PILGRIM NUCLEAR POWER STATION
MARINE ENVIRONMENTAL MONITORING PROGRAM
REPORT SERIES NO. 5

FINAL REPORT ON IRISH MOSS (*Chondrus crispus*) HARVESTING ALONG THE PLYMOUTH SHORELINE AND IMPACT ASSESSMENT OF PILGRIM STATION ON THE FISHERY, 1971-1982

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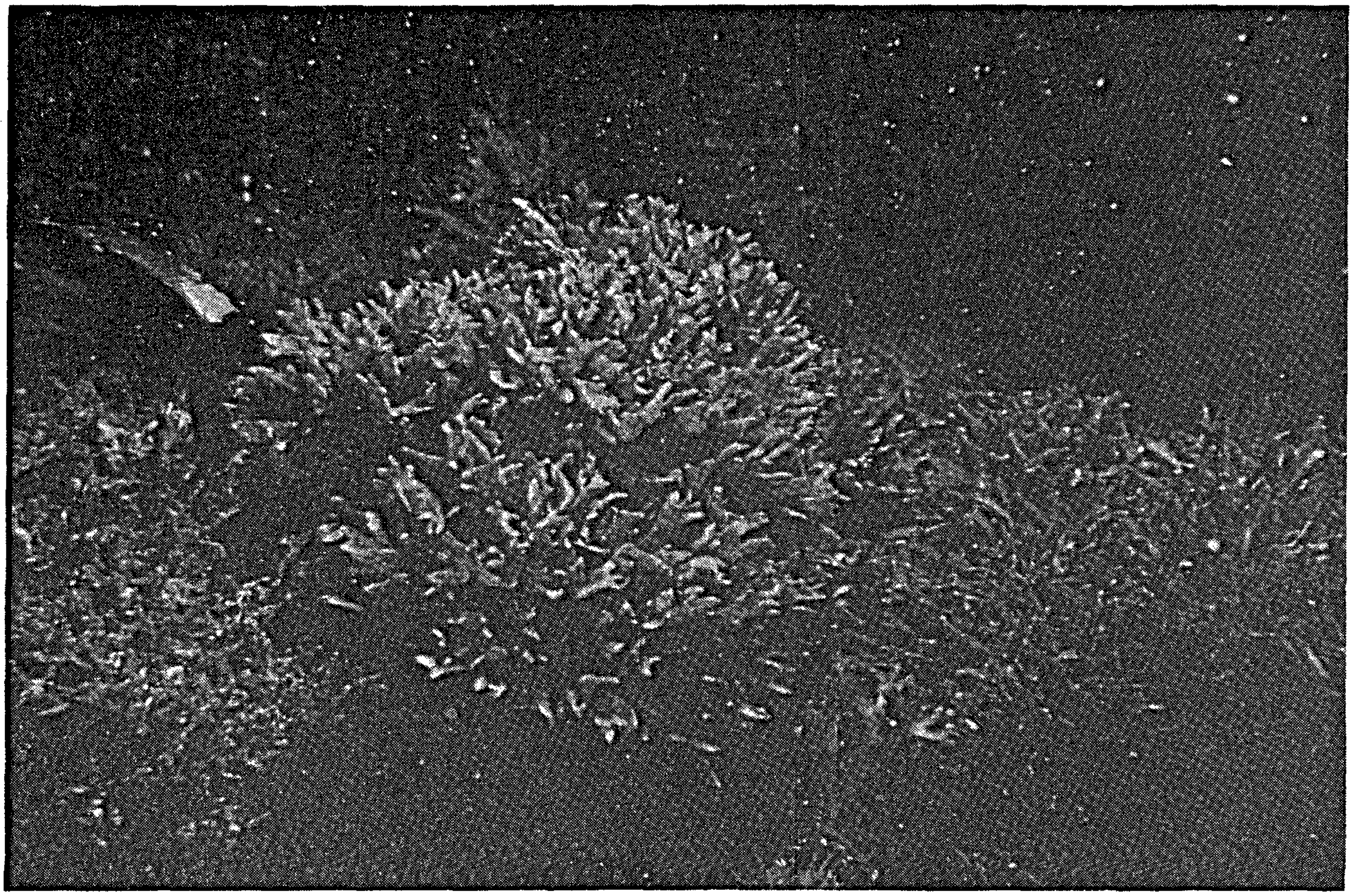

FRONTISPIECE. *Chondrus crispus* (Irish moss), a commercially important resource, is a dominant subtidal benthic plant growing in the environs of the Pilgrim Nuclear Power Station. *C. crispus* is particularly prolific on the fringes of the PNPS thermal discharge plume.

FINAL REPORT
ON
IRISH MOSS (*Chondrus crispus*) HARVESTING ALONG THE PLYMOUTH SHORELINE AND IMPACT ASSESSMENT OF PILGRIM STATION ON THE FISHERY, 1971-1982

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December 30, 1992

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

I. SUMMARY

Irish moss (*Chondrus crispus*), a commercially valuable red macroalga, has been harvested along the western shore of Cape Cod Bay since the 1800's. Pilgrim Nuclear Power Station's thermal discharge is located in the middle of what has been called one of the major commercial beds of *C. crispus* on the western Atlantic coast. Annual commercial harvests from the Pilgrim area have reached 2.3×10^5 kg (one-half million lbs). Surveys of the harvest were undertaken from 1971 to 1982 to assess whether the operation (via entrainment, impingement, and heated waste-water discharge) of Pilgrim Station impacted harvesting of the Irish moss resource in the offsite waters of Cape Cod Bay.

Harvesting procedures are described, and landing data (harvest, effort, and harvest rate) are compared for surveillance and reference areas and for preoperational and operational study years. There was an overall downward trend in landings and effort in the study area from 1971 to 1982. Harvest rate (kg/hr), calculated as a measure of *C. crispus* harvest per unit of effort, was used as an index of the fishery. Statistical analyses were run to test the null hypothesis that there was no difference in harvest rates between the discharge and prime reference area. The results were inconclusive. There was no significant difference in harvest rates during the operational years between Areas 1 (reference) and 5 (surveillance), but there was a significant difference during the preoperational period. This invalidates the utility of these two areas to assess plant impact and points to other factors that can

affect the harvest rate of *C. crispus*.

One meaningful statistical test result was that MDC - Maximum Daily Capacity - (a measure of power plant operation) had a significant negative impact on *C. crispus* harvest rate; however, MDC accounted for less than one percent of the variation in the rate. We estimate that about one percent of the *C. crispus* in Area 5 has been impacted by the discharge current, which created a relatively small denuded zone and an even smaller zone of stunted plants unfit for harvesting. Thus, there is an impact from Pilgrim Station on Irish moss, but it is very localized.

II. INTRODUCTION

Chondrus crispus Stackhouse is a perennial marine macroalga (seaweed). Reportedly in centuries past, people along the rocky coast of Ireland harvested a prolific red seaweed carrageen, which today is known familiarly as Irish moss (*C. crispus*). Highly valued by the Irish, it was dried and mixed with milk to make a rich, nutritious pudding.

C. crispus also occurs along the western North Atlantic coast from Nova Scotia, Prince Edward Island, and Newfoundland to New Jersey (Taylor 1962), growing best in the cooler waters of northern New England and the Canadian Maritime Provinces.

