A Comparison of Two Rearing Sites of the Giant Kelp *Macrocystis integrifolia* in Sitka Sound, Alaska

Samuel H. Rabung

Alaska Sea Grant College Program
Report 90-02
1990

Alaska Sea Grant College Program
138 Irving II
University of Alaska Fairbanks
Fairbanks, Alaska 99775-5040
(907) 474-7086

A Comparison of Two Rearing Sites of the Giant Kelp *Macrocystis integrifolia* in Sitka Sound, Alaska

Samuel H. Rabung
Alaska Aquaculture Incorporated
P.O. Box 1288
Wrangell, Alaska 99929

AK-SG-90-02
1990

Price: $3.50

Elmer E. Rasmuson Library Cataloging-in-Publication Data

Rabung, Samuel H.
A comparison of two rearing sites of the giant kelp Macrocystis integrifolia in Sitka Sound, Alaska.

(AK-SG-90-02)

1. Macrocystis integrifolia. 2. Kelps. 3. Marine algae--Alaska--Sitka Sound. I. Alaska Sea Grant College Program. II. Title. III. Series: Alaska sea grant report ; 90-02.

QK569.L53R33 1990
doi:10.4027/ctrsgkmisa.1990

ACKNOWLEDGMENTS

This publication was produced by the Alaska Sea Grant College Program. Cover design and artwork is by Karen Lundquist, text formatting is by Ruth Olson, and editing is by Sue Keller. Alaska Sea Grant is cooperatively supported by the U.S. Department of Commerce, NOAA Office of Sea Grant and Extramural Programs, under grant number NA86AA-D-SG041, project number A/75-01; and by the University of Alaska with funds appropriated by the state.

Samuel Rabung submitted this paper to the Aquatic Resources Department, Sheldon Jackson College, Sitka, Alaska, as a senior thesis in December 1987.

TABLE OF CONTENTS

ABSTRACT

In order to test the suitability of a site for the rearing of *Macrocystis integrifolia,* ten sporophytes were transplanted from a wild patch at Whiting Harbor, Sitka, Alaska, to a site located behind the Sheldon Jackson College salmon hatchery in Sitka. Growth and survival were compared at the locations from April 4 to May 28, 1987. Growth at Whiting Harbor was significantly greater than growth at Sheldon Jackson College (SJC). A freshwater lens at the SJC site is thought to have impaired growth of the upper blades on the plants. For this reason the SJC site is not suitable for *M. integrifolia.*

Attempts were made to artificially culture *M. integrifolia* at the SJC facility. Culturing from spore release through gametophyte stages to maturation and zygote fertilization was successful. However, culturing of the new sporophytes was not successful.

INTRODUCTION

Background Information

The giant kelp, *Macrocystis integrifolia* Bory, has the potential to become a major contributor to future renewable energy resources as well as to food production for the increasing world population. Experimental sea farms for producing food and energy have been designed and some testing has been undertaken to develop the needed technology for utilizing *Macrocystis* in this manner (Harger and Neushul 1983, Chapman and Chapman 1980, Wise and Sylvestri 1976).

The principal industrial use of *Macrocystis* at present is the production of algins and alginates for use in various industries such as textiles, paper and cardboard, paint, pharmaceuticals, plastics, and especially the food industry in America. Historical records show that the use of seaweeds in agriculture is a very old and widespread practice wherever there are rich supplies. This involves their use not only as food for animals, but also as fertilizer for the soil (Chapman and Chapman 1980, Sleeper 1980, North 1976, 1971). The principal components of the edible algae are carbohydrates, small quantities of protein and fat, ash, and water (80-90 percent), as well as many essential trace elements (Rosell and Srivastava 1985, Chapman and Chapman 1980, North 1971).

Macrocystis has been used traditionally as a food source by the Native peoples along both coasts of the Pacific, especially when coated by herring spawn (Shields et al. 1985). At present, herring roe-on-kelp is a multimillion dollar industry with the majority being consumed in Japan (Whyte 1979).

Macrocystis has traditionally been harvested from wild stocks; only recently have attempts been made at culturing the plant. Harvest strategies have been developed for some wild stocks (Coon 1982), and restoration of wild stocks and habitat improvement programs have been initiated to increase abundance in some areas. Restoration and habitat improvement include removing sea urchins and other predators, removing competitor plants, transplanting, creating artificial substrate, and culturing and seeding techniques (Foster and Schiel 1985, Druehl 1979, Wilson et al. 1979, North 1976).

There recently has been increased interest in re-opening a herring roe-on-kelp fishery in southeast Alaska. It is generally assumed that such a fishery would rely on the mariculture of kelp because of the damage done to wild stocks during the last roe-on-kelp fishery in the Sitka area in the 1960s (Stekoll 1987). The roe-on-kelp market in Japan pays the highest price, up to $14 a pound, for roe-on-*Macrocystis*; therefore the culture of *Macrocystis* will be the main component of the new fishery (Stekoll 1987). This new fishery, however, is dependent on locating an adequate herring roe resource that has not yet been allocated to a fishery (Pierce 1987). There is currently a herring roe-on-kelp fishery in Prince William Sound which relies on wild *M. integrifolia* harvested in the Sitka area. These fishermen have expressed great interest in the possibility of buying cultured *Macrocystis*.

Scope of the Study

Sheldon Jackson College in Sitka is developing a mariculture program which includes the culture of kelps. The SJC kelp culture program includes developing a mariculture laboratory facility but needs an ocean rearing area to complete the rearing cycle of *M. integrifolia*. An area as close to the laboratory as possible would be convenient, and easy to supervise. The area immediately in front of the SJC hatchery appeared to meet these needs. Since *M. integrifolia* was not found there, this study was conducted to determine the suitability of the site for culturing this plant. For this study I tested the SJC site by (1) transplanting whole sporophytes to the SJC site and comparing growth and survival and environmental conditions with a control site, and (2) culturing *M. integrifolia* in the laboratory. I did not, however, outplant young sporophytes at the SJC site and at the control site for comparing growth and survival.

Biology of Giant Kelp

Macrocystis integrifolia ranges from Monterey, California, to Sitka, Alaska. The plants grow on rocks in the lower-most intertidal and upper subtidal zones to a depth of about 8 meters, in areas close to the open ocean but not exposed directly to heavy surf (Scagel 1963, 1967).

