The Development of an Edible Kelp Culture Technology for British Columbia

III. Third Annual Report

Louis D. Druehl

marine resources branch
Ministry of Environment
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THE DEVELOPMENT OF AN EDIBLE KELP CULTURE TECHNOLOGY FOR BRITISH COLUMBIA

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by

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and

Bamfield Marine Station

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ABSTRACT

This third annual report records progress made in designing and evaluating the technology necessary for rearing the edible kelp (kombu) species *Laminaria groenlandica* Rosenvinge and *Cymathere triplicata* (Post. & Rupr.) J. Ag. in British Columbia. Wild plants of *L. groenlandica* have completed their growth on kombu farms and have been harvested. Generally these plants were larger and less lacerated than equivalent plants collected from the wild. Laboratory-produced seed of *L. groenlandica* has shown good growth at several kombu farms, and will be harvested this summer (1981). Genetically identical seed of *L. groenlandica*, produced from cloned gametophytes, has shown excellent growth on a kombu farm, indicating the possibility of a shorter growing season. *Cymathere triplicata* has been successfully grown to maturity on kombu farms in Barkley Sound. Key environmental parameters distinguishing the existing kombu farms have been identified. These parameters when compared with the summer 1981 harvest data, will provide us with environmental predicters of kombu growth which will allow us to select optimal kombu farm sites.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The following individuals and institutions contributed to this study. Their assistance is greatly appreciated.

Ms. R. Boal is senior technician on the project and is primarily responsible for seed production; Ms. A. Lindwall assists in seed production and is primarily responsible for the epiphyte monitoring programme; Ms. K. Lloyd is primarily responsible for the sporophyte cloning studies; and Ms. S. Smith-Pakula is primarily responsible for kombu farm maintenance and environmental monitoring.

Ms. A. stewart developed a device which allows us to quantify water motion; Ms. B. Jenkins typed this manuscript; Mr. R. Baden assisted in farm construction and motor maintenance; Mr. L. Giguère designed statistical programmes and models for kombu farm site selection. Mr. S. Villeneuve, sponsored by a Province of Quebec fellowship and an NSERC research grant to Dr. L. Druehl, provided information regarding depth effects on kombu growth; Mr. W. Roland assisted in designing the epiphyte monitoring programme; and Mr. R. Long provided the photographs in this report.

The kombu farm established in Masset was made possible by the Haida Band Council, West Coast Information Research Group, Mr. J. Wilson, Mr. W. Brown and Mr. R. Brown. The Nelson Island kombu farm was established with the assistance of Tidal Rush Marine Farms, and the Sointula kombu farm was monitored by the Marine Resources Branch. Pacific Rim Mariculture assisted in establishing some of the kombu farms in Barkley Sound. Many residents have assisted in and tolerated the Barkley Sound kombu farms, notably, Mr. W. Wenstob and family, Mr. and Mrs. L. Mogensen, and Mr. and Mrs. R. Peel.

Throughout this study we have enjoyed the services of the Bamfield Marine Station. Canadian Benthic Ltd. assisted in field work and conducted all nutrient analyses. Simon Fraser University provided services and allowed me a leave of absence to conduct this study. The Bamfield Life Saving Station kindly "rescued" one of us on 3 January 1981.

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INTRODUCTION

This report discusses progress made during the third fiscal year (April 1980 - March 1981) in developing the biotechnology necessary for an edible kelp culture industry. Edible kelp is known as kombu, and includes some of the smaller species in the order Laminariales. These plant products are intended for domestic and foreign markets.

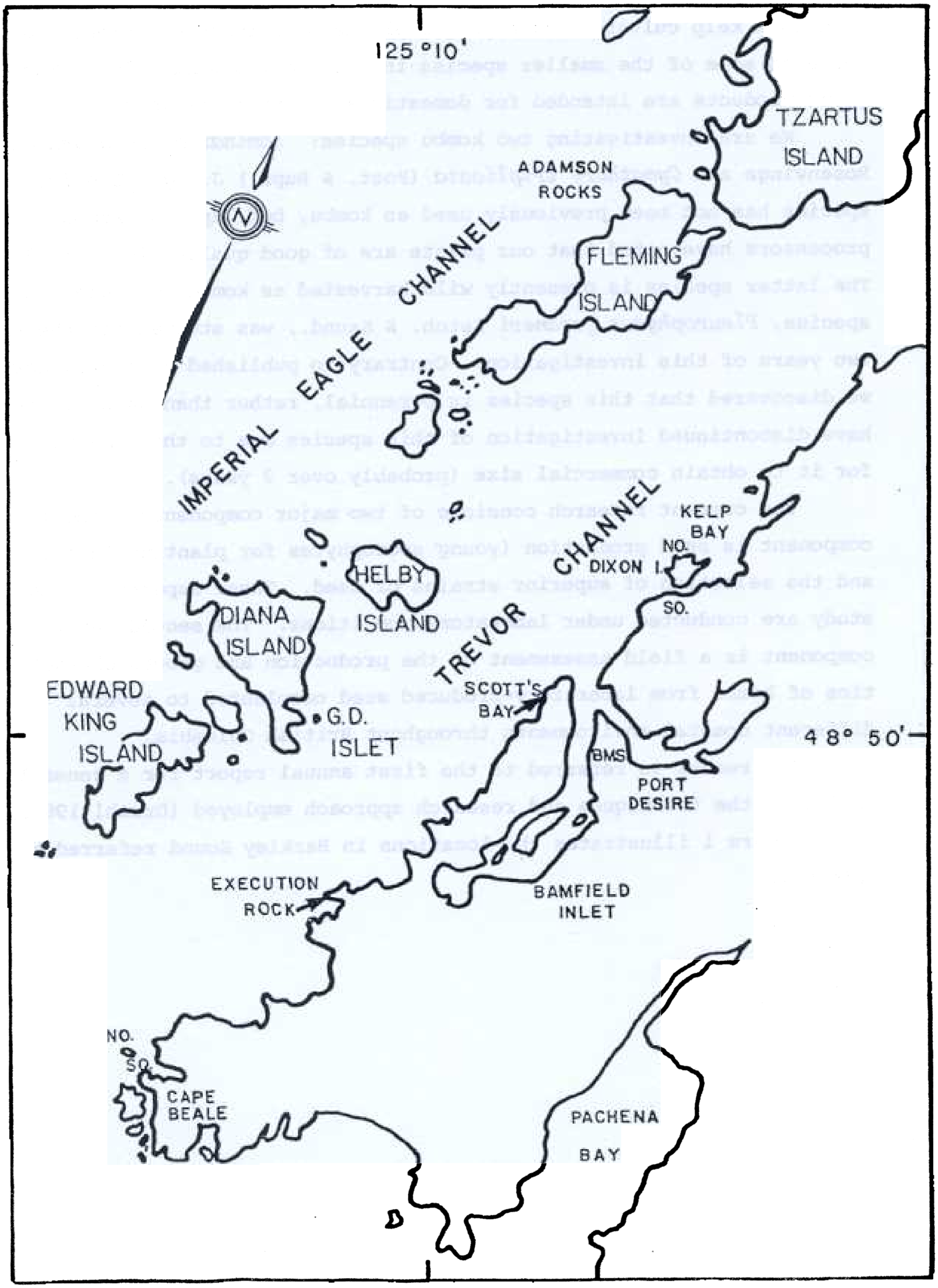
We are investigating two kombu species: *Laminaria groenlandica* Rosenvinge and *Cymathere triplicata* (Post. & Rupr.) J. Ag. The former species has not been previously used as kombu, but Japanese kombu processors have noted that our plants are of good quality (Druehl 1980b). The latter species is presently wild harvested as kombu in Japan. A third species, *Pleurophycus gardneri* Setch. & Saund., was studied for the first two years of this investigation. Contrary to published accounts, however, we discovered that this species is perennial, rather than annual. We have discontinued investigation of this species due to the time required for it to obtain commercial size (probably over 2 years).

The current research consists of two major components. The first component is seed production (young sporophytes for planting in the sea) and the selection of superior strains of seed. These aspects of the study are conducted under laboratory conditions. The second major component is a field assessment of the production and growth characteristics of kombu from laboratory-produced seed outplanted to several different coastal environments throughout British Columbia.

The reader is referred to the first annual report for a general review of the techniques and research approach employed (Druehl 1980a).

Figure 1 illustrates the locations in Barkley Sound referred to in this text.

Figure 1. Locations in Barkley Sound, British Columbia, referred to in this study.



KOMBU FARMS

1. Rope Culture of Wild *Laminaria groenlandica*

Kombu farms were established initially to discern differences in growth potential of *L. groenlandica* cultivated in different localities and at different depths. The first farms, established in 1979, were seeded with wild plants in their first year of growth. By using these plants as seed, we were able to obtain preliminary data on plant behaviour during their second and final growth season one year early, as we were not equipped to outplant laboratory seed until the following year Table 1 gives the seeding dates, locations and initial dimensions of the plants used in this study.

During May and June 1980 these plants were harvested, weighed and measured. After these initial measurements were made, heavily epiphytized distal portions of the blades were trimmed off and the plants re-measured. They were then air/sun dried on a cobble beach on Dixon I., and stored for future evaluation.

On the basis of the May 1980 harvest, the Helby Island kombu farm produced the largest final product, with Tzartus and Kelp Bay plants being generally smaller. The Helby I. and Kelp Bay plants had blades of about the same thickness (as measured 30 cm from blade base), and Tzartus I. plants had the thinnest blades.

The amount of plant material trimmed to remove heavily epiphytized blade tissue was used as an indication of the degree of epiphytism. On the basis of the May 1980 harvest data, epiphytism most severely affected the plants in Kelp Bay, followed by Helby I. and Tzartus I.

The size of the harvested plants did not vary significantly with depth from 1 to 4 m below the surface (Table 2, Kelp Bay).

The Kelp Bay plants harvested in June weighed approximately one third more than the May-harvested plants. However, the degree of epiphytism, as estimated by weight after trimming the blade tissue, was considerably greater for the plants harvested in June (ca. 42%) than for those harvested in May (ca. 28%).

Mean blade thickness decreased from May (0.8 mm) to June (0.6 mm)

Table 1. Mean sizes (± 1 S.D.) of wild *Laminaria groenlandica* (first year plants) at time of transplantation and the sites seeded with these plants. All plants were collected from Dixon Island (n greater than 20).

Location	Transplant Date	Wet Wt. (g)	Length (cm)	Width (cm)
Kelp Bay	May 1979		trimmed to 30 cm	13.0 ± 5.6
Helby Island	Sept. 1979	34.4 ± 10.8	43.2 ± 11.6	11.5 ± 2.3
	Sept. 1979	7.6 ± 4.6	17.6 ± 6.8	6.7 ± 2.6
	Nov. 1979	5.9 ± 3.6	15.0 ± 4.9	4.5 ± 1.6
Tzartus Island	Sept. 1979	13.1 ± 5.6	26.6 ± 8.1	7.5 ± 1.3
	Nov. 1979	5.8 ± 3.2	16.0 ± 5.8	4.3 ± 1.5

Table 2. Mean dimensions (± 1 S.D.) of wild *Laminaria groenlandica* plants grown on ropes and harvested. Trimmed values indicate the loss of blade tissue due to heavy epiphytism.

