Fishery Research Bulletin No. 91-03

Assessment of the Recovery of Rockweed Kelp, *Fucus*, Following Experimental Removals and Observations On Its Growth Under Natural Conditions in Norton Sound, Alaska

by

Gene J. Sandone

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Alaska Department of Fish and Game

Division of Commercial Fisheries

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ACKNOWLEDGMENTS

A feasibility study concerning the growth and recolonization of *Fucus* in Norton Sound was conducted by Daniel Bergstrom in 1983. Mr. Bergstrom's investigation laid the groundwork for field methods contained in this report. Many people contributed toward the collection and processing of the *Fucus* growth and recolonization data of this report. Alaska Department of Fish and Game employees making important contributions included Hubert Angaiak, Craig Whitmore, Lisa Gluth, Gary Knuepfer, Charles Lean, William Arvey, Debby Burwen, and Helen Hamner. Biometric support was provided by Linda Brannian. Critical review of this manuscript by Linda Brannian, William Arvey, Lawrence Buklis, and Charles Lean was appreciated.

ABSTRACT

The commercial harvest of Pacific herring *Clupea harengus pallasi* spawn on kelp for human consumption was initiated in Norton Sound in 1977. Rockweed kelp *Fucus sp.* dominates the intertidal community of Norton Sound and comprised 100% of the plant material in the spawn-on-kelp harvest. Concern has been expressed by Alaska Department of Fish and Game staff and by members of the public that the repeated and continued annual commercial harvest of spawn on kelp from the same specific area in conjunction with other natural factors may eliminate local populations of *Fucus*. Elimination or degradation of the *Fucus* beds within the major spawning grounds would in turn decrease herring spawning success. This study was initiated in 1984 to address this concern by estimating recolonization rates, recovery time, and growth rates of the *Fucus* resource in southern Norton Sound. Although Norton Sound has been closed to the commercial harvest of herring spawn on kelp since 1985, future commercial spawn-on-kelp harvests are possible through regulatory changes by the Alaska Board of Fisheries. The results of this study could be useful in formulating management strategies for these fisheries.

Area recolonization and population recovery of rockweed kelp *Fucus sp.* in southern Norton Sound, Alaska was evaluated based on measurements of percentage of cover, total number of plants, number of harvestable plants, and biomass following experimental harvesting. No significant differences in percent cover, number of harvestable plants, and biomass were observed in control plots during the study period. However, total number of plants observed in control plots in August 1985 were significantly greater than observed in June and September 1984. Kelp bed plots subjected to a simulated spawn-on-kelp harvest were statistically indistinguishable from control conditions after one growing season (June–September 1984). Plots subjected to complete removal of all plants required two growing seasons (June 1984–August 1985) to approximate control conditions. Mean recolonization rates of denuded areas exceeded 9,000 plants per m^2. Growth rates of individual *Fucus* plants of up to 128 mm per growing season were deemed adequate to insure rapid replacement of harvested large plants. I concluded that annual harvests of spawn on kelp from the same kelp bed will not have detrimental effects on *Fucus* population size or structure in southern Norton Sound.

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INTRODUCTION

Pacific herring *Clupea harengus pallasi* annually spawn in Norton Sound, Alaska (Figure 1), between mid-May and late June. Herring deposit their adhesive eggs primarily on kelp *Fucus sp.* and inorganic substrates in the intertidal and subtidal zones of the shoreline. Hatching usually occurs within 15 to 20 d depending on water temperatures (Outram 1985). Aerial survey observations of herring milt releases, in conjunction with spawn deposition surveys, have indicated that the major herring spawning grounds in Norton Sound occur within the St. Michael Subdistrict of southern Norton Sound (Figure 2).

The commercial harvest of herring spawn on kelp was initiated in Norton Sound in 1977 with the delivery of less than 1.0 tonne. The harvest increased in subsequent years, peaking in 1981 with a documented harvest of 42.2 tonnes (Table 1; Lebida et al. 1985). *Fucus* comprised 100% of the plant material in the wild spawn on kelp harvest. The commercial harvest of spawn on kelp was prohibited in Norton Sound by regulation in 1985 (ADF&G 1985). Total estimated value of the annual harvest to the fishermen has varied from $2,723 in 1978 to $73,000 in 1980 (Table 1). The contribution of the spawn-on-kelp harvest to the total exvessel value of the Norton Sound commercial herring fishery has ranged from 2% in 1979 and 1984 to 45% in 1978. However, during the last 4 years of the fishery the spawn-on-kelp harvest contributed less than 6% to the total exvessel value of the Norton Sound commercial herring fishery.

Both the sac roe and spawn-on-kelp herring fisheries of Norton Sound have been managed under emergency order authority. Guideline harvest levels prevent overexploitation of the herring resource and provide for an orderly and annual sustained harvest. In-season management regulation of the herring spawn-on-kelp fishery commenced in 1981 with the closure of the commercial season by the Alaska Department of Fish and Game (ADF&G). In subsequent years both the opening and closing of the fishery were regulated by emergency order authority. An area-specific closure around Stuart Island (Figure 2), initiated prior to the 1980 commercial season, limited the area open to the commercial harvest of spawn on kelp in Norton Sound (ADF&G 1980). This closure was specifically designed to protect the subsistence spawn-on-kelp harvest (C. Lean, Alaska Department of Fish and Game, Nome, personal communication). Subsequently, an additional area between Wood Point and the mouth of Wagon Box Creek (Figure 2) was closed to the taking of herring spawn on kelp prior to the 1981 commercial fishery (ADF&G 1981). This closure was designed to protect the *Fucus* resource from overexploitation (C. Lean, Alaska Department of Fish and Game, Nome, personal communication). In 1982 this area-specific closure was extended to include the coastal area between Wood Point and Golsovia River (Figure 2). A 30-tonne spawn-on-kelp harvest guideline for the coastal area between Canal Light Point and Wood Point in southern Norton Sound was also adopted by the Alaska Board of Fisheries prior to the 1982 commercial herring fishing season (ADF&G 1982). The spawn-on-kelp fishery closure in 1985 mollified public concerns regarding the possible overexploitation of the herring resource (L.J. Schwarz, Alaska Department of Fish and Game, Kodiak, personal communication).

Concern was expressed within ADF&G and by members of the public over the possible degradation and decimation of the *Fucus* resource by the repeated annual harvest of herring spawn on kelp, specifically in the vicinity of Leibes Cove near the village of St. Michael (Figure 2). This area supported a large portion of the annual commercial spawn-on-kelp harvest. Although Norton Sound is presently closed to the commercial harvest of herring spawn on kelp, future commercial harvests are possible through regulatory changes by the Alaska Board of Fisheries.

