An Assessment of *Ascophyllum nodosum* Harvesting Methods in Southwestern Nova Scotia

Glyn J. Sharp

Fisheries and Oceans Canada
Resource Branch
Invertebrates and Marine Plants Division
Halifax, Nova Scotia B3J 2S7

July 1981

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1012

Government of Canada
Fisheries and Oceans

Gouvernement du Canada
Pêches et Océans

Canadian Technical Report of Fisheries and Aquatic Sciences

These reports contain scientific and technical information that represents an important contribution to existing knowledge but which for some reason may not be appropriate for primary scientific (i.e. *Journal*) publication. Technical Reports are directed primarily towards a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries management, technology and development, ocean sciences, and aquatic environments relevant to Canada.

Technical Reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report will be abstracted in *Aquatic Sciences and Fisheries Abstracts* and will be indexed annually in the Department's index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Details on the availability of Technical Reports in hard copy may be obtained from the issuing establishment indicated on the front cover.

Rapport technique canadien des sciences halieutiques et aquatiques

Ces rapports contiennent des renseignements scientifiques et techniques qui constituent une contribution importante aux connaissances actuelles mais qui, pour une raison ou pour une autre, ne semblent pas appropriés pour la publication dans un journal scientifique. Il n'y a aucune restriction quant au sujet, de fait, la série reflète la vaste gamme des intérêts et des politiques du Ministère des Pêches et des Océans, notamment gestion des pêches, techniques et développement, sciences océaniques et environnements aquatiques, au Canada.

Les Rapports techniques peuvent être considérés comme des publications complètes. Le titre exact paraîtra au haut du résumé de chaque rapport, qui sera publié dans la revue *Aquatic Sciences and Fisheries Abstracts* et qui figurera dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1-456 de cette série ont été publiés à titre de Rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457-714, à titre de Rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715-924 ont été publiés à titre de Rapports techniques du Service des pêches et de la mer, Ministère des Pêches et de l'Environnement. Le nom de la série a été modifié à partir du numéro 925.

La page couverture porte le nom de l'établissement auteur où l'on peut se procurer les rapports sous couverture cartonnée.

Canadian Technical Report of
Fisheries and Aquatic Sciences 1012

June 1981

AN ASSESSMENT OF ASCOPHYLLUM NODOSUM HARVESTING METHODS IN SOUTHWESTERN NOVA SCOTIA

by

Glyn J. Sharp

Fisheries and Oceans Canada, Resource Branch
Invertebrates and Marine Plants Division
P.O. Box 550, Halifax, N.S. B3J 2S7

Cat. No. Fs 97-6/1012 ISSN 0706-6457

Correct citation for this publication:

Sharp, G.J. 1981. An assessment of Ascophyllum nodosum harvesting methods in southwestern Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 1012: v + 28 p.

CONTENTS

ABSTRACT

Sharp, G.J. 1981. An assessment of Ascophyllum nodosum harvesting methods in southwestern Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 1012: v + 28 p.

Since 1959 Ascophyllum nodosum resources in southwestern Nova Scotia estimated at 180 000 t have been exploited at 6 000 t year^{-1} for alginate production by Scotia Marine Products Ltd. The harvesting method has evolved over 18 years from entirely hand methods to 80% mechanical methods. In the summer of 1978, a study examined the effects of mechanical harvesting (the Aquamarine Harvester) and compared them with those of the hand cutter rake. Harvest sites with a known harvest history were examined for residual biomass and population structure and a controlled experiment was conducted in one location. The residual biomass of recently cut areas was 6.0 kg m^{-2} to 7.2 kg m^{-2} versus 14.0 kg m^{-2} in area harvested 2 years previous. In areas freshly harvested by the mechanical cutter, the incidence of harvest was 26.0% to 60.5% of sampled areas. An area cut by the mechanical harvester had a mean stump height of 31.2 $\pm$ .6 cm versus a mean stump height of 23.8 $\pm$ 12.9 cm in an adjacent hand cut area.

Incidental harvest of holdfast material was 16.1 $\pm$ 8.4% by weight for the manual cutter rake and 1.9 $\pm$ 1.1% for the mechanical cutter. It was recommended that the cutter rake be banned due to its adverse effect on recruitment. The mechanical cutter must be made more efficient and the harvests strategy be revised to reach a MSY for this resource.

RÉSUMÉ

Sharp, G.J. 1981. An assessment of Ascophyllum nodosum harvesting methods in southwestern Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 1012: v + 28 p.

Dupuis 1959, les ressources en Ascophyllum nodosum du sud-ouest de la Nouvelle-Écosse, estimées à 180 000 t, sont exploitées au taux de 6 000 t/an^{-1} pour la production d'alginates par la société Scotia Marine Products Ltd. Sur une période de 18 ans, la méthode de récolte a évolué, depuis une opération entièrement manuelle à une opération mécanisée à 80%. A l'été 1978, on entreprit une étude des effets de la récolte mécanique (par la moissonneuse Aquamarine) et comparé avec ceux du râteau coupeur. Nous avons examiné des sites avec un historique de récolte connu, en vue de déterminer la biomasse résiduaire et la structure de population. On mena également une expérience contrôlée à un site. La biomasse résiduaire d'aires récemment coupées est de 6,0 kg m^{-2} à 7,2 kg m^{-2} versus 14,0 kg m^{-2} dans une aire coupée 2 ans auparavant. Dans les régions fraîchement coupées par la moissonneuse, la récolte représente 26,0 à 60,5% des régions échantillonnées. La hauteur moyenne de souches dans une aire coupée à la moissonneuse était de 31,2 $\pm$ .6 cm versus une hauteur moyenne de 23,8 $\pm$ 12,9 dans une région avoisinante coupée à la main.

La récolte fortuite de crampons est de 16,1 $\pm$ 8,4% en poids pour le râteau coupeur manuel et de 1,9 $\pm$ 1,1% pour la moissonneuse. Nous recommandons l'interdiction du râteau coupeur à cause de ses effets nuisibles sur le recrutement. De plus on devra améliorer l'efficacité de la moissonneuse et réviser les stratégies de récolte afin d'atteindre le RMS de cette ressource.

INTRODUCTION

Ascophyllum nodosum (Linnaeus) LeJolis, commonly known as rockweed and hereafter referred to as Ascophyllum, is a brown algae belonging to the order Fucales. It is ubiquitous in the intertidal zone in the western North Atlantic between 40° and 65°N latitude and in the eastern North Atlantic between 42° to 72°N latitude. A comprehensive literature review for this species was published (Baardseth, 1970) and an update is in preparation (Sharp).

Utilization of Ascophyllum in the northwest Atlantic until 1959 was limited to fertilizing coastal agricultural lands. MacFarlane (1952) estimated a standing crop of 180 000 t from Cape Sable Island to Chebogue, Yarmouth County, which likely was responsible for Kelco Corporation of California, U.S.A., establishing a Canadian subsidiary, Scotia Marine Products Ltd., at Lower Woods Harbour in Shelburne County, N.S., to utilize this resource. This operation began as a pilot plant to test the possibility of alginate extraction from fucoids. However, within two years it utilized 6 000 t of raw material per year. An exclusive provincial license to harvest rockweed and kelp extending from Cape Sable Island, Shelburne Co., to St. Mary's Bay, Yarmouth Co., was granted to this company to harvest rockweed and kelp.

Management regulations under this license consisted of general cautions concerning abuse of the resource and the following restrictions on the harvest method.

> "No person shall harvest rockweed unless he:
>
> a) uses an instrument that severs with a cutting action;
> b) leaves a length of at least 5 inches (12.5 cm) above the holdfast."