1980 Harvest Date	Location & Transplant Date	n	Depth (m) of sample	Wet Wt. (g) before trim	Wet Wt. (g) after trim	Length (cm) before trim	Length (cm) after trim	Width (cm) @ 30 cm	Thickness (cm) @ 30 cm
23 May	Kelp Bay May 1979	11	1 - 2.3	287 ± 94	211 ± 76	82 ± 23	57 ± 18	38 ± 5	.08 ± .01
		8	2.3 - 3	246 ± 87	181 ± 63	75 ± 33	50 ± 13	30 ± 7	.08 ± .01
		13	3 - 5	265 ± 137	184 ± 101	82 ± 27	56 ± 11	31 ± 10	.08 ± .01
18 June	Kelp Bay May 1979	11	1 - 2.3	358 ± 117	192 ± 54	73 ± 20	43 ± 10	32 ± 10	.06 ± .01
		18	2.3 - 3.6	384 ± 132	231 ± 93	82 ± 25	54 ± 19	35 ± 8	.06 ± .01
		19	3.6 - 5	310 ± 146	217 ± 62	69 ± 32	54 ± 13	35 ± 11	.06 ± .01
24 May	Helby I.	5	1 - 5	490 ± 179	434 ± 151	121 ± 25	95 ± 18	51 ± 12	.08 ± .01
	Sept. 1979	4	1 - 5	288 ± 148	227 ± 117	89 ± 24	70 ± 22	35 ± 13	.06 ± .01
	Nov. 1979	6	1 - 5	457 ± 209	351 ± 169	127 ± 37	95 ± 30	42 ± 15	.08 ± .01
24 May	Tzartus I. Sept. 1979	10	1 - 5	371 ± 205	325 ± 169	103 ± 27	81 ± 25	38 ± 9	.07 ± .01
	Nov. 1979	6	1 - 5	390 ± 89	383 ± 94	112 ± 12	107 ± 16	40 ± 7	.07 ± .01

for the plants harvested from Kelp Bay. This change in thickness was not expected on the basis of our observations on wild plants surveyed in 1979. Wild plants from Diana I. increased in thickness from a mean of 0.9 mm in May, to 1.0 mm in June 1979 (Druehl 1980b). However, wild plants collected from Dixon I. in June 1980 had a mean thickness of 0.7 mm indicating that for this parameter, rope-grown plants were similar in size to wild plants growing in the same locality. Comparison of other dimensions of rope-grown and wild *L. groenlandica* indicated that the former obtained a larger size and were less lacerated than the wild plants (Fig. 2).

The drying of three rope-grown plants was monitored under natural sun/air conditions in June 1980. The plants were dried in direct sun (air temperature 17 C) with a light breeze (Fig. 3). Table 3 records the weight loss under these conditions for 2 h 50 min, and subsequently in a forced-air drying oven (60 C) for 24 h.

In conclusion, these data demonstrate that it is possible for *L. groenlandica* grown on rope farms to obtain harvestable size in a total growth period of 18 months.

The growth potential and degree of epiphytism of rope-grown plants were observed to vary with location and harvesting time. Further, rope-grown plants were found to be generally larger and less lacerated than wild plants.

2. Location Effects on the Growth of *Laminaria groenlandica* Seed on Ropes

Preliminary studies on wild plants grown on rope indicated that even within a fairly limited geographic area, different growth potentials could be realized. To more systematically test this observation, laboratory-produced seed (sporophytes less than 4 mm in length) were outplanted to four locations in Barkley Sound and one location near Sointula, Malcolm I., between January and March 1980.

The seed was spaced at 50 cm intervals along the rope and none of the resulting sporophytes were thinned from the clusters of seed. The largest plant in each of several (10-20) representative clusters was measured at approximately monthly intervals.

Tables 4-6 provide an indication of the growth behaviour of seed grown at the four Barkley Sound farms. On the bases of length, width

Figure 2. Comparison of wild (right) and rope grown *Laminaria groenlandica* (left). Both plants are from Dixon Island and are approximately 18 months old. Photographed May, 1980.

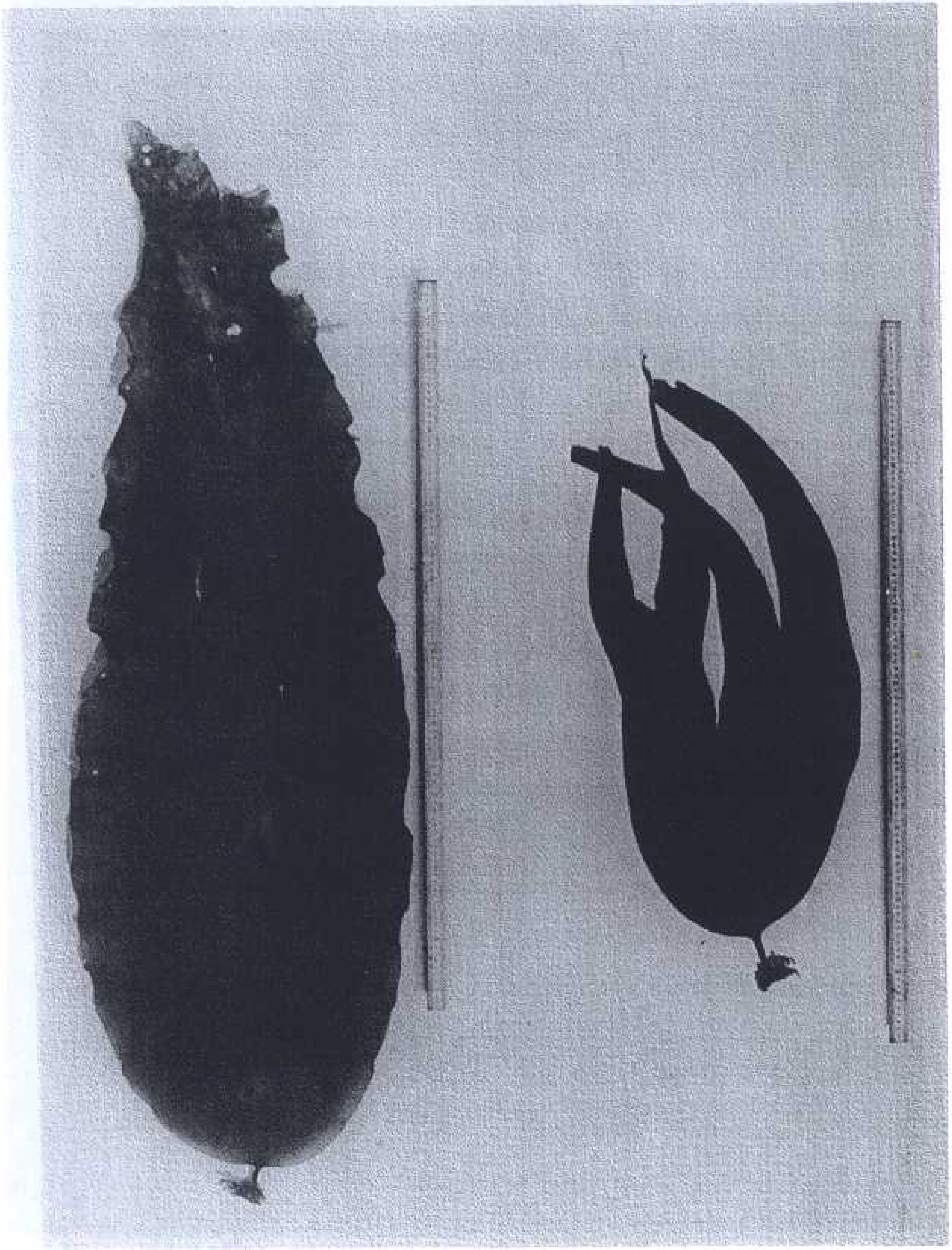


Figure Ai:/ dryin *Laminaria groenlandica* Di

Table 3. Sun-drying time and weights of three Kelp Bay *Laminaria groenlandica* plants harvested from ropes in June 1980.

Time	Weight (g)		
	a	b	c
11:00	310	325	275
12:30	85	100	75
13:50	60	60	50
after 24 hrs. @ 60C	43	52	39

and approximate blade surface area, all net growth had ceased by October 1980. Net second year growth had commenced by January 1981, and in March (the time of the final measurement reported here), the dimensions of plants from all four populations exceeded those observed throughout 1980.

The Helby I. and Adamson's Reef farms were planted in January 1980, and the Scott's Bay and Execution Rock farms in February. By April 1980 the Helby I. plants had attained six times the blade surface area of the other three populations (Fig. 4). Plants at the other three farms were of approximately the same dimensions in April in spite of the month difference in planting times. Comparison of change in blade surface area from November 1980 to March 1981 indicated a considerable differential in growth potential between plants of the four farms as they entered their second year of growth. The smallest November population (Adamson's Reef) showed the greatest percentage increase in blade surface area (ca. 250%), while Helby I. plants increased the least (ca. 130%). Execution Rock and Soctt's Bay plants increased approximately 200% over this period.

During 1980, the thickest plants developed at Helby I. and the thinnest plants developed at Scott's Bay and Execution Rock (Table 7). By March 1981, the thickest plants were observed at Execution Rock.

Laminaria groenlandica seed from Barkley Sound was planted at Sointula in February 1980. All of this seed was lost, however, probably from abrasion by drifting material. This farm was reseeded in March 1980, and the subsequent growth monitored until September, when all of the plants were destroyed by drifting kelp (*Macrocystis* and *Nereocystis*) (Table 8).

In conclusion, good growth characteristics were observed for outplanted seed of *L. groenlandica* at all farm sites. Further, differences in blade surface dimensions and blade thicknesses were evident between the various farm sites. The final evaluation of seed response to the different growth localities will be made in May-June 1981 when plants from all populations will be harvested.

3. Spacing and Thinning Effects on the Growth of *Laminaria groenlandica* Seed Grown on Ropes

The density of plants along a rope may affect the final dimensions

Table 4. Mean lengths (± 1 S.D.) of the largest *Laminaria groenlandica* plant in each of 10-20 seed clusters. The initial size at time of outplanting was 0.4 cm long or less.

Location & Outplant Date	April 1980 length (cm)	July 1980 length (cm)	Sept.1980 length (cm)	Oct.1980 length (cm)	Nov.1980 length (cm)	Jan.1981 length (cm)	Feb.1981 length (cm)	March 1981 length (cm)
Scott's Bay 21 Feb. 1980	29 ± 6	49 ± 20	66 ± 19	67 ± 14	58 ± 25	54 ± 12	64 ± 15	85 ± 19
Execution Rock 21 Feb. 1980	33 ± 6	92 ± 22	89 ± 9	87 ± 14	54 ± 16	64 ± 12	68 ± 14	97 ± 12
Helby Island 24 Jan. 1980	71 ± 10	67 ± 15	55 ± 14	54 ± 10	41 ± 10	28 ± 5	38 ± 6	56 ± 19
Adamson's Reef 27 Jan. 1980	33 ± 8	62 ± 14	67 ± 15	66 ± 11	45 ± 7	53 ± 6	60 ± 12	84 ± 21

Table 5. Mean widths (± 1 S.D.) 30 cm from blade base of the largest *Laminaria groenlandica* plant in each of 10-20 seed clusters. The initial size at time of outplanting was 0.4 cm long or less.

Location & Outplant Date	April 1980 width (cm)	July 1980 width (cm)	Sept.1980 width (cm)	Oct.1980 width (cm)	Nov.1980 width (cm)	Jan.1981 width (cm)	Feb.1981 width (cm)	March 1981 width (cm)
Scott's Bay 21 Feb. 1980	7 ± 1	12 ± 4	15 ± 3	16 ± 3	15 ± 4	17 ± 2	16 ± 2	30 ± 8
Execution Rock 21 Feb. 1980	7 ± 1	19 ± 4	20 ± 5	17 ± 4	16 ± 3	18 ± 4	13 ± 2	27 ± 3
Helby Island 24 Jan. 1980	18 ± 3	20 ± 3	17 ± 3	18 ± 3	15 ± 5	13 ± 3	14 ± 3	25 ± 6
Adamson's Reef 27 Jan. 1980	6 ± 1	14 ± 3	16 ± 3	13 ± 8	12 ± 3	13 ± 3	14 ± 4	18 ± 5

Table 6. Surface area of the largest *Laminaria groenlandica* plant in each of 10-20 seed clusters. The initial size at time of outplanting was 0.4 cm long or less.

