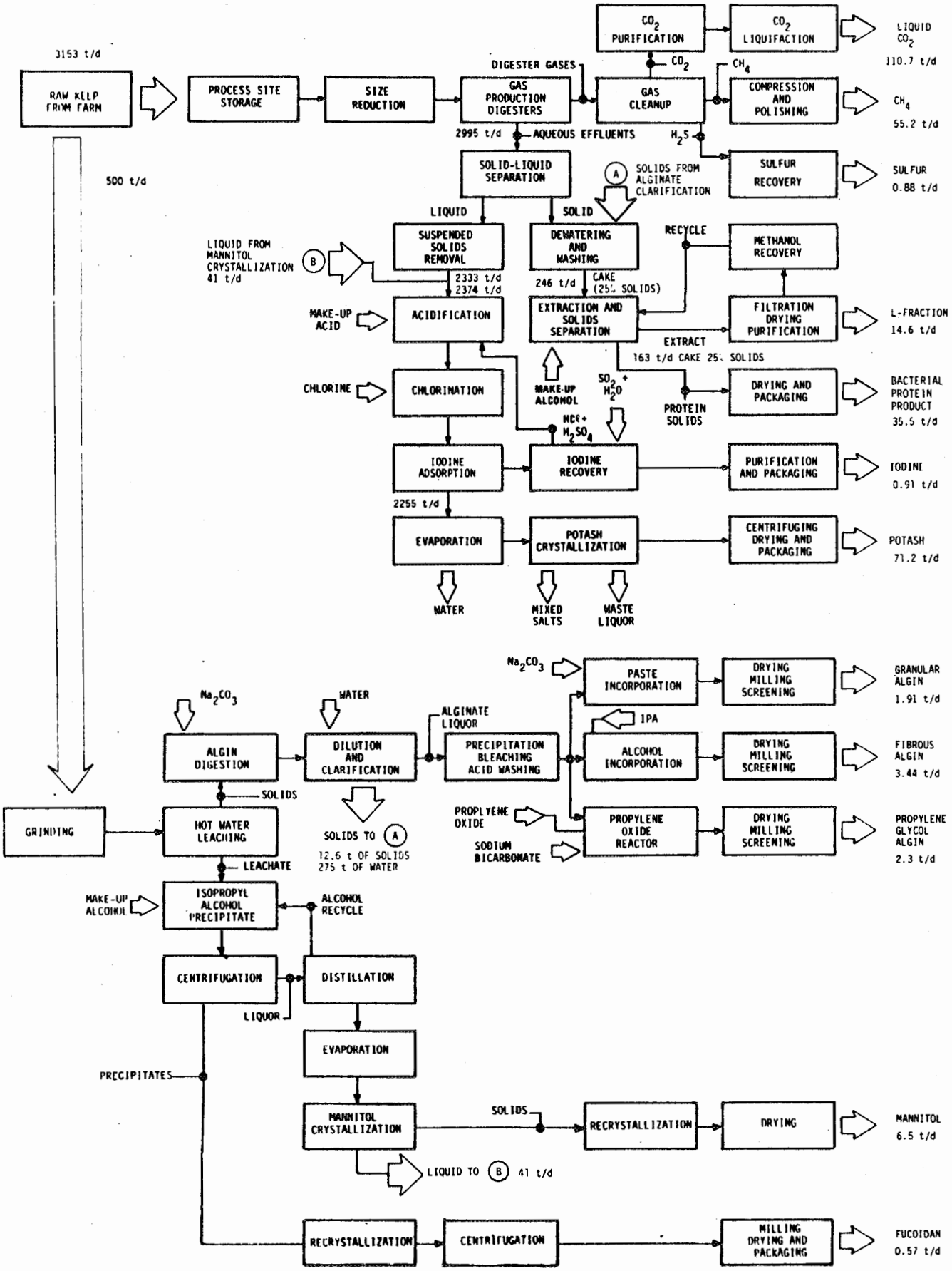


Figure 5.5-7. Estimated Daily Production of Various Products in Scenario 2

TABLE 5.5-14. ALGIN RECOVERY-CAPITAL COST ESTIMATES

Basis: 500 Tons/day of raw kelp
7.65 Tons/day of algin products

1. Feedstock Operations and Leaching 2.2×10^6

   a. Three vertical hammer mills: one 100 HP; two 75 HP with 3/8" screens.
   b. Two Moyno pumps 25 HP
   c. One 75,000 gal cone bottom, storage tank, steel.
   d. One 15,000 gal formalin storage tank, steel.
   e. One 200 gal agitated dilution tank & metering system
   f. Three 75,000 gal cone bottom gel storage tanks.
   g. Suitable storage silo and solution system for soda ash.
   h. Metering system for 10% sodium carbonate solution.
   i. One countercurrent flow leaching system consisting of five 5000 gal tanks equipped with turbine mixers, five revolving screens and suitable transfer pumps.
   j. One 25,000 gal leach water storage tank

2. Digestion 0.38×10^6

   a. Four 20,000 gal steel tanks with turbine mixers and tangential steam injectors.
   b. Four transfer pumps (150 gpm approx.)
   c. Suitable metering system for steam.

3. Dilution 0.3×10^6

   a. One 25,000 gal enclosed tank with turbine mixer, steel.
   b. Steam injector for hot water
   c. Suitable metering system for inlet water and heat.
   d. Suitable viscosity and temperature controllers.
   e. One 100,000 gal. surge tank, steel

4. Filtration 4.4×10^6

   a. Three centrifuges, stainless steel, 5 tons/hr.
   b. Filters to remove remaining solids from liquor
   c. Three 25,000 gal surge tanks, one at head of each line
   d. Suitable pumping system for liquor transfer

5. Precipitation and Acid Line 2.36×10^6

   Three systems in parallel made up as follows:

   a. One 25,000 gal clear liquor surge tanks on each line.
   b. One 5,000 gal. steel tank, propellor type agitator. Steel
   c. One gyratory screen, 60 in. in diameter, stainless steel
   d. Four 5,000 gal. tanks with turbine mixers. Rubber or plastic coating

TABLE 5.5-14. ALGIN RECOVERY CAPITAL COSTS ESTIAMTE (Cont)

e. Four gyratory screens, 48 in. in diameter, stainless steel
f. One screw press, stainless steel 10 in. diameter.
g. Five transfer pumps, approx. 100 gpm
h. One shallow surge tank with screw conveyor 1,000 gal, stainless steel
i. One milling fan - 3 ft. diameter, reinforced blades, stainless steel 25 HP
j. One jacketed reactor 3 ft in diameter x 12 ft in length, stainless steel

6. Incorporation System 2.8×10^6

a. One mixing and kneading machine. Sigma blades. Double U trough 500 gal. Tilting unload mechanism. 100 HP
b. One performated plate extruder. Hobart meat chopper type, stainless steel. 10 HP
c. Four 2,000 gal enclosed stainless steel tanks with turbine mixers
d. Two suitable slurry pumps, 10 HP, stainless steel
e. Two 48 in., gyratory screens, stainless steel, 30 mesh screens
f. Three 10" diameter screw presses, stainless steel
g. Two solvent pumps. 25 gpm, stainless steel
h. Two 300 cu. ft. jacketed rotary vacuum reactors and dryers.
i. Two fluidized bed dryers, 40 sq. ft. area, stainless steel.
j. Three two-deck gyratory screens. 48 in. diameter, stainless steel
k. Three 50 HP, hammer mills, stainless steel
l. Twelve stainless steel storage bins. 300 cu. ft. Screw conveyor discharge.
m. Three Air Mixer blenders 300 cu. ft., stainless steel, automatic loading.
n. Three automatic drum loading and weighing machines.
o. Three pneumatic conveying systems for milling, screening, storage and blending steps.

TABLE 5.5-15. MANNITOL RECOVERY-CAPITAL COST ESTIMATE

Basis: - 500 Tons/day of raw kelp
- 6.5 Tons/day of mannitol production

1. Evaporation and Crystallization 5.9×10^6

   a. One submerged tube, forced circulation evaporator possessing a volume of 25,000 gals and a heating area of 1,000 sq. ft., operating at 100 psi. To evaporate 50,000 lbs per hour. Stainless steel.
   b. Suitable pumps, condensers and control equipment to permit a continuous operation.
   c. One 15,000 gal vacuum crystallizer to permit cooling one 10,000 gal batch of evaporator concentrate per day.
   d. One 15 cu ft basked centrifuge. Stainless steel; gravity feed
   e. Suitable controls, pumps, etc. to unload crystallizer and move mother liquor to crude mannitol crystalizer (c) and to the potassiumchloride-iodine operation.
   f. Portable containers for crude mannitol.
   g. One 500 gal. solution tank with turbine mixer.
   h. One vacuum crystallizer, 5000 gal. capacity. Stainless steel
   i. One 15 cu ft basket centrifuge. Stainless steel; gravity feed.
   j. Suitable controls and mother liquor pump for above.

2. Finishing Mannitol 0.9×10^6

   a. One stainless steel counter current rotary dryer, 3 ft in diameter by 30 ft in length.
   b. One 48 in gyratory screen.
   c. One 25 HP hammer mill, stainless steel
   d. One drum loading and weighing system.

TABLE 5.5-16. FUCOIDAN RECOVERY - CAPITAL COST ESTIMATE

Basis: - 500 Tons/day of raw kelp
- 0.57 Tons/day of Fucoidan production

1. Precipitation 0.9×10^6

   a. Two 15,000 gal. tanks with turbine mixers. Steel
   b. Suitable pump and meter controls for leach water and isopropyl alcohol
   c. Two 20 cu ft backet centrifugals, stainless steel
   d. One 500 gal. surge bin and screw conveyor.
   e. One 2 ft. milling fan, 10 HP, stainless steel
   f. One 300 gal. solution tank with agitator, steel
   g. One 1,000 gal. precipitation tank with agitator, steel

2. Drying and Finishing 0.26×10^6

   a. One 100 cu ft rotary vacuum dryer. Jacketed for steam.
   b. One 10 HP stainless steel hammer mill
   c. One 24 in. gyratory screen - 2 decks, stainless steel
   d. One 50 cu ft Air Mix blender
   e. One drum loading and weighing machine.
   f. Suitable air-veying system for above.

3. Isopropyl Alcohol System 0.52×10^6

   a. One isopropyl alcohol still 3 ft in diameter with equivalent of 20 bubble cap plates. Equipped with re-boiler, stainless steel
   b. Suitable pumps and controls for automatic operation.
   c. Storage tank, 30,000 gal capacity, steel
   d. Pumps for feed to precipitator and return to run-down solvent. Meter for in-going material.

TABLE 5.5-17. IODINE RECOVERY PRODUCTION-COST ESTIMATES

Basis:

- $800,000 for an iodine production system from subsurface brines. The system includes granular media filtration, acidification, chlorination, iodine adsorption on carbon, iodine desorption, and purification. Production capacity, 120 tons/year.[21] Influent brine iodine concentration 200-600 ppm.
- Kelp aqueous effluents also have similar iodine concentrations.
- Mass Flow Rate = 2703 T/Day, Scenario 1

  = 2374 T/Day, Scenario 2

  (Iodine is concentrated in the mannitol crystallizer liquor; liquid mass flow decreases in the second scenario, but the mass of iodine remains the same.)
- Estimated Capital Cost = $1.52 x 10^6 for either case.
- Annual Production = 330 tons for either case.
- Estimated cost for the solids separation process downstream of the digesters = $0.6 x 10^6 (sedimentation tanks)
- Major operating costs include costs of chemicals, primarily chlorine.

Total Chlorine Requirment @ 0.66 lbs chlorine/lb of iodine
= 1200 lbs/day

Acid Requirement for pH Adjustment
= 7500 lbs/day

TABLE 5.5-18. LIQUID CARBON DIOXIDE-PRODUCTION COST ESTIMATE

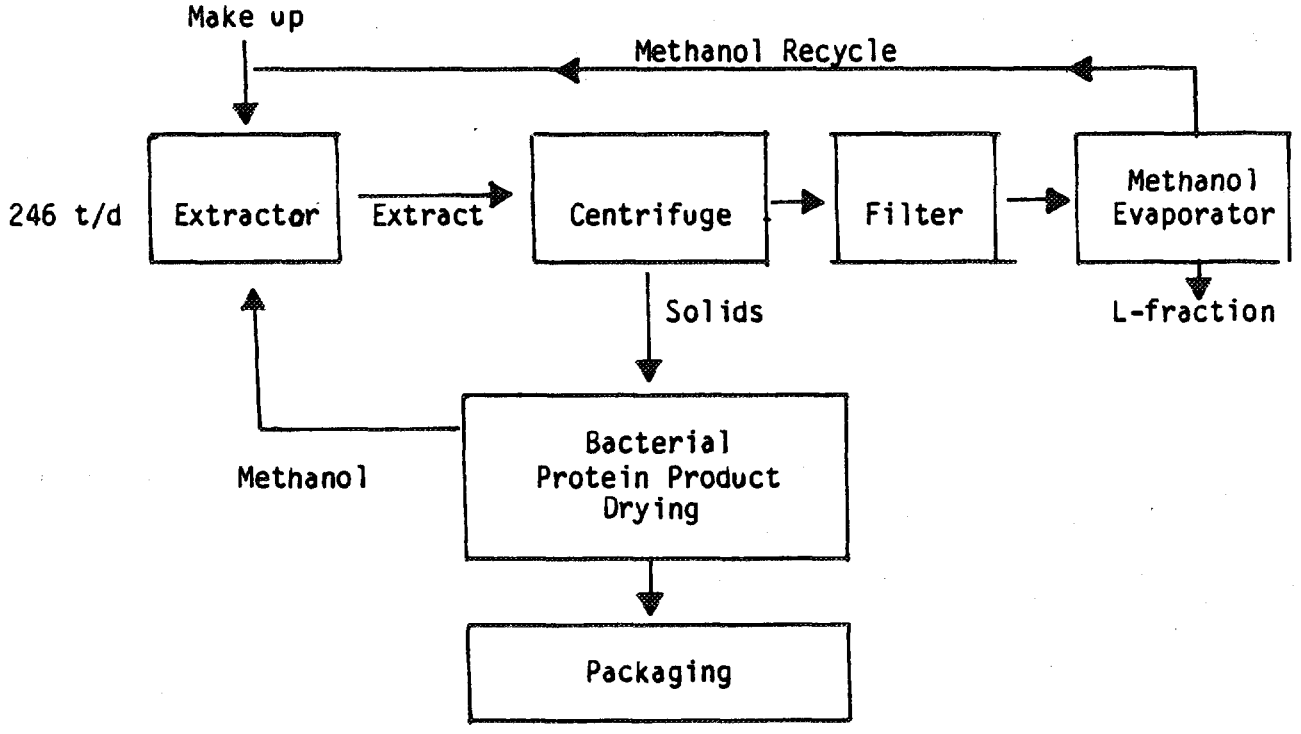
Basis:
- 90% CO_2 recovery efficiency
- 128 tons/day production for scenario 1
- 111 tons/day production for scenario 2
- $15,000/daily ton capacity as capital investment for a nominal plant size of 250 t/day[14].
- 0.6 power law for different sizes.