These regulations were made a part of the Atlantic Coast Marine Plant Regulations under the Federal Fisheries Act in 1977. The present study was initiated to determine the characteristics of the principal harvesting methods as they affect standing crop and regrowth of the Ascophyllum resource in S.W.N.S.

METHODS OF EXPLOITATION

During the first ten years of operation, Scotia Marine Products bought Ascophyllum from fishermen who cut the plants

with scythes or scottish sickles and gathered the floating rockweed in small seine nets. Problems with continuity of supply and overharvesting led to a company-controlled harvest in 1968 and subsequently to the development of mechanical harvest methods. An aquatic weed harvester H-650 (The Aqua Marine Harvester, Aqua Marine Corp., Wabasha, Wisconsin) was modified for use in the marine environment (Fig. 1). Initially, the hand and mechanical harvesting methods were used in a complementary fashion; the former where the latter was inefficient or could not operate (A. McArthur*, pers. comm.). However, by 1976-1977 four Aqua Marine harvesters provided 80-90% of the raw material needs.

The Aqua Marine H-650 Harvester is a 5 000 kg double-pontoon barge, of overall dimensions 10.5 m long by 2.9 m high by 4.9 m wide, propelled by hydraulically driven paddle wheels (Fig. 1). The rockweed is cut in a 2.4 m swath by a reciprocating mower bar. A conveyor belt picks up the severed fronds and transports them to a holding bay. When the bay is loaded (1.4 t capacity), a second conveyor belt moves the harvest to a discharge belt and into a transport barge. The operator overlooks the cutter blade and, by means of hydraulics, raises and lowers the cutter-conveyor in response to plant height. The cutter bar is protected from damage by a bumper and shock-absorbing system. The operator maneuvers the unit by controlling the rotation speed and direction of port and starboard paddle wheels.

The cutting operation begins on half flood tide and continues to half ebb tide. The four mechanical harvesters work within a 0.5 km radius of a 120 ton capacity transport barge. Within this area, they move independently, cutting where the A. nodosum is floating and water depth is greater than 50 cm. The machine moves back and forth over each shoreline section to remove the majority of accessible material. Since the cutter unit frequently encounters boulders, the unit must be lifted and lowered repeatedly. A clump of plants may be recut several times, lowering the stump height on each run or cutting more shoots. The operator subjectively decides when he has reached the maximum yield for an area. This decision is influenced by an incentive payment for tonnage above a set weekly quota. The rate of harvest depends greatly on the standing crop, bottom relief, currents, and the prevailing weather conditions. The daily average is 13.6 t per machine. The cutting height is determined by the operator's control of the cutter bar. Water clarity, sun angle, and surface turbulance are important factors restricting the operator's efficiency.

Manual harvest methods are in use today in Argyle Sound, Wedgeport, and Digby Gut. In the Wedgeport/Argyle

---

*A. MacArthur, former manager of Scotia Marine Products, Yarmouth, N.S., Canada

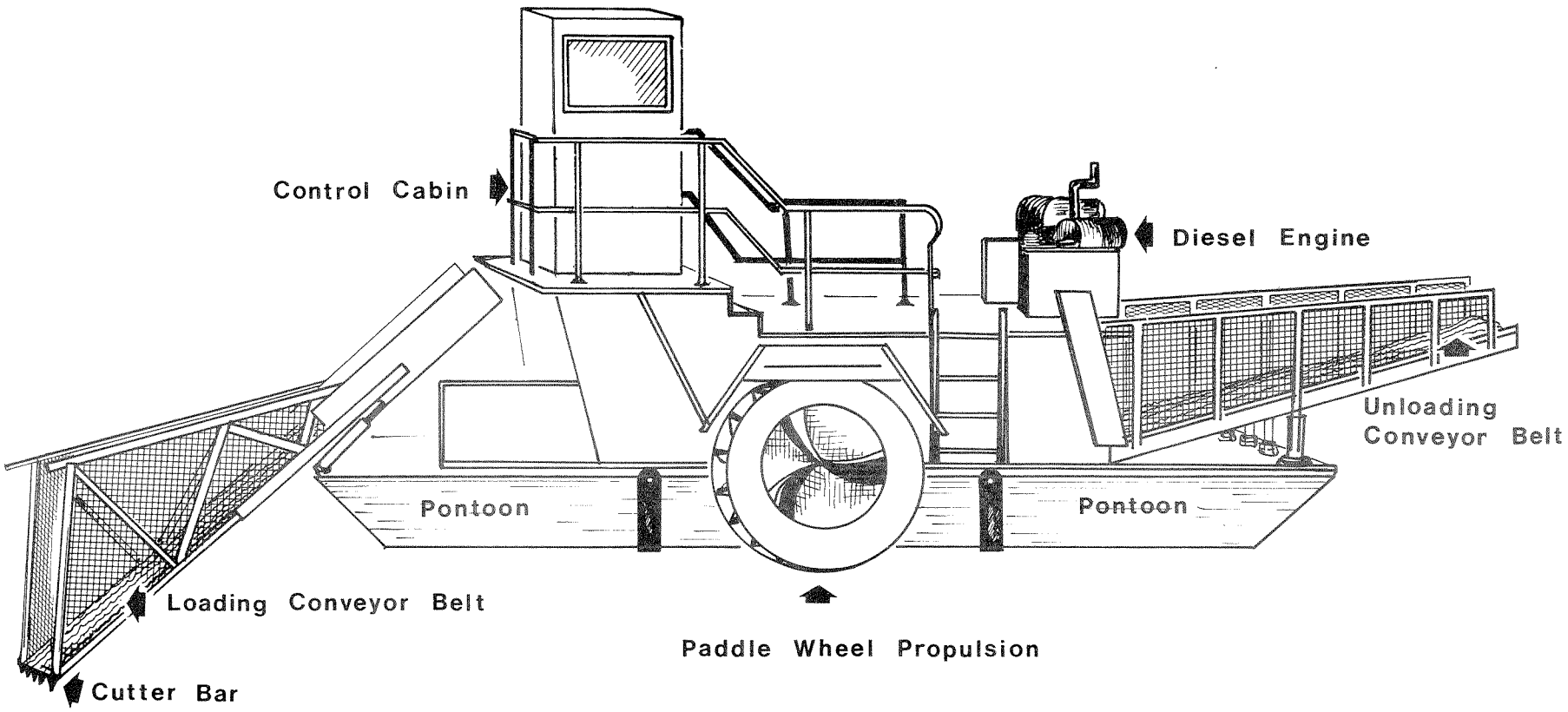

Figure 1. Aquamarine Aquatic harvester H650 modified for marine use.