The seaweed is harvested as a source of carrageenan, a hydrocolloid unique for its jellying, suspension, and viscosity properties (Lilly 1968). Carrageenan, as a natural food additive, is a utilitarian thickening agent and has been used in the manufacturing and processing of such diverse products as beer, meat, dairy products, toothpaste, leather, paper, and pharmaceuticals (MacFarlane 1968).

Dawson (1956) reported that Irish moss was harvested for more than a century from the waters off Scituate, Massachusetts. An Irish moss harvesting industry developed locally over 50 years ago by Mr. Paul Vantagoli, who formed the company, Sea Moss Inc., of Kingston, Massachusetts. He initially supplied Irish moss to a Cambridge company that manufactured hand lotion and cosmetics and subsequently sold moss to small local breweries in New Bedford and Fall River. During the 1940's, a firm in Massachusetts began using carrageenan to stabilize homogenized chocolate milk. This company ultimately merged with a competing firm in Maine to form Marine Colloids, which produced and distributed carrageenan throughout the United States. In turn, Sea Moss Inc. provided Irish moss to Marine Colloids, which has purchased more than 9.1 million kilograms (20 million pounds) of Irish moss and other seaweeds from three continents (Kelly 1990).

Annual commercial harvests of Irish moss in the amount of 2.3 x 10^5 kg (one-half million pounds) and valued at $25,000 (5¢ per lb) have been landed in the past from the coastal waters of Plymouth, Massachusetts, where this species is a dominant among subtidal macrophytes (Stone and Webster 1975).

The objective of the investigation was to survey the Irish moss fishery in the vicinity of Pilgrim Station and assess impact of the power station on the harvest of *C. crispus* in the offsite waters of western Cape Cod Bay. *C. crispus* is sessile and thus subject to station-related impact via the thermal plume (waste heat and current). Entrainment of their reproductive spores, even though they are non-buoyant, is also possible. Landing data were collected from 1971 to 1982, which included two preoperational (1971-1972) and ten operational years (1973-1982). These records provide a historical accounting of landings from this local commercial fishery (Lawton et al. 1984).

III. LIFE HISTORY

Irish moss is not a moss but belongs to the taxonomic group of plants called Rhodophyta, which are red algae. Algae do not have true roots, stems, or leaves found in higher plants. A plant body of this type is referred to as a thallus. Generally 8 cm to 15 cm (3 in to 6 in) in height, the thalli of *C. crispus* usually occur in bushy clumps, consisting of dichotomously branched, flattened blades that terminate apically in fronds (leaflike structures) and basally in a slender cartilaginous stalk containing a disklike holdfast that attaches to the substrate (Figure 1).

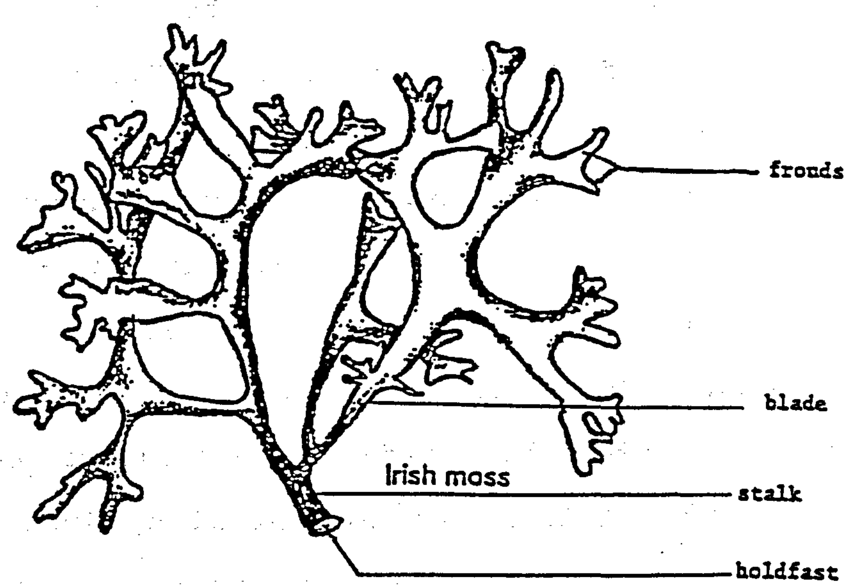

Figure 1. Sketch of *Chondrus crispus* Stackhouse (actual size).

The ecology of this alga, which has bearing on potential impact of power plant effects, has been studied by Mathieson and Prince (1973), Prince and Kingsbury (1973) and Mathieson and Burns (1975), among others. Requiring a solid surface for attachment, it grows on ledges, boulders, cobble, and shells (MacFarlane 1968). Growth is enhanced in moderately exposed locales by the action of waves, tides, and currents which maintain a nutrient supply and retard siltation and epiphytic attachment. Productivity is related to the amount of appropriate substrate in an area. The most extensive populations occur on massive outcrops (ledges) and boulders, while more limited stands occur on smaller rocks and shells. Ryther et al. (1976) reported that the Irish moss population off the Plymouth shoreline is centered primarily in the areas of subtidal rock from low water to about 7.6 m (25 ft) below mean low water (MLW).

The vertical distribution of *C. crispus* throughout its range extends from about +1 m to -18 m (+3.3 ft to -59 ft) MLW. Intertidal stands are much smaller with fewer plants than those in deeper water because the rates of photosynthesis and respiration are adversely affected by desiccation and temperature changes. The lower limits of distribution are controlled by incident light, water transparency, availability of solid substrate, and competition for space. *C. crispus* has a limited tolerance to silt-sand coverage. Prince and Kingsbury (1973) found in Plymouth, Massachusetts that below 6 m (20 ft) MLW in depth, the density of *C. crispus* decreased, and is replaced by the red macroalga, *Phyllophora* spp.. The blue mussel (*Mytilus edulis*) also competes with *C. crispus* for space.

C. crispus tolerates a wide range of temperatures and salinities. A highly variable morphology has been recognized and described (Taylor 1962; Ryther et al. 1976), which apparently is linked to the plant's tolerance to varying conditions of growth. Specific environmental features of its habitat determine the characteristics of the ecotype. Color of each plant appears related to light intensity (MacFarlane 1968). Height and frond width are influenced by water depth and exposure to air. Intertidal plants generally are short and broad, while subtidal plants tend to be taller and narrower (MacFarlane 1968). Prince (1971) observed *C. crispus* plants generally to be small in the shallow subtidal zone of Plymouth waters but found substantially larger plants with highly dichotomized fronds in deeper waters (≈ -9 m or -30 ft) MLW. Nevertheless, the size, weight, and condition of the plants can vary somewhat even within the same general locale (Ryther et al. 1976).

A euryhaline species, *C. crispus* can carry on respiration and photosynthesis efficiently between 8‰ and 40‰ salinity. Primarily a shallow subtidal species, *C. crispus* is exposed to temperature fluctuations but not to the same extent as endemic intertidal flora. In laboratory culture experiments on survival, growth, and reproduction, Prince (1971) reported the ideal temperature range was 15° to 19° C (59° to 66° F). Mathieson and Burns (1971) added that photosynthesis of excised *C. crispus* tissue peaked at 20°C

(68°F). According to Neish et al. (1977), the maximum growth rate occurred at about 20°C (68°F). Thermal stress becomes pernicious to metabolism at temperatures above 26° C (79°F) (Mathieson and Burns 1971).