- Capital cost for CO_2 system for Scenario 1, 150 t/d capacity = $\$2.75 \times 10^6$
- Capital cost for CO_2 system for Scenario 2, 125 t/d capacity = $\$2.5 \times 10^6$
- Energy required for the process is the major operating cost, estimated at 180-200 KW Hr per ton of CO_2

TABLE 5.5-19. L-FRACTION AND BACTERIAL PROTEIN-PRODUCT COST ESTIMATE

Basis:

- 246 t/d of wet cake, 25% solids containing L-fraction and the bacterial protein.
- Extraction with methanol for 3 hours, 80% methanol by volume in the extraction process; stainless steel tank with a mixer, five 50,000 gallon tanks.
- Methanol from the extractor is evaporated and recycled.
- The bacterial protein rich solids are separated using stainless steel centrifuges, and the extract is filtered prior to evaporation. A pressure leaf or tubular filter used as the basis of costing, 2500 ft^2 area.



- Bacterial protein processing consists of drying and packaging the cake from the L-fraction centrifuges. Drying done in a stainless steel, indirect, steam-heated jacketed, rotary dryer.
- Metnanol recovered during drying is recycled.
- Makeup methanol assumed at 1 lb/lb of L-fraction product.

TABLE 5.5-19. L-FRACTION AND BACTERIAL PROTEIN-PRODUCT COST ESTIMATE (Cont)

- Capital cost for the L-fraction system for Scenario 1 or 2 (includes extraction system, centrifuges, filters, and methanol recovery and recycle) = 4.29×10^6

- Capital cost for the bacterial protein product For Scenario 1 or 2 (Includes dryer and packaging) = 0.77×10^6

- Capital cost for the dewatering and washing processes upstream of the extraction system (Includes solids thickening and vacuum filtration) = 1.8×10^6

- Major operating requirements include:

For L-fraction,	225×10^6 BTU/day of steam 1500 KW Hrs./day of electricity' 29200 lbs/day of methanol
For Bacterial Protein	77×10^6 BTU/day of steam 200 KW Hrs/day of electricity

TABLE 5.5-20. POTASH RECOVERY-CAPITAL COST ESTIMATE

Basis:
- 2568 t/d of aqueous stream (Scenario 1), contains 3.6% by wt. of KCl in solution.
- Need to evaporate 193,000 lbs/hr of water to achieve saturation with respect to KCl
- Use 200,000 lbs/hr of evaporation capacity for design purposes.

Capital Cost

Evaporater	$12.06 Million
Crystallizers	$ 6.56
Centrifuges	$ 1.0
Dryers	$ 1.34
Other	$ 0.5
Total	$21.46 Million

Using 0.6 power law for the evaporater portion of the cost in which estimated feed is 2255 t/d but the output product is the same,

Estimated cost for Scenario 2 = 11.15 + 6.56 + 1.0 + 1.34 + 0.5

= $19.55 Million

TABLE 5.5-21. PROCESS EQUIPMENT-INSTALLED COST SUMMARY

	Scenario 1 (MM $)	Scenario 2 (MM $)
Algin	-	12.44
Mannitol	-	6.8
Fucoidan	-	1.68
Iodine	2.12	2.12
Liquid CO_2	2.75	2.5
L-Fraction	6.09	6.09
Bacterial Protein	0.77	0.77
Potash	21.46	19.55
Process Equipment Installed Costs (exclusive of land)	33.19	51.95
Excluding Potash Recovery	11.73	32.40

TABLE 5.5-22. SUMMARY OF DAILY OPERATING REQUIREMENTS - SCENARIO 1

	Iodine	L-Fraction	Bacterial Protein	CO_2	Total
Water, Cu Ft	200	800	800	200	2000
Steam, MMBTU	-	225	77	-	302
Electricity, KWH	500	1500	200	21000	23200
Operating Labor, Man-Hrs.	48	84	40	40	212
Sulfuric Acid, lbs.	7500	-	-	-	7500
Chlorine, lbs.	1200	-	-	-	1200
Methanol, lbs.	-	29200	-	-	29200
Fuel Oil, gallon	-	-	-	-	200

TABLE 5.5-23. SUMMARY OF DAILY OPERATING REQUIREMENTS - SCENARIO 2

	Algin	Mannitol	Fucoidan	Iodine	L-Fraction	Bacterial Protein	CO_2	Total
Water, Cu Ft	150,000	-	-	200	800	800	200	170,000
Steam, MMBTU	1,000	1,312	142	-	225	77	-	2,776
Electricity, KWH	20,400	2,250	627	500	1,500	200	21000	46,477
Operating Labor, Man-Hrs	440	132	24	32	56	24	24	732
Sodium Carbonate, lbs.	15,300							15,300
Calcium Chloride, lbs.	18,837							18,837
Hydrochloric Acid, lbs.	12,000							12,000
Calcium Hypochlorite, lbs.	1,360 (527 lbs Cl_2)							1,360
Formalin, lbs.	8,500							8,500
Isopropyl Alcohol, lbs.	8,500		911					9,411
Propylene Oxide, lbs.	8,500							8,500
Sulfuric Acid, lbs.				7,500				7,500
Chlorine, lbs.				1,200				1,200
Methanol, lbs.					29200			29,200
Fuel Oil, gallons								500

Table 5.5-14. Algin
Table 5.5-15. Mannitol
Table 5.5-16. Fucoidan
Table 5.5-17. Iodine
Table 5.5-18. Liquid Carbon Dioxide
Table 5.5-19. L-Fraction and Bacterial Protein
Table 5.5-20. Potash
Table 5.5-21. Summary of Process Equipment Installed Costs
Table 5.5-22. Summary of Daily Operating Requirements - Scenario 1
Table 5.5-23. Summary of Daily Operating Requirements - Scenario 2

The costs are in 1982 dollars, and where needed M & S equipment cost index[22] was used to adjust the costs to 1982 levels. Capital and operating costs for the sulfur recovery system were previously factored into the gas production system[1] and therefore, are not detailed in this analysis. Daily operating requirements including operating labor for various chemicals and products for the two scenarios are summarized in Tables 5.5-24 and 5.5-25. It can be seen from Tables 5.5-24 and 5.5-25 that labor requirements for the processing of iodine, L-fraction, bacterial protein, and carbon dioxide have been scaled down in Scenario 2. The basis for adjustment is that a higher efficiency in labor utilization may be expected in the second scenario which is about three times larger than the system in Scenario 1. The operating requirements for potash are also not included in these tables, since as discussed below, its recovery does not appear to be economically justifiable.

Table 5.5-21 shows that of all the products, potash has the highest capital investment requirement. However, anticipated revenues from its sale are among the lowest as shown in Table 5.5-7. Using the data in these two tables, investment ratio* for each product can be calculated. These ratios are shown in Table 5.5-26 using Scenario 2 for illustration purposes. The investment ratio is the highest for potash production; furthermore, by including potash recovery, the ratio for the production system as a whole increases. The same is expected in Scenario 1. Table 5.5-24 also includes typical investment ratios for various industries, and clearly the value for the potash recovery is abnormally high. The reason for this is that the aqueous stream available for potash recovery is very dilute in KCl concentration approximately 3.5 percent and large evaporators are needed to remove

* Defined as capital investment required per dollar of annual sales revenue; Capital Investment/Annual Sales Revenue

TABLE 5.5-24. COMPARATIVE INVESTMENT RATIOS FOR SCENARIO 2

Algin	0.74
Mannitol	0.47
Fucoidan	1.34
Iodine	0.44
Liquid CO_2	1.78
L-Fraction	0.57-0.19
Bacterial Protein	0.96
Potash	12.5
Total System (excluding the gas and sulfur production components)	1.00-0.71
Total System (excluding the gas and sulfur production components, and without the potash production)	0.65-0.45

TYPICAL INVESTMENT RATIOS[18]

Refinery Units	3.58-3.72
Organic Chemicals	2.18-2.65
Inorganic Chemicals	2.58-2.96
Pulp and Paper	1.92-3.32

Note: To compare the values in the table with those in the enclosed block, multiply by 1.926 to use Total Capital Required as the basis instead of the Installed Process Equipment Cost. The factor 1.926 is derived from Table 5.5-25.

TABLE 5.5-25. ESTIMATE OF TOTAL CAPITAL INVESTMENT

	Scenario 1 (MM $)	Scenario 2 (MM $)
Process Equipment Installed Cost	11.73	32.40
Add 20% Contingencies	2.34	6.48
Battery Limits Plant Capital Cost (BLCC)	14.07	38.88
Site Preparation, 4% of BLCC	0.56	1.55
Industrial Buildings, 4% of BLCC	0.56	1.55
Storage Facilities, 12% of BLCC	1.69	4.66
Utility Plant, 4% of BLCC	0.56	1.55
Auxiliary, 1.5% of BLCC	0.21	0.58
Offsite Piping, 3% of BLCC	0.42	1.16
Fixed Investment (FI)	18.07	49.93
Add 15% for Engineering and Fee	2.11	7.49
Total Fixed Investment (TFI)	20.78	57.42
Working Capital, 10% of FI	1.81	5.0
Total Capital Required (exclusive of land costs)	22.59	62.42

water before KCl can crystallize. Using a capital investment ratio of 24 for the potash system, (12.5 multiplied by 1.926) at 8 percent cost of money, the gross sales from potash do not cover the finance costs alone. The capital investment is also very high compared with traditional minebased sources of potash production; $130-180 for the mine based sources[9,11] versus approximately $1700 estimated for the kelp based system in terms of per ton of annual KCl. There are additional operating costs and expenses in producing potash which have to be met. In addition to the high capital costs, the operating costs of the potash recovery are also expected to be fairly high due to the energy costs for evaporation. Based on relatively higher recovery cost considerations, both capital and operating, potash production is economically unjustifiable, and would decrease profits from the overall system.

In the schemes shown in Figures 5.5-6 and 5.5-7, there are process steps which lead to production of more than one product. There was no attempt made to allocate the capital or operating cost of those process steps among the various end products. However, care was taken to ensure that costs for all process steps were included. In Scenario 2, the costs of raw kelp feedstock handling and of performing various operations are allocated to the algin production process, although other products such as mannitol, fucoidan, and others are also produced. Similarly, the costs of the solid-liquid separation and suspended solids removal processes in either of the two scenarios are allocated to the Iodine process. The costs of the dewatering and washing processes for the solids fraction are allocated to the L-fraction and not shared with the bacterial protein product. In the case where the L-fraction was not recovered, one of the options investigated, the costs of the dewatering and the washing processes for the solids fraction, were assigned to the bacterial protein product.

5.5.6 ECONOMIC ANALYSIS

As stated earlier, the key objective of this task is to determine how the recovery of various chemicals and products from kelp or digester effluents can affect the economics of the gas production process. To achieve that, objective, it is necessary to develop data on total capital investment requirements, total operating costs and expenses, and revenues anticipated from the sale of the various products manufactured.

Table 5.5-25 shows the buildup of total capital required for the two scenarios from installed costs of the process equipment included in Table 5.5-21. The

factors used for site preparation, industrial buildings, storage facilities, utility plant, auxiliary, and offsite piping are typical of those for chemical plants as reported by Guthrie.[18] The factors for contingencies, engineering and fee, and working capital are typical of those used in such analyses. No estimate for land cost is included in the total capital investment requirements.

Table 5.5-26 summarizes the annual plant operating costs for the two scenarios. Using the operating requirements data developed previously (Tables 5.5-24 and -25), and the unit prices and rates in Table 5.5-27, annual costs for utilities, chemicals, and operating labor are calculated. The costs are based on 365 days/year operation. Direct supervisory labor cost is estimated to be 20 percent of the direct operating labor. The factors for labor overhead, plant maintenance, general plant overhead, insurance and real estate and property taxes are typical of those used in these analyses.[23] The total operating cost estimates reported in Table 5.5-26 do not include costs for the raw kelp itself.

Table 5.5-28 summarizes the estimated annual production and sales revenues of each product. The annual production estimates are based on 365 days per year operation. The sources for the prices of these chemicals and products were discussed earlier. The three algin products are valued individually since their prices differ over a factor of 2. Bacterial protein product is valued the same in Scenario 1 and 2, although the protein concentration in the product from Scenario 1, in which 100 percent of the farm production of kelp is anaerobically digested, is expected to be somewhat higher. This difference is considered to be insignificant for purposes of this analysis, particularly since the gross revenues from its sale contribute only a small fraction, 2 to 5 percent, to the overall gross revenues.

The profitability analysis of the two scenarios is shown in Table 5.5-29. In addition to the direct and indirect manufacturing and plant operating costs, there are other expenses. Selling expense is the major one, particularly for a product such as algin which requires a substantial and constant effort in applications development and customer service. L-fraction is classified in the same category as algin. To provide for the selling expenses which include salesmens' wages and commissions, warehousing, advertising, and customer service, 18 percent of the gross sales are allocated. Research and development required to develop new applications and products is another significant item, and 4 percent of the gross sales revenues are earmarked for that purpose. Administrative overhead which

TABLE 5.5-26. SUMMARY OF ANNUAL PLANT OPERATING COSTS

	Scenario 1 (MM $)	Scenario 2 (MM $)
Water[1]	0.01	0.86
Steam[1]	0.55	5.03
Electricity[1]	0.74	1.47
Fuel Oil[1]	0.09	0.23
Chemicals[1]	1.56	5.69
Direct Operating Labor	0.85	2.94
Supervisory Labor (20% of direct labor)	0.17	0.59
Labor Overhead[2] (75% of operating + supervisory labor)	0.77	2.65
Plant Maintenance (6% of BLCC)	0.84	2.33
General Plant Overhead[3] (1.5% of BLCC)	0.21	0.58
Insurance and Real Estate and Property Taxes (2% of TFI)	0.41	1.15
Total Plant Operating Costs	6.20	23.52

1 Includes a 25% factor over the operating requirements estimates made in Tables 5.5-22 and 5.5-23.

2 Labor overhead includes fringe benefits, shift premiums, and overtime.

3 Includes purchasing, shipping, plant safety, plant security, medical, janitorial, grounds maintenance, railroad switching operator, etc.

TABLE 5.5-27. UNIT PRICE AND RATE DATA

*	Water/Wastewater Charge	$1.50/1000 gallons
*	Steam	$4/MMBTU
*	Electricity	7¢/KWHr
*	Fuel Oil	$1/gal.
*	Sodium Carbonate	$84/Ton
-	Calcium Chloride	$84/Ton
-	HCl	$58/Ton
-	Chlorine	$145/Ton
-	Formalin	$200/Ton
-	Isopropyl Alcohol	$1.85/gal.
-	Propylene Oxide	$0.465/lb.
-	Sulfuric Acid	$61/Ton
-	Methanol	$0.71/gal.
*	Operating Labor Rate	$11/Hr.