The description varies with latitude and locale, but generally *M. integrifolia* is one of the largest brown algae in the sporophyte phase (Figure 1), and is deep brown to yellow in

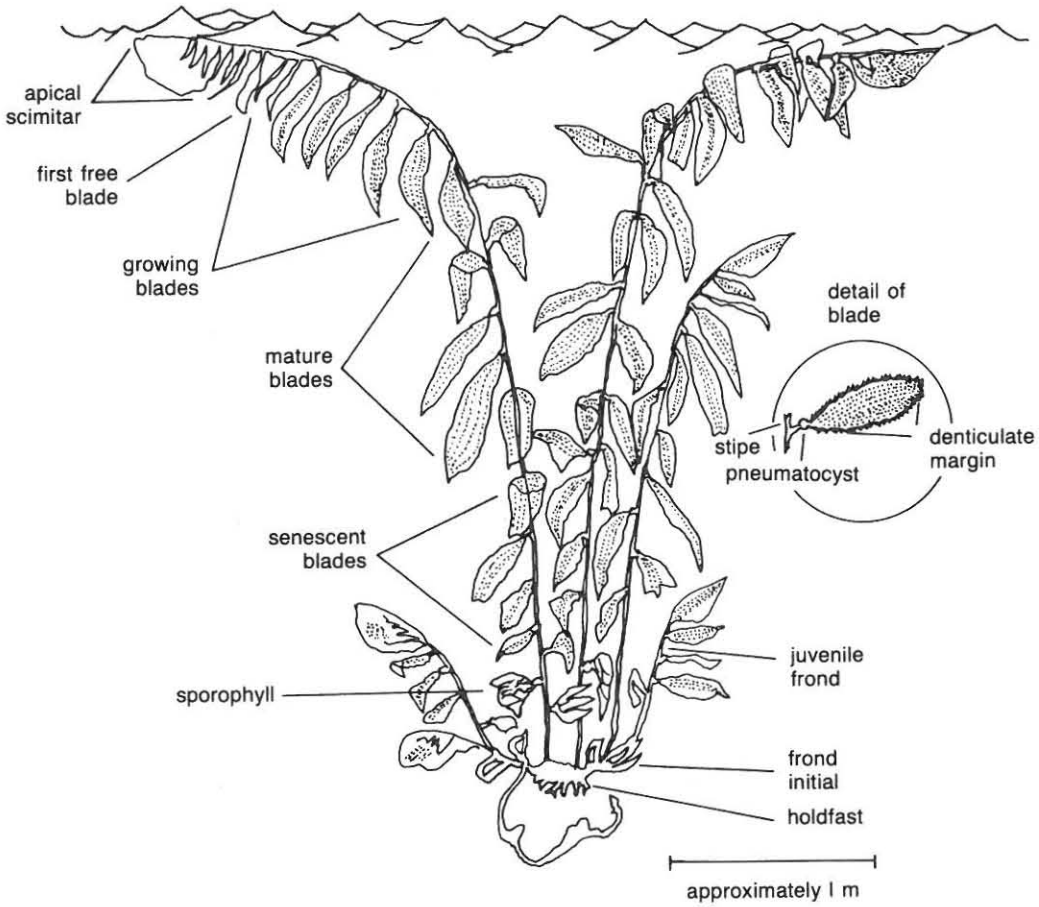

Figure 1. Semi-diagrammatic sketch of *Macrocystis integrifolia* (from Coon and Roland 1980).

color. It has a strap-shaped creeping rhizome, 2-4 cm wide. The rhizome is profusely and dichotomously branched, and is attached closely to the substrate by branched root-like holdfasts which arise from the margins. Numerous erect main stipes arise from the rhizome. The stipes are slender, up to 1 cm in diameter and up to 30 m long. Leaf-like branches (blades) arise at intervals along the stipe. The blades are flattened, 25-35 cm long and up to 5 cm wide (longer and up to 30 cm wide in Sitka Sound) with irregularly furrowed surfaces and toothed margins. The blades taper gradually to the end and are abruptly rounded at the base to a spherical or oval float (pneumatocyst) at the point of attachment on the stipe. The terminal blade, located at the apex (apical scimitar) of the stipe, is split at the base with several new leaf-like branches in various stages of separation (Scagel 1967).

Like all giant kelps, *M. integrifolia* exhibits complete alternation of generations, and both the gametophyte and sporophyte can be perennial (Figure 2). The sporophyte phase can live for 16 to 30 years and the gametophyte phase (in the vegetative form) can live three to four years.

The gametophyte phase is microscopic and haploid and germinates from motile spores of sporophylls, which are specialized blades of the sporophyte. Release of spores takes place when the walls of the sporangia weaken and rupture, creating thin, light areas on the sporophyll. The spores settle and lose their flagella within 12 hours of release. The spores germinate within three days and produce dumbell-shaped gametophytes.

The vegetative, filamentous form of the gametophyte is produced in low light or low nutrient conditions. This form is few celled and can live three to four years. It is seen growing on rocks in the intertidal zone as brown "slime." In the vegetative form, the gametophyte cannot reproduce.

The reproductive form of the gametophyte is produced in high light intensity conditions. The female may be unicellular with an oogonium, while the male is multicellular (7-10 cells). Fertilization is oogamous, with the male bi-flagellated sperm swimming to the female oogonium. The male gametophyte degenerates after fertilization, while the female persists until the sporophyte germinates. Gamete formation to zygote germination takes 13 days, and within a few weeks the gametophyte degenerates. *Macrocystis integrifolia* can progress from zygote germination to mature sporophyte in 8-12 months.

In the sporophyte phase the plant is diploid and macroscopic. The sporophyte is the phase that is seen growing in the ocean, and can grow from a single cell to 20 m in 8-12 months. Growth begins with a filamentous form which lasts for a few days to two weeks. The filamentous form then becomes a blade that is one cell thick. Differentiation takes place in a few months and the juvenile sporophyte form appears. The principal growth period occurs from early April to the end of May (R. RaLonde, SJC, personal communication). North (1971) gives a detailed account of the life history and development of *Macrocystis*.

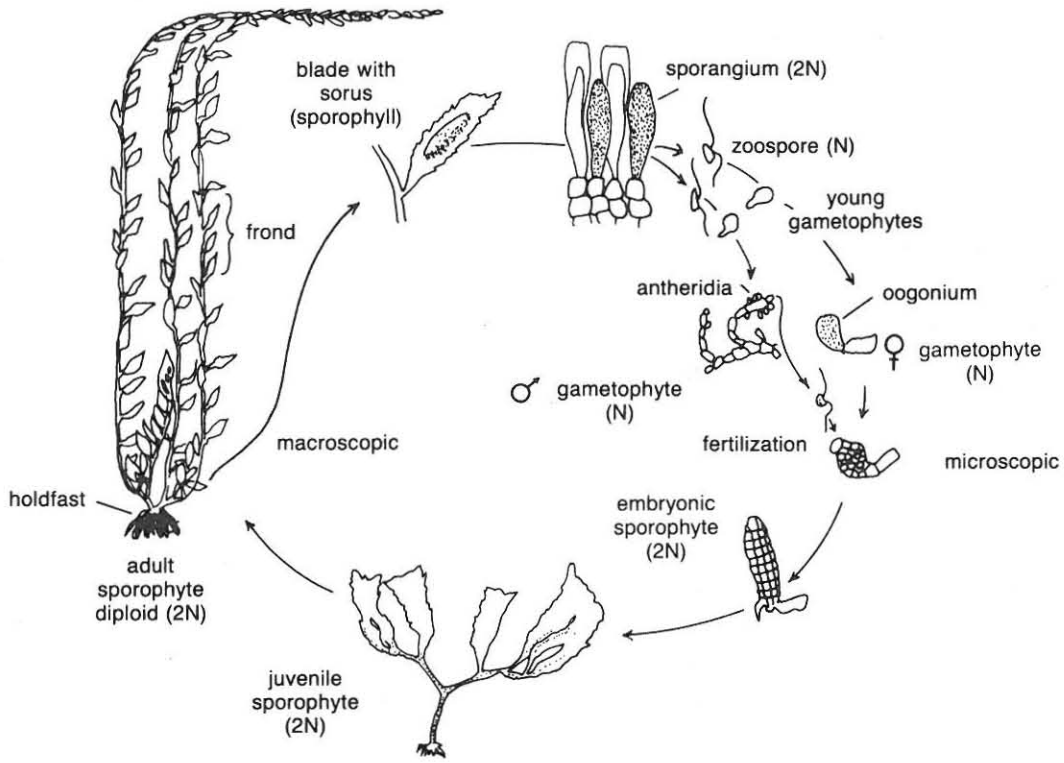

Figure 2. The morphology and life history of *Macrocystis* (from Foster and Schiel 1985).