Fixed nitrogen as ammonium or nitrate ions is often the limiting nutrient in seawater for its growth. Phosphate also is important to growth and maintains the integrity of the thallus, i.e., lessens spontaneous fragmentation. Maximum growth occurs in late summer because of favorable incident light and temperature. During the growing season, fronds of *C. crispus*, on average, can grow an amazing three percent each day. Individual plants can reach 8 cm to 15 cm (3 in to 6 in) in height.

Reproduction intensifies in late spring and summer (Prince 1971). There is both sexual and asexual reproduction. Spores (carpospores and tetraspores) are produced and dispersed into the water. The modes of seasonal reproduction of *C. crispus* have been described by Mathieson and Prince (1973), Prince and Kingsberry (1973), and Mathieson and Burns (1975).

IV. STUDY AREA

The abiotic benthic marine environment near Pilgrim Station is comprised primarily of two kinds of substrate - hard rock and sand. Ambient water temperatures (surface and bottom) have ranged from -1° C (30° F) in winter to 23° C (73° F) in summer (Lawton et al. 1983). Thermal stratification often occurs during the summer months, with a well-defined thermocline occurring at about 10 m (32.8 ft) during July and August (Davis 1984). Salinity (surface measurement) in the Irish moss study area does not vary much from 32‰. A range of 31 - 32‰ was reported for this area by Davis (1984). Water circulation in the Plymouth area is affected by both tidal flow and the coast-wide movement of water from Massachusetts Bay and the rest of Cape Cod Bay (Bumpus 1974). A large tidal amplitude (mean = 2.8 m) (≈ 9 feet) and relatively shallow depth result in substantial water exchange in the study area (Davis 1984).

Macroalgae dominate the rocky bottom, and much of the benthic fauna are associated with or directly dependent upon these plants and the cover they provide. In the vicinity of the power plant, *C. crispus* is the principal component of the shallow subtidal plants. In fact, Prince and Kingsbury (1973) reported that Pilgrim Station's thermal discharge occurs in the middle of one of the major commercial Irish moss beds on the western Atlantic coast. The general distribution of this species along the Plymouth coastline from Manomet Point to Warren Cove is depicted in Figure 2.

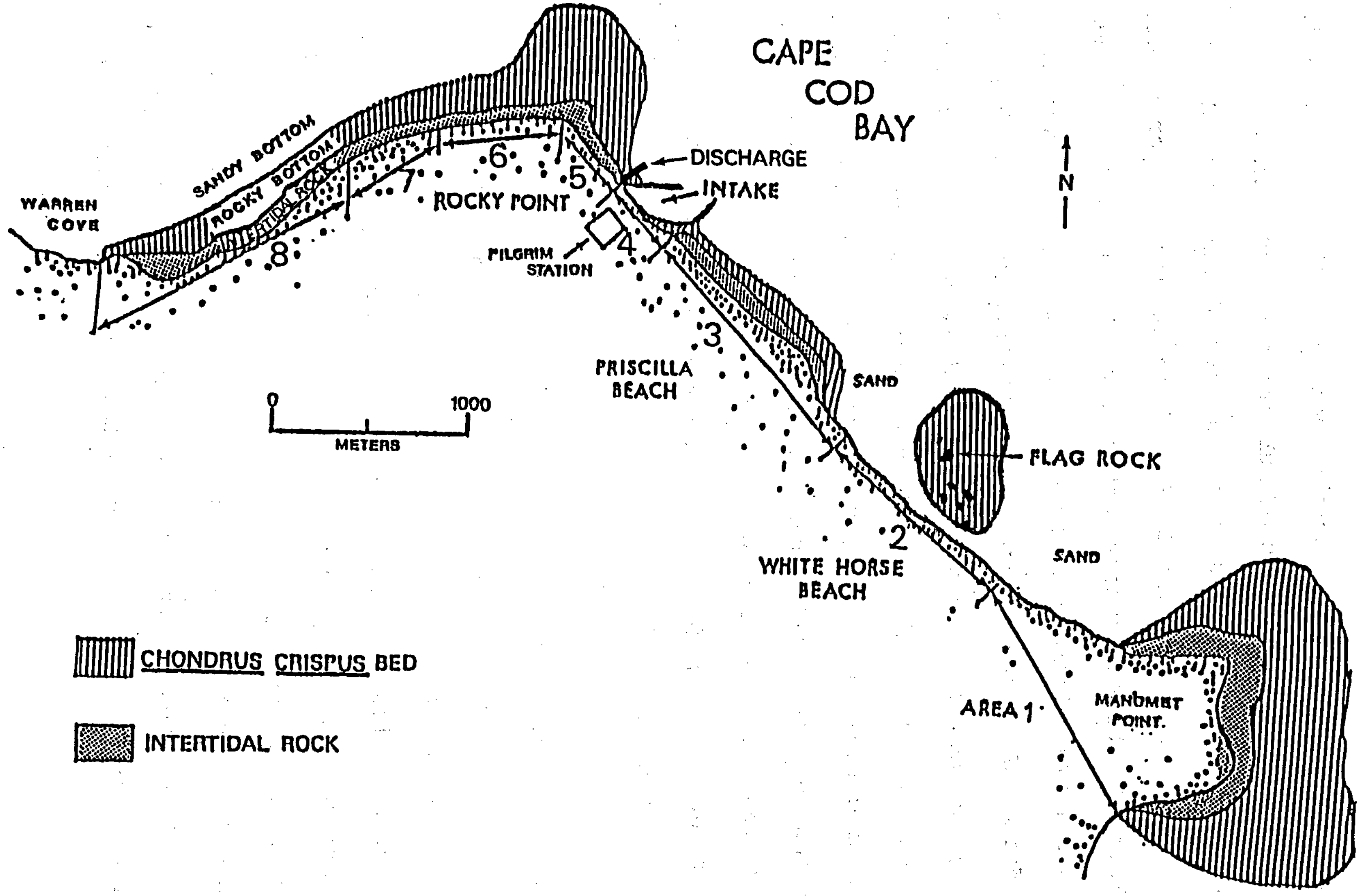

Figure 2. Distribution of Chondrus crispus stands along the Plymouth shoreline.
(According to Ryther et al. 1974)

V. HARVESTING METHODS

Techniques and equipment for harvesting Irish moss in the Plymouth area have changed very little since the 1800's. In one of the few fisheries that has involved primarily manual labor, handraking has predominated, but harvesting also has been done by diving, using a suction pump, or collecting moss that has dislodged and washed ashore. The only specialized harvesting implement used by hand-rakers is the long-handled mossing rake. Typically, it is constructed of a cast bronze rake head attached to an aluminum or wooden handle, often 3.8 m (12 ft) long, by a piece of tapered steel bolted to the head of the rake and fitted into a ferrule on the handle. The head typically has 25 to 30 teeth 15 cm to 20 cm (6 in to 8 in) in length (Plate 1).

The rakers, colloquially called 'mossers', were paid by the pound (0.45 kg) wet weight landed by Sea Moss, Inc., who bought the moss harvested from Plymouth waters. The fishermen, primarily students out of school for the summer, worked alone or in pairs from rowed or powered skiffs and dories. An outboard-powered boat was a distinct advantage to a raker, providing increased mobility to reach less exploited stands of moss. Most boats were equipped with a collection net for moss storage which also facilitated weighing and off-loading the harvest to a truck. The harvested moss was transported to the headquarters of Sea Moss, Inc. in Kingston, where it was furnace-dried before being trucked in bundles to Marine Colloids in Maine.