Ref: Prices of chemicals as reported in Chemical Marketing Reporter, February 21, 1983

TABLE 5.5-28. ESTIMATED ANNUAL PRODUCTION AND SALES REVENUES

	Scenario 1		Scenario 2	
	Annual Production (t/yr)	Sales Revenue (MM $)	Annual Production (t/yr)	Sales Revenue (MM $)
Algin				
- Granular, $2.75/lb	-	-	698	3.84
- Fibrous, $4.50/lb.	-	-	1256	11.30
- Propylene Glycol, $5.60/lb.	-	-	838	9.40
Mannitol, $3/lb.	-	-	2395	14.37
Fucoidan, $3/lb.	-	-	208	1.25
Iodine, $7.25/lb.	330	4.78	330	4.78
Liquid CO_2, $35/ton	46355	1.62	40150	1.40
L-Fraction, $1-3/lb.	5329	10.66-31.97	5329	10.66-31.97
Bacterial Protein, $70/ton	13000	0.91	13000	0.91
Total Revenues		17.97-39.28		57.91-79.22

TABLE 5.5-29. PROFITABILITY EVALUATION OF BY-PRODUCTS/CO-PRODUCTS

	Scenario 1 (MM $)	Scenario 2 (MM $)
Gross Sales Receipts	17.97-39.28	57.91-79.22
Direct and Indirect Manufacturing Costs (exclusive of depreciation and feedstock costs)	6.20	23.52
Selling Expenses[1] (18% of gross sales)	3.23-7.07	10.42-14.26
Research and Quality Control (4% of gross sales)	0.72-1.57	2.32-3.17
Administrative Overhead[2] (3% of gross sales)	0.54-1.18	1.74-2.38
Amortization (10 Yrs, 12%, St. Line)	3.68	10.16
Pretax Profits (excluding kelp cost)	3.60-19.58	9.75-25.73
ROI, %	15.9-86.7%	15.6-41.2%
Operating Margin[3] before taxes	24.6-49.8%	16.8-32.5%

1 Includes salesmens' wages, commissions, warehousing, advertising, and customer service.

2 Includes executives' compensation, support functions such as Finance, Accounting, Relations, Legal, computer services, and office expenses.

3 Pretax Profits/Gross Sales Receipts

includes executives' compensation and other major business support functions is estimated at 3 percent of the gross sales. These factors are derived from those suggested in Perry's Handbook[23], and were selected to be on the high side of the suggested ranges. Plant life is assumed to be 10 years which is typical of certain chemical manufacturing facilities. A straight line depreciation method was assumed at an annual 12 percent cost of capital. The pretax profits are calculated at $3.60-19.58 million dollars in Scenario 1 and at 9.75-25.73 million dollars for Scenario 2. The range in the pretax profits results from whether the L-fraction is valued at $1/lb or $3/lb. Table 5.5-29 also shows values for the return on investment (ROI) and operating margin. The production of by-products and co-products appears to be very attractive from a business viewpoint even if L-fraction was never to exceed $1/lb. At $3/lb of L-fraction, the ROI values increase severalfold such that the payout time for Scenario 1 is just over a year and about 30 months for Scenario 2.

a. Effect on Gas Cost. In the integrated gas and chemicals production system, net revenues (pretax profits) may be used to reduce gas cost directly. Table 5.5-30 shows the impact on gas cost for Scenarios 1 and 2. Parsons has estimated a gas cost reduction of $5.94/MMBTU resulting from 5 million dollars of by-product/ co-product revenues (pretax profits)[1].

A linear relationship was assumed as a first order approximation based on this data point and is shown in Figure 5.5-8. Using this relationship and Parsons' data on production capacity versus gas cost which is shown in Figure 5.5-9, net gas cost is calculated. Only the low end of the pretax profits range are considered, corresponding to $1/lb L-fraction. An additional cost of 1.2 million dollars is allocated to Scenario 2 to account for the 500 tons/day of raw kelp used for production of various products. This cost is based on kelp production cost estimates reported by Parsons[1]. In Scenario 1, the total feedstock cost is allocated to gas alone. The calculated gas cost is $9.20/MMBTU for Scenario 1 and $4.85/MMBTU for Scenario 2. The recovery of by-products and co-products thus offers potential for dramatic reductions in gas cost; by about 30 percent if by-products are recovered from digester effluents alone, and by about 65 percent if about 15 percent of the farm output is devoted exclusively to the production of high value chemicals in addition to recovering by-products from the digester effluents.

TABLE 5.5-30. EFFECT ON GAS COST

	Scenario 1	Scenario 2
Pretax Profits (excluding kelp cost), MM $	3.60	9.75
Annual Kelp Cost, MM $	0	1.2
Pretax Profits (including kelp cost), MM$	3.60	8.55
Estimated Gas Cost Reduction, $/MMBTU	4.27	10.15
Baseline System Gas Cost (No revenues from by-products co-products) $/MMBTU	13.47 (3 MMSCFD)	15.0 (2.6 MMSCFD)
Net Gas Cost, $/MMBTU	9.20	4.85
- Includes revenues from by-products/co-products		
% Reduction in gas cost due to by-products/co-products	31.7	67.7

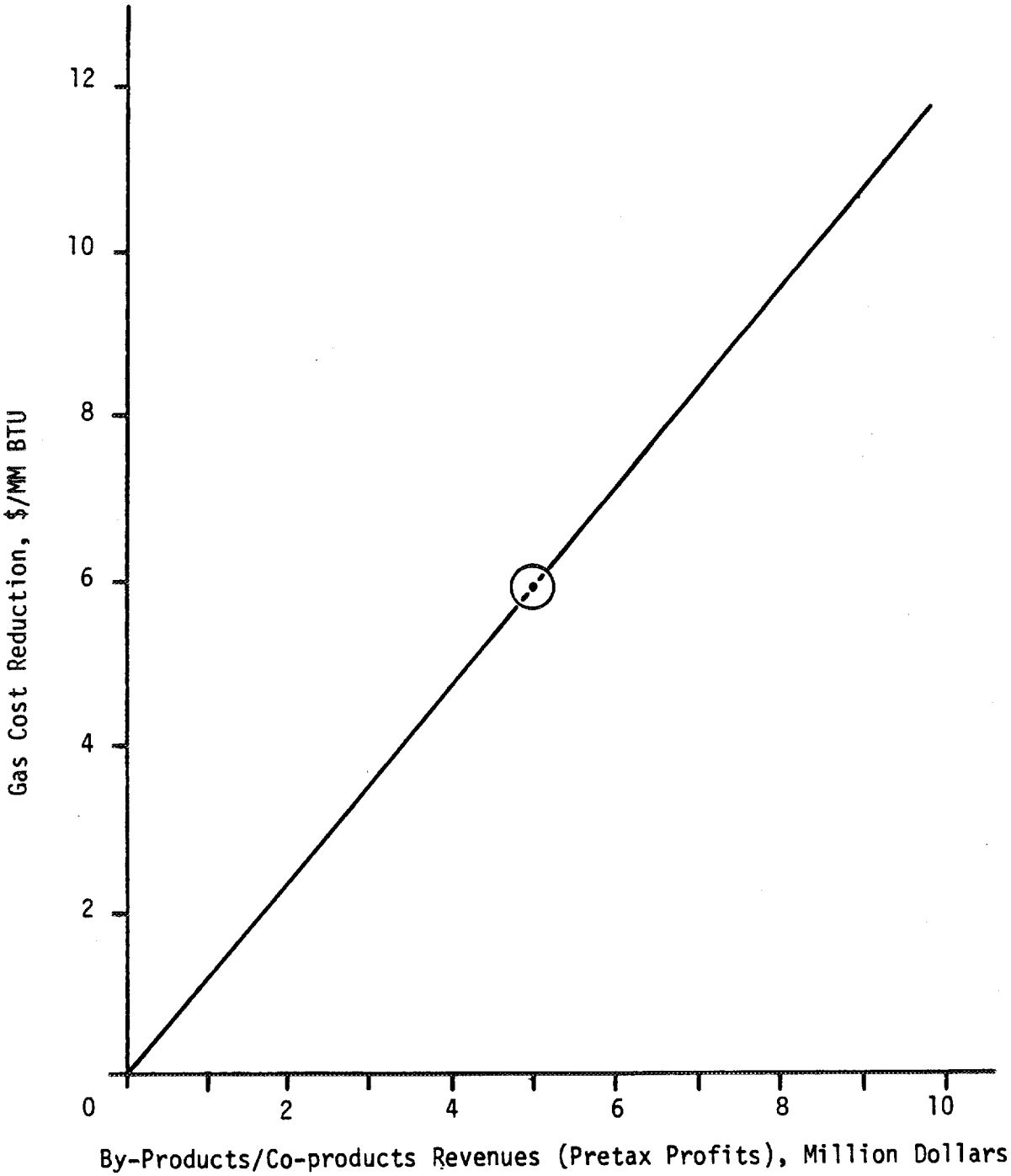


Figure 5.5-8. By-Product/Co-Product Net Revenues Versus Gas Cost Production (Data Points from Parsons' Report[1])

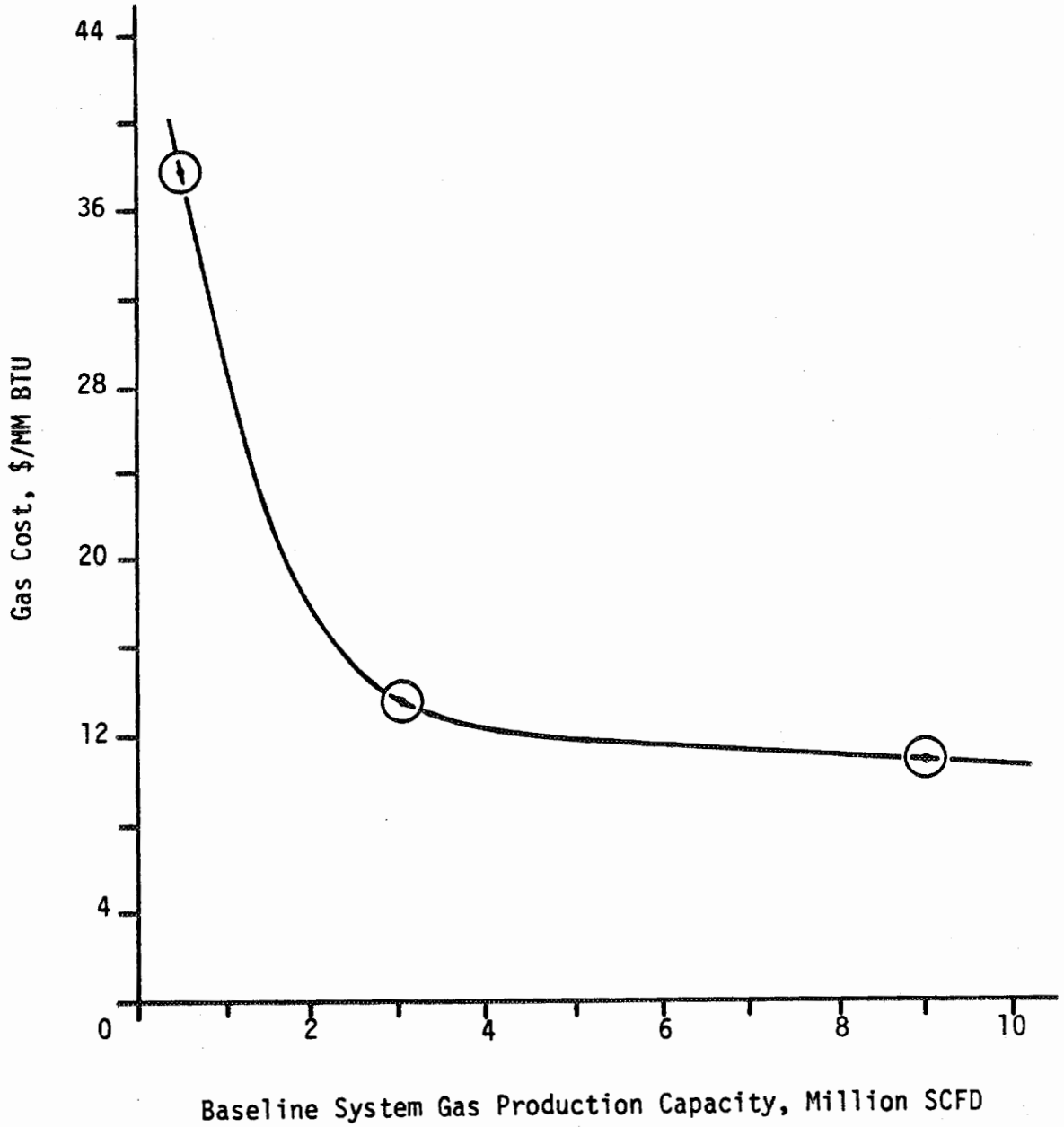


Figure 5.5-9. Gas Production System Capacity Versus Gas Cost (Data points from Parsons' Report[1])

b. Sensitivity of L-fraction Cost. Of the chemicals and products considered, L-fraction has the most technical uncertainty, followed by fucoidan and bacterial protein. Fucoidan is a new product for which a market has to be developed. The bacterial protein product has not been actually tested in animal/pountry feed diets for acceptability. Of the three, L-fraction hs the most economic impact on gas cost. The sensitivity of L-fraction to gas cost is analyzed by assuming a 50 percent increase in the capital and operating costs of recovering the L-fraction. The data on this case are shown in Table 5.5-31. The net gas cost is estimated at $12.03/MMBTU in Screnario 1 (versus $9.20/MMBTU without the cost increase), and at $7.32/MMBTU in Scenario 2 (versus $4.85/MMBTU without the cost increase). These costs correspond to valuation of the L-fraction at $1/lb, the low end of the range. At $3/lb of the L-fraction, enough pretax profits are realized to cover the gas production costs completely and still make some profit.

c. Product Portfolio Selection. In a multiproduct system such as is being analyzed in this study, it is necessary to examine the costs and the benefits of each of the products individually to ensure that the lowest net gas cost is achieved. Such an examination will also help understand the sensitivities of various products individually to the overall system economics. The analysis was carried out for L-fraction, the bacterial protein product, and fucoidan which as mentioned earlier have key uncertainties associated with them. The results of this analysis are included in Table 5.5-32. Selected key results are also shown in Figure 5.5-10. As shown in Figure 5.5-10, the lowest gas cost is achieved when L-fraction is recovered. Furthermore, under the conditions selected, the recovery of either the bacterial protein product or fucoidan tends to increase the net gas cost and generally diminishes the investment attractiveness (lower ROI and operating margin).

In Scenario 1, a gas cost increase of approximately five percent is estimated if bacterial protein products were to be recovered along with iodine and carbon dioxide. However, when L-fraction is also recovered along with these three products, the net gas cost is reduced by approximately 22 percent. Considering the technical and marketing uncertainties in the bacterial protein evaluation, its effect on the gas cost can be considered only marginal. The most attractive product portfolio in Scenario 1 from an economic viewpoint thus may consist of iodine, carbon dioxide, and L-fraction with an estimated gas cost reduction of 30 to 35 percent. In fact, the analysis could be extended to carbon dioxide also, with the possible outcome that only iodine and L-fraction need to be recovered in

TABLE 5.5-31. SENSITIVITY OF GAS COST TO L-FRACTION RECOVERY COSTS

Basis: 50% increase in capital and operating costs of recovering L-fraction.

	Scenario 1	Scenario 2
Gross Sales, MM $	17.97-39.28	57.91-79.22
Direct and Indirect Manufacturing Costs (without raw kelp costs), MM $	7.63	24.65
Feedstock Costs, MM $	-	1.2
Selling Expense (18% of gross sales), MM$	3.23-7.07	10.42-14.26
Research and Quality Control MM$	0.72-1.57	2.32-3.17
Administrative Overhead (3% of gross sales)	0.54-1.18	1.74-2.38
Total Capital Requirement, MM $	28.51	68.27
Total Fixed Investment, MM $	26.2	62.8
Amortization (10 Yrs, 12%, St. Line), MM $	4.64	11.11
Pretax Profits, MM $	1.21-17.19	6.47-22.45
ROI, %	4.2-60.3	9.5-32.9
Net Gas Cost, $/MMBTU	12.03 -*	7.32 -*
Gas Cost Reduction, %	10.6 -*	51.2 -*

*Net revenues (pretax profits) from by-products/co-products more than meet the cost of methane production.