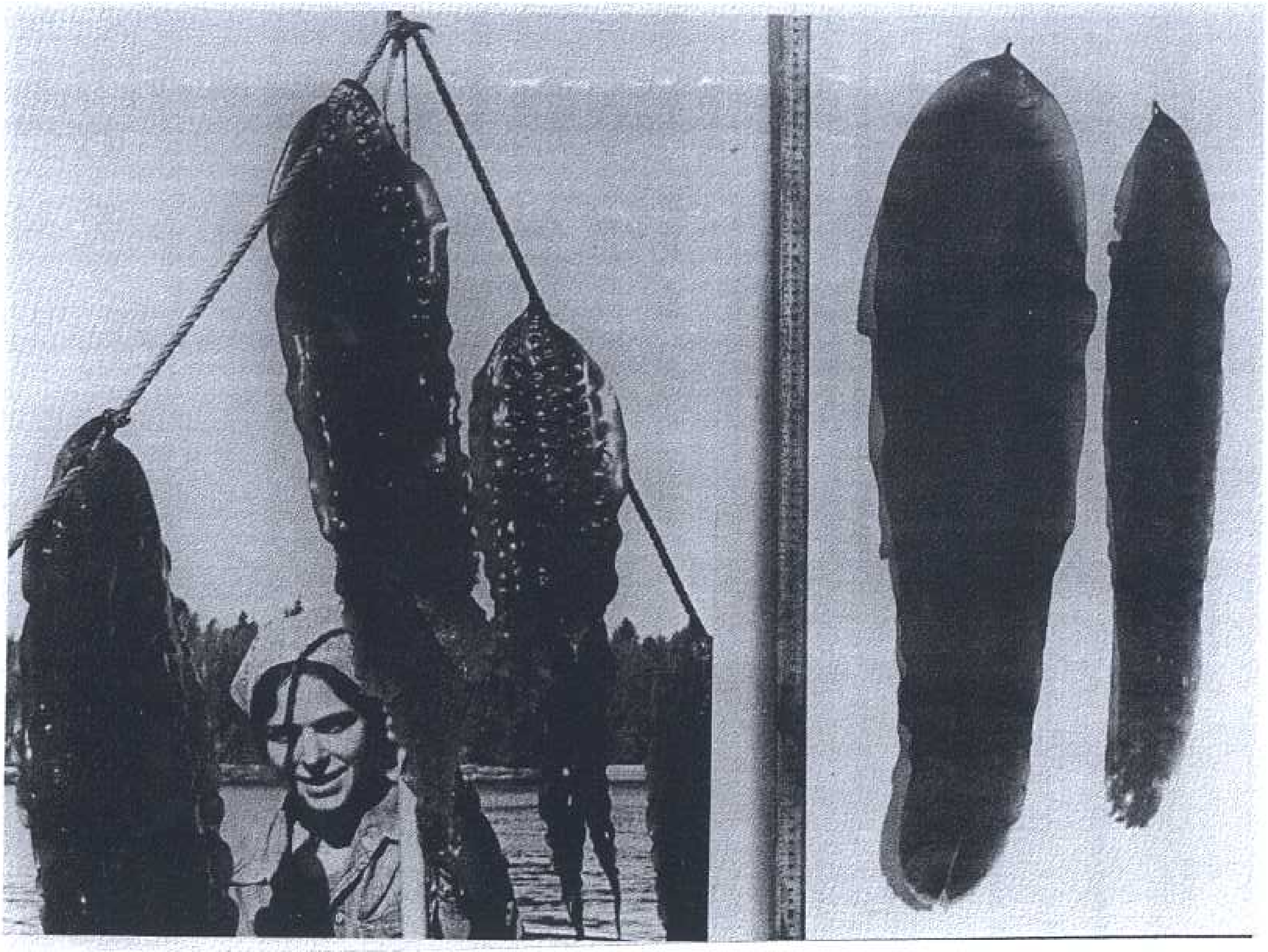
Location & Outplant Date	April 1980 (cm^2) length x width	July 1980 (cm^2) length x width	Sept. 1980 (cm^2) length x width	Oct. 1980 (cm^2) length x width	Nov. 1980 (cm^2) length x width	Jan. 1981 (cm^2) length x width	Feb. 1981 (cm^2) length x width	March 1981 (cm^2) length x width
Scott's Bay 21 Feb. 1980	194	588	990	1072	870	918	1024	2550
Execution Rock 21 Feb. 1980	214	1748	1780	1479	864	1152	884	2619
Helby Island 24 Jan. 1980	1278	1340	935	972	615	364	532	1440
Adamson's Reef 27 Jan. 1980	205	868	1072	858	540	689	840	1932

Table 7. Mean blade thicknesses (± 1 S.D.) 30 cm from blade base of the largest *Laminaria groenlandica* plant in each of 10-20 seed clusters. The initial size at time of outplanting was 0.4 cm long or less.

Location & Outplant Date	Oct. 1980 thickness (cm)	Nov. 1980 thickness (cm)	Jan. 1981 thickness (cm)	Feb. 1981 thickness (cm)	March 1981 thickness (cm)
Scott's Bay	.06	.06	.08	.07	.03
21 Feb. 1980	± .01	± .02	± .01	± .01	± .01
Execution Rock	.07	.09	.08	.05	.05
21 Feb. 1980	± .01	± .01	± .01	± .01	± .01
Helby Island	.06	.10	.09	.06	.03
24 Jan. 1980	± .01	± .01	± .01	± .01	± .01
Adamson's Reef	.08	.09	.09	.05	.04
27 Jan. 1980	± .01	± .01	± .01	± .01	± .01

Table 8. Mean lengths, widths and thicknesses (± 1 S.D.) of *Laminaria groenlandica* grown on ropes at Sointula from 26 March 1980 (n = 20). The initial size of these plants was 0.4 cm long or less.

Date	Measurements (cm)	
30 May 1980	length	67 ± 21
	width @ 30 cm	17 ± 5
24 June 1980	length	75 ± 30
	width @ 30 cm	24 ± 6
9 Sept. 1980	length	76 ± 22
	width @ 30 cm	25 ± 6
	thickness @ 30 cm	.04 ± .03



igure ust *Laminaria groenlandica* seed the Helby sland kombu farm and comparison Helby land seed eft and Adamson Reef seed gh Th ts approximately ong in anuary 80 Photographed Apr 80 and morphological features of the cultivated seed. Preliminary studies were initiated to determine the response of *L. groenlandica* seed to spacing intervals (30 vs. 50 cm between seed clusters) and density of plants in each seed cluster (5, 12, or unthinned plants per cluster; unthinned seed clusters usually bore more than 20 plants per cluster).

The Helby I. and Execution Rock farms were seeded at 30 and 50 cm intervals in January and February 1980. In March 1980 Helby I. seed at 30 and 50 cm intervals were thinned to 5 or 12 plants or not thinned, and Execution Rock plants at 30 cm intervals were thinned in September 1980. In March 1981, seed in its second year of growth spaced at 50 cm intervals was thinned to 5 plants per seed cluster at Execution Rock.

Plants grown at 30 and 50 cm intervals did not appear to be significantly different in size as observed from July 1980 to March 1981 (Table 9). Further, over this observation period, thinning did not appear to strongly affect the dimensions of the plants at Helby I. or Execution Rock (Tables 9, 10). There was a tendency for the thinned plants to be wider during 1980, but this difference was lost by March 1981.

A final assessment of spacing and thinning effects will be made at the time of harvesting during the summer of 1981.

4. Depth Effects on the Growth of *Laminaria groenlandica* Seed Maintained at Different Depths

Mr. Serge Villeneuve has established kelp farms at three locations (Bamfield Inlet, Kelp Bay and Helby I.) to assess the effects of depth on the growth of *L. groenlandica*. These farms are designed to provide substrate for first and second year plants at 0, 1, 3, 5, 7, 9 and 12 m below the surface. The general trends he has observed thus far are: 1) the most rapid growth for first year plants occurs at 3 m between April and May, and at 5 m for the remainder of the year; 2) the most rapid growth for second year plants occurs at 1 m between March and May and at 7 m for the remainder of the year; 3) net growth at optimal depth continues until August for first year plants and until June for second year plants. After those months, erosion of blade tissue equals or exceeds the production of new tissue.

The above results suggest a strategy for optimizing growth characteristics by seasonally altering the depth at which the plants are

Table 9. Spacing and thinning effects on the growth of *Laminaria groenlandica* planted as seed at Helby Island in January 1980. Mean values (± 1 S.D.) were derived by measuring the largest plant in each of 10-20 clusters of plants. Thinning was executed during March 1980.

		1 cluster/30 cm			1 cluster/50 cm		
Date	Measurements (cm)	Unthinned	12 plants/ cluster	5 plants/ cluster	Unthinned	12 plants/ cluster	5 plants/ cluster
24 July 1980	length	85 ± 11	87 ± 2	94 ± 15	67 ± 15	86 ± 16	70 ± 8
	width @ 30 cm	24 ± 5	22 ± 3	25 ± 3	20 ± 3	22 ± 3	24 ± 4
3 Sept. 1980	length	77 ± 11	71 ± 12	84 ± 9	55 ± 14	72 ± 13	61 ± 8
	width @ 30 cm	24 ± 3	23 ± 5	25 ± 4	17 ± 3	22 ± 6	24 ± 3
1 Oct. 1980	length	69 ± 11	73 ± 11	80 ± 11	54 ± 10	67 ± 13	55 ± 6
	width @ 30 cm	23 ± 5	24 ± 3	25 ± 4	18 ± 3	21 ± 5	23 ± 3
	thickness @ 30 cm	.07 ± .01	.07 ± .01	.07 ± .01	.06 ± .01	.07 ± .01	.07 ± .01
17 Nov. 1980	length	46 ± 13	46 ± 17	60 ± 10	41 ± 10	44 ± 15	44 ± 9
	width @ 30 cm	20 ± 6	20 ± 4	22 ± 3	15 ± 5	20 ± 3	22 ± 3
	thickness @ 30 cm	.10 ± .02	.10 ± .01	.10 ± .01	.10 ± .01	.10 ± .01	.10 ± .01
1 Jan. 1981	length	40 ± 11	41 ± 7	55 ± 12	28 ± 5	43 ± 11	37 ± 7
	width @ 30 cm	17 ± 3	18 ± 3	21 ± 3	13 ± 3	18 ± 3	18 ± 4
	thickness @ 30 cm	.09 ± .02	.10 ± .01	.09 ± .01	.09 ± .01	.09 ± .01	.09 ± .01
30 Jan. 1981	length	44 11	40 ± 8	48 ± 9	38 ± 6	39 ± 9	37 ± 9
	width @ 30 cm	14 3	16 ± 4	18 ± 4	14 ± 3	15 ± 4	15 ± 3
	thickness @ 30 cm	.04 .01	.05 ± .01	.06 ± .01	.06 ± .01	.06 ± .02	.07 ± .02
10 Mar. 1981	length	69 ± 14	62 ± 12	61 ± 16	56 ± 19	56 ± 13	45 ± 17
	width @ 30 cm	29 ± 5	28 ± 5	25 ± 5	25 ± 6	27 ± 5	23 ± 4
	thickness @ 30 cm	.04 ± .01	.03 ± .01	.03 ± .01	.03 ± .01	.04 ± .01	.03 ± .01

Table 10. Effects of thinning on *L. groenlandica* planted as seed at Execution Rock in February 1980. Measurements indicate means (± 1 S.D.) of the largest plant from each of 10-20 plant clusters. Thinning was executed during March 1980.

