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MARINE BIOMASS:
NEW YORK STATE SPECIES
AND SITE STUDIES

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Marine Biomass: New York State Species and Site Studies

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PREPARED FOR

New York State Energy Research
and Development Authority
Gas Research Institute
New York State Gas Group

ERDA Project Manager
Jeffrey M. Peterson

GRI Project Managers
James R. Frank
Kimon T. Bird

PREPARED BY

D.F. Squires and L. McKay
New York Sea Grant Institute
of State University of New York
and Cornell University

in collaboration with

Boudewijn Brinkhuis
DeWitt Davies
Dennis Hanisak
Herbert Herman
Bruce Macler
William Peterson

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NOTICE

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ABSTRACT

Nine species of indigenous New York seaweeds were surveyed for potential as feedstock for methanogenesis. Laminaria and Gracilaria are primary candidates on the basis of growth studies and gas yield data provided by General Electric. Agardhiella, Codium, and Fucus merit further study. A two species (warm and cool water) cropping system appears feasible in terms of year-round sustained yield. Initial data suggest nitrogen is not limiting in New York coastal waters.

Preliminary data from raft culture experiments suggest that some species' yields may be higher in the field than in the laboratory. Important technical gains were made in affixing attached-growth-mode species to substrates.

Sites for use in larger scale experimental structures around Long Island were evaluated for their environmental and use-conflict parameters. Several sites in Smithtown Bay have the requisite features. The New York Bight was evaluated for potential sites for ocean farms. Environmental and use-conflict features for this area were identified on overlay maps.

Five novel biomass farm designs were engineered and tested by computer models for survivability. Several of the evaluated designs have been or will be constructed. Novel mooring, anchoring and wave-dampening devices were also considered in this phase of work.

SPONSOR'S COMMENTS

The New York State Species and Site Studies 1981 Annual Report makes a major contribution to the GRI/ERDA/NYGas effort in the development of methane supplies from marine biomass. This program has been designed to provide for the gradual program from greenhouse to field experiments. The ultimate objective of the program has been to determine the performance parameters of the seaweed multicrop production system in New York. Once subsystems such as farming and planting techniques are developed, the data can be used in a preliminary economic and systems analysis study to generate both potential gas costs of a New York marine biomass system and determine which options would best serve the needs of the gas industry and the ratepayer. Upon favorable evaluation, the research phase of the New York project could enter into a more intensive research and development phase which would be strongly hardware orientated.

The future direction of this project, as it now stands will be to obtain critical yield data in both the greenhouse cultures and on raft modules. Research on the nutrient requirements of biomass candidates will determine more clearly whether there is a need for fertilization. An experimental test plot for a multi-cropping experiment is being designed after field trials with small raft prototype modules to ensure the design feasibility. It is anticipated that this multi-cropping experiment will be initiated in 1983. These data, along with biomass conversion results and appropriate systems analyses, will be used to assess the feasibility of the multi-cropping concept in New York regional waters.

SUMMARY

Laminaria and Gracilaria have been selected as primary cool and warm-water species for the New York marine biomass program.

A site for further testing of large raft/experimental farm designs and operations has been selected in Smithtown Bay, Long Island Sound. Potential sites for large scale biomass farming in New York Bight have been identified using criteria of environmental variables and use conflict.

The concept of a two-species multi-cropping approach to biomass production in environments having wide temperature fluctuations is being developed.

Nine species of indigenous New York macroalgae have been surveyed for their potential as feedstock for methanogenesis. Laboratory culture yield data and chemical analyses/gas yield data provided by General Electric have been used to reduce this list. Laminaria and Gracilaria are identified as primary candidates. Agardhiella, Codium, and Fucus will receive additional study. Rejected as candidates are Ascophyllum, Ulva, and Palmaria.

Data on nitrogen requirements and the possibility of growth enhancement by nutrient enrichment are still being prepared. Initial studies suggest that nitrogen will not be a limiting factor for macroalgal growth in New York's nearshore waters. A two-species (cool and warm water) multi-cropping system suggested by laboratory data, is shown to be a means of obtaining year round yield.

Raft culture experiments were initiated. Preliminary data suggest that for some species field yield may exceed laboratory yield. Effective means of affixing attached-growth-mode species to rope substrates were developed.

Sites for use in larger scale raft and experimental farm structures at a number of locations on Long Island were evaluated for their environmental and use-conflict parameters. Several possible sites in Smithtown Bay were identified as having requisite environmental and logistic features.

Using a technique of overlay maps, possible future sites in the New York Bight for large scale biomass farming were identified. Used in the evaluation process were environmental parameters critical to the macroalgal species and other uses which might conflict with biomass farming. Among the latter are commerical and sport fishing, marine transportation, Outer Continental Shelf (OCS) oil and gas development and ocean dumping.

A number of novel engineering designs for biomass farms were considered in a conceptual development project. Each design was evaluated by computer models for its survivability in the test site environment. Several designs meeting this criteria have been evaluated and one or more will be constructed as rafts. New approaches to mooring, anchoring, wave-dampening devices were also considered.

Laboratory and field culture of the candidate species should be continued with the objective of gaining enhanced yields. Such improvements can be obtained by strain selection, better nutrient environment and by controlling reproductive cycles, among others.

Harvesting techniques for attached-growth-mode species must be investigated. Raft culture experiments should be undertaken to identify characteristics of plants that are needed for engineering design criteria.

Marine fouling has been shown to be a major problem. Further study of fouling organisms and their control is a critical element to achieve a successful program.

A workshop on macroalgal raft and farm design will be held in 1982 to allow the program's design engineers to benefit from the experience of others in the field.

OVERALL PROJECT OBJECTIVE

The objective of the project is to develop a feasible system for the production of cost competitive methane from marine biomass feedstocks using anaerobic digestion.

SUMMARY OF PREVIOUS WORK PERFORMED

DECEMBER 2, 1979 to OCTOBER 31, 1980

The New York State Marine Biomass Program was initiated in December 1979 as an alternative site study for the marine biomass project led by General Electric for the Gas Research Institute. Cofunding from the New York Gas Group (NYGAS) and the New York State Energy Research and Development Authority (ERDA) was provided for the period December 2, 1979 through October 31, 1980. Four tasks were undertaken as a part of that contract:

1. Evaluation of nine species of indigenous seaweed proposed as potential feedstock for methanogenesis. Included were species of Fucus, Ascophyllu, Ulva, Laminaria, Gracilaria, Codium, Neoagardhiella (now Palmaria) and "introduced" Macrocystis. This task was to be accomplished through preliminary investigation of yield of the various species and from compositional and gas yield analyses by General Electric made on wild specimens.
2. Commencement of experiments on growth and yield of seaweeds under laboratory conditions.
3. Investigation of the environmental characteristics of selected sites for a biological test farm.
4. A legal analysis of problems associated with off-bottom seaweed culture in the New York region including a review of permitting and licensing procedures at federal, state and local governmental levels; development of necessary legislation to permit off-bottom culture; and consideration of the socio-political factors which would enter into test site selection.

Construction of an appropriate greenhouse facility proved somewhat more difficult and costly than anticipated with the result that the "task-collection of environmental data on potential sites for a test farm" was delayed for a year. Once the greenhouse laboratory at the Flax Pond Laboratory of the State University of New York at Stony Brook was completed, a number of problems with the existing salt water pumping system restricted the number of cultures which could be simultaneously maintained. The greenhouse became fully operational in September, 1980, when a temporary auxiliary saltwater line was installed.

A literature survey conducted on the nine candidate species indicated how little was known and the contradictory nature of the data.

Major accomplishments of the first year included the completion of laboratory facilities and the initiation of culture work. An extensive survey of the patterns of underwater land-ownership and the jurisdictional issues surrounding nearshore underwater lands was completed. This was the first such comprehensive analysis undertaken. Finally, Macrocystis was successfully transferred to the Flax Pond Laboratory, but failed to grow under the environmental extremes of the east coast maritime climate.

The research effort established a facility on the east coast in which marine biomass studies could be undertaken and developed a research team to conduct the experiments. About four months of growth and yield data were obtained from culture experiments, but were not sufficient to indicate the economic feasibility of the marine biomass concept. Raft culture experiments were also started. Criteria by which the candidate species list could be narrowed were jointly drawn up by researchers from General Electric and Marine Sciences Research Center. Criteria for evaluation of alternative sites for test farms were developed.

RESEARCH PROGRAM

DECEMBER 1, 1980 to NOVEMBER 30, 1981

Objectives

1. Determine first principles of the culture, growth, performance and requirements of 10 species of indigenous New York seaweeds.
2. Culture selected species of these outside the laboratory to determine, in part, requirements for their cultivated growth in open waters.
3. Compare the productivity of indigenous seaweeds with that of *Macrocystis*.
4. Provide samples of indigenous seaweeds for chemical and digestion analysis.
5. Evaluate environmental characteristics of potential locations for biomass farms.
6. Develop information requirements for permits and licenses for biological test farms.
7. Commence conceptual design for a biological test farm.

Work Plan

The work plan for the year was encompassed in four tasks:

Task 1. Plant Growth and Nutrition

A. Baseline Greenhouse Studies

1. Growth, performance, and yield studies
2. Light and nitrogen effects upon growth
3. *Macrocystis* studies

Develop a body of information, based upon laboratory experiments, on the growth rates, and performance under various culture conditions, and yield of the candidate species. Determine nutritional requirements for optimal growth as well as the effects of light, temperature, and water flow upon the productivity of the nine candidate species. Examine seasonal relationships of these parameters and their relationship to productivity. Determine the nitrogen requirements of the candidate species for optimal productivity. Culture *Macrocystis* under ambient conditions (those permitting survival of the specimens) as a means of obtaining baseline data on the productivity of this species in east coast conditions.

B. Raft Culture Experiments

1. Design and fabrication of culture rafts
2. Raft culture experiments

Provide basic information on the performance of seaweeds grown in quasi-farm conditions. Productivity and behavior of a subset of the candidate species list, grown in raft culture, are critical for the development of basic parameters for farm design and to determine the actual performance of indigenous forms under free and attached, surface and midwater culture conditions.

C. Species Collection and Field Studies

1. Species collection
2. Field observations

Provide materials from wild stocks for chemical analysis and digestion experiments to be conducted by General Electric. Sample a diversity of species and environmental situations to provide a range of analytical data as a means of identifying potential high yield stocks from which to select culture specimens.

Task 2. Test Site Evaluations and Selection

Examine candidate test sites from an oceanographic viewpoint to determine their suitability for seaweed culture. Analyze and synthesize existing information; where required, acquire additional data through on-site measurements of physical and chemical oceanographic parameters and analysis of substrate conditions.

Task 3. Sites for Location of Marine Biomass Farms

Examine potential sites for location of marine biomass farms in the New York Bight region. Apply environmental criteria as well as existing and/or potential use conflicts in making a selection.

Task 4. Alternative Designs for Rafts and Test Farm Modules

Develop alternative designs for raft and test farm modules using information derived from greenhouse and raft culture studies. Define engineering requirements of the seaweeds; explore the range of design alternatives; and examine the kinds of materials that may be used in farm design.

WORK PERFORMED

Task 1. PLANT GROWTH AND NUTRITION

A. Baseline Greenhouse Studies

1. Growth, performance and yield studies

Four cultures were started for each of the nine candidate species as specimens were collected. Table 1 shows the month in which each of these was started and the period over which growth data was obtained. Two tanks were supplied with seawater at a rate of 20 volume turnovers per day. Two other tanks were supplied seawater at 2 volumes per day augmented by ammonium nitrate pumped from a head tank to maintain a minimum nitrogen concentration of 30 μm. Nitrogen addition experiments were started in April 1981. These experiments were done to determine whether some species might be nitrogen limited at certain times of the year. Nitrate and ammonium concentrations (Fig. 2) of incoming and culture tank water were monitored weekly. Water flow rates were monitored and adjusted several times per week.

Seaweeds were cultured in the tanks in a suspended state, except for some *Palmaria* and all *Laminaria* cultures which were attached to PVS pipe. Attempts were made to remove epiphytic material and grazers from the cultures. All tanks were thoroughly scrubbed at least bi-weekly. Growth of the seaweeds was determined by weekly wet weight measurements of seaweeds in each tank. The average daily specific growth rate for each species was calculated as:

$$\mu = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

where μ is the $\% \cdot da^{-1}$ specific growth rate. Table 2 shows these rates averaged for each month for the nine species. Table 3 gives our analyses of wet weight/ dry weight relationships. Initial wet weight of seaweed in each tank ranged from 250 to 1500g or 1000 to 6000g wet$\cdot m^{-2}$. Two tanks of each species, one each of the seawater and enriched seawater cultures, were cropped back to the initial density while the other two tanks were allowed to growth without cropping (except when necessary to provide material for analysis). This experiment allowed crude determination of the maximum density that might be attained by the various species at different times of the year.

For ease of presentation, the growth and performance of each species will be discussed separately. This will be followed by our assessment of the suitability of the species for biomass culture.

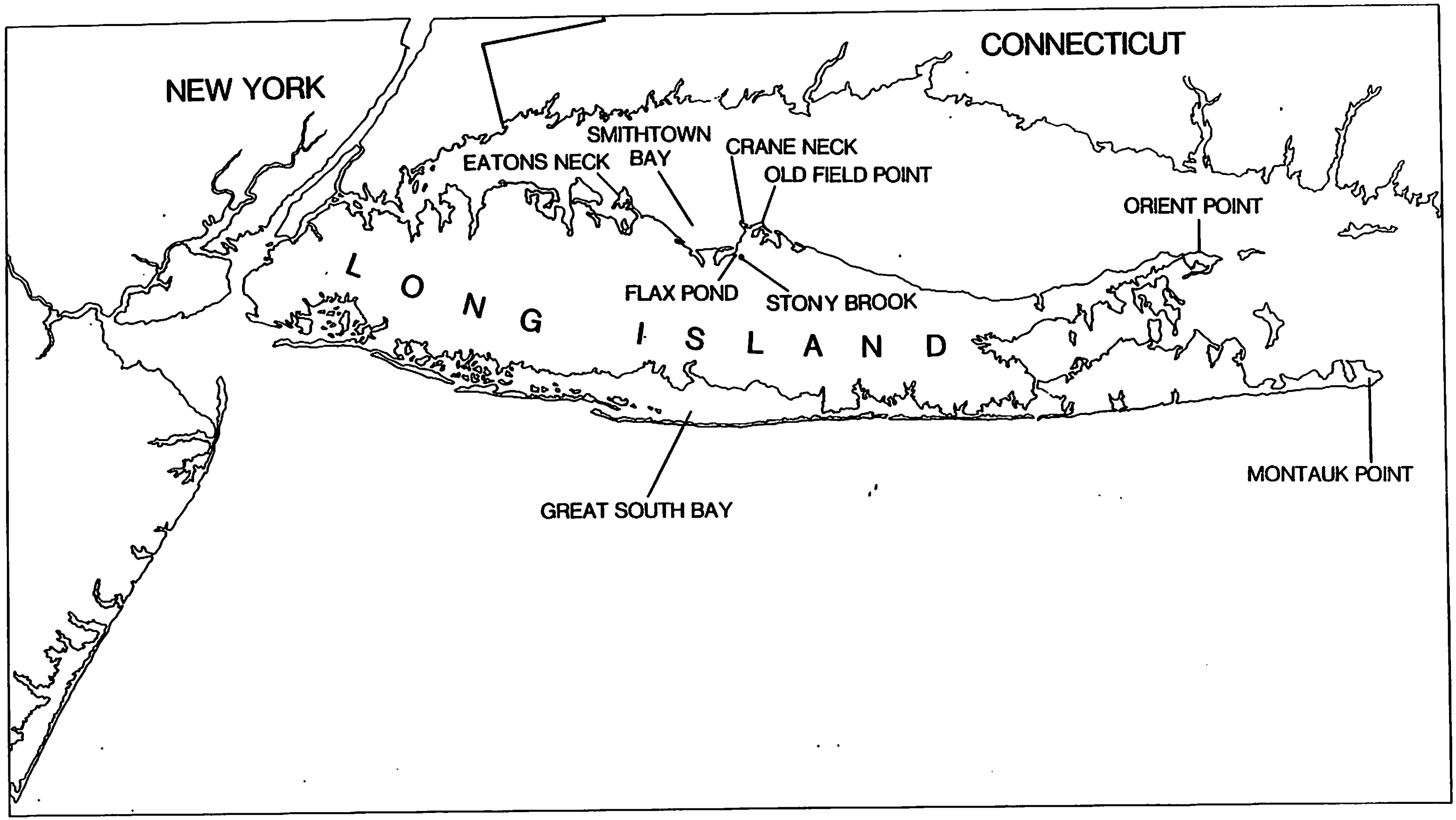

Figure 1. Locator Map: Long Island

Table 1. Species culture history for December 1980 - November 1981.

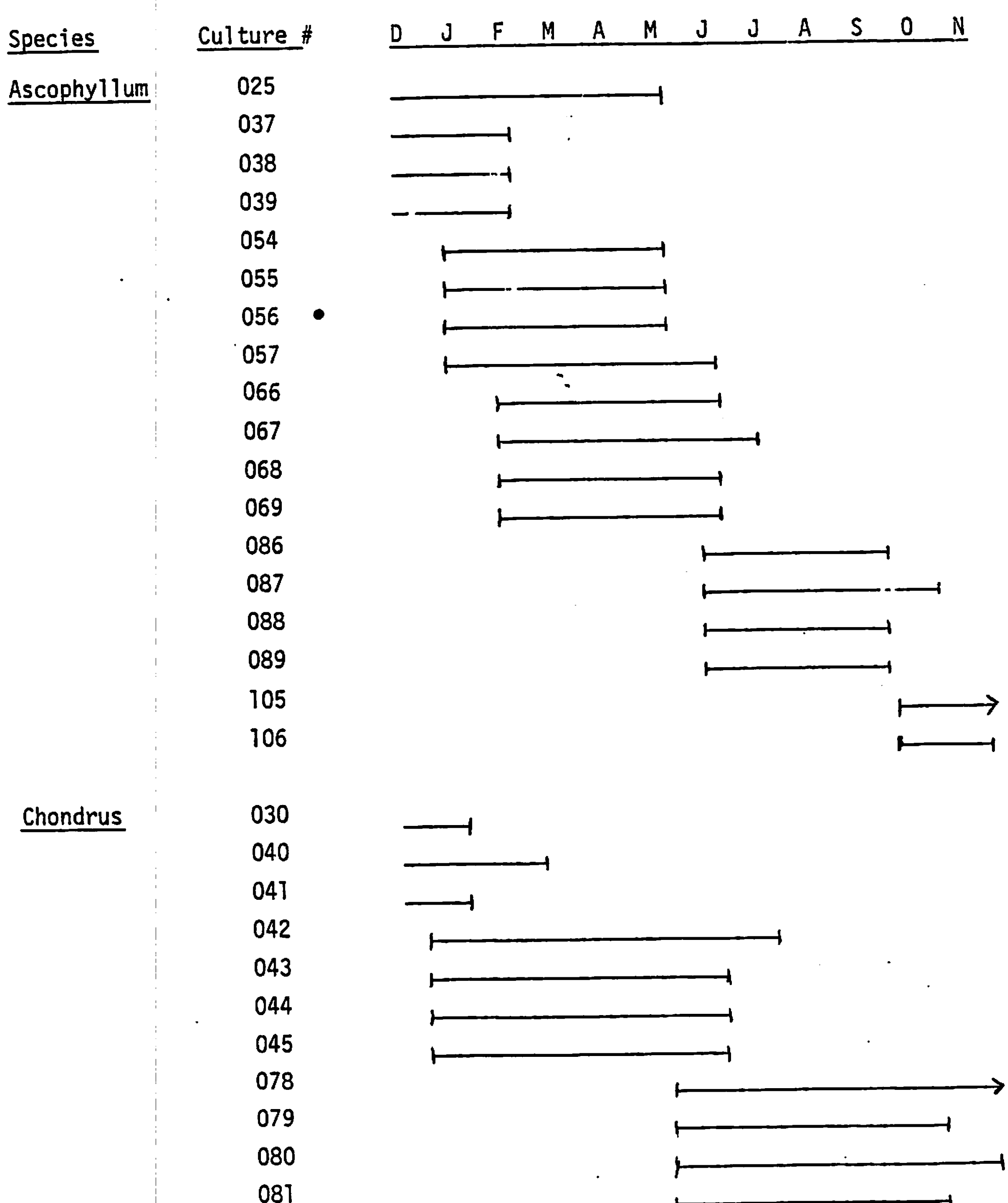

Table 1 (continued).

Species	Culture #
Palmaria	058
	059
	060
	061
	076
Ulva	003
	014A
	014B
	014C
	014D
	028
	098
	099
	114
Fucus	026
	035
	036
	046
	047
	048
	049
	062
	063
	064
	065
	082
	083
	084
	085
	090
	091
	092

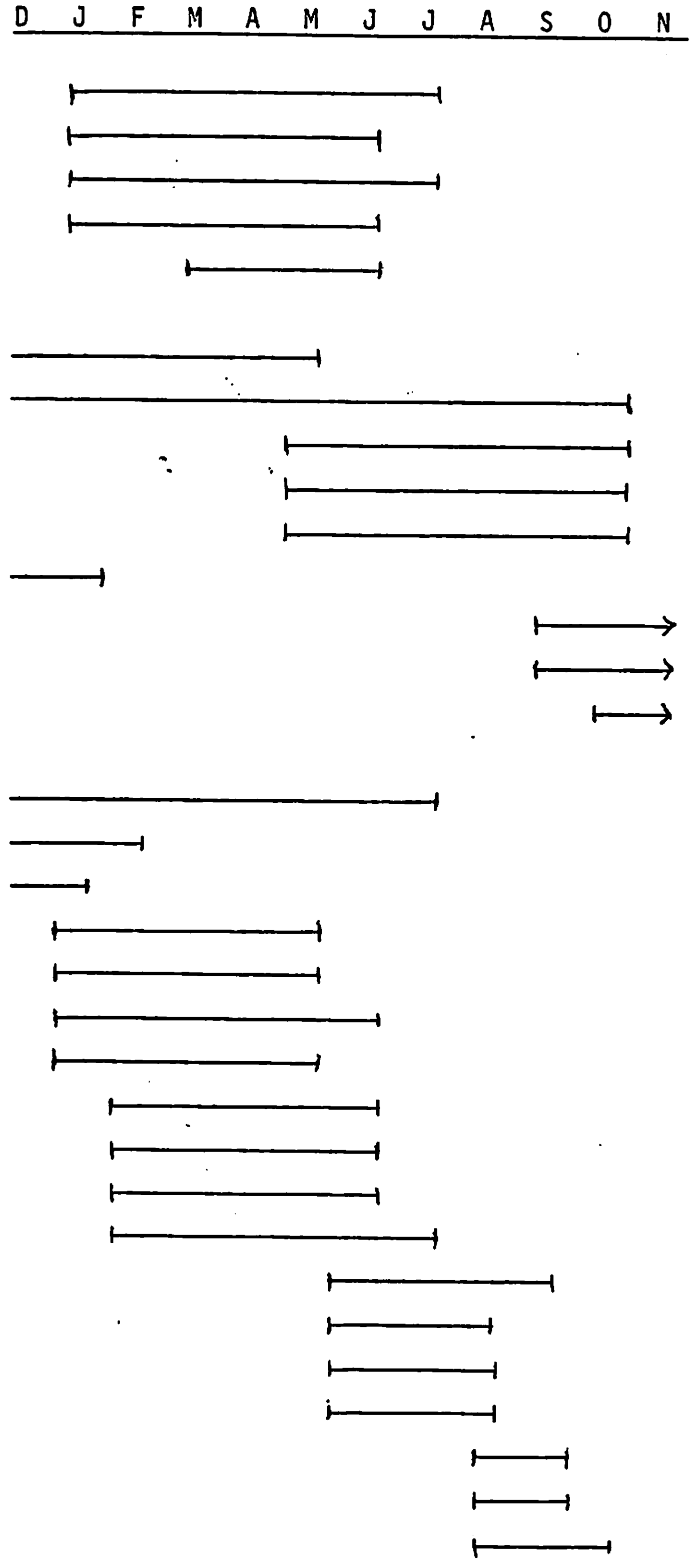

Table 1 (continued).

Species	Culture #
Fucus (cont.)	093
	102
	103
	104
	119
Codium	005
	015
	023
	070
	071
	072
	073
	096
	097
	112
Agardhiella	075
	077A
	077B
	077C
	077D
	094
	095
	111
	112
	113
	120
Gracilaria	074A
	074B
	074C
	074D
	100

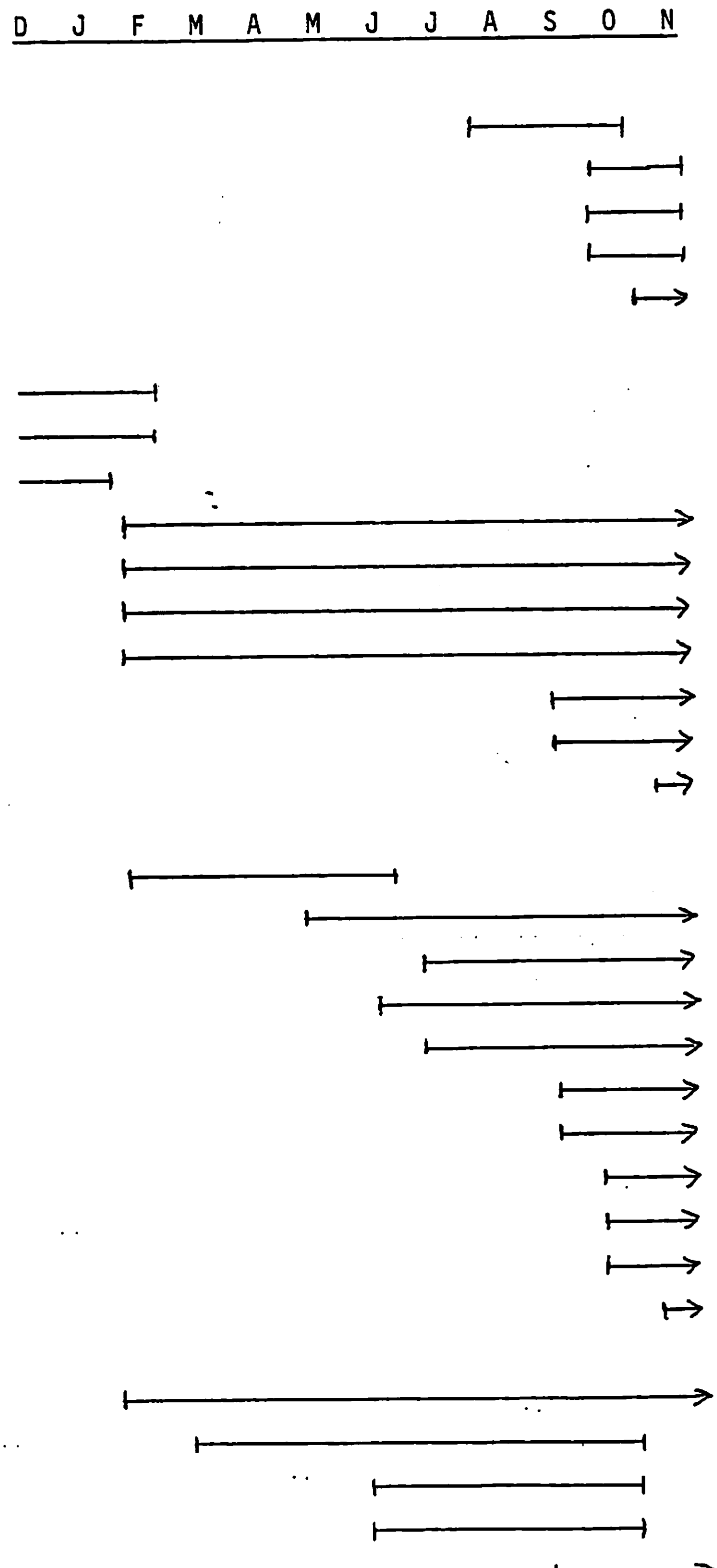

Table 1 (continued).

Species	Culture #	D	J	F	M	A	M	J	J	A	S	O	N
Gracilaria (cont)	107											|——	——>
	108											|——	——>
	109											|——	——>
	110											|——	——>
	121											|—	—>
Laminaria	031	——	—|										
	032	——	—|									
	033	——	—|									
	050		|——	——	——	——	——	——	—|				
	051		|——	——	——	——	——	——	—|				
	052		|——	——	——	——	——	——	—|				
	053		|——	——	——	——	——	——	—|				
	115											|——	——>
	116											|——	——>
	117											|——	——>
	118											|——	——>

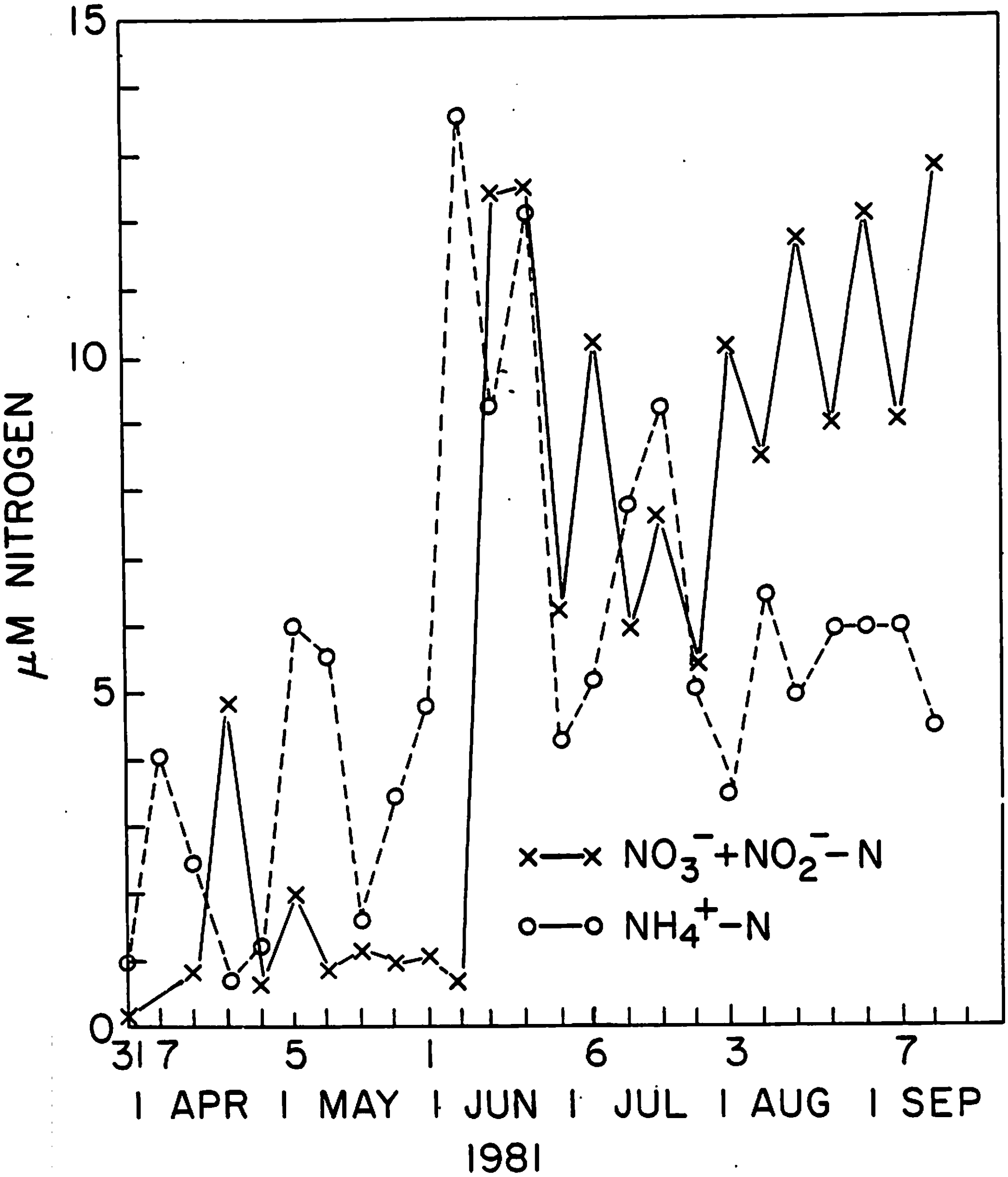

Figure 2. Weekly variations in nitrate and ammonium nitrogen concentrations in water supplied to unenriched culture tanks. Abssical units are 7 days.

Table 2. Average daily specific growth rates (%·da^{-1}) during each of the months the nine candidate species were cultured in unenriched seawater tanks. (NC = no culture available; 0 = no net growth or lost weight).

Species	1980 Dec	1981 Jan	Feb	Mar	Apr	MONTH May	Jun	Jul	Aug	Sep	Oct	Nov
Ascophyllum nodosum	<1	<1	<1	<1	<1	<1	<1	<1	0	0	<1	0
Chondrus crispus	<1	<1	0	<1	<1	<1	<1	<1	0	0	<1	0
Palmaria palmata	NC	NC	2	1	<1	<1	0	0	NC	NC	NC	NC
Ulva rigida	<1	<1	0	0	1	1.5	1.5	<1	1	<1	<1	<1
Fucus vesiculosus	<1	<1	<1	<1	1	<1	<1	0	1	0	<1	0
Codium fragile	<1	0	<1	<1	1	1.5	1.5	1.1	1	1	0.6	<1
Agardhiella tenera	NC	NC	NC	<1	1	6	3	6.1	2	1.3	1	0
Gracilaria tikvahiae	NC	NC	NC	<1	<1	2.7	3	4.4	4	3	2.5	1
Laminaria saccharina	<1	2	2	2	1.5	1	<1	0	NC	NC	1	1

Table 3. Mean % dry weight composition of seaweeds in greenhouse cultivation.

Species	% Dry Weight
Agardhiella tenera	8.3
Ascophyllum nodosum	18.7
Chondrus crispus	17.3
Codium fragile	5.8
Fucus vesiculosus	16.7
Gracilaria tikvahiae	8.8
Laminaria saccharina	17.8
Palmaria palmata	11.8
Ulva lactuca/rigida	16.6

Ascophyllum nodosum

We cultured a variety of *Ascophyllum* isolates obtained from the salt marsh Flax Pond and rocky shore material collected from Connecticut. *Ascophyllum* performed poorly in our culture tanks. Some growth (see Table 2) was evident in the winter and spring months however, most individual cultures did not last much beyond two months. Rocky shore material that had receptacles (air bladders) large enough to provide buoyancy deteriorated after a few weeks of growth in this floating state. A combination of high light intensity often caused the receptacles to be damaged, resulting in a rupture and sinking of the material. It was also noticed that grazing by a variety of amphipods and isopods caused damage to these structures. Rocky-shore material undergoes reproductive development of conceptacles (fruiting bodies) during the spring. After release of gametes, these structures disintegrate, resulting in a significant loss of biomass.

Specimens collected from Flax Pond fared somewhat better. These salt marsh varieties usually do not undergo sexual reproduction but reproduce vegetatively by fragmentation. The receptacles of salt marsh specimens are considerably smaller, therefore the material is not buoyant. Specimens obtained near the mean low water (MLW) mark at Flax Pond have larger receptacles than material obtained 1 m above MLW. Frequently, receptacles are absent altogether in these high salt marsh specimens. Growth in salt marsh varieties was somewhat better than in rocky shore material. Figure 3.B shows the typical weight records of plant material in the tanks during the spring months, the best growth period. The material typically sits at the bottom of the tank in clumps, despite constant aeration. We noted occasional severe grazing damage by amphipods and isopods which resulted in biomass decreases. Brinkhuis has previously noted that salt marsh *Ascophyllum* in Flax Pond produces about 600 g dry weight$\cdot m^{-2} \cdot yr^{-1}$ (approx. = 3000 g wet weight). By comparison tank cultured material produced less than 1000 g wet$\cdot m^{-2} \cdot yr^{-1}$. In nature in its intertidal habitat, *Ascophyllum* is typically exposed to the atmosphere for 30 - 60% of the day. This exposure may reduce the grazing we noted in the tanks as well as other damage caused by continual submergence. It is not really known if species normally found intertidally are even capable of growth while continually submerged. These may require exposure to "toughen" their structural integrity.

Specimens floating at the surface of the tanks occasionally became fouled with blue green algae and a green alga, *Enteromorpha*. Specimens at the bottom of the tanks experienced little fouling by epiphytes, but became fouled by tunicates during the summer months. Fertilized cultures did not show enhanced growth.

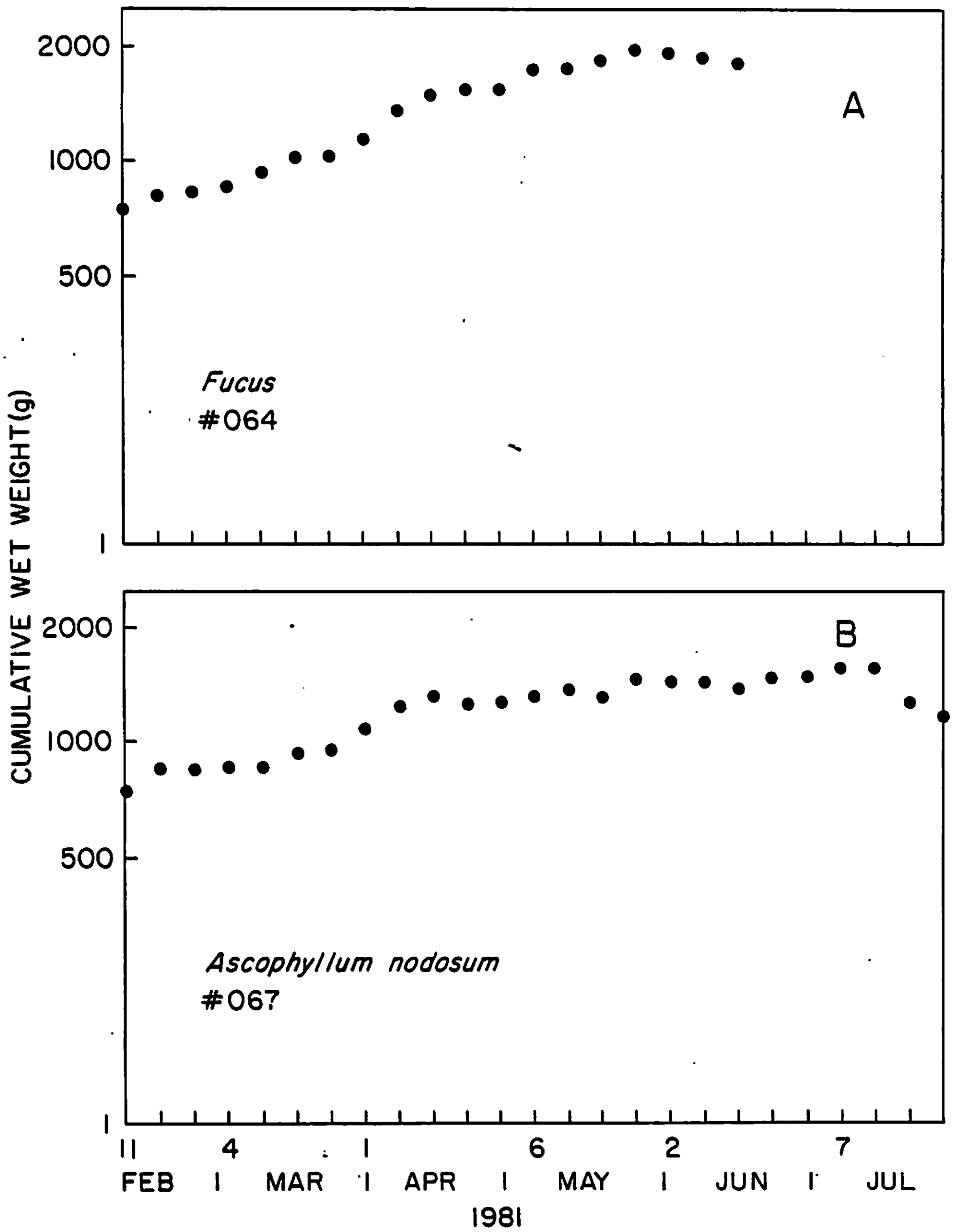

Figure 3. Wet weight variations in Fucus vesiculosus (A) and Ascophyllum nodosum ecads (B).

Our conclusion is that Ascophyllum nodosum (and its salt marsh varieties) is a poor candidate for biomass culture in a continually submerged state as might be experienced in floating net/pen culture.