The intertidal plant community of Norton Sound, which is dominated by *Fucus*, appears to be continually threatened by the harsh environmental conditions of Norton Sound. Ice scour, intensive wave action, freeze desiccation, and possible slow growth and recolonization rates because of the cold temperatures and short growing season, are factors which may inhibit *Fucus* survival in Norton Sound. Concern has been expressed that repeated and continued annual commercial harvest of spawn on kelp from the same specific area in conjunction with other natural factors may eliminate local populations of *Fucus*. Elimination or degradation of the *Fucus* beds within the major

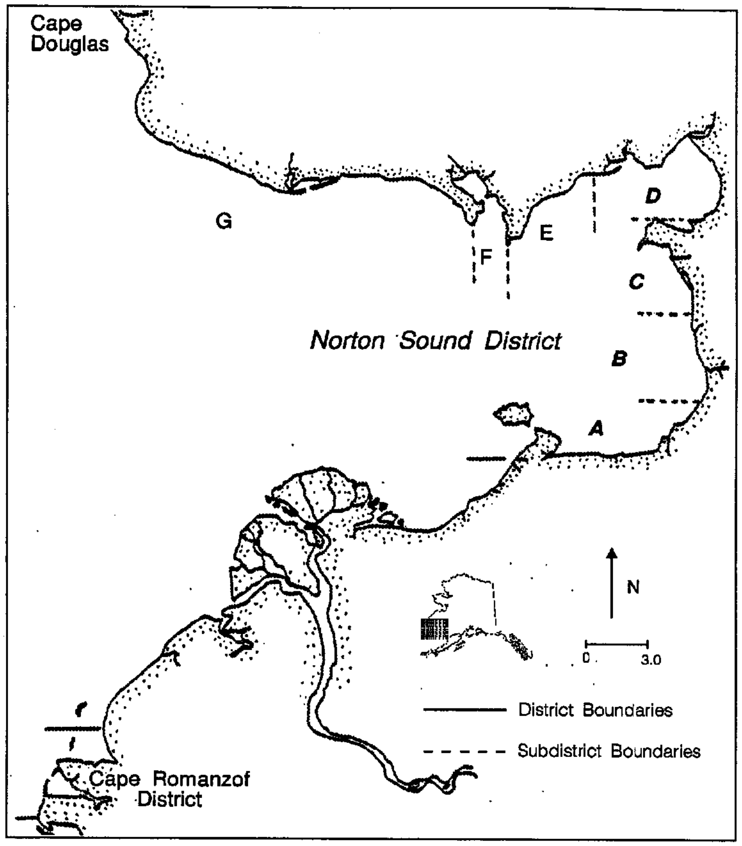

FIGURE 1.—Subdistricts of the Norton Sound District in the eastern Bering Sea, Alaska, where A = St. Michael, B = Unalakleet, C = Cape Denbigh, D = Norton Bay, E = Elim, F = Golovin Bay, and G = Nome Subdistricts.

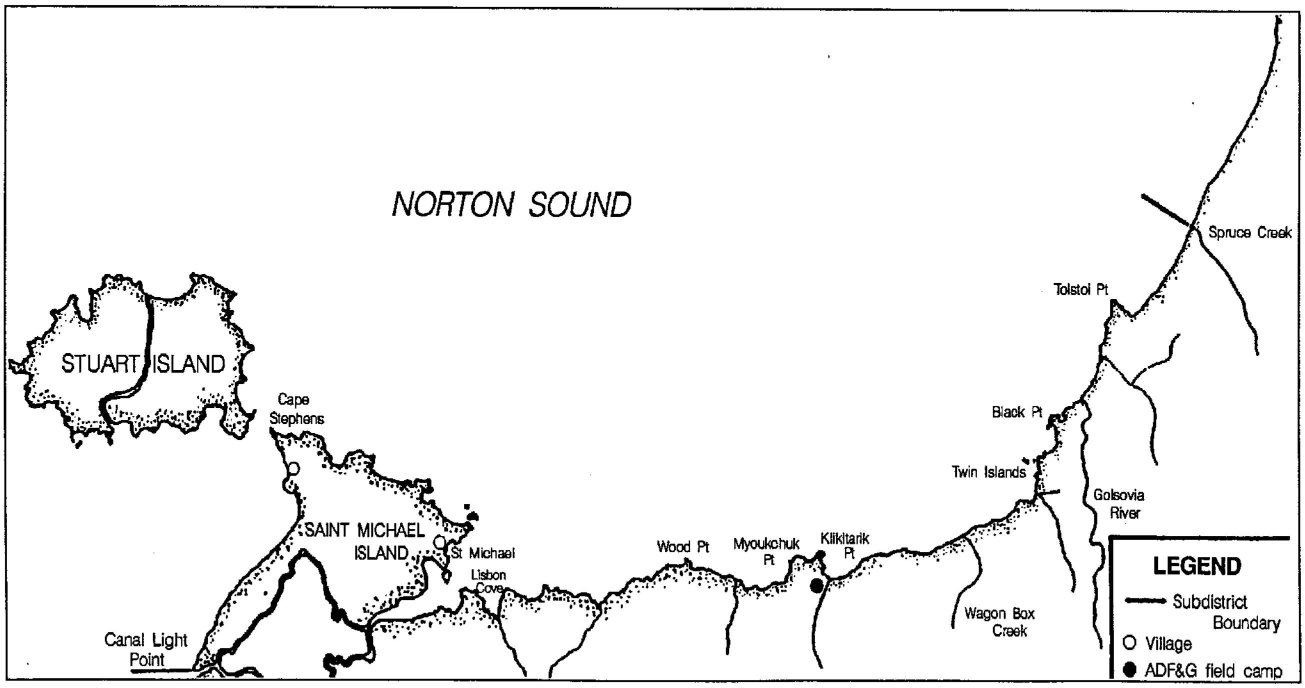

FIGURE 2.—St. Michael Subdistrict of the Norton Sound District in the eastern Bering Sea, Alaska.

spawning grounds would in turn decrease herring spawning success.

In 1978, ADF&G began intensive studies of the *Fucus* resource in the Togiak area of Bristol Bay (Figure 3) in response to concerns of possible overexploitation of *Fucus* in the intertidal and subtidal zones (Clark and Buklis 1978; McBride et al. 1982). These studies attempted to monitor *Fucus* biomass within the Togiak area from 1978 to 1981. Although the point biomass estimate decreased over the years, significant differences could not be demonstrated primarily because of the large variance associated with the samples (McBride et al. 1982). Based upon growth and recolonization of *Fucus* in Bristol Bay, Stekoll et al. (1984) recommended that harvested beds in that area of Alaska be closed for two growing seasons to allow the plants to recover to pre-harvest biomass and plant size-frequency levels.

This study was initiated to determine the recolonization rates, recovery time, and growth rates of *Fucus* in Norton Sound and to provide information from which the effects of repeated spawn-on-kelp harvests on the *Fucus* population could be extrapolated. Additionally, the results of this study could be useful in formulating management strategies for possible future commercial spawn-on-kelp fisheries. The specific objectives were:

1. determine the response of the *Fucus* biomass to harvest as well as to a removal of all *Fucus* plants;
2. determine *Fucus* recolonization rates in denuded areas; and
3. determine the growth rates of individual *Fucus* plants under natural conditions.

TABLE 1.—Harvest, number of fishermen, and estimated value of the commercial spawn-on-kelp (*Fucus*) harvest in Norton Sound District, 1977–1985 (adapted from Lebida et. al 1985).

Year	Harvest (tonnes)	Number of Fishermen	Estimated Value ($)
1977	< 1.0		
1978	3.4	0	2,723
1979	11.8	19	15,576
1980	22.2	20	73,000
1981	42.2	22	45,000
1982	34.9	74	57,585
1983	26.5	35	38,500
1984	17.5	32	21,500[a]
1985[b]			

a Harvest of 3.0 tonnes of spawn on kelp from 0.91 tonnes of imported *Macrocystis sp.* not included in the totals. Estimated value was $20,000.

b Commercial spawn-on-kelp harvest prohibited in Norton Sound by regulation.