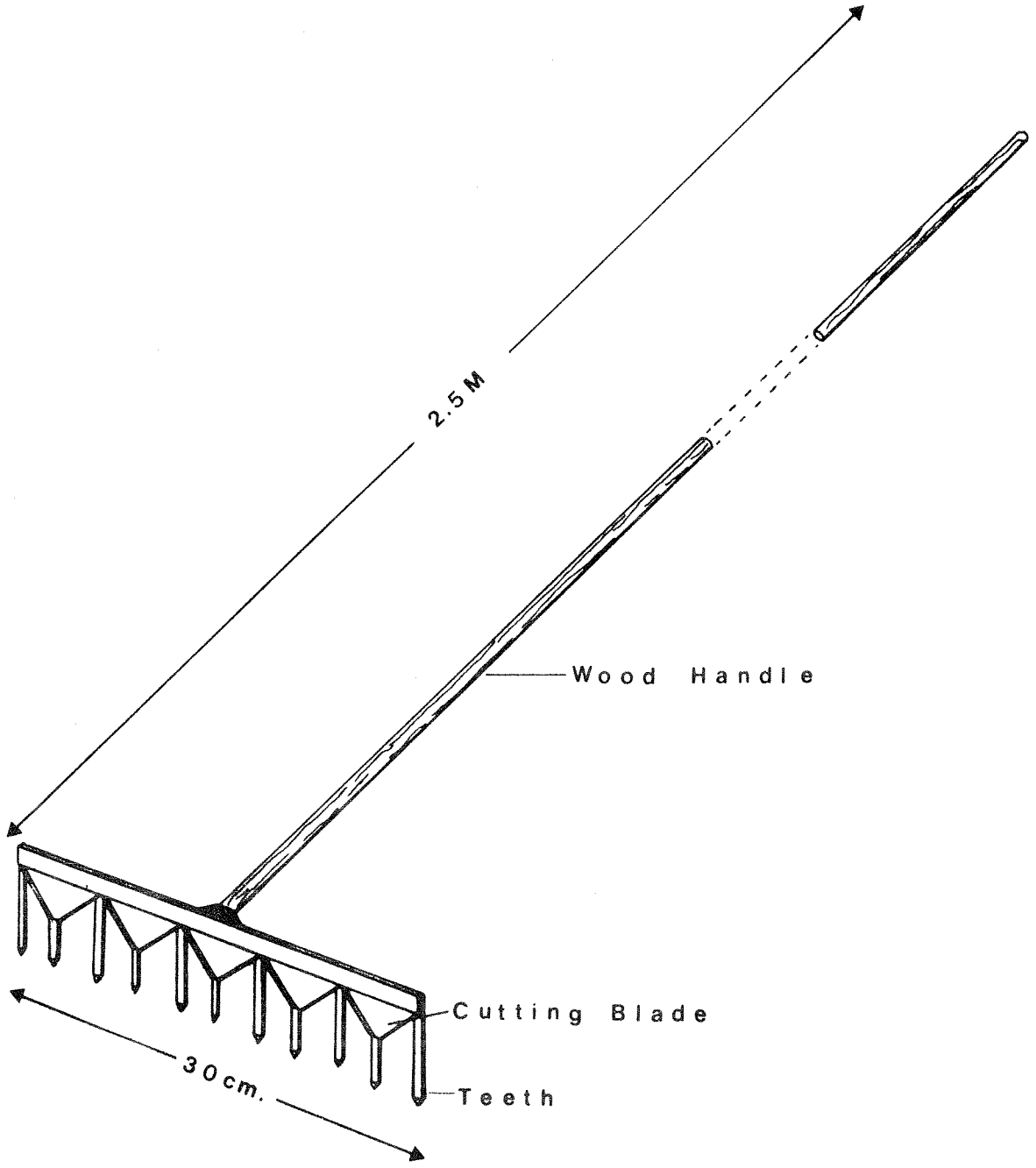

Figure 2. Ascophyllum cutter rake consisting of a modified Chondrus rake with hay mower cutting teeth.

Sound area a cutter rake (Fig. 2) is used to cut and load the rockweed in one operation. The rake is a modified Irish moss (Chondrus crispus) handrake (MacFarlane, 1952; Pringle, 1979). Two-thirds of the rake tines are removed and are replaced by hay mower cutting teeth. In the Digby area, the original hand sickle or scythe method is used to cut the plants during a low tide; it is then loaded into carts.

METHODS

Shoot Classification and Terminology

The following are formal definitions (Baardseth, 1970) of terminology for Ascophyllum morphology as illustrated in Figure 3:

Shoot: The complete morphological structure produced either by a fertilized egg or by a special initial cell.

Basal Shoot: Shoots arising from the basal regenerative light green region of older shoots.

Lateral Shoot: Shoots arising from lateral slits of all shoots.

Stump: A shoot lacking an apical cell.

Normal Shoot: No evidence of harvest.

Holdfast: A conical, compact disc of tissue attaching the plant to the substrate.

Plant: An assemblage of shoots and stumps arising directly or indirectly from a common holdfast.

In this study, stumps were placed in two categories; recently and not recently harvested. A truncated shoot with light green wound tissue and sharp edges was evidence of recent harvest. Stumps which were severed one month or more previous had normal, Ascophyllum coloration. If shoot diameter exceeded 3 mm, the wound would often have a serrated edge caused by the mower.

Total shoot length was the length from the holdfast to the apex. In the case of stumps with a lateral shoot exceeding the stump length, two measurememements were recorded: stump length and maximum shoot length. All measurements were made to 0.5 cm with a meter stick.

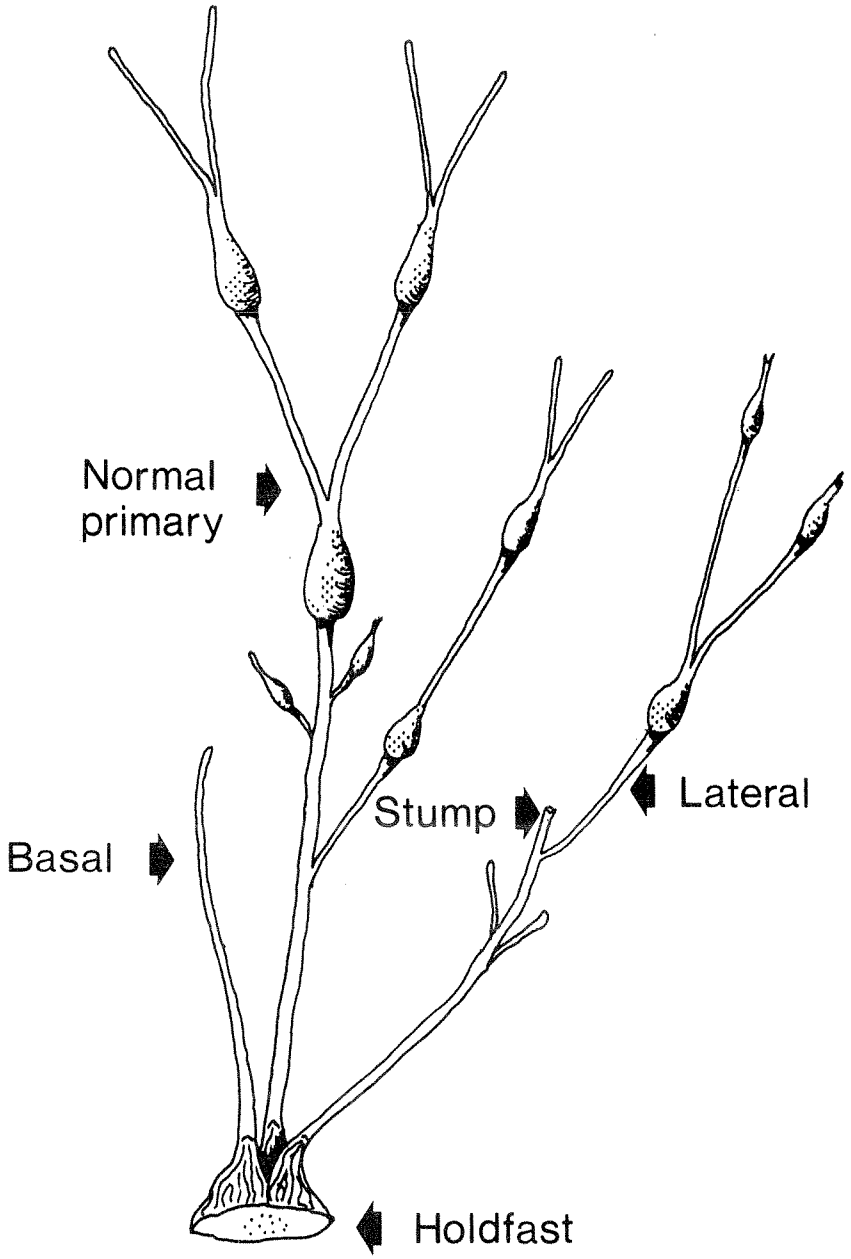

Figure 3. Ascophyllum nodosum illustrating morphological terminology.