Date	Measurements (cm)	Unthinned	1 cluster/30 cm: 12 plants/ cluster	1 cluster/30 cm: 5 plants/ cluster
2 Oct. 1980	length	87 ± 14	82 ± 12	73 ± 16
	width @ 30 cm	17 ± 4	18 ± 3	20 ± 5
	thickness @ 30 cm	0.07 ± 0.01	0.07 ± 0.01	0.06 ± 0.02
26 Nov. 1980	length	54 ± 16	55 ± 10	49 ± 12
	width	16 ± 3	19 ± 2	18 ± 4
	thickness	0.09 ± 0.01	0.10 ± 0.01	0.09 ± 0.01
5 Jan. 1981	length	64 ± 12	53 ± 15	47 ± 12
	width	18 ± 4	15 ± 4	16 ± 3
	thickness	0.08 ± 0.01	0.09 ± 0.01	0.09 ± 0.01
29 Jan. 1981	length	68 ± 14	62 ± 7	50 ± 12
	width	13 ± 2	14 ± 2	12 ± 3
	thickness	0.05 ± 0.01	0.04 ± 0.01	0.04 ± 0.01
10 March 1981	length	84 ± 34	96 ± 22	64 ± 12
	width	27 ± 4	30 ± 6	28 ± 4
	thickness	0.04 ± 0.01	0.04 ± 0.01	0.04 ± 0.01

grown. We have now modified some of our farms to allow for an easy change in vertical position of the plants.

5. Rope Culture of *Cymathere triplicata* Seed

Microscopic seed of *C. triplicata* was outplanted to the Kelp Bay, Tzartus I. and Helby I. kombu farms 19 January 1980. Sporophytes visible to the naked eye were first noted 26 February, and by March the plants were approximately 15 cm in length. The plants increased in length until May and in width and thickness until September (Table 11, Fig. 5). Soral development commenced in August and all plants were fertile by September. Most of the plants became eroded to 10-15 cm blade length but persisted into January 1981. Our field observations in Barkley Sound indicate that wild populations of *C. triplicata* become scarce by November, and those plants remaining also have very little blade tissue. We were able to obtain seed from our rope-grown plants, however, even as late as January.

The *C. triplicata* grown in Barkley Sound (both wild plants and rope plants) have much smaller and thinner blades than do wild plants observed in the Sointula area. We are presently comparing the growth of seed from both localities in several environments to distinguish between environmental and genetic effects on *C. triplicata* growth and morphology.

On the basis of our experience with *C. triplicata* it appears that this species is amenable to rope culture. Although this same species is at present harvested commercially for kombu in Japan, ours is the first attempt to cultivate it.

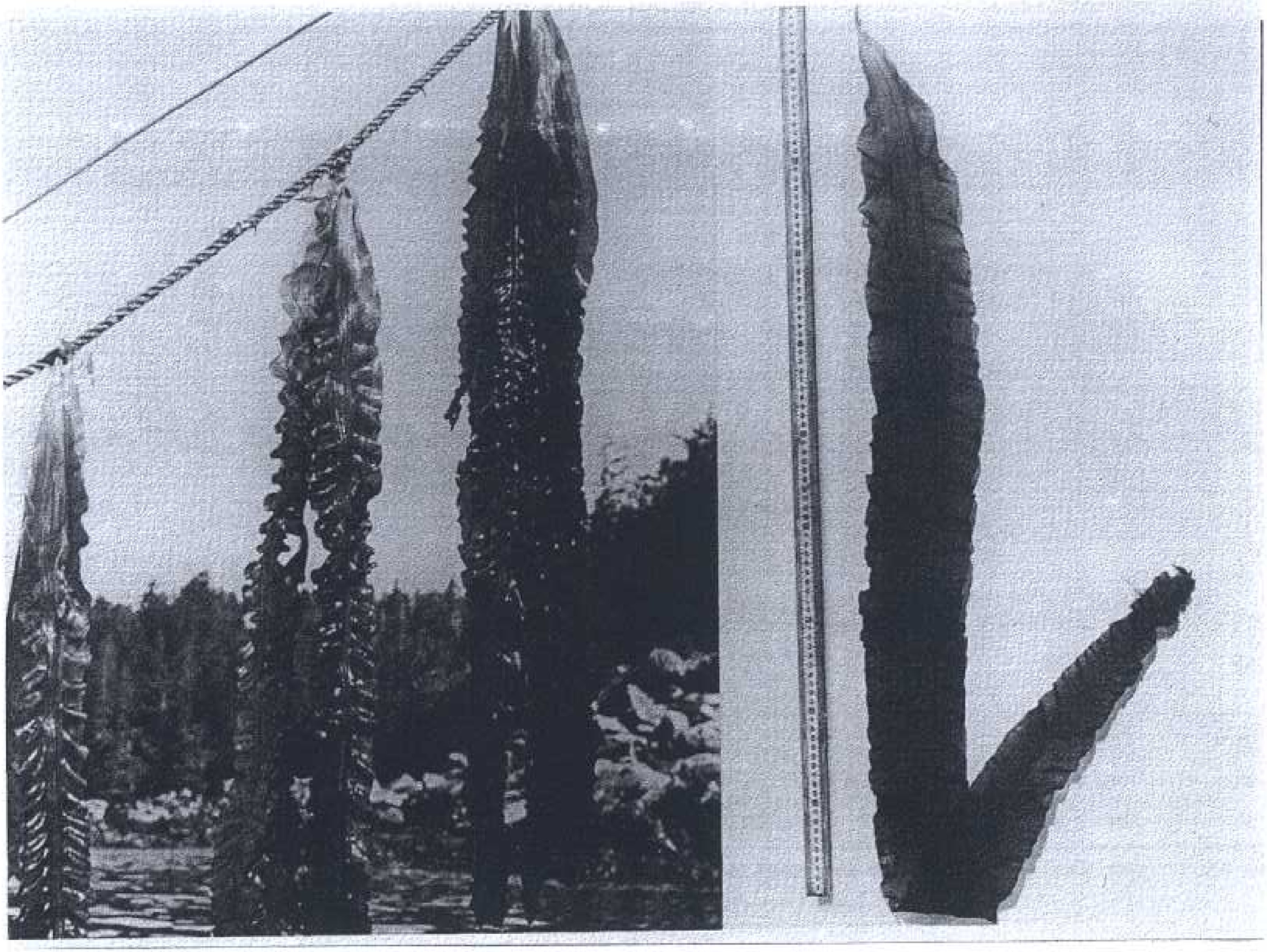
6 Modified Kombu Farm Structures

We have modified the physical structure of the kombu farm to better suit the growth and substrate requirements of kombu seed. Presently, we work with two basic farm types.

The first type, referred to as the surface farm, is essentially a large letter "H" where the horizontal section of rope supports the kombu plants. The vertical lines extending from the horizontal line to the surface buoys, can be lengthened or shortened to move the plants into a more favourable growth environment. This farm is usually anchored by 45 gal. oil drums filled with concrete.

Table 11. Mean dimensions (± 1 S.D.) of *Cymathere triplicata* seed outplanted 19 January 1980. Measurements are from the largest plant in each cluster (n = 5-12).

Location	Measurement (cm)	10 April 1980	12 May 1980	14 July 1980	27 Aug. 1980	26 Sept. 1980
Kelp Bay	length		130 ± 22	128 ± 50	71 ± 38	55 ± 7
	width @ 30 cm		9 ± 1	11 ± 3	12 ± 3	18 ± 1
	thickness @ 10 cm					0.16 ± 0.06
Tzartus I.	length		122 ± 31	98 ± 39	48 ± 25	45 ± 10
	width @ 30 cm		9 ± 2	12 ± 4	12 ± 5	13 ± 3
	thickness @ 10 cm					0.17 ± 0.04
Helby I.	length	80 ± 15	141 ± 47			
	width @ 30 cm	7 ± 3	10 ± 2			
	thickness @ 10 cm	0.06 ± 0.02				



igure seed and individual plan of *Cymathere trip icata* grown the lby sland kombu arm Microscopic eed outplanted January 80 Photographed May 80

The second farm type, the bottom farm, differs from the surface farm in that the plants are held at a constant distance above the ocean bottom, with the depth from surface varying with the tides. The plants are supported by a horizontal rope 2-3 m above the bottom, at a depth of approximately 7-10 m below the surface. Since less drag is encountered by this type of farm, small concrete anchors (ca. 0.5 m^3) are adequate.

The surface farm is designed for both *C. triplicata* and *L. groenlandica*, and the bottom farm for *C. triplicata*, which we feel may show superior growth characteristics at greater depths.

7. Kombu Farms Initiated in 1981

Several new farms have been established in 1981 (Table 12). The purpose of these farms is to test the effects of the following parameters on kombu production: a) geographic location, b) maintenance of plants at constant vs. seasonally altered depth, c) seeding with plants from different sources, and d) the effects of farm type on plant performance.

Two new geographic locations for kombu farms have been added to our study sites. Two farms have been established in Masset, Queen Charlotte Islands, in conjunction with the Haida Band, and two farms have been established on Nelson Island, near Pender Harbour, in co-operation with Tidal Rush Marine Farms. These locations differ from our earlier study sites in that they are both subjected to considerable tidal currents. The Nelson I. site is of particular interest in that the farms are adjacent to an intense salmon farming operation, which may significantly increase the available nutrients required for plant growth. Both the Haida Band and Tidal Rush Marine Farms have expressed interest in future kombu farming.

The success of our farms depends to a large extent on the availability of people to observe the farms on a regular basis. This point is emphasized by the loss of our first Sointula crop to drifting kelp. Drifting kelp and logs are common phenomena in British Columbia coastal waters, and their presence requires regular vigilance.

Table 12. Kombu farms initiated in 1981; (S) refers to the surface farm type and (B) to the bottom farm type.

Location	Seed Type	Seed Source	Seed Outplant Depth
Scott's Bay	*Laminaria groenlandica*	Barkley Sound	(S) 2m from surface
	Cymathere triplicata	Barkley Sound	(S) 2m from surface
Execution Rock	*L. groenlandica*	Barkley Sound	(S) 2m from surface
	C. triplicata	Barkley Sound	(S) 2m from surface
	C. triplicata	Malcolm Island	(S) 2m from surface
Helby I	*L. groenlandica*	Barkley Sound	(S) 2m from surface (S) 5m from surface (S) 2m to be moved to 5m from surface (B) 5m below low water
	C. triplicata	Barkley Sound	(S) 2m from surface (S) 2m to be moved to 5m from surface (B) 5m below low water
	C. triplicata	Malcolm Island	(S) 2m from surface (S) 2m to be moved to 5m from surface (B) 5m below low water
Adamson's Reef	*L. groenlandica*	Barkley Sound	(S) 2m from surface
	C. triplicata	Barkley Sound	(S) 2m from surface
	C. triplicata	Malcolm Island	(S) 2m from surface
Masset Sointula Nelson I.	*L. groenlandica*	Barkley Sound	(S) 2m from surface (B) 5m below low water
	C. triplicata	Barkley Sound	(S) 2m from surface (B) 5m below low water
	C. triplicata	Malcolm Island	(S) 2m from surface (B) 5m below low water

SEED PRODUCTION

Generally, seed of *L. groenlandica* can be predictably produced within 50 days. *Cymathere triplicata* is not as reliable, but we usually can obtain seed plants from our cultures. We presently believe that *C. triplicata* may require a greater light intensity to induce sporophyte production.

Frequently, our cultures become contaminated with a unicellular, non-motile green alga. This plant does not destroy the kombu seed but it appears to retard the seed development.

Approximately 20 strains of *L. groenlandica* and *C. triplicata* are being cultured under red light conditions. These cultures will be used to test for genetic differences between strains and to produce seed at times outside the normal seed production period.

Cultures of *C. triplicata* gametophytes maintained in darkness have been successfully used to produce seed of this species out of season by re-introduction to light.

Cloned *L. groenlandica* seed, produced from red-light reared gametophytes has been outplanted to Adamson's Reef, 28 October 1980. This seed has grown very well and by March 1981 the dimensions of these plants were approaching those of seed planted the previous February (Table 13). The implication here is that this seed, produced out of season and planted late in the year, is now behaving as though in its second year of growth. This discovery opens the possiblity of producing *L. groenlandica* kombu in approximately one year rather than 18 months.

Table 13. Mean dimensions (± 1 S.D.) of cloned *Laminaria groenlandica* seed outplanted to Adamson's Reef 28 October 1980. Measurements are derived from the largest plant in each cluster (n = 15).