Palmaria palmata

Palmaria is known as a cold water species and occurs north of Long Island during the winter-spring period. Wild populations in Massachusetts, Maine and the Maritime Provinces are commercially harvested for the edible product known as Dulse. We obtained culture material of this red alga from Connecticut and Montauk Point (Long Island's southeastern point). We made one successful collection at Montauk Point from material floating in the water column after a storm.

Initially, cultures of Palmaria were established by attaching specimens to PVC pipe placed in the bottom of the tank. Figure 4 depicts the growth of this material during the spring of 1981. During April, many of the plants reproduced sexually. In the latter part of the month, young germlings (< 1 mm long) were noted on the PVC material while much of the adult material fragmented and became detached from the pipes. In this decay specimens became chlorotic, losing most of their red pigmentation. Dehiscent specimens still looking healthy were isolated and cultured as floating material in a separate tank. Growth of the floating material (Fig. 4) was significantly greater than that observed for attached specimens. This may be due to a combination of less sediment fouling and exposure to more light for floating material. Most of the germlings found on PVC pipes in April died during subsequent weeks due to sedimentation in the tanks.

We observed significant growth of this subtidal species only during the early spring months in the greenhouse tanks. Palmaria's sexual reproductive cycle gives it the attribute of being easily seeded on substrates. We did not observe any fouling by epiphytic species. Enrichment with ammonium nitrate did not appear to be beneficial to these cultures.

We conclude that Palmaria is a poor candidate for biomass culture in New York waters, principally because of its short growing season.

Chondrus crispus

We initiated several sets of cultures of this economically important red alga. Wild populations in the Northeast are commercially harvested for carrageenan extraction. Much research on this species has been conducted at the

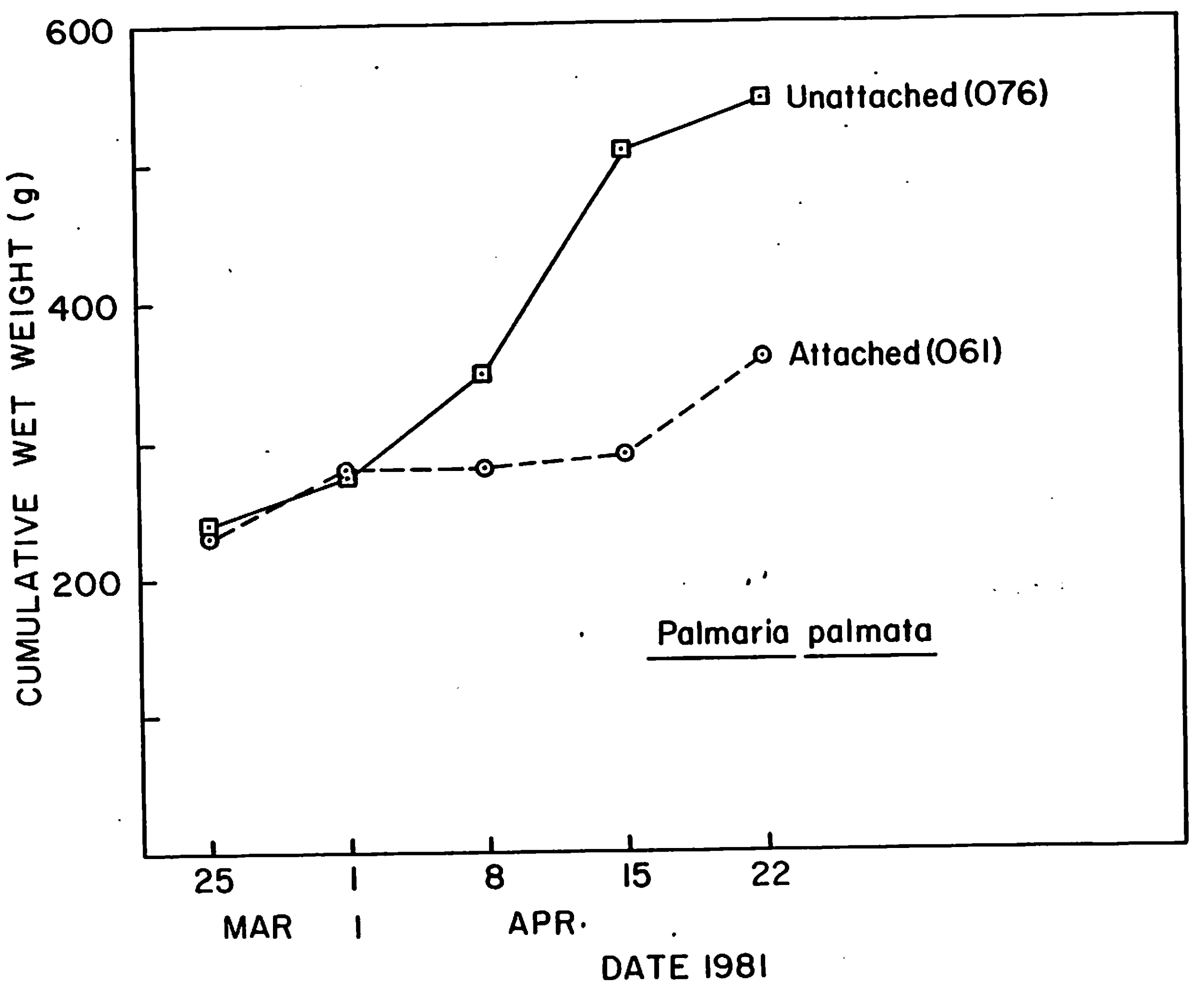

Figure 4. Wet weights recorded for attached and unattached, floating Palmaria palmata.

Atlantic Regional Laboratory in Halifax, Nova Scotia where several rapidly growing strains have been isolated. We only attempted culture of specimens collected locally near Flax Pond and from Montauk and Orient Points, where several large stands have been observed.

We obtained erratic growth in all of our cultures. The material was grown unattached and maintained in suspension by aeration. Until early fall (1981), this aeration probably provided insufficient agitation, as most of the material remained at the bottom of the tanks. Figure 5 shows a growth pattern typical of several of the cultures. The spring months yielded the best growth spurts although a similar growth pattern (not shown) was observed during the fall months. These growth spurts were usually of short duration and were followed by episodes of tip erosion. Chondrus specimens remaining at the bottom of the tanks were subjected to sedimentation and fouling by tunicates in the summer months. Occasional sets of the blue mussel, Mytilus edulis, were also noted.

Specimens collected fresh from Flax Pond were occasionally a yellow-brown color, suggesting a nitrogen deficiency. After some weeks in the culture tanks, these specimens took on the typical reddish color, while those growing in nitrogen enriched cultures became a dark red color indicating a better nitrogen nutritional state. However, we could not detect any significant enhancement of growth rate among the enriched cultures.

We conclude that Chondrus crispus from Long Island is a poor candidate for biomass culture. The plant is too small to be harvested easily from fixed substrates and it appears to grow poorly in a floating net/pen culture.

Ulva lactuca/rigida

We have cultured this green leafy alga from material collected in Great South Bay, Flax Pond, Montauk, and Orient Points and Connecticut. At first, we assumed we were working with the species lactuca, but recent taxonomic studies by others at Stony Brook and the University of Connecticut have determined that most of the material from Flax Pond is of the species rigida. As many as four species occur around Long Island which can only be separated by microscopic examination of cellular arrangement or by gel electrophoresis.

We have maintained cultures of Ulva for over 16 months. It exhibits a bimodal growth peak, with best growth in the late spring and late summer. Growth stopped and heavy fragmentation and brittleness of the thalli occurred during the winter months. During mid summer, Ulva develops spores/gametes within the cells of the leafy thallus. When these reproductive cells rupture to release the spores/gametes, patches of holes appear in the thalli causing them to fragment into small

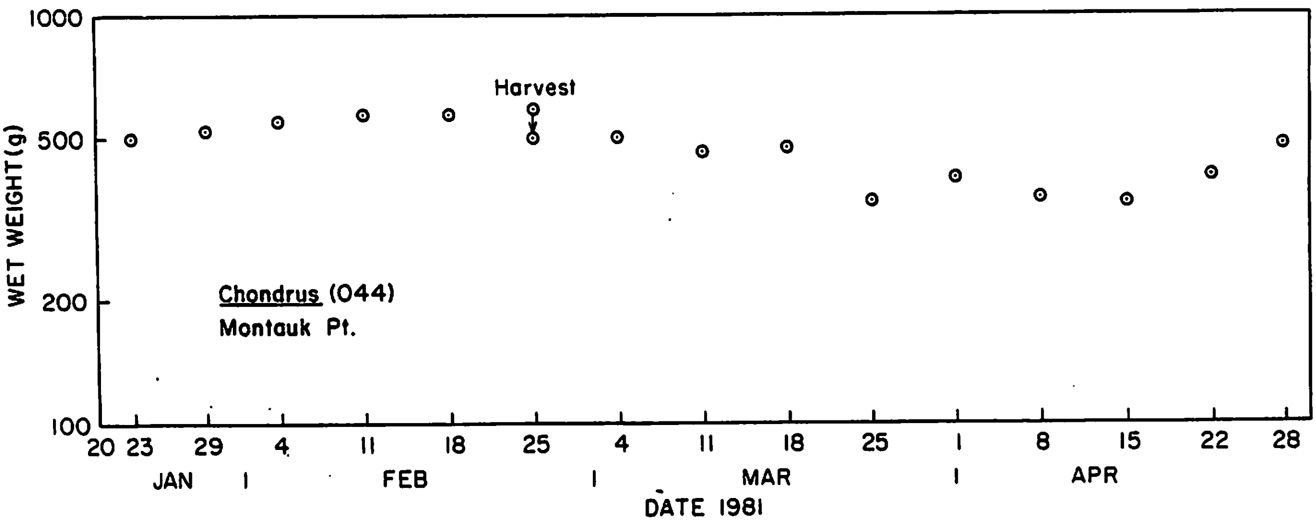

Figure 5. Wet weight variations in Chondrus crispus. The arrow indicates harvesting of the culture.

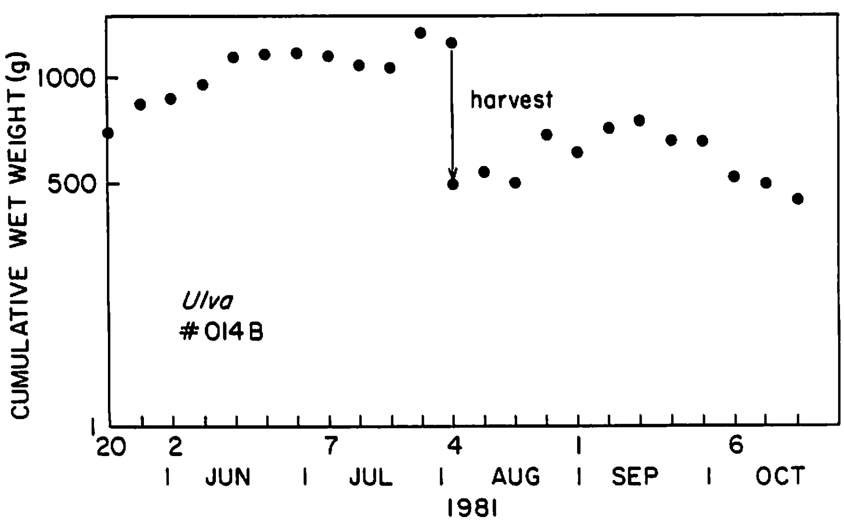

Figure 6. Wet weight measurements in Ulva lactuca/rigida. The arrow indicates harvesting of the culture.

pieces. During periods of good growth, these holes may fill in. Figure 6 shows the growth observed in our cultures. Several of these grew at rates up to 21 g dry weight$\cdot m^{-2} \cdot da^{-1}$ during August and September but virtually ceased in October. During periods of good growth, the specific growth rate approached 2%$\cdot da^{-1}$.

No severe fouling problems were encountered during the study. During the summer, smaller specimens remaining at the bottom of the tanks became colonized by tunicates. We observed no nitrogen enhancement of growth in the cultures throughout the year.

We conclude that biomass culture of _Ulva_ in New York waters is probably not feasible. Its bimodal growth peak would present difficulty in seeding and harvesting the species in large scale, open water seaweed farms.

Fucus vesiculosus

Culture material of this brown species was obtained frequently from Flax Pond and Montauk and Orient Points. Low intertidal specimens from Flax Pond are typically _F. vesiculosus_, bearing receptacles and conceptacles. This species may also be found on the higher intertidal marsh flats. We obtained _Fucus distichus_ from Montauk and Orient Points. _Fucus vesiculosus_ and _F. distichus_ are typically attached to rocks and shell substrate and have sexual reproduction cycles. Salt marsh material from the high intertidal frequently lacks air bladders and only reproduces vegetatively by fragmentation. Sexual reproduction in _Fucus_ occurs at irregular intervals during the spring, summer, and fall.

Tank cultures of _Fucus_ that had air bladders and/or fruiting bodies floated in tanks. Freshly collected material grew reasonably well between February and June (Fig. 3.A). Dehiscence of reproductive tips and decay of vegetative tips resulted in significant biomass losses during the summer and winter months. In the field, _Fucus_ is intertidal and is usually exposed for 20 - 40% of the tidal cycle. Continual submergence may also affect the species. We occasionally noted severe fouling by blue-green algae and _Enteromorpha_ especially in nitrogen enriched cultures. During summer months, heavy grazing damage from amphipods and isopods was observed.

Cultures of _Fucus_ typically ceased growth within two months of initiation regardless of when started. Most of the material collected in the field is mature specimens. Young germlings are difficult to locate in quantity due to the general lack of intertidal rocky substrates and the irregular and somewhat predictable reproductive cycles of the species. However, the frequent reproduction in the species may make it desirable from the standpoint of seeding seaweed farms.

Although we observed poor growth in tank cultures, raft culture experiments indicated good growth may be attainable. We will continue to evaluate the potential of this species by obtaining more raft growth data. Enhancement of growth by nitrogen enrichment has not been satisfactorily documented. Brinkhuis has previously noted that the species produces up to 3000 g wet weight$\cdot m^{-2} \cdot yr^{-1}$ in Flax Pond.

Codium fragile

We have cultured specimens of this green alga for over 15 months. Material has been collected from Flax Pond, Montauk and Orient Points and Great South Bay. The species occurs in nature both floating and attached to hard substrates (rock, shell, wood, and rope). It first appeared in Long Island waters during the late 1950's and has since spread to all shallow marine waters of Long Island.

Growth of Codium is first noticeable in late March. It grows rapidly (up to 1.0%$\cdot da^{-1}$) during periods when water temperatures are 10 - 16°C and may grow up to 2.0%$\cdot da^{-1}$ during the summer months. Codium floats at the surface of tanks during the summer months when rapid photosynthesis results in gas bubbles becoming trapped in the thalli. During periods of slow growth, it usually sinks to the bottom of tanks. Growth of Codium virtually ceases in November. During September and October, the species produces spores as the water temperatures fall through 15 - 16°C. These spores settle on any hard substrate, germinate and overwinter as small filamentous patches. In the spring, these mats develop into erect thalli.

We have cultured this species at several densities. Two cultures started in August, one at a density of 250 g dry weight$\cdot m^{-2}$ and the other at a density of 140 g dry weight$\cdot m^{-2}$. Both attained, within two months, the summer maximum density of 1600 g dry weight$\cdot m^{-2}$ (Fig. 7). Cultures started in February exhibited much the same pattern (Fig. 8). Between February and July, cultures harvested weekly back to an initial density of 4500 g wet$\cdot m^{-2}$ yielded about 14000 g wet$\cdot m^{-2}$ while unharvested cultures started at the same density yielded 16000 g wet$\cdot m^{-2}$. All cultures attained a maximum density of 20000 g wet$\cdot m^{-2}$ in July. We feel that this is probably limited by light availability and possibly some nutrient other than nitrogen.

Since about 8% of Codium wet weight is dry matter, 20000 g wet$\cdot m^{-2}$ corresponds to about 1600 g dry$\cdot m^{-2} \cdot yr^{-1}$. If it were possible to seed and harvest more often, e.g., seed March-harvest July; seed August-harvest September, double this value might be attained.

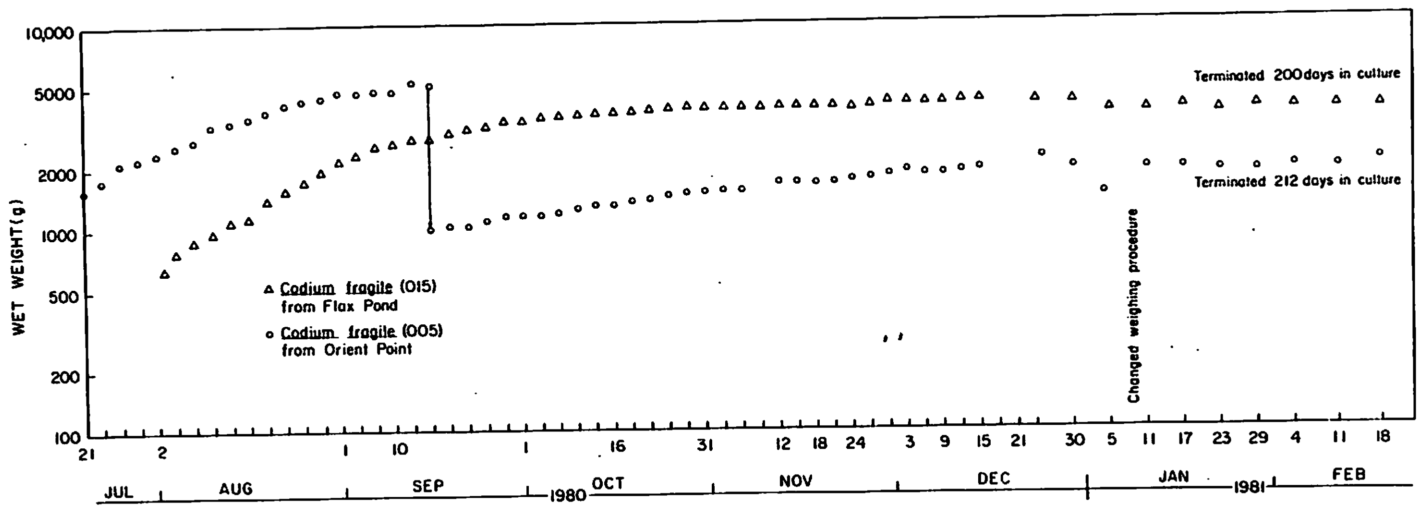

Figure 7. Wet weight increases in two Codium fragile cultures during 1980-81. Arrow indicates harvesting of culture.

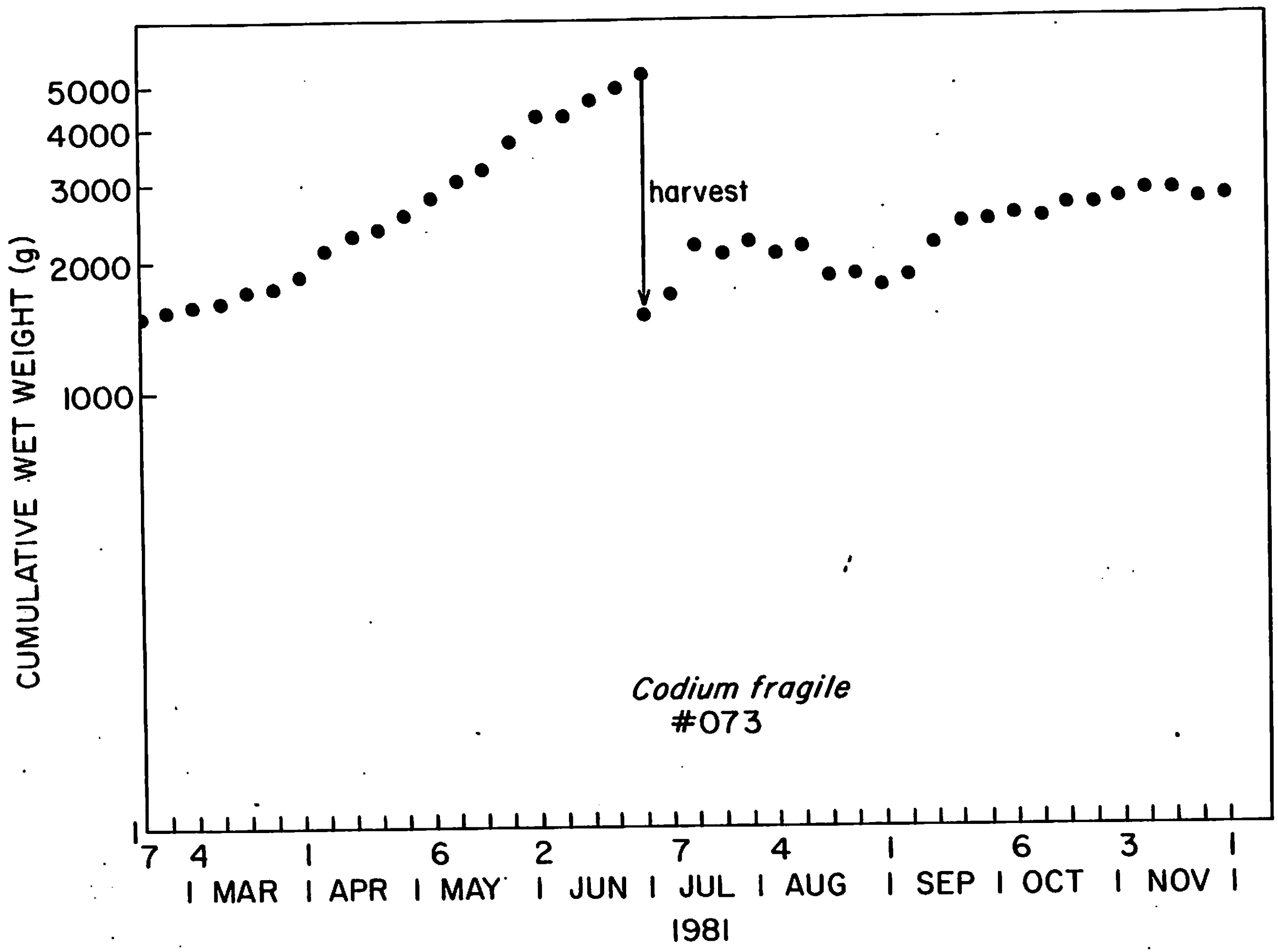

Figure 8. Wet weight variations in Codium fragile during 1981. The arrow indicates harvesting of the culture.

We noted no significant differences in growth of encriched cultures. In research to be done, we will try to control the reproductive cycle of Codium to produce seed at will. The potential of Codium as a biomass crop will then be better assessed. At the moment, it is attractive because it grows rapidly for about the eight warmer months and may be easily seeded onto substrates compatible with other attached species. We are also continuing to grow the species on the rafts.

Agardhiella tenera

We cultured specimens of this red alga collected from Flax Pond during the summer of 1980. It was removed from small rocks and cultured in a suspended state. The plants grew well (Fig. 9) but became reproductive after only two weeks. After spore release, the plants were epiphytized by Ceramium rubrum and fragmented severely. It was not until May, 1981 that we were able to collect substantial quantities of Agardhiella again. Then, several hundred grams were collected floating in the surf along the shore of Great South Bay. It grew well and by July we were able to grow enough biomass to stock a number of other tanks. Figure 10 depicts the typical growth of this species during the summer and fall months. As noted in Table 2, this species is capable of growth at $6\% \cdot da^{-1}$ in tank cultures. We attempted to segregate material that became reproductive. Both reproductive and vegetative material grew well. Reproductive plants did experience some fouling by Ceramium and Polysiphonia (two small filamentous red algae) but fragmentation was minimal. No nitrogen enrichment effects on growth were noted.

We will continue to work with Agardhiella. Specimens collected locally do release spores, an attribute that may simplify seeding of a seaweed farm. It is basically a warm water species-- it grows very well from May until October. We will initiate experiments to culture spores and offspring to better develop our understanding of this species.

Gracilaria tikvahiae

This red alga is very similar to Agardhiella tenera in color, morphology, and productivity. We obtained several hundred grams of Gracilaria tikvahiae in February from Ft. Pierce, Florida (Harbor Branch), where work on this species has been underway for several years. The material is sterile, i.e., does not undergo sexual reproduction. It survived local cold temperatures well and started to grow rapidly in April (Fig. 11). During some weeks, the tank cultures grew at rates

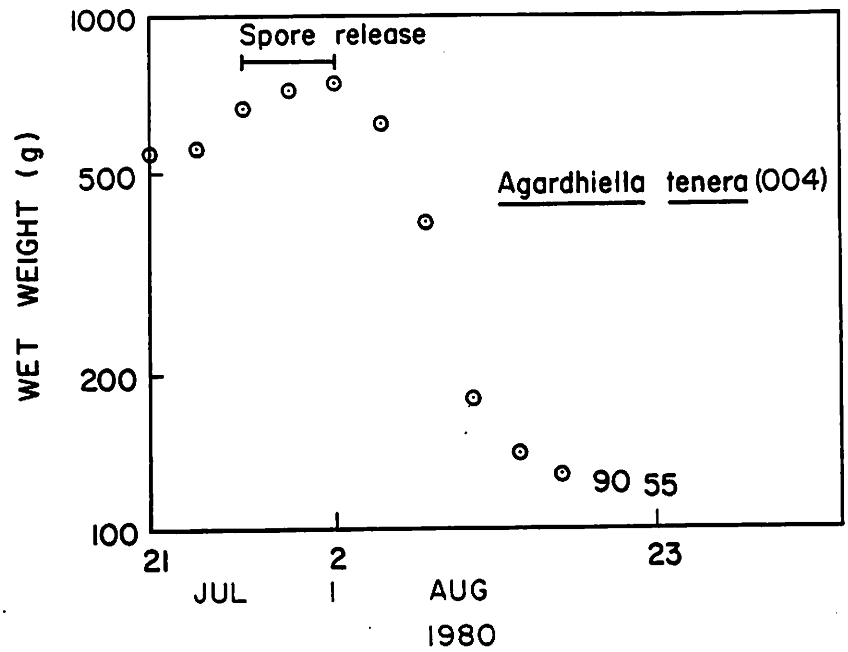

Figure 9. Growth and spore release of *Agardhiella tenera* during late summer of 1980.

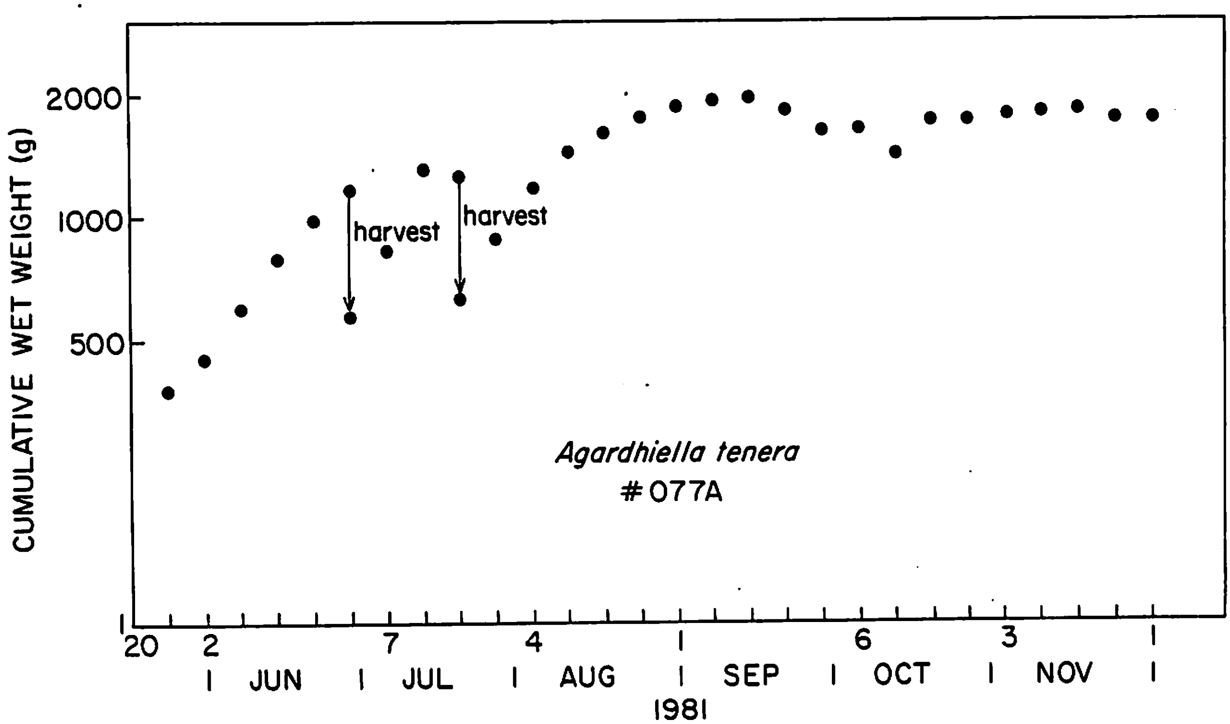

Figure 10. Wet weight variations in *Agardhiella tenera* during 1981. Arrows indicate times of culture harvest.

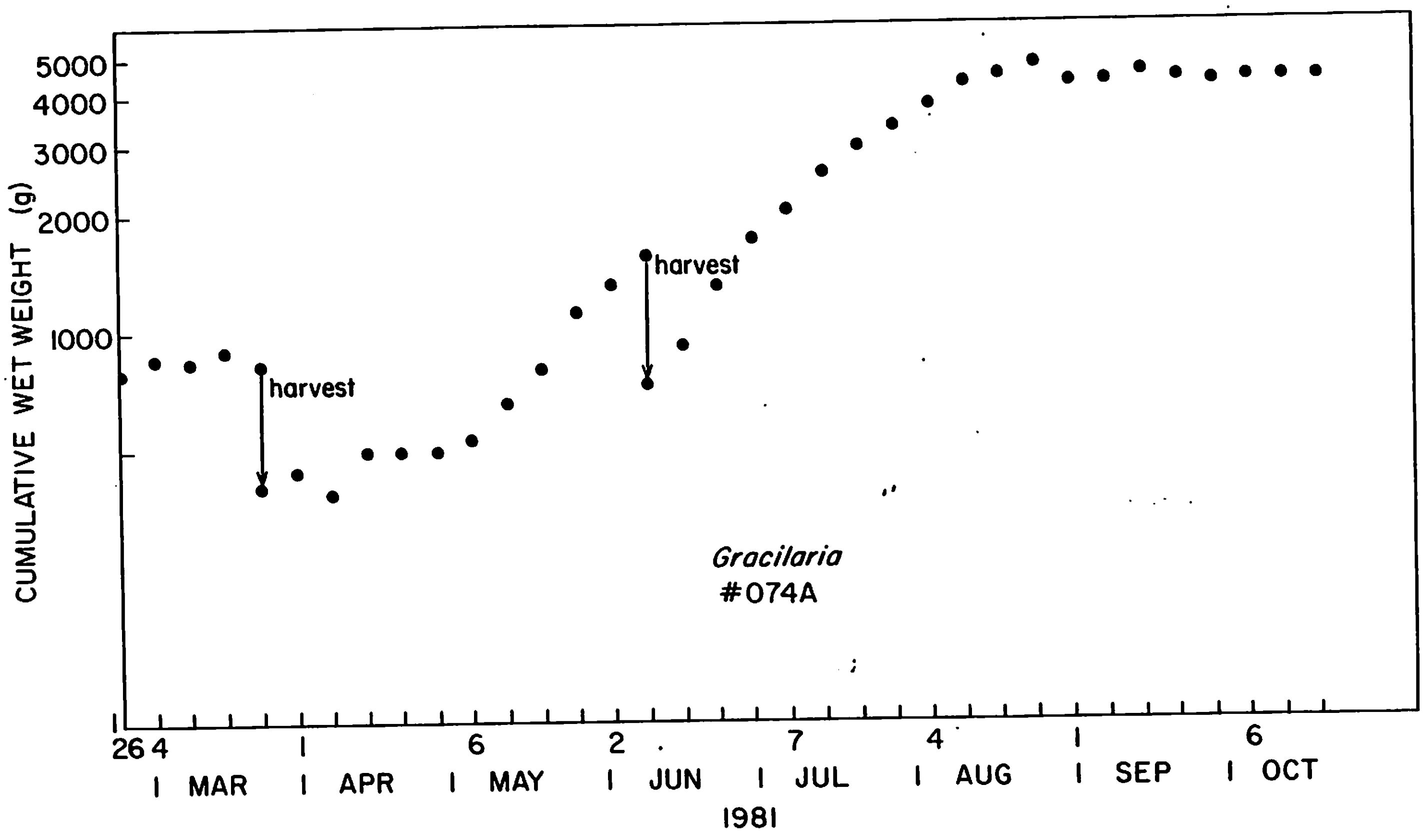

Figure 11. Wet weight increases in a typical Gracilaria tikvahiae culture. Arrows indicate times of culture harvest.

up to 8%·da^{-1}. In the period May - June, Gracilaria produced approximately 19 g dry weight·m^{-2}·da^{-1}. No nitrogen enrichment effects on growth were noted.

This species is a promising biomass candidate for culture in New York waters. One could grow vegetative species in net/pen systems, but thus far no satisfactory system has been designed. The material we have cultured is vegetative. We have not been able to locate quantities of vegetative G. tikvahiae locally although there is possibly some material to be found in shallow ponds on Shelter Island. Reproductive species of Gracilaria, probably foliifera, have been collected in Flax Pond and in Great South Bay. Stocking a seaweed farm is facilitated by using species having a sexual life cycle. Otherwise, enough biomass for stocking the farm must be overwintered for growout the next year. Relatively little is known about growth of sexually produced material on rope and other substrate material. We intend to initiate these types of studies if we can obtain sexual clones, or use the similar genus, Agardhiella.

Laminaria saccharina

We started cultures of Laminaria in the fall of 1980. Material collected in August and September from Flax Pond and Montauk and Orient Points was mature and reproductive, but did not grow when placed in culture tanks. In January 1981 we obtained a number of young sporophytes from Montauk Point. These sporphytes were trimmed to about 10 - 15 cm overall length, attached to PVC pipe and held at the bottom of the tanks. Little growth was observed until early February when water temperatures started to climb after having been at 0 ± 1°C for eight weeks (see Fig. 12). Figure 13 shows the five-fold increase in biomass of six plants held in one culture tank between February and April. We also recorded length increases of blades and stipe of 24 plants. While individual plants exhibited wide variation (Fig. 14), cumulative length increases from 22 January to 22 April ranged from 225 to 1750 mm. The mean cumulative length increase for all plants was 750 mm, while the increase for the best 25% growing plants was 1350 mm. Average growth rates were 2%·da^{-1}.

We initiated culture nitrogen enrichment experiments in March (daily addition) and April (continuous addition). Both enriched cultures (#50 and #51) grew significantly faster than unenriched cultures (#52 and #53) during the month of April (Figures 15 and 16). Although this nitrogen enhancement of growth was proven to be significant ($p < .05$) by a t-test comparison of paired means using arcsin transformed data, the difference between enhanced and non-enhanced growth amounted to only about 10 - 15%. Laminaria productivity in culture during April

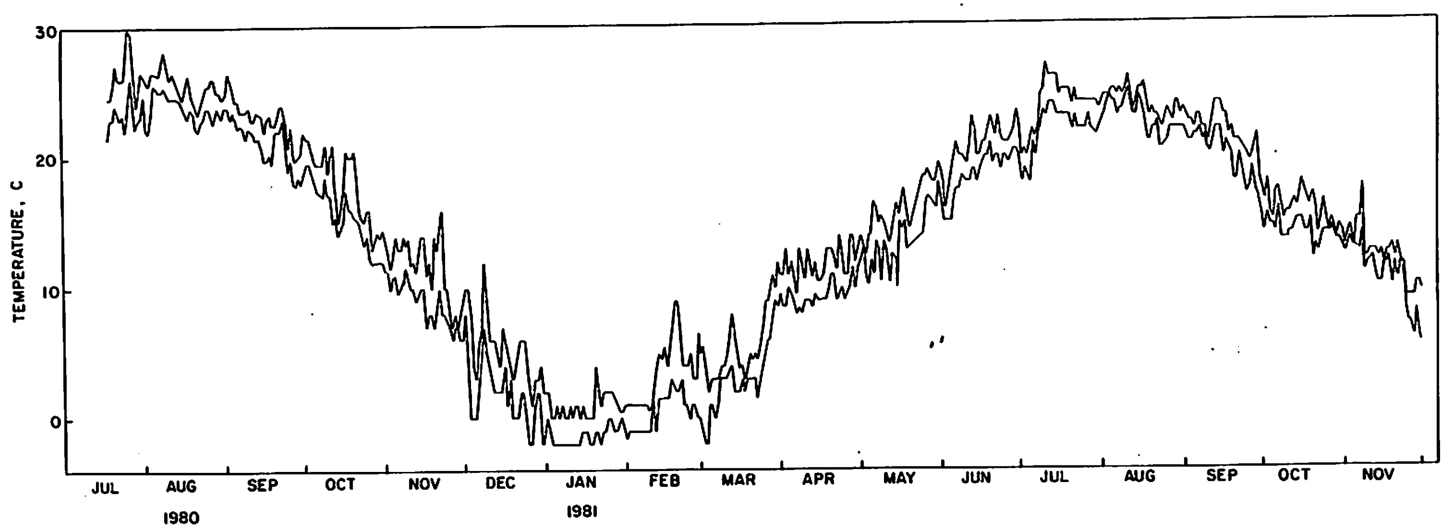

Figure 12. Daily minimum and maximum water temperatures recorded in culture tanks.

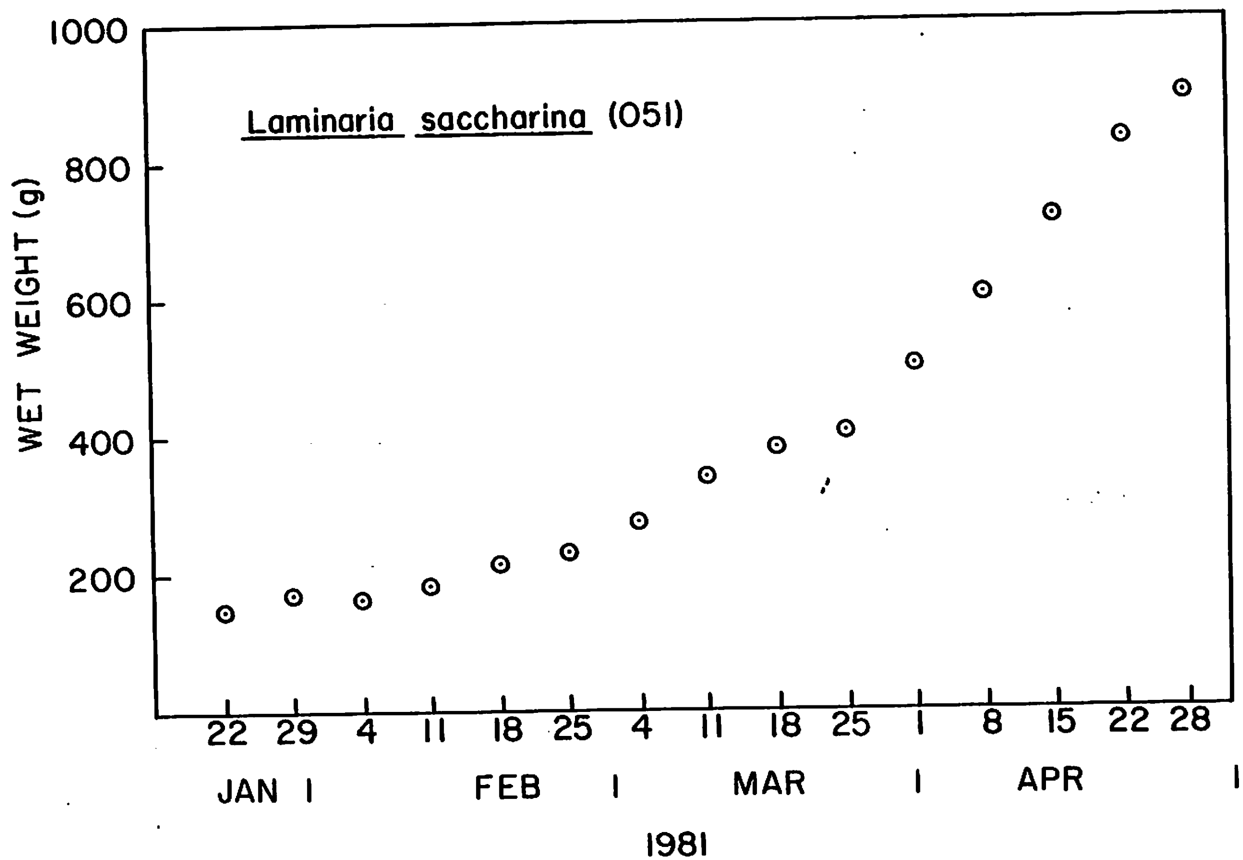

Figure 13. Weight increases of 6 _Laminaria saccharina_ plants in early 1981.