Uncontrolled Harvest Sites

Biomass and population structure

The harvest records of Scotia Marine Products Ltd. describe the harvesting history of 2.2 km by 2.6 km sectors from Cape Sable Island to Chebogue. These sector records include only the SMP mechanical harvest (90% of total landings). The history of hand harvested areas is available from anecdotal reports only.

The immediate effects of mechanical harvesting on biomass and population structure was examined at 5 sites (H-1 to H-5) harvested in the spring and summer of 1978 (Fig. 4). Four sites (B-1, B-2, W-1, W-2), which were harvested one year or more previously, were sampled for biomass only.

At each site, four 0.25 m wide, strip transects, 5 m apart and perpendicular to the shoreline, were established through the A. nodosum zone. These strip transects were divided into 1 m sections. All plants, including holdfasts, within each 1 x .25 m section were scraped from the substrate and weighed to 0.1 kg on spring scales. From each 0.25 m^2 area, a subsample of 100 shoots was taken haphazardly for length measurements and classification at sites H-1 to H-5.

Controlled Harvest Site

A single site (P-1) (Fig. 4) was chosen on Roberts Island to compare mechanical and hand harvesting methods. At this site a portion of the shoreline was divided into three 50 m sections (Fig. 5): hand-harvested, control, and mechanical-harvested. Within each section at 10 m intervals, 0.25 m wide strip transects perpendicular to the shoreline, permanently marked, were laid out from the upper limit of the Ascophyllum zone down to a maximum distance of 45 m. Within each 0.25 m^2 section, 100 shoots (primary basal and stumps), chosen haphazardly, were measured for length and classified in situ. Following harvest of the site, the shoots in quadrats with evidence of harvesting were remeasured.

Incidence of Holdfasts in Harvests

Five, 20 to 45 kg sample units were removed from the vessel's hold either during or following harvest. The plants were separated into three categories - shoots with holdfasts attached, shoots associated with greenish basal tissues, and cut or broken shoot portions. The wet weight of each category was measured to 0.5 kg and the number of holdfasts was counted. As well, mechanically harvested plants were sampled from the raw material storage bin at Woods Harbour and treated the same way.

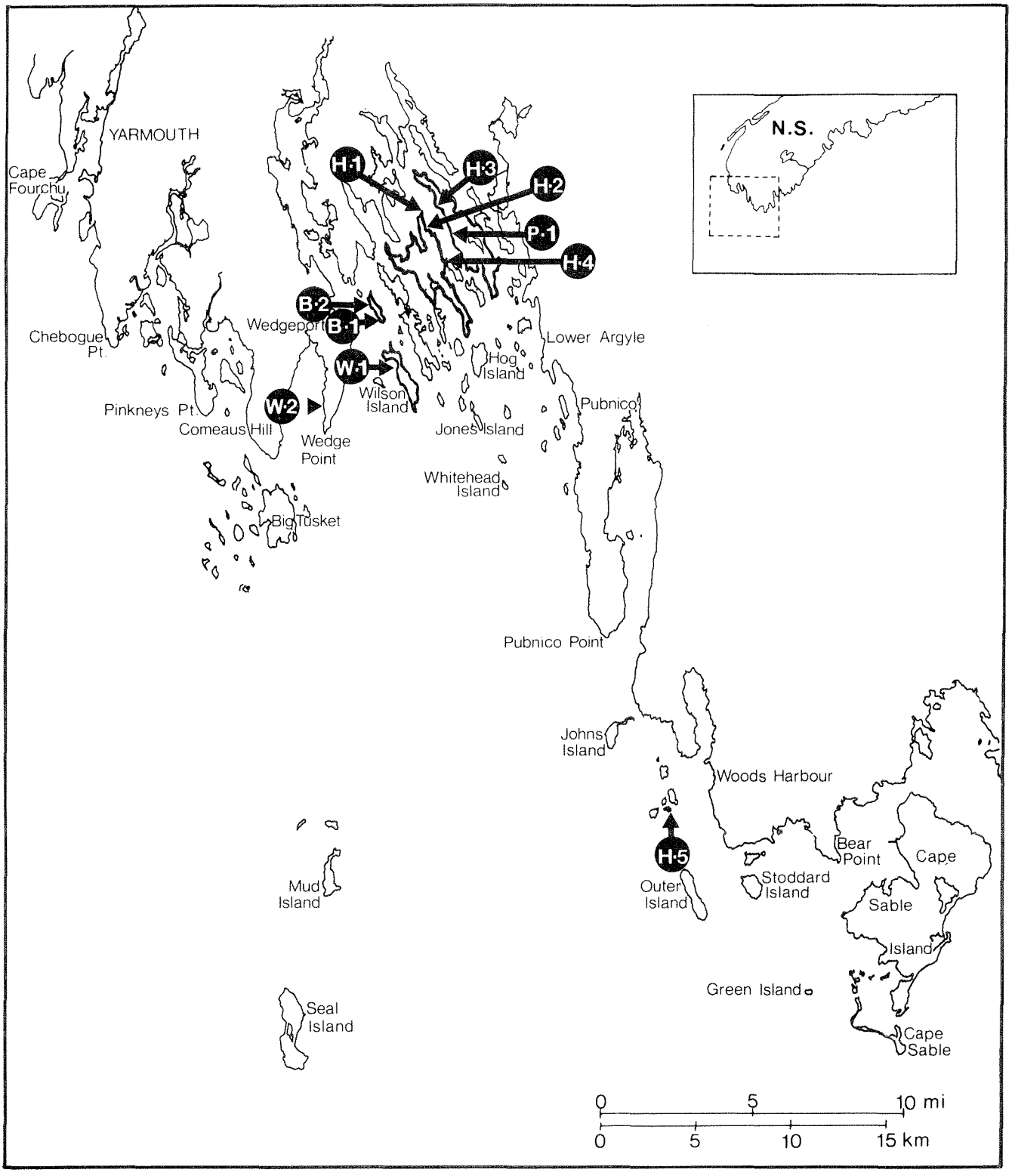

Figure 4. Study sites in Lobster Bay, Yarmouth County and Woods Harbour. Insert – Southwestern Nova Scotia areas.
H-1 – Morris Island North; H-2 – Morris Island Northeast;
H-3 – Roberts Island West; H-4 – Morris Island South;
H-5 – Raspberry Island, Woods Harbour;
P-1 – Roberts Island West; B-1 – Mike's Island South;
B-2 – Mike's Island North; W-1 – Wilson Island;
W-2 – Tuna wharf.