Date	Measurements (cm)	
4 Jan. 1981	length	6 ± 4
	width @ 10 cm	2 ± 1
5 Feb. 1981	length	17 ± 9
	width @ 10 cm	8 ± 3
	thickness @ 10 cm	.02 ± .01
10 Mar. 1981	length	49 ± 18
	width @ 30 cm	18 ± 5
	thickness @ 30 cm	.03 ± .01

CLONING OF KOMBU SPOROPHYTES

The culture of kombu is presently dependent, among other things, upon the successful completion of the alternate haploid stage of the laminarialean life history. Since this involves meiotic cell division to produce haploid spores, the genotypes, and therefore the phenotypes, of the sporophytes that arise in the following generation, are unpredictable.

In our previous annual reports, a method was described for cloning the gametophyte generation to produce genetically identical sporophytes. This has proven to be a successful technique, but as pointed out previously, the drawback of this method is that the kombu quality of the sporophyte clones is not known until these plants have reached harvestable size.

For these reasons, we have been attempting to clone the sporophyte directly, and thus bypass meiosis and the gametophytic generation altogether. The techniques used have been modified from Saga *et al.* (1978) and Fries (1980). The basic procedure has been to collect a plant with good kombu qualities and excise the meristematic region at the blade base. This is wiped with paper towels, and immersed in 1% NaOCl for 20-30 min. The tissue is then rinsed in sterile sea water, cut aseptically into pieces approximately 1.0 x 0.5 cm, and these are placed in either liquid or solid sterile enriched medium (PES - Provasoli, 1968; PESI - Tatewaki, 1966; 8g agar$\cdot l^{-1}$). The cultures are then placed in cool white fluorescent light at 10C.

Several age classes of *Laminaria groenlandica* have been cultured in this manner, including laboratory-produced seed 2-4 cm in length. These young plants did not stand up well to treatment in NaOCl, however, and hence all cultures eventually become contaminated. Non-meristematic regions of blades which showed callus-like growth have also been used.

After several weeks in culture, tissue originating from all the above sources showed signs of differentiation into macroscopic tufts of gametophyte-like filaments (Fig. 6). These filaments apparently arose by some other process than meiosis, since care was always taken to ensure that no soral tissue was used for culturing. If this is the case, then these "gametophytes" are diploid, in contrast to the typical haploid laminarialean gametophytes. Similar results were observed by Nakahara and Nakamura (1973), who found diploid monoecious gametophytes developing from diploid blade tissue of *Alaria crassifolia* Kjellm.

In certain older cultures, structures resembling unilocular sporangia have been observed growing as branches from the gametophyte-like filaments (Fig. 6). These have occasionally been observed in the process of releasing flagellated spores (Fig. 6). The spores remain motile for a period of time, then settle down and germinate in a manner similar to typical laminarialean spores, differentiating into filaments appearing identical to those from which the sporangia arose. As yet, we do not know whether mitosis or meiosis within the sporangia give rise to these spores.

Experimentation with various additions to the culture media, i.e. 2.0 $mg \cdot l^{-1}$ indole acetic acid, 0.2 $mg \cdot l^{-1}$ kinetin, 20 $g \cdot l^{-1}$ sucrose, singly and in combination, and controls with no additions, all appear to promote filamentous growth and sporangia production equally well. Thus far, no sporophytes have been observed in these cultures, but we are experimenting with media types, photoperiod, seasonality of original sporophyte tissue used, and alternative culture techniques.

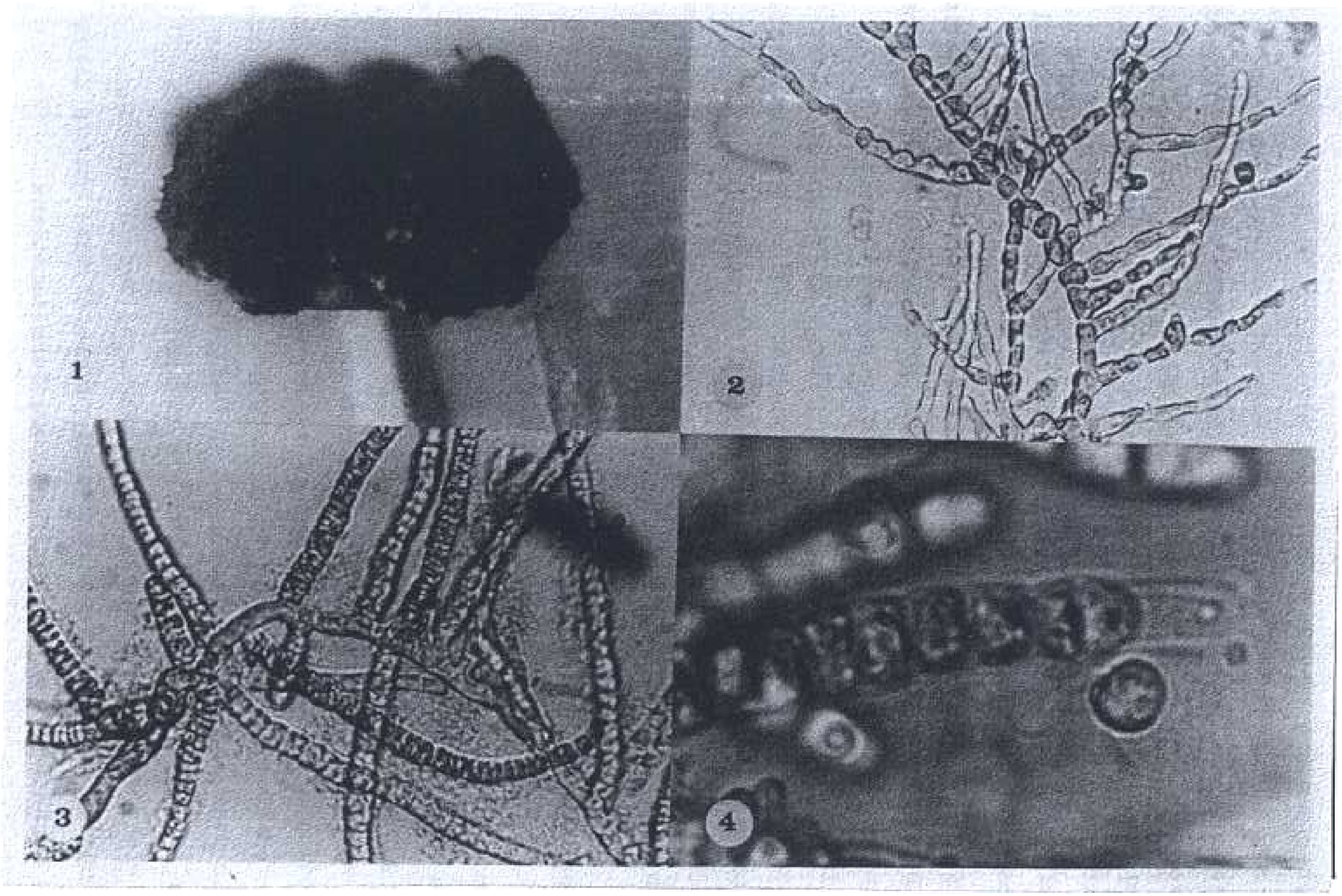


Figure 6. Gametophyte-like plants arising from tissue cultures of *Laminaria groenlandica* sporophytes. 1) Piece of sporophyte tissue on agar with filamentous tufts covering surface (x 23). 2) Detail of filaments in 1) above (x 1000). 3) Filament with structures resembling unilocular sporangia (x 1400). 4) Biflagellated spore just released from sporangium above it (x 6200).

ENVIRONMENTAL MONITORING

1. Epiphytism

Epiphytic fouling of the kombu farms adversely affects the rope structures, and decreases the value of the harvested kombu. We have initiated a comprehensive epiphyte monitoring programme which may provide us with clues as to how to avoid detrimental epiphytism.

In February 1981 we established a series of seeded vertical lines which were attached to some of the existing kombu farms. The degree of epiphytism of these lines as a function of location, depth and time will be quantified using methods described by Roland (1980).

In preparation for the research described above, general observations were made monthly on epiphytes occurring on *L. groenlandica* seed outplanted January-February 1980 (Table 14). the major epiphytes which were abundant during the harvest season were: diatoms, *Membranipora*, and *Obelia*. The nesting gammarid amphipod, though not abundant, did cause considerable damage by gluing portions of the blades together. Generally, the epiphytes were restricted to the older, non-growing blade tissue. However, the protozoan *Ephelota*, and diatoms were common on young growing tissue.

2. Water Motion

Water motion has been recognized as a very important factor affecting the quality of cultured kombu in Japan (Hasegawa, pers. comm.). Nutrient and gas exchange, both primary factors influencing productivity, are directly affected by water movement, since the depth of the boundary layer surrounding a plant is a function of water velocity. Wheeler (1980) has demonstrated that for the giant kelp *Macrocystis pyrifera* (L.) C. Ag., photosynthetic production can be enhanced threefold by increasing water velocity over the blade surface from 0 to 4 $cm \cdot sec.^{-1}$. Water motion which is too violent, however, can limit production (Gerard and Mann, 1979). The importance of this environmental parameter thus necessitates its objective measurement at the various kombu farm locations.

The difficulties involved in measurement of nearshore water motion have been circumvented by most marine ecologists by adoption of a subjective classification system, e.g. "exposed vs. sheltered" terminology.

Table 14. Epiphytes occurring on *Laminaria groenlandica* seed outplanted in Barkley Sound January-February 1980.

Date	diatoms	macroalgae	*Ephelota*	tunicates	*Membranipora*	*Tricellaria*	*Obelia*	gammarid amphipods	egg cases	caprellids	littorines	mussels	crabs
Feb. 1980	X												
March			X										
April	X		X										
	X												
June	X				X		X	X	X	X	X		X
July	X	X		X	X		X	X	X	X	X	X	X
	X			X	X		X	X		X			
	X	X			X	X	X	X	X	X	X	X	
	X	X			X	X	X	X		X	X	X	
					X			X	X			X	
Jan. 1981					X		X	X	X		X	X	
	X				X			X	X		X	X	
March	X		X		X	X	X	X			X	X	

Excluding prohibitively expensive multi-directional flow-meters, there have been as yet no entirely satisfactory objective methods developed. The two most popular procedures involve either a drogue arrangement (Charters *et al.*, 1969; Jones and Demetropoulos, 1968), or the use of plaster of Paris objects whose erosion rates are supposed to reflect the intensity of water motion experienced (Muus, 1968; Doty, 1971; Gerard and Mann, 1979). Both of these methods were investigated for their reliability and applicability to the kombu farm studies.