Most commercial harvesting in Plymouth was done from Rocky

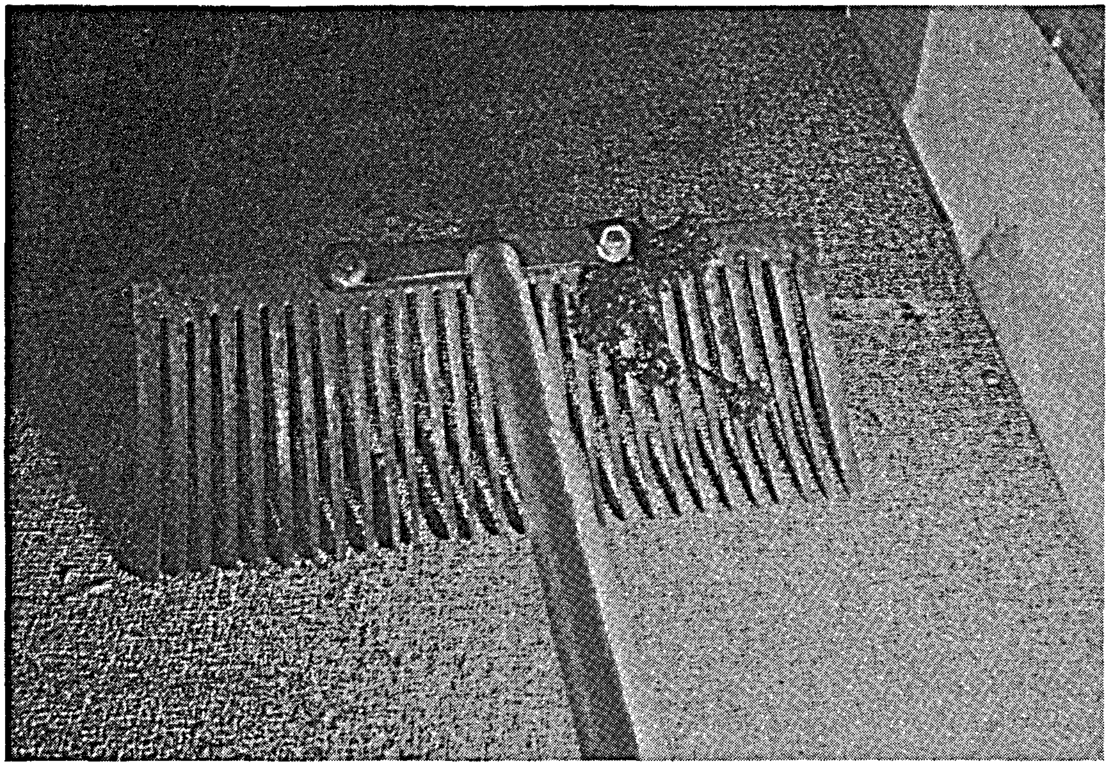

Plate 1. The "mossing" rake used to harvest Irish moss off Pilgrim Station is constructed of a cast bronze rake head attached to a 12-foot aluminum or wooden handle. The rake head typically has 25 to 30 long tines in which the raked moss becomes entangled and is torn free.

Plate 2. The landing site for raked Irish moss in the Pilgrim Station area is White Horse Beach. Most of the boats involved in the fishery were moored off the beach.

Point to Manomet Point. Raking areas were selected by the fishermen on a particular day based on wind direction and speed, resultant sea state, tide, mobility of the fishing vessel, and each raker's perception of where moss was abundant. The number of working days and resultant harvest in a season were influenced by weather patterns and overall sea conditions.

The embarkation/landing site was White Horse Beach, tangential to Flag Rock (Figure 2; Plate 2). The boats used for 'mossing' also were moored off this beach. The distribution of *C. crispus* dictated that harvesting be done near shore beginning on an ebbing tide. Tidal cycles and amplitude regulated effort and influenced harvesting spatially. Generally, because of water depth and the nature of the fishery, moss was accessible to rakers during the last two hours of a daylight falling tide through the first two hours of the incoming tide. Work hours were extremely irregular because the starting time varied each day with the time of low tide.

Actual harvesting involved lowering the mossing rake over the side of the boat to the sea bottom and scraping the rocky substrate in areas having known concentrations of Irish moss. The angle of the rake head on the handle positioned the teeth nearly parallel to the bottom. Fronds of moss entangled between the rake's teeth were torn free, generally leaving smaller fronds and the plants' holdfast structures intact and attached to the substrate, enabling the moss to regenerate. The harvester then retrieved the rake, and the collected moss was pulled from the rake's teeth and stored.

The operation continued until the flooding tide increased water depth to a point that raking became impossible.

At the conclusion of each harvesting outing, rakers returned to the landing site (Plate 3), where the collecting net was hoisted out of each boat by hand or a boom on a truck and weighed by the buyer. The moss then was loaded onto the bed of a large truck owned by Sea Moss, Inc. for shipment (Plate 4).

Plate 3. Fishermen are seen back at the landing site on White Horse Beach with their harvests of Irish moss. Stored in collection nets, the moss is being lifted out of two boats.

Plate 4. The harvested Irish moss was weighed and then loaded onto the bed of a large truck for shipment to the drying facility. The fishermen were paid by the pound (wet weight) of moss landed at the going price of five cents a pound in the 1970's.

VI. STUDY METHODS

In 1971, we began compiling landing data for Irish moss commercially harvested in the Pilgrim area. The harvesting season was generally early June through August, but occasionally ran from late May through mid-September. Records were collected for 12 consecutive years (1971-1982), which generated a substantial data base. To examine impact of Pilgrim Station on the harvest and to facilitate data comparisons, we judgmatically divided the immediate coastline that included Pilgrim Station into eight geographical areas, all containing stands of *C. crispus* (Figure 2). Natural, easily recognizable bounds were used to delineate areas where possible; otherwise, area limits were established by ranges painted on large rocks. All rakers were informed of our study and the boundaries of each area by the data collector. Area 1 (Manomet Point), far removed from the zone of discharge influence, was designated the prime reference area. Area 2 (White Horse Beach) was a secondary reference area. Area 5, encompassing the cooling water discharge, was the surveillance area. The total harvesting area encompassed 2.35 km^2 (581 acres) (Ryther et al. 1974).

A seasonal Massachusetts Division of Marine Fisheries (MDMF) employee, stationed at White Horse Beach, recorded daily landings of Irish moss (wet weight) by raker throughout the harvesting season for all 12 survey years. Times of departure and return of each boat and the area or areas fished also were noted. Each raker was asked to estimate actual raking time and percent of harvest by area when more than one area was fished on a single trip. If proportional catch and effort data were not known or reported, the landings were not included in subsequent harvest rate calculations and analyses. Harvest rate (kg/hr) was used as an index (catch per unit effort) of the fishery. Harvest effort in hours of raking was obtained by subtracting travel time to and from the areas worked from the total time elapsed recorded upon landing. Using harvest rate reduced the bias when comparing landings from areas of unequal size. Nonetheless, harvest rates were influenced by rakers' interest, aptitude, and experience, as well as the abundance of the crop in a given location at a particular time. An important factor is the 'learning' effect, where new fishermen with time and experience, increase their efficiency and learn the best areas to harvest. This effect can obscure real changes in abundance of the stock.