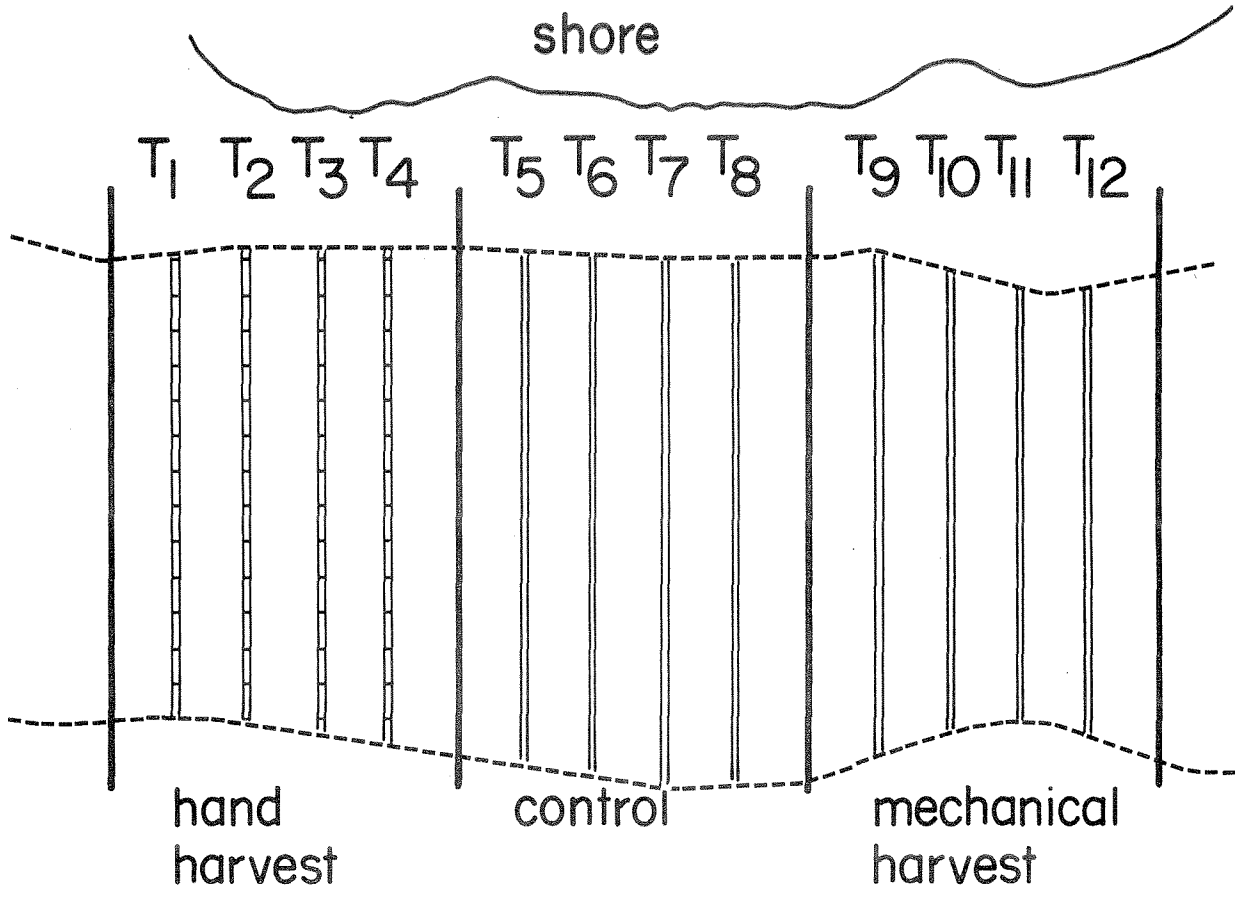

Figure 5. Experimental design for the permanent study site Roberts Is. (P-1). All transects were divided into 1 x .25 m areas as illustrated in the hand harvest sector.

RESULTS

Uncontrolled Harvest Sites

Biomass

The recent (1970-1978) harvest history of the study sites is described in Table 1. Overall, the highest mean standing crops were found at the Mike's Island sites south (3.3 ± 3.1 kg/ 0.25 m^2) and north (3.5 ± 3.5 kg/0.25 m^2) and Wilson Island (3.1 ± 2.7 kg/0.25 m^2) (Fig. 6a). The cover of Ascophyllum within the sampled area was 65% and 86% respectively. Harvest history for these sites shows the lowest incidence of harvest and tonnage removed (Table 1). The Tuna Wharf (85% cover) and Wilson Island (76% cover) sites had a significantly higher biomass than the Morris Island and Roberts Island sites (Fig. 6a). When percent cover at these sites was discounted by eliminating all samples with a zero value, the biomass values remained in the same relative order (Fig. 6b).

All samples combined in Sites H-1 to H-5 (1978 harvest sites), with evidence of a recent harvest, had a significantly higher mean biomass ($P < 0.05$) 2.6 ± 2.7 kg/0.25 m^2 ($n = 131$) than those without evidence of recent harvest 1.9 ± 2.2 kg/0.25 m^2 ($n = 182$).

Incidence of harvest was defined as the percentage of sample areas containing evidence of recent harvest. Evidence of harvest was found in 131 out of 313 sampled areas. The Raspberry Island site (H-5) had the highest harvest incidence at 60.5 ± 12.7% (Fig. 7). Sites at Roberts and Morris Islands ranged from 48 ± 18% to 26 ± 22.3% harvest incidence. The pattern of harvest at each site was patchy (Fig. 8), with the upper end of each transect harvested less than the mid to lower sections.

An index of the degree of harvest is the ratio of stumps to normal shoots. Sites H-1 to H-3 had a stump to normal ratio greater than 1; Sites H-4 and H-5 were less than 1 (Table 2).

Population structure

All sites, excepting Sites H-1 and H-5, had significantly different mean shoot lengths (all categories of shoots combined) (Fig. 7). For sites H-2 to H-4, the range of means between sites was not large (6.8 cm) and always skewed to shoots less than 10 cm. Maximum shoot length ranged from 116 cm at Site H-2 to 174 cm at Site H-1.