METHODS

Recovery

Two 50-m study transects were established in the St. Michael Subdistrict during the summer of 1984: (1) near Klikitarik Point and (2) near Twin Islands ap-

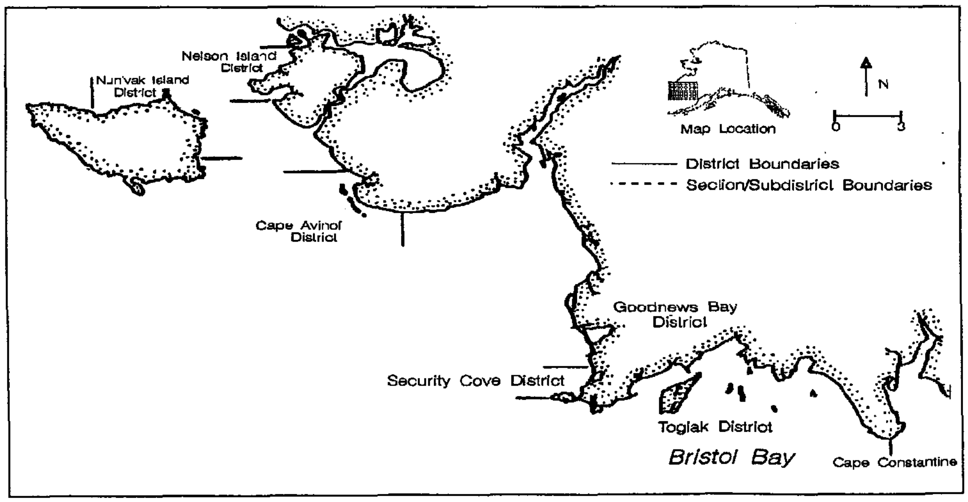

FIGURE 3.—Togiak District in the eastern Bering Sea, Alaska.

proximately 13 km east of Klikitarik Point in the Black Point area (Figure 2). A third transect established near Myouchuk Point was completely destroyed by ice scour during the 1984–85 winter and no data were obtained. Selection of transect location was dependent upon uniformity of the bed and the topography of the rock substrate. All transects were located within the lower half of the intertidal zone. Individual transects were defined by headpins epoxyed into the rock substrate. Transect headpins were located measured distances and directions from either obvious landmarks or established fence posts.

Each study transect consisted of 18 plots, each 0.25 m^2 in size, randomly distributed along the transect. Six plots were randomly selected to serve as controls, and six were selected for each of two treatment types. The two treatment types included (1) removal of all vegetation from the plot (called the *removal treatment*), and (2) removal of all plants greater than approximately 5 cm in length to simulate a commercial spawn-on-kelp harvest (called the *harvest treatment*). Vegetation in control plots was not disturbed. The harvest treatment was designed to approximate the damage done to *Fucus* beds by a spawn-on-kelp harvest. Each plot was defined by epoxy cement markers on at least two corners. Individual plots were identified by a numbered Petersen disc tag glued on one of the marked corners.

Prior to treatment and during subsequent sampling periods, percentage of cover, and depth of *Fucus* as it lay undisturbed on the substrate were examined for each plot in both transects. Estimates of percentage of cover were made visually by either assessing the plot as a whole or by calculating the mean of 25 subplot estimates. The depth of undisturbed *Fucus* was also measured (nearest 0.5 cm) at 25 equidistant locations within each plot. Means of the arithmetic and geometric depths and percentage of cover were used in an attempt to estimate the *Fucus* biomass within a plot.

Prior to treatment all plots were assumed to have been previously undisturbed. *Fucus* biomass, plant number, and plant length data were collected from 11 of the 12 removal treatment plots at the time plots were initially treated in June 1984. Data from these plots were considered representative of the 12 undisturbed control plots. The *Fucus* biomass removed from 1 of the 12 treated plots appeared dead, perhaps from freshwater influence of melting ice. Therefore, the biomass of this plot was discarded and not used in further analysis.

McConnaughey (1985) recommended that 2 to 3 years be allowed between harvests on individual *Fucus* beds in Bristol Bay. Therefore, this study was designed for three growing seasons. One-third (four) of the treated and control plots were to be assessed for biomass and length frequency distribution each year following treatment. Because the assessment destroyed all kelp plants growing within the sampled plot, transects would be exhausted of plots after three perannum sampling periods. However, ice scour during the winter and spring months damaged the definitions of some plots reducing the number available. Because of the lack of undisturbed study plots for analysis, the study was terminated after two growing seasons .

Sampling periods were selected to coincide with the end of the growing season in Norton Sound. *Fucus* growth was assumed to have effectively ended by late August or early September. Therefore, sampling of *Fucus* plots and plant measurements were conducted on September 11 and 12, 1984, and August 27 through 31, 1985. During the September 1984 and August 1985 post-treatment sampling periods, four plots from each treated (harvest and removal) and control group were randomly selected for assessment of the *Fucus* population. However, higher than normal low tides during the September 1984 sampling period precluded the sampling of some selected plots, and only three plots from each group were sampled. The September 1984 and August 1985 assessments were assumed to reflect the growth of *Fucus* within the experimental plots after one and two growing seasons, respectively.

During pre and posttreatment sampling all plants within plots selected for sampling were physically removed. The plants from each plot were collectively weighed (nearest 1 g) to determine biomass, individually measured (nearest 0.5 cm), and enumerated. On occasion, due to the great number of plants in some plots, a subsample of plants was taken for measurement purposes. These data were subsequently expanded based on the entire sample. All subsamples consisted of at least 25% of the total plot biomass.

Plant length frequency distribution data was analyzed because Stekoll et al. (1984) suggested that it is an important factor in determining the condition of a previously harvested *Fucus* population. Plant size was also used to determine the baseline number of plants per plot that were of harvestable size (i.e., 10 cm total length).

Determining Plant Growth

During June 1984, 120 individual *Fucus* plants were selected for individual plant growth study at Klikitarik Point and near the study transect at Twin Islands (Figure 2). All plants were located within the lower half of the intertidal zone. At each location 10 plants were selected within each of six size categories for study. The six size categories were defined as follows: 20–59 mm, 60–99 mm, 100–139 mm, 140–179 mm, 180–219 mm, and greater than 219 mm. A numbered Petersen disc tag was secured with epoxy cement onto the rock substrate a measured distance and direction from the plant to facilitate relocation. A line transect was established through the tagged plant area. Disc tags were located by their measured distance along and vertical distance above or below the transect line.

Total length of each plant was measured, the number of blades were enumerated, sexual maturity was noted (gravid with swollen receptacles or not gravid), and the overall health of the plant was subjectively assessed (good or poor). Because *Fucus* plants are gravid in the late spring and early summer months, general maturity of plants was noted to determine the minimum size of mature and gravid plants. Only plants considered in "good health" were selected for study. Healthy plants appeared dark green and firm, with little or no blade discoloration, whereas plants in "poor health" were discolored and limp.

To increase sample size, 60 additional plants were tagged and assessed in June 1985 at both the Klikitarik Point and Twin Islands locations. The 1984 sample size of tagged plants decreased because (1) difficulty was experienced in relocating many of the plants tagged in 1984, and (2) plant blade enumeration data collected in 1984 was considered questionable and discarded. To facilitate relocation of the plants tagged in 1985, an additional Floy tag was cemented to the rock substrate so that the end of the Floy tag nearly touched the sampled *Fucus* plant. In 1984 inconsistent plant blade counts resulted from the lack of a working definition of *plant blade*. In 1985 a specific definition was employed which resulted in a more definitive count of plant blades. A plant blade was defined as a dichotomy separated from the next nearest dichotomy by more than one third of its length (McConnaughey 1985). As in 1984, plants tagged in 1985 were equally divided by location into the six previously defined size categories, all tagged plants were located within the lower half of the intertidal zone, and only plants in "good health" were selected for study.