The environmental requirements of *M. integrifolia* vary depending on life stage, depth, latitude, and locale. This alga requires a substrate of small rocks or cobble in moderately wave-exposed areas, to a substrate that is solid such as a boulder when subjected to appreciable tidal currents (Coon and Roland 1980).

Foster and Schiel (1985) listed the following requirements for the genus *Macrocystis* (from research on *M. pyrifera*): The optimum temperature ranges from 12 to 24°C, and salinity needs to be relatively constant at around 33 ppt (parts per thousand). *Macrocystis* generally can grow only to a depth where irradiance is reduced to about 1 percent of surface light. There are 11 known nutrient requirements for *Macrocystis*; these are C, O, N, P, Mn, Fe, Co, Cu, Zn, Mo, and I. Of these, N is known to be limiting sometimes in nature, and P, Mn, Fe, Cu, and Zn also may be limiting in nature at times.

METHODS

The suitability of the SJC hatchery site for *M. integrifolia* culture was tested in the spring of 1987 by (1) transplanting whole sporophytes from Whiting Harbor to the hatchery site and comparing the growth and survival of sporophytes between the two sites, and (2) collecting sporophylls and inducing reproduction in the laboratory.

Site Selection

Scattered patches of *Macrocystis integrifolia* are found throughout Sitka Sound, but I have not seen any of great size. For a collection and control site, I chose a large patch approximately 100 m long and 10 m wide at Whiting Harbor (57°03'03"N, 135°22'15"W) at the northeast end of the Sitka airport runway, only 1.9 miles (3.1 km) from SJC. The Whiting Harbor site has a depth between 4 and 5 meters, there is no freshwater runoff, and the bottom is composed of large and small boulders, some cobble, and sand. It is semi-enclosed but does receive a considerable amount of ocean swell and chop.

The experimental site in front of the SJC facility (57°03'59"N, 135°19'19"W, Figure 3) varies between 4 and 5 meters deep, has considerable freshwater input from the SJC salmon hatchery and hydro-electric flume, and consists of a silt and sand bottom. The SJC site is not enclosed, but is protected from direct ocean waves by nearby islands. It does, however, receive substantial ocean swell as well as chop from boats using nearby Crescent Bay boat harbor. Both the experimental and control sites have *Laminaria groenlandica*, a related kelp, present in fairly large numbers.

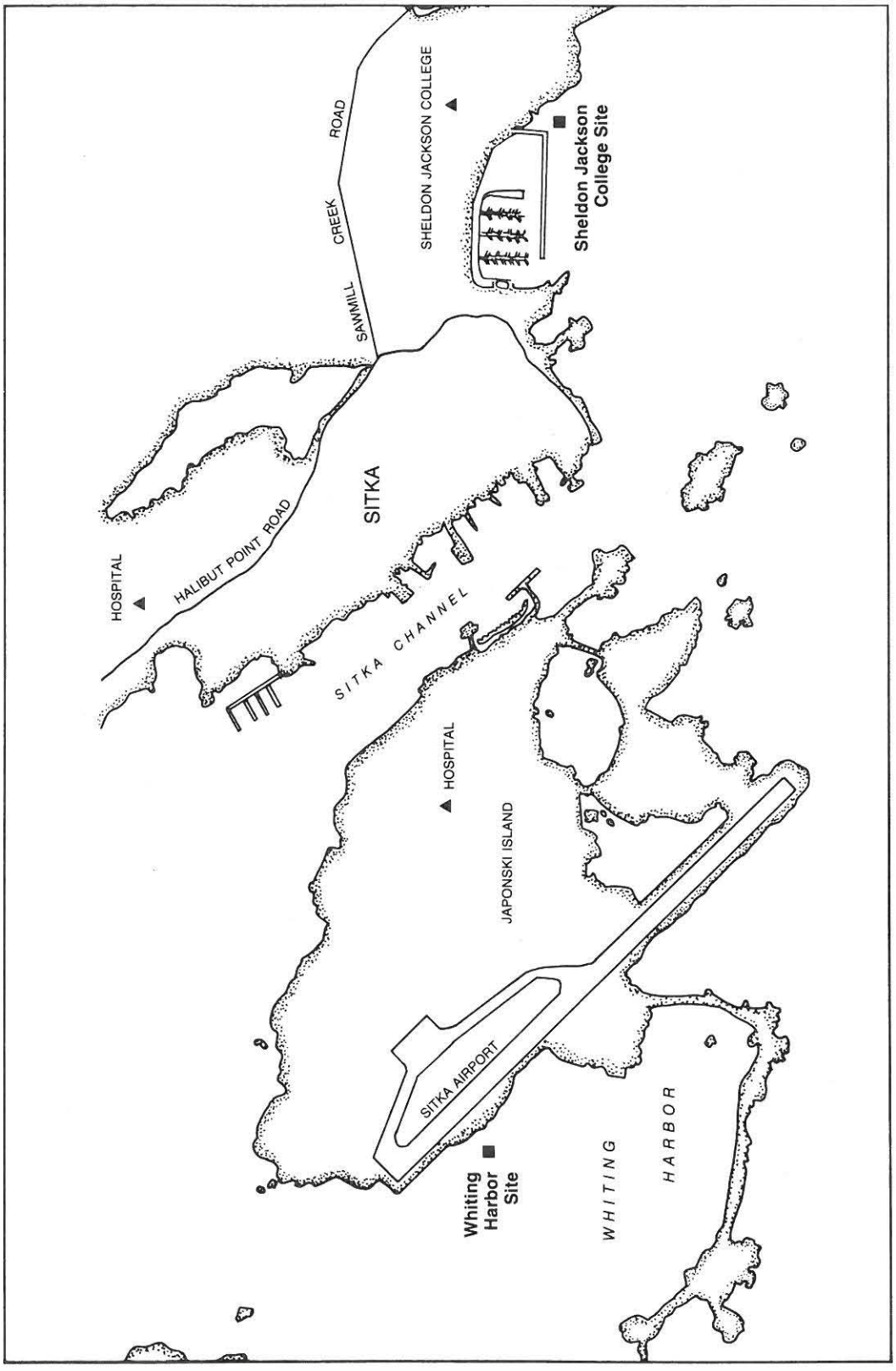

Figure 3. Map of Sitka area, showing location of *Macrocystis integrifolia* study sites.

Transplanting Sporophytes

During February 1987, 10 sporophyte fronds were obtained by scuba diving at Whiting Harbor. The fronds were removed with the substrate to which they were attached if possible, or by cutting as much of the holdfast as possible away from the substrate. The fronds were transported to the SJC site, a five to ten-minute trip by boat, in a 0.9 m x 1.2 m x 0.6 m plastic tub filled with seawater. The holdfasts of plants that were cut loose from the substrate were attached to cement blocks (weighing approximately 4.5 kg) with twine prior to resubmergence at the SJC site. Five of the fronds were tagged with Peterson discs for growth monitoring and the other five were controls. The purpose of the controls was to ensure that the experimental treatment of the measured fronds was not affecting their survival. Five fronds were tagged for growth monitoring at Whiting Harbor in the same manner as the transplanted fronds. The remainder of the patch at Whiting Harbor was the control for that site.