TABLE 5.5-32. EFFECT OF PRODUCT PORTFOLIO SELECTION ON SYSTEM ECONOMICS AND GAS COSTS

	Product Portfolio	Total Fixed Investment, MM $	Total Capital Required, MM $	Operating Costs, Amortization and Other Expense, MM $/Yr	Gross Sales, MM $/Yr	Pretax Profits, MM $/Yr	ROI, %	Operating Margin, %	Gas Cost Reduction * %	Net Gas Cost, * $/MMBTU
SCENARIO 1	• Iodine • Carbon Dioxide	8.59	9.33	4.59	6.4	1.81	10.7	28.3	16	11.32
	• Iodine • Carbon Dioxide • Bacterial Protein	13.12	14.26	6.03	7.31	1.28	9	17.5	11.3	11.95
	• Iodine • Carbon Dioxide • Bacterial Protein • L-Fraction, $1/lb	20.78	22.59	14.37	17.97	3.60	15.9	24.6	31.7	9.20
SCENARIO 2	• Algin • Mannitol • Iodine • Carbon Dioxide	42.3	45.9	38.16	45.1	6.94	15.1	15.4	55	6.76
	• Algin • Mannitol • Iodine • Carbon Dioxide • Fucoidan	45	48.9	40.12	46.3	6.18	12.6	13.3	49	7.66
	• Algin • Mannitol • Iodine • Carbon Dioxide • Fucoidan • Bacterial Protein	49.54	53.85	42.37	47.25	4.88	9.8	10.3	38.6	9.20
	• Algin • Mannitol • Iodine • Carbon Dioxide • Fucoidan • Bacterial Protein • L-Fraction, $1/lb	57.42	62.42	49.36	57.91	8.55	13.7	14.7	67.7	4.85

* Scenario 1: Parsons Baseline Gas Cost = $13.47/MM BTU
Scenario 2: Parsons Baseline Gas Cost = $15.0/MM BTU

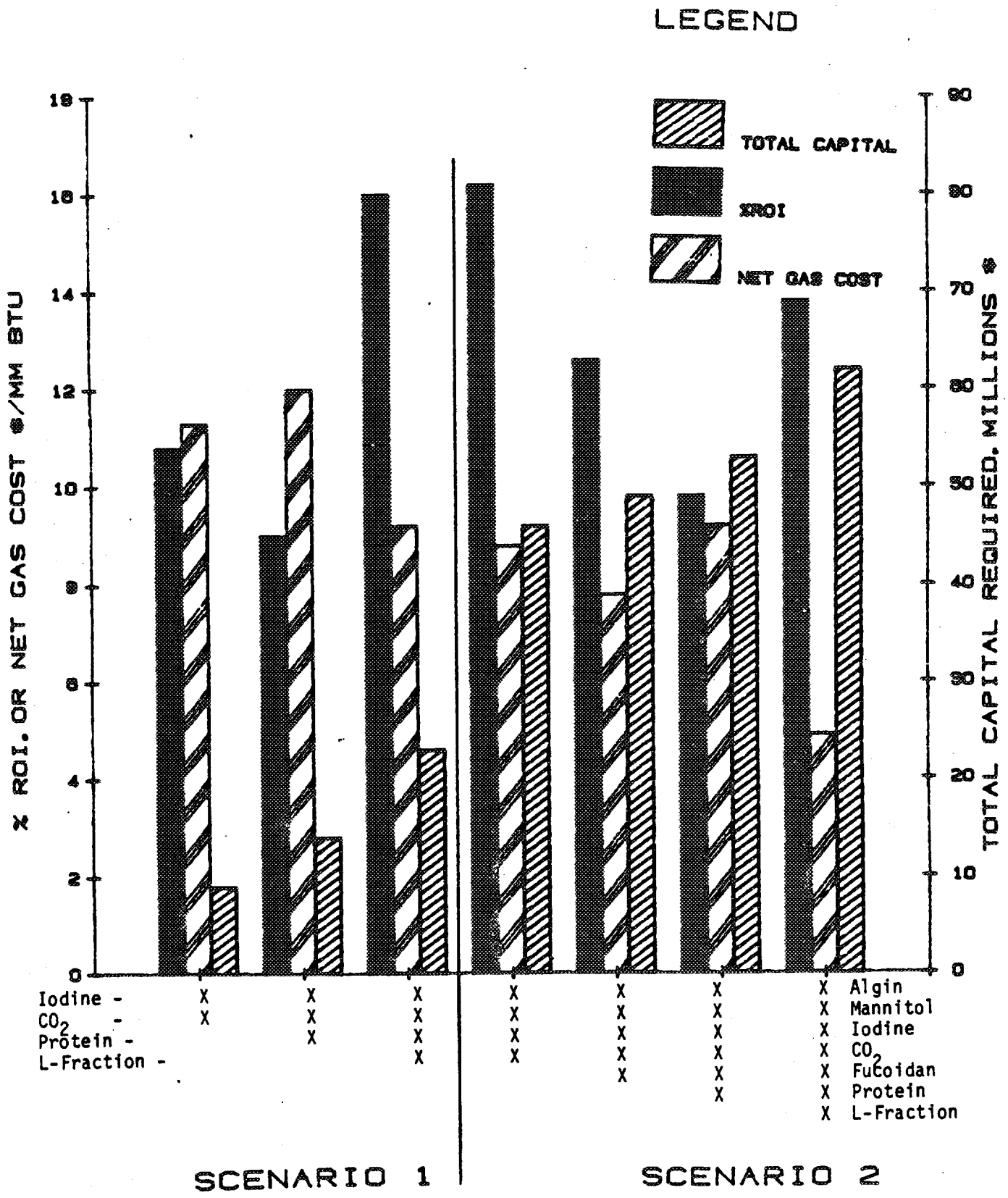


Figure 5.5-10. Effect of Product Portfolio Selection on Gas Costs and Investment Criteria (L-Fraction at $1/lb)

order to achieve the lowest gas cost and simultaneously optimize other investment criteria such as; total capital investment, ROI, and operating margin.

Similar results are obtained for Scenario 2 which show that the additional recovery of fucoidan along with algin, mannitol, iodine, and carbon dioxide, causes the net gas cost to increase by approximately 13 percent, from $6.76 to $7.66 per million BTU. Adding bacterial protein to the portfolio causes the net gas cost to further increase to $9.20/MMBTU, an additional 20 percent increase. However, with the L-fraction (valued at $1/lb, the low end of the range), the net gas cost decreases sharply to $4.85/MMBTU which is a decrease of over 50 percent from the $9.20/MMBTU cost. It seems therefore that for either the bacterial protein product or fucoidan, unless there are dramatic decreases in their recovery costs or increases in their values, there is little economic incentive to include them in the product portfolios. Taking into account their technical and marketing uncertainties, it seems more appropriate not to include them. The optimal portfolio thus in all probability may consist of algin, mannitol, iodine, L-fraction, and possibly carbon dioxide with an estimated gas cost reduction of 65 to 80 percent from the Scenario 2 estimated cost of $15.00/MM BTU.

d. By-Products Only Versus By-Products and Co-Products. The answer to this question lies in whether the L-fraction is a high value product worth $3/lb and more or a relatively low value product worth $1/lb or less. Using Parsons' data,[1] it can be calculated that in Scenario 1, 11.34 million dollars in pretax profits are needed to completely pay for the cost of gas, and net 12.62 million dollars are needed in Scenario 2. As shown in Figure 5.5-11 and Table 5.5-29, at $3/lb, the production of chemicals in either scenario generates enough pretax profits to cover the cost of producing gas, and still provide returns on investment. At the same time, capital investment required for Scenario 2 is about 3 times as much as that for Scenario 1. The overall investment requirement and the ROI therefore favor Scenario 1 for a high value L-fraction product.

At $1/lb of L-fraction, the production of co-products such as algin and mannitol is necessary to achieve the lowest net cost of gas. In the extreme case (L-fraction of no value) the productin of algin and mannitol co-products is of even greater economic significance. With a low or no value for L-fraction, the gas cost reduction achievable becomes directly tied to the farm kelp fraction that is used exclusively for algin and mannitol.

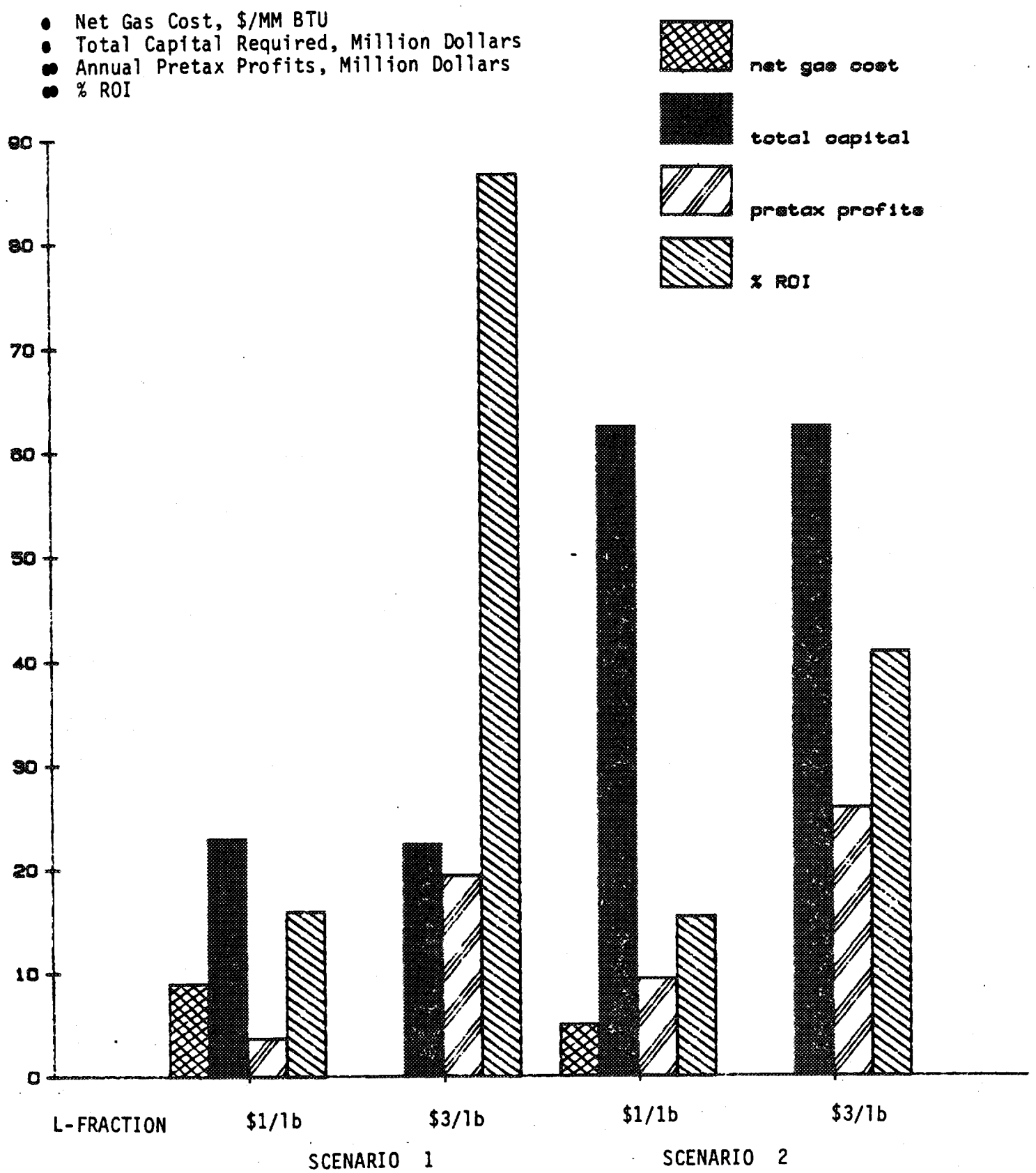


Figure 5.5-11. Effect of L-Fraction Value on Gas Cost and Pretax Profits (at $3/1b of L-Fraction, Net Gas Cost is Zero)

e. Financial Analysis. The sensitivity of the project finances to matters such as debt/equity makeup, the cost of debt, investment tax credits, alternative methods of depreciation, and income taxes have not been included in the above analysis due to the limited scope of the study. In order to simplify the analysis, 100 percent equity financing and straight line depreciation method at a fixed 12 percent annual rate were assumed. Partial debt financing of the project at an annual rate less than 12 percent would improve the ROI and further decrease the net gas cost. The inclusion of investment tax credits would further enhance economic attractiveness of the project.

It is suggested that this economic analysis be extended to include the effects of the various financial parameters mentioned above in a fashion which is compatible with the utility financing method of the gas production system.

Sensitivities of various parameter values selected should also be evaluated. To complete the financial analysis, the effects of inflation over the lifetime of the project should be factored in, and a detailed cash flow analysis should be carried out.

5.5.7 RECOMMENDATIONS:

a. Based on the results of this study, there is little doubt that the production of by-products and co-products can effect major reductions in gas cost and dramatically change the overall economics of the gas production system. Research on by-products and co-products therefore should be assigned a high priority and pursued vigorously. Recommended areas of investigation include:

- Preparation of larger samples of L-fraction from raw kelp and digester effluents; detailed characterization and testing for potential applications in specialty plastics, adhesives, and controlled-release materials.
- Acquisition of technical and process data on co-production of mannitol and algin from raw kelp.
- Acquisition of process data on the recovery of iodine from aqueous digester effluents.

Other potential areas of investigation include gathering process data on the recovery and the testing of the bacterial protein product from digester effluent and the coproduction of fucoidan (with that of algin and mannitol) from raw kelp. Under the assumptions made, bacterial protein and fucoidan appear to be of marginal value in terms of ability to reduce methane cost. However, that would

change if a basis could be developed to assign higher values to them. The tests and the data on these products should be designed to reduce uncertainties in their costs and values and to help determine that their production is economically justifiable.

b. The economic analysis does not explore the effect of variation of key elements of the financial structure such as debt/equity ratio of the investment, investment tax credits, costs on a life-cycle basis, inflationary effects, and income taxes.

It is recommended that these parameters be factored into future analyses consistent with the financial structure of the gas production portion of the system and that an integrated and complete economic analysis be carried out. A more detailed sensitivity analysis is also recommended.

BIBLIOGRAPHY

1. Brehany, J.J., "An Economic and System Assessment of the Concept of Nearshore Kelp Farming for Methane Production", Final Report prepared by Ralph M. Parsons Company for GRI, Report No. 5082-511-0627, (April 1983).

2. Tompkins, A.N., "Marine Biomass Program", Annual Report for September 1980 December 1982 prepared by General Electric Company for GRI and SERI, GRI Report No. GI 81-0118.

3. Hart, M.R., et. al., "Kelp Pretreatment and Separation Process", Annual Report on the Energy from Marine Biomass Project by the WRRC, USDA, Albany, California for the AGA, April 1977 - June 1978.

4. Saddington, A.W., "Production of Organic and Inorganic Chemicals from Kelp," Contract Report for General Electric, February 1982.

5. Absalom, S.T., "Iodine", in Mineral Facts and Problems, U.S. Department of the Interior, Bureau of Mines, 1980 Edition.