Descriptive analyses were performed by area, month, and year. Analysis of the individual rakers and their landings over the years was not particularly insightful. There was a high turnover with workers entering and leaving the fishery regularly. Only one raker fished all 12 years of the survey. It was obvious in any given year that there were highliners in the fishery who landed a disproportionate amount of Irish moss. Their landings did not necessarily dovetail with the overall findings (pooled data) year to year.

Harvest rates were severely skewed (skewness = 2.177, t_{skew} = 75.068, $P < 0.001$) and heteroscedastic (Kolmogorov-Smirnov Goodness of Fit Test, $P < 0.001$) among areas, months, and years. The data were then $\log_{10}$ transformed, but were still skewed (skewness = -0.401, t_{skew} = -16.46, $P < 0.001$), and significantly heteroscedastic (Kolmogorov-Smirnov Goodness of Fit Test, $P < 0.001$). Accordingly, the Kruskal-Wallis one-way analysis of variance and the Mann-Whitney U-Wilcoxon Rank Sum W test were used to test for differences in harvest rate between years, months, and areas.

In spite of the violations of variance homogeneity and normality assumptions, analysis of variance (ANOVA) of $\log_{10}$ harvest rate data was used for its ability to partition variance into various effects. Relying on the robustness of ANOVA, probability values were interpreted loosely. This was done for Areas 1 (prime reference area), 2 (secondary reference), and 5 (surveillance) using different combinations of months and years. For some analyses, data from May and September were not used because of the small number of records available. To investigate a 'treatment' effect, i.e., the impact of the thermal discharge, we also employed the Mann-Whitney U-Wilcoxon procedure to test if there was a significant difference ($P \leq 0.05$) in harvest rate between Areas 5 and 1 for preoperational and operational years. To address possible inherent spatial differences between Areas 1 and 5, data collected from Area 2 (reference) were then substituted for Area 1, and the analyses were re-run.

To overcome differences in harvesting effort between months and years, $\log_{10}$ harvest rate data were weighted to generate an even number of samples for each month. The Mann-Whitney U-Wilcoxon Test and a simple ANOVA were run for the preoperational and also the operational years for Areas 1 and 5 and Areas 2 and 5.

Finally, regression analysis was performed for $\log_{10}$ harvest rate data and power station MDC (measure of plant thermal power level) for all years and months when data were collected. Multiple regression analysis was run to incorporate month and year.

VII. RESULTS AND DISCUSSION

Landings

Over the 12 years (1971-1982) of the survey, harvesting of Irish moss began as early as mid-May and concluded as late as mid-September. However, 98% of the landings were obtained from June through August, making this fishery one of relatively short duration. The harvest peaked in July most years. This was also true for the *C. crispus* fishery in southwestern Nova Scotia (Sharp and Roddick 1982).

A total of about 350 rakers plied the study area at one time or another from 1971 to 1982. On a yearly basis, the number of harvesters ranged from 39 to 80 per harvesting season. Hand-raked landings from the study area (Figure 2) for the 12 years totaled 1.4 x 10^6 kg (3.1 million lbs). The annual harvest averaged 116,634 kg (257,200 lbs). The mean daily landing (pooled for rakers and years) was about 1,852 kg (4,000 lbs). Areas 1,2,5 and 6 (Figure 3) consistently provided the largest landings, with the combined

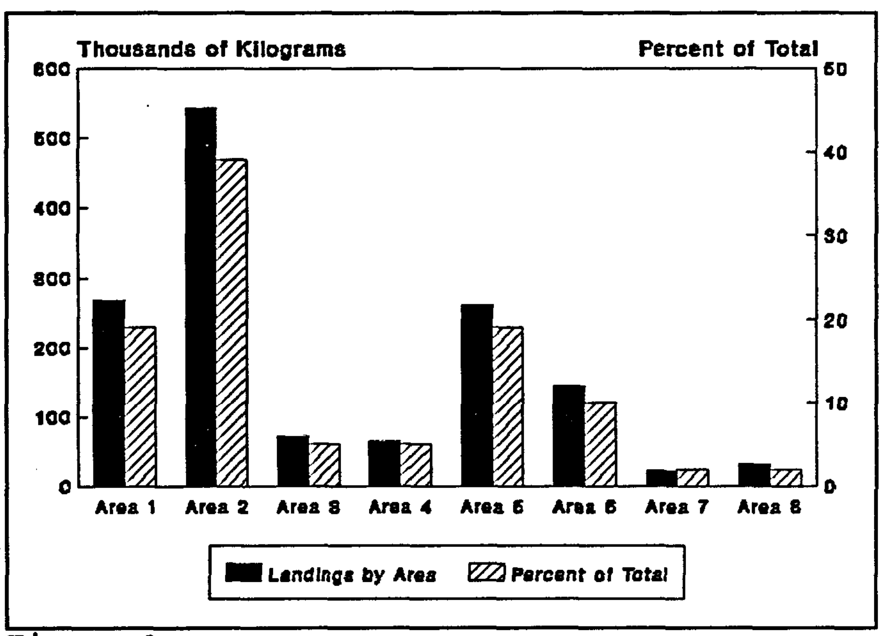

Figure 3. Landings (kgs) and percent composition by area of Irish moss harvested in the environs of Pilgrim Station from 1971-1982 (pooled).

harvest from these four areas comprising 78% to 95% of the yearly totals.

The largest annual landing came from reference Area 2 (White Horse Beach) in 1976, closely followed by the landing at the prime reference area - Manomet Point (Area 1) - in 1972 (Table 1). The major harvesting area shifted in 1974 from Area 1 to Area 2, which claimed the highest landings thereafter. Proximity and accessibility to the landing/unloading site in Area 2 evidently had bearing on this shift.

Area 2 ranked first in overall landings for the 12-year survey, comprising 39% of the grand total. Area 1 ranked second, followed by Area 5. In a yearly analysis, landings from Area 5 (includes the area impacted by the thermal discharge) ranked second for half the years surveyed while Area 1 ranked third for half the years. Ryther et al. (1976) conducted an underwater survey and deemed that the best quality *C. crispus* plants came from Manomet Point (Area 1) and White Horse Beach (Area 2), while the plants off Rocky Point were of a good quality nearest Pilgrim Station, but of a lesser quality moving northeasterly towards Area 6 (Figure 2).

The harvest from Area 6 was fourth overall, while Areas 3 and 4 (north of White Horse Beach up to and including the power plant's intake embayment) were relatively low yield areas. Ryther et al. (1976) reported finding relatively little Irish moss in Area 4, between the power plant's intake breakwaters, but the quality was better than average for the whole area. By far, the lowest landings and poorest quality *C. crispus* came from the southern edge

Table 1. Irish moss raker harvesting data from the Pilgrim study area, 1971-1982.