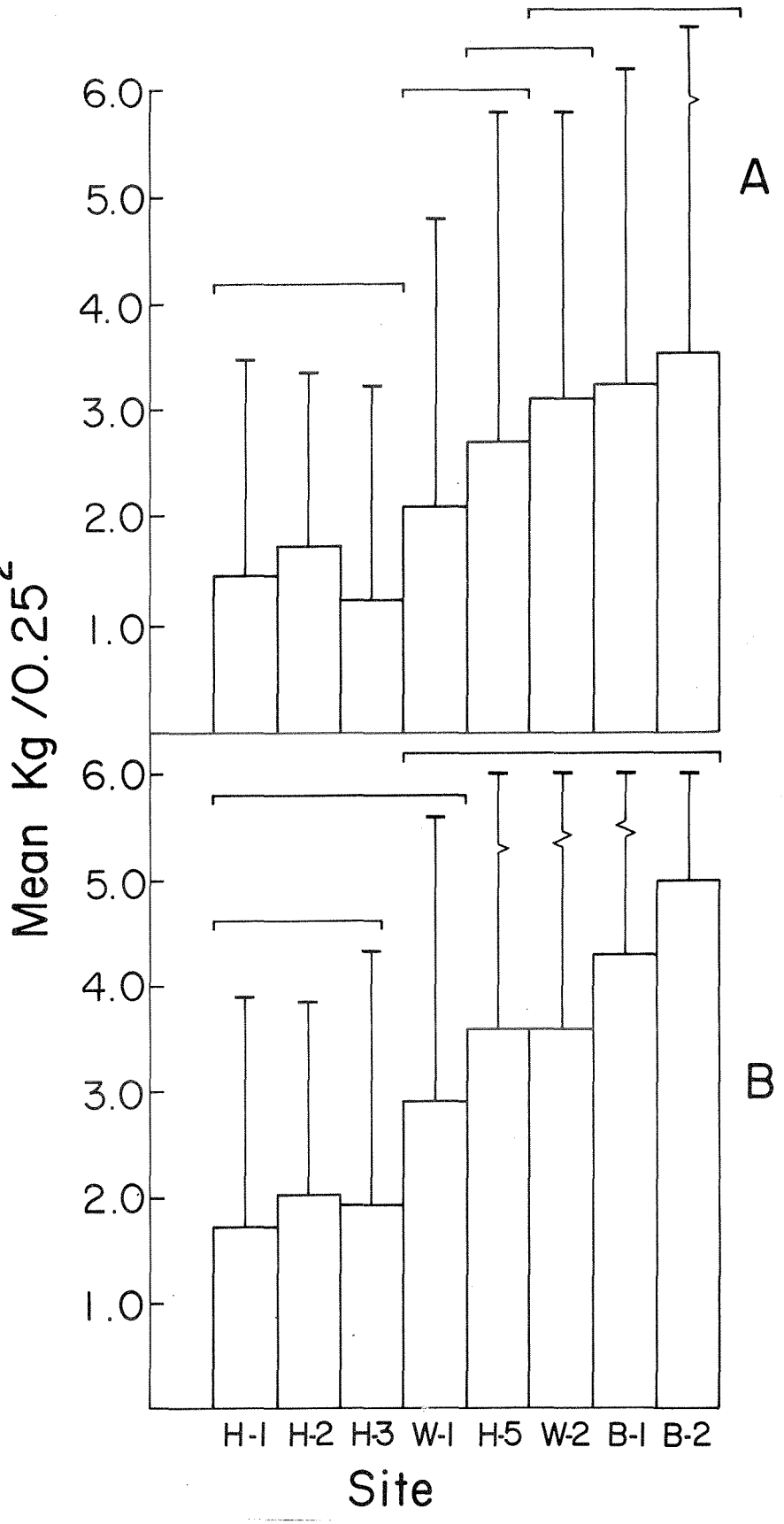

Figure 6a. Mean biomass of A. nodosum/0.25 m^2 on four transects including 0 values following harvesting.
H-1 - Morris Island North; H-2 - Morris Island Northeast;
H-3 - Roberts Island West; H-5 - Raspberry Island, Woods Harbour
W-1 - Wilson Island; W-2 - Tuna Wharf;
B-1 - Mike's Island South; B-2 - Mike's Island North.

Figure 6b. Mean biomass/0.25 m^2, excluding 0 values.

Table 1. Harvest history of Ascophyllum study sites in southwestern Nova Scotia.

Site	Location	Harvest history by year () = tonnage			
H-1	North Morris Is.	1972[a]	1974[b] (745)	1975[c] (747)	1978[c] (629)
H-2	Northeast Morris Is.	1972[a]	1974[b] (745)	1975[c] (747)	1978[c] (629)
H-3	Northwest Roberts Is.	1972[a]	1974[b] (745)	1975[c] (747)	1978[c] (818)
H-5	Raspberry Is. Woods Harbour		1974[c]	1977[c]	1978[c]
W-1	Eastern Wilson Is.	1972[a]	1974[a&c](307)	1976[c] (814)	1977[a]
W-2	Tuna Wharf Wedgeport		1974[a&c](224)	1976[c] (414.8)	1977[a]
B-1	South Mikes Is.		1974[c]	1976[c] (94)	
B-2	North Mikes Is.		1974[c]	1976[c] (94)	

[a]Possible hand harvest

[b]Partial harvest

[c]Mechanical harvest

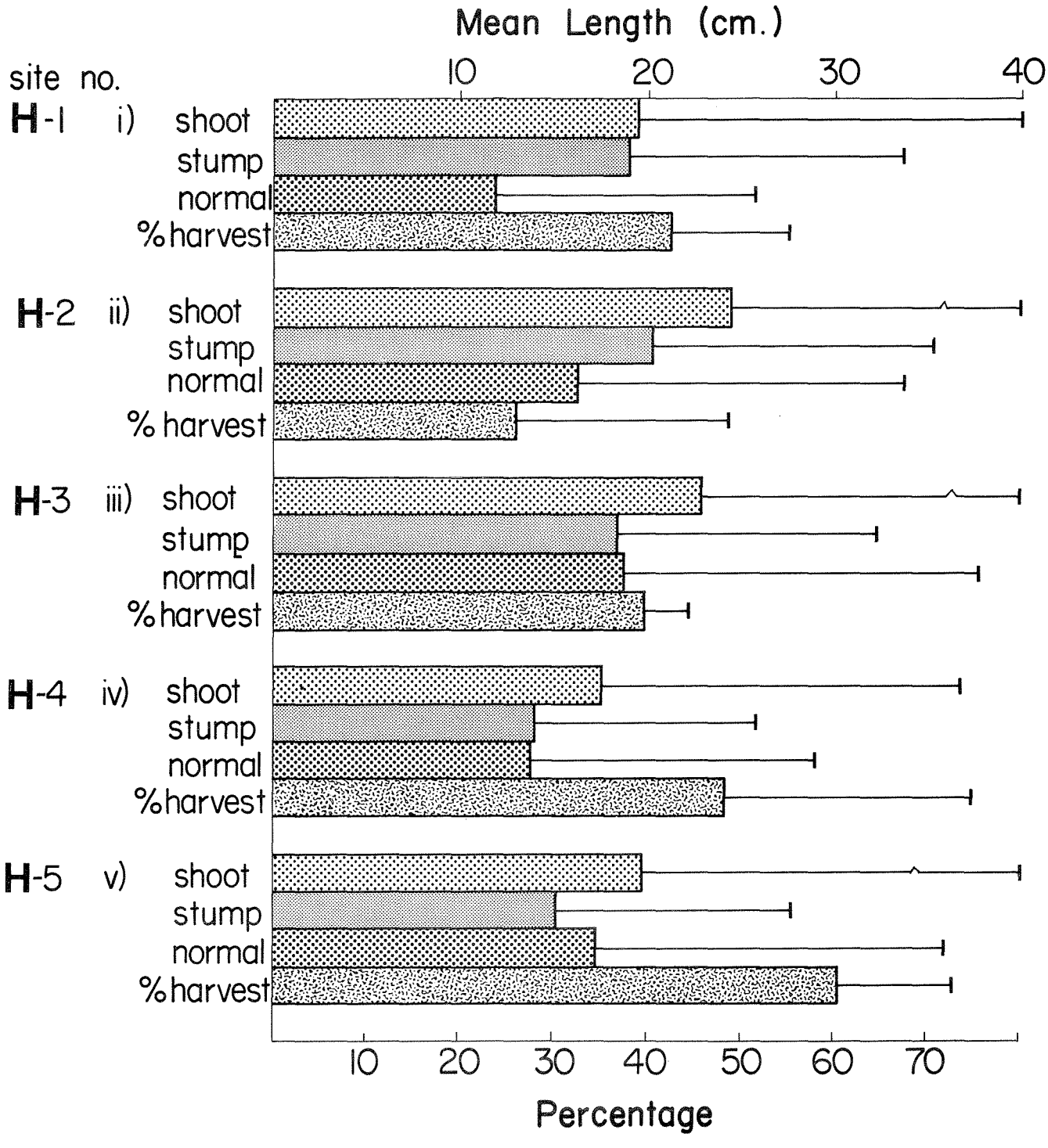

Figure 7. Mean shoot length and % incidence of harvest at 5 study sites in southwestern Nova Scotia. Mean length of the total shoot population stumps and normal shoots. The percentage incidence of harvest. Standard deviation + − T.