6. Mazac, C.J., "Iodine and Iodine Compounds", in Kirk and Oliver Encyclopedia of Chemical Technology, Vol. 13, 649-677.

7. Moss, J.R., "Essential Considerations for Establishing Seaweed Extraction Factories", in the Marine Plant Biosmass of the Northwest Coast, by R.W. Krauss Ed. , Oregon State University Press, 301-314 (1977).

8. Hall, E.N., "The Ocean Resource Challenge", in the Marine Plant Biomass of the Northwest Coast, by R.W. Krauss Ed. , Oregon State University Press, 357-376 (1977).

9. Mineral Inorganics in Chemical & Engineering News, Page 9-13, Oct. 25, 1982.

10. Searls, J.P., "Potash", in Mineral Facts and Problems, U.S. Department of the Interior, Bureau of Mines, 1980 Edition.

11. Sheldrick, W.F., and Stier, H., "World Potash Survey", World Bank Staff Working Paper No. 293, Sept. 1978.

12. Dancy, W.B., "Potassium", in Kirk & Oliver Encyclopedia of Chemical Technology, Vol. 18, 912-950.

13. Ballou, W.R., "Carbon Dioxide", in Kirk and Oliver Encyclopedia of Chemical Technology, Vol. 4, 725-742.

14. Private communications with AIRCO Company, King of Prussia, Pa.

15. Private communications with Cardox Company, Chicago, June 1982.

16. Benson, F.R., "Polyhydic Alcohols", in Kirk & Oliver Encyclopedia of Chemical Technology, Vol. 1, 754-778.

17. Private communications with ICI United States, Inc. March 1983.

18. Gulhine, K.M., "Process Plant Estimating Evaluation and Control", Craftsman Book Company of America, 1974.

19. Hall, R.S., et. al., "Current Costs of Process Equipment", Chemical Engineering, 80-116, (April 1982).

20. Private communications with E. Renneburg & Sons Co. , Baltimore, Md., (Oct. 1982).

21. Private communications with North American Brine Resources, Oklahoma City, Oklahoma (June - Oct., 1982).

22. Perry, J.H., Editor, "Chemical Engineers' handbook", 4th Edition, McGraw Hill, (1974).

5.6 LOST TEST FARM

5.6 LOST TEST FARM

5.6.1 BACKGROUND

On November 20, 1981, General Electric was informed by the Experiment Team from the California Institute of Technology that the machinery buoy section of the Offshore Test Platform (OSTP) was missing from its moored position. The system had been in place since September 1978 in a location approximately four nautical miles offshore from Laguna Beach, California. Although no active testing was being conducted with the OSTP at the time of the disappearance, all major hardware components were in good condition and were being maintained in a proper and timely manner, and serviced as required by the terms of the navigational permits for the system. At the time of the loss, the system was being evaluated by GRI for future open-ocean experimentation related to the Marine Biomass Program.

All interested parties including the Gas Research Institute (GRI); Solar Energy Research Institute (SERI); U.S. Coast Guard; Insurance Carriers; and Legal Counsel were immediately informed of the reported disappearance. Sea and aerial searches were conducted immediately following the reported loss, but no evidence of the missing hardware was sited over an area roughly ninety miles in radius from the original mooring.

General Electric personnel had last visited the OSTP on November 4, 1981. At that time, a full underwater and above water inspection was conducted, navigational lights were checked and replaced where necessary, and the routine maintenance tasks were performed to allow for an additional three to four weeks of unattended operation. There were no hardware anomalies uncovered during the November 4th maintenance visit.

From sworn affidavits of coastal eyewitnesses, the precise time of the buoy's disappearance was bracketed between 8 a.m. on November 18th and 8 a.m. on November 19th. U.S. Coast Guard and Marine Coastal Station weather logs indicated that atmospheric conditions from November 4th thru November 20th were mild, sea state conditions were relatively calm, and ocean currents were minimal in the area of the OSTP. Thus, the environmentally imposed loads during this time period were orders of magnitude below the design condition. In particular, there were no weather anomalies reported from November 18th to November 19th and, in fact, sea conditions were approximately 50 percent calmer on November 18th than during the preceding week.

After thoroughly reviewing the data at hand and after detailed technical analyses of "probable causes", it was clear to General Electric that the buoy was lost due to the imposition of some external, non-environmental force. Clearly, internal cable degradation from corrosion, abrasion or fatigue could not have uniformly weakened all three cable legs such that all three cables would have parted at different locations over a period of one day under minimal induced loading conditions. In the jargon of the insurance world and as stipulated in our all risks insurance coverage, it was obvious that the buoy was lost due to "an external cause". Therefore, on behalf of GRI, General Electric instituted a claim through our brokers for full recovery of the $500,000 insured value of the kelp farm buoy.

Throughout 1982, extensive negotiations were conducted with the insurance "world" associated with our claim. The complexity and interrelationships, and sheer size of the "cast of characters", who in one way or another have something to do with our claim are no less than incredible. A flow chart of the insurance "world" we directly or indirectly dealt with in 1982 would show ten different agents, brokers, administrative underwriter representatives and technical underwriter representatives as well as nineteen different insurance companies, all interrelated in one way or another with respect to our claim. Despite our efforts in educating and re-educating the cast of characters with respect to the hardware system that was lost, and our efforts in providing the near endless stream of support documentation requested by the insurance people, little progress has been made with respect to settling our claim. The lead agency, Southern Marine and Aviation Underwriters and their parent company, Sedgwick Offshore Resources of London, as well as the lead underwriting insurance companies, Sovereign and Planet and their technical representatives, the London Salvage Association have procrastinated, obfuscated and generally been extremely oblique with respect to our claim. They have not specifically rejected our claim nor have they accepted it. The net result is that they have held up payment of the $500,000 since March 1982! It is becoming apparent to General Electric that the insurance people will continue in this procrastinating non-commital vein until such time as GRI, as the assured, institutes or at least clearly shows their intent to institute legal action to recover the full insurance proceeds plus compensatory "bad faith" damages from all the underwriters and assurers involved.

5.6.2 TECHNICAL ANALYSES IN SUPPORT OF CLAIM

The following analyses were conducted to investigate the probable cause of the loss and to determine whether an internal component failure could have been a contributing factor.

5.6.2.1 Ultimate Load Capability of OSTP Mooring Swivel

The mooring swivel was analyzed to determine whether or not it was the weak link that could have been responsible for the loss of the OSTP.

The results of the analysis indicated that the mooring swivel had a minimum cable load capability of 288,000 pounds. This value is substantially higher than the 198,000 pound breaking strength of 1-1/2 diameter 6 by 19 IWRC cable. Neither of these two loads include any degradation due to immersion in salt water for three years.

A summary of the capability of other parts of the mooring swivel is shown in Table 5.6-1.

5.6.2.2 Failure Analysis of the OSTP Mooring System

This section presents analyses which address the failure of the OSTP mooring system and the resulting loss of the OSTP itself. The analyses are based on the following observations at the mooring site:

- The OSTP was missing.
- All three catenary lines between the spring buoys and the mech buoy had failed.
- Two catenary lines failed at the mech buoy end and appeared to be tension failures in the 1-1/2 inch cable.
- The third catenary line failed at the spring buoy end in the 1-5/8 inch cable; there was no apparent radius in the cable near the break.
- All three mooring lines between the spring buoys and the ocean floor were intact.

It is highly unlikely that a single mooring line could become entangled with a passing body and fail the other two mooring lines before it failed itself. Therefore, it is assumed for the purposes of these analyses that the mech buoy itself was the loaded body and was pulled free of its moorings by an unknown accident.

TABLE 5.6-1. SUMMARY OF SWIVEL CAPABILITY

Item	Ultimate Load Capability* (lb)
2-1/2 in. Shackle	500,000
Shackle Pin	416,000
Lug Shear T.O.	295,300
Lug Tension	586,600
Joint Bolts	600,000
Plate Bending Bolted Joint	288,100
Bending + Axial LD @ 13.03o	291,300
Thru Flange @ 45o	301,400

. . Swivel capability without corrosion allowance is 288,000 lb. ultimate.

* Tension Load in Wire Rope

There are three analyses presented in this section. The first is a static mooring analysis of a mooring leg to determine the magnitude of loading conditions which could cause a failure as described above. The second analysis addressed a mode in which the OSTP fails at the upper swivel joint and loses its floatation, thereupon, dropping until stopped by the catenary lines to the spring buoys. The third analysis examines the dynamic loads generated in the system by a ship or barge striking the mech buoy at different velocities.

a. Static Mooring Analysis

The static mooring analysis models the OSTP as a single leg mooring system as shown in Figure 5.6-1 and Table 5.6-2. This simulates the case in which a load is slowly applied to the mech buoy in plane with a mooring leg.

The analysis was performed using a planar finite element mooring program (EBMOOR). A lateral load of 150,000 pounds was applied to the mech buoy, and a 80,000 pound upward force was applied at the attachment point of the spring buoy (maximum buoyancy of spring buoy) line to the mooring line (the intersection of lines A, B and C, item 10 connecting plate). The breaking strength of the 1-1/2 inch cable in the mooring sytem was assumed to be 190,000 pounds, and the breaking strength of the 1-5/8 inch cable was assumed to be 225,000 pounds. The results of the analysis indicate that the 1-1/2 inch cable in the mooring leg (D6 in Figure 5.6-1) will break before the 1-1/2 inch cable in the catenary line (A8 in Figure 5.6-1). The analysis also shows that the required deflection to generate a static load of 150,000 pounds at the mech buoy is 1,000 feet. The results of the mooring analysis are shown in Figures 5.6.-2 and 5.6-3. Figure 5.6-2 shows the load developed in the mooring leg versus the distance from the mech buoy along the mooring leg. Figure 5.6-3 shows the deformed shape of the mooring leg required to generate the forces shown in Figure 5.6-2. This analysis indicates that if the 1-1/2 inch cables have the assumed strength (190,000 pounds), a slowly applied static load could not have failed the system in the manner described at the beginning of this section, but rather, would have failed the line to the anchor. (Item D6 in Figure 5.6-1.)

b. Dynamic Analysis of a Failure of the Upper Swivel Joint

This analysis assumes that the mode of failure was a failure of the upper swivel joint. This would allow the remainder of the OSTP (the arms, upwelling pipe and 15,000 pound weight at the bottom of the upwelling pipe), which weighs about 50,000 pounds wet, to drop through the water until the motion is stopped by the catenary lines and lines to the spring buoy (lines A and B in Figure 5.6-1).

A computer model was created for the analysis which calculated the speed at which the system was dropping and the force generated in the catenary line when the slack in the line is taken up.

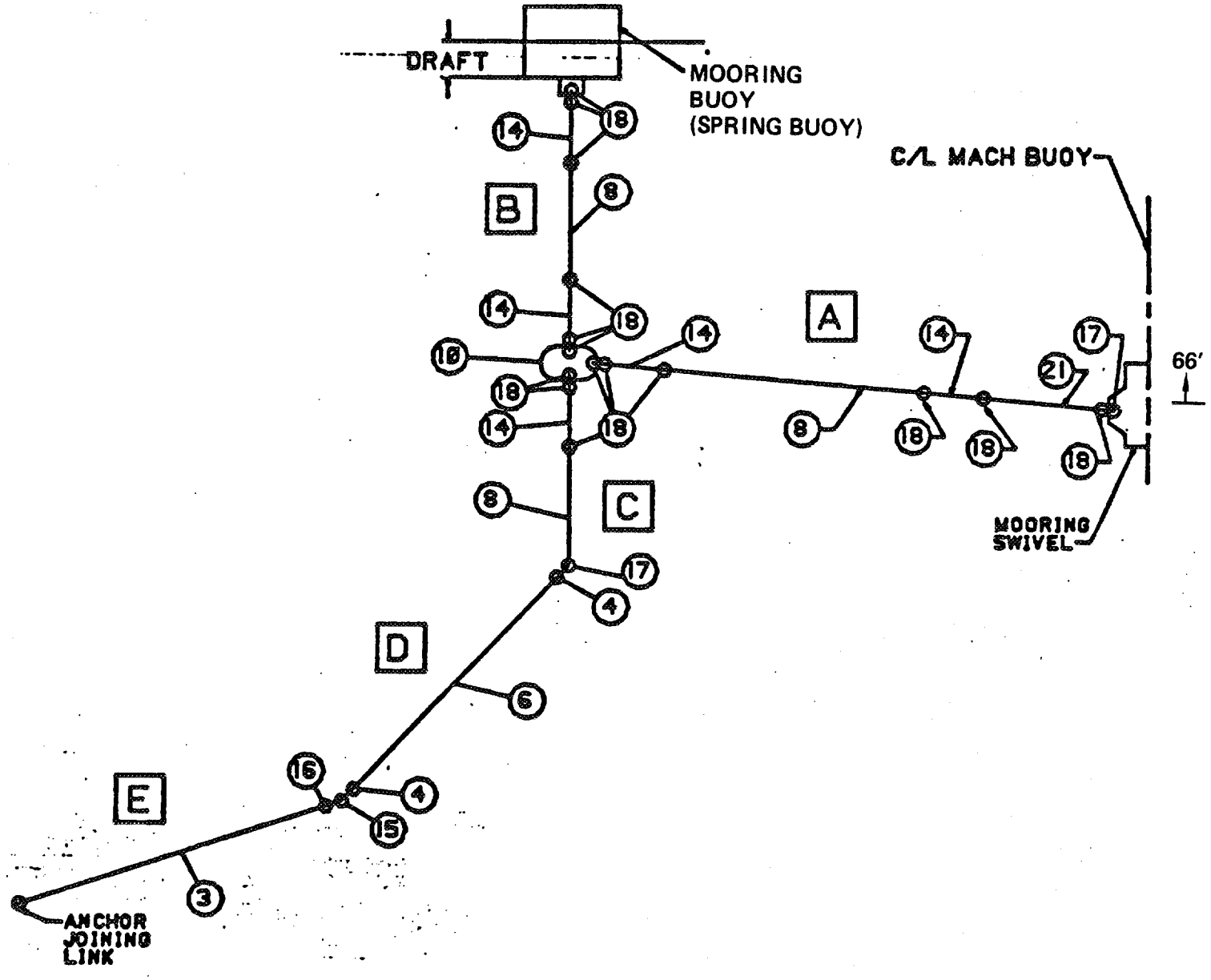


Figure 5.6-1. Single Leg Mooring System

TABLE 5.6-2. STATIC MOORING ANALYSIS

I.D. Code**	Item	Length	Length (Ft)	Unit Wgt (*)	Total Wgt (*)
	Mooring Swivel Radius	31 + 1.38"	--	--	--
17	2-1/2 in. Anchor Shackle	10.5 in.	0.88	101.69	101.69
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
21	1-1/2 in. IWRC Cable	8.0 Ft	8.00	3.0/Ft	24.00
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
14	5 Links 2 in. Chain	28.7 in.	2.39	40/Ft	95.60
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
8	1-5/8 in. IWRC Cable	300 Ft	300.00	3.52/Ft*	1056.00
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
14	5 Links 2 in. Chain	28.7 in.	2.39	40/Ft	95.60
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
10	Connecting Plate	7.07 + 1.25 in.	0.69	198.45	66.15
A	Length between Mach Buoy & Mooring Drop Line		320.95		

* Note: Weights per foot are in water. All others are in air.