(a) Landings (kg, wet weight):

Area	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	Total
1	41,743.0	60,477.1	23,875.2	28,220.7	20,684.2	14,100.2	13,390.3	13,399.3	14,846.3	16,547.3	8,128.5	12,705.3	268,117.5
2	36,295.7	51,951.3	20,645.6	41,905.8	41,015.4	62,639.9	59,412.5	49,748.6	33,165.0	55,371.0	47,555.4	41,513.5	541,219.6
3	5,242.3	8,645.2	1,877.9	5,835.6	7,230.4	10,743.5	7,151.0	5,604.2	4,935.2	6,429.8	4,944.2	2,753.4	71,392.6
4	10,380.6	13,989.9	3,490.5	3,991.7	6,246.1	2,735.2	7,407.3	3,832.9	5,615.6	3,694.6	768.9	1,762.2	63,915.4
5	36,739.3	35,209.3	8,461.9	12,934.4	32,822.5	25,852.9	29,885.4	17,223.2	13,737.3	21,273.8	10,716.3	14,837.3	259,693.7
6	17,724.4	25,812.6	11,224.3	7,777.0	33,409.9	11,902.5	12,657.7	4,062.0	11,167.6	6,956.0	226.8	1,186.2	144,106.9
7	6,484.2	8,114.0	0.0	86.2	4,443.0	986.6	0.0	1,004.7	31.8	0.0	0.0	0.0	21,150.5
8	14,977.9	13,455.1	226.8	0.0	1,283.7	68.0	0.0	0.0	0.0	0.0	0.0	0.0	30,011.5
Total	169,587.4	217,654.5	69,802.2	100,751.4	147,135.1	129,028.8	129,904.2	94,875.0	83,498.7	110,272.4	72,340.1	74,757.8	1,399,607.7

(b) Collecting effort (hours):

Area	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	Total
1	404.8	559.3	313.6	278.3	240.6	172.2	154.8	150.9	175.6	174.3	80.9	175.3	2,880.6
2	434.8	783.2	350.7	392.0	559.8	843.0	978.3	708.7	427.6	675.8	584.0	480.4	7,218.3
3	61.6	107.7	30.6	82.7	90.3	163.5	134.4	53.5	91.4	83.5	68.0	27.0	994.2
4	132.7	174.2	48.7	34.0	55.0	51.4	113.0	62.6	106.5	51.0	12.6	22.1	863.8
5	412.5	386.9	125.9	143.2	310.4	294.7	343.3	235.6	173.6	238.9	124.7	177.3	2,967.0
6	187.5	272.1	148.8	89.9	256.9	105.3	143.6	40.8	111.4	64.8	1.5	7.9	1,430.5
7	97.4	95.5	0.0	1.4	27.1	12.6	0.1	6.6	0.4	0.0	0.0	0.0	241.1
8	141.1	134.8	3.0	0.0	11.9	1.2	0.0	0.0	0.0	0.0	0.0	0.0	292.0
Total	1,872.4	2,513.3	1,021.3	1,021.4	1,552.0	1,643.7	1,867.5	1,258.5	1,086.4	1,288.3	871.7	890.0	16,887.5

(c) Harvest rate (kg/hr):

Area	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	Area Mean
1	103.1	108.1	76.1	101.4	86.0	81.9	86.5	88.8	84.5	94.9	100.5	72.5	93.1
2	83.5	66.3	58.9	106.9	73.3	74.3	60.7	70.2	77.6	81.9	81.4	86.4	75.0
3	85.1	80.3	61.4	70.6	80.1	65.7	53.2	104.8	54.0	77.0	72.7	102.0	71.8
4	78.2	80.3	71.7	117.4	113.6	53.2	65.6	61.2	52.7	72.4	61.0	79.7	74.0
5	89.1	91.0	67.2	90.3	105.7	87.7	87.1	73.1	79.1	89.0	85.9	83.7	87.5
6	94.5	94.9	75.4	86.5	130.1	113.0	88.1	99.6	100.2	107.3	151.2	150.1	100.7
7	66.6	85.0	0.0	61.6	163.9	78.3	0.0	152.2	79.4	0.0	0.0	0.0	87.7
8	106.2	99.8	75.6	0.0	107.9	56.7	0.0	0.0	0.0	0.0	0.0	0.0	102.8
Annual	90.6	86.6	68.3	98.6	94.8	78.5	69.6	75.4	76.9	85.6	83.0	84.0	82.9

of Warren Cove (Areas 7 and 8). The latter are farthest away from the embarkation site and are exposed to the adversities of prevailing winter winds and ice floes from nearby Plymouth Harbor-Kingston, Duxbury Bay (Lawton et al. 1984).

There was a significant downward trend in landings from the study area during the survey years as determined by linear least squares regression, P = 0.02 (Figure 4). The highest landing was obtained in 1972, followed by the lowest in 1973 (the first year of plant operation). The 68% decline in 1973 was not restricted to Area 5 but occurred throughout the entire harvesting area (Table 1).

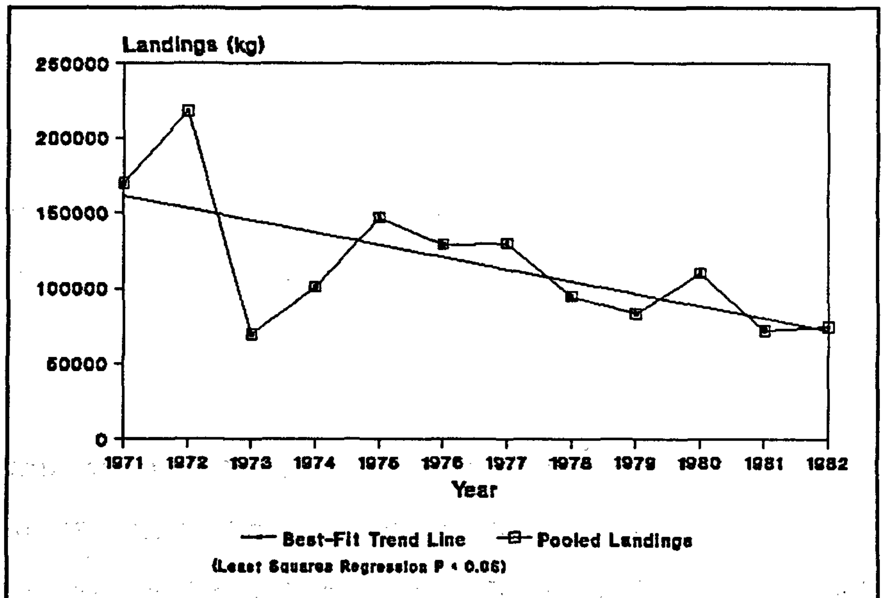

Figure 4. The declining trend of Irish moss landings from the Pilgrim study area (pooled area data) for 1971-1982.

The difference in yield (pooled study area data) between 1972 and 1973 was significant (Mann-Whitney U - Wilcoxon Rank Sum W test, P < 0.0001), but cannot be explained by any single factor. There were 18 fewer raking days (weather related), 14 less 'rakers', and only 4 versus 11 two-tide days (days when two tides could be worked during daylight hours) in 1973. Sharp and Roddick (1982) found in the Irish moss fishery of Southwestern Nova

Scotia that accessibility of the resource was more important than yearly variations in stock abundance after the harvesting month of June. In the Pilgrim study area, however, it appears there also was a real decline in the Irish moss standing crop in 1973, as indicated by the reduced harvest rates throughout all the areas raked.

Landings generally rebounded in 1974 even though the total effort in raking hours was essentially equal to that in 1973. The harvests in 1976 and 1977 were quite similar to each other in total landings; this was also the case with 1981 and 1982 (Table 1). The harvest for the latter two years was only slightly larger than the low of 1973. For whatever reason, effort was at its lowest level in 1981 and 1982.