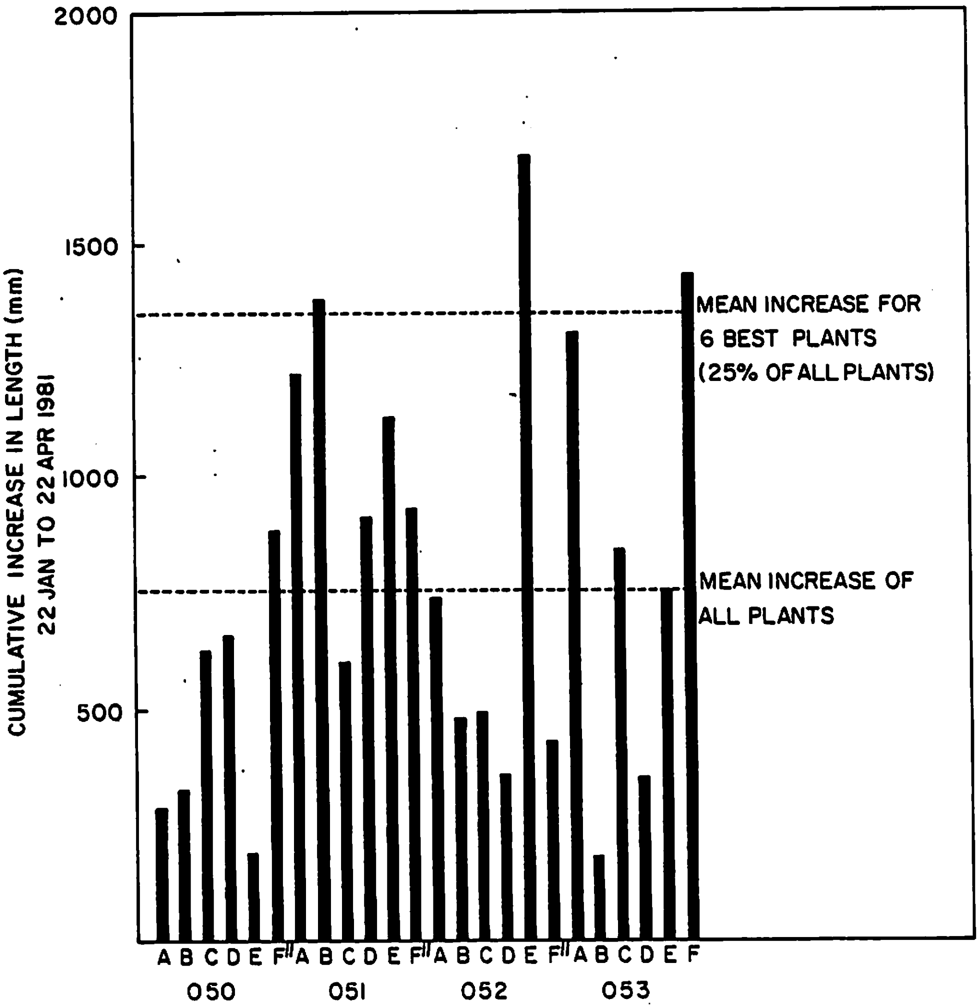

Figure 14. Cumulative length increases of 24 Laminaria saccharina plants. Note the large degree of variation in growth in individual plants.

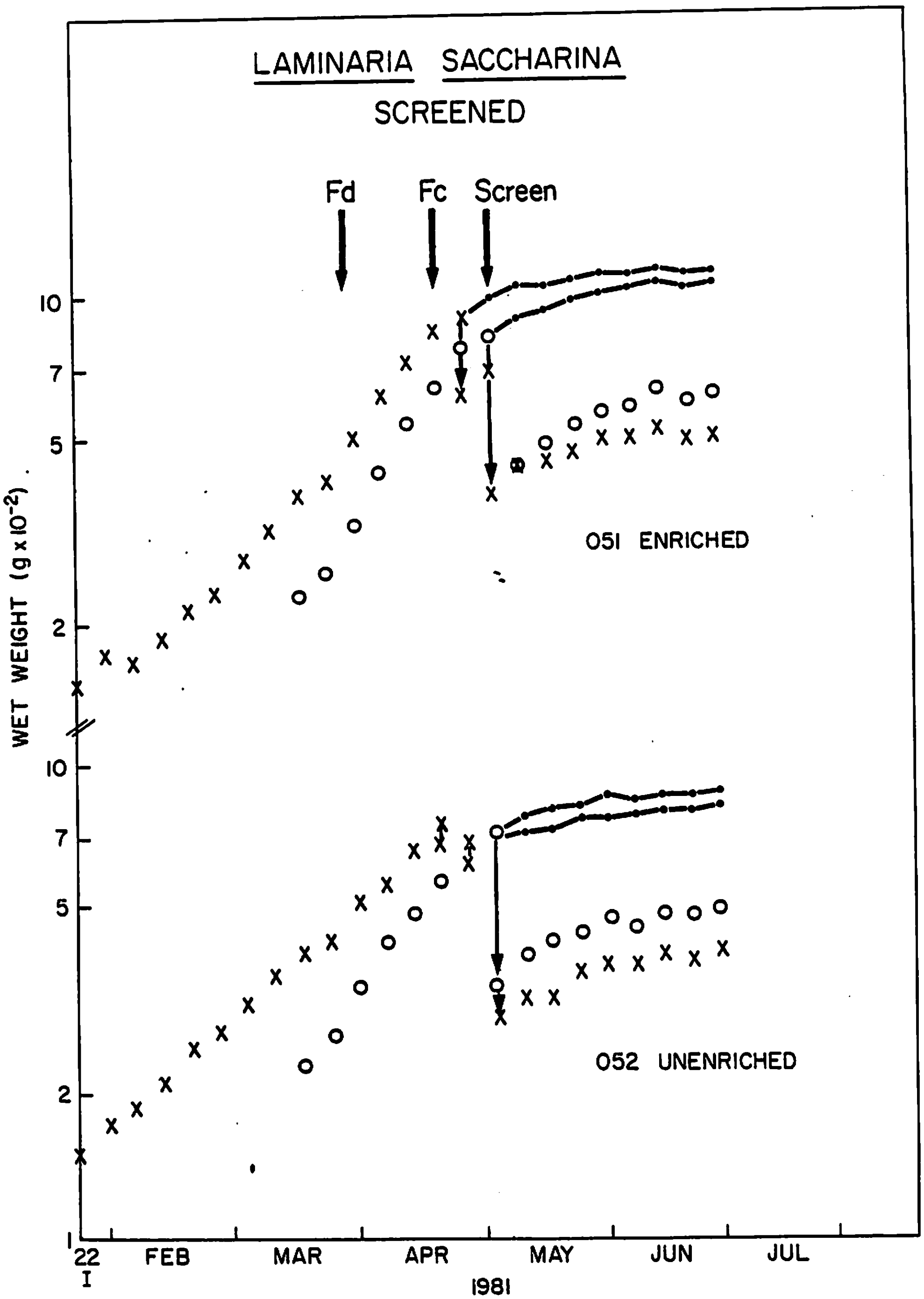

Figure 15. Growth of Laminaria saccharina plants (enriched - Fd = fertilized daily; Fc = fertilized continuously - starting at time indicated by arrow, and unenriched) when light was reduced by 66% at time indicated. Each line represents six plants. Dashed lines represent extrapolated growth.

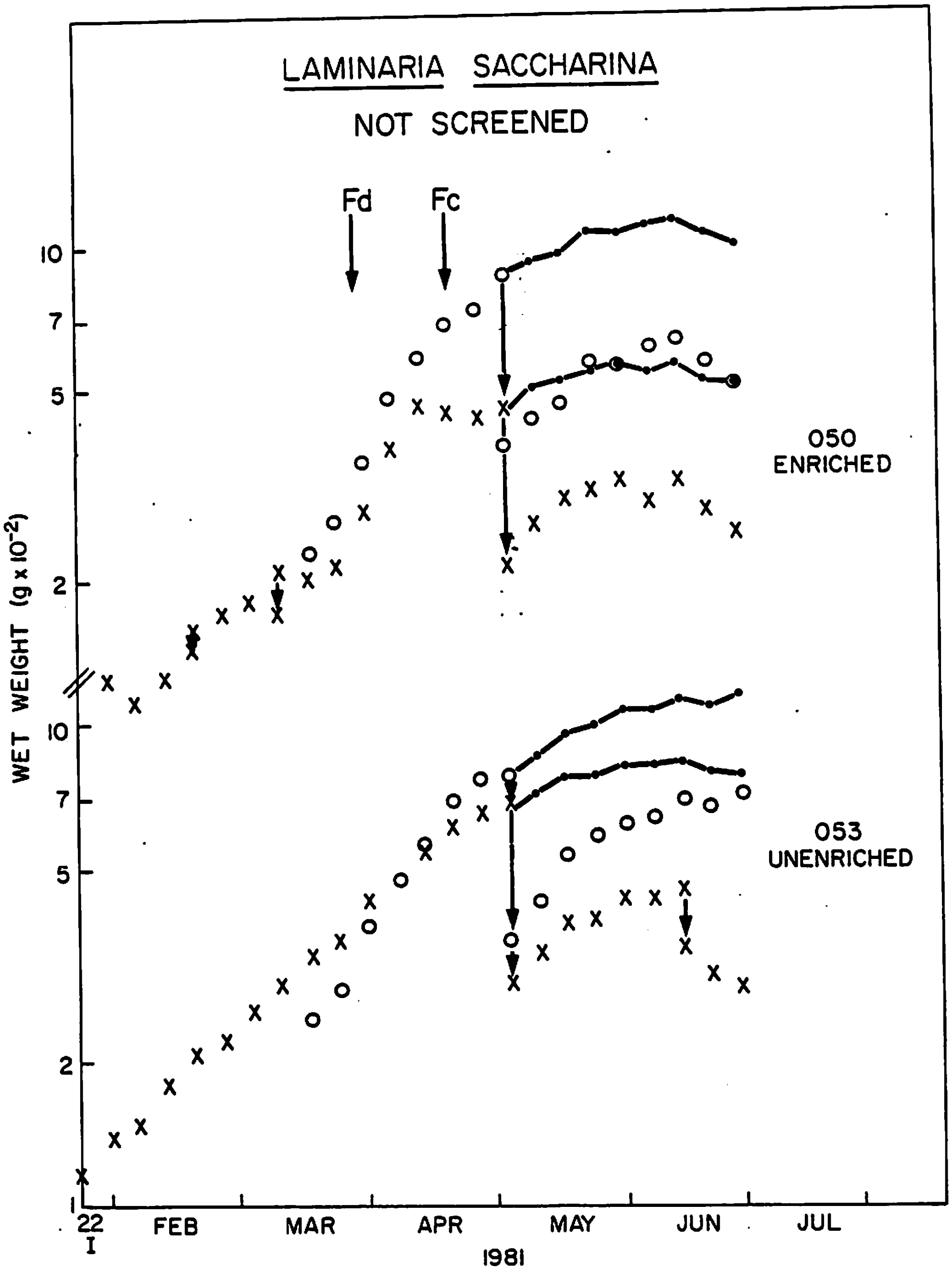

Figure 16. Growth of Laminaria saccharina (enriched - Fd = fertilized daily; Fc = fertilized continuously - starting at time indicated by arrow, and unenriched) when cultures were exposed to ambient light levels. Each line represents six plants. Dashed line represents extrapolated growth.

was approximately 14 g dry weight$\cdot m^{-2} \cdot da^{-1}$.

It should be pointed out here that this productivity value, as are all others presented in this report, is a nominal value. We do not yet have productivity estimates under conditions of optimum density.

Laminaria saccharina is capable of excellent growth during periods of cold water temperatures. The optimum growth was linear as a function of time at temperatures between 6 and 16°C. In June, plants in culture tanks started to deteriorate. Screening (reduction of light by 66% of ambient) did not appear to have an effect on reducing loss of plants in May and June. We did not note any reproduction in cultured material before it disintegrated in early July. Subsequent attempts to obtain and culture material during the latter part of the summer met with failure. In mid-October, we obtained large quantities of young and second year plant material from Crane Neck and Eatons Neck. The young plants were obviously produced during September and early October from gamete production in Laminaria's microscopic stage. Second year sporophyte material had probably been produced in the spring or previous fall. These specimens had an area of new meristematic growth at the base of the blade, with older, often fertile pieces of blade at the apex. The new growth region in these older plants was often enlarged or twisted. All plants were trimmed back to approximately 10 - 15 cm overall length and have been growing well during November. But this is too brief an experience to provide data. We now have a total of over 100 plants in culture with an additional 150 plants growing on pipe frame racks at Crane Neck.

Task 1.A.2. Light and nitrogen effects upon growth

This task concentrated on how two important environmental factors (light intensity and nitrogen) affected the photosynthesis of two seaweed species, Codium fragile and Fucus vesiculosus, at different times of the year. Cultures of these species were seasonally established in a 3X3 matrix of light intensity and nitrogen concentration conditions. Light intensity reaching the cultures was controlled by adding or removing neutral density screens: Resulting light intensities were 100%, 66%, and 35% of ambient sunlight. Nitrogen, as NH_4NO_3, was "pulsed" into the cultures. That is, a large dose of nitrogen was added each morning while the seawater flow was off for two hours. Nitrogen added in this manner was equivalent to a continuous nitrogen enrichment of 0, 10, and 20 μm. For these cultures, the turnover rate of seawater was 4 volume exchanges/day. Cultures grown in the 3X3 matrix of light and nitrogen were harvested back to their initial weights (900 g for Codium, 450 g for Fucus) at the time of each weighing. Three additional cultures of each species were grown at the different nitrogen levels and 100% ambient sunlight. Weekly harvests of these cultures were not made, the plant density being allowed to increase to assess the effects of higher culture densities on photosynthesis.

Cultures of both species were assayed by ^{14}C for their photosynthetic potential. New cultures were established about 2 weeks before the intended initiation of ^{14}C incubations. After the acclimatization period, weekly assays of 3 plants from each culture were started by placing the specimens under a "light gradient table." This table is basically a running seawater table placed under a bank of 8 deluxe-cool-white fluorescent tubes. Under this known, and constant, light source, plants are incubated in 1 liter bottles containing filtered seawater mixed by water-driven stir plates. Temperature is kept constant by pumping a continuous flow of seawater around the incubation bottles. Light intensity reaching the bottles can be altered by adjusting the distance between the light bank and the incubation bottles or by using neutral density filters.

Before the ^{14}C is injected into the bottles, they are placed under the light bank for 15 - 20 minutes to allow the plants to acclimate to the light conditions. Incubations last for 1 hour and were always around midday (i.e., 1000 - 1400 hours). After the incubation is complete, the plants are quick-frozen and then lyophilized and stored for future analysis.

To date, we have completed a summer (July) and fall (October/November) series of incubations. We plan additional runs for January and April, 1982, to provide an adequate data series. Analysis of our first two series of incubations have just begun. We have just gained access to a tissue oxidizer elsewhere on the Stony Brook campus and have purchased the necessary reagents and solvents. We anticipate eliminating the backlog of plant materials for analysis in the next two months.

We had initially proposed to determine the nitrogen uptake of selected species of seaweeds using the ^{15}N method. Unfortunately, the laboratory we had hoped would assay our material is no longer accepting samples. We therefore decided to use the more conventional method of measuring uptake by disappearance of inorganic nitrogen from the medium. The experiments have been further delayed due to lack of culture space. Some preliminary experiments have begun on nitrogen uptake by <u>Fucus</u>. While these experiments will be continued in the next contract year, there are several interesting preliminary observations concerning this important nutrient.

The rationale for concentrating nutrient studies on nitrogen is that there is persuasive evidence in the literature that, in the marine environment, nitrogen is the most likely limiting nutrient for species that grow best during the summer months. This observation is further supported by nutrient data from our cultures (Table 4). All three of our best warm-water species preferentially took up ammonium over nitrate. This is consistent with most other reported observations on nitrogen preference by seaweeds. If nitrogen had been limiting, the effluent levels from culture tanks would have been much lower and more nitrate/nitrite would have been removed. Additionally, nitrogen deficiency is usually visually discernible as alteration in pigmentation. Throughout the year, our cultures remained deeply pigmented, an observation suggesting that nitrogen limitation is unlikely

Table 4. Removal of inorganic nitrogen by unenriched cultures of *Agardhiella*, *Codium*, and *Gracilaria* during the period of peak growth during summer 1981 (mean values of weekly samples June 15 - September 15, 1981).

	Nitrate + Nitrite µM	Ammonium µM	Total Inorganic Nitrogen µM
Incoming Seawater	9.58	6.44	16.02
Agardhiella effluent	8.28	3.77	12.05
Codium effluent	8.32	4.59	12.91
Gracilaria effluent	7.98	1.01	8.99

Task 1.A.3. Macrocystis studies

To get comparative data with Macrocystis experiments on the west coast, we obtained Macroycystis pyrifera juvenile sporophytes from Dr. Wheeler North at California Institute of Technology. Water for these culture tanks was pre- and post-filtered through a gravel/sand filter to prevent accidental introduction and water temperature was permitted to reach local ambient levels. One batch of approximately 30 plants was obtained in August, 1980 and a second batch was shipped to us in late September. These young plants (2 - 6 cm long) were set up in "North deep trough" tanks. Plants obtained in August were placed in water at ambient temperature (21 - 23°C) under screens that reduced light intensity by 66% and brought up to ambient temperature over a period of two days. These plants all deteriorated by the third day.

The second batch was kept at 13°C by circulating cold well-water around the "North" tanks. At the time of their collection, water temperature at Newport Beach, California, was 8°C. These plants grew well during October and November, 1980. Several bladders had developed on most plants, and they had a well developed meristem region. In early December, the surviving plants (about 15) were placed in our culture tanks since they had grown too large for the "North" tanks. In early December, ambient temperatures dropped to 10°C and by the end of December to 2°C. Through this period, the plants had grown about 50 cm. January 1981 saw water temperatures of -1 to +1°C. Macrocystis stopped growing, but appeared to survive intact, but after about the fifth week of temperatures less than 2°C, they started to deteriorate rapidly. By mid-February, there were only 4 plants left and these had decayed by the end of the month.

We conclude that culture of Macrocystis pyrifera in New York water is not practical. The annual temperature variation is too great at its extremes. The plants could not survive prolonged cold temperatures below 2°C, which typically occur for 6 - 8 weeks. Although our attempts to grow juveniles at warm summer temperatures were not conducted under the best of conditions for the plants had not acclimated long enough, it is well known that the species is not capable of survival and growth at temperatures above 18 - 19°C. Thus, culture of Macrocystis in the field could only be conducted in the spring and fall months, when temperatures are approximately 4 - 16°C (the known range of temperature for growth). This would amount to a total period of 5 - 6 months -- mid-March to mid-May and October to mid-December. Such bimodal growth seasonality could be difficult to accommodate. Experiments with this species were discontinued after discussions with the Gas Research Institute.

Task 1. PLANT GROWTH AND NUTRITION

B. Raft Culture Experiments

1. Design and fabrication of culture rafts

The purpose of raft design experiments is, in part, to begin to understand the mechanical problems of this technology before expending intensive efforts on a test farm. To this end two types of rafts were constructed: an open steel "bed-frame" to which individual plants would be attached; and, a lexan mesh cage, in which freely floating plants would be contained (see Figures 17 and 18). These rafts would be suspended from surface floats at fixed depths and tethered to anchors. Fixing the depth at which rafts were placed removed ambient light as a variable and ensured that the plants would always have sufficient water over them.

Designs for the two types of rafts were modifications of existing versions: the lexan mesh cage was used in a preliminary study on Fucus in 1980; the bed-frame had been used in an intertidal study on Fucus in earlier years. Three cage-type rafts, each having three cages of different mesh size, were constructed for the floating-plant cultures. Each raft had a total surface area of approximately $5m^2$. Three metal frame-type rafts were constructed to hold PVC racks for 90 plants each. These rafts have a surface area of approximately $4m^2$. Rafts were built in February and March, 1981, and deployed in Flax Pond in late March and early April when the water had warmed sufficiently to permit diving.

The physical environment of Flax Pond is characterized by sandy bottom and a depth of 13 ft. mean low water (MLW). Currents range a maximum of 1 knot at ebb with shifting eddies. Wave action is minimal. One raft of each type was set at a depth of 1 m and one of each type at 3 m. Sixty-five pound Danforth anchors on chain were set at both the upstream and downstream ends of the rafts, to hold them perpendicular to the water flow. The rafts proved stable under these conditions.

Seaweed cultures on these rafts were started in April and May (Table 5). The cage rafts contained 6 cultures of Fucus and three of Codium at each depth. The frame-type rafts held Fucus, Codium, and Laminaria. These cultures were observed weekly and maintained until August, when the rafts were moved to Smithtown Bay.

The Smithtown Bay site for location of rafts was chosen for its proximity to an artificial fishing reef constructed by the town of Smithtown. This is in an area with a silt bottom and a depth of about 36 ft. MLW. At this site, currents are generally less than 1 kt, but wave-heights could be as much as 3 - 4 ft., since this area is in exposed, open water. The New York State Department of

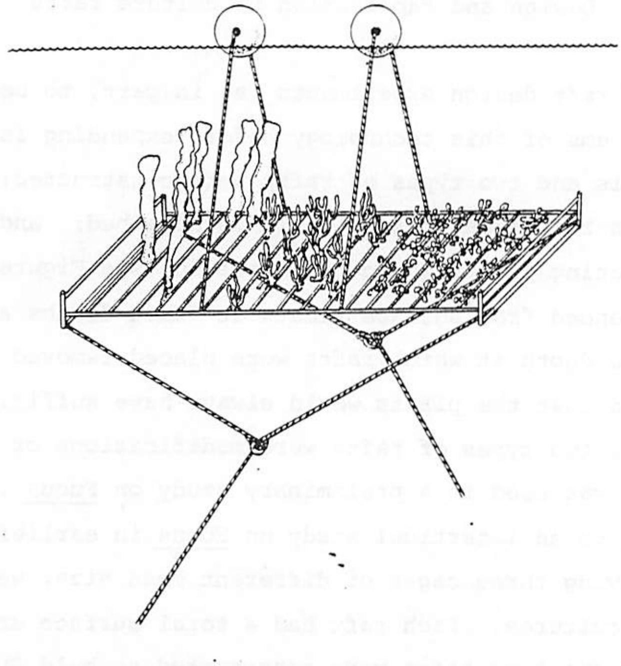

Figure 17. Illustration showing typical bed-frame raft used in field culture.

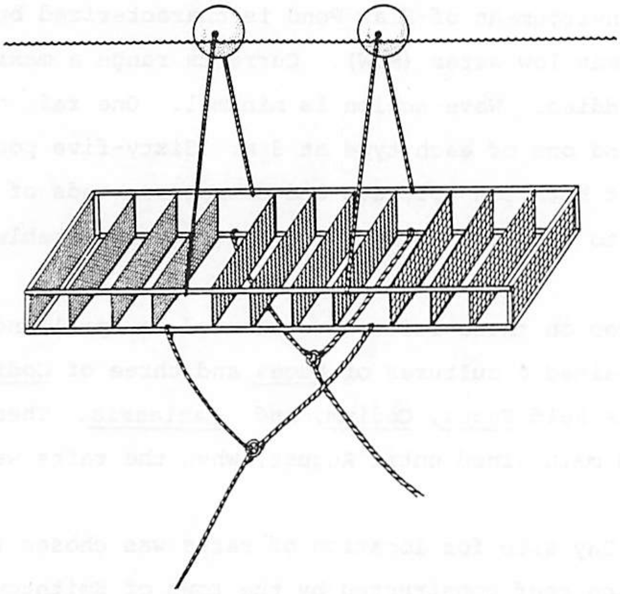

Figure 18. Illustration showing multiple compartment screened cages used in field culture.

Table 5. Raft Culture Experiments Milestones.

	1981										
	J	F	M	A	M	J	J	A	S	O	N
Permit Process			X	X	X	X	X				
Raft Construction		X	X	X							
Deployment Flax Pond			X	X						X	
Culturing Flax Pond				X	X	X	X	X		X	
Deployment Smithtown Bay							X				
Culturing Smithtown Bay							X	X	X	X	
Deployment Crane Neck										X	X
Culturing Crane Neck											X

Environmental Conservation holds the U.S. Army Corps of Engineers permit for the artifical fishing reef. That permit was modified to allow deployment of our rafts. This permit process was completed in July, approving deployment of subsurface rafts, surface floats, and appropriate marking buoys as required by the U.S. Coast Guard. This modification alters the existing permit by providing for "hazards to navigation at the surface". This permit expires December 31, 1981 but is renewable.

Deployment of rafts in Smithtown Bay began in July. One nine-cage raft was placed at 1 m depth and one at 3 m depth. One 90 plant open frame-type raft was placed at 1 m depth and one at 3 m. These were anchored to concrete-filled 40 ft. tanks that were part of the extant reef structure. These moorings used subsurface floats on stainless-steel cables and swivels donated to the project by NOAA. The rafts were suspended from surface floats by stainless-steel cable. Identification and warning buoys were likewise moored to delineate the corners of our site.

Seaweed cultures of <u>Fucus</u> and <u>Codium</u> were started in July and August. <u>Fucus</u> was placed in the cages and both <u>Fucus</u> and <u>Codium</u> were attached to the frames. These cultures were measured and observed weekly through September, unless weather conditions precluded fieldwork.

The frame and cage designs proved inadequate in Long Island Sound waters. The short wavelength wave action common to all but the calmest days led to rapid wear and subsequent failure of the float systems, resulting in the rafts sinking to the bottom. Repeated corrosion of the nicopress sleeves used on the cable fittings was an unexpected problem also leading to mooring failures.

The presence of the rafts in Smithtown Bay attracted considerable attention from the boating public. Private and commercial fishing boats operated within the site, although it was declared a restricted-use area by the Coast Guard. Vandalism, theft, and accidental damage by boaters became a larger problem than environmental factors. Buoys and floats were stolen. Mesh cages were ripped by hooks and anchors and the attached plants torn off. By the end of September losses could not be replaced effectively and in October the remaining rafts and moorings were removed.

It became clear that mesh cages and rigid attachments for the plants on the open frames did not work well. The cages fouled so badly that light could not penetrate and the plants did not grow. Plants on the open frame rafts were often sheared off by abrupt vertical movements of the frame as it rode the waves. To solve this problem, plants were enmeshed in rope and the ropes were loosely attached to the open frames. This system worked very well. Although the frames continued to move with the waves, the ropes and plants remained in place in the water column. As a consequence, we shifted to use of rope as the attachment substrate for all subsequent work.

Open frame-type rafts were refurbished and redeployed in November off Crane Neck. The frames are set on the bottom on legs buried in the sand and weighted with cinder blocks to minimize shifting during storms. Depths of the frames are at 3 ft. MLW and 8 ft. MLW. These depths allow the frames to be close to shore for servicing by shore-entry SCUBA divers and will allow us to monitor cultures even on icy or stormy days through the winter. These frames were stocked in late November with Laminaria and some Codium and Fucus. Though several storms have passed over the Sound since the cultures were begun, plant loss has been negligible.

Task 1.B.2 Raft culture experiments

The purpose of raft culture experiments is to measure growth and evaluate the characteristics of the candidate species under field conditions. The first cage type cultures started in Flax Pond in April included Fucus and Codium and frame-type cultures were of Fucus, Codium, and Laminaria. The cultures were monitored weekly for wet weight change and general condition. Problems immediately rose with fouling of the mesh on the cages. The biologic environment of Flax Pond is characterized by a shallow tidal pond and a great deal of detritic and living material in the water column. This material stuck to the cages, blocking the mesh and providing sites for epiphytic and epifaunal recruitment. Filamentous red algae and amphipods were the primary organisms involved. Cages were scrubbed weekly to clean the mesh, but quickly refouled. This was particularly serious for the smallest meshes, although in time, all fouled completely. Once the epiphytes were established, other organisms such as fish and shrimp were attracted to and settled on the cage surfaces. However, there was no evidence of grazing on the plants. Due to these obstructions to light penetration, growth of both Fucus and Codium in the cages was less than 1% throughout the summer.

Plants attached to PVC pipes on the open frames (see Table 6.A.) were initially more successful. After deployment, there was a period of plant material loss as weak pieces broke loose. This was followed by good growth (μ= 3-5% increase$\cdot da^{-1}$) until August. In fact this growth rate was higher than what was observed in the laboratory (see Table 6.B). However fouling by bryozoans became severe. Eventually both Fucus and Codium plants were completely overrun, although Codium seemed more resistant. Since the weight increases from animal material could not be distinguished from the plant, weighings became meaningless and cultures were terminated. New cultures immediately became fouled, suggesting that the fouling was seasonal and from the water rather than the substrate.

Raft cultures were established in Smithtown Bay in July. It was immediately obvious that the method for attaching plants to the PVC pipe was inadequate. Losses of part or entire plants equalled a biomass loss of around 5%$\cdot da^{-1}$. Several alternatives were tried, including the use of bungy cord as a shock-absorber and pegboards placed horizontally to restrict vertical movement. The best results were obtained by entwining plants on ropes loosely attached to the frames. Actual plant growth was then on the order of 2 - 3%$\cdot da^{-1}$ until September, when Fucus began to fragment. Fouling was minimal over this period, with amphipods, caprellids and barnacles as the dominant fouling species. No grazing by fish was observed.

Table 6. A Raft Culture Experiment Growth Rates.

Exponential Growth Rates — % wet weight increase/day

	1981							
	A	M	J	J	A	S	O	N
Flax Pond								
Fucus, Floating	<1	<1	<1	<1			0	
Codium, Floating	0	0	0					
Fucus, Attached		1.9	2.9	5.3	2.6		0	
Codium, Attached		<1	2.8	3.7	1.6		<1	
Laminaria, Attached		<1	1.8	<1	0			
Smithtown Bay								
Fucus, Floating					2.6/1.8*			
						<1	<1	
Fucus, Attached				<1	2.1	<1	<1	
Codium, Attached				<1	3.2	3.2		
Crane Neck								
Laminaria, Attached								3.4/2.8*

* one meter depth/3 meter depth

Table 6.B. Comparison of Flax Pond Raft Culture Growth Rates to Laboratory Growth Rates (% Wet Weight Increase·da^{-1})

Fucus	1981			
	May	June	July	August
Raft	1.9	2.9	5.3	2.6
Lab	<1	<1	0	1

Codium	1981			
	May	June	July	August
Raft	<1	2.8	3.7	1.6
Lab	1.5	1.5	1.1	1

Cage cultures in Smithtown Bay were less affected by detritic fouling than in Flax Pond, but barnacles set shortly after deployment. The increase in weight of the rafts resulting from barnacle growth eventually overcame the lift of the floats and the cages sank. Since the bottom of the bay at this point was below the photic zone, no growth occurred while the rafts were on the bottom. Individual plants in the cages also became covered with barnacles making weights suspect. These problems, as well as loss of plants and rafts from other environmental and human causes, led to the eventual abandonment of the Smithtown Bay site in October.

With the onset of bad weather, a site at Crane Neck was established for winter cultures of *Laminaria*, *Codium* and *Fucus*. Initial growth rates are about 3% wet weight increase$\cdot$day^{-1}. Epiphytes and fouling have been minimal, perhaps due to sand scouring by storms or the decline in water temperature.

Task 1. PLANT GROWTH AND NUTRITION

C. Species Collections and Field Studies

1. Species Collections

Samples of the candidate species were collected for our culture work and for analyses by General Electric. Frequent trips to Flax Pond, Great South Bay, Montauk and Orient Points were made to obtain these samples. Other samples were obtained from Connecticut courtesy of Dr. Charles Yarish, University of Connecticut and Dr. Milan Keser, Millstone Nuclear Power Plant. The following is a list of the samples provided to General Electric for analysis.

Species	Date and Place Collected		Culture No.
Ascophyllum nodosum	01/28/81	Greenhouse	
	02/11/81	Greenhouse	037
	02/11/81	Greenhouse	038
	02/11/81	Greenhouse	039
	02/11/81	Flax Pond	
	05/20/81	Greenhouse	025
	06/09/81	Greenhouse	057
	06/18/81	Greenhouse	066
	06/18/81	Greenhouse	068
	06/19/81	Flax Pond	
Chondrus crispus	12/02/80	Old Field Point	
	01/19/81	Montauk Point	
	02/11/81	Greenhouse	030
	02/11/81	Greenhouse	040
	05/06/81	Montauk Point	
	06/18/81	Long Island Sound	
	06/18/81	Greenhouse	044
Codium fragile	02/18/81	Greenhouse	005
	02/18/81	Greenhouse	015
	01/20/81	Greenhouse	023
	02/16/81	Captree Island	
	05/06/81	Montauk Point	
	05/30/81	Greenhouse	074
	06/04/81	Flax Pond	
	06/02/81	Greenhouse	
	06/10/81	Greenhouse	070
Fucus vesiculosus	01/19/81	Montauk Point	
	02/11/81	Greenhouse	035
	02/11/81	Flax Pond	
	05/26/81	Flax Pond	
	05/26/81	Greenhouse	53-1
	06/04/81	Flax Pond	
	06/04/81	Flax Pond	
	06/04/81	Flax Pond	
	06/05/81	Flax Pond	
	06/05/81	Flax Pond	

Species	Date and Place Collected		Culture No.
Fucus vesiculosus	06/18/81	Flax Pond	
	06/18/81	Greenhouse	062
	06/18/81	Greenhouse	064
Laminaria saccharina	01/19/81	Montauk Point	
	03/14/81	Montauk Point	
	05/06/81	Greenhouse	050
	06/03/81	Shinnecock Inlet	
	06/05/81	Montauk Point	
	06/05/81	Greenhouse	052
Ulva lactuca	05/06/81	Montauk Point	
	05/20/81	Greenhouse	003
	06/04/81	Shinnecock Bay	
	06/04/81	Shinnecock Bay	

Task 1.C.2. Field observations

During May, an extensive survey from Oyster Bay east to Wading River, a distance of 36 miles, was conducted to locate and identify sources of seaweed. A series of 12, 1/2 hour SCUBA surveys was undertaken by two-person teams in areas known to contain rocky substrate. One large stand of Laminaria (several acres) at Eatons Neck, at the western end of Smithtown Bay was located. Ulva was also prevalent in that area. Another, smaller bed of Laminaria was found at Crane Neck, just west of Flax Pond. Chondrus was prevalent there. At Old Field Point, just east of Flax Pond, an almost pure stand of Chondrus was found. At Wading River, several sunken barges in 3 - 6 feet of water provided a substrate for Ulva and Codium, along with numerous species of filamentous red algae. No concentrations of seaweeds were found at any of the other sites visited.

In September-October the seaweed beds at Eatons Neck and Crane Neck were again examined. We obtained many small specimens of Laminaria at both locations, although the population at Eatons Neck appeared to be slightly further developed. Plants from there were a few centimeters longer and appeared in better condition than those from Crane Neck. Fragments of older plants still containing fertile portions (sori) were abundant at Eatons Neck and less prevalent at Crane Neck, reflecting the general density difference observed in May. We concluded that spore release from adult sporophytes occurs during August-September and that gametophytes generate sporophyte germlings during September-October.

Task 2. TEST SITE EVALUATION AND SELECTION

The purpose of this task was to evaluate the ecological suitability of three sites as experimental marine algae farms. Three potential sites were identified during the previous contract year by DeWitt Davies, Long Island Regional Planning Board, based on a set of ecological, legal, political and logistical considerations. One was located in Long Island Sound within Smithtown Bay, and two sites were in the Peconic Bays within Orient Bay and Hog Neck Bay. The general locations of these areas are shown in Figure 19. Various environmental data were gathered by Davies and summarized in the 1980 final report. The research undertaken this year was to obtain and evaluate existing oceanographic and ecological data collected at or near the three sites, gather additional data where necessary, and then choose the "best" site for an experimental farm.

Discussions with the project biologists and engineers resulted in the identification of the following general objectives:

1. To determine which environmental factors might be important to successful culturing of seaweed in the field,
2. To compile available published reports and unpublished data that pertain to the factors identified from the first objective,
3. To measure various environmental factors in the field in order to gain a better understanding of the oceanographic characteristics of the sites, and
4. To assess the suitability of the sites for seaweed culture.

Environmental factors studied included (1) circulation and hydrography, (2) light penetration into the water column, (3) ambient concentrations of nitrate-nitrogen and the possible importance of anthropogenic nitrogen, (4) wind and wave conditions, (5) ice cover, and (6) fouling and grazing organisms.

In November, 1981, the entire research team met and discussed the candidate sites using environmental data we had collected. At that time it was decided to abandon further consideration of the Peconic Bay sites. During the winter of 1980-1981 it had been observed that ice cover in the Peconics was up to 18 inches thick. Ridging of the ice near shore, where the test farm might have been placed, was extreme. Winter culture experiments, critical to this project, could not be carried out under those extreme conditions.

While those Peconic Bay sites offered the advantage of having privately-held lease tracts of underwater lands which would assure sole purpose usage they were logistically difficult requiring extensive commuting by researchers. Smithtown Bay, while environmentally advantageous, poses great problems of

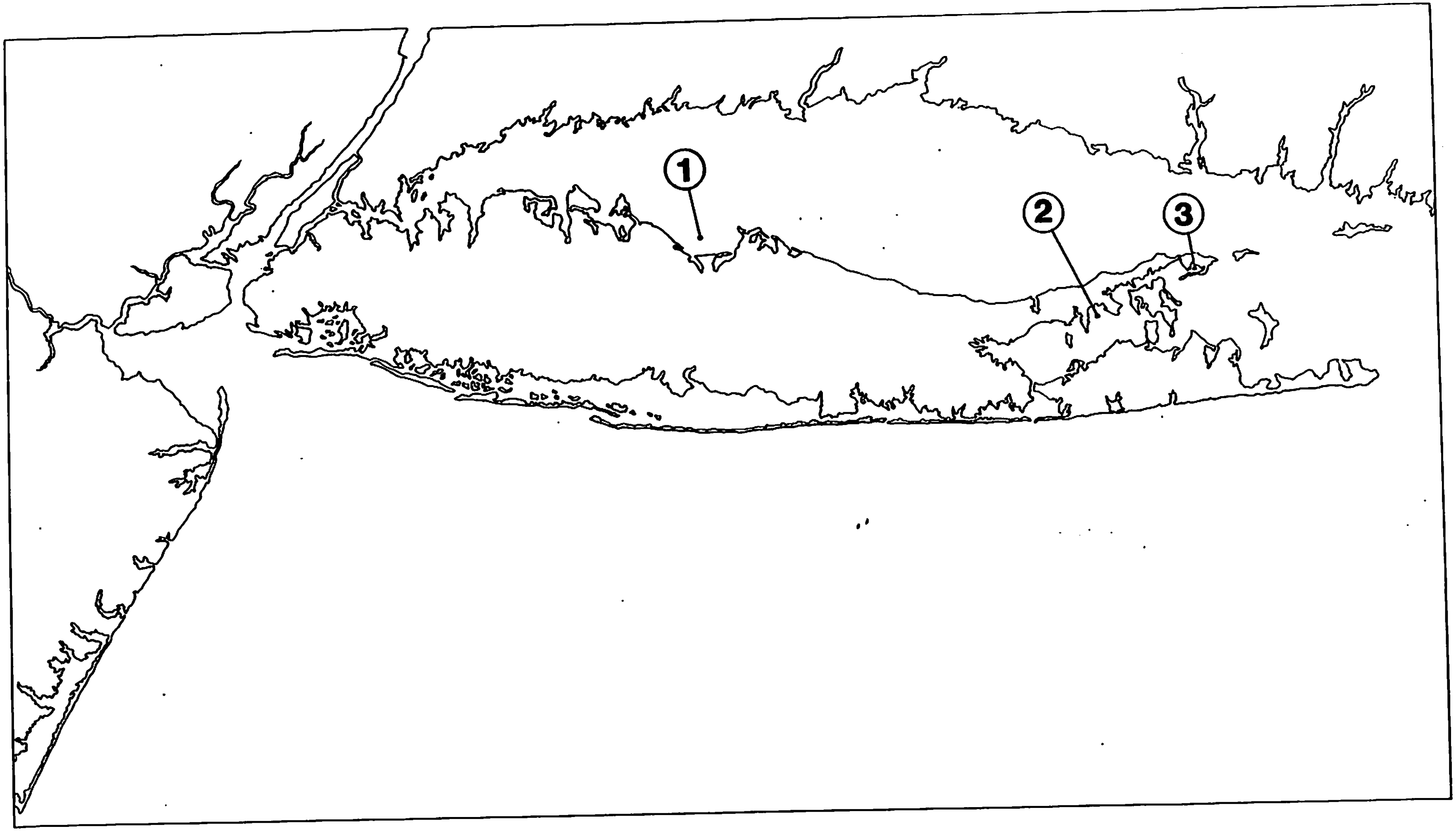

Figure 19. Locations of three possible sites for marine biomass culture are shown. Site 1 is in Smithtown Bay, Site 2, Hog Neck Bay and Site 3, Orient Harbor.

vandalism from recreational fishermen and boaters.