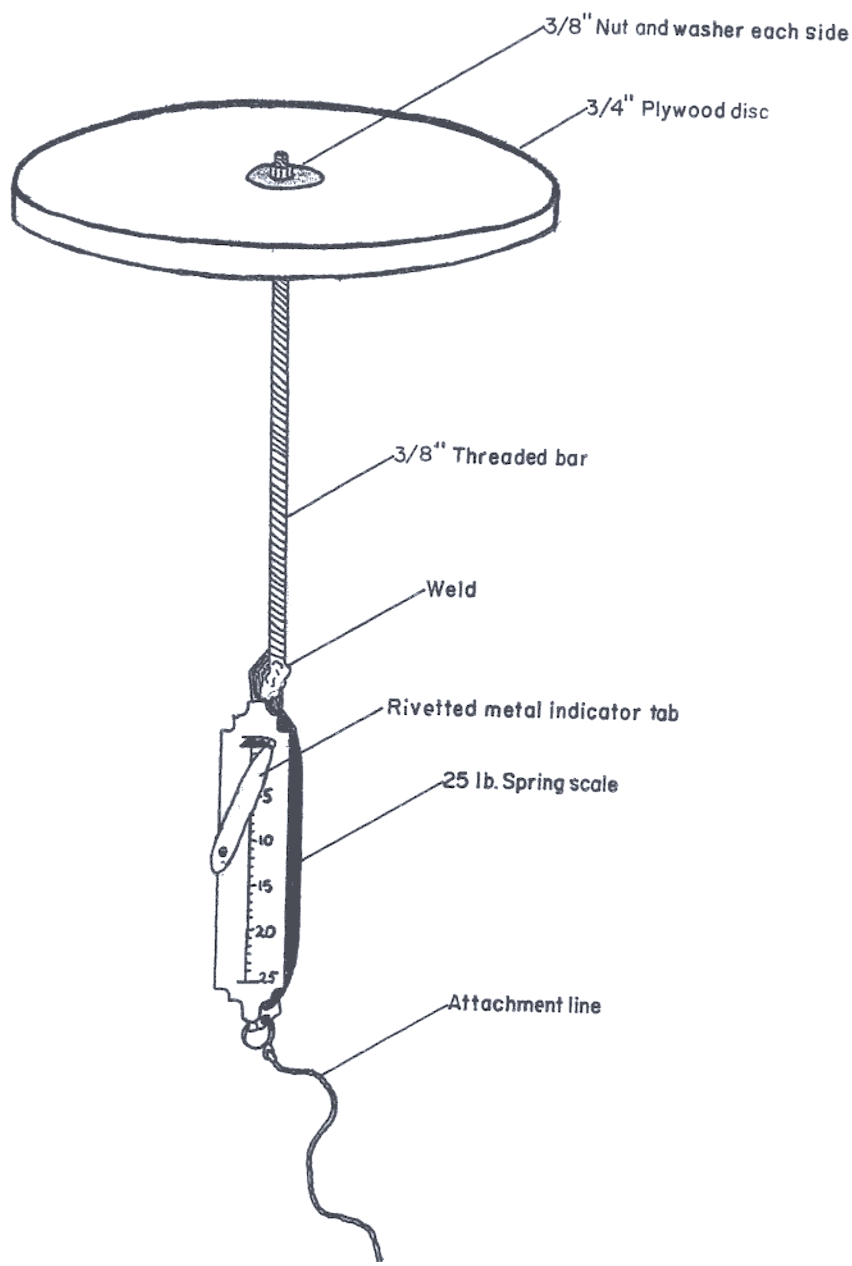
The plaster erosion studies were conducted using plaster of Paris cylinders. The cylindrical shape was recommended by Paul LeBlond (pers. comm.), who contends that other shapes such as the spheres used by Muus (1968) and Gerard and Mann (1979) and the "clod-cards" used by Doty (1971), interfere with water flow by creating local turbulence, which in turn irregularly biases erosion rates. By measuring diameter loss in the mid-section of a cylinder, one is able to get a clearer picture of the dissolution rate caused by laminar flow.

The cylinders were made in PVC (polyvinyl chloride) pipe molds (3 x 11 cm) using three different plaster formulae: a) with latex paint added as recommended by Valerie Gerard (pers. comm., 1980), b) with one half the above amount of latex, and c) with no latex. They were allowed to set for at least two hours after pouring, then oven-dried at 55C for a time period appropriate for each of the formulae tested.

In order to relate cylinder erosion rates to water movement, the cylinders were calibrated in a flow-through water tunnel at discrete water velocities ranging from 0.160 $m \cdot sec.^{-1}$ to 0.755 $m \cdot sec.^{-1}$. The water tunnel used was a flow-through respirometer designed to study fish swimming physiology. Temperature, which can affect dissolution rates (Muus, 1968), was maintained at 11C ± 1C with a thermostatically controlled refrigeration system. Control cylinders were suspended in still water at 11C for the same time period as their corresponding test cylinders. Mid-section diameters were recorded upon removal from the water. In later studies when weight loss was also considered, the cylinders were redried at 55C and reweighed.

The drogues used in this study measure maximum drag caused by water movement during a given observation period (Fig. 7). They were attached to the horizontal kombu lines so that they would float below the surface

Th drogu .gne quan .fy water mo



of the water. Passing waves and currents pull on the wooden disc causing extension of the graduated spring scale which in turn causes the riveted tab to record a reading.

The drogues were calibrated in the tidal narrows in Grappler Inlet. Water velocity was measured by recording the time it took a neutrally buoyant marker (grapefruit) to pass along a 10 m line, and corresponding readings were taken on the drogue.

The calibration results for the plaster/latex cylinders (both formulae) were poor, with no observable trend in the relationship between water velocity and dissolution rates. In calibrating the no-latex cylinders, both diameter and weight changes were considered, since preliminary field tests indicated length differences in cylinders which were set out at the Execution Rock and Kelp Bay farms. Figure 8 shows the results of the no-latex cylinder calibrations. Although the variability was great, erosion rates appeared to increase as a function of water velocity.

The drogue calibration results are shown in Figure 9. Variability was again high but not unexpected, considering the crude nature of the devices and the calibration technique.

In conclusion, we have elected to use the drogues to quantify the water motion at each kombu farm. Their inexpensive construction and ease of calibration makes them suitable for our needs. We are now prepared to quantify water motion, perhaps the last remaining major environmental variable in our monitoring programme.

3. Physical and Chemical Parameters, Excluding Water Motion

An environmental monitoring programme designed to assist in identifying optimal sites for kombu farming, and to better understand the plants' response to a seasonally changing environment, has been conducted at all farm sites in Barkley Sound. Seasonal change in all monitored environmental variables is illustrated for two kombu farms -- Helby I. and Kelp Bay (Fig. 10).

To test for seasonal differences for each parameter at each farm site we arbitrarily divided the year into a summer period (April-October) and a winter period (October-April). The mean values for each period were compared using a Student's t test, with data for April and October omitted. Environmental data were collected weekly.

Figure 8. Relationship between diameter loss of plaster of Paris cylinders and water velocity. Vertical bars indicate S.D., n = 4.

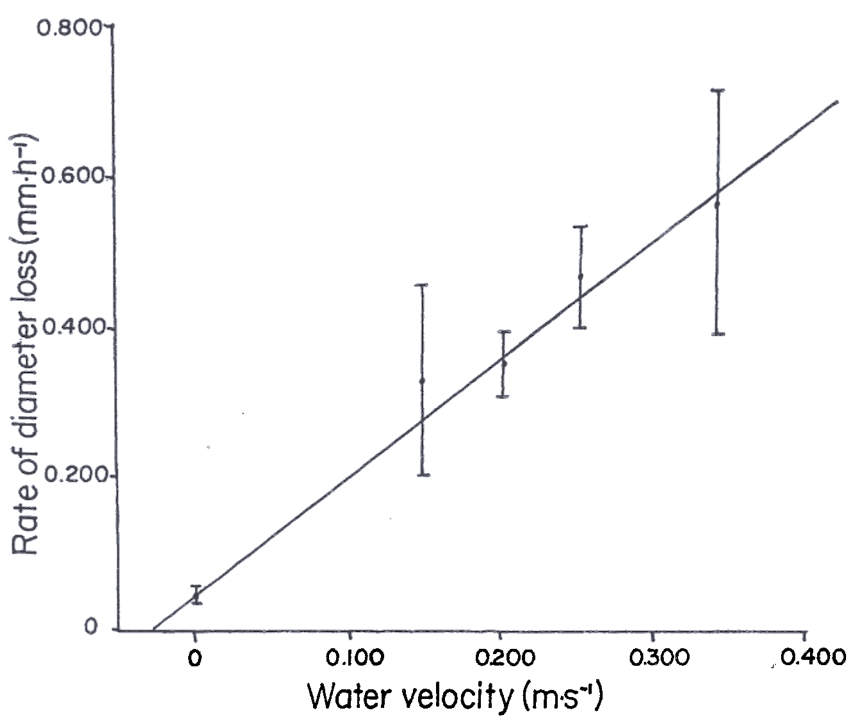
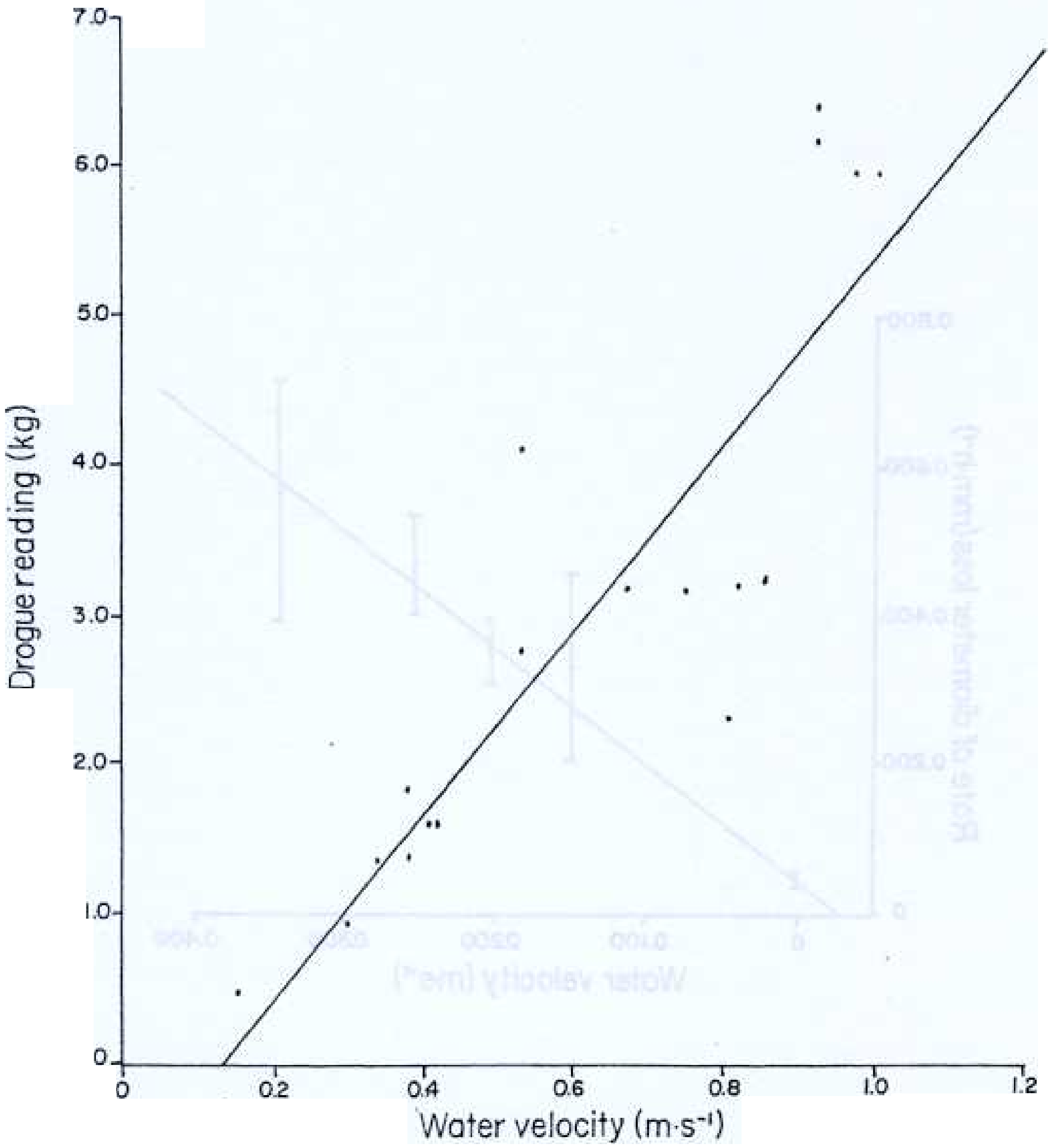


Figure 9. Relationship between drogue readings and water velocity. (r=0.88)



Significant seasonal differences were observed for all parameters monitored, excepting cloud cover, for at least one kombu farm site (Tables 15, 16). Seasonal differences in seawater temperature were pronounced at all farms and depths, whereas salinity was consistently distinctive only at 4 m depth. Nutrients showed the greatest seasonal fluctuations at surface and 1 m depths, with seasonality becoming indistinguishable at 4 m.