Growth of the blades was determined by taking weekly measurements of the increase in blade length. Ten blades of each of the five experimental fronds at both sites were monitored. The blades were measured starting with the fifth free blade from the top on each frond (Figure 1) at the time of the initial measurement. They were numbered 1 to 10 from the top down. Each experimental blade was punched with a small hole near the attachment to the pneumatocyst and the distance from the pneumatocyst to the punched hole was measured according to the method of Parke (1948). This distance was measured weekly to determine the change in blade length. Maximum width of each blade also was measured on a weekly basis.

Survival of the transplanted experimental *Macrocystis* was compared to the survival of the transplanted control plants and to the experimental and control plants at Whiting Harbor. Survival was divided into two categories: blade survival, with death being defined as more than 3/4 of the blade degenerated; and frond survival, with death being defined as the degeneration or loss of many pneumatocysts resulting in the stipe falling to the bottom, or the complete severance and loss of the frond.

Testing Environmental Conditions

Temperature, salinity, nitrate concentration, and light penetration at the SJC site were compared with those at the Whiting Harbor control site by measuring these variables weekly from April 4 to May 28. The depth at each site varied considerably when measurements were taken because of daily tidal fluctuations. For this reason, temperature, salinity, and nitrate measurements were taken at the surface, halfway down, and at the bottom, except on May 2 and May 28 when temperature and salinity measurements were taken at 1-meter intervals from the surface to the bottom.

Temperature was measured to the nearest 0.5°C with a hand-held thermometer at the surface and with a Yellow Springs Instruments temperature-salinity meter from the surface to the bottom.

Salinity was measured to the nearest 0.5 ppt with a YSI temperature-salinity meter from the surface to the bottom.

Light penetration was measured with a standard 20-cm secchi disc between 10:00 AM and 2:00 PM and with an ambient-underwater irradiometer at 1-meter intervals from the surface to the bottom.

Water samples were collected at the surface, halfway down, and at the bottom with a Nansen bottle and analyzed in the laboratory for nitrate content. Nitrate concentrations were measured with an Orion research model 701A Digital Ionalyzer equipped with a model 93-07 nitrate ion electrode. Reagent grade solid silver sulfate was added to the samples prior to nitrate analysis to prevent chloride ion interference (J. Marcello, SJC, personal communication).

Reproduction with Sporophylls

Sporophylls were collected from Whiting Harbor on September 22, October 15 an 27, and November 22. They were brought into the laboratory at SJC as a source of spores in order to artificially culture them to the juvenile sporophyte stage. All culture vessels, substrates, and media were sterilized to minimize contamination from bacteria, blue-green algae, diatoms, flagellates, and other algae, using the methods of Stekoll (1987) with modification. All containers were either autoclaved or treated with 1:1 chlorine bleach:hot water (70°C) for 3 one-hour soakings, then rinsed once with iodophor followed by distilled water. Sterilization of air stones, settling substrates and frames, and glass microscope slides was accomplished by boiling in distilled water for one hour. Liquids were sterilized by filtering through a 0.45 micron Millipore-type filter.

Sporophylls were collected by cutting them free from the stipe with a knife while scuba diving. The sporophylls were kept in buckets of seawater while being transported to SJC. At the laboratory the sporophylls were sorted, washed and clipped onto rods in a seawater bath until used for spore release. The seawater bath was a 2.4 m x 0.9 m x 15 cm deep wooden trough with unfiltered seawater pumped from a depth of about 12 m.

Inducing spore release and culturing of gametophytes began by holding the sporophylls in the seawater bath, at about 11°C and 30 ppt salinity, until ripe, according to the methods of Stekoll (1987) with modification. Mature sporophylls were brushed clean in sterile seawater with a stiff brush, then dried thoroughly with a cotton rag or paper towels. The blades were then placed on several paper towels in a sterile metal pan and covered with more paper towels. Sterile seawater was poured on the towels to dampen them and the pan

was covered with clear plastic kitchen wrap. The covered sporophylls were then placed in a refrigerator at 2-4°C for two to four hours. Following that, the sporophylls were placed in a beaker of sterile seawater at 9-12°C under fluorescent lights, keeping the ends of the sporophylls out of the water with a sterile petri-dish lid or clothespins to reduce mucilage production.

If the sporophylls were mature at this point, swimming spores were released within 45 minutes, clouding the water a light yellow-brown color. The density of the spores was determined by fixing a small sample of the spore suspension with formalin and counting on a hemocytometer under a microscope. The density of the spore suspension was adjusted to about 20,000 spores per ml by dilution with sterile seawater. The spore suspension was then poured over the settling substrate in a sterile container, and a transparent cover was placed on the container. The container was kept in the seawater bath at 9-12°C and under fluorescent lights producing about 40-50 micro-Einsteins per m^2 per second.

Cremona (a non-fraying synthetic string) was used as the settling substrate and was wrapped around a plexiglass frame to keep the strands apart and off the bottom. Microscope slides were placed in the container for spores to settle on in order to monitor growth and development. After 24 hours the spore suspension was discarded and replaced with 3.0 liters of sterile, Provasoli enriched seawater with iodine (PESI) (Tables 1 and 2). The final step in this phase was the formation of gametophytes following spore germination.

Laboratory Culture of Gametophytes

The gametophytes were maintained in culture in the lab and induced to mature and release gametes, leading to fertilization and germination forming the sporophyte generation. The temperature and light intensity were maintained as before and the culture was given a 16:8 hour light:dark cycle as recommended by L.D. Druehl (personal communication).

Water movement was provided by aeration using an air stone fed by an aquarium pump. The air was filtered in line by a 0.30 micron filter to minimize chemical and bacterial contamination. Germanium dioxide was added to the media to inhibit diatom growth when diatoms were detected (Table 1). Since GeO_2 can also be harmful to the *Macrocystis*, it was used only when necessary and the media was changed within two days of application on the recommendation of L.D. Druehl and M. Stekoll (personal communication). The PESI media was changed at least once weekly for three weeks. A section of the string was examined for sporophyte growth and a microscope slide from the culture was examined for plant growth and development each time the media was changed.

Table 1. PESI media for *Macrocystis* culture (from Stekoll 1987, Provasoli 1966).

PESI stock solution:		
Na_2 glycerophosphate		0.50 g
$NaNO_3$		3.50 g
Fe (0.1 mg/ml of 1:1 M FeEDTA)		250 ml
P II Metal Mix		250 ml
KI (1.4 mg/ml)		1.0 ml
Tris (hydroxymethyl) aminomethane		6.05 g
or Tris HCl		7.88 g
B vitamins		10 ml each
Deionized water	to	1.0 L final vol.

Method: Adjust pH to 7.8 with HCl or NaOH before making the final dilution to 1.0 L. Sterilize by filtering through a 0.45 micron filter. For working solutions, add 20 ml of PESI stock to 1.0 L of sterile seawater. To inhibit diatom growth, add 2.0 ml of 250 mg/ml germanium dioxide to each 1.0 L of the working solution.