We concluded that the artificial reef site in eastern Smithtown Bay should be abandoned and a more westerly site chosen. We are discussing with the Long Island Lighting Company a site not too distant from their Northport oil platform approximately 2 miles offshore. The sites in Smithtown Bay are shown in Figure 20.

Smithtown Bay

General Description. Smithtown Bay is located on the north shore of Long Island approximately 50 miles east of New York City. Figure 20 shows the outline of the Bay, various geographical features, and bathymetry. The Bay is bordered by Crane Neck and Stony Brook on the east and by Eatons Neck on the west. The seaward boundary is conveniently defined by a line running from the tip of Crane Neck west to the tip of Eatons Neck which is roughly parallel to the 60 foot isobath, except for the shoaler portions of the western one-quarter of the Bay. The south shore of the Bay is lightly developed, with public lands owned by the Towns of Brookhaven, and Smithtown, and the State of New York.

Freshwater input into the Bay is from groundwater outflow and the Nissequogue River. The latter provides an insignificant volume of freshwater relative to the volume of the Bay. Tidal exchange between River and Bay is high, however, with flows into and out of the River mouth on the order of one to two knots.

Circulation Patterns. Circulation within the Bay and adjacent waters of Long Island Sound were deduced from the work of Riley (1956), Wilson (1981), National Ocean Survey Tidal Charts, other navigational charts, and our own drogue measurements. These measurements were supplemented by discussions with physical oceanographers at the Marine Sciences Research Center.

Flow within Long Island Sound is dominated by the tides. Flow direction alternates approximately every six hours, running generally eastward (on outgoing or ebb tide) and westward (incoming or flood tides). Circulation patterns within the Bay were studied by making drogue (Lagrangian) measurements. Figure 21 summarizes these results. Trajectories shown are averages from duplicate measurements. All measurements were made on ebb tide to determine if nutrient-rich water from the Nissequogue River moved either directly offshore from the River mouth or past the experimental test site (station D on Figure 21).

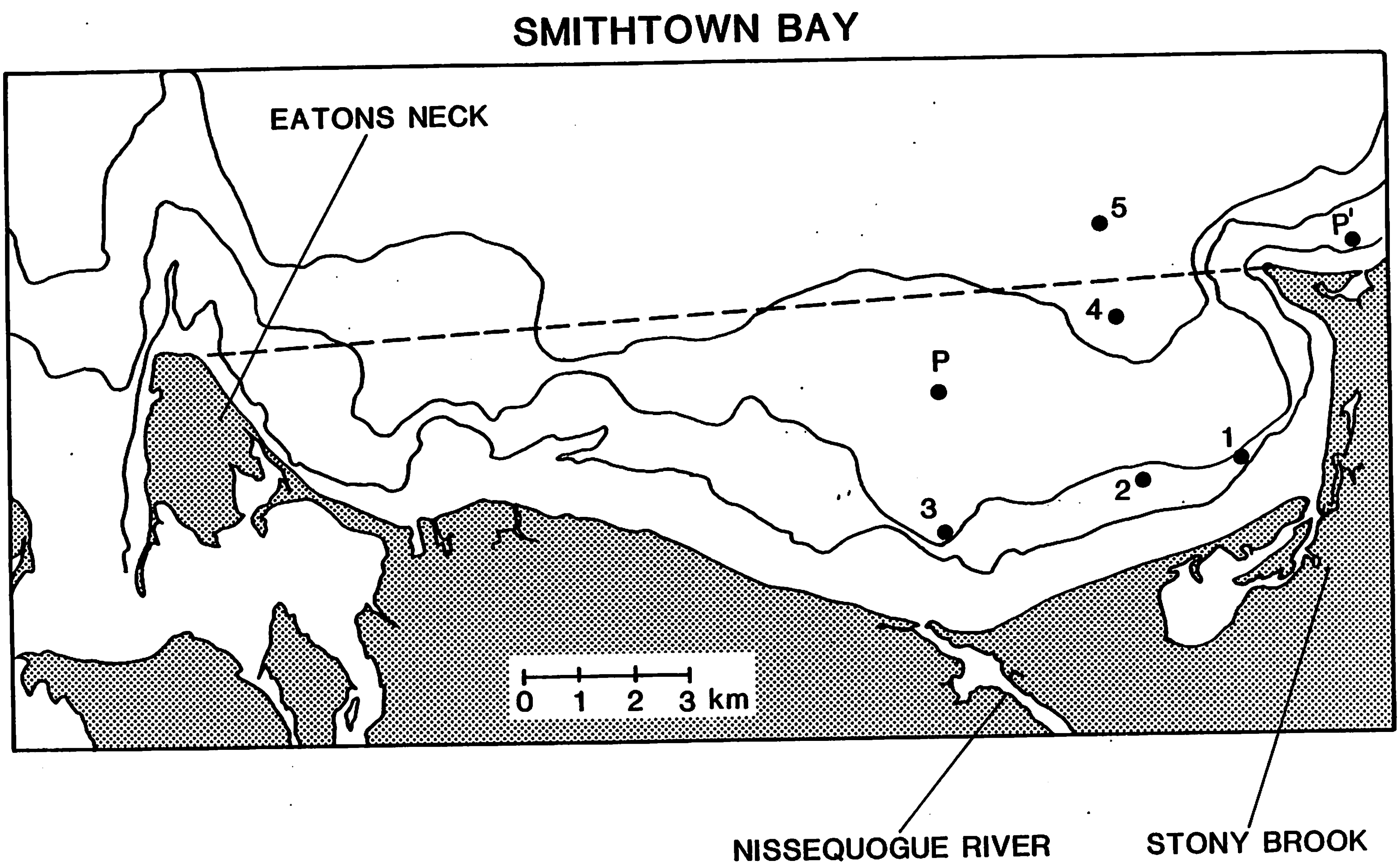

Figure 20. Smithtown Bay, Long Island Sound. Numbers 1-5 identify the stations which were visited regularly from May through November 1981. The letters "P" and "P'" show the locations of two sites which will be used for field experiments during the 1982 study year. Location "P" is our prime location. Bathymetric contours shown are at 20 foot intervals.

Circulation patterns within the Bay were more complex than we had expected. Some of the drogues moved along a track parallel to bathymetric lines as might be expected, but others moved across the bathymetry, from shallow to deep water. We have too few measurements to resolve the complexities and can only say that on ebb tides, water within the eastern one-third of the Bay tends to move directly northward out of the Bay rather than first eastward then northward following the bathymetric contours of the Bay.

Flow velocities are greatest in the vicinity of headlands. Maximum speeds at Crane Neck ranged from 1.0 to 1.5 knots and at Eatons Neck, 0.7 to 1.4 knots maximum, during ebb tide. On the flood tide, maximum velocities were 0.8 to 1.3 knots at Crane Neck and 0.6 to 0.7 knots at Eatons Neck. Velocities averaged over six-hour time intervals on ebb tide at both headlands were approximately 1.1 knots. Flow rates are less during flood tide, averaging 0.3 knots at Eatons Neck and 0.6 knots off Crane Neck.

At location F (Figure 21), continuous measurements of flow were made by Wilson (1981) using current meters moored during the period 25 May to 25 August 1980. Flows at that point, approximately two miles north of Eatons Neck, were as strong as at Eatons Neck. Maximum and minimum speeds ranged between 0.8 and 1.1 knots on both ebb and flood tides. Occasional maximum speeds of 1.6 knots were registered.

Differences in ebb and flood flow rates reflect the fact that the tides tend to flow into estuaries such as Long Island Sound along the right hand side of the estuary (looking up the estuary) on ebb tide, and flow is out of the estuary along the left side. Such a flow regime is advantageous to the Marine Biomass project because nutrient-rich water originating from the eutrophic western Sound region tends to flow out of the Sound along the New York shore rather than the Connecticut shore. Thus there is potential for a continuous year around supply of nutrients to the Smithtown Bay site.

Flow rates along the mouth of the Bay (that is within the 60 foot isobath) are not well known. Velocities are certainly reduced compared to the headland regions but the magnitude of the differences is not known. Two of the drogue measurements made at ebb tide at locations B and C (Figure 21) showed offshore movement of water at rates of 0.7 and 0.3 knots respectively. At station D, this year's experimental site, flows were always sluggish, at 0.1 knots. At station E, the drogues moved parallel to the shoreline at a rate of 0.5 knots.

Some knowledge of flow across the mouth of the Bay was gained from study of tidal charts drawn with the aid of a numerical tidal model. One such set of data predicts maximum ebb speeds of 0.5 knots at Crane Neck and speeds approximately

EBB TIDE

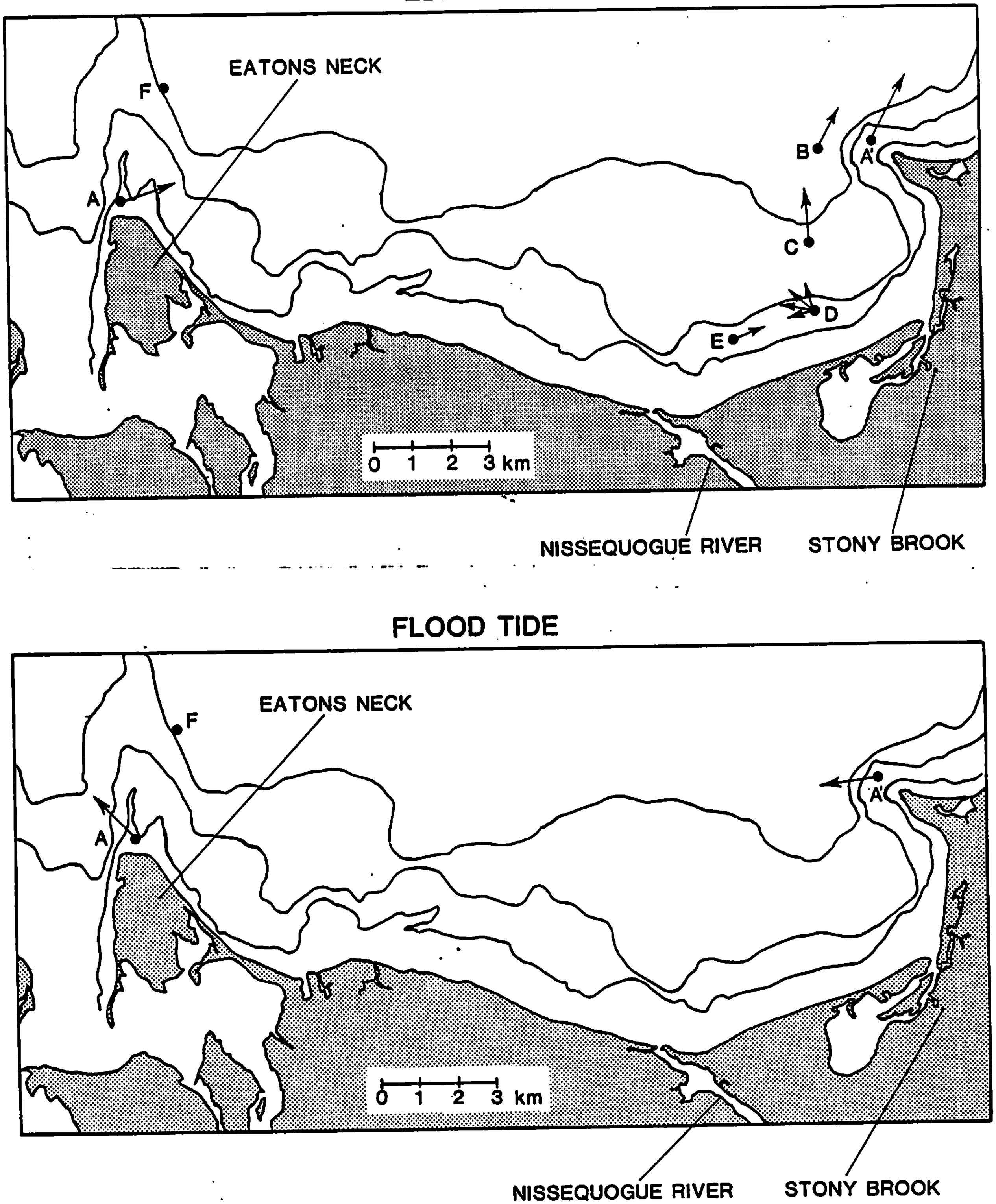

Figure 21. Results of drogue measurements. B-E indicate positions where our drogue measurements and stations A and A' are results of other studies. Position F marks the point where one current meter was moored.

one-half that value along the mouth of the Bay. Assuming that the numerical model has failed to correctly predict intensification of flow around headlands such as Crane Neck, but that the relative speeds are modeled correctly, we can assume that maximum speeds along the mouth of the Bay are on the order of 0.5 to 0.6 knots.

In summary, flow within Smithtown Bay is dominated by the tides. Maximum speeds occur in the vicinity of the two headlands, approximately 1.0 to 1.5 knots. Along the mouth of the Bay speeds are no more than 0.5 to 0.7 knots and within the Bay proper, one can expect flow rates of 0.1 to 0.5 knots.

Salinity. Salinity is not likely to be a limiting factor for growth of seaweed. Freshwater runoff into the Bay is not great. The average salinity varies over a narrow range, about 28‰ ± 0.5‰, during all seasons except spring. In spring months, values as low as 24-25‰ have been recorded for central Long Island Sound. Within Smithtown Bay we found a range of 26.0 to 28.0‰ during our mid-May to mid-November study.

Temperature. Temperature is an important limiting factor, varying over the range 0°C to 24°C. Long Island Sound therefore offers both a temperate and sub-tropical climate to marine organisms depending upon the time of the year.

Temperature data are shown in Figure 22. In Long Island Sound and Smithtown Bay, the period when the water temperatures exceeded 18°C were June to October. An eight month cool water growing season (mid-October through mid-June) and a four month warm water season (mid-June until mid-October) can be expected.

Water Column Stratification. Selection of experimental sites must take into account stratification of the water column because nutrients cannot be resupplied to the upper layers of the water column without vertical mixing. Strong pycnoclines (density gradients) inhibit vertical mixing, so regions characterized by strong vertical density gradients must be avoided.

Nearshore waters of Long Island Sound, including Smithtown Bay, tend to be either well-mixed or only marginally stratified because of tidal mixing. This characteristic of Long Island Sound is tremendously advantageous. Long Island is highly productive in part because tidal mixing resupplies nutrients to the photic zone during all months of the year. Primary productivity by phytoplankton is about 400 g $C \cdot m^{2} \cdot yr^{-1}$, which ranks Long Island Sound among the most productive marine systems.

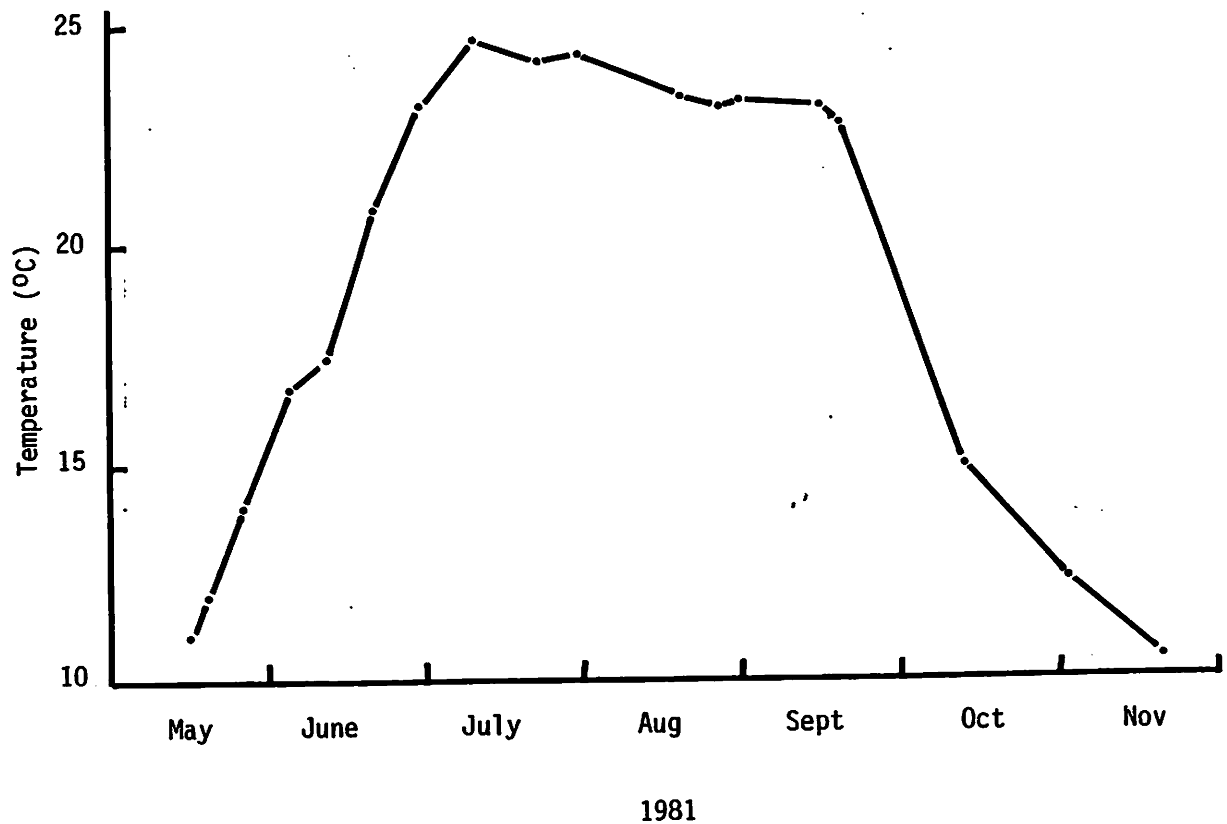

Figure 22. Temperature measurements taken at the mouth of Smithtown Bay.

The ability of the tides to mix the water column is given by the expression:

$$E = \frac{C_D \cdot \overline{U}^3}{h}$$

where E is the tidal energy dissipation rate, C_D the drag coefficient ($=10^{-3}$), $\overline{U}$ the average tidal velocity over one six-hour tidal cycle, and h, water depth. All units are centimeter-gram-seconds (cgs). The tendency for the water cclumn to be well mixed or stratified is given by:

$$S = \log_{10} (1/E)$$

where S is the stratification parameter. Study of various bodies of coastal water has shown that the value $S<1$ indicates well mixed water, the range $1<S<2$, marginally stratified conditions, and $S>2$, highly stratified water. At average tidal velocities of 30 $cm \cdot sec^{-1}$ such as found along the shore of Long Island Sound and along the mouth of Smithtown Bay (water depth 18 m), the value of the stratification parameter is $S = 1.8$, indicating marginally stratified conditions.

For best seaweed growth, we will want to avoid stratified waters, so the rafts should be moored in water depths no greater than 16 m if mean tidal velocities are 25 $cm \cdot sec^{-1}$ and 27 m if tidal velocities are 30 $cm \cdot sec^{-1}$. Clearly, more measurements of tidal velocities will be required to make precise decisions on location of an experimental farm. Water depth and tidal velocities are the two crucial parameters. A location near the mouth of Smithtown Bay where tidal currents are on the order of 0.5 knots, or perhaps nearer to Crane Neck where velocities are in excess of 1.0 knots would be good choices. These two suggested locations are indicated in Figure 20 by a "P" and "P'". Water depths at P are about 15 m and at P', about 10 m, well within the marginally stratified zone. The site chosen for last year's work was poor because tidal mixing was low.

__Light__. Light penetration into the water column was measured with a 20 cm diameter Secchi disk. Secchi depths (D) were converted to extinction coefficients (k) using a standard empirical formula,

$$k = 1.7/D$$

The extinction coefficient may be used to calculate the depth of the photic zone, usually taken to be the depth at which incident light (I_o) is 1% of the surface illumination. The expression,

$$I_z = I_o \cdot e^{-kz}$$

where z is water depth and the other variable defined above, is rearranged below to facilitate calculation of the 1% light depth:

$$(\ln .01/-k) = Z_{1\%}$$

Extinction coefficients ranged from 0.34 to $0.85 \cdot m^{-1}$ at the experimental site (Station 2) and 0.34 to $0.81 \cdot m^{-1}$ at the mouth of Smithtown Bay (Station 5, Figure 20). The average values during the May - November measurement period were $0.55 \cdot m^{-1}$ (test site) and $0.54 \cdot m^{-1}$ (Bay mouth). The depth of the photic zone averaged 8.5 m with a range of 5.4 to 13.5 m.

Riley's (1956) 1952 - 1954 data (Figure 23) indicates that extinction coefficients tend to be highest and the most variable from December until March. Values were in excess of 1.0 (1% light depth of 3 m) during these winter months. During the other months of the year Riley found about the same range as we did although his average extinction coefficient was closer to 0.7, equivalent to a 1% light depth of 6.6 m. The dashed line on the lower panel of Figure 23 indicates the average extinction coefficient for Smithtown Bay for May - November 1981. Very few of Riley's measurements fall below this average, indicating that the waters of Smithtown Bay are much more transparent than at Riley's central Long Island Sound situations. Since such great regional differences are not likely, this fact raises the possibility that the water quality of Long Island Sound has improved over the past thirty years.

Optimal light intensities for seaweed growth are being worked out by the biologists. It is clear from our measurements that culture of seaweed in the field will have to be done at shallower depths in winter than summer. Extinction coefficients of 0.5 during spring, summer and fall preclude the possibility of growing seaweed on the floor of the Sound in deep water. At depths greater than 8 m, algal growth will almost certainly be light limited. Midwater culture is imperative at depths ranging from near the surface to no more than perhaps 5 m.

Nutrients. In most marine environments, nitrogen is usually the nutrient which limits plant growth. Between the three-month interval mid-May to mid-August nitrate-nitrogen was at nearly undetectable levels (Figure 24). During other months values range from highs of 10 -15 µM to about 2 µM. The implication of these

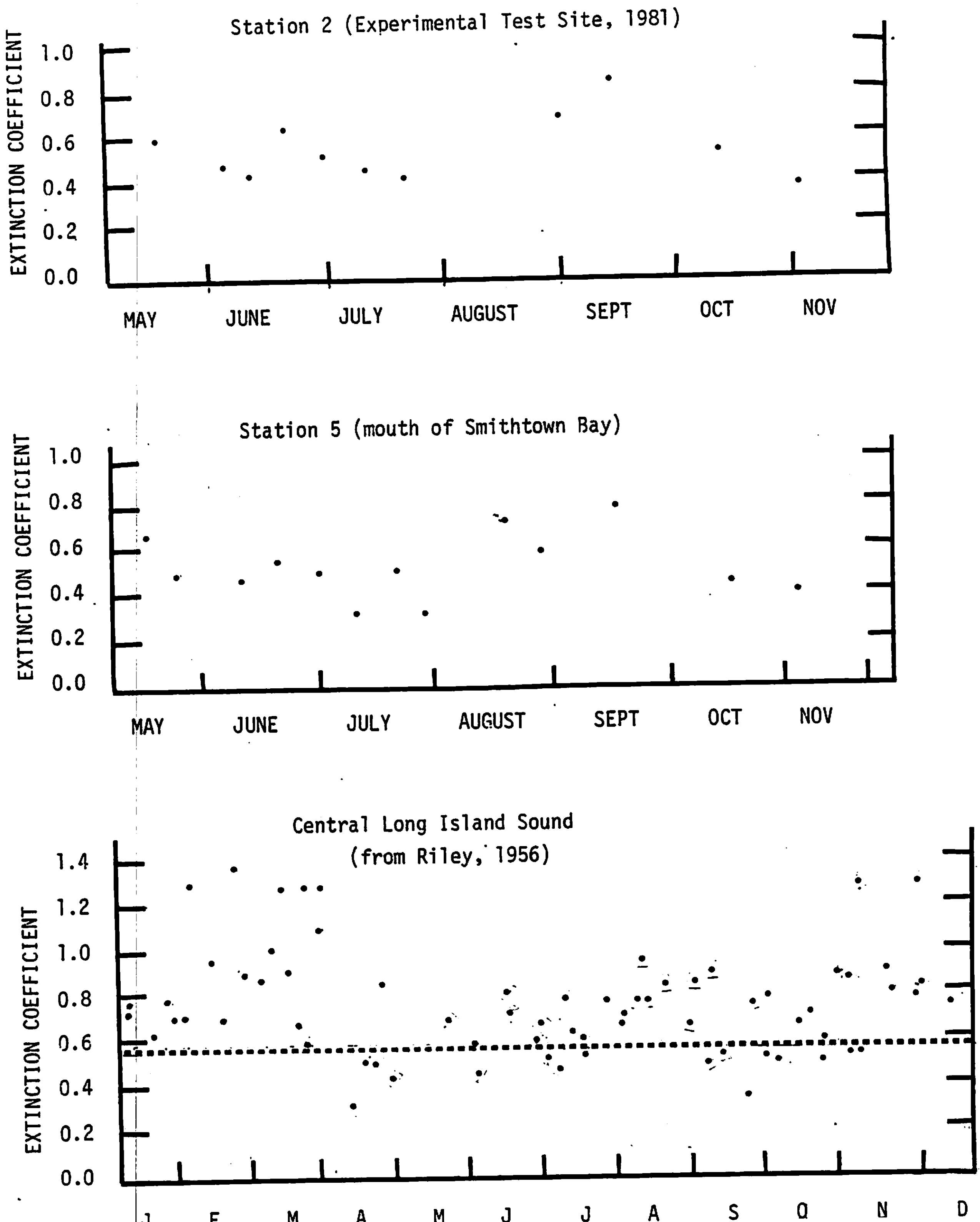

Figure 23. Seasonal variation of extinction coefficient. The upper two panels are our measurements and the lower is from Riley's study of Long Island Sound. Values of the extinction coefficients are highest in winter, lowest in summer.

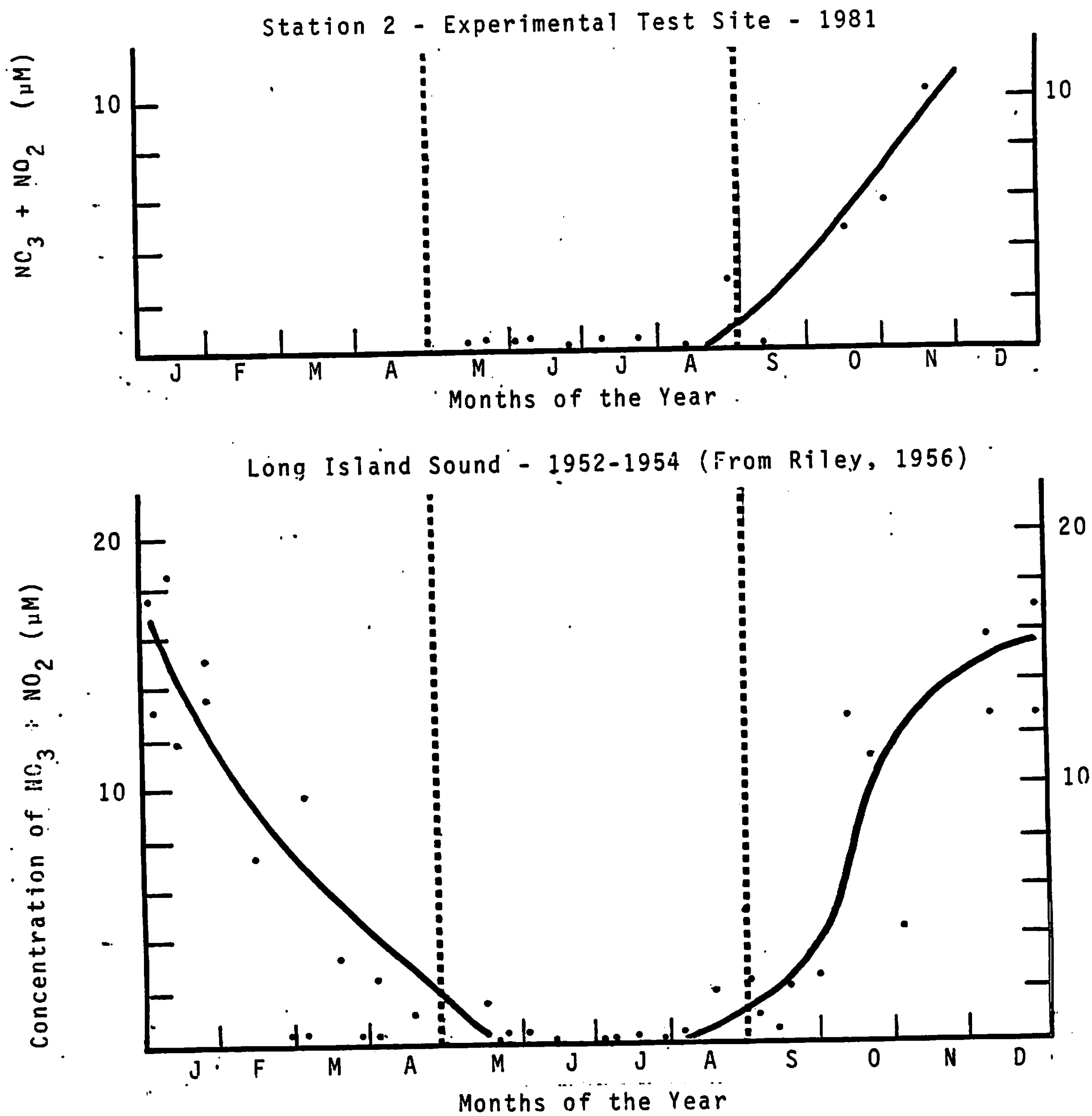

Figure 24. Nitrate-nitrogen concentration in Long Island Sound. Between the time interval of mid-May until mid-August, nutrients are very nearly zero. The interval of potential nutrient limitation is indicated by the vertical dashed lines.

findings is that the cool water seaweed species will be growing in high nutrient conditions during nearly all months of their growing season. The warm water species on the other hand will be living in a nitrogen deficient environment during the first two months of their growing season (mid-June to mid-August) and a high nutrient environment during the second two months.

We did not measure ammonia-nitrogen. The few measurements available from past work (Hardy, 1972) suggest that ammonia does not accumulate in any great concentration, reaching no more than 1 - 2 μM in central Long Island Sound waters. These values are typical of most coastal waters not influenced by domestic sewage effluents.

A description of the nitrate-nitrogen environment requires statements about rate of supply of the nutrient as well as concentration. The key variable is the flux of nutrient, not concentration alone. The flux past a point is calculated by:

$$\text{Flux} = \text{velocity} \times \text{concentration}$$

Since we have measurements of both water flow rates and nitrogen concentration, flux can be calculated. The daily needs of the seaweed determined from laboratory flow-through culture systems can then be compared to field flux rates to determine if growth is nutrient limited or not.

The flux of ammonia-nitrogen is more complicated because the rate of supply is dependent upon the rate at which it is excreted by bacteria, zooplankton, fish and benthic organisms. We know nothing about these rates because measurements of ammonia regeneration are well beyond the scope of this project. It is fair to assume that ammonia is regenerated at high (but unknown) rates in Long Island because the biomass of regenerating organisms is rather high. The key question is how well do seaweeds compete with phytoplankton for the ammonia pool.

Anthropogenic Nitrogen. There is one man-derived source of new nitrogen to Smithtown Bay, the sewer outfall from Kings Park Hospital which disposes secondary treated sewage through a 24" diameter pipe at a point approximately one mile north of the Nissequogue River mouth, near our Station 3. Because of this outfall, shellfishing is prohibited within a one mile diameter circle centered on the outfall. We occasionally saw enhancement of nitrate-nitrogen at Station 3 compared to Stations 1 and 2 but results were extremely variable, suggesting that sewage discharge is erratic.

Stony Brook Harbor and Bay were surveyed on two occasions to determine if any nutrient-enriched water flushes from that region. On both dates, shown in Figure 25, nitrate concentrations inside the bay and harbor were the same as outside, within Smithtown Bay proper. We can therefore assume that Stony Brook Harbor is not a nutrient source.

Wind and Wave Observations. Approximately 23,000 observations on wind speed and direction, and wave height and period were obtained from the U.S. Coast Guard, Eatons Neck Lighthouse, made at three-hour intervals for the years 1980 and 1981. Wave parameters were estimated visually but wind data are from anemometer measurements. The data are briefly summarzied here and in Table 7. In general, calm conditions prevail during the warm months from May to August. During autumn and winter, only about three days in 10 are calm. Maximum wind speeds during any one month usually range between 20 and 30 knots. Speeds in excess of 30 knots are infrequent, occurring only six times in 1980 and 10 times in 1981. A speed of 40 knots was recorded once, in March 1981. Speeds in excess of 10 knots occur about one-half of the time during winter.

Wind direction is generally from the northwest in winter and southwest in summer. This means that Smithtown Bay is exposed to winter storms but somewhat sheltered during summer storms. This is unfortunate because the most intense storms come from the northwest.

Wave heights are generally less than two feet with maximum heights about five feet. Since the fetch of Long Island Sound is so short relative to the direction of the dominant northwesterly winds, wave periods never exceed three seconds: Storms immediately result in short-period choppy seas. After a storm, wave energy dissipates rapidly and the sea surface returns to a calm condition within hours.

Ice. Smithtown Bay did not freeze in winter 1980 but has frozen completely during intense Arctic storms. Ice formed during these storms usually breaks up quickly. Ice could be a problem because water beneath it continues to circulate due to tidal forcing. This action sets up strong shear forces on mooring cables or structures. Since ice forms down to perhaps 15 cm, the structures below that depth might not be affected.

Interference by Fouling and Grazing Organisms. Fouling organisms (barnacles and bryozoans) and grazers (amphipods) were a problem at the Smithtown Bay experimental site. Their abundance may be related to the site which was directly over an artificial reef, an excellent habitat for (among other things) amphipods,

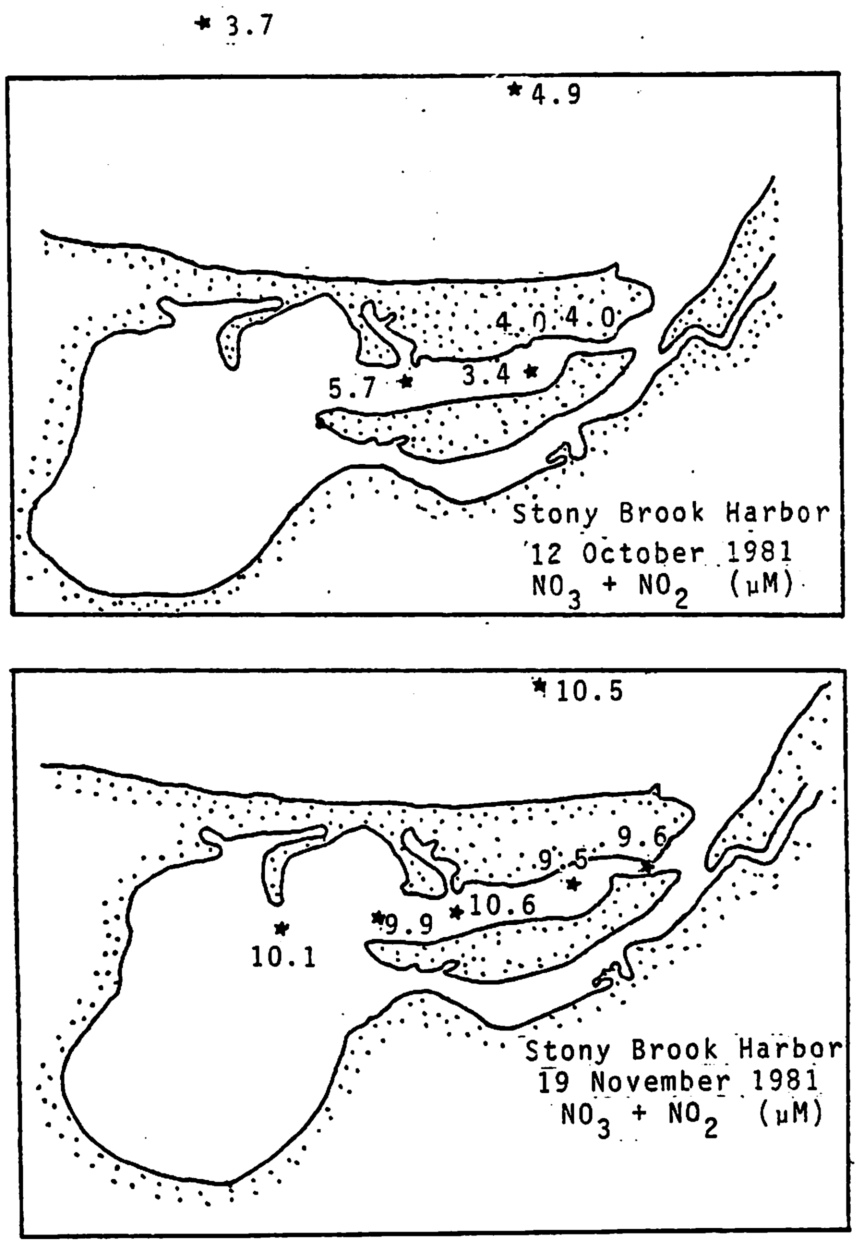

Figure 25. Concentration of nitrate-nitrogen in Stony Brook Harbor in October and November 1981. The harbor does not appear to be a source of nutrients to Long Island Sound.

Table 7. A summary of the wind and wave data collected at Eaton's Neck Coast Guard Station.

	Percent of observations > 10 knots	Maximum speeds	Percent of observations CALM	Percent of observations SEAS > 2 ft	Percent of observations PERIOD=3 sec	Maximum wave height
January 1980	40	31	41	22	59	4
February	55	26-30	36	26	65	4-5
March	40	26-30	53	28	46	4-5
April	17	21-25	54	16	46	3-4
May	4	16-20	80	1	20	2-3
June	12	26-30	79	3	22	4-5
July	7	21-25	85	3	15	4-5
August	13	21-25	75	13	24	3-4
September	12	16-20	59	12	41	3-4
October	32	33	32	21	64	5
November	49	21-25	32	22	68	3-4
December	42	35	32	19	67	3-4
January 1981	42	34	49	15	51	4-5
February	34	38	46	21	54	3-5
March	40	40	44	12	56	5-6
April	31	26-30	54	10	46	5-6
May	8	21-25	68	3	32	2-3
June	13	16-20	73	2	27	2-3
July	11	21-25	53	7	47	3-4
August	11	16-20	32	11	68	4-6
September	33	32	17	35	65	4-6

adult barnacles and bryozoans. At night, the amphipods move up into the water column to feed and thus get into the biomass. Adult barnacles and bryozoans are abundant on the reef so their planktonic larvae are also abundant there.

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Task 3. SITES FOR LOCATION OF MARINE BIOMASS FARMS

There were two objectives for this task: 1) Identification and assessment based upon existing information of biomass farm sites in the New York region; 2) Definition of additionally required research to permit evaluation of potential biomass farm sites. We assumed, for this task, that large scale farms might be operational by 1990-2000. A commercial scale marine biomass farm is envisioned to cover about 100 square miles of ocean surface.

The economic viability of the marine biomass concept is sensitive to transportation costs. Therefore, the location of the staging area for assembly, deployment and operation of the farm and the digestor site(s) are of prime importance when evaluating potential offshore sites. We assumed, for the purposes of this study, that the onshore operating area would be located in the Port of New York and New Jersey.

This analysis of available information is reported in four parts:

3.1 Specification of ecological/environmental criteria, to the extent possible, utilizing information from laboratory and biological test farm experiments now underway on candidate seaweed species.

3.2 Results of a literature search to identify data sources on the spatial and temporal distribution of relevant physical, chemical and biological parameters categorizing the New York Bight.

3.3 An inventory of existing uses of the sea surface, water column and sea bed in the study area.

3.4 Summary of the findings and conclusions on relative merits of various areas. In this analysis, conflicts and constraints of farm operations with existing or proposed uses are identified. Research required to fill informational gaps is reported in each of the sections.