Plants initially tagged during June 1984 and June 1985 were relocated and subsequently sampled for linear growth in September 1984 and for number of blades in August 1985. Hence, mean growth increments can also be expressed as growth rates based upon one growing season. Breakage of plants between initial tagging and subsequent reassessment caused some plants to show a negative growth increment. In this study, mean gross growth increments were calculated from positive and negative growth values, and the mean net growth increments were calculated from only the positive growth increment values. Gross growth was considered an indicator of overall plant population growth; net growth was considered a conservative estimate of potential or maximum growth.

Statistical Analysis

Stepwise multiple linear regression analysis was used to determine the best model for nondestructively estimating *Fucus* biomass from all plots during each sampling period and prior to experimental treatment. Actual biomass measurements after removal of all plants from sampled plots were regressed on percentage of cover and the mean (arithmetic and geometric) depth of *Fucus* as it occurred undisturbed on the substrate of all sampled plots. Acceptability of the model required a significant ($P < 0.10$) relationship between independent and dependent variables and a coefficient of determination (R^2) of at least 0.80.

Analysis of variance (ANOVA) was used to determine if significant within sample-period differences in plant biomass, cover, total number of plants, and number of harvestable-sized plants occurred between treatments and controls. ANOVA was also employed to determine if significant among sample-period differences occurred within treatments and controls for each of the above-mentioned biological parameters during the study period.

Because of small sample sizes, control plots were pooled that were not significantly different with regards to measured parameters. This included data

TABLE 2.—Comparison of mean percentage of *Fucus* cover in plots by treatment type prior to treatment in June 1984.

Treatment Type	Number of Plots	Mean Percent Cover[a]	SD
Harvest	12	58.8	24.64
Control	13	69.2	19.73
Removal	12	78.8	16.67

[a]Means encompassed by the same vertical line are not significantly different (LSD test, P < 0.10).

TABLE 3.—Comparison of mean number of *Fucus* plants in removal plots before treatment (June 1984) and in control plots after treatment (Sept. 1984, August 1985).

Date	Number of Plots	Mean Number of Plants[a]	SD
June 1984	11	679.8	446.32
Sept. 1984	3	1,129.0	1,064.89
Aug. 1985	4	3,452.0	3,177.36

[a]Means encompassed by the same vertical line are not significantly different (LSD test, P < 0.10).

pooled from the 11 removal plots collected during removal treatment (assumed to represent the conditions in all plots prior to treatment), plus data from the September 1984 and August 1985 samples of the controls. This pooled, pretreatment and control-plot data represented an *overall unperturbed control condition.* If ANOVA indicated that significant differences occurred among treatment types or sampling periods, then the least significant difference (LSD) test was used to explore which of the means were significantly different (STSC 1985). A chi-square goodness-of-fit test was used to determine significant differences in the length frequency of *Fucus* plants among treatments and controls and among sampling periods within treatments and control.

Individual plant growth measurements for each size classification were pooled for the two sampling periods to obtain a better representation of plant growth over the duration of the study. Analysis of individual plant growth data included ANOVA by plant size category using gross growth measurements and also net growth measurements. Significant differences between the size classes were determined using the LSD comparison test of means.

Analysis of plant blade counts included only plants initially tagged in June 1985 and reassessed in August 1985. Inconsistent counts of individual plant blades in 1984 resulted in questions concerning the reliability of the data. Therefore, these data were discarded. Statistical analyses similar to the tests used to determine significant differences among and between size categories for linear plant growth were employed to test for significant differences among and between plant-size classes assessed for plant blade number changes between June and August 1985. However, due to the small sample size of plants assessed for blade numbers these results should not be construed to apply to the total *Fucus* population. Significance level for all tests was set at 0.10.

RESULTS

Recovery

Nondestructive Biomass Assessment

Although a significant relationship was detected between biomass, cover, and depth of vegetation ($P < 0.0001$), the coefficient of determination (R^2) value of 0.59 was considered unacceptable. Because the nondestructive biomass estimate was considered too imprecise for the purposes of this study, plot biomass assessment was carried out by the removal and collective weighing method. McConnaughey (1985) used a similar nondestructive method to estimate volume of *Fucus* within a plot, but he also indicated that the technique was problematic and error-prone.

Pretreatment Plot Measurements

Prior to treatment percentage of *Fucus* coverage was assessed in June 1984 in all plots. Mean percent *Fucus* coverage of plots by treatment type ranged from 58.8% in the harvest treatment plots to 78.8% in the removal treatment plots prior to treatment (Table 2). ANOVA indicated that significant differences in percentage of coverage existed among pretreatment plots ($P = 0.0802$). LSD analysis for pairwise comparisons further indicated that the coverage of the harvest and removal treatment plots differed significantly prior to treatment, but neither the harvest nor the removal treatment plots differed significantly from the control plots prior to treatment (Table 2). Differences in number of plants and biomass of harvest treatment and control plots prior to treatment could not be determined using non-destructive methods. However, initial control conditions regarding total number of plants, number of harvestable plants, and biomass were assessed using the *Fucus* plants collected from the pretreatment removal plots in June 1984 (Table 3).

Control Treatment Plot Measurements

Fucus cover of control plots did not significantly vary throughout the study period (P = 0.5619). Additionally, number of large plants (P = 0.8136) and biomass (P = 0.8091) of control plots and pretreatment removal plots, which were considered representative of the undisturbed control plots, did not significantly vary throughout the study. However, the number of plants per plot significantly differed by sample date (P = 0.0225). The mean number of plants within control plots increased during the study period (Table 3). Total number of plants in control plots was significantly (P < 0.0100) higher in August 1985 than plant numbers observed during June and September 1984. However, differences in the total number of plants per plot during June and September 1984 were not significant (P > 0.0100). The five-fold increase in mean plant number from June 1984 to August 1985 may have partially resulted from more complete and effective sampling of small plants in August 1985. Control-plot data for the study period are summarized in Table 4.

Casual observations suggested that total number of plants increased in relation to the surface area of the plot covered by barnacles, regardless of the shading effect of larger plants. The rough surface of barnacle-covered substrate could retain more spores and afford a better nursery area for germlings than smooth rock. Substrate relief also differed among plots. Therefore, surface area available for plant colonization probably also differed. Because plot location and treatments were assigned on a random basis, the effect of barnacles and surface area on plant numbers was assumed to be nonsignificant across treatments and sampling periods. However, this hypothesis was not tested.

Mean length frequency distributions for June 1984, September 1984, and August 1985 control plots (Figure 4) were significantly different from each other (P < 0.0001). However, because the number of large plants and *Fucus* biomass did not significantly differ in these plots over time, the temporal change in the length frequency distribution was probably attributable to the increased numbers of small plants.

TABLE 4.—*Fucus* mean percentage of plot coverage, total number of plants, number of harvestable plants (≥ 10.0 cm), and biomass in control plots prior to treatment in June 1984 and after treatment (September 1984, August 1985).

	Plots Coverage			Total No. of Plants		
Treatment Dates	Number of Plots	Percentage of Cover	SD	Number of Plots	Mean No. of Plants	SD
June, 1984 (Pretreatment)	13[a]	69.2	19.73	11[b]	679.8[b]	446.32[b]
Sept., 1984	11	77.9	20.81	3	1,129.0	1,064.89
August, 1985	8	70.4	21.56	4	3,452.0	3,177.36

	Total Number of Harvestable Plants (≥ 10.0 cm)			*Fucus* Biomass		
Treatment Dates	Number of Plots	Mean Number of Plants	SD	Number of Plots	Mean Biomass (g)	SD
June, 1984 (Pretreatment)	11[b]	110.4[b]	52.82[b]	11[b]	1,166.0[b]	698.07[b]
Sept., 1984	3	102.7	75.25	3	909.7	427.26
August, 1985	4	88.5	61.54	4	1,035.0	514.99

aControl plots.

bBased on treatment plots prior to treatment. Data collected from these plots were considered to represent initial conditions at control plots.