RESULTS

Of the five fronds measured at Whiting Harbor, three survived for at least 10 days (April 8 to April 18) and two survived for at least 24 days (April 8 to May 2). The exact date of death is not known as the sites were checked weekly. On May 28, the Whiting Harbor contol fronds were in good condition, but there were no experimental fronds left. Of the five fronds measured at SJC, three survived for at least 7 days (April 4 to April 11), two survived for at least 28 days (April 4 to May 2), and one survived for at least 54 days (April 4 to May 28). On May 2 there were no surviving control fronds at the SJC site. The cause of death at the Whiting Harbor site was attributed to the subsistence herring roe-on-kelp harvest. The blades of some marked fronds that were reachable from the surface were cut off at the pneumatocysts shortly after herring spawned in the area. The cause of death at the SJC site was unknown; some fronds were gone completely and some were observed lying on the bottom decaying. The herring did spawn at the SJC site but the blades were not harvested. Several plants were submerged by the weight of the spawn but reappeared two weeks later after the eggs hatched and measurements were continued.

The greatest growth of an individual blade at Whiting Harbor was 49 mm in 10 days (April 8 to April 18). The greatest growth of an individual blade at SJC was 6 mm in 28 days (April 4 to May 2). Growth at the Whiting Harbor site was significantly greater than that

Table 2. Stock solutions for PESI stock (from Stekoll 1987, Provasoli 1966).

FeEDTA			
A.	$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$		0.702 g
	$Na_2EDTA \cdot 2H_2O$		0.665 g
	Deionized water	to	1.0 L
or			
B.	FeNaEDTA		0.657 g
	Deionized water	to	1.0 L
P II Metal Mix			
$Na_2EDTA \cdot H_2O$			1.00 g
H_3BO_3 (boric acid)			1.14 g
$FeCl_3 \cdot 6H_2O$			49 mg
$MnSO_4 \cdot 1H_2O$			123 mg
$ZnSO_4 \cdot 7H_2O$			22 mg
$CoSO_4 \cdot 7H_2O$			4.8 mg
Deionized water		to	1.0 L

Method: Add EDTA to about 800 ml of deionized water first, then add metal salts and bring to volume.

B vitamins	
Vitamin B_{12} (cyanocobalamin)	1.0 mg/100 ml
Biotin	0.5 mg/100 ml
Thiamine·HCl	50 mg/100 ml

Method: These vitamins can be made up separately or together. Store at 4°C if sterile filtered, or freeze in 10 ml aliquots.

at the SJC site (T test, P = .11) (Figure 4). Growth of the upper five blades was greater than the growth of the lower five blades on all the experimental fronds at the Whiting Harbor site. At the SJC site the growth of the upper five blades was not greater than that of the lower five blades on any of the experimental fronds.

Light penetration was greater at Whiting Harbor than at SJC on April 4, 11, 18, and 28 and May 2, but was attenuated at approximately the same rate at both sites (Figure 5). Light intensity at both sites was never below 2.3 micro-Einsteins per m^2 per second, the minimum required for kelp growth (Foster and Schiel 1985).

Temperatures at both sites were usually within about one degree of each other except on May 28 when the SJC site was about three degrees cooler (Figure 6).

At the SJC site the surface salinity was always lower, and there was a marked increase in salinity with depth illustrating the presence of a freshwater lens (Figure 7) down to approximately 2 m depth.

Nitrate concentrations from approximately 25 ppm (parts per million) to approximately 100 ppm were measured at both sites, indicating either unusually high nitrate levels from unknown sources or some sort of systematic error in measurement, most likely the latter.

Table 3 summarizes the results of the laboratory culture of gametophytes and sporophytes from sporophylls collected at Whiting Harbor. Many of the samples had gametophytes, and a few very small sporophytes were observed in culture samples four weeks after spore release. Spores were released on November 1 also but were lost due to equipment failure.

DISCUSSION AND RECOMMENDATIONS

The results of this study show that the SJC site probably is not suitable as an outplanting site for *M. integrifolia*. This is primarily due to the considerable freshwater lens from the SJC salmon hatchery and hydro-electric flume. The plants showed poor growth in the upper blades at the SJC site, within the freshwater lens.

Light limitation is one of the most important factors influencing *Macrocystis* growth (Jackson 1987). The lower light intensity at the SJC site probably was not limiting because the level of intensity never was below the lower light limit for kelp growth (Foster and Schiel 1985, Fei and Neushul 1984). Adult *Macrocystis* are generally insensitive to changes in subsurface light because they can transport the photosynthetic products from the surface canopy toward the holdfast (Foster and Schiel 1985, McCleneghan and Houk 1985, Lobban 1978). This could have been a problem at the SJC site with the degeneration of the upper canopy caused by the freshwater lens. It is possible that the degeneration of the upper canopy caused by the freshwater lens at the SJC site reduced the amount of

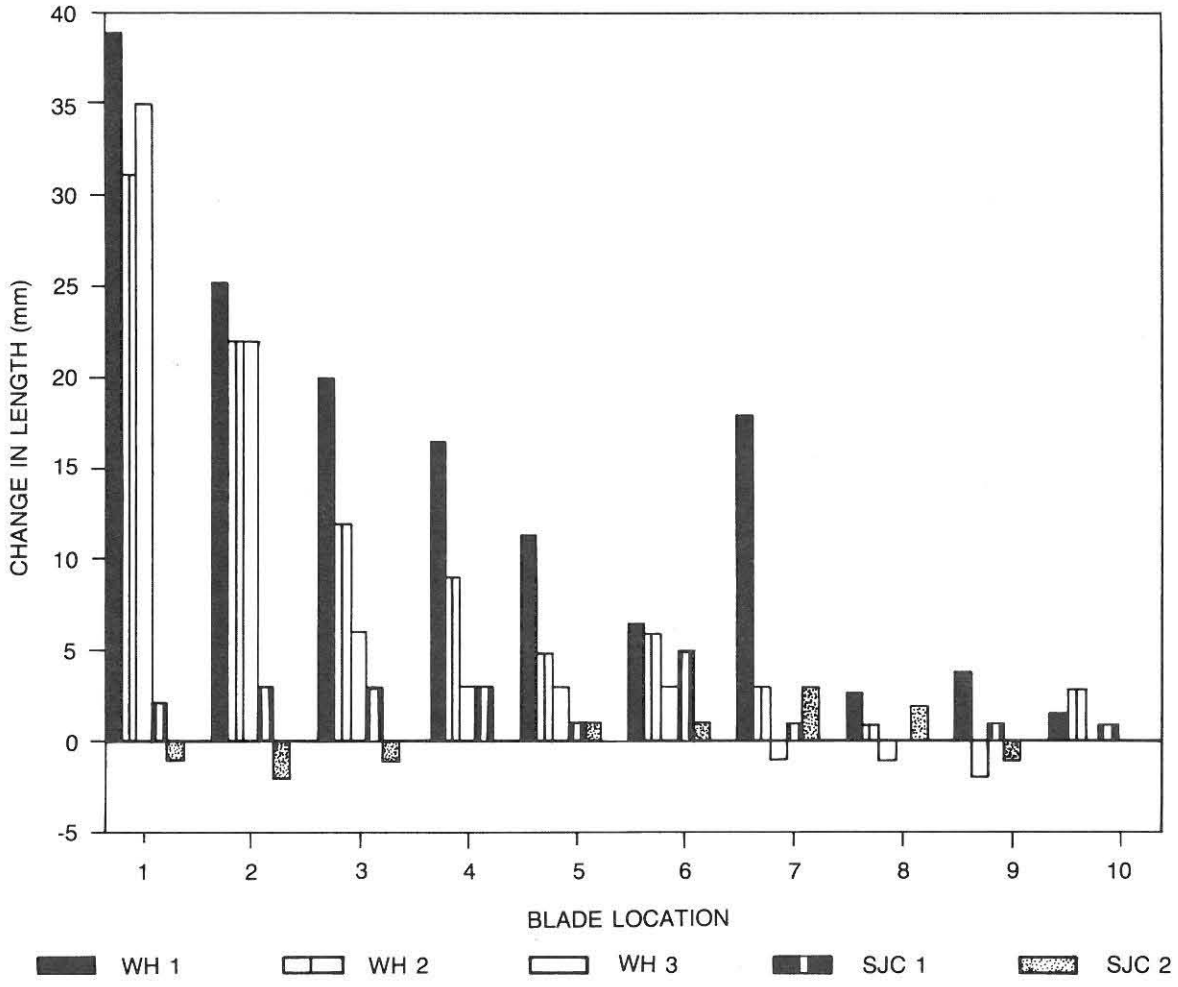

Figure 4. Kelp blade growth at Whiting Harbor and SJC, April 11 to May 2, 1987. (WH1 extends only to April 18.)