To test for differences between the kombu farms, a one-way analysis of variance was conducted on summer and winter data for each environmental parameter (Table 17).

The seven farms could be distinguished only by surface salinity and sea state during the winter period. These two parameters also distinguished the farms during the summer period, and with a higher probability. Several other environmental parameters also distinguished the seven kombu farms during the summer (Table 17). The parameters which best distinguished the farms ($P \leq 0.001$) were seawater temperature (surface, 1, 2 m), salinity (surface, 1 m), sea state, NH_4 (1 m), and PO_4 (1 m). Water transparency (K value, secchi depth), cloud cover and NO_2 were of no value in distinguishing stations ($P > 0.05$).

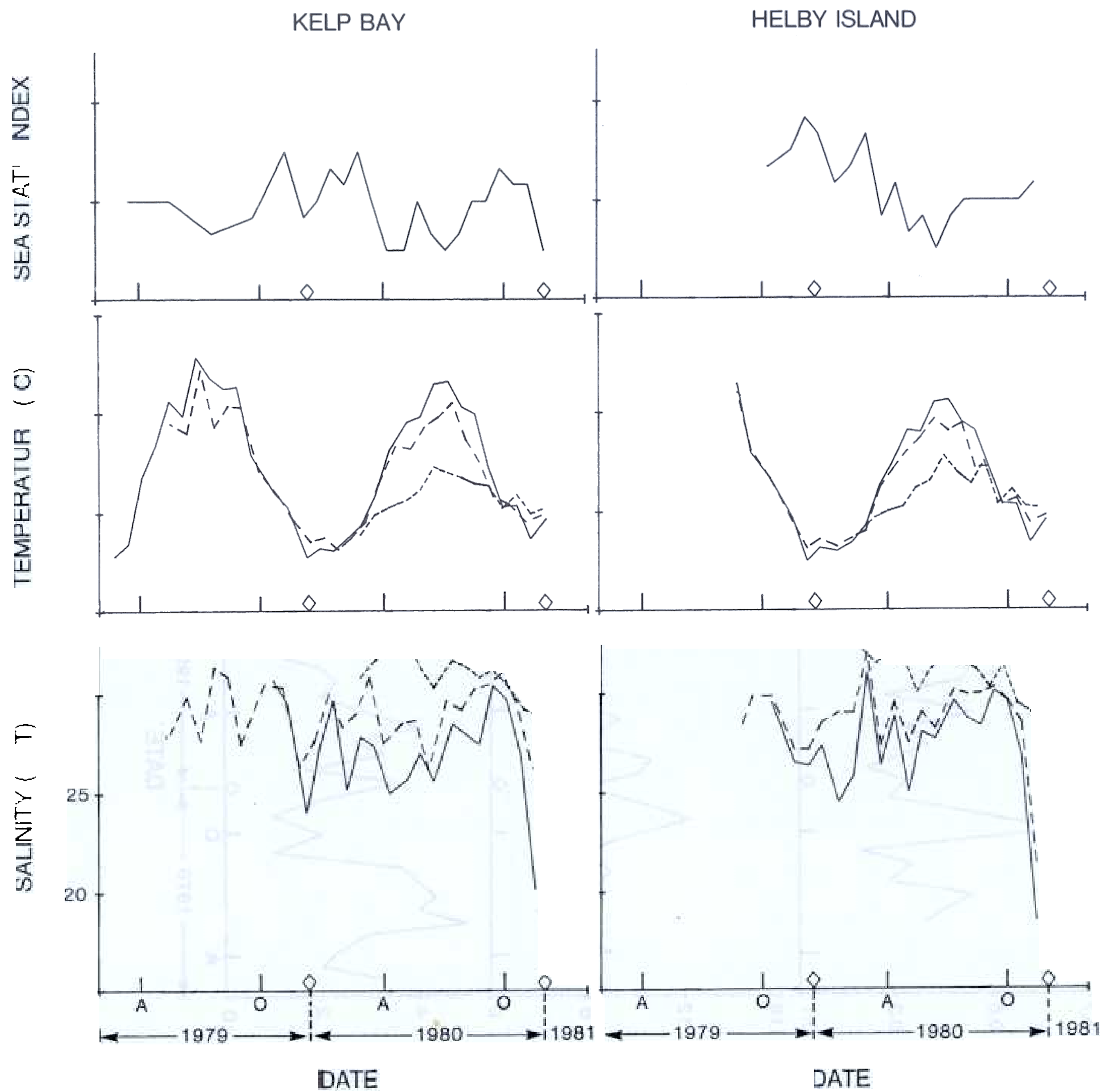
These data indicate that to distinguish between sites one need only monitor a few parameters during the summer period. However, year-round data on a wide range of environmental parameters are required to understand biological processes important to the growth and maturation of kombu.

We will continue to collect data for all parameters at all Barkley Sound sites until June 1981, at which time the kombu will be harvested. The biomass and morphological features of the plants harvested from each site will be compared with the environmental features of that site. This process will determine which environmental parameters that distinguish the farms, also predict the best sites for farming kombu.

An attempt is being made to conduct an environmental monitoring programme at the kombu farms outside Barkley Sound. However, the lack of instrumentation and the difficulty of analyzing nutrients at the time of collection limits the variables we can assess.

During 1980 the Marine Resources Branch collected some nutrient data at the Sointula kombu farm (Table 18). The values recorded for Sointula are considerably higher than those for Barkley Sound sites.

Figure 10. Seasonal variation in all monitored environmental variables for Helby Island and Kelp Bay. Readings were taken weekly. The values presented are the average of three consecutive weekly readings. Where more than one line occurs on a graph the solid line represents surface conditions, the long dash represents conditions at 1 m and the short dash represents conditions at 4 m. The sea state index is a scale of 1 (calm) to 5 (heavy seas). K values represent the light extinction coefficient between 1 and 3 m.



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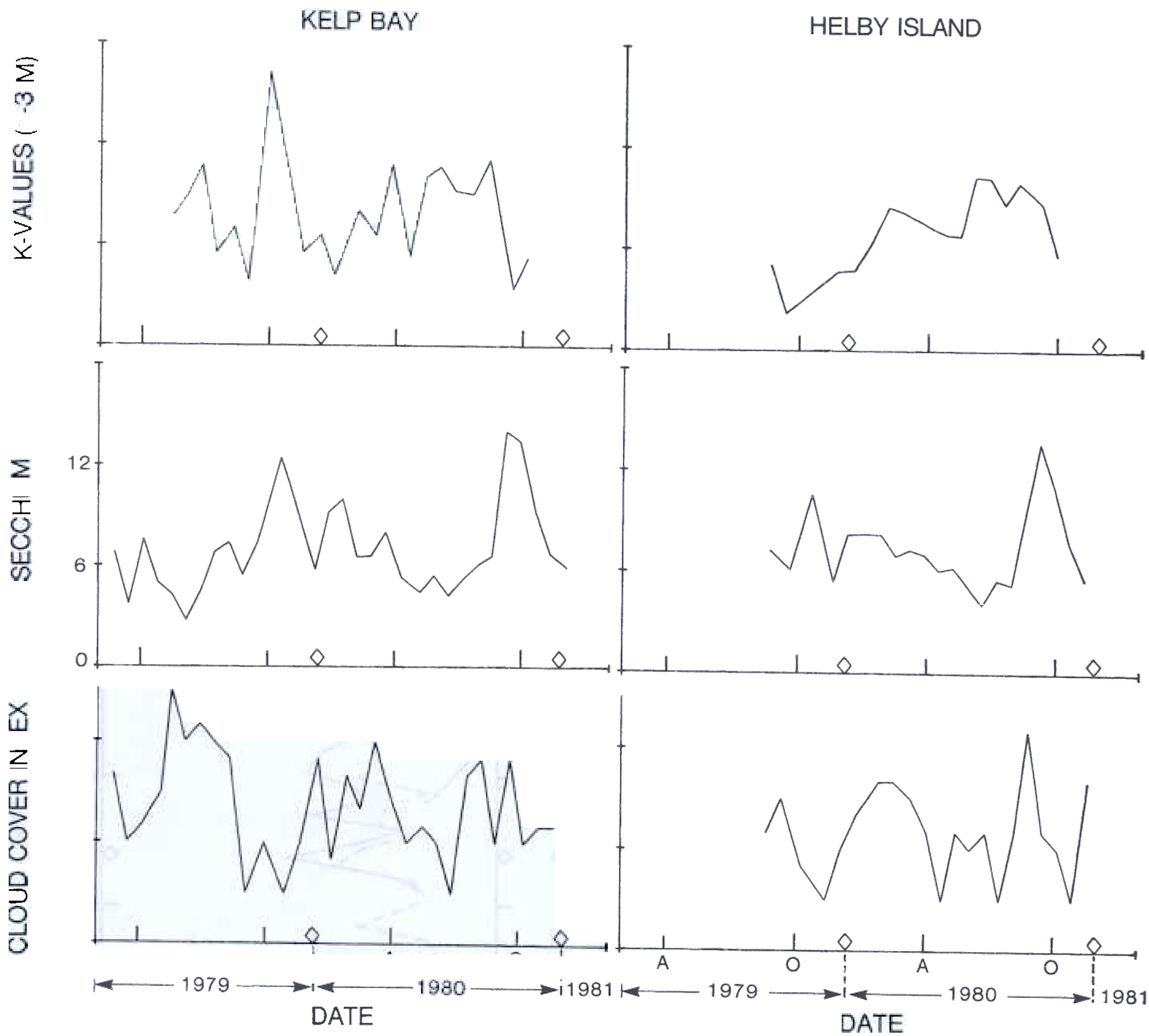

KELP BAY
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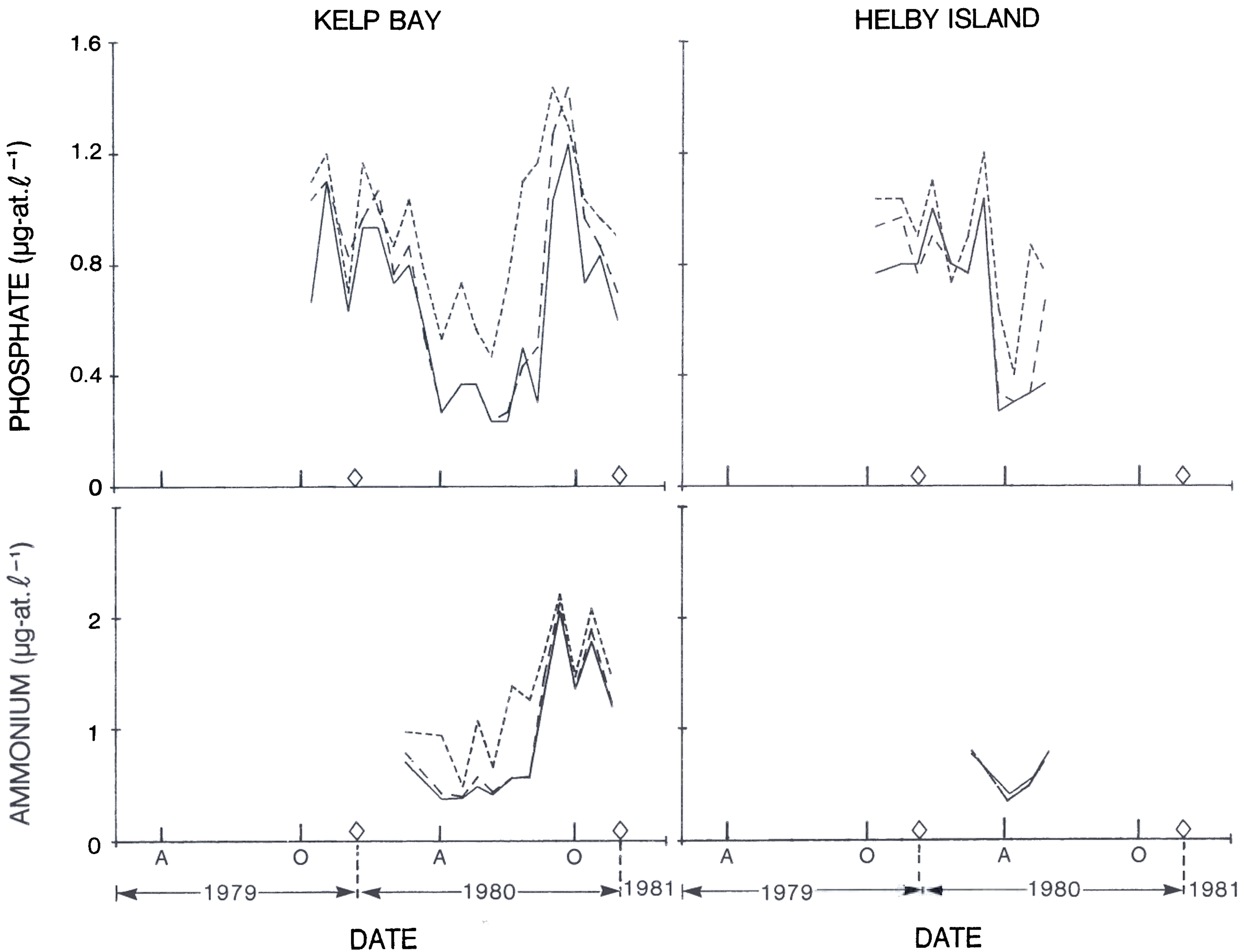