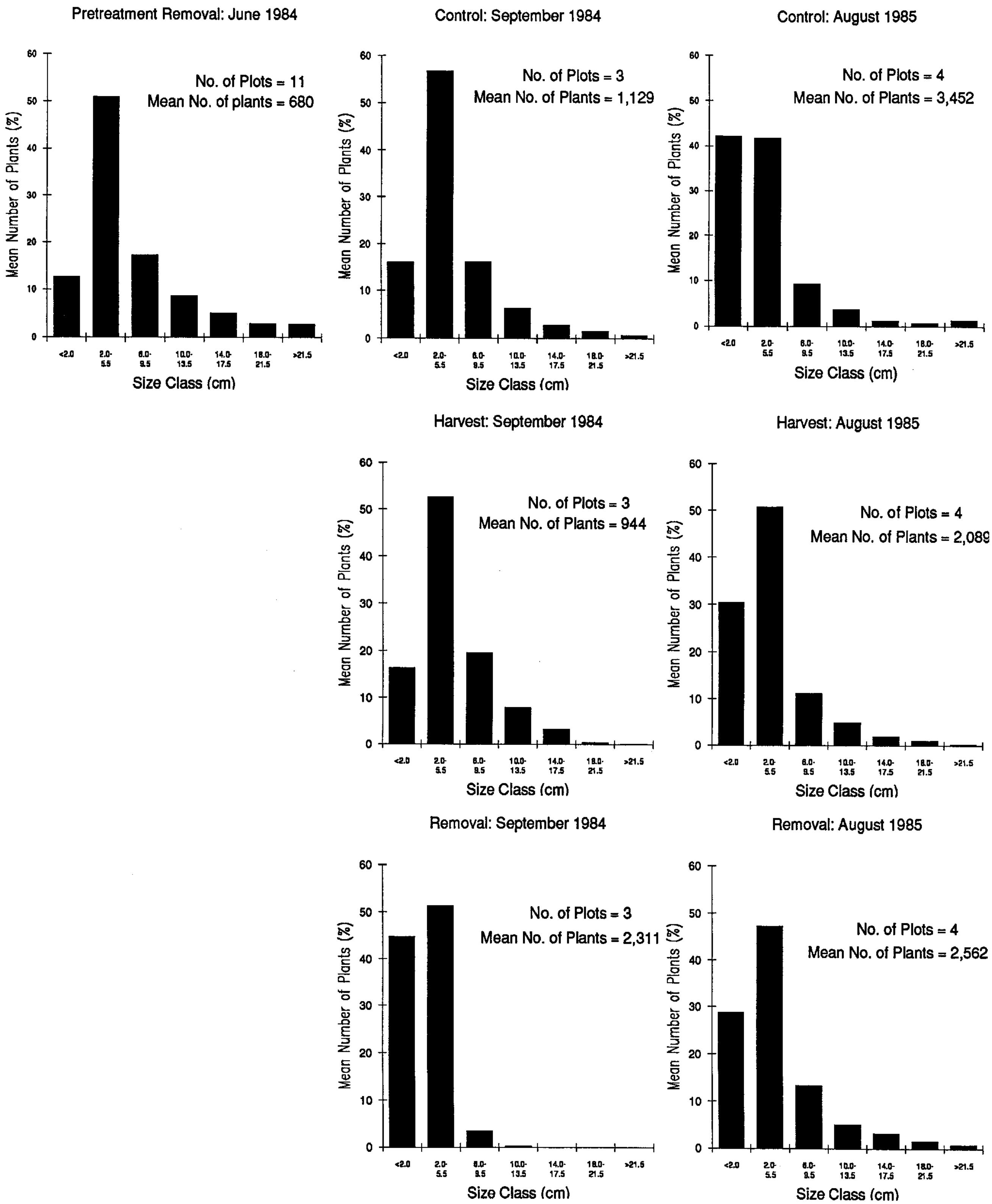

FIGURE 4.—Mean length frequency distribution of Fucus plants from sampled control, harvest treatment, and removal treatment plots, June, 1984–August, 1985. Data collected from the removal treatment plots in June, 1984 (pretreatment) were assumed to represent initial unperturbed conditions in control and treatment plots.

TABLE 5.—*Fucus* mean percentage of plot coverage, total number of plants, number of harvestable plants (≥ 10.0 cm), and biomass in harvest treatment plots prior to treatment in June 1984 and after treatment (September 1984 and August 1985).

Treatment Dates	Plots Coverage: Number of Plots	Plots Coverage: Percentage of Cover	Plots Coverage: SD	Total No. of Plants: Number of Plots	Total No. of Plants: Mean No. of Plants	Total No. of Plants: SD
June, 1984 (Pretreatment)	12	58.8	24.64	11[a]	679.8[a]	446.32[a]
September, 1984	7	72.0	19.96	3	944.3	206.12
August, 1985	8	69.0	21.88	4	2,089.0	1,710.50

Treatment Dates	Total Number of Harvestable Plants (≥ 10.0 cm): Number of Plots	Total Number of Harvestable Plants (≥ 10.0 cm): Mean Number of Plants	Total Number of Harvestable Plants (≥ 10.0 cm): SD	*Fucus* Biomass: Number of Plots	*Fucus* Biomass: Mean Biomass (g)	*Fucus* Biomass: SD
June, 1984 (Pretreatment)	11[a]	110.4[a]	52.82[a]	11[a]	1,166.0[a]	698.07[a]
September, 1984	3	102.7	53.72	3	712.0	299.63
August, 1985	4	139.5	76.74	4	1,081.0	573.86

aIncludes pretreatment data from removal treatment plots. Because plants in these plots had not been manually removed previously, the data from these plots represent the pretreatment harvest plots or initially unperturbed conditions.

Harvest Treatment Plot Measurements

No significant differences in total number of plants ($P = 0.3114$), number of large plants ($P = 0.5198$), or *Fucus* biomass ($P = 0.3735$) were found between harvest treatment plots assessed during September 1984 and August 1985. Additionally, percentage of *Fucus* cover in pretreatment harvest plots did not significantly deviate from the harvest treatment plots assessed in September 1984 and August 1985 ($P = 0.4171$). The absence of significant differences between sampling periods indicates that harvest treatment plots fully recovered after only one growing season (June to September, 1984). Harvest treatment plot data for the study period are summarized in Table 5.

Removal Treatment Plot Measurements

Significant differences were observed in the number of large plants ($P < 0.0037$), biomass ($P = 0.0050$), and percentage of cover of *Fucus* ($P = 0.0041$) in the removal treatment plots during the study period. However, total number of plants per plot remained relatively stable from the September 1984 to August 1985 sampling period ($P = 0.8909$). Percentage cover of the removal treatment plots in September 1984 was approximately 30% less than pretreatment coverage (Table 6). However, because the initial treatment removed all *Fucus* plants within the plot, reducing cover to zero, these data could also be interpreted as a substantial recolonization. No significant difference in percentage coverage was observed between the pretreated removal and the removal treatment plots sampled in August 1985 (Table 6). These data indicate that *Fucus* coverage of the removal treatment plots returned to pretreatment levels after two growing seasons.

Mean number of harvestable plants (≥10 cm) and biomass in the removal treatment plots sampled in August 1985 also increased dramatically over removal treatment plots sampled September 1984 (Tables 7 and

TABLE 6.—Comparison of mean percentage of *Fucus* cover in removal treatment plots before treatment (June 1984) and after treatment (September 1984, August 1985).