Figure 8. The pattern of harvest at the Morris Island site (H-1).

Ascophyllum - absent

Ascophyllum - present

Ascophyllum - harvested

xm _____ Horizontal distance from the upper limit of Ascophyllum

Height Relative to lower limit of Ascophyllum

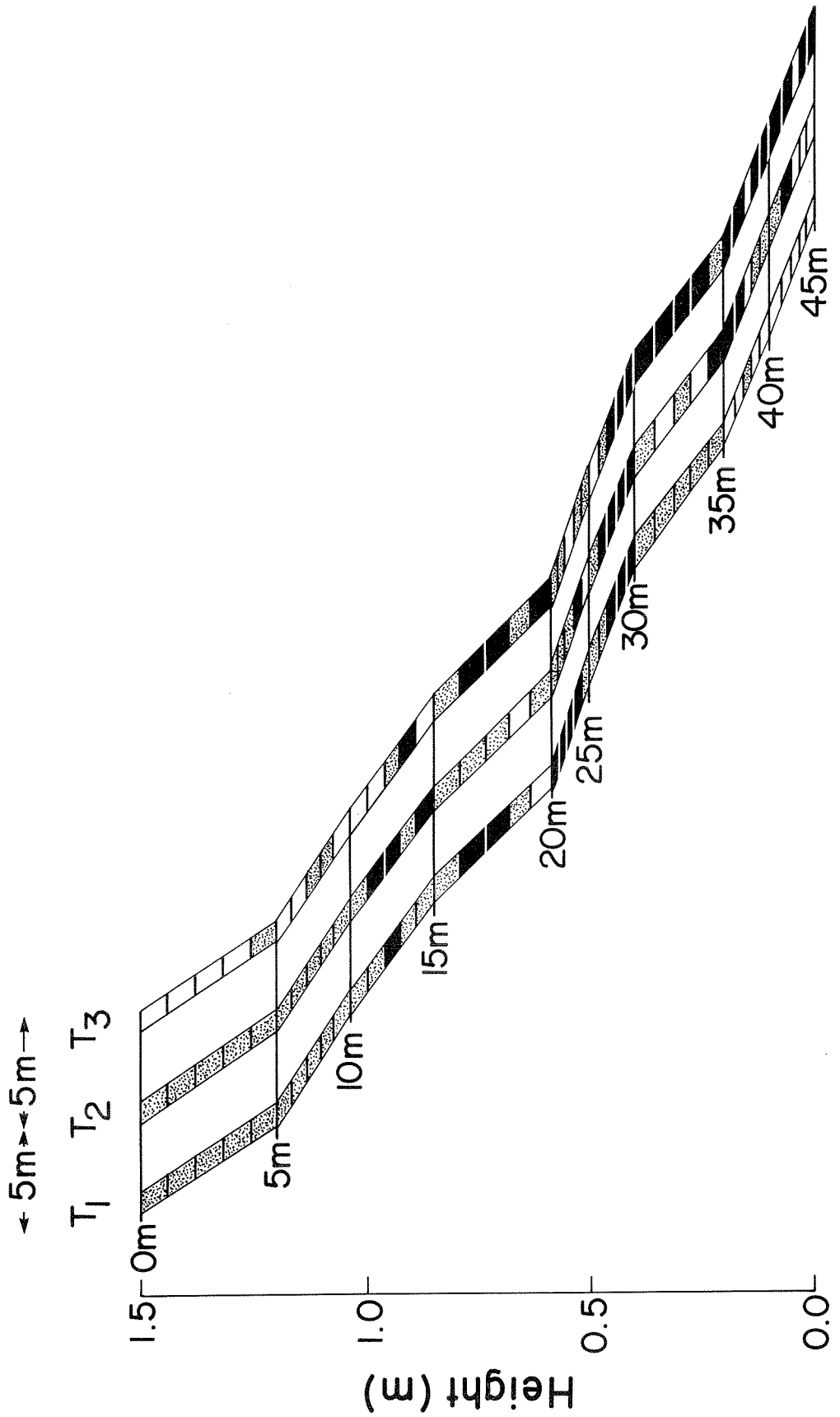
Height (m)
1.5
1.0
0.5
0.0
0m
5m
10m
15m
20m
25m
30m
35m
40m
45m
T1 T2 T3
5m 5m

Table 2. Harvest impact index, ratio of all stumps to undamaged (normal shoots) at 5 harvested sites in southwestern Nova Scotia.

Site	Code	Stump/Normal
Morris Is. (N)	H-1	1.2
Morris Is. (NE)	H-2	1.7
Roberts Is. (W)	H-3	1.0
Morris Is. (S)	H-4	0.7
Raspberry Is.	H-5	0.5

The mean stump length ranged between 14.0 ± 11.9 at Site H-4 to 20.2 ± 15.0 cm at Site H-2 (Fig. 7). Mean stump lengths were significantly different between sites except at sites H-1 and H-3 ($P < 0.05$). The maximum stump length recorded was 99 cm. The skewed pattern of length distribution, with over 35% of the stump population below 10 cm in length, was similar at all sites (Fig. 9a-e). In the total stump population consisting predominantly of old stumps, shorter stumps are less likely to have laterals or dichotomous branches; the mean length of stumps without laterals exceeding stump length was 13.2 ± 13.2 cm versus 26.0 ± 14.0 cm for stumps with laterals exceeding stump length. Over 50% of the stumps without laterals exceeding stump length were below 10 cm; less than 10% of stumps with laterals exceeding stump length were below 10 cm (Fig. 10a, b). There was a direct correlation between stump length and length of associated laterals or dichotomous shoots (total length = 2 x stump length) (Fig. 11).

The mean cutting height of the mechanical cutter was 35.2 ± 0.6 cm with a normal distribution (skewness = 0.4) (Fig. 12a). Less than 10% of the 1978 cut stumps were below 15 cm in length. The mean length of the total stump population was 16.1 ± 0.2 cm (Fig. 12b).

Differences in normal mean shoot length were likely due to environmental differences between sites. Normal shoots were predominantly below 10 cm in length (Fig. 7). The mean length of normal shoots was significantly different for sites H-2, H-3 and H-4, ranging between 11.9 ± 14.7 to 18.6 ± 19.9 cm.

Controlled Harvest Site

Prior to harvesting, the mean length of stumps in the mechanically harvested population was 13.1 ± 11.1 cm and 12.9 ± 10.4 cm in the hand harvested population. The normal shoot length between the mechanical harvested sector (20.2 ± 18.3 cm) and the hand harvested sector (20.8 ± 18.3 cm) were not significantly different. Following harvesting in both sectors, a significant ($P < 0.05$) increase in the mean stump length, 6.3 cm and 3.0 cm respectively, was observed. Subdividing the stumps into freshly harvested and others (one year or more since the last harvest) in the mechanical harvest sector, a large proportion of this increase was due to freshly harvested stumps with a mean length of 31.7 ± 12.4 cm (Fig. 13a, b).