** Note: Refer to Figure 5.6-1 for locations.

TABLE 5.6-2. STATIC MOORING ANALYSIS (Cont)

I.D. Code**	Item	Length	Length (Ft)	Unit Wgt (*)	Total Wgt (*)
20	Buoy Attachment	7.5 + 1.25 in.	0.73	---	---
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
14	5 Links 2 in.Chain	28.7 in.	2.39	40/Ft*	95.60
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
8	1-5/8 in. IWRC Cable	43.0 Ft	43.00	3.52/Ft*	151.36
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
14	5 Links 2 in. Chain	28.7 in.	2.39	40/Ft*	95.60
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
10	Connecting Plate	7.07 + 1.25 in.	0.69	198.45	66.15
B	Length of Mooring Buoy Drop Line		53.10		

* Note: Weights per foot are in water.
All others are in air.

** Note: Refer to Figure 5.6-1 for locations.

TABLE 5.6-2. STATIC MOORING ANALSIS (Cont)

I.D. Code**	Item	Length	Length (Ft)	Unit Wgt (*)	Total Wgt (*)
10	Connecting Plate	7.07 + 1.25 in.	0.69	198.45	66.15
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
14	5 Links 2 in. Chain	28.7	2.39	40/Ft*	95.60
18	2 in. Anchor Shackle	7.75 in.	0.65	51.75	51.75
8	1-5/8 in. IWRC Cable	43.0 Ft	43.00	3.52/Ft*	151.36
17	2-1/2 in. Anchor Shackle	10.5 in.	0.88	101.69	101.69
C	Anchor Cable Drop Line Length		48.91		
4	3 in. Anchor Shackle	13.0 in.	1.08	178.0	178.0
6	1-1/2 in. IWRC Cable	1670 Ft	1670.00	3.5/Ft*	5846.00
4	3 in. Anchor Shackle	13.0 in.	1.08	178.0	178.0
D	Anchor Cable Length		1672.16		
15	2 in. End Link	7.75 (Est)	0.65	52.00	52.00
16	2 in. Kenter Joining Shackle	7.75 (Est)	0.65	52.00	52.00
3	2 in. Di-Lok Chain	1350 Ft	1350.00	40/Ft*	54000.00
?	Joining Link	6.0" (Est)	0.50	52.00	52.00
E	Anchor Chain Length		1351.80		

* Note: Weights per foot are in water.
All others are in air.

** Note: Refer to Figure 5.6-1 for locations.

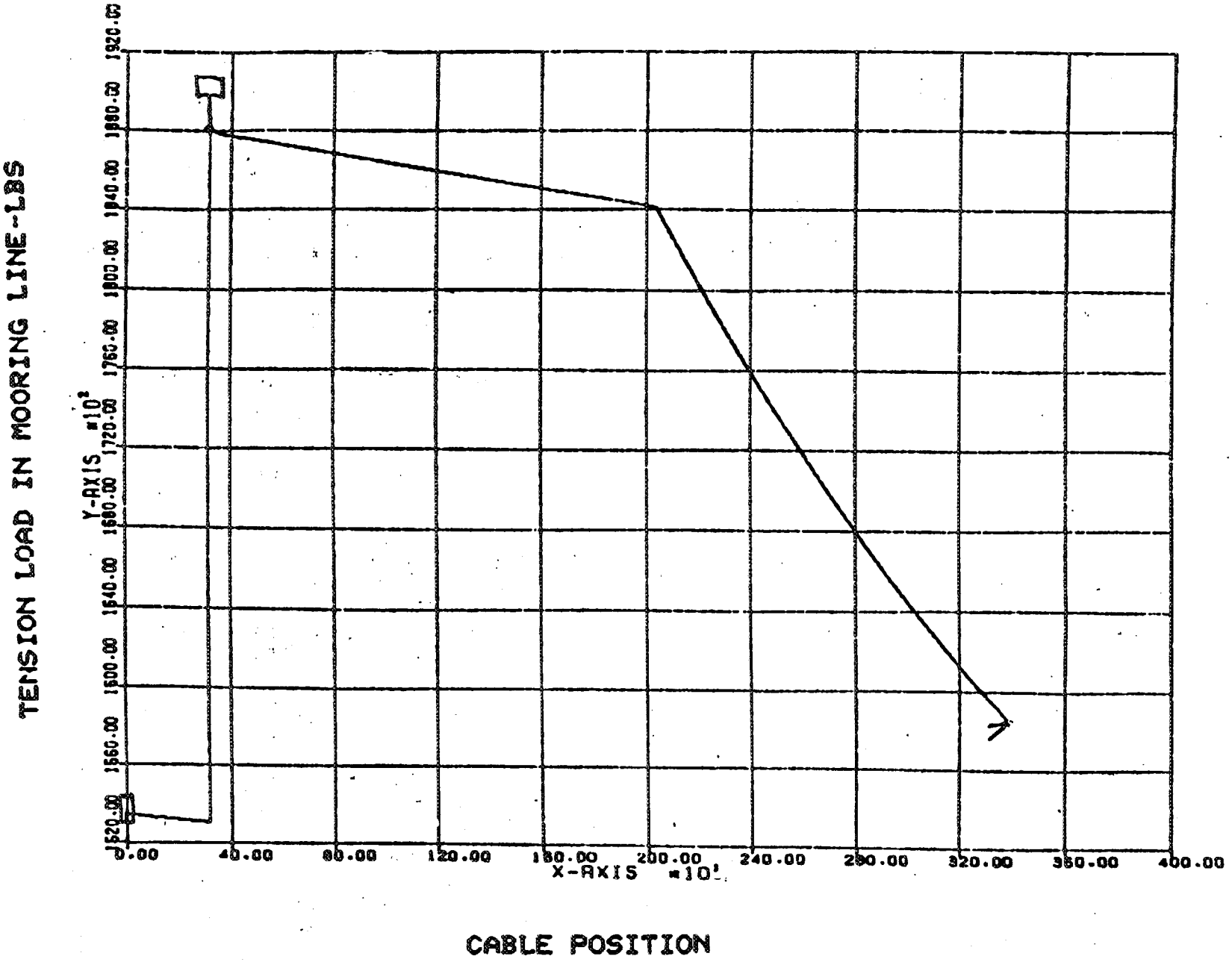


Figure 5.6-2. Tension vs. Mooring Leg Position with a 150.000 lb Force at the Mech Buoy

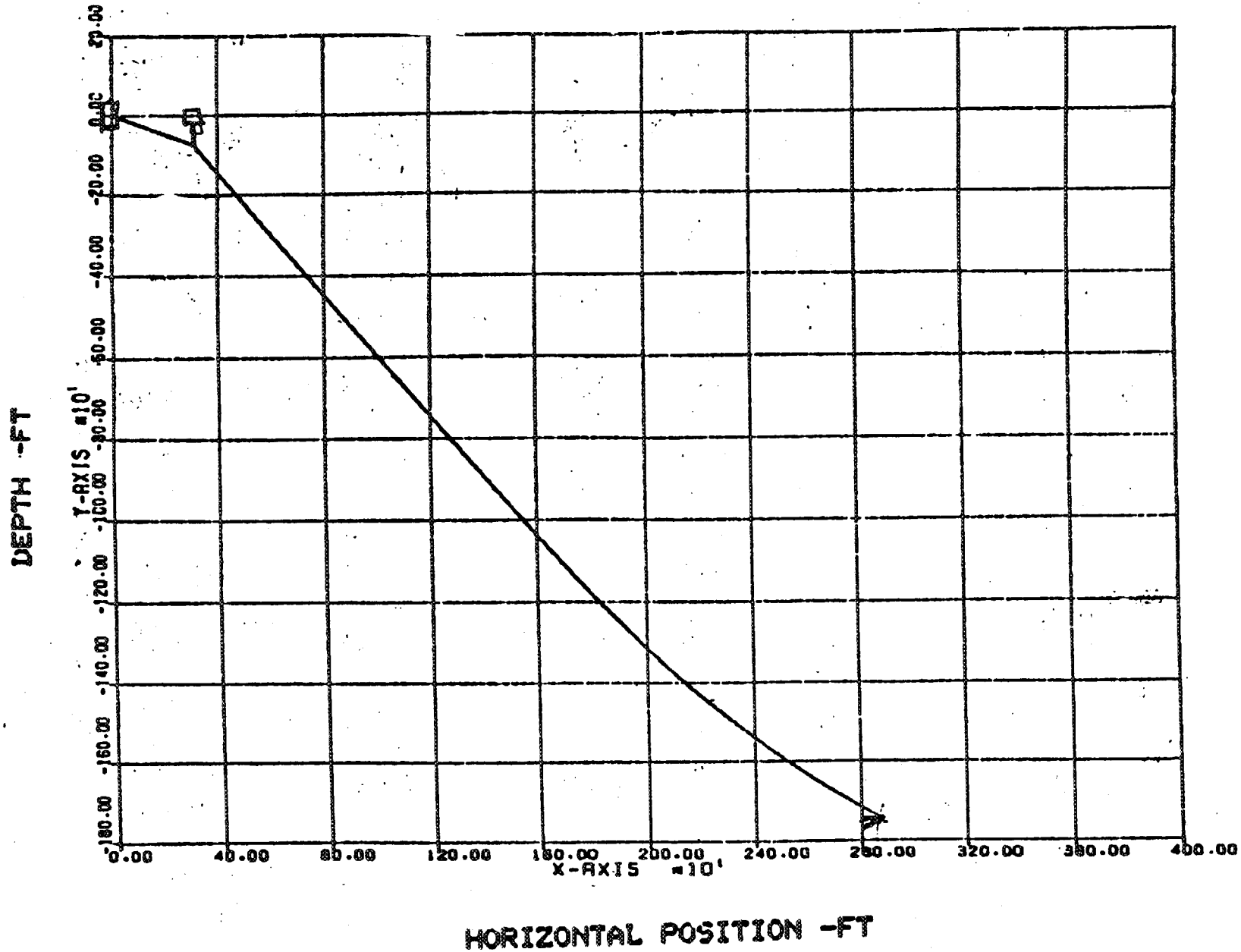


Figure 5.6-3. Mooring Leg Shape with a 150,000 lb. Force at the Mech Buoy

The following assumption were made in the generation of this computer model:

1. The drag area of the system is 173 ft^2 (two arms not folded)

2. The only forces acting upon the system until the catenary line is snapped are weight and drag

3. The weight at the bottom of the upwelling pipe strikes the bottom after a drop of 200 feet

4. A single catenary line takes the load of the entire system dropping

The results indicated that the system will rapidly reach a terminal velocity of 17.1 ft/sec and drop at that rate until the bottom weight hits the ocean floor. Then the system will slow to a new terminal velocity, 14.3 ft/sec before the catenary line is snapped. The force generated in a single catenary line when the line is snapped by the momentum of the dropping system on one end and the structural and hydro-dynamic inertia of the spring buoy on the other end is 111,486 pounds. (See Figure 5.6-4.) If the weight at the bottom of the upwelling pipe did not strike the ocean bottom, the cable load would still be less than 134,000 pounds. The strength of the catenary line is assumed to be 190,000 pounds. Therefore, this type of accident would not fail the system in the manner described at the beginning of this section.

c. Dynamic Analysis of Mech Buoy being Struck by a Ship or Barge

This analysis addresses the accident in which a ship strikes the mech buoy and the buoy becomes attached to the ship in some manner. The following assumptions were made for this analysis:

1. The coefficient of restitution between the mech buoy and the ship is zero

2. The spring buoy is submerged and has the maximum structural and hydrodynamic inertia

3. The propulsion force of the ship remains constant throughout the accident

A model was generated to solve for the peak load in the catenary line versus ship speed and weight. The results of this analysis are shown in Figure 5.6-5. The results show that a ship of 1500 tons or greater moving at 10 knots will fail the catenary cable. At 5 knots ship velocity, a ship inertial mass in excess of 10 times this value would be required (>20,000 tons).

d. Conclusions

Of the three modes of failure addressed in this report, the only method which will generate the 190,000 pound load required to fail the system in the catenary lines requires the interference of a large outside force (i.e., a large ship or barge).