Date	Number Plots	Mean Percent Cover[a]	SD
Sept. 1984	8	55.4	19.76
June 1984	12	78.8 |	16.67
Aug. 1985	6	89.2 |	12.73

a Means encompassed by the same vertical line are not significantly different (LSD test $P < 0.10$).

TABLE 7.—Comparison of mean number of harvestable *Fucus* plants (≥10.0 cm) observed in the removal treatment plots in September 1984 and August 1985.

Date	Number of Plots	Number of Plants[a]	SD
Sept. 1984	3	12.7	11.15
Aug. 1985	4	166.8	49.97

a The means were significantly different (LSD test, $P < 0.10$).

TABLE 8.—Comparison of mean *Fucus* biomass observed in the removal treatment plots in September 1984 and August 1985.

Date	Number of Plots	Mean *Fucus* Biomass (g)[a]	SD
Sept. 1984	3	184.3	142.23
August 1985	4	1,227.0	353.89

a The means were significantly different (LSD test,$P < 0.10$).

8). Numbers of harvestable plants increased by a factor of 13, and biomass increased by a factor of approximately 7 between these sample periods. Additionally, mean length frequency distributions (Figure 4) of removal plots sampled in September 1984 and August 1985 were significantly different from each other ($P < 0.0001$). Removal treatment plot data for the study period are summarized in Table 9.

Although not statistically tested, percentage of cover estimates and casual observations in August 1985 of the number of plants within the removal plots sampled in September 1984 (two consecutive years of plant removal) indicated that recolonization rates of *Fucus* were similar to plots which received only one removal treatment. These observations indicate that Fucus plants continually recolonize an area as long as there are plants which produce spores in the vicinity.

Comparison of Fucus Response by Treatment

September 1984

Analysis of variance (ANOVA) indicated that significant differences occurred in the number of plants ($P = 0.0454$), number of large plants ($P = 0.0346$), biomass ($P = 0.0405$), and percentage of cover ($P = 0.0729$) among treatment and control plots sampled after one growing season. The observed mean values for harvestable plants, biomass, and percentage of cover of controls were significantly higher than for removal treatment plots (Table 10, 11, and 12, respec-

TABLE 9.—*Fucus* mean percentage of plot coverage, total number of plants, number of harvestable plants (≥ 10.0 cm), and biomass in removal treatment plots, June 1984–August 1985.

Treatment Dates	Plots Coverage: Number of Plots	Plots Coverage: Percentage of Cover	Plots Coverage: SD	Total No. of Plants: Number of Plots	Total No. of Plants: Mean No. of Plants	Total No. of Plants: SD
June, 1984 (Pretreatment)	12[a]	78.8	16.67	11[a]	679.8	446.32
September, 1984	8	55.4	19.76	3	2,311.3	2,063.63
August, 1985	6	89.2	12.73	4	2,562.0	2,356.36

Treatment Dates	Total Number of Harvestable Plants (≥ 10.0 cm): Number of Plots	Total Number of Harvestable Plants (≥ 10.0 cm): Mean Number of Plants	Total Number of Harvestable Plants (≥ 10.0 cm): SD	*Fucus* Biomass: Number of Plots	*Fucus* Biomass: Mean Biomass (g)	*Fucus* Biomass: SD
June, 1984 (Pretreatment)	11[a]	110.4	52.82	11[a]	1,166.0	698.07
September, 1984	3	12.7	11.15	3	184.3	142.23
August, 1985	4	166.8	49.97	4	1,227.0	353.89

aIncludes pretreatment data from the removal treatment plots. The biomass collected from one original removal treatment plot was discarded after collection because it appeared dead. Associated data were collected from the virgin *Fucus* biomass removed from removal treatment plots. Because plants in these plots had not been manually removed previously, the data represent the initial control conditions.

TABLE 10.—Comparison of mean number of harvestable *Fucus* plants (≥ 10.0 cm) per plot by treatment type, September 1984.

Treatment Type	Number of Plots	Number of Plants[a]	SD
Removal	3	12.7	11.15
Harvest	3	102.7 |	53.72
Control	18	104.2 |	55.31

a Means encompassed by the same vertical line are not significantly different (LSD test, P < 0.10).

tively). Similarly, mean values obtained from the harvest treatment plots were significantly higher than the removal treatment plots for large plants (Table 10) and percentage of cover (Table 12). Due to the high variability in biomass measurements and the small sample size of the harvest and removal treatment plots, significant differences were not demonstrated between the harvest and removal treatment plots (Table 11).

Mean number of plants was significantly higher in the removal treatment plots than both the control or the harvest treatment plots (Table 13), indicating a significant recolonization response after the removal treatment. The mean number of *Fucus* plants which recolonized removal treatment plots was in excess of 2,300 per 0.25-m^2 plot, or over 9,000 per m^2 of kelp bed. Although recolonization of removal plots was substantial in terms of numbers of plants, these data indicate that the biomass and number of harvestable plants of the removal treatment plot required more than one growing season to recover to the overall unperturbed control condition. Significant differences between control and harvest treatment plots for plot coverage, number of plants, number of large plants and biomass were not demonstrated. The absence of significant differences between harvest and control treatment plots indicates that plot recovery, in terms of the above-mentioned parameters, was complete one growing season following the initial harvest treatment. Additionally, the absence of significant differences within harvest treatment plots between the September 1984 and August 1985 sampling periods indicates that gains in biomass and number of harvestable plants may not be significant during the second growing season. A recovery period of no longer than one growing season for the harvest treatment plots is further supported by the absence of significant differences in percentage of cover for harvest treatment plots throughout the study.

TABLE 11.—Comparison of mean *Fucus* biomass per plot by treatment type, September 1984.

Treatment Type	Number of Plots	Mean *Fucus* Biomass (g)[a]	SD
Removal	3	184.3 |	142.23
Harvest	3	712.0 | |	299.63
Control	18	1,094.2 |	604.23

aMeans encompasssed by the same vertical line are not significantly different (LSD test, P < 0.10).

TABLE 12.—Comparison of mean percentage of *Fucus* cover per plot by treatment type, September 1984.

Treatment Type	Number of Plots	Mean Percentage of Cover[a]	SD
Removal	8	55.4	19.76
Harvest	7	72.0 |	19.96
Control	11	77.9 |	20.81

a Means encompassed by the same vertical line are not significantly different (LSD test, P < 0.10).

August 1985

Differences among sampled treatment plots for total number of plants, number of large plants, biomass, and percentage of cover per plot were not significant (P = 0.7414, P = 0.1341, P = 0.7055, and P = 0.1462, respectively) two growing seasons after the initial treatment of the study plots. The complete recovery of the removal treatment plots to the overall unperturbed control condition was most likely the direct result of a reduction in intraspecific competition among the *Fucus* plants for available sunlight. It ap-

TABLE 13.—Comparison of mean number of *Fucus* plants per plot by treatment type, September 1984.

Treatment Type	Number of Plots	Mean Number of Plants[a]	SD
Control	14	776.1 |	603.55
Harvest	3	944.3 |	206.12
Removal	3	2,311.3	2,063.63

a Means encompassed by the same vertical line are not significantly different (LSD test, P < 0.10).

pears that the removal of large plants from a plot stimulates growth of smaller plants. The total removal of all plants initially stimulates growth of the germlings, which in two growing seasons rival the plants in the control plots in all parameters measured. Therefore, the above analysis indicates removal treatment plots recovered to control conditions after two growing seasons.