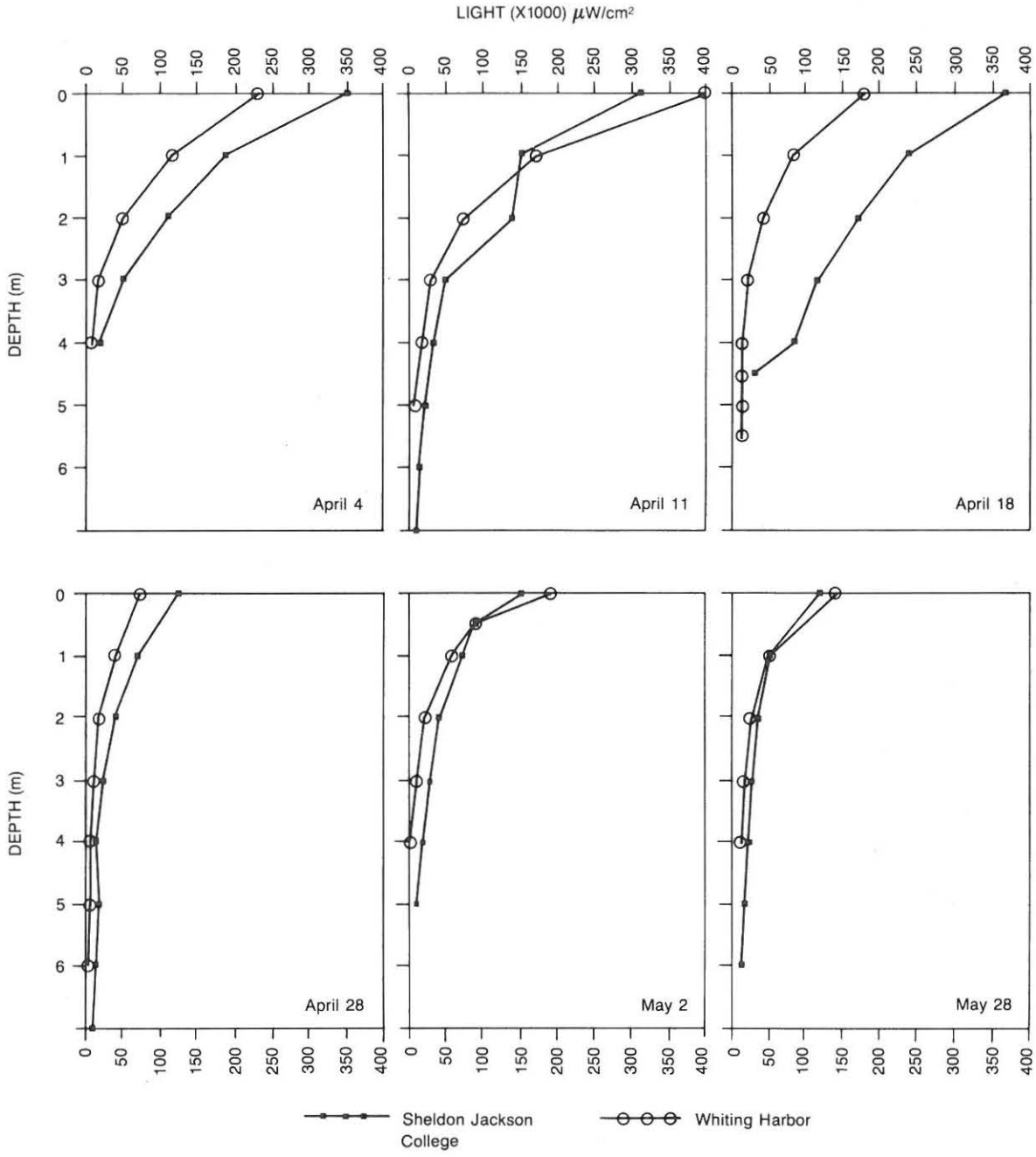

Figure 5. Light intensity at different depths on April 4, 11, 18, and 28 and May 2 and 28, 1987. One watt per m^2 is approximately equal to 5 micro-Einsteins per m^2 per second.