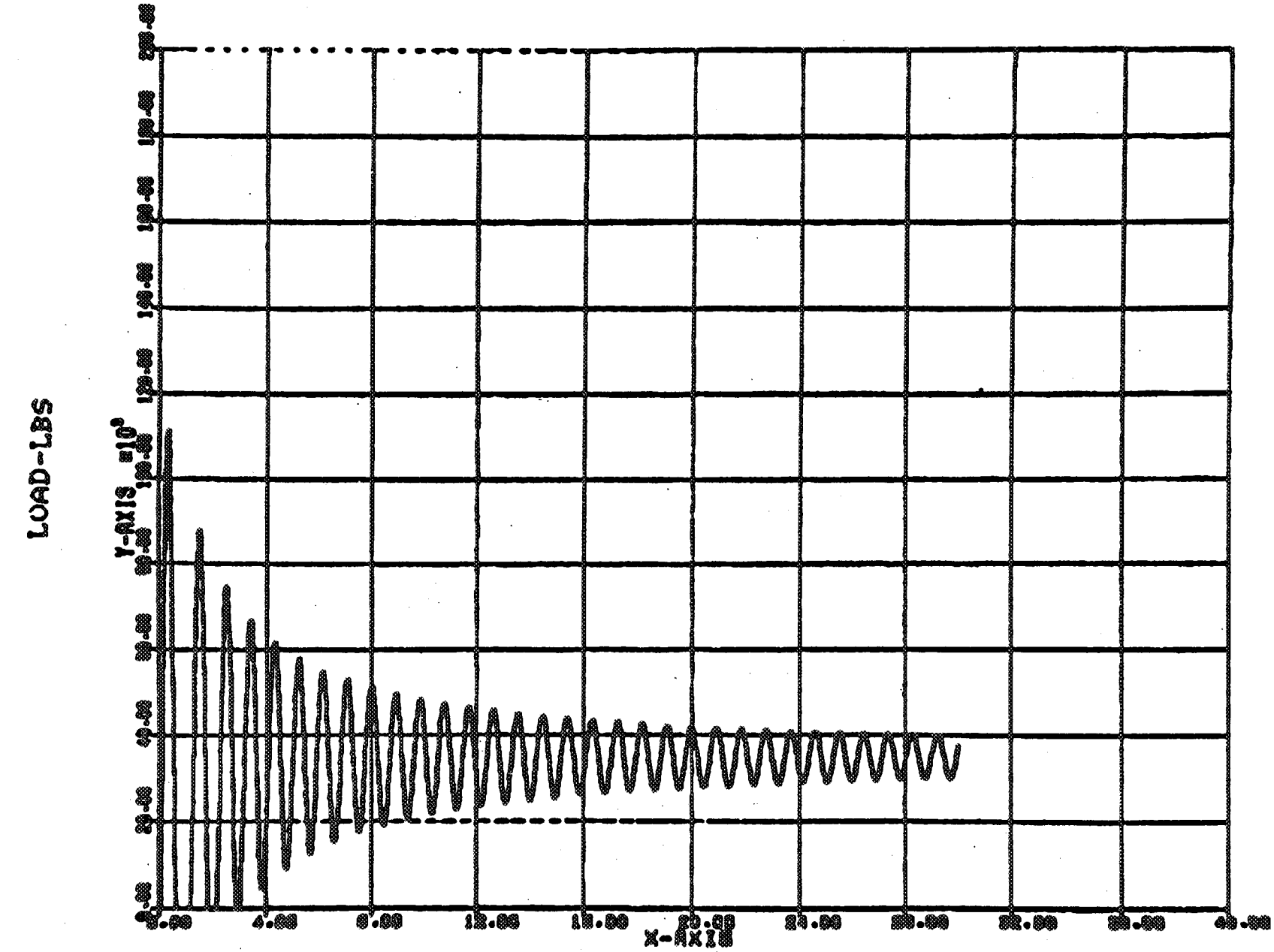


Figure 5.6-4. Load in Catenary Line Versus Time

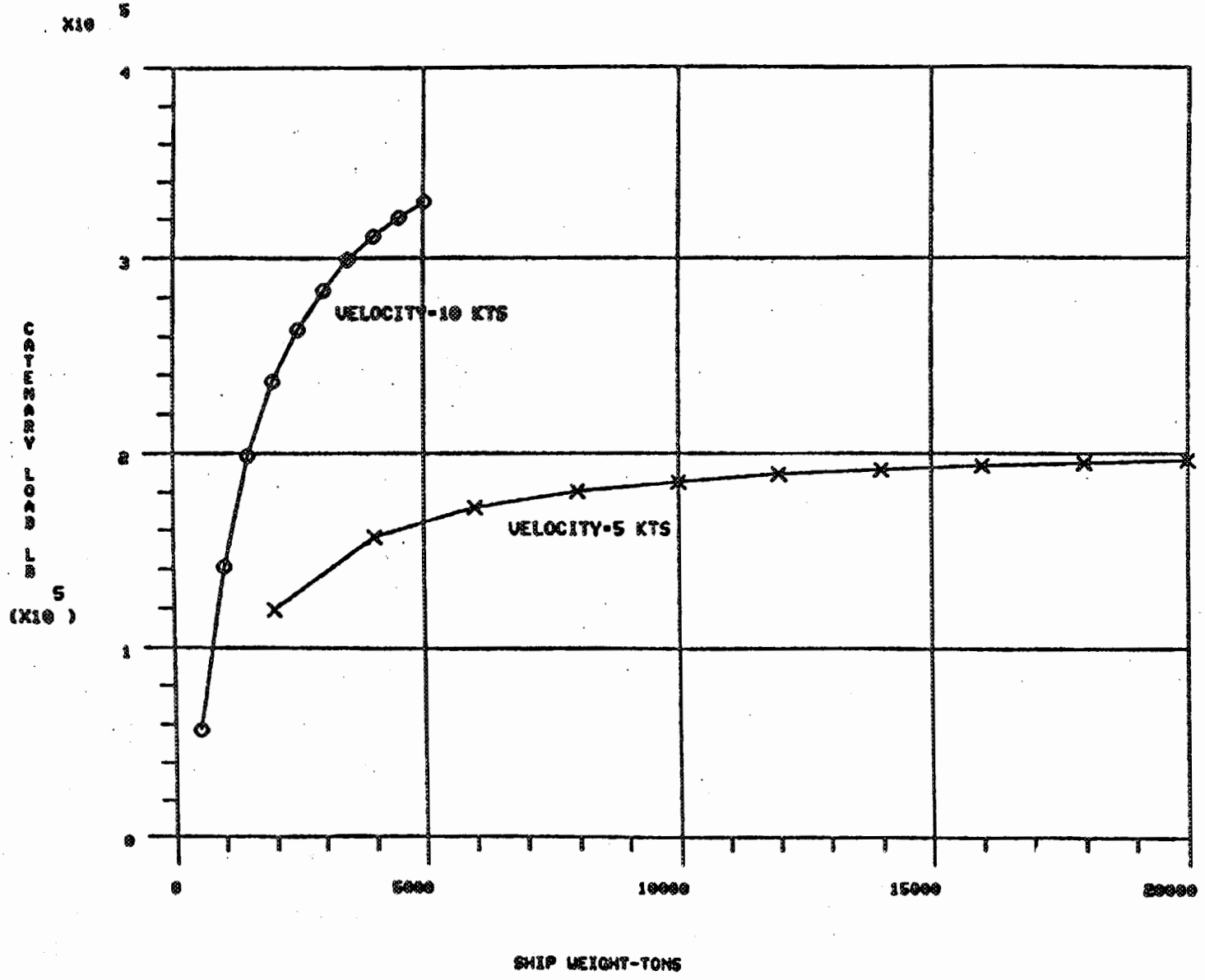


Figure 5.6-5. Ship Weight Versus Peak Catenary Load

Based on design margins and worst case environmental loads (wind, waves and current) dynamic loads generated are insufficient to cause cable failures.

5.6.2.3 Estimated Spring Line Tension Due to OSTP Environment During Period of System Loss

a. Summary of Results

The loss of the OSTP machinery buoy occurred between the morning of 11/18/81 and the morning of 11/19/81. Sea state in the area was reported running 3 to 4 foot wave height with 10 second period. Wind during the day was 0 to 3 knots SW. Maximum (surface layer) steady state currents and tidal currents are estimated at 0.6 knot and 0.3 knot respectively. Under these conditions, a conservative engineering estimate of drag and inertial loads indicates that the maximum tension in a single spring line would have been in the range 4800 to 6800 pounds depending on assumptions used to estimate inertial effects due to wave accelerations. This represents 2.5 to 3.6 percent of the breaking strength of a new 1-1/2 inch IWRC wire rope spring line element. If it is further assumed that the buoy was partially flooded and floating with the weather deck awash, the load range still only represents 2.6 to 4.1 percent of new cable strength.

It is also noted that on the morning of 11/15/81, just four days prior to the buoy loss, the system survived seas of 6 to 8 foot with 11 second period. Environmental loads on the spring line under these conditions are estimated to be 1-1/2 to 2 times higher than those encountered on the day of disappearance.

b. Environmental Conditions

Observations of sea and wind conditions in the area during the period 11/11/81 to 11/22/81 were obtained from the Newport Beach Lifeguard Station. The site of the wave observations is at a point approximately 1/2 mile off Newport Beach and in sufficiently deep water so that waves at the reported heights are essentially "deep water" waves. The observation site was approximately six miles north of the OSTP mooring site so that general sea conditions at the two sites are assumed comparable for purposes of this present analysis.

The maximum sea condition recorded on 11/18/81 was four foot waves with 10 second period. This case was assumed for the load estimates below. Note that wave heights of up to eight feet with 11 second period were recorded on the morning of 11/15/81. These wave conditions would have resulted in wave-driven and hydrodynamnic drag loads on the buoy hardware significantly higher than those encountered with four foot sea conditions on the day of the buoy loss. A set of load estimates was also generated for the higher wave conditions of 11/15/81 in order to compare overall drag loads and line tensions for the two cases.

The logs of the Laguna Beach Lifeguard Station were also checked for sea observations during this period. Their records indicated somewhat lower wave heights, so the Newport Beach data were used for conservatism.

Large scale "steady" current values and peak tidal currents were estimated from well documented historical data for the area and current data acquired by the GE Company during the course of the Marine Biomass Program.

The data indicate the following vertical distribution of these contributors to total current:

Depth Range (ft)	Large Scale Current (fps)	Tidal Current (fps)
0-40	1.0	0.5
40-80	1.0	0.3
80-250	0.2	0.1
250	0.2	0

The large scale current is somewhat variable in direction while the tidal current is variable in both magnitude and direction. For purposes of this loads estimate, these current components are assumed to be always aligned in the same direction for conservatism. It should be noted that these current levels are based primarily on data acquired during the April-July time period, while the current-data summary for the area of interest indicates that shallow currents in the Fall are generally somewhat lower than those in the Spring and Summer months which adds another degree of conservatism to the estimates.

c. Wave Orbital and Total Velocities

Wave orbital velocities are calculated assuming circular orbits which decay in magnitude with depth. The decay with depth is estimated using linear wave theory since the wave heights are very small relative to water depths, i.e., the waves are assumed to be sinusoidal, deep water waves. Assumption of a more peaked wave form would result in lower loads since the orbital velocities fall off more rapidly with depth in those cases.

For 10 to 11 second deep-water waves, the wavelength was estimated to be 500 feet. The variation of wave orbital velocity with depth used for the present estimates is presented in Table 5.6-3.

TABLE 5.6-3. WATER VELOCITY VERSUS DEPTH

Depth (ft)	Peak Orbital Velocity (fps) 4 ft Wave	8 ft Wave	Peak Total Velocity* (fps) 4 ft Wave	8 Ft Wave
0	1.3	2.3	2.8	3.8
20	1.0	1.8	2.5	3.3
40	0.79	1.4	2.3	2.9
60	0.63	1.2	1.9	2.5
80	0.49	0.86	1.8	2.2
100	0.36	0.65	0.66	0.95
150	0.22	0.40	0.50	0.70
200	0.13	0.20	0.40	0.50
250	0.07	0.10	0.40	0.40
250	0	0	0.20	0.20

* Sum of peak orbital velocity, large-scale current and peak tidal current all aligned and in phase.

Although it is more likely for the wave propagation and orbital velocity to be in a direction different from the steady-state and tidal currents, the conservative assumption is made in the present estimates that these three water velocity components are always in phase and aligned in the same direction. The total maximum current, as a function of depth, is estimated by adding the three components and is also shown in Table 5.6-3.

d. Load Estimates

Load and cable tension estimates were made for the following assumed buoy conditions and wave conditions:

1. Nominal, 18 ft freeboard, four foot waves
2. Buoy flooded, zero freeboard, four foot waves
3. Nominal, 18 ft freeboard, 8 foot waves
4. Buoy flooded, zero freeboard, 8 foot waves

Loads were estimated using two different techniques to account for the effects of hydrodynamic loads due to the wave orbital accelerations. A maximum hydrodynamic drag was calculated using a quasi-steady assumption which employs peak total water velocity to calculate the drag acting on each section of the buoy. Standard drag coefficients for cylindrical sections (depending on Reynolds Number) were assumed and the total drag load determined by summing the drag components estimated for each part of the machinery buoy, substrate and upwelling pipe. The drag of the spring line cable was estimated and found to be negligible. The diameter, length, drag area, and drag coefficients for the various components of the buoy system are presented below.

Hardware Element	Length (ft)	Diameter (ft)	Drag Area (Ft^2)	C_D
Buoy Upper Sect.	40	9	360/198*	1.0
Buoy Lower Sect.	15	6	90	1.0
Upwelling Hoses	(3) x 30	1	90	1.5
Steel Upwell Pipe	24	2.3	56	1.2
Spider Poles**	(6) x 50	1.3 (effective)	260	1.2
PE Upwell Pipe (Upper Part)	170	213	391	1.5
PE Upwell Pipe (Lower Part)	1300	2.3	2990	1.5

* Only 198 ft^2 of the total 360 ft^2 are presented to the flow with 18 ft freeboard.

** Total projected area of six poles normal to flow direction. "Effective" diameter used to account for pole stiffeners.

The resulting quasi-steady maximum hydrodynamic loads are tabulated in Table 5.6-4 for the cases indicated "a".

A second load estimation technique was employed where a hydrodynamic load component was calculated using the sum of the large-scale steady-state current and the tidal current for the quasi-steady water velocity. An inertial drag force component due to the water accelerations associated with the waves was then added. The inertial component was estimated using the simplified methods for determination of wave force coefficients on circular piles. In determining the force contributions, only the depth-dependent orbital velocity of the wave was used to compute the inertial force component. The inertial load component was always significantly larger than the quasi-steady hydrodynamic contribution using this method. These predicted loads are tabulated in Table 5.6-4 identified as cases "b".

e. Cable Tension and Strength Margins

The buoy load estimates were employed to estimate the cable tension due to the buoy and environmental conditions assumed. A single, 300 feet, 1-5/8 inch IWRC wire rope catenary spring line was assumed at 5 lb/ft. It was also assumed that both ends of the catenary were at the same depth of approximately 60 feet so that, with negligible cable drag load, the cable angle and tension were the same at either end. Cable tension and angle required to react the machinery buoy drag loads were then calculated and compared to the breaking strength for new wire ropes of 1-1/2 inch IWRC and 1-5/8 inch IWRC (a short length of 1-1/2 inch IWRC was used as a connecting element in the spring line). The results are presented as the last four columns in Table 5.6-4 where the tension values are also presented as a percentage of breaking strength for new wire rope.

TABLE 5.6-4. LOAD AND CABLE TENSION RESULTS

Case	Wave Height (ft)	Buoy Free Board (ft)	Load Assumption [1]	Hydro Load (lb)	Inertial Load (lb)	Total Load (lb)	Cable Tension (lb)	Cable Angle [2] (deg)	% Break Strength [3] 1 1/2 in. IWRC	% Break Strength [3] 1 5/8 in. IWRC
1a	4	18	H Only	4768	-	4768	4827	8.9	2.5	2.1
b	4	18	H + I	1938	4813	6751	6793	6.3	3.6	3.0
2a	4	0	H Only	4910	-	4910	4967	8.7	2.6	2.2
b	4	0	H + I	2064	5709	7773	7809	5.5	4.1	3.5
3a	8	18	H Only	8005	-	8005	8040	5.4	4.2	3.6
b	8	18	H + I	1938	11524	13462	13483	3.2	7.1	5.6
4a	8	0	H Only	7662	-	7662	7699	5.6	4.1	3.4
b	8	0	H + I	2064	14105	16169	16186	2.7	8.5	7.2

Notes: 1 H Only = Quasi-steady maximum hydrodynamic loads analysis
H + I = Steady hydrodynamic + wave-driven inertial loads analysis

2 Spring line depth equal at both ends, cable angles equal and measured down from horizontal.

3 Break Strength - 1 1/2" IWRC = 190000 lb
- 1 5/8" IWRC = 225000 lb

f. Conclusions

The most probable condition on the day of the buoy loss corresponds to case 1a or 1b in Table 5.6-4. Even with the more conservative of the two methods for estimating loads, the cable tension due to the environment should have been no greater than 3.6 percent of the breaking strength of a new 1-1/2 inch spring line element. Even in the worst case predicted for the four foot sea condition with the flooded buoy, the tension was only slightly greater than 4 percent of breaking strength. The results for cases 3a and 3b indicate that the system probably survived loads in the range of 4.2 to 7.1 percent breaking strength, i.e., 1.7 to 2.0 times as high, during the higher sea conditions of 11/15/81, four days prior to the buoy loss.

5.6.3 FORMAL POSITION OF THE GENERAL ELECTRIC COMPANY AS CURRENTLY FILED WITH THE INSURERS

On November 1, 1982, General Electric transmitted a position paper to the insurers stating all the background and relevant facts with respect to the insurance claim for the lost buoy. This position paper, which was approved by GRI, has never formally been addressed nor have the points been accepted or refuted by the insurers. The only response came in a telex on November 30, 1982 when the insurers again did not accept or reject our claim but simply said that "..... GE has not to date submitted evidence to prove beyond a reasonable doubt that the buoy was lost as a result of an external cause. ....." It was after receipt of this telex that General Electric advised GRI to communicate directly with the insurers their intent to institute legal action to recover the full value of the insurance plus associated compensatory damages.

The following section presents the position paper that General Electric filed with the insurers on November 1, 1982.