We decided to define the geographic scope of the study area as follows:

1. Seaward limit - the 100 fathom (183 m) isobath marking the edge of the continental shelf as determined from NOS Navigation Chart 12300.
2. Eastern boundary - a straight line from the terminus of the New York-Rhode Island boundary, as defined by the RB horn buoy at the northern end of Block Channel to the 100 fathom isobath (NYDEC, 1977).
3. Northern boundary - the line connecting Montauk Point with the RB horn buoy at the New York-Rhode Island boundary; the south shore of Long Island; and the line from the jetty at Rockaway Inlet southwest to the New York-New Jersey boundary line adjacent to Ambrose Channel.

4. Western boundary - the New York-New Jersey boundary to Ambrose Horn, continuing along the northern boundary of the Hudson Canyon to Ambrose Traffic Lane to points of intersection with the 100 fathom isobath.

The total area defined above is nearly 20,000 km^2. The areas associated with various depth zones are indicated below:

Depth Zone		Area (km^2)	Area (mi^2)
0-25 fathoms	(0-46 m)	6,675	2,580
25-50 fathoms	(46-91 m)	11,090	4,260
50-100 fathoms	(91-181 m)	2,175	840
		19,940	7,680

The study region is shown in Figure 27.A.

Task 3.1 Ecological/Environmental Criteria.

In this part of the study, only three of the nine local seaweed species under investigation were considered for biomass farming. These are: Codium fragile, Gracilaria tikvahiae, and Laminaria saccharina. The ecological/environmental criteria developed in the Marine Biomass Program in New York State Waters, Final Report for 1980, are:

Physical Criteria

Depth
Light
Current Velocity
Wave Action
Water Temperature and Seasonal Growth Patterns
Ice Conditions

Chemical Criteria

Nutrient Content
Growth Inhibitors and Toxic Constituents

Biological Criteria

Fouling
Interspecific Interactions

These criteria are discussed sequentially in this section, and conclusions are drawn concerning the extent to which they can be applied in this study, given the current state of knowledge of seaweed biology and farm design.

Physical Criteria

Depth. Codium and Laminaria normally require attachment to substrates for optimal growth. Codium commonly attaches to exposed shellfish and grows best at depths between 1 and 2 meters; Laminaria requires a hard substrate not greater than 5 meters deep for optimal growth. Codium and Gracilaria can be grown as free floating species.

Conclusions: Containment devices may be needed to hold Codium and Gracilaria. A fixed substrate is optimal for Codium and Laminaria. Growth requirements dictate that the water depth of substrate should be at least 5 m. Engineering considerations involving mooring of modules, etc., impose additional depth requirements. Potential sites must therefore have a water depth of at least 10 m.

Light. Light levels in the water column decrease as depth or turbidity levels increase. Gracilaria requires high light intensity; Laminaria and Codium require lower light intensity. Determination of the light level (vertical penetration) requirements for optimal growth of the candidate species is the subject of current research. Turbidity plumes from the Hudson/Raritan estuarine discharge may significantly reduce light intensity. These plumes generally tend to follow the New Jersey coast.

Conclusions: High turbidity areas should be avoided. Information on the greatest depth of light extinction in the New York Bight is needed.

Current Velocity. The range of minimum current velocities that will support growth is not well known at this time. Preliminary information indicates that minimum current threshold velocities on the order of 5 - 15 $com \cdot sec^{-1}$ are required for the efficient exchange of nutrients and wastes from seaweed surfaces. In general, the higher the current velocity, the greater the nutrient influx.

Conclusion: More biological information is needed before this criterion can be applied.

Wave Action. Some wave action is needed to break up laminar water layers on seaweed surfaces to disperse nutrients. Some waves enhance water circulation and large waves impose critical stresses on plant tissues and engineering structures. The effects of wave action are reduced as depth increases. The maximum stress that seaweeds can withstand before being damaged remains to be explored.

Conclusions: Areas subject to large wave action should be avoided. More biological information is required before this criterion can be applied.

Water Temperatures and Seasonal Growth Patterns. Laminaria exhibits highest growth rates from August to June when water temperature ranges from 6 to 16°C. Codium and Gracilaria grow fastest during the period May through October at water temperatures up to approximately 26°C and demonstrate poorer growth when the temperature is below 12°C.

Conclusions: In general, Laminaria is a "cold water" seaweed and Codium and Gracilaria are "warm water" seaweeds. The range of seasonal water temperatures in the surface layers needs to be determined to allow predictions of growing season length for each species.

Ice Conditions. Sea ice poses engineering and biological limitations. Frozen salt spray on structures above the sea surface in winter may cause design problems.

Conclusion: Sea ice formation and patterns of drifting ice in the Bight should be determined.

Chemical Criteria

Nutrient Content. Ambient nitrate, ammonia and phosphate levels and the mass flux of nutrients are of major importance to plant growth. The two principal sources of nutrients in the New York Bight are on-welling from the continental shelf and the Hudson-Raritan estuarine discharge. Laboratory studies on nutrient requirements of seaweeds are in progress.

Conclusions: Site selection on the basis of this criterion must await completion of ongoing research. Information on site-specific nutrient levels in the New York Bight is needed.

Growth Inhibitors and Toxic Constituents. Copper and other heavy metals can be toxic to seaweeds. The toxicity impacts of various other pollutants on seaweeds are not well known.

Conclusions: Information concerning seaweed tolerances to toxics and the horizontal and vertical distribution of pollutants in the New York Bight is needed. Highly contaminated areas should be avoided.

Biological Criteria

Fouling. Competition between seaweeds and fouling organisms poses important problems for large scale farming operations. The distribution of fouling organisms depends on water depth, current velocity and dispersal characteristics of the organisms.

Conclusion: More information on fouling organism/seaweed/structure relationships is required before this criterion can be utilized.

Interspecific Interactions. Interspecific interactions among the three candidate species need to be investigated. Farm biomass may also provide a significant food source for herbivorous organisms.

Conclusions: Interspecies factors pertain primarily to farm design, not site selection. This factor is not considered further.

Task 3.2. Results of Literature Search for Physical, Chemical and Biological Parameters of the New York Bight.

The purpose of this section is to summarize information germane to the application of the ecological/environmental criteria previously developed. Extensive bibliographies on the New York Bight have been published. Current data sources and bibliographic citations are maintained in computer form by Environmental Data Service of NOAA and are available to users.

Circulation Patterns

Circulation in the New York Bight is influenced by wind velocity and direction, tides, water density, Coriolis effects and seabed topography. High spatial and temporal variation in these factors causes a poorly defined circulation pattern of high variability. However, a general picture of circulation within the Bight can be drawn. A southwesterly current drift characterizes the western shelf region while the eastern portion of the Bight experiences a net northwestern flow. The result is a general counter-clockwise circulation in the Bight proper, with surface velocities of 5 to 20 $cm \cdot sec^{-1}$ common off the coast. During the summer months, however, strong southerly winds can reverse surface current directions in western Bight waters causing a northward flow for extended periods.

Near-surface waters of the Bight tend to flow offshore while deeper, more saline waters move shoreward. However, this tendency is subject to variation depending on wind direction and speed. Average current velocities generally increase offshore and decrease with depth; for example, a 6 $cm \cdot sec^{-1}$ current at a 2 m depth decreases to less than 4 $cm \cdot sec^{-1}$ at 25 m and 1.5 $cm \cdot sec^{-1}$ at 35 m.

Much of the water flowing across the continental shelf in a southwest direction through the Bight originates in the Gulf of Maine-Georges Bank area and experiences a net transport of approximately $2.0 \times 10^5 m^3 \cdot sec^{-1}$. Consequently, the mean residence time of water within the New York Bight is in the order of 9 months.

Light Transmission

Although vertical light transmission is a major influence on primary production rates, surprisingly few data exist on this parameter in the New York Bight. But, turbidity measurements in the form of transmissivity data have been extensively collected by the MESA New York Bight Project, NOAA.

The mean photic zone light energy in the near-estuarine, or apex, portion of the Bight peaks in August and reaches a minimum in December; typical values are 105 and 6 $gcal \cdot cm^{-2} \cdot da^{-1}$, respectively. Light extinction coefficients (measured with Secchi disk) in the apex vary from $0.2 \cdot m^{-1}$ in November to $1.7 \cdot m^{-1}$ in June. At a station located five miles south of Shinnecock Inlet, extinction coefficients range from slightly less than $0.2 \cdot m^{-1}$ in October to greater than $0.8 \cdot m^{-1}$ in August. Photic zone depths are generally greater than 10 m in the apex and increase at the outer apex. However, in June and July, photic zone depths are less than 10 m at the inner apex. Reduction in light transmission is primarily related to the concentration of nonphotosynthetic suspended particles.

Light extinction data from a station just east of Montauk Point, New York are presented in Table 8. Photometer depths were recorded at levels of 75%, 50%, 25%, 10%, and 1% incident light (-0.0 depth indicates photometer reached bottom before the 1% transmission level was attained).

The 1% light depth was generally greater for a station five miles south of Shinnecock Inlet than for stations within the apex; stations in the outer apex tended to have a greater than 1% light depth than inner apex stations. See Figure 26.

Wave Height

Although wave heights are variable and difficult to measure, a brief account of wave height characteristics in the New York Bight is presented. Greater than 50% of waves from all directions in the Bight have heights between 1 and 3.5 m. The portion of waves greater than 10 m is about 2%. Between 30% and 40% of all waves are from the southeast and, of these, approximately 27% are between 2 and 5.5 m. Wave heights decrease toward shore.

In December, between 60% and 70% of coastal waves are less than 1.5 m. Offshore, fewer than 50% of the waves are less than 1.5 m in height. Wave height decreases through the year reaching a minimum in August when 80 - 90% of nearshore waves are less than 1.5 m and approximately 80% of offshore waves are less than 1.5 m. Wave heights increase from September until the December maxima are reached.

Seasonal Temperatures and Salinity Distributions

The seasonal cycle of water temperature distribution in the New York Bight is well defined. During February, surface water temperatures near the coast

Table 8 - Vertical Light Transmission Near Montauk Point, New York.

19 June 1973 Location $41^{\circ}05.80'N$; $71^{\circ}46.30'W$ Depth: 16m

Photometer Depth (m)	0.6	1.2	2.3	5.0	-0.0
Transmission (%)	75	50	25	10	1

From: Hollman, R., (editor). 1976. Environmental Atlas of Block Island and Long Island Sound Waters. Vol. II Physical and chemical database at observed and standard depths 1970 through 1973. New York Ocean Science Laboratory Technical Report No. 0035.

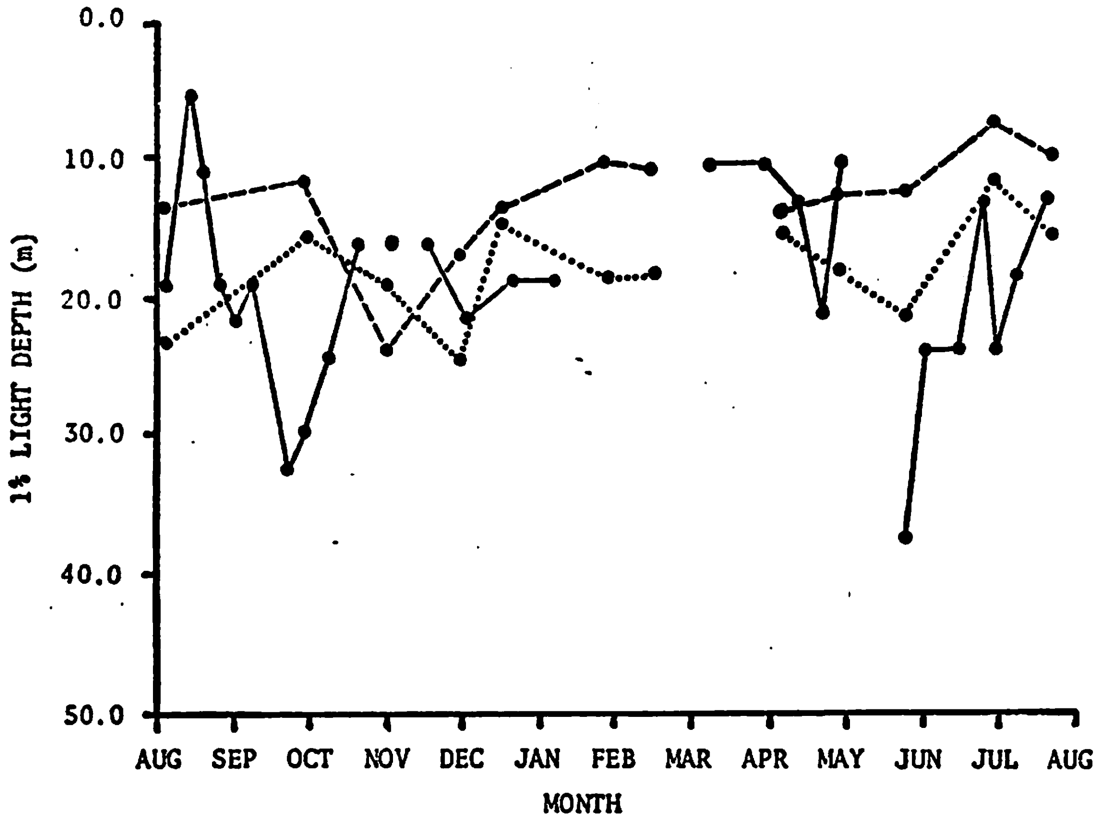

Figure 26. Annual variation in the 1% light depth for the inner apex (dashed lines) and outer apex (dotted lines: Hollman R., 1976) and for a station 5 miles south of Shinnecock Inlet (solid lines: Wold, E. 1977).

average approximately 2°C increasing to about 10°C farther offshore. As spring approaches, coastal waters warm to 8°C while offshore temperatures remain relatively unchanged until May. In the period May to June, nearshore temperatures average 17° to 20°C with a decreasing gradient to 7.5°C at the southern boundary of the Bight. A strong thermal stratification is formed during this period. Maximum surface temperatures of 24° to 26°C usually occur in early August. During autumn, local winds cool the sea surface and disrupt the thermal stratification. An average temperature of 14° to 18°C typifies surface shelf waters in October. As winter approaches, cooling occurs most rapidly near shore with surface water temperatures decreasing below 8°C. At this time, thermal stratification is established. Temperatures continue to decline until the winter minimum of 2°C is reached in late January.

The annual variation in salinity distribution in the New York Bight results from seasonal changes in the quantity of river runoff, evaporation and precipitation and the degree of mixing with more highly saline offshore slope waters. In late February surface salinity values reach a maximum of 33°/oo on the inner shelf, increasing offshore to 34°/oo at the shelf edge. Vertical salinity increases by only 0.005°/oo·m^{-1} at this time. In May, the addition of freshwater from river sources reduces the salinity to less than 32°/oo along the coastline; values of 33°/oo and 34°/oo typify the southern border of the Bight. A vertical salinity gradient of 0.4°/oo·m^{-1} is common near estuary mouths resulting from the high influx of spring runoff. As summer advances, surface salinities in the apex vary spatially from 27°/oo to 30°/oo; offshore values approximate 32°/oo. Vertical mixing in autumn increases nearshore surface salinity to 32°/oo and reduces the vertical gradient to less than 0.005° /oo·m^{-1} by December. Surface salinity continues to increase until late February. Seasonal temperatures and salinity distributions are presented in Table 9 and in Figure 27.A.

Occurrence of Sea Ice

There is no published information on the occurrence of sea ice in the New York Bight. Lt. Commander Leone of the U.S. Coast Guard Service stated in a telephone conversation of 28 September 1981 that he doubted whether ice occurred to any large degree in the New York Bight. A report by the U.S. Army Corps of Engineers (1965) claimed no ice problems along ocean frontage between Fire Island and Jones Inlets.

Sector A

	W	SP	SU	F
Salinity °/oo	31.6	30.4	29.8	31.9
Temp. °C	2.8	5.6	18.9	14.8
Nitrate μg/l	96	43	14	39
Phosphorus μg/l	32	14	22	27
Chlorophyll α μg/l	11.3	10.9	6.4	3.8

Sector B

	W	SP	SU	F
Salinity °/oo	32.8	30.8	30.5	31.4
Temp. °C	2.8	6.0	17.0	15.5
Nitrate μg/l	39	12	3	15
Phosphorus μg/l	18	6	18	20
Chlorophyll α μg/l	2.5	0.8	0.5	3.3

Sector C

	W	SP	SU	F
Salinity °/oo	33.2	32.1	31.6	33.0
Temp. °C	5.6	6.7	13.0	12.9
Nitrate μg/l	24	8	9	25
Phosphorus μg/l	15	9	10	18
Chlorophyll α μg/l	1.5	0.5	0.4	3.4

Sector D

	W	SP	SU	F
Salinity °/oo	32.4	31.3	32.1	33.2
Temp. °C	4.8	9.0	20.0	12.4
Nitrate μg/l	42	12	6	32
Phosphorus μg/l	26	13	12	23
Chlorophyll α μg/l	2.3	1.7	1.1	3.6

Sector E

	W	SP	SU	F
Salinity °/oo	33.8	33.5	32.0	34.3
Temp. °C	12.0	12.0	21.5	15.2
Nitrate μg/l	78	8	8	13
Phosphorus μg/l	15	5	4	12
Chlorophyll α μg/l	0.8	1.4	0.2	1.6

Sector F

	W	SP	SU	F
Salinity °/oo	33.2	33.6	33.2	34.4
Temp. °C	9.8	10.8	22.1	17.2
Nitrate μg/l	75	7	6	22
Phosphorus μg/l	16	6	6	13
Chlorophyll α μg/l	0.9	1.0	0.3	1.9

Table 9. Seasonal and geographic variation in water quality in the New York Bight study area.

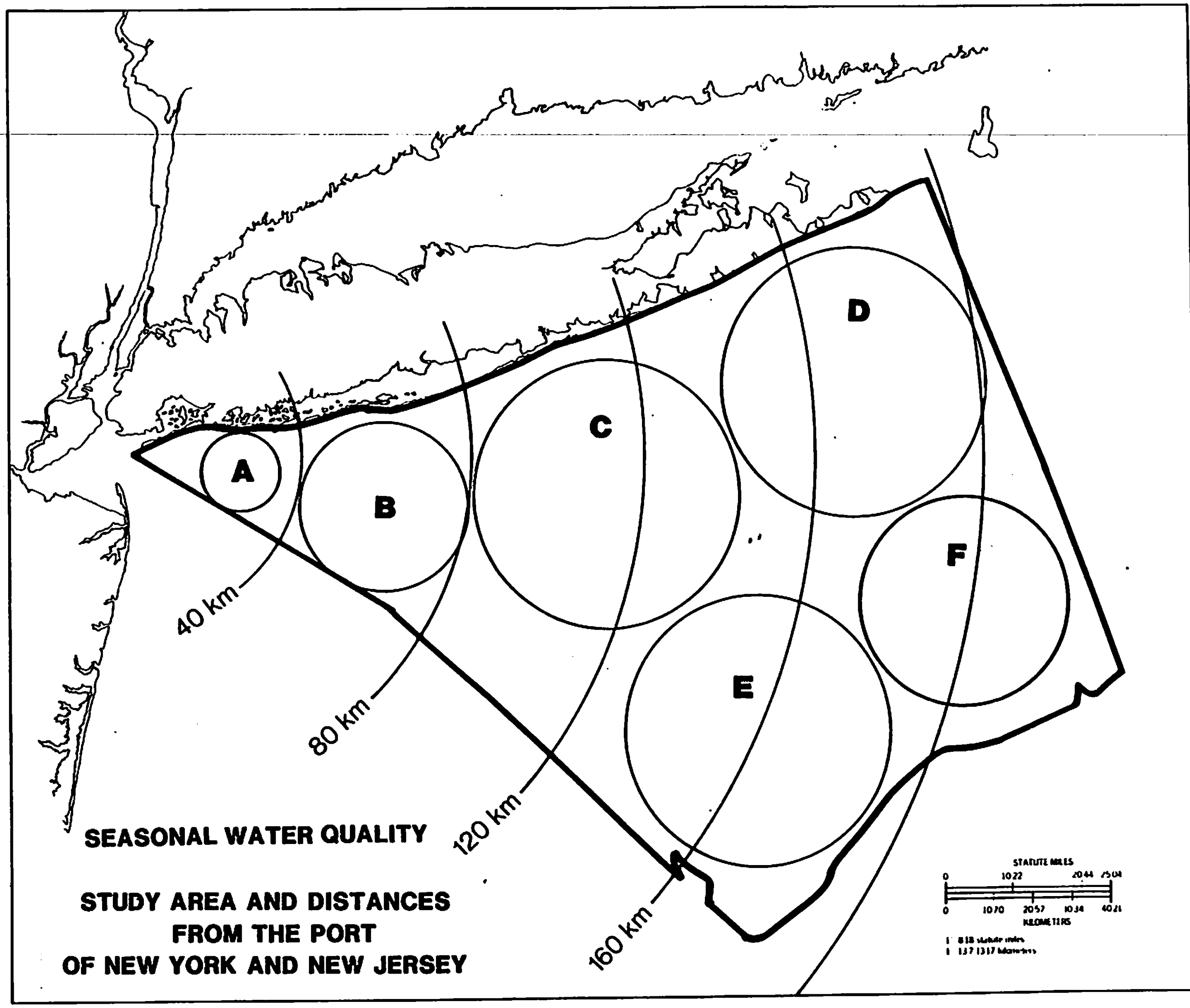

Figure 27.A. Distances from Port of New York and New Jersey and Seasonal Water Quality.

Distribution of Nutrients

The distribution of nutrients in the study area is primarily determined by transport of ocean water across the shelf, and locally influenced by discharge from the Hudson-Raritan estuarine system, direct dumping of waste materials into the apex, and runoff from Long Island and New Jersey. It has been estimated that approximately 4 billion $kl \cdot da^{-1}$ of domestic wastes enter the New York Bight. These wastes contain about 90 metric tons of nitrogen and 36 metric tons of phosphorus.

Inorganic phosphorus concentrations are highest at the apex, decreasing toward the southern boundary of the Bight. In January, surface values along this gradient range from approximately 30 $\mu g \cdot l^{-1}$ to less than 10 $\mu g \cdot l^{-1}$. Bottom waters tend to have slightly higher concentrations due to depletion of inorganic phosphorus in the photic zone. Seasonal variation is minimal. However, the spring algal bloom reduces phosphorus concentrations near the apex to approximately 18 $\mu g \cdot l^{-1}$ in May.

Surface nitrate levels in the apex show a seasonal decline from about 60$\mu g \cdot l^{-1}$ in February to 8 $\mu g \cdot l^{-1}$ in July. In April, a concentration of 110 $\mu g \cdot l^{-1}$, resulting from spring runoff, presents an exception to the general downard trend. Nitrate concentrations increase steadily from the July minimum to the February values. Offshore surface waters in the Bight geneally exhibit lower nitrate levels than apex waters. Seasonal distributions of phosphorus and nitrogen are presented in Table 9 and in Figure 27.A.

Heavy Metal Concentrations

At present, the effects of heavy metal concentrations on algal tissues are largely undetermined. A summary of the distributions of these potentially harmful constituents is presented here. Iron levels in the top 5 m of apex waters range from about 200 $\mu g \cdot l^{-1}$ in January to an average of 40 $\mu g \cdot l^{-1}$ for the remainder of the year; the background level for iron in the open ocean is 10 $\mu g \cdot l^{-1}$. In April, a secondary peak of 30 $\mu g \cdot l^{-1}$ results from the spring runoff input. Concentrations decline with distance from the apex. Unusually high iron concentrations are indicative of acid-iron waste discharge at the acid waste dump site.

From Januaryto May, copper levels in the apex decrease from about 4.7 $\mu g \cdot l^{-1}$ to 3.5 $\mu g \cdot l^{-1}$. Subsequent increases during summer average greater than 8 $\mu g \cdot l^{-1}$. A value of 3 $\mu g \cdot l^{-1}$ typifies open ocean waters.

Surface cadmium concentrations decline from a peak of 8.9 $\mu g \cdot l^{-1}$ in February to less than 0.5 $\mu g \cdot l^{-1}$ in May. During July and the remaining summer months, concentrations average 1.5 $\mu g \cdot l^{-1}$ and 0.8 $\mu g \cdot l^{-1}$, respectively. The background level for cadmium in the open ocean is 0.1 $\mu g \cdot l^{-1}$.

Data on zinc concentrations are limited. In February, August, and September, surface levels approach 40 $\mu g \cdot l^{-1}$. A concentration of 20 $\mu g \cdot l^{-1}$ is documented for October with a subsequent increase to 35 $\mu g \cdot l^{-1}$ in November. A representative background ocean level of zinc is about 10 $\mu g \cdot l^{-1}$.

Manganese concentrations in the apex of less than 1 $\mu g \cdot l^{-1}$ in February are lower than typical open ocean values of 2 $\mu g \cdot l^{-1}$. Surface manganese levels increase to 28 $\mu g \cdot l^{-1}$ in April. Mean concentrations vary from 5 $\mu g \cdot l^{-1}$ to 15 $\mu g \cdot l^{-1}$ during the remainder of the year.

Productivity

Primary production in the New York Bight is affected by vertical mixing, light transmission, temperature, and the availability of nutrients. The relative importance of these parameters as limiting factors to productivity is equivocal. However, in general, lower quantities of nitrogen during summer and lower water temperatures and light levels during winter tend to limit primary production during these seasons.

Increased solar radiation and water temperatures and the relaxation of winds reduce thermal stratification in March and April resulting in a phytoplankton bloom. At this time, vertical mixing transports nutrients from bottom waters to the surface; chlorophyll _a_ concentrations reach about 19 $\mu g \cdot l^{-1}$ in the apex. During summer, surface waters warm more rapidly than bottom waters, re-establishing thermal stratification which prevents mixing. Consequently, the nutrient supply is decreased and chlorophyll _a_ values fall to 4 $\mu g \cdot l^{-1}$. Chlorophyll _a_ concentrations remain at this level until October when vertical mixing replenishes nutrients and and autumn bloom results. After the autumn bloom, productivity declines until February. At this time, chlorophyll _a_ concentrations increase to 6 $\mu g \cdot l^{-1}$ in the Bight apex. In general, productivity decreases offshore, with typical chlorphyll _a_ levels of 1 $\mu g \cdot l^{-1}$ and 0.5 $\mu g \cdot l^{-1}$ at the southern Bight boundary during spring and fall, respectively. Data on seasonal distributions of chlorophyll _a_ in the Bight are presented in Table 9.

Task 3.3. Inventory of uses of the sea surface, water column and sea bed in the New York Bight.

Commercial Fishing

The New York Bight lies within the larger Middle Atlantic Bight and represents an ecotone between several discrete environments. Partly as a result of its location, and partly as a result of its submarine geology, the New York Bight is inhabited by a wide range of fishes from the boreal, oceanic, tropical and temperate water groups at various points in their life cycles. This association forms the resource base for the commercial fishery in the New York Bight region and is exploited by both foreign and domestic fishermen who fish for a variety of species.

Developing an accurate picture of commercial fishing activity is a difficult task. Compiling fishing statistics presents a myriad of problems; fishermen tend to be transient and adamantly independent. This attitude prevents the compilation of dependable statistics for almost any aspect of the industry, especially the location of where fish are caught.

Foreign fishing fleets account for a significant amount of the fishing effort which takes place in the Mid-Atlantic region. Traditionally, foreign fishermen have followed fish populations that move north in the summer and south in the fall during their annual migration. With the advent of modern fishing techniques, the foreign fleet has diversified and become more intensive. The level of foreign fishing activity peaked in the mid-1970's. In 1977 the number of foreign fishing vessels observed in waters off the northeastern U.S. from Georges Bank to Cape Hatteras ranged from 291 in February to 21 in July with an average of 127 per month. It is not possible to precisely locate where this foreign fishing activity presently occurs.

The domestic component of the New York Bight fishery consists of fishermen with home ports from Maine to South Carolina, but is especially important to the states of New York and New Jersey. An analysis of 1980 National Marine Fishery Service data indicates that there are approximately 285 commercial fishing vessels (of at least 5 tons) in New York and 751 in New Jersey. The majority of these vessels are trawlers and dredges. While not all of these vessels utilize the Bight, the majority of their fishing is done in Bight waters.

Only general data on the location of domestic fishing activity in the New York Bight are available. These data have been grouped under broad statistical areas used by the National Marine Fisheries Service. As a result of this informational shortfall, several methods have been developed in an attempt to locate fishing activity. One approach is to locate prime habitat areas as an indication of where fishermen will fish. This approach was used by the Bureau of Land Management in its analysis of proposed oil and gas lease sales. Another method is to use data compiled from trawler surveys. The final option is to ask fishermen where they fish.

The difficulty with applying these techniques is that they tend to generate results encompassing the entire study area. An attempt was made to combine the methods in order to indicate which areas within the New York Bight are the most important to commercial fishermen. The major data sources for this synthesis were U.S. Dept. of Interior, Bureau of Land Management, OCS oil and gas lease documents, National Marine Fishery Service documents and maps prepared by the Long Island Fishermen's Association.

This analysis is presented in Figure 27.B. and can be used to indicate general areas of commercial fishing activity. From this map it can be seen that there are four major components to the commercial fishery of the New York Bight. The near shore fishery forms a belt within about 30 km of the New York-New Jersey shoreline and is based on fish such as striped bass and weakfish. The second fishery is associated with the continental shelf break and the various canyons in the Bight, and is dependent upon such species as the tilefish and butterfish. Important sea scallop and ocean quahog fishing grounds make up the third component of the Bight fishery. The final area of commercial fishing activity is the zone between 10 and 70 km off the coast of New Jersey; this is the traditional bastion of the surf clam industry. These commercially important fishing grounds are not mutually exclusive and tend to overlap to varying degrees. It should also be noted that fishery resources are based on biological conditions which are highly variable and in constant flux.

Recreational Fishing

As a result of increased leisure time, greater affluence and increased access, participation in marine recreational fishing has reached new heights. This is especially true for areas such as the New York Bight, which is adjacent to the highly urbanized New York metropolitan area and is accessible to residents of the entire northeastern United States.

Recreational fishing in the New York Bight takes a number of forms. However, in the context of site selection for a marine biomass farm, fishing from boats represents the most significant possible conflict with farm operation.

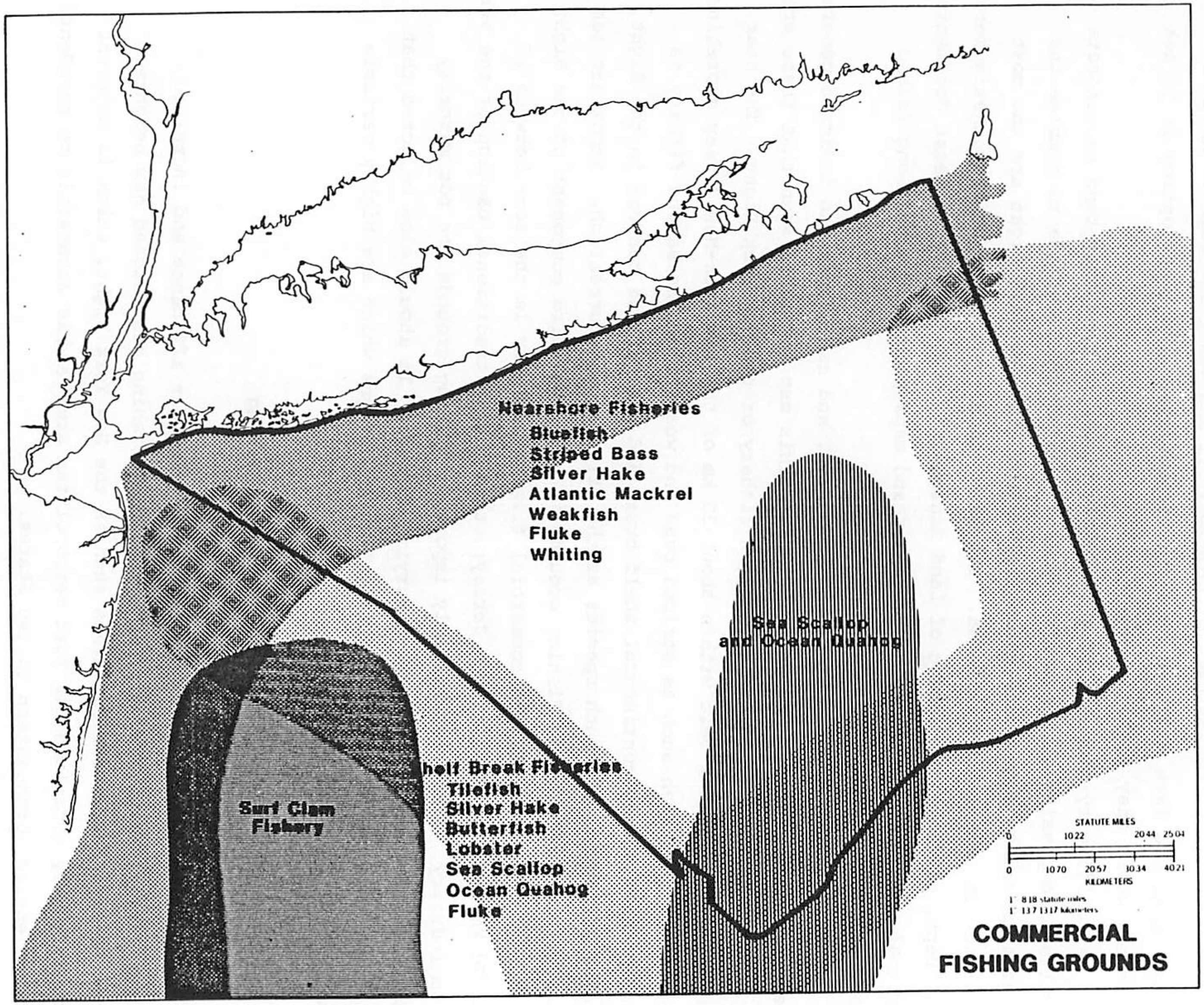

Figure 27.B. Commercial Fishing Areas.

The location and intensity of this activity is highly variable and dependent upon a wide range of factors. Despite this variability, it is possible to make some generalizations about the use of the Bight for recreational fishing.

Information regarding the numbers of marine anglers utilizing the New York Bight is fragmentary and inconclusive. Approximately 5.3 million people participated in marine recreational fishing in New York and New Jersey waters yearly during the mid-1970's. There are about 103 party boats and 154 charter boats on Long Island; most of these are capable of ocean operation. When this figure is combined with the 100 party boats and 225 charter boats on the Atlantic Coast of New Jersey and private craft, of which there are an estimated 1.1 million in New York and New Jersey on fresh and marine waters, it is likely that a significant portion of the 5.3 million marine anglers utilize the waters of the study area, at least occasionally.

Although some recreational fishing takes place year round in the New York Bight, fishing tends to be concentrated in the period from March/April to about October/November. The peak activity occurs in the summer months of June, July and August.

The location of recreational fishing tends to be concentrated near-shore and around various south shore inlets. Due to the generally flat topography of the sea floor in the New York Bight, boats that venture offshore tend to congregate around structures that attract and hold fish, such as reefs, wrecks and rock outcroppings at canyon heads. Thus, while it is not possible to locate exactly where all recreational fishing takes place within the New York Bight, important features relating to recreational fishing are shown in Figure 27.C. The map locates major artificial fishing reefs, popular fishing grounds and popular wrecks. The level of activity at any of these locations varies both seasonally and from year to year.

Military Activity

A large portion of the study area is contained within the Narragansett Bay (Military) Operating Area which extends from the Hudson Canyon east to Block Canyon from approximately 10 miles offshore to beyond the shelf break. These areas have been established for training of surface, submarine and air units in addition to providing designated zones for testing ordinance, aircraft and ships of the U.S. Armed Forces and other Federal agencies. The types of operations that take place within these operating areas include but are not limited to, submarine operations, gunnery practice, sea trials, radar tracking and general warship operations.

The public is not generally precluded from using operating areas, and mariners

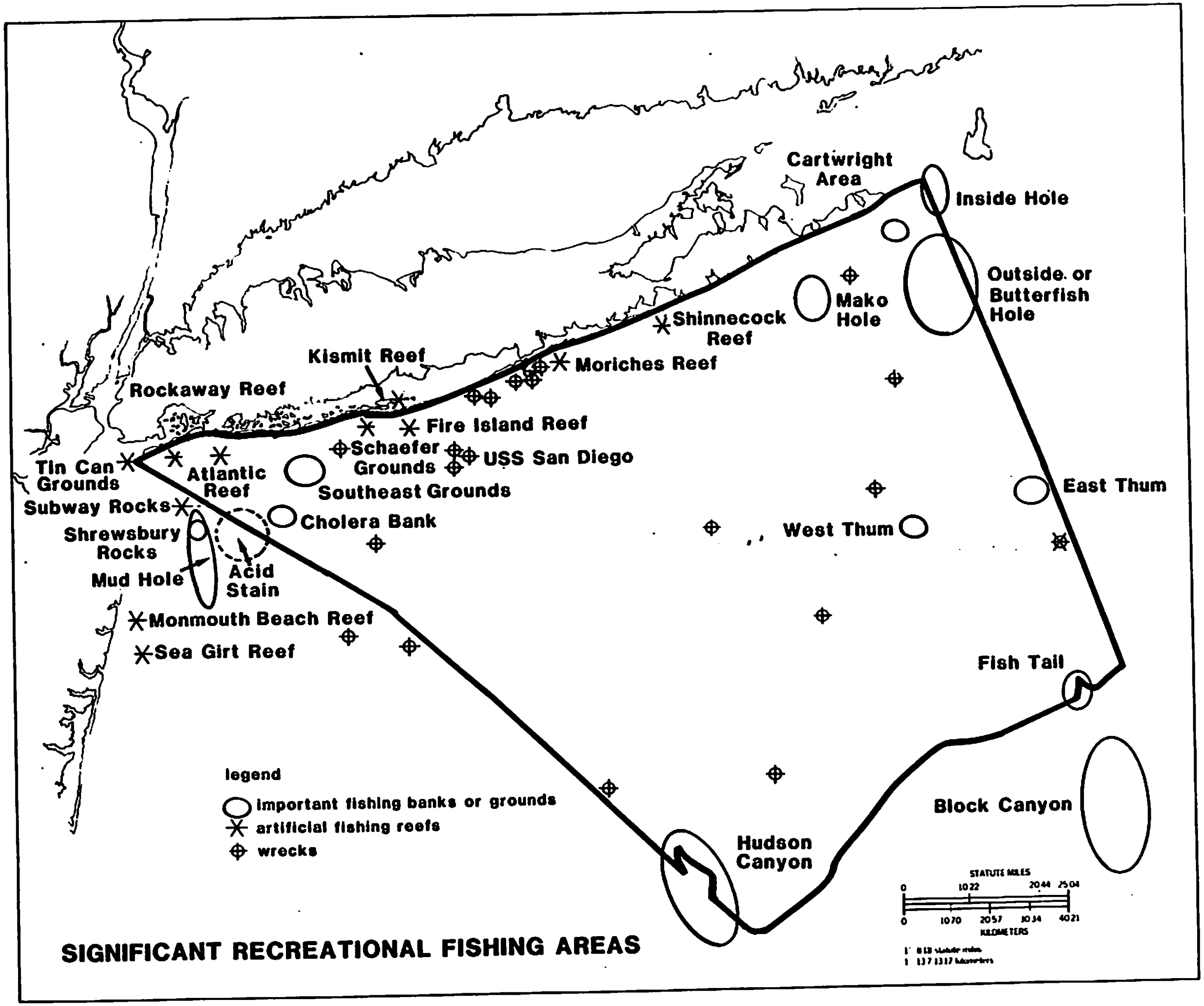

Figure 27.C. Recreational Fishing Areas.

are notified of military operations that may interfere with navigation through local Coast Guard Districts. The amount of surface area utilized by military operations is highly variable and difficult to document.

It is not known if military operations would receive priority over a biomass farm. Of primary importance in this region are submarine activites associated with the base located in New London, Connecticut. The defense implications of biomass farm location and operation should be addressed in the future. Responsibility for directing and coordinating military operations in the Narragansett Bay Operating Area rests with the Commanding Officer, Fleet Area Control and Surveillance Facility, Virginia Capes, Virginia.

Oil and Gas Development

Development of the Outer Continental Shelf (OCS) resources will result in the displacement of some of the traditional uses of shelf waters, and preclude some future uses. This displacement may be the result of exploration, development or transportation activities associated with OCS energy development. The New York Bight is particularly sensitive to the impacts of OCS energy development due to its location at the junction of the North and Mid-Atlantic regions.

The leasing of OCS tracts for oil and gas exploration and development is the responsibility of the Bureau of Land Management's (BLM) Outer Continental Shelf Office. BLM in conjunction with various other Federal agencies (and public input) selects areas with potential oil and gas reserves, conducts competitive bidding for likely areas and leases these areas to interested parties. To date, there have been two lease sales in the Mid-Atlantic region (#40 and #49) and one in the North Atlantic (#42), with one pending (#52 tentatively scheduled for October, 1982).