Chi-square analyses of the 1985 length frequency distributions indicated significant differences ($P < 0.0001$) among treatments and controls (Figure 4). Additionally, length frequency distributions of all control plots sampled (Figure 4) were also significantly different from each other over time ($P < 0.0001$). Because control plots were undisturbed, differences in the length frequency distributions were due to natural disturbances. Apparently, the high degrees of freedom afforded by the great number of plants per plot, allowed even slight naturally occurring changes in the distributions to be statistically detected. Because of the dynamics of plant length frequency distribution within control plots, these measurements were not used as a criterion for determining the status of experimental plots in relation to controls.

Individual Plant Growth

Changes in individual plant length during the two study periods, June–September 1984, and June–August 1985, ranged from -186 mm to 128 mm (Figure 5). The overall mean gross growth increment per growing season, or mean gross growth rates, were 26.4 mm and 57.4 mm, respectively (Table 14). The greatest loss in plant length occurred in the larger plant size categories. Additionally, the number of plants which were observed to lose length increased as total plant length increased (Figure 5).

Mean plant size within size classes 20–59 mm, 60–99 mm, 100–139 mm, and 140–179 mm increased during the study period. Mean plant size decreased in

TABLE 14.—Mean length and comparison of gross and net linear growth increments of tagged *Fucus* plants by size category initially measured in June 1984 or 1985 and subsequently remeasured in September 1984 or August 1985, respectively.

	Mean Plant Length					
	June 1984 & 1985			Sept. 1984 & Aug. 1985		
Size Category (mm)	n	Mean Length (mm)	SD	n	Mean Length (mm)	SD
20–59	40	35.3	10.1	29	85.0	30.5
60–99	40	77.5	10.5	20	118.4	40.3
100–139	40	119.8	9.5	23	163.7	65.8
140–179	40	156.5	10.8	25	188.8	66.9
180–219	40	193.3	10.5	18	187.3	94.1
> 219	40	245.7	22.0	20	221.6	85.7
Total	240	130.1	71.3	135	156.5	79.9

Gross Length Increment[a]				Net Length Increment[b]			
Size Category (mm)	n	Mean Length (mm)[c]	SD	Size Category (mm)	n	Mean Length (mm)[c]	SD
> 219	20	-22.7	87.2	180–219	13	44.0	41.3
180–219	18	-5.2	95.8	20–59	28	52.2	27.1
140–179	25	33.4	67.6	< 219	9	54.0	18.4
60–99	20	41.9	8.8	60–99	17	54.2	25.9
100–139	23	43.5	67.5	140–179	20	60.9	68.0
20–59	29	49.4	30.6	100–139	17	77.2	27.9
Total	135	26.4	70.2		104	57.4	30.4

[a]Includes both negative and positive linear growth increments.

[b]Includes only the positive linear growth increment.

[c]Means encompassed by the same vertical line are not significantly different (LSD test, $P < 0.10$).

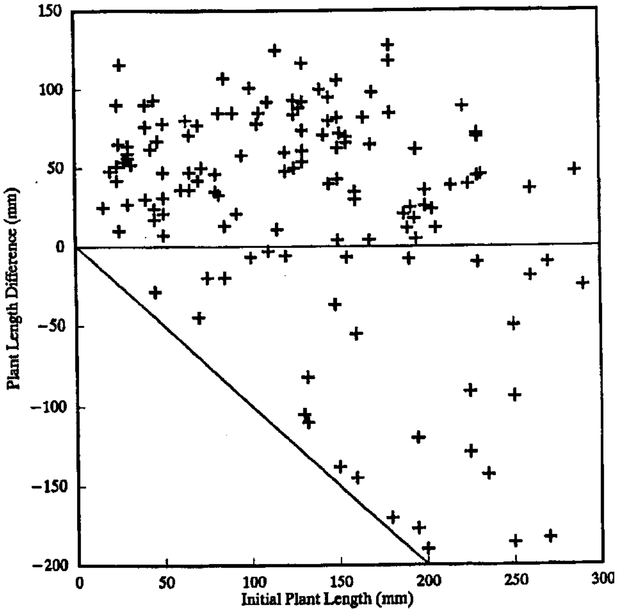

FIGURE 5.—Scatter plot of the gross length difference of tagged *Fucus* plants initially measured in June 1984 and 1985 and remeasured in September 1984 and August 1985, respectively.

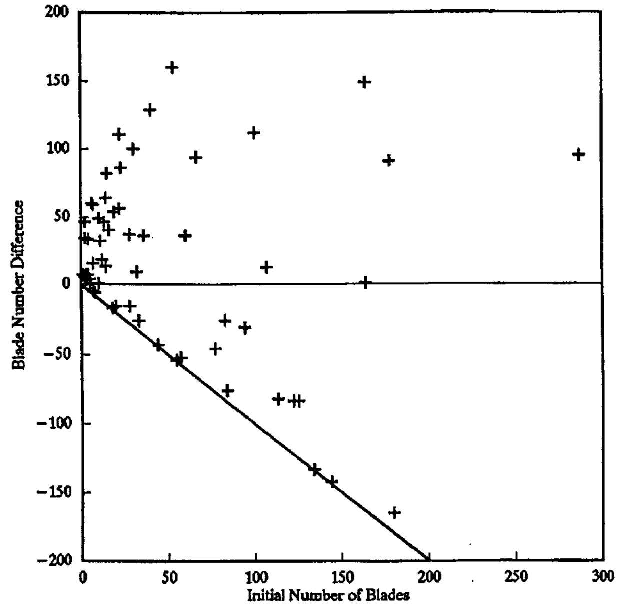

FIGURE 6.—Scatter plot of the gross difference in blade number of tagged *Fucus* plants. Blades of tagged plants were initially enumerated in June 1984 and re-enumerated in August 1985.

two largest size classes. Mean gross growth increments ranged from -22.7 per growing season in the largest category to 49.4 mm in the smallest size category. As stated earlier these growth increments were calculated based on plant growth during one growing season and, therefore, can also be considered growth rates for one growing season. ANOVA indicated that significant differences in mean gross growth rates existed among plant size categories ($P = 0.0012$). Mean gross growth rates of the four smallest size categories were not significantly different from each other (LSD comparison test, ($P < 0.1000$). Likewise, the mean gross growth rates of the two largest size categories were not significantly different from each other. However, the four smallest size categories had significantly higher mean growth rates than the largest two size categories (Table 14).

ANOVA of the mean net growth rates by plant size categories was also conducted. The mean net growth rate or increment for each plant size class was calculated from measurements of plants which increased in size from initial measurement. This analysis was conducted in order to obtain an indication of the potential growth rate by size class based upon one growing season. Mean net growth increments ranged from 44.0 mm to 77.2 mm per growing season. ANOVA indicated that significant differences in mean net growth rates occurred among size classes ($P = 0.0446$). LSD comparison of mean net growth indicated that the 100-139 mm size class had a significantly higher mean net growth rate, (77.2 mm per growing season), than 4 of the 5 other size categories. The net growth rate of the 140–179 mm size category did not significantly differ from the lowest nor from the highest mean net growth rate because of high sample variance (Table 14). Because minimal breakage of plants most likely occurred within the first two size classes, 20–59 mm and 60–99 mm, it appears that these two size classes have lower maximum growth rates than the 100–139 mm size class. This discrepancy in growth rates was most likely caused by the shading effect of larger plants on smaller plants. Because some breakage occurs in plants which have a positive growth increment, the mean net growth increment should be viewed as a minimal estimate of potential or maximum growth. Because plant breakage occurs more often in the larger-sized plants it is difficult to estimate the potential growth of these plants.