5.6.3.1 Position Paper on File with Insurers

"TO: Sedgwick Group Ltd. November 1, 1982
Sedgwick Offshore Resources, London, England

ATTN: Paul Riches/Simon Boxall

RE: General Electric Company
Kelp Spar Buoy - Lost November 20, 1981

Pursuant telex from Ken Francis (SMU&A) on 10/11/82 and 10/18/82 requesting re-statement to Underwriters of claim information and probable cause of loss, we offer the following:

(a) The buoy was last observed in place on Wednesday, 11/18/81 at 8 a.m. by Mr. Bruce Baird, Chief of Marine Safety (Senior Lifeguard), City of Laguna Beach, California. Mr. Baird stated that the buoy was not on site on Thursday, November 19, 1981. The buoy was also reported missing to the Coast Guard on November 19, 1981 by Mr. Dennis Sullivan. Mr. Sullivan is a local resident of Irvine, California who has stated that he regularly viewed the buoy via a spyglass through his living room window. General Electric was notified on November 20, 1981 that the buoy was missing by Dr. Valrie Gerard of Cal-Tech. Dr. Gerard is a principal experimenter who was conducting kelp biomass research with the aid of the Kelp Spar Buoy. General Electric was subsequently notified by the Coast Guard that the buoy was reported missing by Mr. Dennis Sullivan.

Routine maintenance visits to the buoy were scheduled at seven to fourteen day intervals. Actual visits were a function of weather conditions and needed maintenance actions. During the two months prior to the loss of the buoy, maintenance visits were made on 11/4, 10/22, 9/29, 9/19, and 9/2/81. In addition to actual maintenance visits, the buoy was routinely observed "in place" by Cal-Tech personnel as part of their experimentation activities.

(b) As stated above, the site of the buoy was visited by Cal-Tech personnel on November 20, 1981. Later that day, General Electric personnel visited the site to confirm loss and inspect remaining mooring hardware.

(c) Documentation has been provided to Southern Marine and Aviation Underwriters Inc. verifying that the policy warranties as set forth in Paragraph No. 10 of Cover Note 58531 have been complied with. These warranties are:

10 (a) - That the United States Coast Guard is notified and installation marked on navigation charts.

10 (b) - London Salvage Association and/or United States Salvage Association approve location and arrangements.

10 (c) - All United States Coast Guard regulations complied with.

General Electric Company again states that the above warranties as related to the insured Kelp Spar Buoy have been fully complied with.

(d) General Electric alleges and firmly believes that the insured Kelp Spar Buoy was lost due to 'external cause'. This allegation has clearly been General Electric's position since our December 2, 1981 meeting with Underwriters' representative, Mr. R. McIntosh. Our position is based on the preponderance of evidence at hand, some of which is summarized below:

(1) Weather conditions at the location of the Kelp Spar Buoy were calm during the period of time from the last maintenance visit (11/4/81) and the date the buoy was reported missing (11/20/81). No storms were noted by local weather monitoring stations. Winds were not excessive, and sea states (waves and currents) were normal. More specifically, weather and sea state conditions were very calm between 8 a.m. November 18, 1981 when the buoy was observed by Mr. Bruce Baird and November 20, 1981 when Dr. Gerard noted the buoy missing. Cal-Tech personnel were conducting experiments in the ocean (at locations other than the Kelp Spar Buoy) during this period.

(2) During the November 4th maintenance visit to the Kelp Spar Buoy, a complete above water and below water inspection was conducted. All hardware down to the depth of the mooring swivel was inspected. (The mooring swivel was the physical attachment point of the buoy to the three anchor legs.) All hardware was reported normal. There was no evidence of equipment abnormalities (i.e. tears or kinks in the mooring cables, excessive wear at moving joints or hardware corrosion).

(3) The buoy was lost when three mooring cables parted. Two cables were 1-1/2" in diameter and parted near the mooring swivel, and one cable was 1-5/8" in diameter and parted near the attachment to the anchor line. The system was designed to withstand the environmental loads imposed by a fifty year storm (forty foot waves and two knot currents) with only one of the three mooring cables intact. That is, even if two of the three cables parted, the system would still be "on station" (but within a larger watch circle) with only one cable intact. Model tests were used to verify this design. Clearly, there was no weather condition approaching the design conditions.

(4) Visual inspection of the torn ends of the recovered cables reinforce the view that an outside, external force failed the cables.

(5) The buoy was fabricated with foam filled compartments in order to provide excess buoyancy and assure flotation in the event that the internal work space of the buoy filled with water. If the mooring cables parted with no specifically applied external force involved, the buoy would be adrift in the open ocean or beached somewhere on the West Coast. In either event after ten months, a sighting would probably have occurred. (Two aerial searches shortly after the reported loss were conducted by General Electric - 11/21/81 and 11/23/81 - with no sightings.) However, if the cables parted due to an external force, that external force would drag and submerge the buoy and associated hardware. Submersion of the assembly to a critical depth could have caused the foam to collapse and subsequently reduce the reserve buoyancy. Water entering the internal work space would be sufficient to sink the buoy.

(6) Extensive failure analysis via detailed computer models, has shown that only a large, dynamically applied external force impacting on the Kelp Spar Buoy could have caused failure of first one, then the other two, buoy mooring cables in sequence. Even in the unlikely event that the upper part of the buoy (with the foam buoyancy chamber) separated from the lower steel structure (with no buoyancy) such that the steel structure was free falling, the one and one-half inch cable would not fail. Even if the force generated by this free falling body was instantaneously applied to only one of the three cables (a physical impossibility), the cable would not fail. Further, if the system did separate, the floating upper part with the foam buoyancy chambers would be adrift in the ocean and would have been sighted.

(7) The probability of a large vessel colliding with the Kelp Spar Buoy and/or entangling with one or more of the three mooring lines is very real. Extremely large vessels have been sighted in the general area of the buoy, and it is conceivable that submarines have also passed nearby due to the close proximity of the Naval Base in San Diego.

Mr. Dennis Sullivan, the private citizen who reported the buoy missing, (refer to item (a) above), has stated that during the week in and around the disappearance of the buoy, a large cable laying vessel was sighted in the area of the buoy. In general, all of the members of General Electric's team who have been involved in experimentation on the Kelp Spar Buoy have, on occasion, sighted large cargo vessels, tankers, and work boats in the general area of the buoy.

Although the exact form of the "external cause" can never be specifically identified, the preponderance of evidence clearly supports an external force as the cause of loss of the Kelp Spar Buoy. It is General Electric's belief that the external force was applied by a large tanker or by a large submarine.

General Electric is agreeable to having Underwriters conduct testing of the recovered cables. It is understood that the cost of this testing will be borne by Underwriters. General Electric must caution Underwriters that the cables have been out of the water for over ten months, and it is questionable that metallurgical testing of the bitter ends and/or strand-by-strand analysis of failed sections will be useful. At this point, tensile tests appear to be the only useful procedure to employ. In any event, whatever procedures Underwriters decide to employ, it must be clearly stated, and agreed to by all parties, as to how and against what criteria the results of these tests will be used in respect to General Electric's claim. Cable testing is destructive in nature, and evidence will be consumed as part of the tests. General Electric must have assurance from all of the Underwriters and insurance companies involved in Cover Note 58531 that the results will be accepted in determining whether our loss was due to external cause.

General Electric and our customer, the Gas Research Institute, are anxious to resolve this matter as expeditiously as possible, and our efforts over the past ten months have been clearly supportive of this desire. Upon receipt of this telex, we will expect a clear and definitive statement as to Underwriters position in this matter."

ACHIEVEMENTS, PROBLEMS AND CONCLUSIONS

6 MAJOR ACHIEVEMENTS

Four harvests were made at the Goleta Test Farm during 1982. From 12 tons of biomass initially planted, 61 tons were harvested leaving at least 12 tons as a standing crop.

Based on the 1982 test bed data, a harvestable kelp yield of 15 dry ash free tons per acre per year was indicated to be achievable in a commercial production scenario.

Individual plants were shown capable of producing harvestable yields which can be projected to three times the average 15 ton yield.

Continuous year-round fertilization of cultivated kelp was shown not to be required to support the sustained harvestable yield.

Kelp plants can be reliably established and maintained on a nearshore man-made substrate.

As a result of the 1982 work, the GRI was provided with a credible bottom line cost for the production of methane from kelp obtained in nearshore commercial cultivation systems. In addition, detailed analysis of potential co/byproducts provided chemical engineering, economic, and marketing support that a chemical and methane production facility based on kelp feedstocks is a commercially viable option.

7 MAJOR TECHNICAL PROBLEMS

Problems relating to the overall operation of the Marine Biomass Program and corrective actions which either have been or will be taken are summarized within.

a. The second experimental attempt to measure biomass production and yield in the hemidome located at Santa Catalina Island was frustrated by extensive disease problems which were exacerbated by warm summertime temperatures.

   Canopy density declined steadily due to reduction of frond initiation. Summertime canopy losses are also common in natural kelp beds. The application of fertilizer helped to some extent, and it was suggested that further work in this area may alleviate the extensive kelp losses that occur during this warm period.

b. Experimentation in the hemidome was abruptly terminated by a storm-caused tear in the bag late in October. Continued storm-related problems throughout the late fall and early winter of 1982, exacerbated by fatigue of submerged pump parts that had been in continuous use for nearly a year, brought on a decision late in 1982 for cessation of experimental work at the hemidome. The hemidome data was evaluated and a revised program was initiated. The revised program was designed to circumvent the deleterious enclosure effects observed in the first experiment by running shorter tests emphasizing the collection of physiological response rather than yield data.

8 CONCLUSIONS

As can be seen from the findings previously discussed in this report, marine farming is a complex, multi-disciplined undertaking. The researchers who have contributed to this work program have, through their efforts, developed the means with which to address the many unanswered questions within the program.

The year 1982 represented a milestone for the Marine Biomass Program. Kelp yield data was obtained from four harvests at the Goleta Nearshore Test Facility. The Catalina Test Facility was installed and operated, yielding key data on nutrient utilization and light effects.

In support of the central objective of obtaining measurements of harvestable yield from adult plants, a significant body of supplementary data was derived from both test facilities. This included: evaluation of the growth capabilities of individual plants with subsequent identification and selection of high yielding plants; insight into the relationship between kelp productivity, water temperature, solar radiation and nutrition; successful demonstration of planting techniques that can be developed into high rate planting systems; determination of effects of pulse versus continuous fertilization of kelp; and critical preliminary data on the effect of nutritional history on tissue levels of the highly biodegradable kelp constituent mannitol. The data base was incorporated into a comprehensive system specification which was submitted for independent cost estimation. As a result of the 1982 work, the Gas Research Institute was provided with a credible bottom line cost for the production of methane from kelp obtained in nearshore commercial cultivation systems.

A corollary product of the research was the identification of system sensitivities and their potential impacts on commercial production of methane. Identification of subsystem sensitivities and their resultant gas cost impacts has given GRI a solid basis for prioritization of future research expenditures in system development. The results of the economic study were used directly to provide the foundation for the 1983 program which has the objective of testing and refining key technical assumptions which were used in development of system economics.

9. WORK PLAN FOR 1983

9 WORK PLAN FOR 1983

As shown in the previous sections, significant progress was made during 1982 toward the objective of determining the technical and economical feasibility of producing methane from kelp. It is evident, however, that additional work is necessary to verify and supplement the yield and productivity data obtained during the current year.

A major goal, therefore, during 1983 will be to verify the yield results obtained in 1981-1982, as well as to demonstrate how kelp yield might be enhanced by cultivation.

In addition to the yield verification and enhanced cultivation tasks, a computer-based model will be developed integrating physiological functions in Macrocystis that are critical to productivity and yield. This mathematical model should predict yields for various site locations and seasons, harvest frequencies and modes, planting depths, planting densities, and fertilization schedules.

Listed below are the major areas of endeavor which are to be advanced during the 1983 Contract Period:

9.1 YIELD AND BIOLOGICAL STUDIES - CALIFORNIA INSTITUTE OF TECHNOLOGY

a. Field Work Supporting Modeling

1. Activities

(a) Objective - Assess effects of biomass density and depth on kelp productivity and yield to provide detailed information needed for model development.

(b) Description - Measure light, temperature, tissue composition, frond growth rates, in situ photosynthesis and respiration, plant size, frond initiation and mortality, and hapteral growth among three groups of kelp transplants moored at two depths and in two density configurations.

b. Mathematical Modeling

1. Activities

(a) Objective - Develop a computer-based model integrating physiological functions in Macrocystis that are critical to productivity and yield. The model should predict yields for various site locations and seasons, harvest frequencies and modes, planting depths, planting densities, and fertilizing schedules.

(b) Description - Compute inputs for photosynthesis, respiration, nutrient uptake, and translocation to kelp plant growth, taking account of tissue type, tissue location, plant size, and environmental factors (light, temperature, ambient nutrients, water movement, depth, day length, and surrounding plant density). Simulate a variety of harvesting and regrowth cycles.

c. Laboratory Studies

1. Activities

(a) Objective - Study kelp nutrition, photosynthesis, respiration, and factors affecting the chemical composition as needed for model development, supplementing and clarifying field data. Continue studies of kelp photosynthesis, respiration, and nutrition, adding to similar work from the preceding year. Processing samples from field studies.

9.2 KELP BIOMASS PRODUCTION - NEUSHUL MARICULTURE INCORPORATED

a. Yield Verification and Enhancement Studies

1. Activities

(a) Monitor the growth and frond production of sample kelp plants grown on planting lines in densities of:

1.00 Plants/M2
0.25 Plants/M2
0.652 Plants/M2

(b) Fertilize the one-half acre verification plot when needed.

(c) Plant 300 kelp plants in rows on the enhanced-yield plot, and hand-harvest alternate rows of kelp every six weeks.

(d) Fertilize the one-half acre enhanced-yield plot when needed.

b. Farm Maintenance

1. Activities

(a) Maintain line and perform farm protection work; involving weekly survey dives and inspection of anchors, line-terminations and fastenings.

(b) Perform farm planting-line management and surveys, checking for abrasion, plant-tangling, sloughing, grazing-damage and general plant health.

(c) Maintain farming equipment

- Work-boat maintenance, painting, cleaning and routine repairs, and safety equipment maintenance.

- Harvester maintenance, anti-rust lubrication, and safety equipment checks.

- Pier and greenhouse facility maintenance, pipe cleanouts, pump checkouts, storage tank cleanouts and general maintenance and repair.

- Laboratory and fabrication-facility maintenance.

(d) Maintain diving equipment, compressor, air-tank, and regulator maintenance and checkouts.

c. Environmental Monitoring

1. Activities

(a) Continue to make weekly and daily measurements of major environmental variables at the farm site.

(b) Install, test, and operate an automated environmental monitoring system that will collect data and store it on a micro-computer disc for incorporation into the overall project data-base.

(c) Continue to make plots of environmental conditions for each of the four growing periods.

(d) Periodically measure the light levels in the farm.

(e) Document the Chinese method of farm fertilization with measurements of fertilizer levels, residence time and dispersion.

d. International Cooperative Program

1. Activities

(a) Foreign Technology Assessment

(1) Host a visit to the NMI farm and facilities, and to the Marine Botany Laboratory at the University of California, Santa Barbara, by members of the Japanese Marine Biomass Program.

(2) Attend the World Mariculture Society meetings, Washington, D.C.) and present paper on kelp growth and yield.

(3) Attend the International Seaweed Symposium Quingdao, China and present paper on the effects of light on kelp growth and yield. Visit Chinese marine biomass farms and support facilities.

(b) Foreign Technology Exchange

(1) Work with Professor X.G. Fei through May 1983 on kelp photomorphogenesis.

(2) Develop a program with Cao Shuli of the Yellow Seas Fisheries Research Institute, on kelp gametophyte cultivation, cooperatively with the UCSB Marine Botany Laboratory.

(3) Host a visit by Dr. Y. Sanbonsuga of the Hokkaido Regional Research Laboratories, Japan.