Most of the area leased in previous sales is outside the study area. Current interest seems to be greatest for areas along the continental shelf break and along the ancient submarine reef which runs along the edge of the Baltimore Canyon Trough. However, as a result of lease sale #49, Exxon has leased 5 tracts (#163, 164, 206, 207, and 208) within the study area; they are shown in Figure 27.D. Each tract consists of 5,693 acres or about 9 square miles. As a result of sales #40 and #49, some exploration has taken place in this region and is expected to continue. As of this time, the oil companies have not announced any commercial finds of oil or gas in the region.

In addition to the tracts held by Exxon, there are a number of current leases on the shelf to the east and south of the New York Bight, just outside the study area. There are also tracts, also just outside the study area, which may be leased

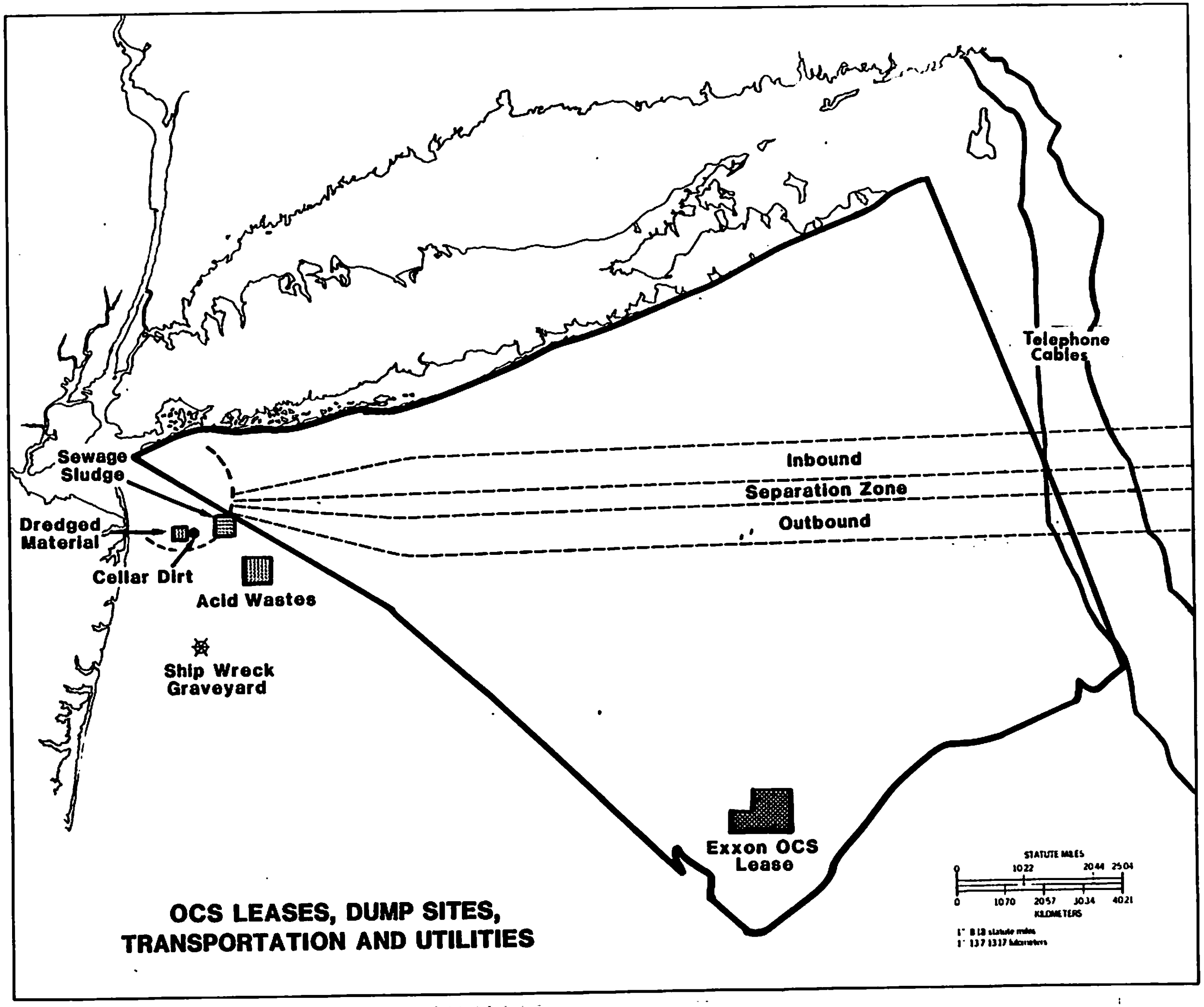

Figure 27.D. OCS Leases, Dump Sites, Transportation and Utilities.

under North Atlantic Sale #52 scheduled for late 1982. Should any of these yield commercially significant amounts of oil or gas, there exists the possibility of renewed interest in sites within the New York Bight not leased at this time.

The degree of conflict between OCS energy activities and other uses of OCS waters varies over the life of the resource development project and is directly related to the amount of oil and gas discovered. The most significant conflicts would be expected to occur during the peak production years. Current projections for the amount of commercially exploitable oil and gas in the Mid-Atlantic range from a low of .36 billion barrels of oil and 1.9 trillion cubic feet of gas to a high 7.3 billion barrels of oil and 28.3 trillion cubic feet of gas. If a commercially significant amount of natural gas is discovered, it is likely that it would be piped to existing facilities through new pipelines. Current tentative plans do not call for any landfalls of these pipelines on Long Island or any major pipelines within the study area.

To the extent that recovered petroleum products replace imports, net tanker traffic patterns into and out of the Port of New York and New Jersey may change as a result of the number of platforms deployed, their placement and timing. This could result in a significant increase in the number of tankers and barges utilizing the study area. Support vessels necessary for oil and gas development could also add to congestion in the Bight.

Transportation and Shipping

One of the possible conflicts with the marine biomass farm involves the most traditional use of the New York Bight: transportation and shipping. The New York Bight contains the Port of New York and New Jersey, America's busiest port. This port is the most important in the nation in terms of cargo and is also a leader in passenger ship handling.

Volume of vessel traffic utilizing New York harbor is compiled by several agencies. The Maritime Association of the Port of New York and New Jersey reports 6,723 vessels calling on Port Authority facilities in 1980. This number does not include internal harbor traffic or movements of tugs and tows. Additionally, a significant amount of petroleum product and construction materials are transported through Rockaway, East Rockaway, and Fire Island Inlets. The volumes of these and sizes of vessels employed are highly variable. It is estimated that East Rockaway receives 12 - 14 barges per week, and Fire Island, about 42 vessels per year.

Locating exact routes used by waterborne commerce is not feasible. However, large tankers and other vessels entering Mid Atlantic ports often use designated Traffic Separation Schemes (TSS) developed by the International Maritime Consultative Organization (IMCO). Vessels of IMCO member nations are required to abide by IMCO regulations while using TSS lanes. These regulations are not intended to supercede, or in any way alter, applicable rules of the road. The TSS consists of an inbound lane, an outbound lane and a separation zone. This scheme is recommended for use by vessels approaching and departing from major harbors, but is not necessarily intended for tugs, tows or other small vessels which traditionally operate outside the usual steam lanes or close inshore.

The New York Bight contains three TSSs: Nantucket to Ambrose, Hudson Canyon to Ambrose and Barnett to Ambrose. The Nantucket to Ambrose Traffic Lane bisects the study area as shown in Figure 27.D. The Hudson Canyon to Ambrose Traffic Lane abuts the western limit of the study area.

Ocean Dumping

Ocean dumping has been a solution to a variety of waste disposal problems in the New York metropolitan region. Formal agreements regarding the location of dump sites in the Bight date back to at least 1888.

Dump sites are segregated by material input type. There are five sites within the Bight: dredged material, sewage sludge, cellar dirt, construction debris, acid wastes, and wrecks. In addition, there is a chemical waste site located at the outer boundary of the Bight. The location of these approved dump sites is listed in Table 10 and shown on the map (Fig. 27.D.). None of these sites are within the study area.

The level of activity associated with ocean dumping is variable but has tended to slightly or sharply decrease according to the type of material dumped. For example, the approved site for dumping of wrecks has been used sparingly in recent years. Only eight vessels were dumped at this site between 1960 and 1977. The acid dump site is currently utilized by only two companies (NL Industries and Allied Chemical), both of which are under EPA implementation schedules to reduce or phase out ocean dumping. Use of the cellar dirt and dredged spoil sites is directly related to the level of construction and harbor maintenance projects in the metropolitan region.

Ocean dumping of sludge has come under increasing scrutiny in the last decade and was scheduled to end in 1981. It now seems likely that dumping will continue. At present there are 12 vessels (six barges and six tankers) that have EPA permits to transport sewage sludge to the existing site. Using estimates of the

Table 10 - Approved Dump Sites in the New York Bight.

Dump Site	Coordinates Latitude and Longitude	Area (sq. kilometers)	Depth (meters)
Sewage Sludge	$40^{o}22'30"N$ to $40^{o}25'00"N$ $73^{o}41'30"W$ to $73^{o}45'00"W$	22.7	24
Dredged Material	$40^{o}21'48"N$ to $40^{o}23'48"N$ $73^{o}50'00"W$ to $73^{o}51'28"W$	6.9	27
Cellar Dirt	$40^{o}23'00"N$, $73^{o}49'00"W$*	3.8	34
Acid Wastes	$40^{o}16'00"N$ to $40^{o}20'00"N$ $73^{o}36'00"W$ to $73^{o}40'00"W$	41.0	24
Wrecks	$40^{o}10'00"N$, $73^{o}42'00"W$*	2.7	60
Chemical Wastes	$38^{o}40'00"N$ to $39^{o}00'00"N$ $72^{o}00'00"W$ to $72^{o}30'00"W$	1,550	1,800

*Center Coordinates of Circular Dump Site.
Source: Table 1 in reference (2).

total sewage sludge dumped and the average carrying capacity of the sewage hauling fleet, it is estimated that approximately 1,100 vessel trips are made to the sewage sludge dump site each year.

Task 3.4. Summary

It is obvious from this preliminary siting analysis that gaps exist in the available environmental information characterizing the study area. Monitoring projects carried out to date in the Bight have been designed to understand the fate and effects of contaminants, fishery resources and other limited topics. Specific studies will have to be undertaken to evaluate specific potential sites. The design of these studies must await completion of research on environmental requirements for biomass production.

It is not possible, at this time, to rank sites for biomass farming. However, locations in the study area where conflicts with other uses are apparent, can be identified now and through a simple process of elimination, areas posing minimal conflict can be identified. Whether or not a specific area with minimal conflict is a suitable site for a farm will depend upon the match of its environmental characteristics with seaweed/production strategy requirements.

Uses potentially conflicting with farm operations include commercial and recreational fishing, military operations, OCS oil development, shipping, and ocean dumping. In general, the commercial fishery is concentrated within a 30 km belt along the New York-New Jersey shoreline, along the continental shelf break and the various canyons in the Bight, and in a zone between 10 and 70 km off the New Jersey coast. Recreational fishing vessels tend to congregate nearshore, around various south shore inlets, and around offshore reefs, wrecks and rock outcroppings. The farm site should be established outside these areas to minimize interference with commercial and recreational fishing ventures.

Most of the study area is located within the Narragansett Bay Military Operating Area. Coordinated planning efforts would be necessary to minimize potential conflicts between biomass farming and military interests.

OCS oil and gas development activities might present obstacles to the operation of a farm in the Bight. The future level of OCS activity will be contingent upon the quantity of petroleum hydrocarbons. At present, only non-commercial quantities have been found. Should commercially significant amounts of oil be discovered, the Bight could experience several impacts: increase in tanker and barge traffic to and from the Port of New York and New Jersey, congestion from support vessels and platforms, and the risk of oil spills. Exxon owns leases on five tracts of approximately 23.2 km^2 (9 mi^2) each in the study area.

Transportation and shipping activities concentrate along coastal regions and near approaches to harbors and inlets. Designated Traffic Separation Schemes serve to restrict traffic to major shipping lanes. These schemes are recommended

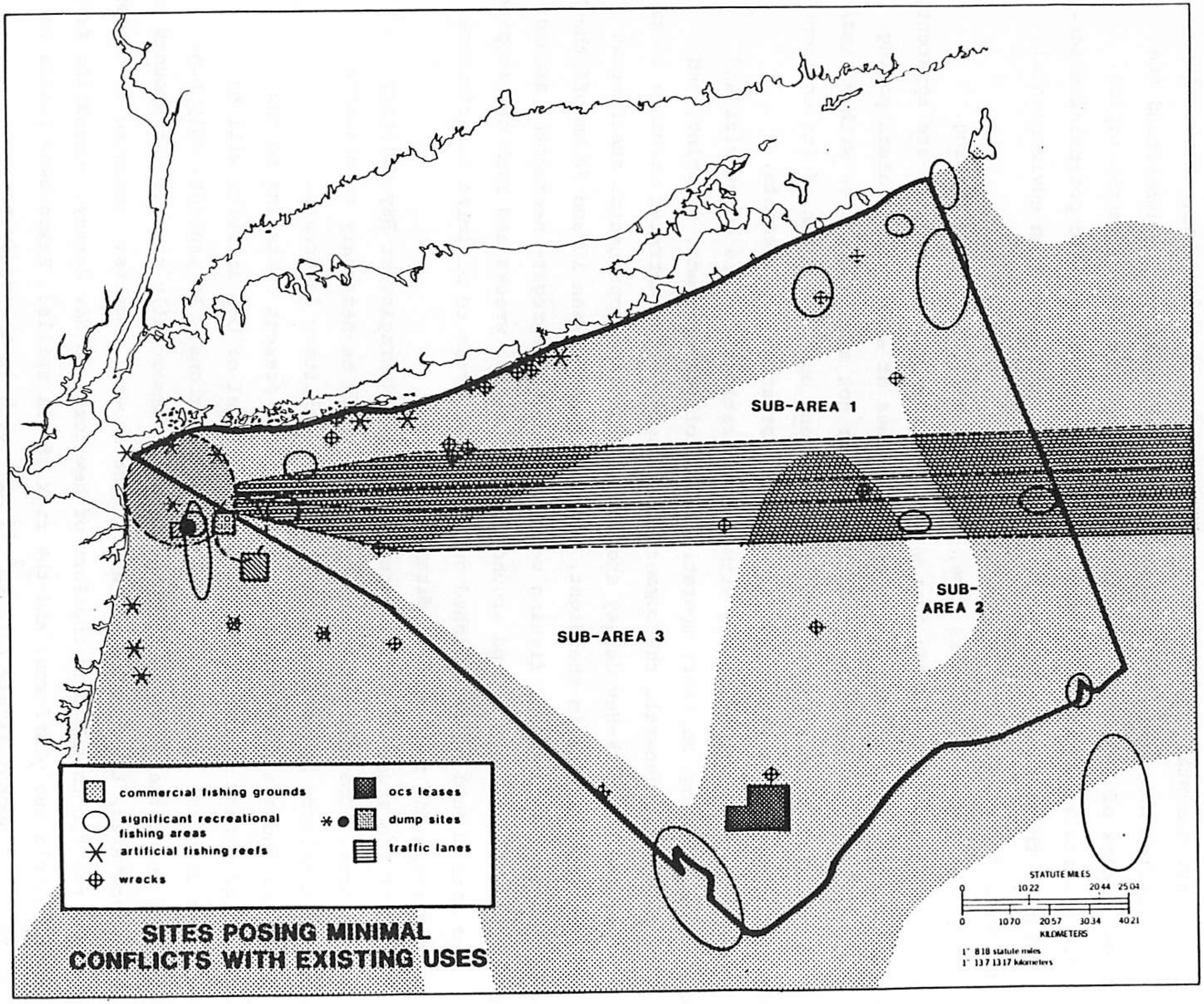

Figure 27.E. Sites Posing Minimal Conflicts With Existing Uses.

for use by large tankers and other vessels approaching and departing from major harbors, but are not necessarily intended for tugs, tows or other small vessels which traditionally operate outside the usual steamer lanes. Obviously, farm locations should be excluded from the traffic lanes.

Ocean dumping sites should be avoided. Their effects are local, however. In contrast, high nutrient concentrations from estuarine outflow favor proximate locations of farms. These trade-offs will have to be considered during the site selection process.

Figure 27.E. has been prepared showing three sub-areas within the study area apparently posing minimal use conflicts with the siting and coperation of a bio-mass farm. Sub-area 1 is located approximately 26 km southeast of Long Island and north of the Nantucket to Ambrose Traffic Lane. Sub-area 2 is located approximately 80 km from Long Island and 200 km from the Port of New York and New Jersey. Triangular in shape, sub-area 3 is located between the Ambrose to Nantucket and Hudson Canyon to Ambrose Traffic Lanes and, at its closest point, is 66 km from the Port of New York and New Jersey.

Additional research will be required to determine which of the three sub-areas is optimal from the environmental point of view. Seasonal water temperatures vary significantly among the three sub-areas. Primary production, as measured by chlorophyll a concentration, appears to be highest in sub-area 1, followed by sub-area 3. Nitrate levels in sub-area 2 are slightly higher than in sub-area 1. Whether or not these environmental differences are significant enough to warrant selection of one sub-area over another cannot be determined at this time.

Available data describing the light field in the study area is scanty. This is a significant data shortfall and studies to obtain information on light profiles and their seasonal variability will be required. The availability of salinity, temperature, and nutrient data obviate the need to conduct surveys of these parameters.

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Task 4. ALTERNATIVE DESIGNS FOR RAFTS AND TEST FARM MODULES

The engineering aspect of the marine biomass project has many facets, all of which are closely related to biological and economic considerations. An effort has thus been made to introduce into our concept project a systematic evaluation of the results obtained by the biology team, always recognizing that raft or farm structures must be built to support living organisms in an extreme environment. Economics have and will continue to play a central role in all engineering design considerations. Structures which have realistic cost/strength ratios together with reasonably achieved station keeping capabilities have been designed for deployment in Long Island Sound.

The preliminary engineering design program ranges from simple test rafts to more fully functional prototype rafts, correlated with novel mooring systems. It is not necessarily intended that the designs discussed here are to be scaled up, but rather to suggest design possibilities and problems which have been encountered.

This task mainly involved raft and mooring-line considerations. Modular rafts were constructed of PVC pipe and extended with conveyor-belt type material and nylon fasteners. This approach is both simple and economical. It is possible to construct numerous rafts and to link them together in a relatively straightforward manner. Qualitative considerations and computer-based calculations led to the conclusion that such a system would be viable in the expected sea states anticipated for the various proposed sites. In fact, the modules, composed of rafts and nylon seaweed substrate material, are stiff, strong and easily deployable structures. It is expected that a system comprised of these structures could act as a workable small-scale test farm for early on-site biomass studies.

The design program has been segmented: basic structural design in light of environmental conditions; materials parameters; and mooring considerations. Specifically, we are concerned with issues of location, cost, materials, size, etc. At this time little will be offered on engineering design projection, except to say that continous harvesting will eventually be a high priority concept. To appreciate the structural requirements for marine biomass conversion, consideration must first be given to a wide range of design needs:

1) The nature of the seaweed will ultimately determine the actual structural design. Most seaweeds have a holdfast and, thus, need a substrate on which to attach. However, some species can grow free floating, requiring only simple containment. Relative to this are the possible benefits of growing different species of seaweed

simultaneously at different levels within the structure.

a) It is desired to employ species having high productivity and which survive winter conditions without disintegrating.

b) The simplest technology is preferred. The emphasis is on floating or short-stiped species as opposed to long-stiped forms or those requiring complex holdfast or support arrangements.

2) Material used for the structure must be inert with respect to sea water degradation over a prolonged period. Since an ideal structure is conceptualized as being essentially permanent while the seaweed is periodically harvested, the strucuture must not corrode or deteriorate at an appreciable rate. Thus, the material strength-related parameters must be relatively constant with respect to sea water.

3) Material comprising the structure must be non-toxic with respect to the seaweed or other sea life.

4) The structure is envisioned as "yielding" with respect to wave systems. There are two alternate methods of considering wave fluctuations: a) The structure is strongly fixed and rigid, so that any wave impinging on the structure will disintegrate; b) The structure will be flexible and thus accommodate any amplitude and frequency of impinging wave front. (Such a structure is envisioned as modular in nature, each unit being independently connected to another.) A wave-flexible system is of special interest because it receives less stress and requires less supportive material which increases cost and weight.

5) The size of the structure is crucial to its design. For example, a large structure would need many segments (units), making unit size increase advantageous. The modular concept has many advantages such as ease of repair; no size limitation since additional modules can be added; simple construction and deployment.

6) Harvesting must be considered in design, the process being straightforward and not labor-intensive.

7) The structure must be ballasted at some level above the sea bottom. Many methods are possible for ballasting, but perhaps the simplest is to have floatation connected to the anchored modules.

The initial design and construction period resulted in the fabrication of modular raft systems. Additionally, a number of new concepts have been introduced by Stony Brook engineering students as senior design projects.

1. <u>Modular Raft Design</u>
   C. Berger & L. Berger
2. <u>Rope Culture Raft Design</u>
   E. Cantwell & L. Rosenfeld
3. <u>Octagonal Modular Growth Raft</u>
   D.C. Sawin & D. Siegal
4. <u>Cylindrical Growth Raft</u>
   R. Florio
5. <u>Multipod Growth Raft</u>
   J. Brenner & J. Bousheed
6. <u>Floatation Systems</u>
   K. Van Camp
7. <u>Floating Tire Breakwaters (FTB)</u>
   E. Cantwell
8. <u>Mooring Systems</u>
   S. Birbiglia, R. Whitebread, & R. Gukain

1. Modular Raft Design

C. Berger and L. Berger

This design was developed for culture of floating or partially buoyant seaweeds. Its design is of individual cubic modules about 5' on a side which can be combined to make larger units.

Individual sections are constructed of 2 1/2" diameter PVC pipe joined by appropriate elbows, tees, and couplings (Figs. 28-30). Nylon mesh bags were utilized in the original fabrication. These were attached to the supporting framework in a fashion which allows for quick-release and harvesting by collection of the entire bag. The bag may, itself, be partitioned horizontally.

The components of the frame are neutrally buoyant because seawater may enter the pipes. Floatation is achieved by polyethylene blocks mounted on the frame.

Modules may be connected by conveyor-belt type materials attached in such a fashion as to provide flexible response of the system to wave motion. Belting couplers are secured with nylon bolts.

Computer simulations of this design have shown that extended arrays such as that shown in Figure 30 would survive in the wide wave spectra of Long Island Sound.

This was the first design concept fabricated and deployed. We have found PVC pipe to be an excellent material for raft construction. However, field

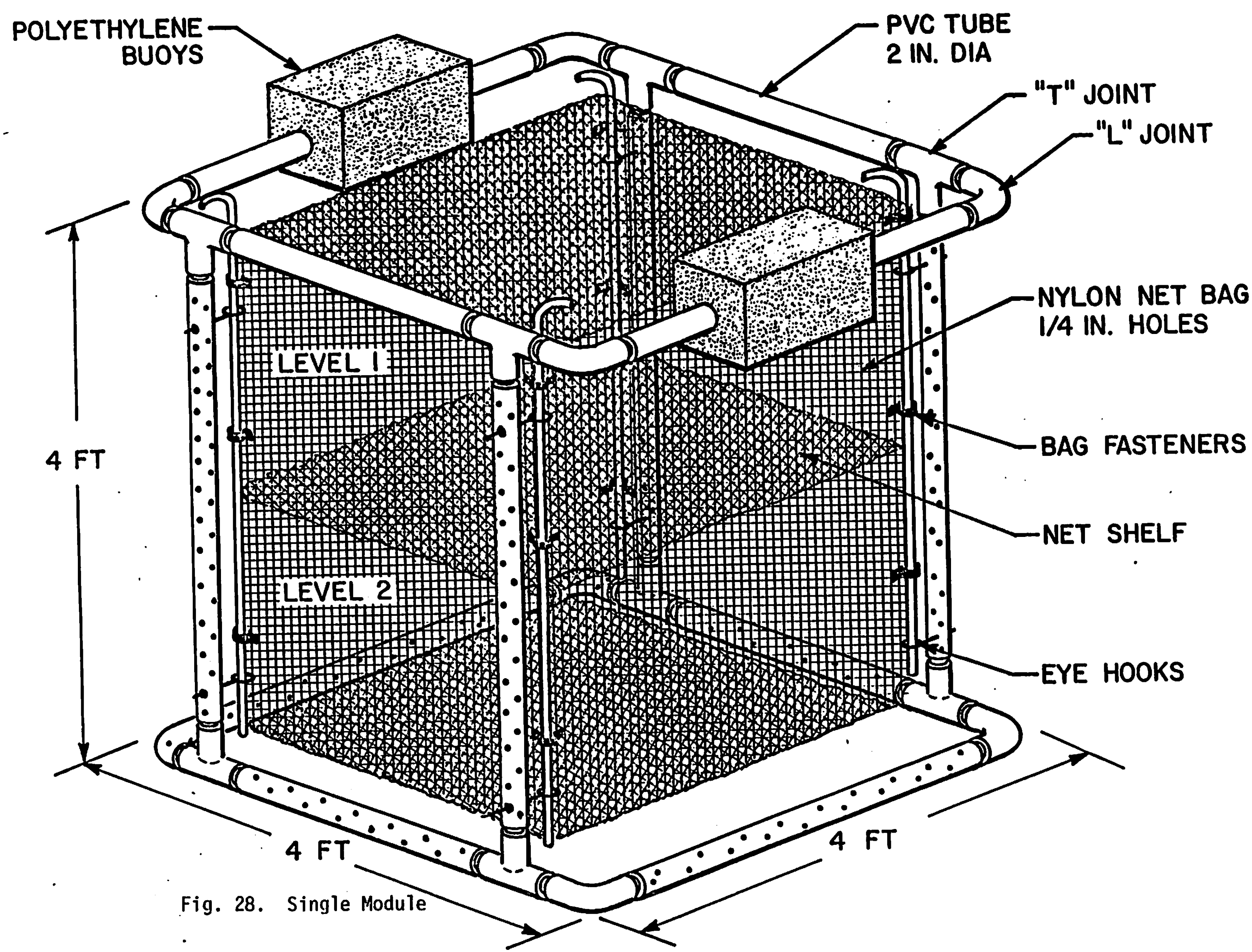

Fig. 28. Single Module

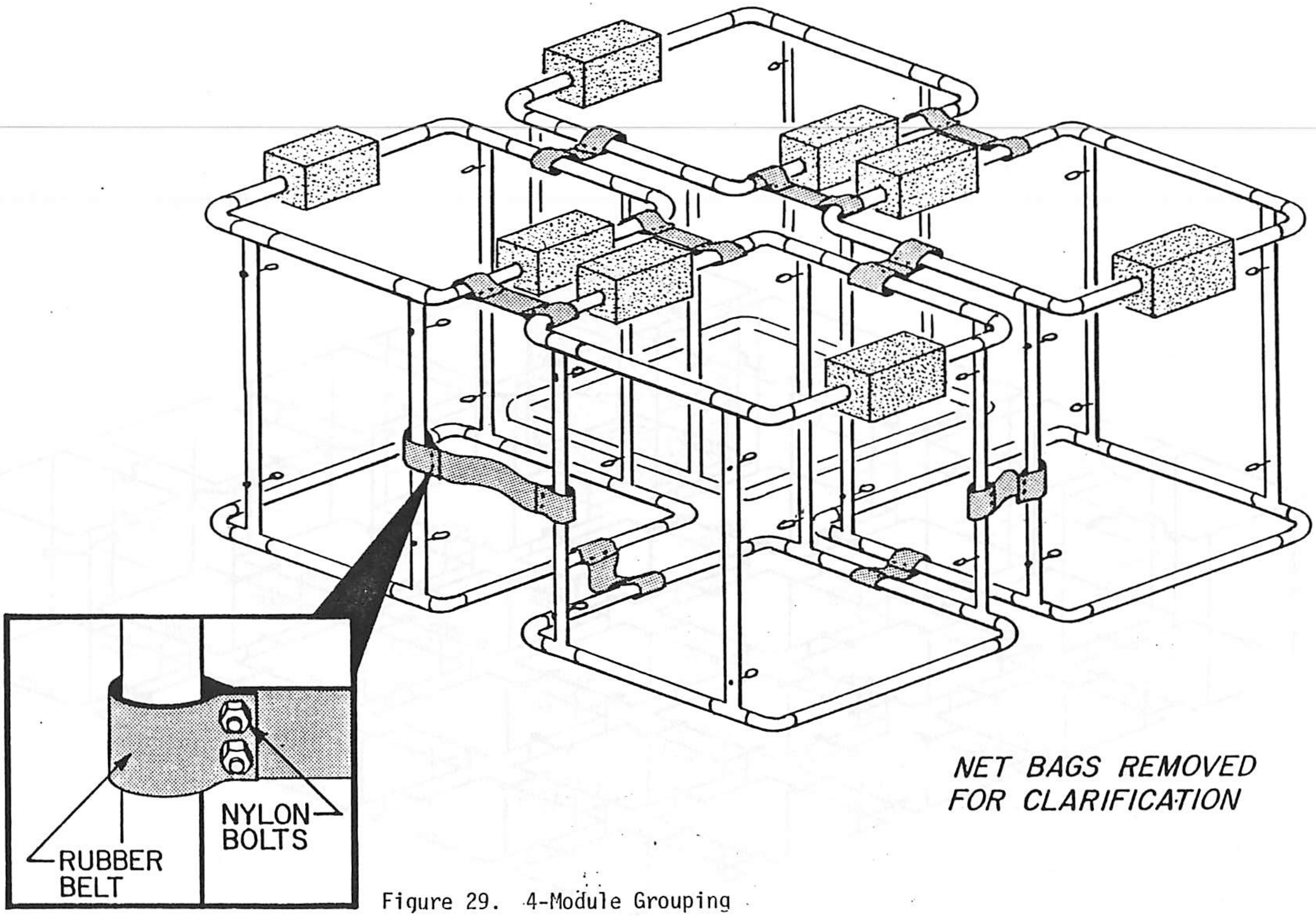

Figure 29. 4-Module Grouping

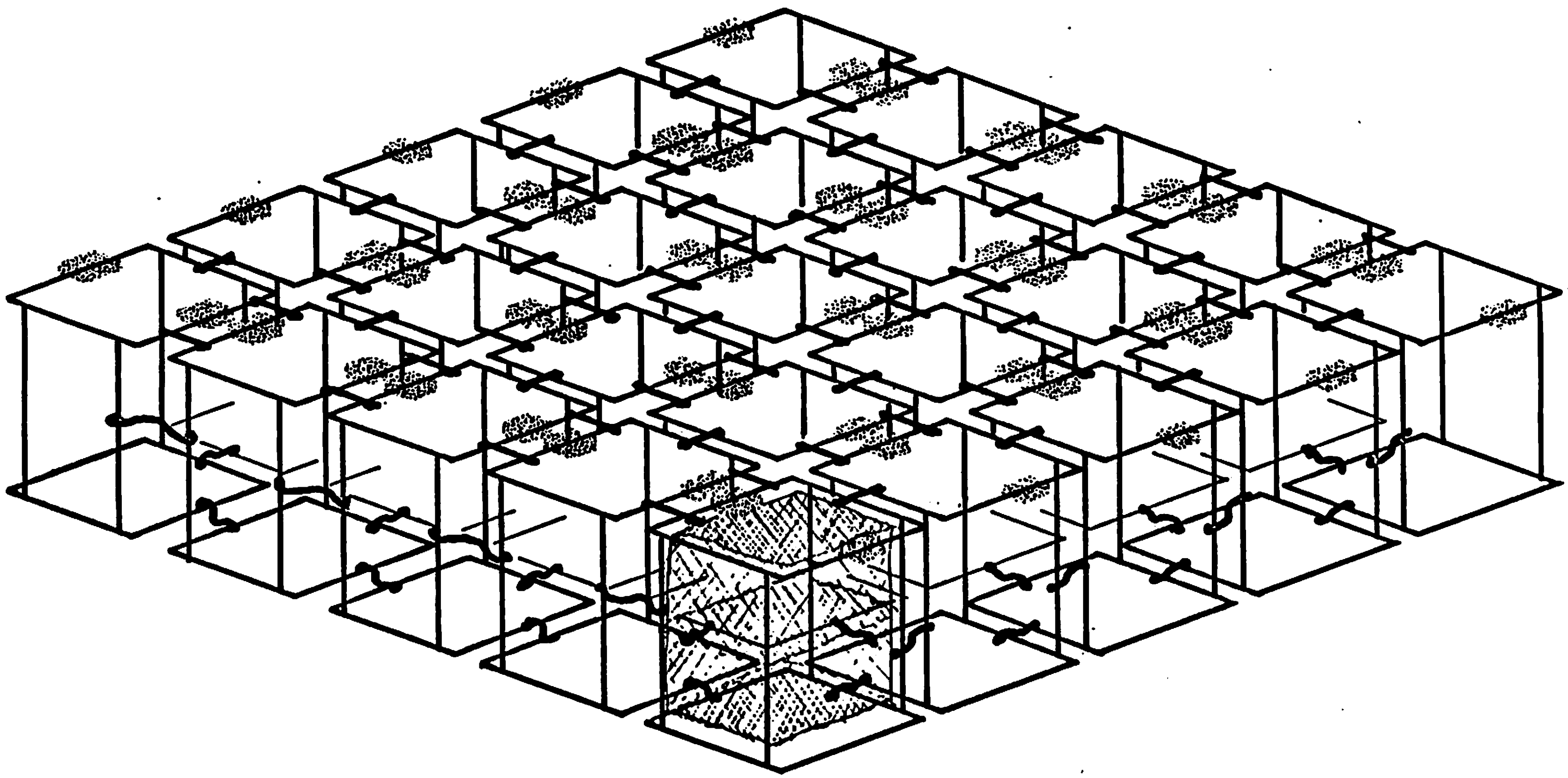

Figure 30. 25-Module Grouping

trials with mesh indicate that this material is easily damaged by "visitors" or in handling and is quickly affected by fouling. Advanced designs would require courser materials, perhaps rope.

2. Rope Culture Raft Design

E. Cantwell & L. Rosenfeld

The question of the attachment of plants to a growing structure was examined. There is expectation among the biologists that eventually algal spores will attach directly to the structure (i.e., employing it as a growth substrate).

The system which best accomodates these needs is one being used in all the major seaweed culturing facilities of the world. It uses woven polypropylene rope, the strands of which are untwisted at a point until a space is created, this being the point where a plant is inserted and the space closed. The plants can be spaced at any desired distance from one another. In actual practice the holdfasts of a plant would attach directly to the rope as spores settled and grew on them.

The rope culture farm is very simple, consisting of an open gridwork of rope (Fig. 31). There are numerous ways in which the grid can be moored. A key advantage of the rope culture system is that by leaving a sufficient amount of slack in the gridwork, it can move freely with the waves. This flexibility creates little stress on a plant at the attachment point. Therefore, the attached algae are not damaged due to accelerations relative to their substrates. Also, since the rope culture farm is an open structure, the plants are not deprived of sufficient sunlight and nutrients due to fouling or large surrounding support structures.

A disadvantage of the rope culture farm is that it is not able to accommodate unattached seaweed species. Also,vertical motions are not as troublesome; the system must be moored to the bottom limiting lateral movements. Strong currents could give rise to lateral accelerations between plant and substrate. A method for damping lateral motion through various mooring schemes will be discussed later.

Two candidate rope materials are nylon and polypropylene. Nylon is the more expensive, stronger, negatively buoyant and will deform up to 400% before breaking. Polypropylene has limited plasticity, but has a fracture strength on the order of 10^3 psi and is also positively buoyant. Fouling will occur with both nylon and polypropylene materials. Overall, due to a lower price and positive buoyancy, polypropylene seems favorable.

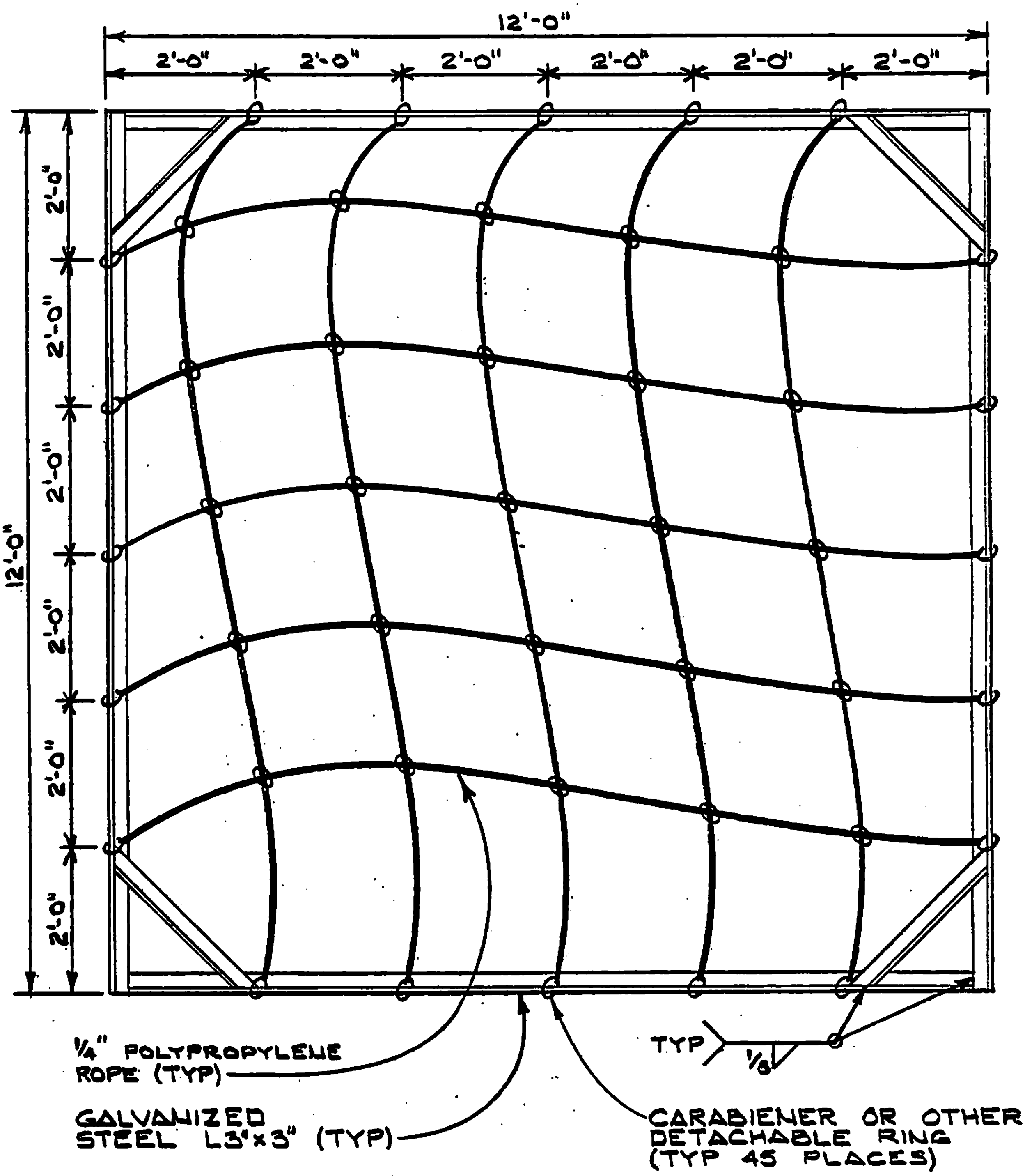

FIGURE 31 - PLAN - ROPE CULTURE

SCALE: 1/2" = 1'-0"

The rope culture farm has considerable potential for scaling-up. The grid might be suspended from a flexible, rectangular frame constructed of buoys and conveyor-belt (Fig. 31). Each corner of the frame is moored to a different anchor, the four anchors being lined up in a rectangle somewhat larger than the grid rectangle. Slack in the mooring lines allows for lateral and horizontal movement of the grid and aids in shape retention. In case of a violent lateral current, one or more of the mooring lines becomes taut. Further current-induced motion forces the structure to move horizontally and vertically down. The upward force of the buoys then conveys a restoring force. By using proper buoys, the effects of strong, sudden storm-induced currents and other extreme conditions can to some extent be dampened.