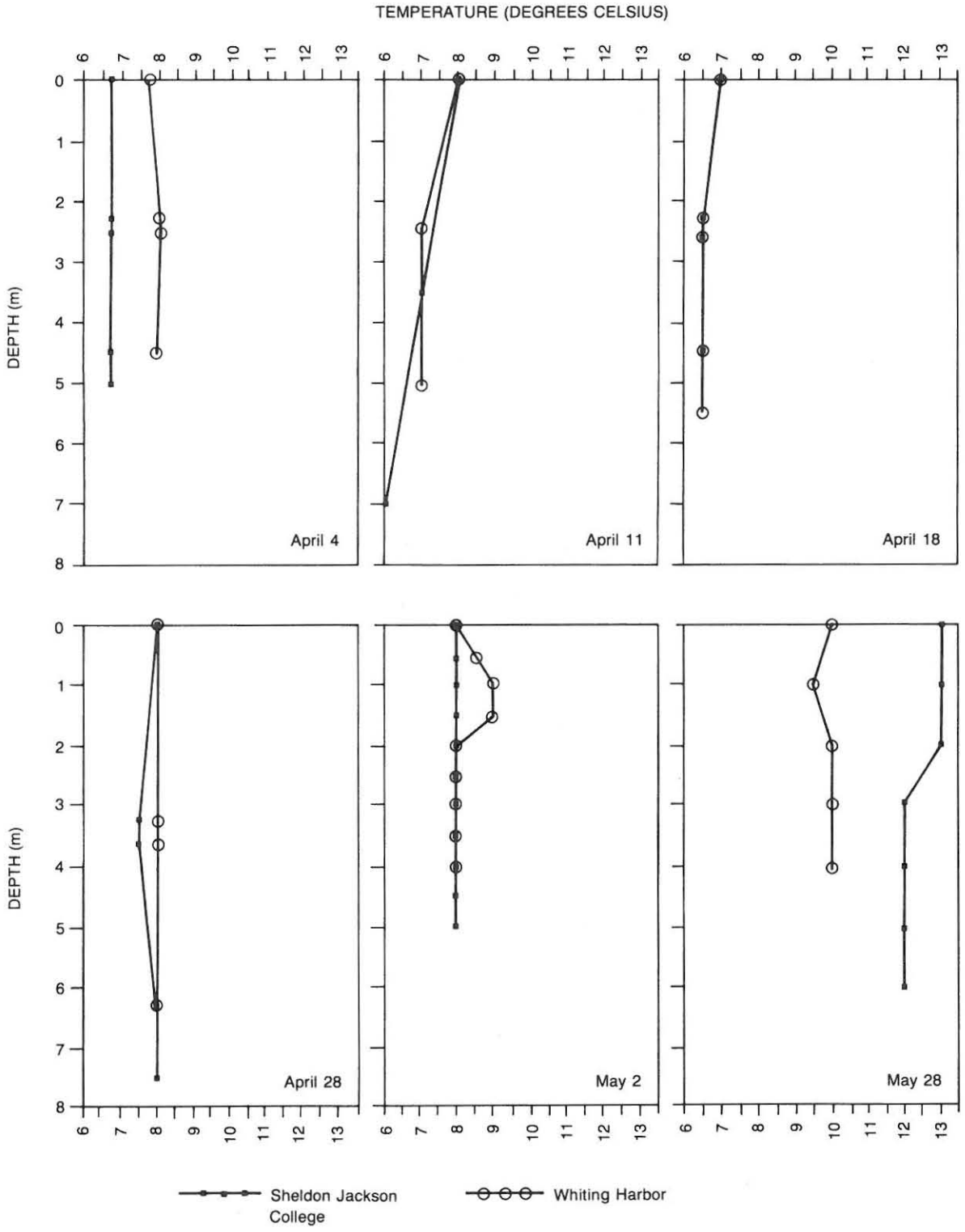

Figure 6. Temperature profiles for April 4, 11, 18, and 28 and May 2 and 28, 1987.

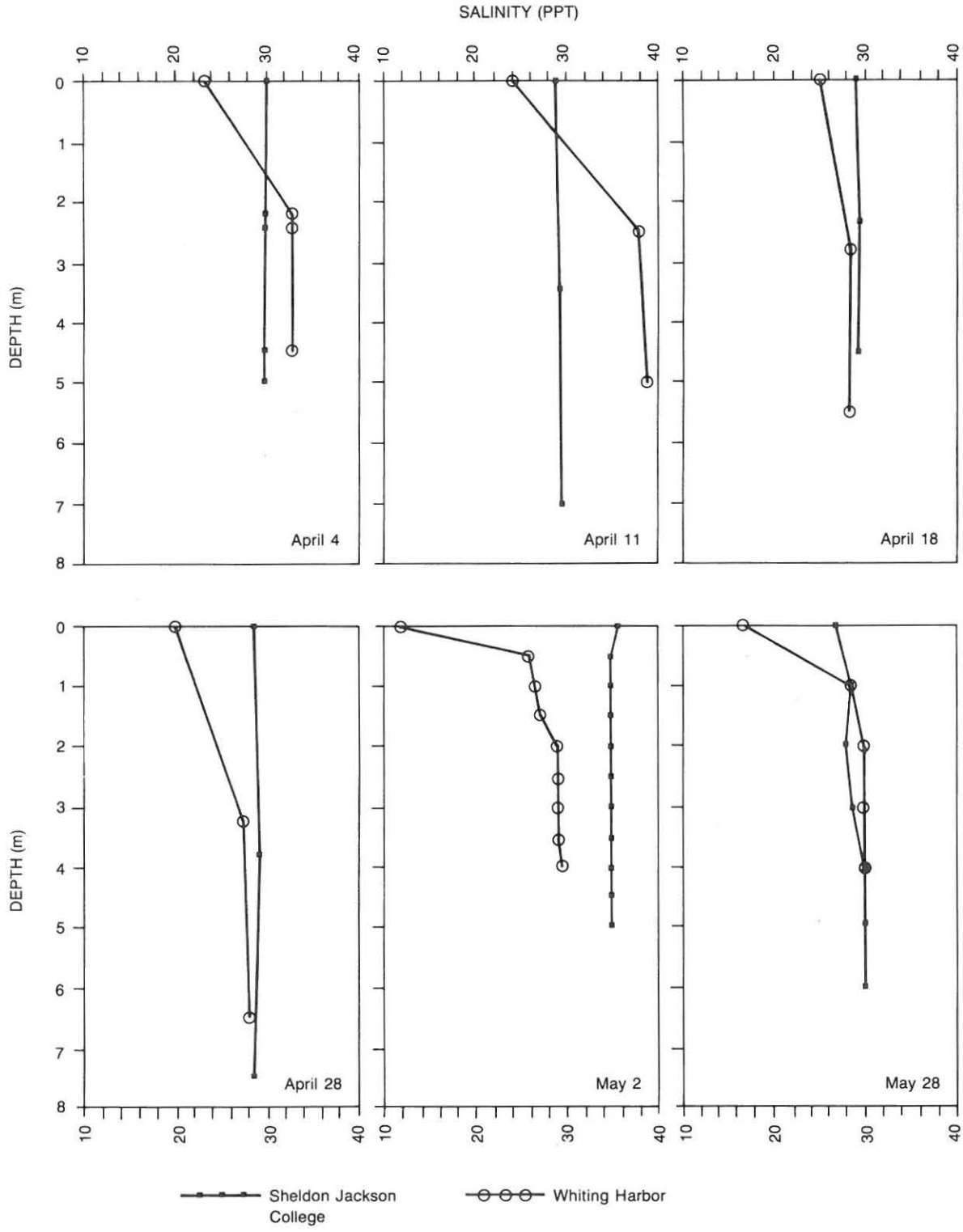

Figure 7. Salinity profiles for April 4, 11, 18, and 28 and May 2 and 28, 1987.

Table 3. Summary of observations of laboratory cultures from sporophylls of *Macrocystis integrifolia* collected in Whiting Harbor, Alaska, Sept. 22, Oct. 15 and 27, and Nov. 22, 1987.

Date of spore release	Date of observation	
Oct. 22 (Culture No. 1)	Oct. 27	Gametophytes
	Nov. 13	Male and female gametophytes, few sporophytes
	Nov. 18*	Gametophytes and dead material
	Nov. 28	Dead
Nov. 2 (Culture No. 2)	Nov. 13	Spores, few gametophytes
	Nov. 18*	Few gametophytes, diatom contaminates
	Nov. 28	Dead

*Observed by M. Stekoll.

photosynthetic products available for transport to the lower portions of the plant, thereby limiting new growth.

The growth dynamics and density of a *Macrocystis* population are variable, and therefore one set of data may not be adequate to determine growth rates for a site (Druehl and Wheeler 1986, Gerard and North 1984, Lobban 1978). The blade growth measured at Whiting Harbor during this study represents the growth under particular conditions. If the study were carried out to completion by outplanting at Whiting Harbor and monitoring growth and survival were conducted again the amount of blade growth could be much different, varying with the subtle differences in the environment from time to time. The results of this study should be viewed as only an indication of environmental conditions and potential blade growth rates at the sites.

A major weakness in this study was the lack of nutrient analysis at the culture sites. The nutrient levels need to be determined in order to evaluate the quality of a site and compare it

with other sites. Researchers in kelp culture should be certain beforehand of the availability and accuracy of equipment and methods to measure these parameters.