Data collected from the 1985 tagging study were not used to determine the minimum plant size for sexual maturity because tagging of plants preceded the onset of the visible indications of plant sexual maturity during this period. Observation of the plant length data in conjunction with general maturity of the plants tagged in June 1984 indicates that no plants within the 20–59 mm size category were gravid. However, 45% of the tagged plants within the 60–99 mm size class were considered gravid. Over 80% of plants greater than 99 mm in length were considered gravid during the June 1984 tagging period. It appears that larger plants mature earlier in the season as evidenced by the extremely swollen condition of the their receptacles observed during sampling. This indicates that plants < 60 mm most likely do not produce spores, while most plants equal to or greater than 60 mm are gravid during the spring.

Number of blades for plants assessed in June 1985 (Figure 6) increased in all but the 180–219 mm size class during the 1985 growing season (Table 15). Overall gross and net mean plant blade increase was 14.4 and 48.8, respectively, for the 1985 growing season (Table 15). Generally, the proportional increase in blade numbers was more substantial in the smaller sized plants. Analysis of variance of gross and net plant blade increment per growing season by initial size classes indicated that significant differences in the change in plant blade number occurred (P = 0.0685 and P<0.0001, respectively). Based upon LSD pair-wise comparisons, plants in the 180–219 mm size category possessed significantly fewer blades than the four smallest plant size classes (Table 12). Net changes in plant blade numbers per growing season, which included only the plants that had an increase in the number of blades from June to August 1985, were significantly higher for the 140–179 mm and 219 mm size groups (Table 14).

As stated above, the loss of plant material from breakage can be more significant in larger plants. However, the potential increase in plant blade number in larger plants is great. It appears that potential increase in plant blade numbers could at least increase geometrically, depending upon the number of times

TABLE 15.—Mean number of plant blades and comparison of and gross and net plant blade increments of tagged *Fucus* plants by size category initially enumerated in June and subsequently reenumerated in August, 1985.

	Mean Number of Plant Blades					
	June 1985			August 1985		
Size Category (mm)	n	Mean Number of Blades	SD	n	Mean Number of Blades	SD
20—59	20	4.9	4.7	14	30.0	31.2
60—99	20	16.9	17.3	12	43.8	28.2
100—139	20	30.8	16.5	7	42.9	52.0
140—179	20	45.9	29.2	8	101.4	90.1
180—219	20	83.5	46.8	11	51.1	47.4
> 219	20	138.7	61.1	9	145.0	146.5
Total	120	53.4	57.2	61	64.3	80.1

Gross Blade Number Increment[a]				Net Blade Number Increment[b]			
Size Category (mm)	n	Mean Number of Blades[c]	SD	Size Category (mm)	n	Mean Number Blades[c]	SD
180—219	11	-35.2	61.8	20—59	14	24.9	26.8
> 219	9	4.7	115.4	180—219	4	25.0	24.5
100—139	7	19.4	54.0	60—99	9	38.0	22.5
20—59	14	24.9	26.8	100—139	5	53.2	46.5
60—99	12	25.4	30.2	219	4	95.2	52.4
140—179	8	54.6	75.1	140—179	5	104.4	37.5
Total	61	14.4	66.5	Total	41	48.8	43.6

aIncludes both negative and positive linear growth increments.

bIncludes only the positive linear growth increment.

cMeans encompassed by the same vertical line are not significantly different (LSD test, P < 0.10).

one blade dichotomizes in a season. It also appears that there is a limit to the number of plant blades one plant can sustain. Similar to the maximum size of *Fucus* plants in Norton Sound, very few plants sampled in 1985 had more than 200 blades (Figure 6). Due to the small number of plants examined, however, caution should be exercised when interpreting these results.

DISCUSSION

Measurements of percentage of cover, biomass, and number of harvestable plants appeared to be useful indicators of *Fucus* recovery after extensive plant removals in Norton Sound. However, the best indicator was probably the number of harvestable plants per plot. Plants 10 cm have been found to account for 90% of the biomass of a *Fucus* population and most of the cover (McConnaughey 1985). Unlike Bristol Bay, length frequency distribution of plants in Norton Sound was not a useful parameter for determining the status of experimental plots in relation to controls primarily because of significant natural fluctuations in the plant length distribution observed within control plots during this study. Part of this apparent instability can be attributed to the greater number of plants per plot in Norton Sound. In experimental plots in Bristol Bay the mean number of plants per plot did not exceed 600 plants (McConnaughey 1985), but mean number of plants in plots of similar size in Norton Sound ranged from 680 to over 3,400. Because of the high degrees of freedom afforded by the great number of plants per plot in Norton Sound, even slight naturally occurring changes in the length distribution were significant.

Shading by large plants limits the recruitment and growth of smaller plants (McConnaughey 1985). As the population evolves to a climax state, biomass remains relatively stable. However, the total number of plants decreases. McConnaughey (1985) stated that although a kelp bed in Bristol Bay recovered in terms of percentage of cover and wet weight in about 1 year, the succession of the community to a population of large, older, relatively sparse plants required 2–4 years. McConnaughey (1985) also surmised that areas subjected to periodic thinning would recover faster than areas left undisturbed for a number of years because the greater number of smaller plants rapidly replace the plants removed. Unlike the kelp beds in Bristol Bay, which may require 2 to 3 years to recover after a spawn-on-kelp harvest (McConnaughey 1985), my study presents evidence that a harvested kelp bed in Norton Sound can recover by the end of the summer of harvest (approximately 2.5 months) in terms of percentage of cover, biomass, and number of large plants. Based on increased number of plants in control plots and the observed loss of plant material from large plants observed in my study, natural processes, such as, wave action and ice scour, may continually remove large plants and plant material from the kelp bed in Norton Sound. This removal prevents the Norton Sound *Fucus* population from reaching, or sustaining, a climax vegetative state. These natural processes probably play an important role in the rapid growth response of the *Fucus* resource in Norton Sound by providing conditions supportive of a large number of small plants, or pre-recruits, which rapidly replace the plants lost. Because I observed individual Fucus plants to grow more than 10 cm in one growing season in Norton Sound, it appears that the annual harvests on the same kelp bed would have no detrimental consequences to the future standing stock of harvestable *Fucus* plants. The increased amount of solar radiation during the spring and summer months, warm coastal water temperatures, which may approach 20° C by early July, and the clear water of Norton Sound, which provides for a large photic zone in the inter- and subtidal area, play important roles in the rapid growth response of the *Fucus* resource in Norton Sound.

Observations of the removal treatment plots in this study indicated that recolonization of *Fucus* on denuded areas is rapid and complete, averaging over 9,000 plants/m^2. Additionally, the total recovery, without a decrease in total plant numbers of removal treatment plots two growing seasons after initial treatment, indicates that subsequent harvests would have little effect on the following year's standing stock of harvestable-size *Fucus* plants. Therefore, it appears that there are no apparent reasons relating to the biology of the *Fucus* to restrict either the amount or the location of the harvest of spawn on kelp within southern Norton Sound. However, if a spawn-on-kelp fishery is reintroduced in Norton Sound, spawn-on-kelp harvest limits should be formulated based upon concern for herring conservation.

Because of the relatively small number of plots assessed in this study, the major *Fucus* beds of Norton Sound should be monitored on a annual basis if a spawn-on-kelp fishery is reintroduced. However, recent observations of the *Fucus* resource in northern Norton Sound, specifically Elim and Golovin Subdistricts (Figure 1), indicate that northern Norton Sound could not support a spawn-on-kelp fishery due to the scattered distribution of the kelp beds and the low density of *Fucus* plants within the beds (D.C. Whitmore, Alaska Department of Fish and Game, Anchorage, personal communications).

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