3. <u>Octagonal Modular Growth Raft</u>

D.C. Sawin & D. Siegal

The "crystal-structure" raft design departs from the typical, less rigid structures which have been employed previously. It is a regular octagon, which was chosen over simpler geometric shapes because it most closely approximates a circle, the most stable structure within a fluid. The framework of this structure consists of PVC piping connected by means of 45° angles, tees and connectors, all of the same material (see Figs. 32 and 33). In order to maintain the structure's rigidity and to seal the joints from the exterior environment, a very strong, water repellent adhesive is used. The external framework is 12 feet long (4 feet per side of octagon) and 6 feet in height. In order to stiffen the outer framework and supply an inner network, a metal grid (Fig. 32) of 4 foot lengths welded together is attached internally. This network consists of tees and inverted-tees so that the grid for the plants may be secured. (Figs. 34 and 35.)

Of utmost importance is the configuration of the plan supporting mesh (or netting) with respect to the plants' growth habit. At the base, or foundation, a very finely meshed net is attached surrounding the diver's 'hole', so that it acts as a filter and traps the released spores enabling continuous re-seeding.

The next highest one or two meshwork(s) are of proportionally larger mesh-size. This allows (a) the holdfast of the seaweed to attach, (b) the individual plants to remain disentagled, (c) the flow of water and nutrients to be undisturbed, and (d) individual plants to be studied and their growth rate recorded. These two primary shelves of mesh can be used for two different species of seaweed (i.e. <u>Laminaria</u>, <u>Codium</u>), depending upon the time of year and amount of sunlight. The active species is placed at the top, with the dormant variety placed approx-

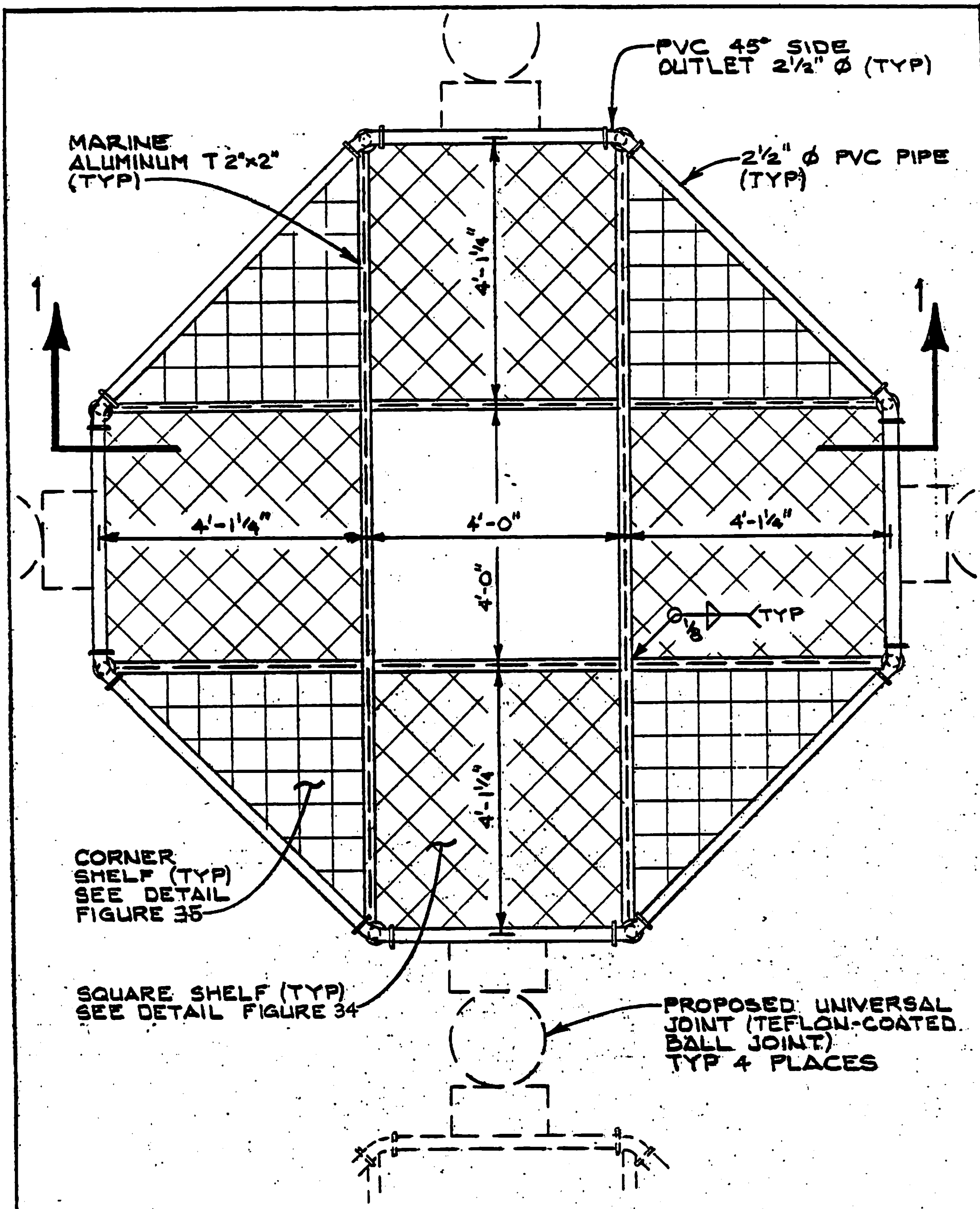

FIGURE 32– PLAN- OCTAGONAL CRYSTAL RAFT

SCALE: ½" = 1'-0"

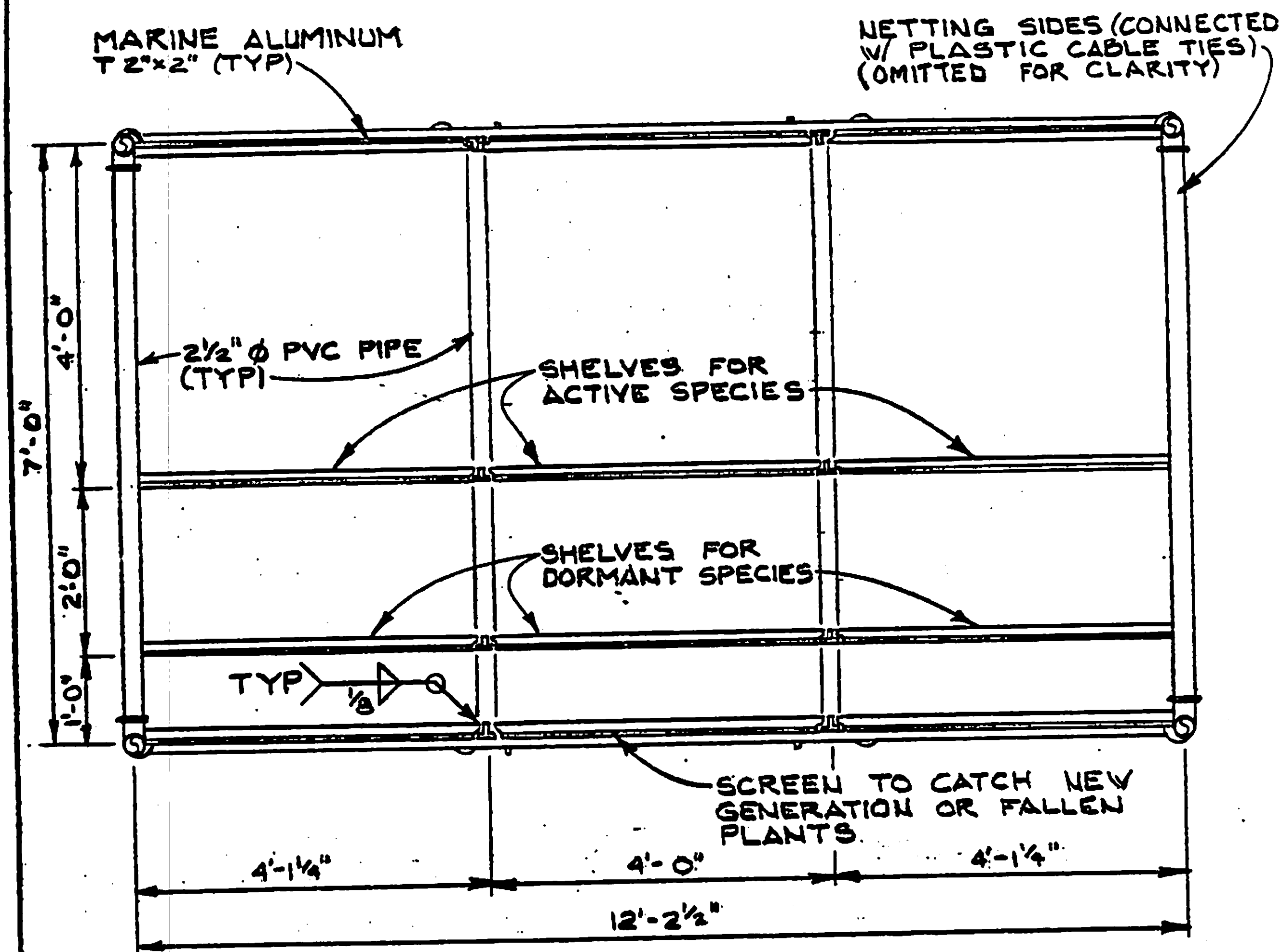

FIGURE 33— SECTION 1-1 ELEVATION
SCALE: ½" = 1'-0"

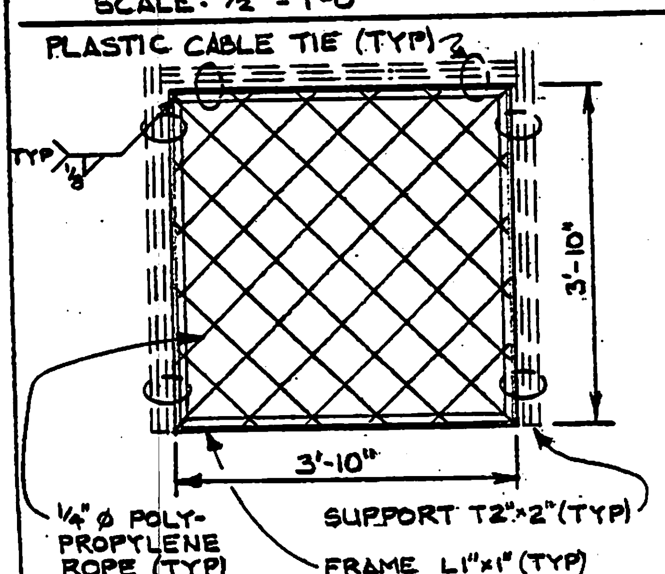

FIGURE 34— SHELF DETAIL
SCALE: ½" = 1'-0" TYP 8 PLACES

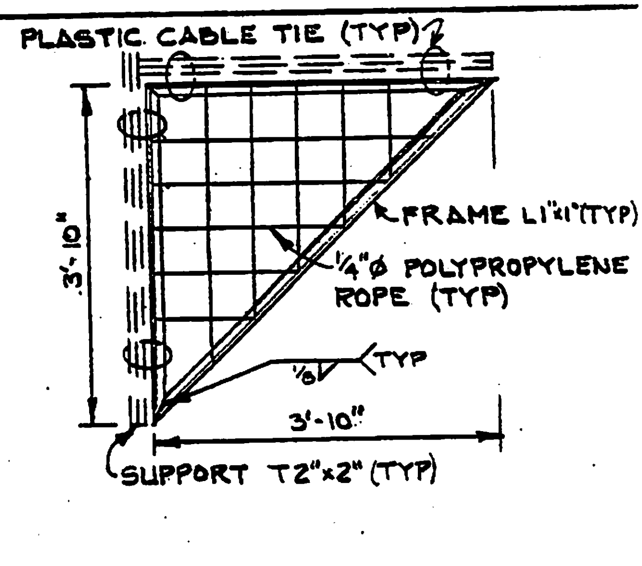

FIGURE 35— SHELF DETAIL
SCALE: ½" = 1'-0" TYP 8 PLACES

imately two feet below. The mesh gridwork is attached to the metal frame through plastic connectors. In the spring and fall the mesh gridworks can be switched so that the active species is on top. The plants are harvested and then the base mesh serves as the new shelf.

Screening covered with polymer encloses the sides of the structure in order to dissipate wave action amongst the plants. The main purpose of this screening is to break-up the wave action while still allowing water flow through the "barrier." By allowing water flow through the structure, lateral stability is increased, such that only bottom and top mooring is required. The polymer coating on the screening is used to prevent fouling.

The top of the structure is totally open, excluding the eaves at the edge. These eaves add to the stiffness of the structure and act as a lip to keep plants from getting caught on the edge.

The octagonal shape lends itself to expansion through connecting a series of the single crystal units to form "organic" wave "forgiving" systems. Through the use of universal joints between two units, the system can be expected to "roll" or flow with the wave motion. Furthermore, in this expanded mode, the volume common to the corners of four units is sufficiently large to permit diver access for inspection of plants.

4. Cylindrical Growth Raft

R. Florio

An early design involved a raft in the shape of an inverted cone. The top has a 4 foot diameter ring, intended for diver access, and a 10 foot diameter base which is the seaweed substrate. Suspended from the top ring are two 12 foot bars which, together with another foot diameter ring connected to it at the same level as the base, constitutes the heart of the system. The top and bottom rings are connected by large mesh in order to reduce wave action. A rope net for culture is attached to the inner lower base.

This design has a number of good points, but some problems as well which require major modifications. The advantages are:

(1) Large growing surface.

(2) Cost efficiency.

(3) Easy access for divers.

The disadvantages are:

(1) When fouled, sunlight is blocked from the seaweed.

(2) The structure is too weak to withstand constant wave action.

A further design was necessary that has increased structural integrity with access to sunlight even under fouling conditions. The second version has a 4 foot diameter ring for diver access at the top and a 24 foot diameter ring as a base. A third ring, 24 feet in diameter, is situated 7 1/2 feet above the base. The top, middle and base ring are all connected by tubing. The raft is meshed only around the two large rings.

The advantages of this design are:

(1) Strength.

(2) Easy access to sunlight under fouling conditions.

5. Multipod Growth Raft

J. Brenner & J. Bousheed

This design uses a series of essentially, unconstrained, buoyant disks as seaweed attachment surfaces. These can most properly be thought of as a number of small rafts (multipod growth rafts or "lilypads") tethered to a larger frame.

The Lilypad Field design is intended as an alternative to the rope-culture concept. A buoyant disk with a single central tether will have considerable freedom to move side-to-side. Similarly, it can be seen that the disk would be free to move downward (with only a slight buoyancy force to overcome). Vertical motion can be achieved in several ways. The one presented here assumes that the lilypads are tethered in groups of three or four to lightweight one-inch OD PVC pipe. These pipes must be heavy enough to overcome the buoyancy of the lilypads, however, so that when mounted loosely in vertical slots, they will be free to slide upward.

6. Floatation Systems

K. Van Camp

A. Motion Attenuation of a Submerged Raft by Motion Averaging

Restriction of vertical motion of a submerged raft is of paramount importance in the design of the mooring and buoy system. Consequently, we have investigated several systems for reducing this motion; one is the system of motion averaging.

The Concept of Motion Averaging

It is necessary to have the raft directly attached to surface buoys, so that the raft may rise and fall with the tides, always maintaining a set distance from the surface. The difficulty with traditional methods of attaching rafts to buoys (i.e., direct cable connection) is that the raft responds to surface waves. Instead of connecting a corner of the raft directly to a single buoy, the raft can be connected to the center of a pipe connecting the two buoys. The effect of this system is that the raft moves vertically a distance that is the arithmetic average of the vertical displacements of the two buoys. If a wave travels as shown in Fig. 36 and the spacing between the buoys is one-half the wavelength, then the raft will not move at all, this being the best possible case. The worst possible case is when the spacing equals the wavelength or a multiple of the wavelength, or when the wave is moving in a direction perpendicular to the plane of the paper. Then the raft will move as much as the height of the wave. Between these two extremes is a wide range of possibilities, all of which tend to reduce the vertical displacement of the raft.

Applying Motion Averaging to Real Wave Conditions

In most cases, the system depicted in Fig. 36 will significantly reduce raft motion. However, one cannot design for most cases, and , obviously, the worst possible case condition is the most important. Only a few sudden accelerations of the raft can destroy a large part of the seaweed crop. Since the worst possible case would give the raft a displacement equal to the wave height, this is an unacceptable condition.

The solution is to create a multi-level system, as shown in Fig. 37. Instead of connecting the raft directly to the pipe between two buoys, another set of ropes and PVC pipe is connected to the two initial pipes. At the center of this second level is another connection point, to which the raft may be attached. It should be noted that the pipes marked as "spacing bars" do not contribute to motion averaging; they are present only to maintain constant distances between the buoys. However, this system may be continued a step further: A third level may be added by using eight buoys instead of four. A pipe-rope combination would connect the two second levels in the same way as were the first two levels. Likewise, 16 buoys could be used to produce a four-level system. In each case, the raft will move as the arithmetic mean of the vertical motions of all the buoys.

Some of the problems encountered in the design of the motion averaging system will now be discussed.

Ballasting and buoyancy: The raft used must be ballasted to maintain position.

Raft Attachment: It is important that the raft be connected to the buoy system at only a single point. This will serve the dual purpose of reducing entanglement and eliminating the need for more buoys. However, the raft will tend to rotate and must, therefore, be connected to the system through a swivel attachment.

Mooring: The entire system may be moored to the seabed at only two points, though more mooring points may be used if desired. Specifically, two of the buoys at

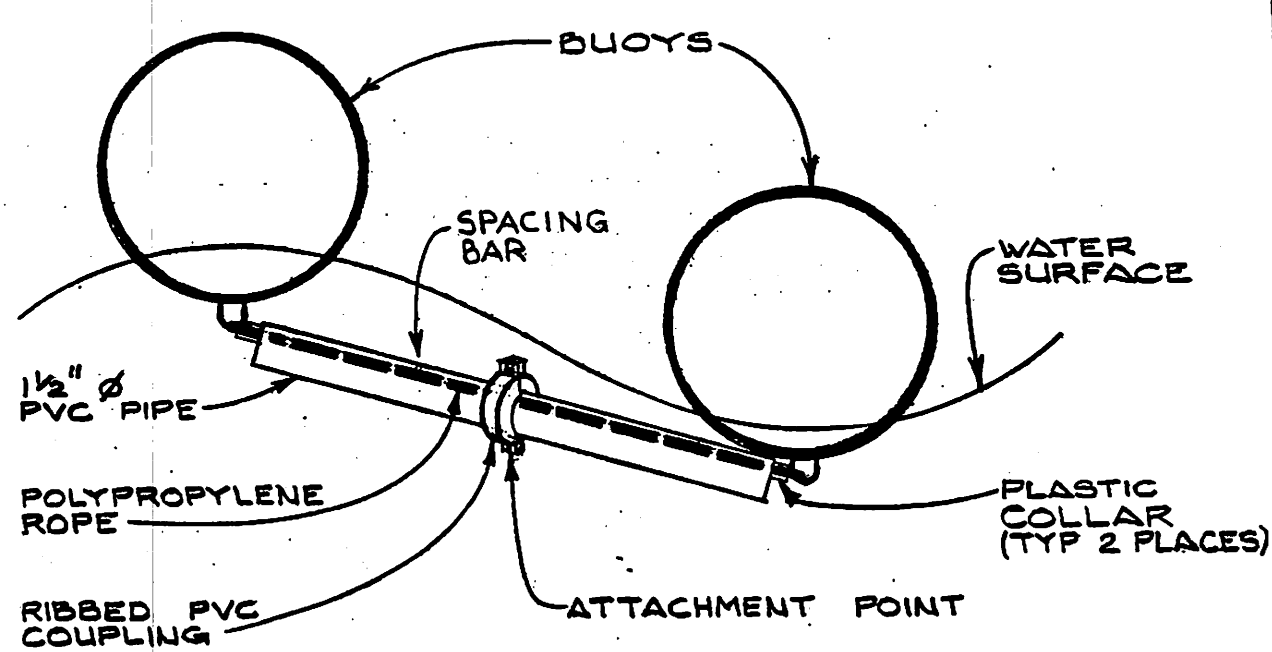

FIGURE 36 – ELEVATION – BASIC COMPONENT OF MOTION AVERAGING SYSTEM

NO SCALE

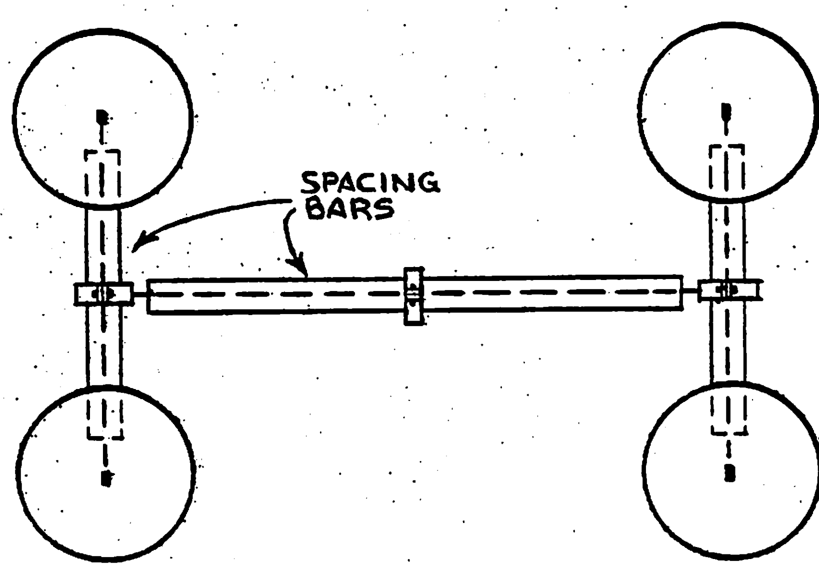

FIGURE 37 – PLAN – TWO-LEVEL SYSTEM

NO SCALE

(EXTRA SPACING BARS BETWEEN BUOYS HAVE BEEN OMITTED FOR CLARITY.)

outermost corners are anchored. The pipes between the buoys maintain constant distances between the buoys: Without them, the buoys would be pulled together by the weight of the raft. The pipes also make mooring each individual buoy necessary. Spacing bars are emplaced to form squares in each set of four buoys, with a diagonal included for angular rigidity. In addition, sets of four buoys are connected to other sets of four buoys in the same fashion.

Number of Levels: The cost of the buoys is a large portion of the cost of the motion averaging system. The number of buoys and therefore, the number of levels must be kept to a minimum. As will be discussed in the next section, 16 buoys are probably necessary. It should be noted however, that concepts recently developed by the Stony Brook Engineering Team may introduce major simplifications into the motion averaging approach.

Results of Computer Modeling

Placement of the buoys is of prime importance in the design of the motion averaging systems. A wave can result in system malfunction if the buoys are incorrectly placed. As discussed previously, one must design for the worst possible case, not the average - and therefore all wavelengths (within the range of physical possibilities) coming from all directions must be accounted for. There are two possible ways to design the spacing of the buoys for optimal motion attenuation:

i) Using uneven spacing between all buoys. In this way, many different waves incident on the structure can be accounted for. The buoys can be positioned so as to require only a small number being in synchronized motion for any given wave. In effect, this method opposes wave periodicity by using non-periodicity.

ii) Spacing design by a modular system. Each module would consist of four buoys, with two or four modules being interconnected, as described above. However, instead of accounting for all wavelengths and directions by examining the entire system at once, the individual modules are first considered. Each module is designed so as to average the motions of only certain waves coming from certain directions. Then, when all the modules are considered simultaneously, the effect is the same as with uneven spacing: motion attenuation for all wavelengths from all directions.

To aid in the design of this spacing, a computer model was developed with the program written by members of the Engineering Team. The model used different arrangements of the buoys employing both methods as described above and calculated the average vertical displacement for the system. Sine waves of varying wavelength and direction, and with varying phases, were used to determine these displacements.

This modeling has not yet been completed, but initial results indicate a motion of the raft of 35% of the wave height may be possible for the worst case. The average motion will be less than 20%. However, these results cannot be stated with certainty until modeling is completed. Preliminary results also indicate that the buoys can be enclosed in a square area of about 35 feet on a side to accommodate rafts of the size discussed in this report.

A layout of a large motion-averaging system is shown in Fig. 38.

B. Elongated Averaging Buoy System

The motion-averaging system discussed above averages displacements of numerous stationary points (16 in the proposed system). However, it would be desirable to further refine this idea so that fewer buoys are used. One possibility is to average the displacements of non-stationary points. A system in which the points being averaged move back and forth as waves passed by them could be highly advantageous. Specifically, these points should oscillate at the same frequency as the waves so they are always positioned on the peaks of the waves.

This apparently complex system can be developed at less than half the cost of the previously discussed motion-averaging system. The system relies on long buoys (fifteen to twenty feet long) lying horizontally on the water. The center of gravity of a buoy which is longer than the wavelength of a passing wave is not displaced as much as a small buoy (assuming wave crests to be perpendicular to the length of the buoy). This is because a buoy longer than one wavelength, but shorter than two wavelengths, touches the two highest points on the passing wave (approximately). Therefore, its center of gravity moves as approximately the average of the two highest points. Since the two highest points do not change vertically as much as two arbitrary points, this system is more efficient than using ordinary small buoys.

If wave crests were always perpendicular to the buoy's length, ten feet (the longest wavelength normally encountered in the Long Island Sound) would be sufficiently long. However, such is not the case, so initially a fifteen foot length will be employed. This gives approximately 40° of latitude with which to work. A wave incident on the buoy within 40° of the perpendicular on either side is sufficiently attenuated. Beyond 40° the buoy loses effectiveness until, at 90°, it is totally ineffective.

Three of these buoys are arranged in the equilateral triangle (Fig. 39). With a 60° angle between each buoy, no two will ever be ineffective at the same time. By connecting the raft to the centers of gravity of the three buoys, which are connected to the spacing bars, the raft should move only slightly. It should be noted that by having all three connection ropes running to a single point, that

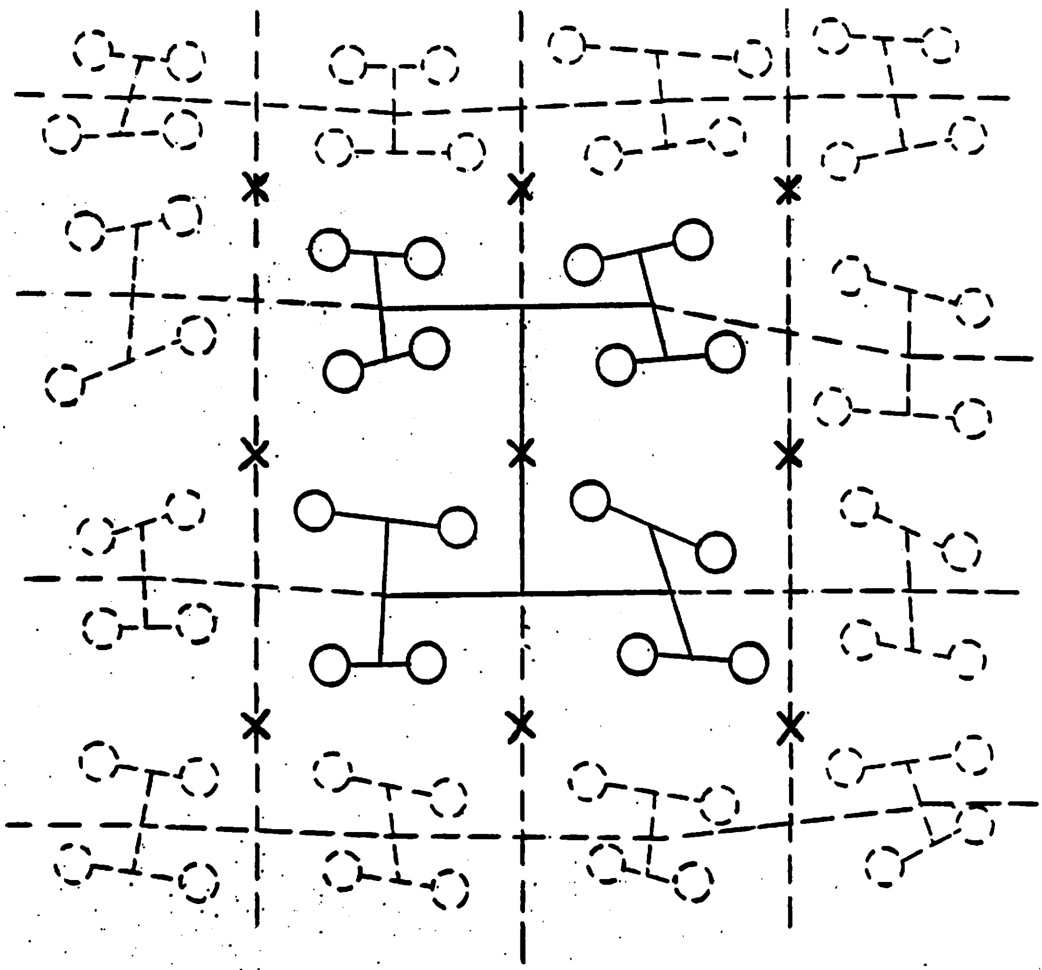

FIGURE 38 – PLAN – PROPOSED LAYOUT FOR LARGE MOTION-AVERAGING SYSTEM

SCALE: 1/8" = 1'-0"

NOTE:
(ADDITIONAL SPACING BARS HAVE BEEN OMITTED FOR CLARITY.)
16 BUOYS AND CONNECTORS IN THE CENTER (SOLID LINES) ARE NECESSARY TO HOLD ONE RAFT AT POSITION MARKED BY CENTER X. ADDITIONAL BUOYS AND CONNECTORS (DOTTED LINES) MAY BE ADDED FOR MORE RAFTS, HELD AT MARKED POSITIONS. AS MORE RAFTS ARE ADDED, THE SYSTEM BECOMES CHEAPER ON A PER-RAFT BASIS:

# RAFTS	# BUOYS REQ'D. PER RAFT
1	16
9	7.1
25	5.8

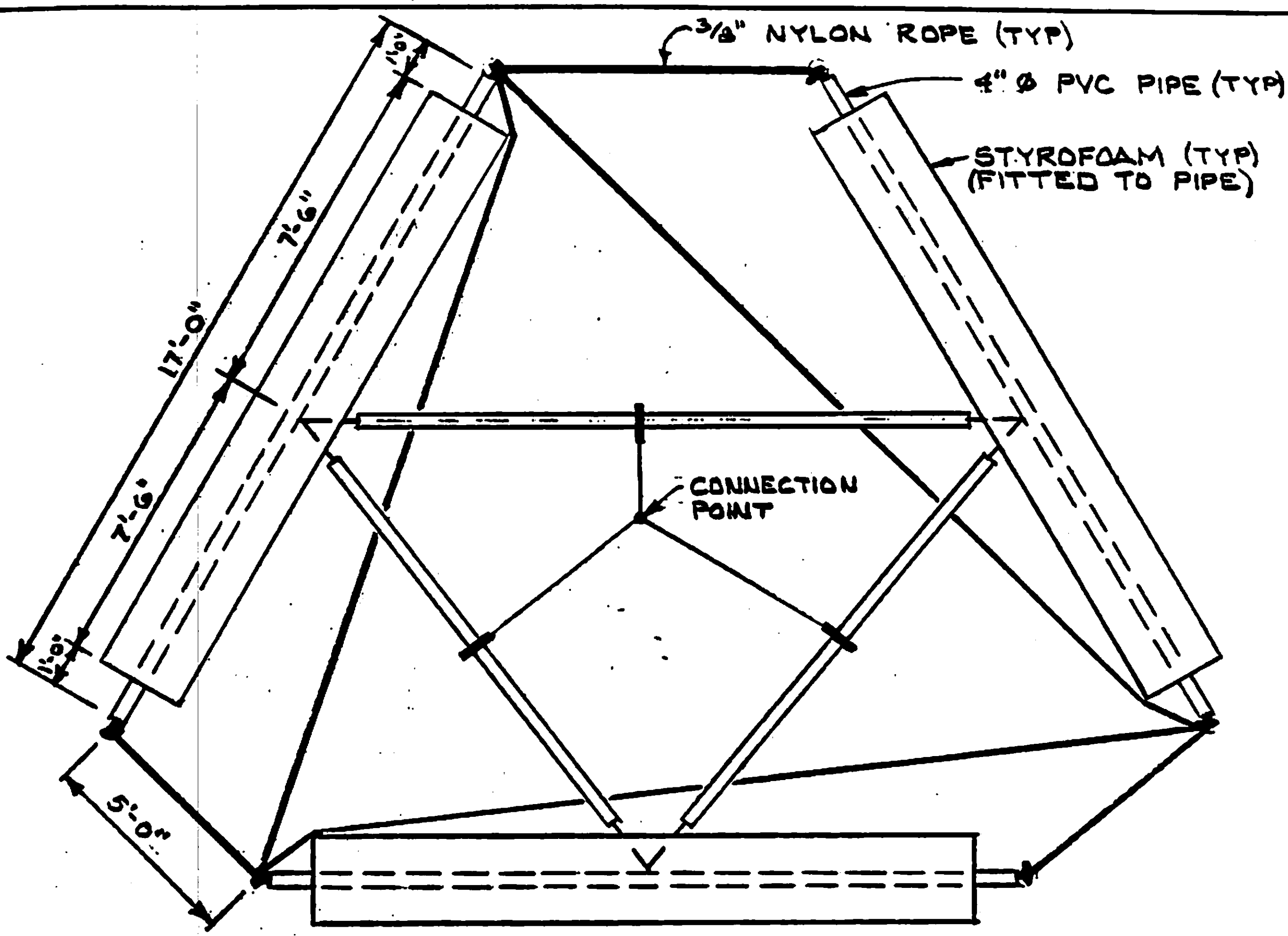

FIGURE 39 – PLAN – ELONGATED BUOY SYSTEM
SCALE: 1/4" = 1'-0"

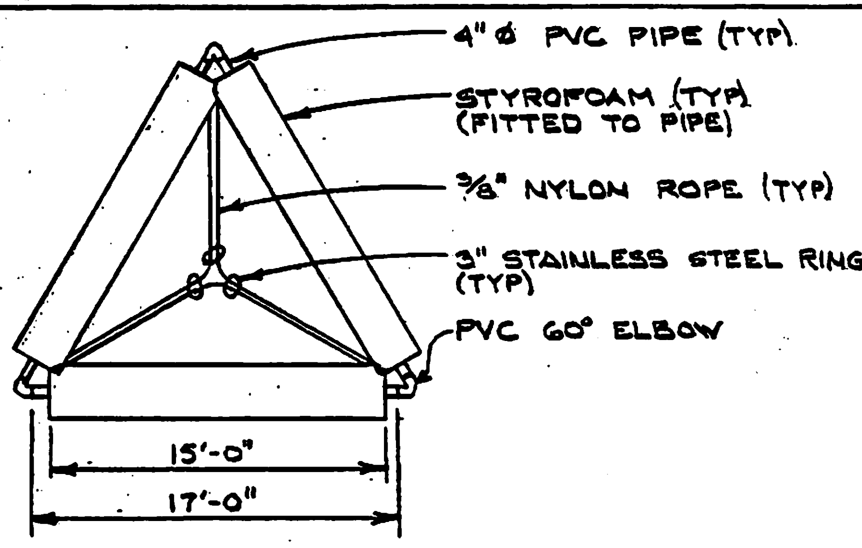

FIGURE 40 – PLAN – TRIANGULAR BUOY
SCALE: 1/8" = 1'-0"

point will move as the average of the <u>two highest</u> (tightest) ropes. This should further decrease raft motion.

The rope network and spacing bars shown on the drawing are necessary to maintain a constant angle and distance between buoys. A constant angle is necessary to assure that the buoys attenuate motions from waves of any direction. A constant distance between buoys is required to ensure that they move independently of each other, thus reducing the risk of two or more buoys oscillating together.

This network of ropes we refer to as a "tensegrity" system, after R. Buckminster Fuller, the designer of several tensegrity or tension-integrity structures. The ropes holding these buoys together operate on the same principle of maintaining rigidity by using tension as an opposing force to compression. The difference is that the buoy system is rigid in two dimensions, whereas Fuller's structures are rigid in three dimensions.

There are other ways of maintaining two-dimensional integrity in this buoy system; for instance, a network of spokes, coupled with an extra spacing bar between the ends of the three buoys, would also work. However, this may not be a practical concept.

Triangular Buoy: A variation on the elongated buoy system is to discard the independence of the motion of the three buoys, and simply connect them rigidly in a triangle (Fig. 40). The ropes and rings shown are intended to further reduce motion. (The raft is connected to all three of the rings.) Tests on a dry model have shown the rings to be very effective. However, an in-water model test is required to ascertain the validity of this concept.

7. Floating Tire Breakwaters Combined with Rafts

E. Cantwell

A floating tire breakwater (FTB) is a low cost, highly effective means of wave attenuation. It is constructed principally of scrap rubber tires using few tools and unskilled labor. The FTB has a high energy absorbing capacity. Well defined design criteria exist for several types of FTB (see references).

An FTB formed in a round or square configuration surrounds an area in which there is significant surface wave attenuation. Surface waves causing frequent and high-acceleration vertical movement of emplaced rafts have caused much of the plant damage seen during the open water research done in New York so far.

Much of the structure and the materials damage experienced with rafts in Long Island Sound has been caused by vandalism and/or carelessness on the part of the boating public. It is suggested that if seaweed farms were "enclosed" by an FTB a boat could come only to its edge, and it would become difficult for individuals to remove, or tie-off to buoys located within the breakwater.

FTB's might also be used as part of the floatation system for growth structures by attaching rafts positioned in the middle and the FTB moorings would anchor the whole system.

Design criteria have been evaluated for a linearly oriented FTB (as opposed to a square of round FTB) in what would be considered extreme conditions in the Long Island Sound. Further work must be done in order to adapt this to an FTB which totally encloses an area of water.

8. Mooring Systems

S. Birbiglia, R. Whitehead and R. Gukian

An adequate solution to the mooring question requires meeting many design criteria. Among those addressed here were:

1. Establishing a stationary mooring conforming to existing regulations.
2. Creating a design reducing shearing stresses on plants and growing surfaces by reduction of wave and current forces and especially violent movement.
3. Maintaining the growing surface at a constant depth (relative to sea surface), but with a capability of change in that depth. This requirement allows for change in height of water column resulting from tides or other factors.
4. Having accessibility by vessel.
5. Being durable, easily assembled, low in cost and maintenance.
6. Being capable of accommodating positively buoyant/rigid rafts, negatively buoyant/flexible rafts, or some other combination.

The design presented utilizes used tires, steel drums and conveyor-belt trimmings (4" width) - all industrial by-products. It may include a circular floating tire breakwater surrounding an independently supported raft to reduce vertical water movements.

The overall details of the mooring system are in Figs. 41 - 43, with details given in Figs. 44 - 48, and an extended system given in Fig. 49.

The mooring location is maintained by cement ballasting on the seabed, limiting drift by not more than a 10 foot radius. The growing surfaces and plants are shielded from large shearing stresses by:

1) Use of a suspension device located in the belt (either bungy or spring) for vertical cushioning (Figs. 42 - 45 and 48).