Effort

Harvesting effort was influenced by resource availability, with weather, wind, and tide being limiting factors. Obviously, the number of harvesters in a given year, influenced by the regional economy and pay scale for mossing relative to other summer employment, had direct bearing on the amount of effort expended. Total effort (pooled data) ranged from 872 hours in 1981 to 2,513 hours in 1972. Spatial allocation of effort apparently was influenced by the distance harvesters had to travel by boat from the mooring site off White Horse Beach. Rakers with manually-powered boats tended to fish in or near Area 2.

There was a significant ($P < 0.05$) downward trend overall in harvesting effort in the study area from 1971 to 1982 as determined by linear least squares regression (Figure 5). This trend ties in with that of the landings. The greatest amount of effort, by far, was expended in 1972, a preoperational year (Figure 5). The second highest year was 1971 (the other preoperational year), followed very closely by 1977 (operational year). Effort fell precipitously in 1981 and remained low in 1982. 'Mossing' in the 1990's has been nearly non-existent in the Pilgrim area.

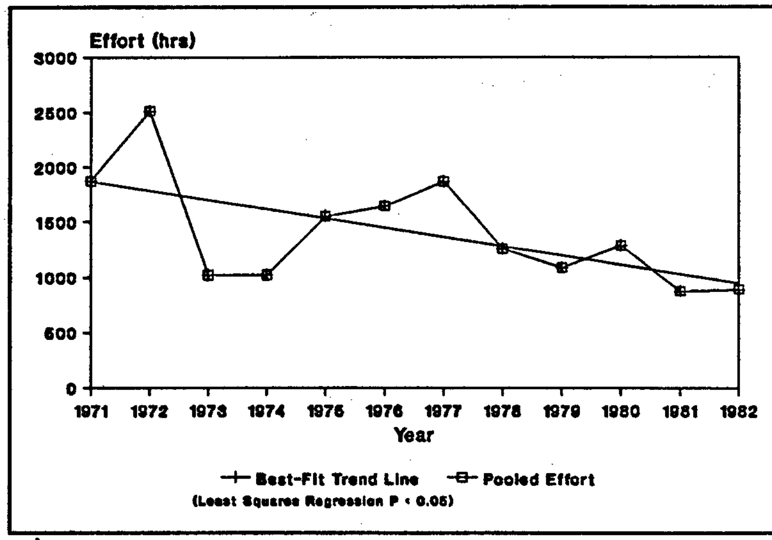

Figure 5. The declining trend in harvesting effort for Irish moss in the Pilgrim study area (pooled data) over the years, 1971-1982.

The distribution of effort expended by area (pooled for years) is found in Figure 6. Area 2 (White Horse Beach), by far, received most of the total effort (43%), which was more than double that of any other area. Area 5 (includes the discharge) ranked

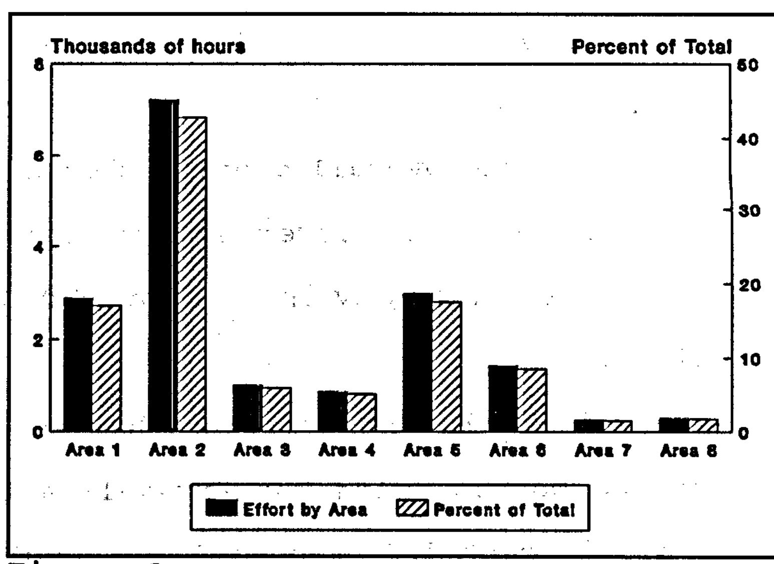

Figure 6. Effort (hours) expended and percent composition by area of effort expended to harvest Irish moss in the environs of Pilgrim Station, 1971-1982, pooled.

second, with Area 1 (Manomet Point), third. Areas 6 and 3 followed, respectively.

Effort was highest each year in Area 2, where in some of the survey years more than 50% of the harvesting occurred. The total effort (pooled for the 12 years) expended in Areas 1 (reference) and 5 (surveillance) was very similar (Table 1). Harvesting time generally declined at both sites during operational years. In 1973, fishing effort was substantially less in all zones as compared to either of the previous preoperational years, concomitant with a marked reduction in harvest. The nadir in effort occurred in 1981.

<u>Harvest Rate (Catch Per Unit Effort)</u>

The annual harvest rate (pooled for all areas) during the survey ranged from a low of 68.3 kg/hr (150.6 lbs/hr) in 1973 to a high of 98.6 kg/hr (217.4 lbs/hr) in 1974, with a time series mean of 82.9 kg/hr (182.8 lbs/hr). Harvest rates declined in all areas in 1973 - many of them significantly - but returned to earlier levels in 1974 and 1975 (Table 1; Figure 5). According to Ryther et al. (1976), the overall densities of *C. crispus* in Zones 1-8 of the Pilgrim area were lower in the autumn of 1973 than in the subsequent three years by an average of 0.64 kg/0.9 m^2 (1.4 lbs/yd^2) wet weight.

Analysis of log_{10}-transformed harvest rate data between years and between months using the Kruskal-Wallis 1-Way ANOVA revealed highly significant differences ($P < 0.0001$) between the components of each grouping. Comparisons were then made between Areas 1 (reference) and 5 (surveillance) and between Areas 2 (reference) and 5 using the Mann-Whitney U - Wilcoxon test and Analysis of Variance (ANOVA) of weighted $\log_{10}$-transformed data. There was no significant difference ($P > 0.05$) in harvest rate between Area 5 and 1 during operational years; however, the two areas differed significantly ($P < 0.001$) during the two preoperational years (Table 2). Areas 5 and 2 were significantly different ($P < 0.001$)

Table 2. Analysis of variance tables from the comparison of weighted $\log_{10}$ harvest data from Areas 1 and 5 for pre-operational (1971-1972) and operational periods (1973-1982).

a) Analysis of Variance Table - Areas 1 and 5, Pre-operational Period (1971-1972)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance of F
Area	1.33	1	1.33	31.16	< 0.001
Within Cells	31.42	739	0.43		
Total	32.75	740	0.04		

b) Analysis of Variance Table - Areas 1 and 5, Operational Period (1973-1982)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance of F
Area	0.002	1	0.002	0.35	0.851
Within Cells	103.22	1713	0.060		
Total	103.222	1714	0.062		

during both the preoperational and operational years (Table 3). Because prestress data were not similar between Areas 1 and 5, or between Areas 2 and 5, we concluded that neither control area was a good reference site when assessing power plant impact.

Catch-per-unit-effort can vary with the abundance of the standing crop, accessibility of the Irish moss beds (influenced by tides, weather, and distance the rakers have to travel), and the motivation and proficiency of the harvesters (Sharp and Roddick

1982).