KELP BAY
HELBY ISLAND
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AMMONIUM (µg-at.ℓ⁻¹)
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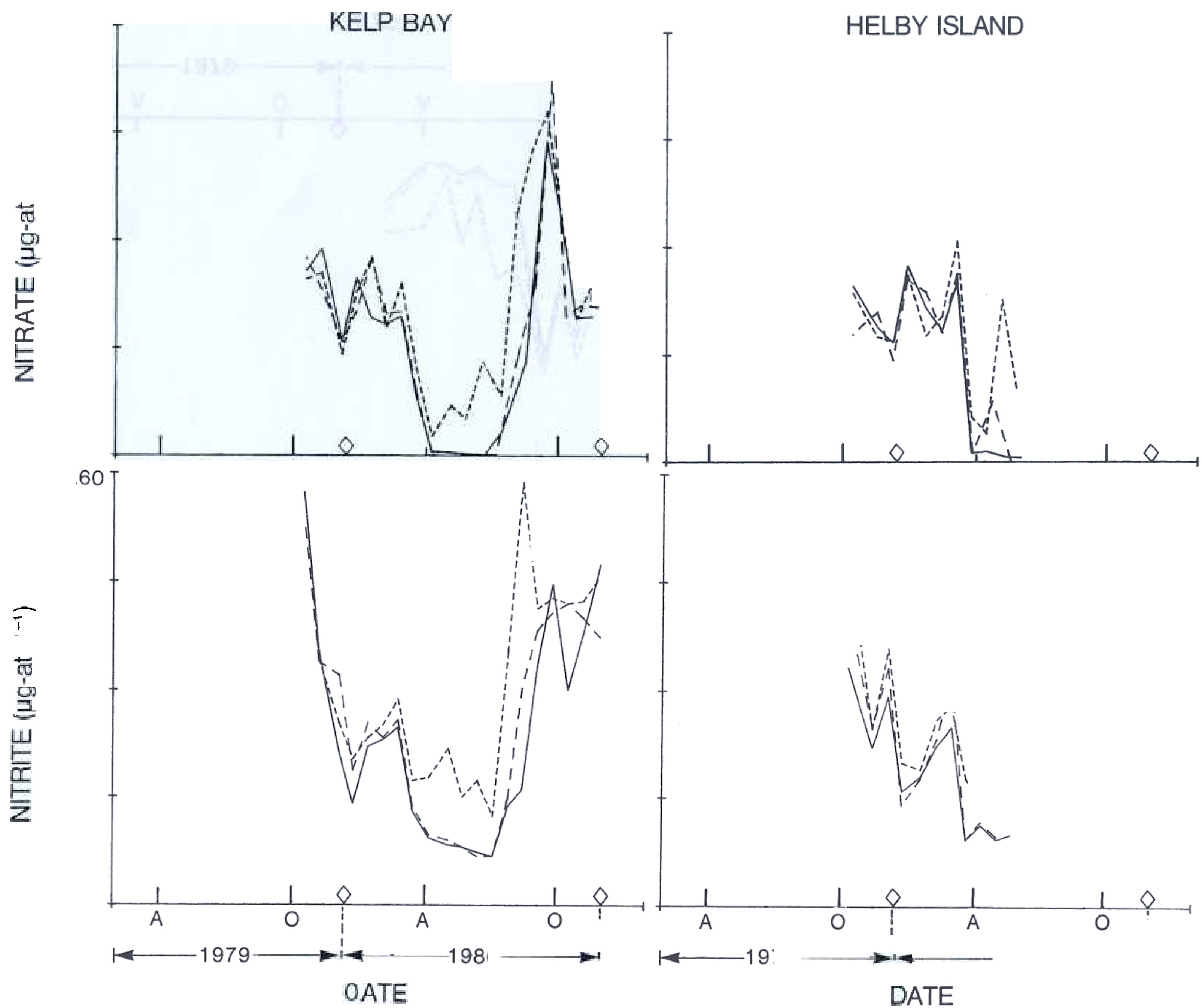
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NITRITE (µg-at ·-1)
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Table 15. Mean values for summer (S) and winter (W) periods for the environmental parameters studied (excluding nutrients). Data were collected weekly, and at most locations in excess of one year. Underlined data indicate a significant difference between seasons ($P \lesssim 0.05$). Sea state was judged from calm (1) to heavy swell (5). Cloud cover was judged from clear sky (1) to total cover (5). K value is the light extinction co-efficient between 1 and 3 m below the surface.

Parameter	Execution Rock		Scott's Bay		Bamfield		Kelp Bay		Helby I.		Tzartus I.		Adamson's Reef	
	S	W	S	W	S	W	S	W	S	W	S	W	S	W
K Value	0.43	0.33	0.42	0.29	0.41	0.33	0.38	0.31	0.37	0.33	0.39	0.30	0.41	0.28
Secchi Depth (m)	6.4	7.6	5.7	7.1	5.2	8.0	5.4	8.1	5.9	7.7	5.4	7.6	4.9	8.3
Temperature (C)														
surface	13.4	9.1	14.6	9.1	14.8	8.9	15.5	9.1	14.5	9.1	15.3	8.8	15.0	8.8
1 m	12.9	9.2	14.4	9.2	14.5	9.2	15.2	9.2	14.2	9.2	15.1	9.0	14.8	9.0
2 m	12.4	9.3	13.8	9.6	14.1	9.6	14.5	9.4	13.7	9.4	14.5	9.4	14.0	9.2
4 m	11.7	9.4	11.6	9.6	12.1	9.7	12.3	9.6	12.3	9.6	12.4	9.6	12.7	9.4
Salinity ($^{o}/oo$)														
surface	29.0	26.8	28.4	27.3	28.3	25.0	27.0	27.0	28.0	26.1	25.9	23.5	28.1	26.2
1 m	29.7	27.8	28.4	27.6	28.4	27.5	27.5	27.5	28.3	26.7	26.8	25.1	28.4	27.8
2 m	30.6	28.6	29.6	28.6	29.4	28.7	28.9	28.3	29.0	27.8	28.9	27.3	29.5	28.9
4 m	31.1	29.3	30.9	29.3	31.2	29.5	31.0	29.6	30.5	29.3	30.3	28.8	30.4	29.0
Sea state	2.8	3.8	2.0	3.7	1.4	2.4	1.5	2.2	1.7	2.6	1.7	1.9	2.6	3.9
Cloud cover	2.1	3.1	2.2	2.4	2.3	2.3	3.0	2.5	2.0	2.3	2.6	2.6	2.1	2.7

Table 16. Mean values for summer (S) and winter (W) periods of the nutrients monitored. Data were collected weekly and at most locations in excess of one year. Underlined data indicate a significant difference between seasons ($P \leq 0.05$).

Nutrient	Execution Rock		Scott's Bay		Bamfield		Kelp Bay		Helby I.		Tzartus I.		Adamson's Reef	
($\mu g\text{-}at \cdot l^{-1}$)	S	W	S	W	S	W	S	W	S	W	S	W	S	W
NH_4 surface	0.85	1.43	0.77	1.40	0.69	1.54	0.49	1.19	0.61	1.49	0.60	1.17	0.61	1.42
1 m	1.10	1.49	0.81	1.43	0.72	1.42	0.52	1.25	0.60	1.49	0.64	1.26	0.60	1.32
4 m	1.35	1.48	1.44	1.38	1.17	1.47	0.93	1.40	1.03	1.64	1.12	1.54	1.03	1.39
NO_3 surface	3.05	7.31	1.71	7.41	1.37	7.44	0.33	7.38	0.70	10.01	0.77	6.64	0.53	6.63
1 m	4.48	7.27	2.53	7.64	1.99	7.33	0.99	7.47	1.86	6.34	0.75	7.33	0.61	6.95
4 m	8.49	7.46	8.22	7.80	5.95	7.38	5.13	7.64	6.24	6.50	5.77	7.26	5.01	7.32
NO_2 surface	0.19	0.31	0.16	0.29	0.17	0.29	0.10	0.32	0.13	0.29	0.13	0.32	0.12	0.27
1 m	0.24	0.29	0.19	0.31	0.18	0.32	0.12	0.33	0.17	0.28	0.15	0.33	0.13	0.29
4 m	0.31	0.30	0.34	0.33	0.25	0.33	0.26	0.35	0.26	0.32	0.29	0.39	0.25	0.31
PO_4 surface	0.52	0.85	0.42	0.87	0.41	0.85	0.33	0.82	0.39	0.85	0.33	0.87	0.33	0.75
1 m	0.70	0.85	0.53	0.92	0.65	0.96	0.36	0.95	0.41	0.83	0.38	0.83	0.33	0.84
4 m	0.97	0.89	1.00	1.00	1.10	0.99	0.77	1.02	0.91	0.97	0.86	0.93	0.68	0.92

Table 17. A one-way analysis of variance comparing summer values and winter values for each environmental parameter separately, between the seven kombu farms. Degrees of freedom >136. Underlined values are P≤0.05.

Parameter	P (Probability) Value: Summer	P (Probability) Value: Winter
K Value	0.703	0.781
Secchi Depth	0.224	0.680
Temperature (surface)	<0.001	0.926
Temperature (1 m)	<0.001	0.974
Temperature (2 m)	<0.001	0.904
Temperature (4 m)	0.048	0.960
Salinity (surface)	<0.001	0.034
Salinity (1 m)	<0.001	0.092
Salinity (2 m)	0.030	0.335
Salinity (4 m)	0.048	0.649
Sea state	<0.001	<0.001
Cloud cover	0.118	0.852
NH_4 (surface)	0.019	0.841
NH_4 (1 m)	<0.001	0.946
NH_4 (4 m)	0.061	0.969
NO_3 (surface)	0.010	0.213
NO_3 (1 m)	0.002	0.264
NO_3 (4 m)	0.287	0.396
NO_2 (surface)	0.621	0.859
NO_2 (1 m)	0.556	0.864
NO_2 (4 m)	0.751	0.662
PO_4 (surface)	0.060	0.822
PO_4 (1 m)	0.001	0.098
PO_4 (4 m)	0.494	0.478

Table 18. Mean nutrient concentrations observed during 1980 at the Sointula kombu farm. Data provided by the Marine Resources Branch, Ministry of Environment.

Month	(n)	μg-at.N·l^{-1} (NO_3 + NO_2)		μg-at.P·l^{-1} (PO_4)	
		Surface	2 m	Surface	2 m
July	(2)	8.70	11.65	1.06	
August	(4)	15.02	10.89	1.57	
September	(4)	15.17	13.07	1.74	1.58
October	(1)	10.99	19.25	1.56	

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