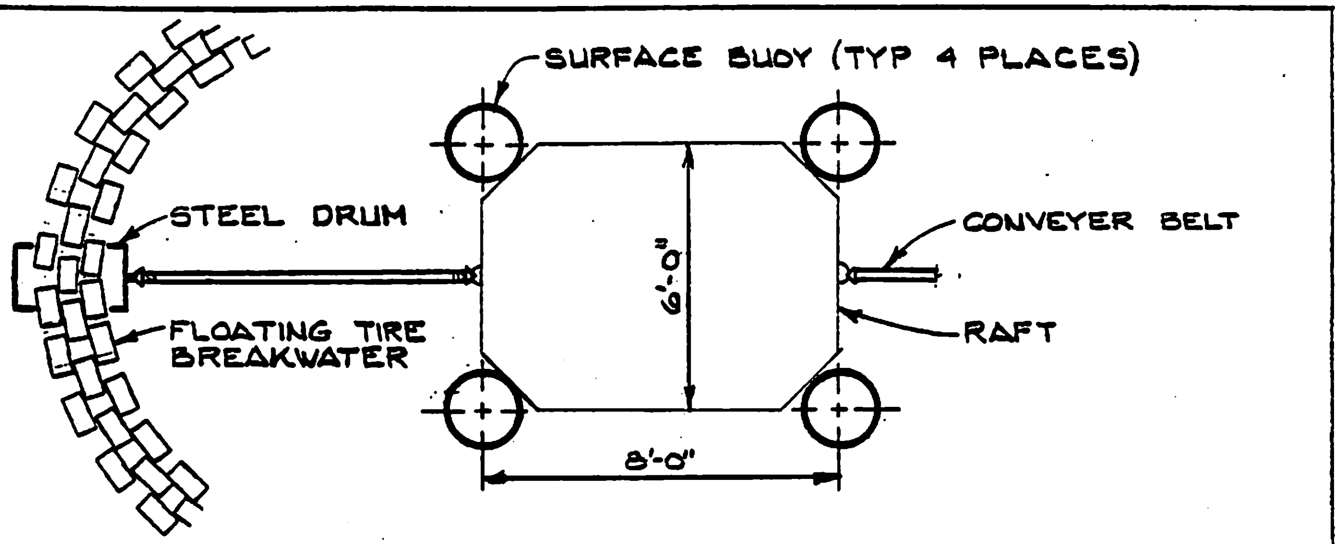

FIGURE 41 – PLAN – MOORING DESIGN
SCALE: 1/4" = 1'-0"

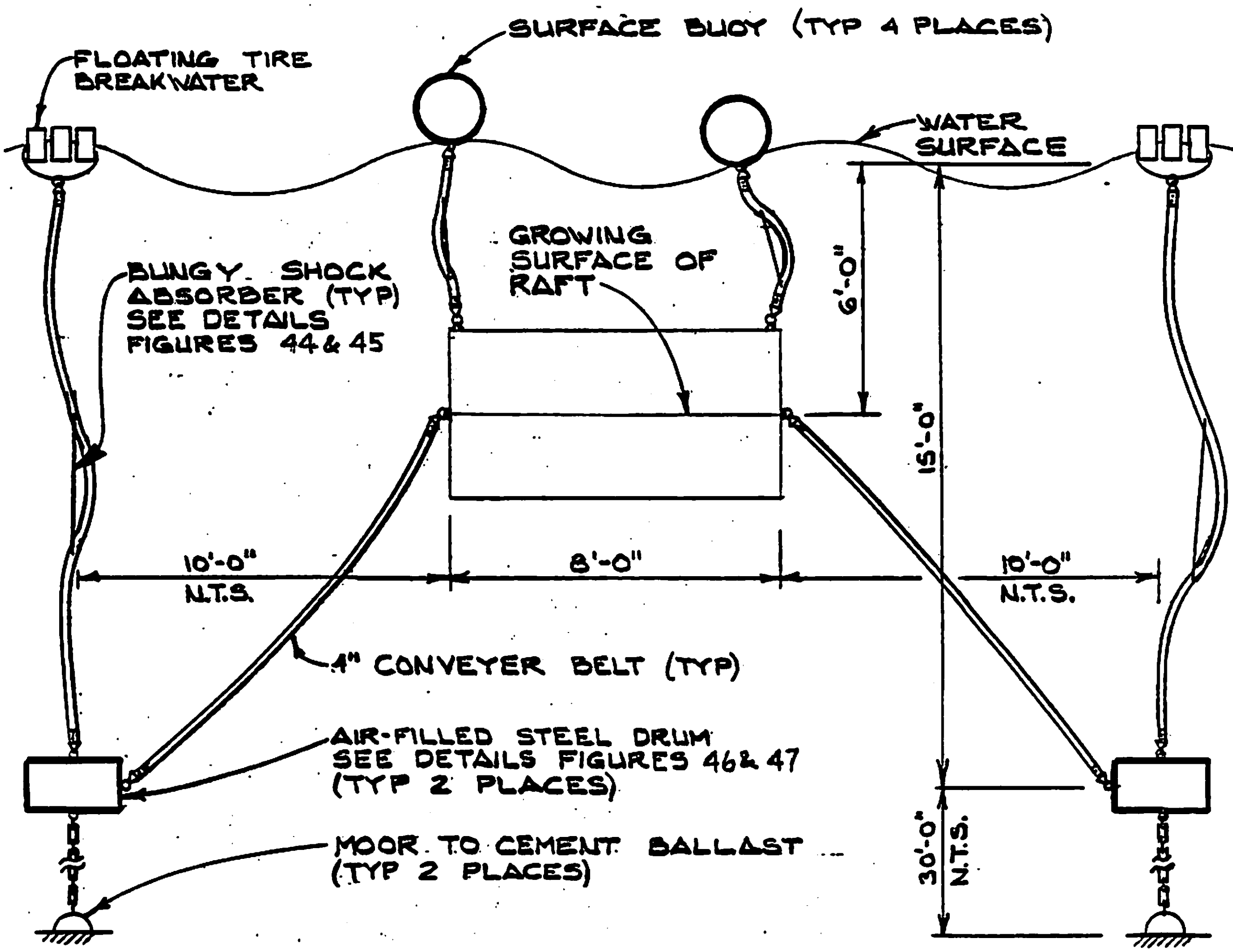

FIGURE 42 – ELEVATION – MOORING DESIGN @ HIGH TIDE
SCALE: 1/4" = 1'-0"

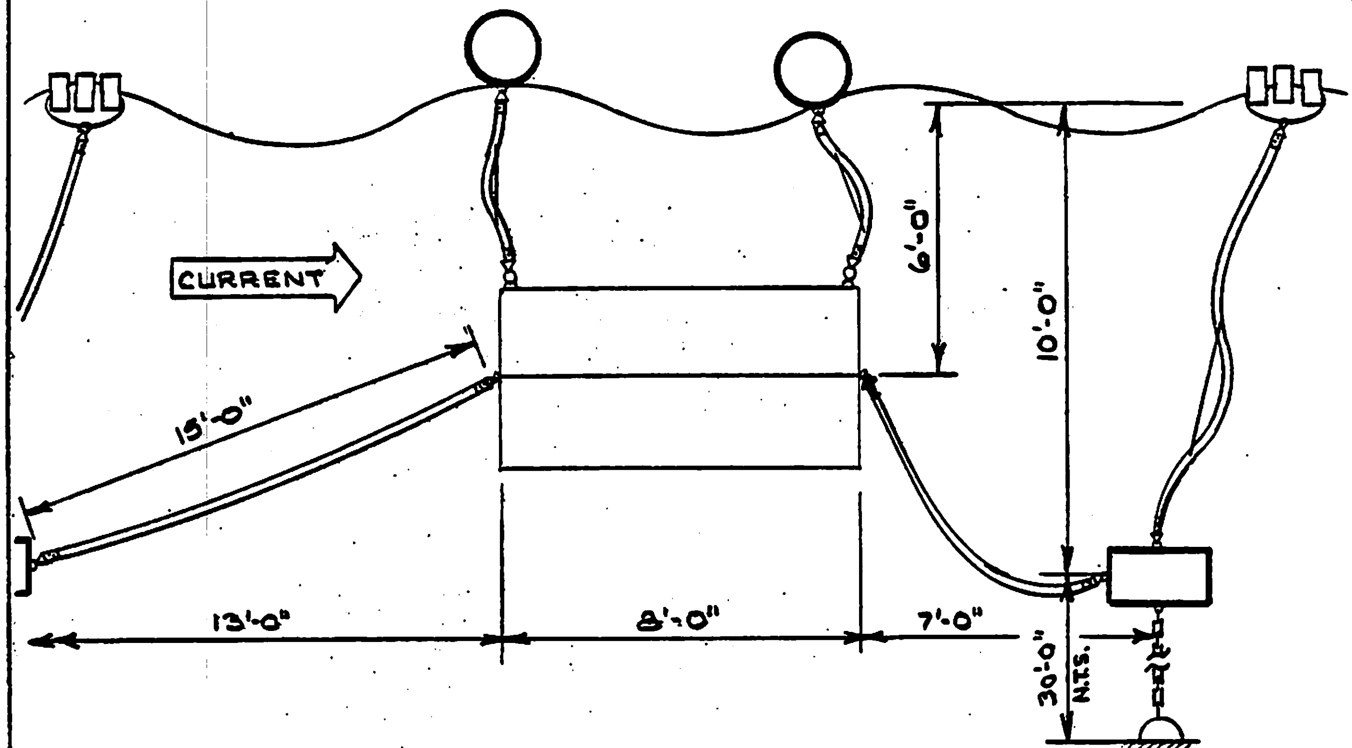

FIGURE 43 – ELEVATION – MOORING DESIGN @ LOW TIDE
SCALE: 1/4" = 1'-0"

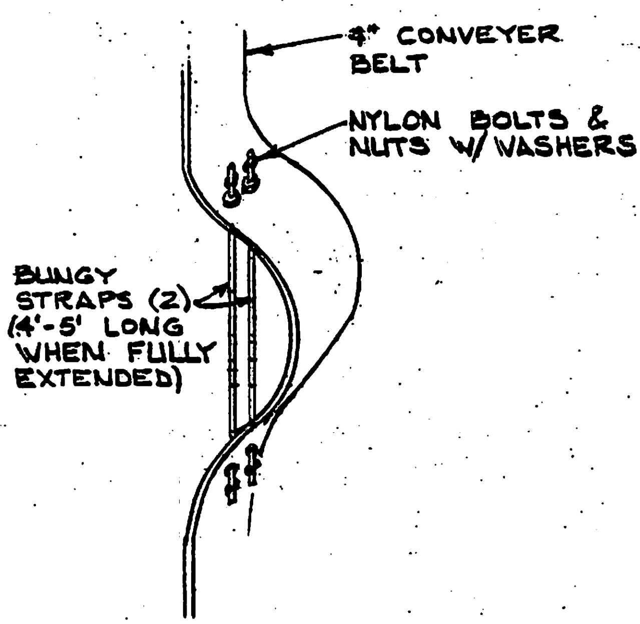

FIGURE 44 – DETAIL – BUNGY SHOCK ABSORBER
NO SCALE

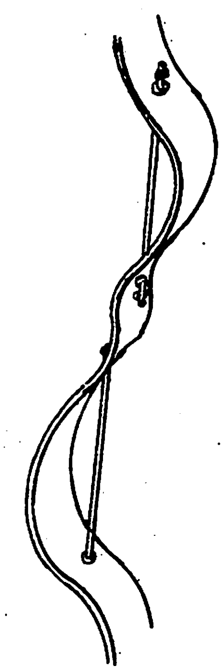

FIGURE 45 – DETAIL – ALTERNATE SHOCK ABSORBER
NO SCALE

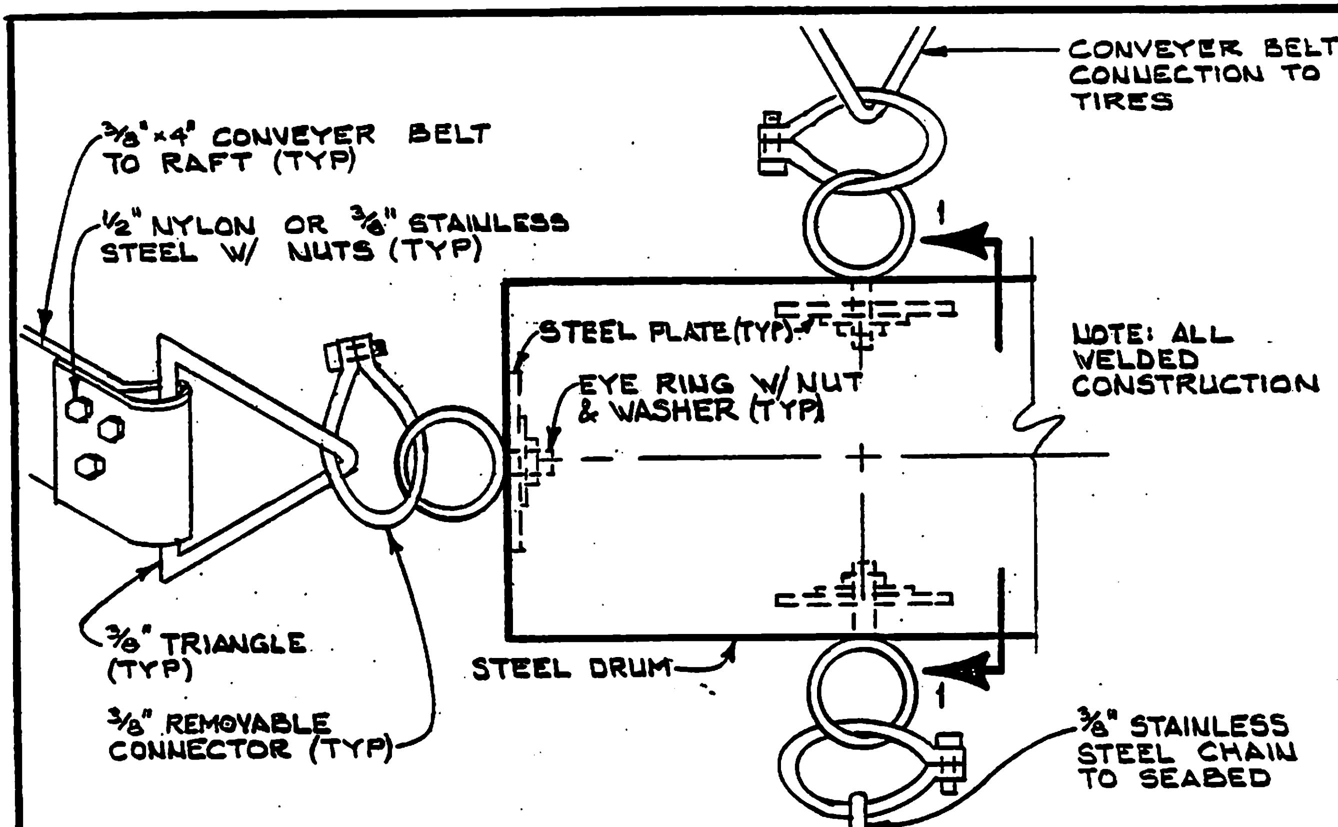

FIGURE 46 – DETAIL – DRUM CONNECTION
NO SCALE

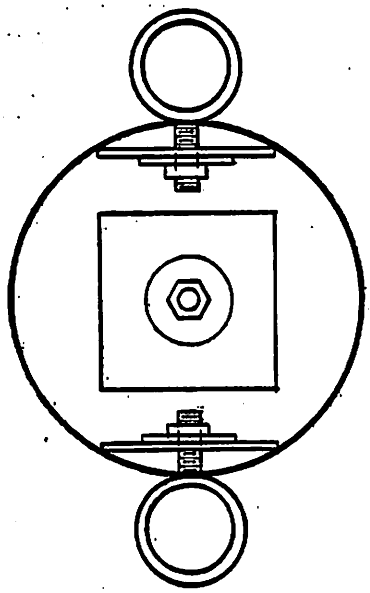

FIGURE 47 – SECTION 1-1. DRUM CONNECTION
NO SCALE

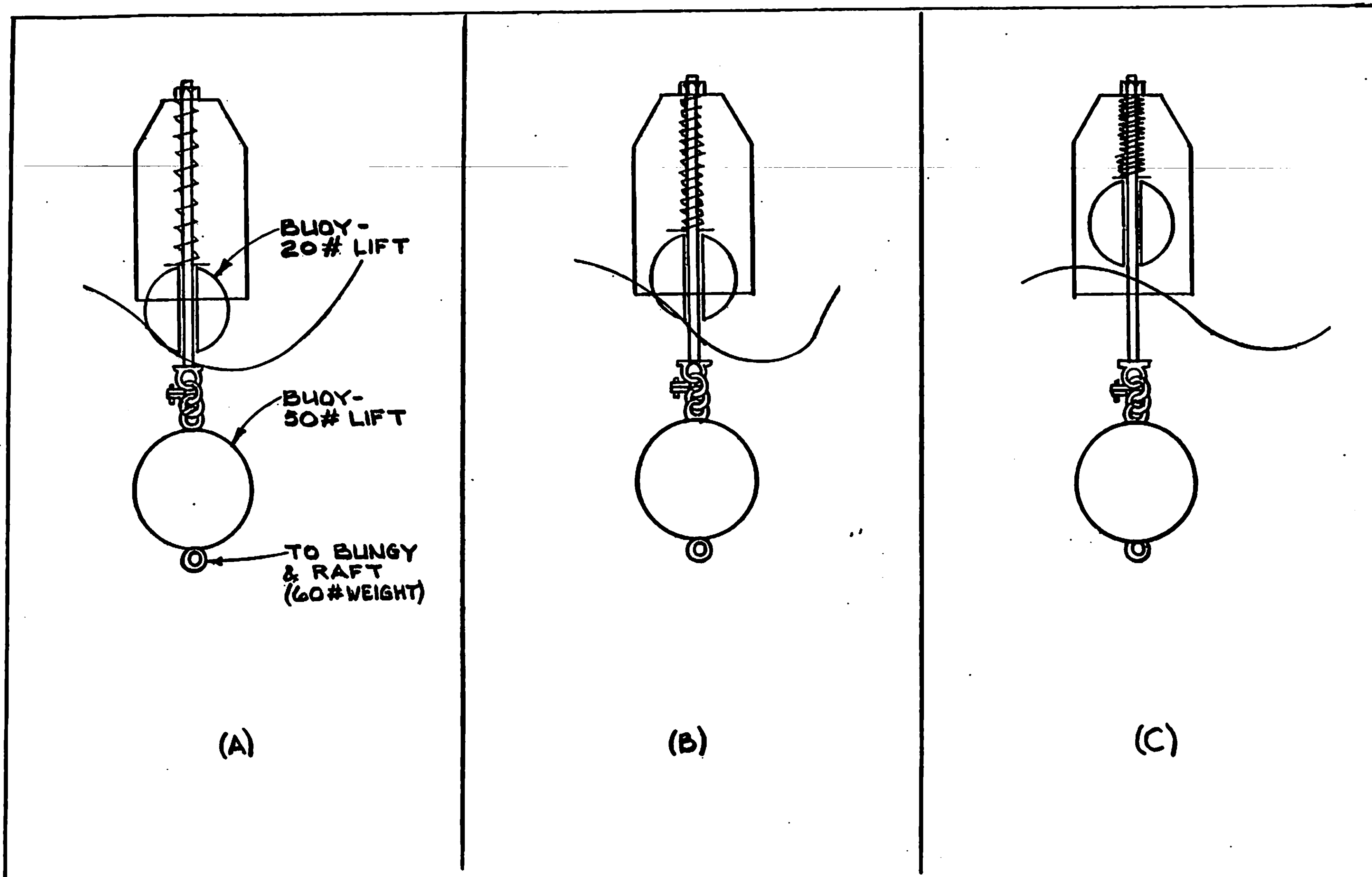

FIGURE 48 – SHOCK-ABSORBING SURFACE BUOY

NO SCALE

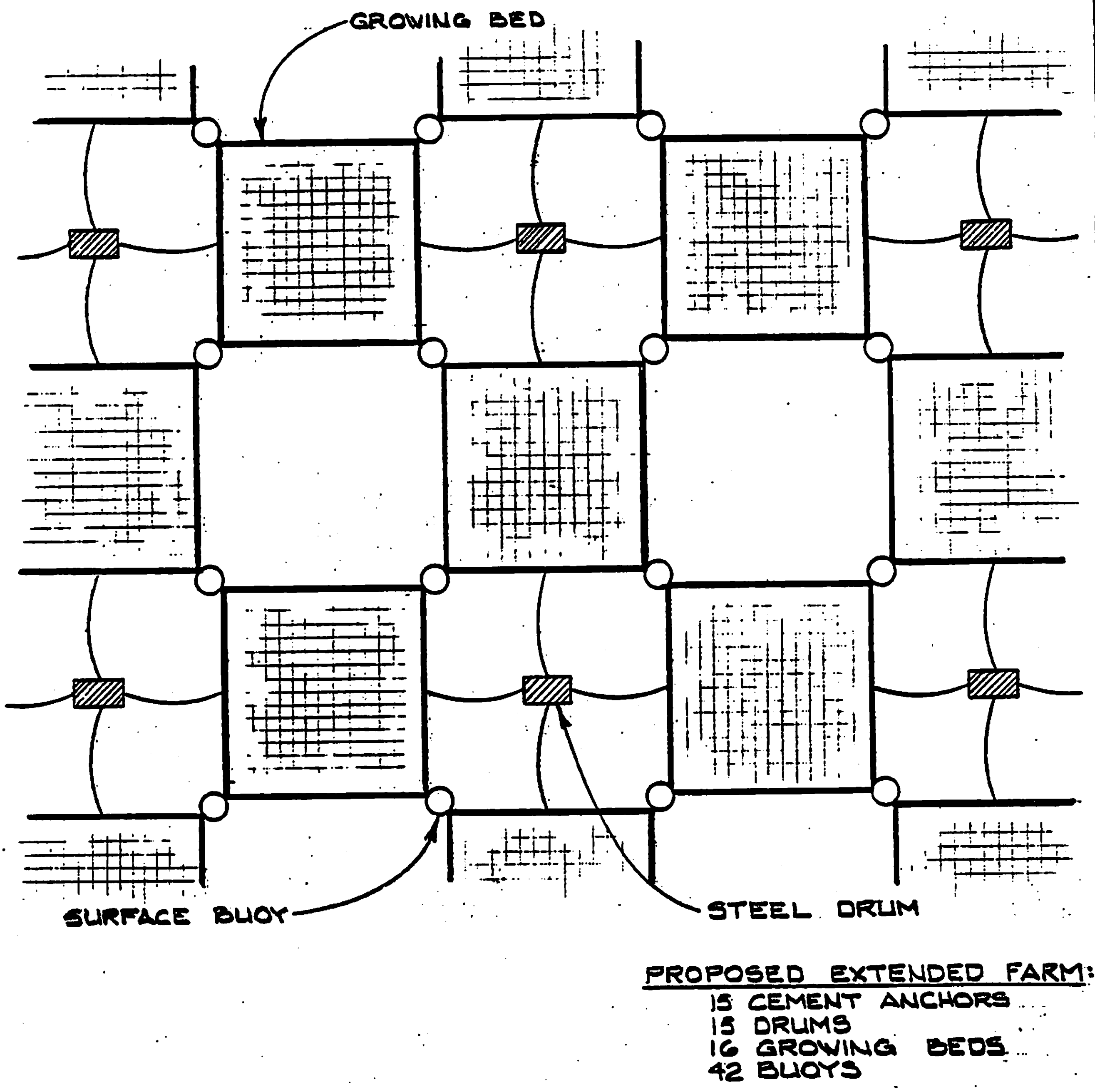

FIGURE 49 - PLAN - EXTENDED MOORING SYSTEM
NO SCALE

2) Use of slack in horizontal mounting of the raft between the drums allowing raft movement with the current.

An alternative surface buoy design may be used along with the suspension device to cushion vertical movement if the floating tire breakwater is not employed (Fig. 48).

Surface buoys damped for wave movement, but allowed to travel vertically with the tides enable the growing racks to be maintained at the optimum growth depth. The belt connecting mooring and raft will also permit changes in depth, depending on the type of seaweed by keeping the growing racks 5 - 10 feet below the surface at all times. Protection from surface craft and ice is provided. Durability and strength are achieved through use of conveyor belt, a proven underwater material with excellent corrosion resistance and strength (Figs. 44 -46); nylon or stainless steel bolts both having superior wearability in marine locations and good tolerance to large bending and shearing forces; thermal-sprayed metallized steel drums, another proven technique for marine applications for corrosion prevention purposes; and, stainless steel chain.

By using the taut line moored steel drums as the superstructure to which rafts are attached, all raft designs can be accommodated, including non-rigid types (Figs. 47 - 48). All fastenings and connections are accomplished through adjustable and non permanent techniques thereby aiding in ease of assembly, deployment and replacement. The design is theoretically expandable by increasing the numbers of drums and surface buoys. If controlled buoyancy rafts are used, one drum could be used for several rafts.

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MAJOR ACHIEVEMENTS/CONCLUSIONS

A full year of culture experience with the candidate species has provided data necessary for the reduction of the number of seaweeds to be considered. Of the nine species on the original list of candidates, four have been found to present significant problems in culture or with productivity and are being dropped from further experimentation. Three others are considered as having some potential if problems of reproduction, culture mode or chemicstry can be solved. These are being retained for further work because of their potential value and the need to retain some diversity in design requirements. Two species have been identifed as strong candidates. Because seasonality of growth is involved in marine biomass production in New York, it is desirable to have a two-crop system: the two species considered as strong candidates represent warm-water and cold-water high performance speciments. A summary of the characteristics of these species follows:

Laminaria saccharina: This is the only species found capable of significant growth during the winter months (November - June). General Electric's analyses indicate that this species is similar to Macrocystis pyrifera and is chemically desirable for biomass feedstock.
CONCLUSION: Laminaria is a strong candidate.

Gracilaria tikvahiae: Growth of this species is particularly good during summer months. It is capable of high productivity during the period May - October. General Electric has not yet analyzed samples of this species, but previous work in Florida indicates its composition is very suitable for gasification.
CONCLUSION: Gracilaria is a strong candidate.

Agardhiella tenera: The growth rate of this species is very similar to that of Gracilaria. A crop showing few signs of sexual reproduction is doing fine, in contrast to previous experience with reproducing strains. Only one sample of this species has been analyzed by General Electric, but it appears suitable from the chemical viewpoint. We recommend pursuing this species to obtain more critical data on life cycles. Although it is very similar to Gracilaria, its sexual reproduction may be used as a strategy of stocking farms, whereas the Gracilaria strain is strictly vegetative, requiring a completely different stocking/harvesting strategy.

CONCLUSION: Agardhiella is a possible candidate.

Codium fragile: The growth of this species is particularly good during April - October. It sexually reproduces in October - November, releasing swarmers that settle onto hard substrates and grow out the following spring. The analysis by General Electric indicates that the species is about 93% water, and that percent volatile solids per bulk weight is very low. At first, it might appear that this is a significant drawback. However, it is not known if this large water quantity is really a problem since digestor size may be increased, etc. Further, in terms of dry weight, percent volatile solids is comparable to other species. Productivity in terms of dry weight is similar to that of some of the species (e.g., Fucus, Laminaria). A topic worth pursuing might be an examination of dewatering methods and their effect on percent volatile solids.

CONCLUSION: Codium is a possible candidate.

Fucus vesiculosus: Growth of this species has been good in the spring and fall months. Although not one of our better candidates under greenhouse conditions, it seems to do particulary well on rafts. We have had some problems with grazing of this seaweed in our tanks, particularly in the summer. General Electric's analyses indicate that the seaweed is favorable for digesion. Continuation of studies to resolve some of the growth difficulties is warranted.

CONCLUSION: Fucus is a possible candidate.

Ascophyllum nodosum: This species performs poorly. Both the rocky intertidal and salt marsh varieties showed a growth spurt in March - April, but did poorly thereafter. Chemical composition is very similar to that of Fucus.

CONCLUSION: Ascophyllum is a poor candidate and should be dropped.

Palmaria palmata: Variable results in growth of this species in the late winter, early spring months have been obtained. It appears to have a very short growing season. It usually coexists with Laminaria. Chemically, it was rated as intermediate in value.

CONCLUSION: Palmaria is a poor candidate and should be dropped.

Chondrus crispus: Growth of this species in culture is poor. Warm temperatures appear to be a major requirement. The species is of intermediate value from a chemcial viewpoint.

CONCLUSION: Chondrus is a poor candidate and should be dropped.

Ulva lactuca: This species shows a bimodal growth peak, with best growth in late spring and late summer. During the summer, it goes reproductive, developing large holes in the thallus. Its highest growth rates are intermediate in comparison to other species. We have difficulty envisioning an open-water culture of this seaweed because of its bimodality. Chemically, it is a desirable species.

CONCLUSION: Ulva is a difficult species to grow consistently and should be dropped.

Experimental design for the work undertaken in the past year included determining nutrient requirements of the candidate species. This research was of high priority because of the importance of determining the need for fertilization of a farm in biological, engineering and economic decisions. Although full data sets have not yet been completed, there is sufficient evidence to suggest that nitrogen, the usual limiting nutrient, will not be a major problem, at least in nearshore waters. Druing the summer very high levels of nitrogen are found in nearshore waters and even offshore waters, in part of a consequence of cultural eutrophication. Pigmentation levels of seaweeds are usually indicative of the nutrient supply available to the plants, with loss of color indicating nutrient deficiency. Culture experiments have shown that all species retained high levels of pigmentation throughout the year suggesting that nitrogen limitation has not occurred.

Continued experimental work will confirm this observation as well as indicate what potential gains could be achieved in yield through fertilization of the farm. These data will permit economic analysis of the desirability of factoring fertilization into the system of biomass production.

Considerable progress was made in learning how to treat plants in field culture. Among the raft culture experiments, the most significant results were achieved in the attached species. Here, the finding that a relatively loose and flexible attachment has the least impact on the mature plant has proven highly significant. Engineering design concepts reflect this finding. Perhaps the most fortuitous finding, although as yet subjective in content, is that several of the species perform better in the field than in greenhouse culture.

The current year has seen the development of a data base which allows many of these fundamental questions on the feasibility of marine biomass production on the east coast to be answered. These findings are fundamental to the development of the future of the program and to assessment of the marine biomass potential by interested parties. Data contained in this report suggest that:

1. Seaweeds native to New York waters and found elsewhere in the northeastern United States can be utilized for the production of marine biomass.
2. The concept of two-species culture, necessary for east coast productivity, has been shown to be feasible as a means of obtaining high yields throughout the year.
3. It is legally possible to farm marine biomass in the nearshore water of New York.
4. Marine biomass farming on a large scale (over 100 square miles in extent) is possible in the New York Bight (the Atlantic Ocean off Long Island) in appropriate environments and without use conflicts.

MAJOR TECHNICAL ISSUES

Field culture experiments yielded more technical problems that greenhouse culture -- a factor of the greater experience with the latter. It is clear from raft culture experience that fouling will be a major problem as biomass production is increased in scale. Fouling effects the farm structure, plant performance, and potentially gas yield through the accumulation of undesired organisms on the structure, around or on plants, and as epiphytes which cannot be separated from the biomass materials. Fouling will receive important attention in future work.

Experience with cage culture rafts clearly indicates that mesh will be a material of less value than anticipated in any structure. Meshes are quickly fouled to the point of light and/or current exclusion. This will be a serious design constraint for the handling of floating species, for as mesh size is increased to reduce the fouling effects, plants are more frequently caught and damaged by wave action.

Minor problems in the scheduling of analytical work have resulted in delays in acquisition of data. Analyses of ^{14}C have been delayed until an available tissue oxidizer was located on the SUNY at Stony Brook campus. It is now anticipated that the backlog of analyses can be quickly reduced. The laboratory by which ^{15}N experimental materials were to be analyzed would not accept additional work. Consequently, an alternative experimental design was adopted.

Also, the continuing problem with water supply in the greenhouse which has been an annoyance in limiting the number and size of experimental cultures maintained is to be alleviated. The State University of New York has let a contract for a new water supply. This work should be completed by the time of increased spring culture work.

The most difficult issues encountered during the program has been that of vandalism and interference with raft cultures by sportfishermen and boaters. While a variety of technical solutions may be sought, most are expensive. The engineering design and biological teams view the solutions to this problem differently. The biological team tends to seek structural solutions to vandalism by incorporating structural protective elements into raft design; the engineering team, conversely, resists designing for purposes of protection because of the increased complexity and costs this incurs.

It is clear that solutions to interference with raft and farm structures must be sought before larger structures are deployed. Initially, we will seek to reduce vandalism by simply moving the site of raft deployment from a known (and productive) artificial fishing reef to some other site. This may lessen the interference from fishermen. Also to be detemined is the degree to which the farm structure acts as a fish "concentrating" device and, therefore, atracts fishermen. Educational programs through the newspapers, radio and television, as well as through boating organizations and sportsment clubs, will be attempted.

SPECIFIC OBJECTIVES AND WORK PLANNED FOR

DECEMBER 1, 1981 to NOVEMBER 30, 1982

Objective 1.

Design a biological test farm for marine biomass which is of sufficient size to permit experimental research on a two-crop system.

Task 1 - Engineering of a Biological Test Farm

Subtask 1a - Development of Design Options

A series of optional designs will be considered in this period. One such option will be the commercially available rope culture farm manufactured in Japan. Each option will be evaluated not only for engineering criteria such as materials, structural design, suitability for the region, etc., but also for its biological utility.

Shortly after the workshop on raft and farm structures (Subtask 1b), a team will be assembled to evaluate the design options which have been identified in this task and which emerge from the workshop. Membership of that team will be determined in concert with ERDA, GRI and NYGAS. The merits of the various options will be considered from the biological and engineering viewpoints. It is anticipated that one, or several, may be selected for further consideration.

Subtask 1b - A National Workshop on Raft and Farm Design

There are currently several macroalgal cultivation projects in the United States and neighboring countries. While not all of these have the production of biomass as an objective, they all have in common the growth of macroalgae under artificial conditions. The purpose of this workshop would be to explore what is being done and the ways in which plant/substrate/support design requirements are being met. It would be proposed to have both biologists and engineers as participants in order that maximum interchange between the biological and engineering requirements of a farm structure might be developed.

A proceeding resulting from the workshop might be published.

Subtask 1c - Design Phase

Development of a detailed design will emerge from a selection of an option(s) based upon the previous tasks. Included in this task is the determination of materials and structural components, of mooring and anchoring systems and incorporating these decisions into the computer simulation studies. The design phase is seen as an iterative series of developments incorporating biological requirements, simulation of environments and engineering criteria.

Subtask 1d - Estimate Cost of Materials, Construction and Deployment of the Farm

Materials to be used in construction will be specified and costed. Procedures and requirements for construction and deployment will be sorked out and labor costs estimated.

Subtask 1e - Identify and Initiate all Procedures to Obtain Required Permits, Licenses and Permissions

Sites in Smithtown Bay, Long Island Sound, and in Peconic Bays have been studied in the past year to determine the oceanographic and biological characteristics of the waters. A selection criteria list drawn up in the last year provides a framework within which site selection can be made. In addition to the physical, chemical and biological characteristics, there are social, political and legal aspects to be considered. Further, logistics of access and ability to service a structure are inherent in making a site decision.

Objective 2.

Provide the necessary biological data to support the design phase.

Task 2 - Field Biological Studies and Experiments

Subtask 2a. Raft culture studies - plant structure interactions and determination of growth rates.

Rafts or other structures developed as concepts for a farm design by the engineering team or developed by the biological team for special purpose studies will be deployed for small-scale culturing of appropriate species. As these structures are placed in the water, a schedule of dives to permit observation of seaweed/structure interactions will be arranged. These activities will be utilized in the determination of plant needs: For example, suitability of materials for seaweed recruitment and fouling susceptibility. Weekly meetings with the design team will be held to evaluate progress in designs and how a particular design will affect seaweed growth potential.

Raft culture of primary species, initiated in 1981, will be continued to obtain a full set of growth data for all seasons. Laminaria, Fucus, and Codium will be grown on rafts designed and built for this purpose. The numbers of plants being grown on rafts designed and built for this purpose. The numbers of plants being grown will be increased to improve the statistical validity of the data of field growth. Existing and new rafts will be stocked and performance of the seaweeds observed during weekly or biweekly dives. Rafts will be situated at several depths to provide data on yields at both surface and submerged situations. Wet weight increases and such phenomena as plant fragmentation, onset of reproduction, etc., will be recorded. Fouling and grazing problems will be monitored during weekly and biweekly dives at the raft sites and these data utilized in fouling grazing studies. Colonization of artificial substrates attached to the rafts and of the rafts themselves will be monitored, particularly during the reproductive phases of the seaweeds. This will provide needed information on self-seeding potentials of those species.

In situ growth rates of Laminaria saccharina will be determined by tagging and making plants in large stands of this species near Eatons Neck and perhaps Shelter Island. This will permit determination of natural losses and of growth rates. It will not be possible to conduct in situ studies of the growth of the other primary seaweeds because they occur as isolated specimens rather than in concentrations. Growth rates of the marked tagged Laminaria will be monitored frequently and some apparently fast growing plants will be removed from the field for culture in the strain selection screening.

Subtask 2b. Collections of specimens from the field for analysis

Collections of samples taken under appropriate conditions and situations will be made from both wild specimens and from cultures. The objective of this task is to increase the data base of biological and chemical knowledge pertaining to the selected seaweeds.

Subtask 2c. Fouling and grazing studies

Algal and other fouling organisms compete with seaweeds for attachment sites on substrates. Their presence may also degrade the biomass of its potential for gasification. Grazing organisms reduce the amount of biomass being effectively produced or may weaken plant structure through grazing. Because of the persistence of fouling problems in the marine environment, there has been an extensive literature developed. Much field data has been collected in the Long Island region, particularly by the U.S. Navy, but his data has not been synthesized. It is anticipated that this survey will yield information of considerable assistance in learning how to cope with fouling. Reproducing the field studies would be prohibitively costly and time-consuming.

From the literature and from observations made by the diving teams which visit the rafts at least once per week, a phenology of fouling organisms will be developed. The timing of onset of reproduction of various organisms having pelagic larvae is variable. By knowing that relationship and perhaps scheduling farm activities with that schedule in mind, some fouling problems may be minimized. Amphipods and isopods have been identified as the major grazers of seaweeds in the laboratory. The extent to which fish will act as herbivores on the seaweeds is not yet known. Field observations by divers may be of assistance in determining this. The extent to which grazing will result in loss of biomass is not known.

Task 3 - Laboratory (Greenhouse) experiments

Subtask 3a. Determine yields of species to be cultivated and their isolated strains.

In order to obtain maximum yields of each of the primary species, at different times of the year, it is necessary to determine the relative optimum density of each. This information can most easily be determined in laboratory experiments. For example, as the path of the sun across the sky becomes lower in winter, the spacing for plants must be greater to provide each with the necessary levels of energy for photosynthesis. The best spacing of plants is not only a factor in biomass productivity, but is also an element of farm design.

Codium, Gracilaria, Agardhiella and Fucus will be grown at three different culture densities, as determined by wet weight of the seaweeds in a standard culture tank. The harvest period will be determined by a reduction in rate of biomass (wet weight) production as the species reaches maximum density in the tank. A fourth culture of the species will be started at different times of the year and allowed to grow to maximum density without harvesting.

By comparing the results of these experiments, the optimum density for maximum growth of the species will be determined and, the strategy for harvesting developed.

Individual plants of Laminaria will be grown in large culture tanks and will be subject to different harvesting frequencies and methods. Specimens of Laminaria will be cut back to a point just above the meristematic region on schedules of 4, 6, and 8 weeks. It is not known to what extent older blade portions contribute to the nutrition of the entire plant, and therefore, to maximum growth. Sampled tissues will be analyzed for CHN and mannitol/laminarin reserves and related to nitrogen exposure history to ascertain the nutritional status of the whole plant by each harvest cycle. The data derived from this experiment should allow determination of the optimum frequency of harvest, and thus, yield.

Subtask 3b. Determination of light, nutrient and temperature requirements of the target species.

Studies of the effects of nitrogen enrichment on the primary species will be continued to provide a full year's data. Because of seasonal changes in the environment, particularly in available nutrients, full seasonal data are required. Understanding how seaweed growth is affected by nutrient concentrations, light intensity, and temperature will be a major factor contributing to the success of large scale cultivation. Unfortunately, there are few known quantitative effects of each of these parameters for the species under consideration. The largest deficiency is how seaweeds are affected by these parameters at various times of the year. ^{14}C photosynthesis studies will be continued to obtain a year-long record of the response of seaweeds grown at three nitrogen loads and light intensities.

Objective 3.

Complete the necessary work to seed, maintain and harvest the crop on the biological test farm.

Task 4.- Operate the biological test farm

Subtask 4a. Seeding of the farm

Selection of those strains of the target species which display optimum characteristics for farming will be preparatory focus for this task. Wide variation in growth behavior and in chemical composition has been noted in culture work. Now a concerted effort will be made to propagate those strains.

Seasonal collections will be made of material from field sites that have been found to have areas of large concentrations of the primary species. Laminaria and Codium collected in this fashion will be grown attached to PVC rods in large culture tanks so that each specimen can be monitored for growth in length and in mass. It is not possible to conduct studies on individual plants of Gracilaria because the material grows in entangled masses. Since each of these species grows optimally in different seasons, the culture of the two species may be staggered. Individual specimens which are most rapidly growing will be segregated and placed in smaller tanks to maintain rapid-growth stocks. These plants will be monitored for the onset of sexual reproduction and every attempt will be made to capture seed from reproduction by providing suitable surfaces (shell, rope, net, and PVC surfaces) for the spores. Germlings will be maintained and their growth and behavior monitored.

Seaweeds which reproduce vegetatively will be monitored for rapidly growing specimens. Those will be segregated and maintained in small tanks until the next optimal season when they will be used as seedlings for new cultures.

Reproductive behavior in these cultures will be compared to that in culture tanks and in the field. We will also use the environmental chamber cultures to determine nutritional requirements of seedlings on different substrates. Some of the material generated in this fashion will be out-planted to the field rafts at different times of year to determine survival capabilities.

This research will emphasize methods to reduce the period of time required for natural reproductive cycles of Laminaria and Codium (Gracilaria is vegetative). The experience and knowledge gained will be necessary for the production of seed to augment stock of large-scale farms. Among the factors known to affect reproduction are light intensity and quality, temperature, and nitrogen.