Table 3. Analysis of variance tables from the comparison of weighted $\log_{10}$ harvest data from Areas 2 and 5 for pre-operational (1971-1972) and operational periods (1973-1982).

a) Analysis of Variance Table - Areas 2 and 5, Pre-operational Period (1971-1972)					
Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance of F
Area	1.58	1	1.58	25.08	< 0.001
Within Cells	52.55	836	0.06		
Total	54.13	837	0.06		

b) Analysis of Variance Table - Areas 2 and 5, Operational Period (1973-1982)					
Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance of F
Area	4.64	1	4.64	65.82	< 0.001
Within Cells	228.61	3246	0.07		
Total	232.25	3247	0.07		

The harvestable standing crop is affected by water temperature, substrate type, currents and scouring, nutrients, biotic competition, epiphytism, light, and past harvesting. All these factors complicate the assessment of power plant impact on the harvest rate of Irish moss.

Assessment of Power Plant Impact

From SCUBA diver observations (SAIC 1992), we estimate that less than 4,047 m^2 (1 acre) within Area 5 is unharvestable for *C. crispus* because of Pilgrim Station operation via waste heat and discharge current, which affects the presence, abundance, and size of the plants. Ryther et al. (1974) calculated the size of Area 5 to be 2.27 x 10^5 m^2 (56 acres); thus, about 1% of Area 5 has been impacted. Grocki (1984) found that this affected area of the effluent had significantly lower *C. crispus* biomass than did control areas, a phenomenon he attributed to a higher percentage of gravel and sand in the outfall area and the scouring effect of the discharge current that creates a denuded zone. In addition, the velocity of the effluent at low tide would be a limiting factor, in itself, to the actual harvesting process in the outfall area.

A multiple regression analysis was performed. The variables were $\log_{10}$ harvest rate data, MDC (index of Pilgrim Station operational status which approximates thermal loading in the outfall), month, and year. All variables were found to have significant effects on harvest rate, i.e., the harvest rate of *C. crispus* was functionally related to MDC, year, and month of harvesting. MDC and month had significant negative effects ($P = 0.0015$ and $P = 0.0241$, respectively) on harvest rate, while the effect of year was positive ($P = 0.228$). However, the combined effects accounted for only one percent of the variation (R square $= 0.01042$) in harvest rate. Due to very large sample size (1,318 d.f.), the test was very powerful and highly sensitive, and a small change was found statistically significant. Other factors, previously mentioned, concerning accessibility of the crop and the motivation and proficiency of the rakers obviously influenced the harvest rate far greater than did the thermal plume.

Landings from Areas 1 and 5 declined markedly in 1973, the first year of plant operation. In fact, effort, landings, and harvest rates declined that year throughout the study area. The harvest rebounded south of the power plant (Areas 1-3) in 1974 but did not recover north of the station until 1975. The average harvest from Area 5 (surveillance) for the operational years (1973-1982) was 48% below the preoperational mean from that area. By way of comparison, the average operational harvest from Area 1 (reference) was 67% below the preoperational level.

Harvest rates from 1972 to 1973 for Areas 1 and 5 showed comparable declines - 29% at the former and 23% at the latter. The mean preoperational harvest rate was 105.7 kg/hr (233 lbs/hr) in Area 1 and 90 kg/hr (198 lbs/hr) in Area 5. Mean operation levels for both areas were 87 kg/hr (192 lbs/hr) and 84 kg/hr (185 lbs/hr), respectively. The harvest rate for these areas was therefore similar during operational raking, with no substantial discharge effect indicated.

Most of the impact of Pilgrim Station operation on Irish moss apparently results from the thermal plume. The local area, observed by biologist - divers in June 1992 to be devoid of *C. crispus* from Station operation extended 105 m (115 yd) out from the discharge canal, with a total area affected of 2130 m^2 (0.53 ac) (SAIC 1992). Stone and Webster's (1975) prediction of a 8,094 m^2 (2 ac) Irish moss exclusion zone off Pilgrim Station for Unit 1 and the then planned Unit 2, based on literature thermal tolerance data (Prince and Kingsbury 1973) for this sessile alga and hydrothermal power plant predictions, was never realized. Unit 2 was never built, and the area impacted by the thermal discharge is much smaller than originally predicted. No impact of power plant entrapment/impingement occurs because no life stages of *C. crispus* are susceptible to these mechanical effects. Although station entrainment of its spores has occurred, thermal tolerance tests on this species (Prince and Kingsbury 1973) suggest there is not an impact of consequence from entrainment (Stone and Webster 1975).

We deem the operation of Pilgrim Station has had a limited impact on the *C. crispus* population from Manomet Point to Warren Cove and on the commercial Irish moss fishery. In general, non power plant-related fluctuations in moss landings were sufficiently large that any change attributable to power plant operation would be minor.

VIII. CONCLUSIONS

Irish moss harvesting in the Pilgrim Station area, which was primarily conducted by handraking, is a local, summer fishery. Most of the fishermen were students on summer vacation who sold their harvest to a local buyer. They were paid by the pound (0.45 kg) wet-weight of moss raked (mean = $0.05 per lb). For the survey years, 1971-1982, the mean annual harvest was 1.17×10^5 kg (128.6 T) at a dockside value of $12,900. The major harvesting areas, in landings were White Horse Beach (Area 2), Manomet Point (Area 1), and Rocky Point (Area 5).

The fishery declined from that in the early 1970's, with an overall downward trend in effort and landings occurring into the 1980's. In fact, the fishery has not been active the last few years in the Pilgrim area with no landings reported. According to the local buyer of *C. crispus*, competition for space on the bottom from blue mussels (*Mytilus edulis*) and a degradation of the quality of the plants from epiphytization have discouraged local commercial raking throughout the study area.

The handraking of *C. crispus* combines highly selective rake action with the harvester's search behavior to produce a low-impact fishery. Ryther et al. (1974) estimated that the annual landings of *C. crispus* from Manomet Point to Warren Cove for 1971-1973 represented a harvest of only about 4% of the resource available in October 1973, and 1-2% of the total standing crop present in 1974.

There was a significant negative regression (P= 0.0015) of Pilgrim Station operation on the commercial harvest rate of *C.*

crispus; however, plant operation explained less than one percent (R square = 0.003) of the variation in the harvest rate. Thus, the relationship between MDC and harvest rate is not biologically important. In effect, the size of the *C. crispus* area impacted by the thermal discharge from Pilgrim Station is small and localized, i.e., < 4,047 m^2 (1 ac), equaling about one percent of the surveillance area (Area 5).

On the basis of best available data, we conclude that the impact of Pilgrim Station on the harvesting of Irish moss has been small.

IX. ACKNOWLEDGEMENTS

We gratefully acknowledge the contribution of James Barrett, who ably conducted the field survey and Steven Cadrin who provided statistical consultation. Paul Vantangoli supplied photos and together with the numerous moss rakers were the source of Irish moss harvest information. To Randall Fairbanks, W. Leigh Bridges, and Robert D. Anderson we extend much appreciation for formulating and guiding the investigation. Messrs. Bridges and Anderson and Ms. Carolyn Griswold critically reviewed the manuscript. Greatly appreciated is the work of Kim Trotto for word processing the report. Finally, we thank the Pilgrim Administrative-Technical Committee for overseeing the entire environmental program at Pilgrim Station and Boston Edison Company for funding.

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