This study shows that *M. integrifolia* can be cultured at the SJC facility. Culture number 1 probably died from photo-inhibition as it was receiving no dark period (L.D. Druehl and M. Stekoll, personal communication). Culture number 2 was discarded because of diatom contamination from the seawater bath. Both of these problems have been solved at this point and another culture can be started. This study would be more conclusive if culturing were carried out to completion by outplanting at Whiting Harbor and monitoring growth and survival.

Stekoll (1987) described three phases in kelp culture: sporophyll collection and release of spores, laboratory culture of gametophytes and sporophytes, and outplanting and maintenance of sporophytes. If techniques for the first two phases as described in this study are followed it would be possible to rear *M. integrifolia* for outplanting. Whiting Harbor is an obvious choice for an outplanting site in the Sitka area as *Macrocystis* grows naturally there. However, when culturing kelp for food, outplanting sites must be located away from sources of pollution to keep the kelp fit for consumption. *Macrocystis integrifolia* can concentrate heavy metals and other toxicants making it unfit for consumption (L.D. Druehl, personal communication). The SJC site is near a boat harbor and Whiting Harbor is near both the airport and the sewage effluent of Sitka. Both sites may receive effluent from Alaska Lumber and Pulp Co. located in Sitka Sound. Anyone culturing kelp for food in these areas should test the plants for elevated toxin levels. Testing for toxicants should be incorporated into evaluation studies for kelp culture sites. Other criteria for evaluation of a site should include interference with other activities. The SJC site was located within the SJC salmon hatchery terminal harvest area and would have interfered with the purse seining of returning salmon (B. Davidson, SJC, personal communication).

An alternative to outplanting the juvenile sporophytes is to rear them in an enclosed tank, where they would be safe from predation and competition, until they reach a certain size. This is being done in California and appears to be very successful (M. Stekoll, personal communication). Future studies of culture sites could include testing the effects of tank rearing prior to outplanting.

In conclusion, there are at least four criteria to take into consideration when assessing the suitability of a site for the artificial culture of *Macrocystis*. The most obvious and important is: Will *Macrocystis* grow there? Does the site meet the light, temperature, salinity, nutrient, and water motion requirements for *Macrocystis*? Another important criterion is: Will kelp culturing interfere with other activities occurring at the site? Third: is the site accessible? Will it be logistically practical to maintain outplanted kelp cultures at this site? And last: If the kelp is being cultured for food, are there sources of toxicants nearby that could render the kelp unfit for consumption? If the site appears to meet these criteria, it is reasonable to conduct a trial outplanting.

REFERENCES

Chapman, V.J. and D.J. Chapman. 1980. Seaweeds and their uses, 3rd edn. Chapman and Hall, New York, 334 p.

Coon, L.M. 1982. *Macrocystis* harvest strategy in British Columbia: Synthetic and degradative processes in marine macrophytes. Walter de Gruyter & Co., Berlin.

Coon, L.M. and W.G. Roland. 1980. Harvesting impacts on *Macrocystis integrifolia:* A preliminary study. Fisheries Development Report No. 12. Marine Resources Branch, Ministry of Environment, Province of British Columbia.

Druehl, L.D. 1979. An enhancement scheme for *Macrocystis integrifolia* (Phaeophyceae). Proceedings of the International Seaweed Symposium No. 9, p. 79-84.

Druehl, L.D. and W.N. Wheeler. 1986. Population biology of *Macrocystis integrifolia* from British Columbia, Canada. Marine Biology 90:173-179.

Fei, X.G. and M. Neushul. 1984. Effects of light on the growth and development of giant kelp. Hydrobiologia 116/117:456-462.

Foster, M.S. and D.R. Schiel. 1985. The ecology of giant kelp forests in California: A community profile. Biological Report 85(7.2). U.S. Fish and Wildlife Service, NASA-Slidell Computer Complex, 1010 Gause Boulevard, Slidell, LA 70458.

Gerard, V.A. and W.J. North. 1984. Measuring growth, production, and yield of the giant kelp, *Macrocystis pyrifera*. Hydrobiologia 116/117:321-324.

Harger, B.W.W. and M. Neushul. 1983. Test farming of the giant kelp, *Macrocystis*, as a marine biomass producer. Journal of the World Mariculture Society 14:392-403.

Jackson, G.A. 1987. Modelling the growth and harvest yield of the giant kelp *Macrocystis pyrifera*. Marine Biology 95:611-624.

Lobban, C.S. 1978. The growth and death of the *Macrocystis* sporophyte (Phaeophyceae, Laminariales). Phycologia 17(2):196-202.

McCleneghan, K. and J.L. Houk. 1985. The effects of canopy removal on holdfast growth in *Macrocystis pyrifera* (Phaeophyta: Laminariales). California Fish and Game 71(1):22-27.

North, W.J. 1971. Introduction and background. In: W.J. North, ed. The biology of giant kelp beds (*Macrocystis*) in California. Nova Hedwigia Beih. 32:1-97.

Parke, M. 1948. Studies on British Laminariaceae. I. Growth in *Laminaria saccharina* (L.) Lamour. Journal of the Marine Biological Association of the U.K. 27:651-709.

Pierce, B. 1987. Aquaculture in Alaska. Alaska State Legislature. House Research Agency Report 87-B.

Provasoli, L. 1966. Media and prospects for the cultivation of marine algae. In: A. Watanabe and A. Hattori, eds. Cultures and collections: Proceedings of the U.S.-Japan Conference in Hakone, Japan, September 1966. Japanese Society of Plant Physiologists, p. 63-75.

Rosell, K. and L.M. Srivastava. 1985. Seasonal variations in total nitrogen, carbon and amino acids in *Macrocystis integrifolia* and *Nereocystis luetkeana* (Phaeophyta). Journal of the Fisheries Research Board of Canada 33:1015-1023.

Scagel, R.F. 1963. Distribution of attached marine algae in relation to oceanographic conditions in the northeast Pacific. In: M.J. Dunbar, ed., Marine distributions. University of Toronto Press, Royal Society of Canada Special Publication No. 5, p. 37-50.

Scagel, R.F. 1967. Guide to common seaweeds of British Columbia. British Columbia Provincial Museum. Handbook No. 27.

Shields, T.L., G.S. Jamieson, and P.E. Sprout. 1985. Spawn-on-kelp fisheries in the Queen Charlotte Islands and Northern British Columbia Coast--1982 and 1983. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1372, 53 p.

Sleeper, H.L. 1980. Algin from *Macrocystis*. In: I.A. Abbott, M.S. Foster, and L.F. Eklund, eds. Pacific seaweed aquaculture: Proceedings of a Symposium on Useful Algae. California Sea Grant College Program, p. 130-135.

Stekoll, M.S. 1987. Artificial growth and propagation of the giant kelp *Macrocystis integrifolia*. University of Alaska, Juneau. SFS-8704.

Whyte, J.N.C. 1979. The quality, handling, and transplanting of kelp for komochi kombu production. In: Proceedings of the Herring Roe on Kelp Workshop. University of Alaska Sea Grant Report No. 79-3, Alaska Sea Grant College Program, 138 Irving II, University of Alaska, Fairbanks, AK 99775-5040.

Wilson, K.C., P.L. Haaker, and D.A. Hanan. 1979. Restoration of *Macrocystis pyrifera* (Phaeophyceae) at Palos Verdes Peninsula, California. Proceedings of the International Seaweed Symposium No. 9, p. 85-89.

Wise, J.J. and A.J. Silvestri. 1976. Mobil process efficiently converts methanol to gasoline. Oil and Gas Journal 74(47):140-142.