A similar pattern was observed in the stump population of the hand harvest where the mean stump length increased to 23.8 ± 12.9 cm from 13.2 ± 10.0 cm. The difference in length

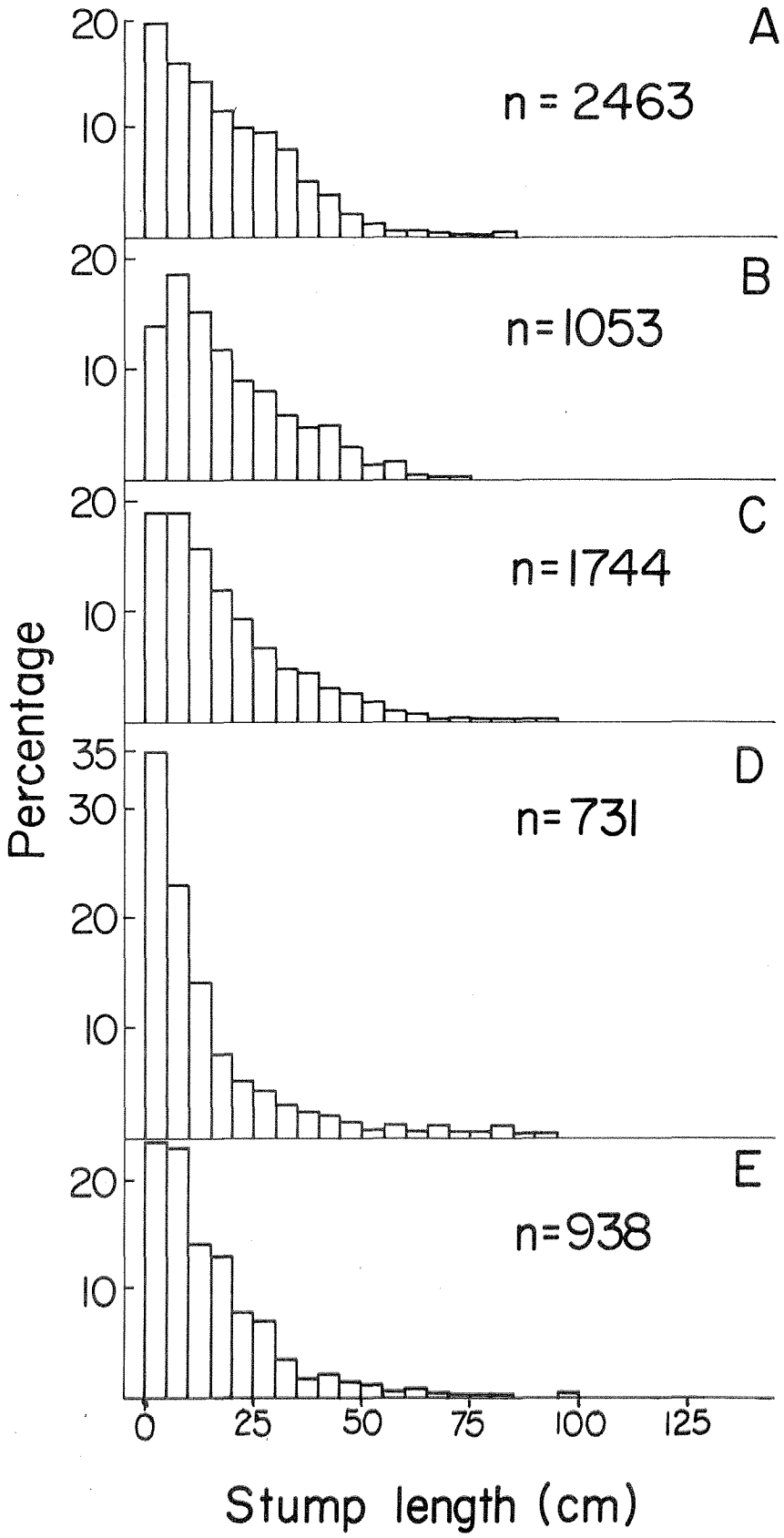

Figure 9. The distribution of stump lengths at five uncontrolled study sites. a - Morris Island North (H-1); b - Morris Island Northeast (H-2); c - Roberts Island West (H-3); d - Morris Island South (H-4); e - Raspberry Island (H-5).

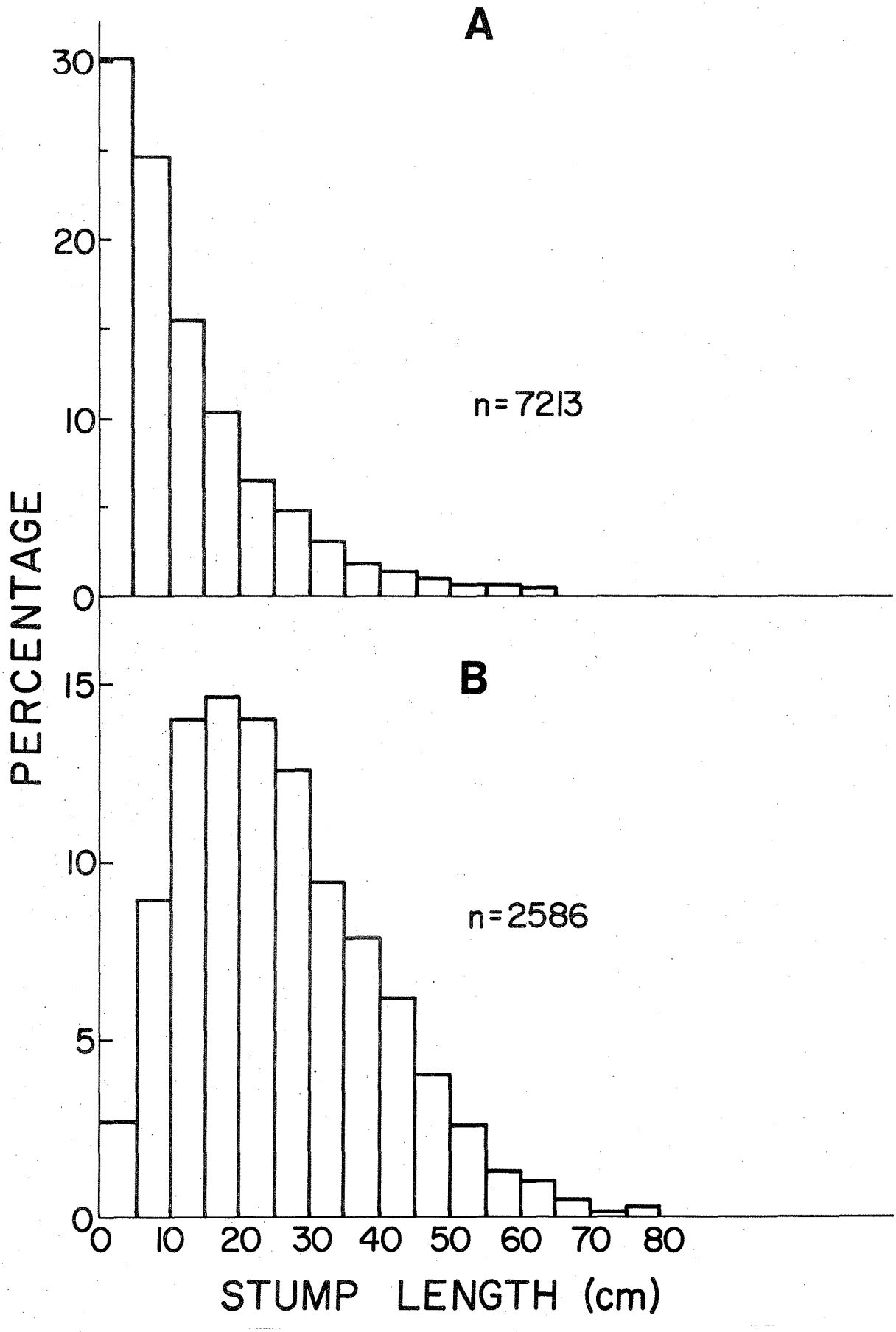

Figure 10. a) Length distribution of stumps with laterals not exceeding stump length; b) laterals exceeding stump length. All sites.

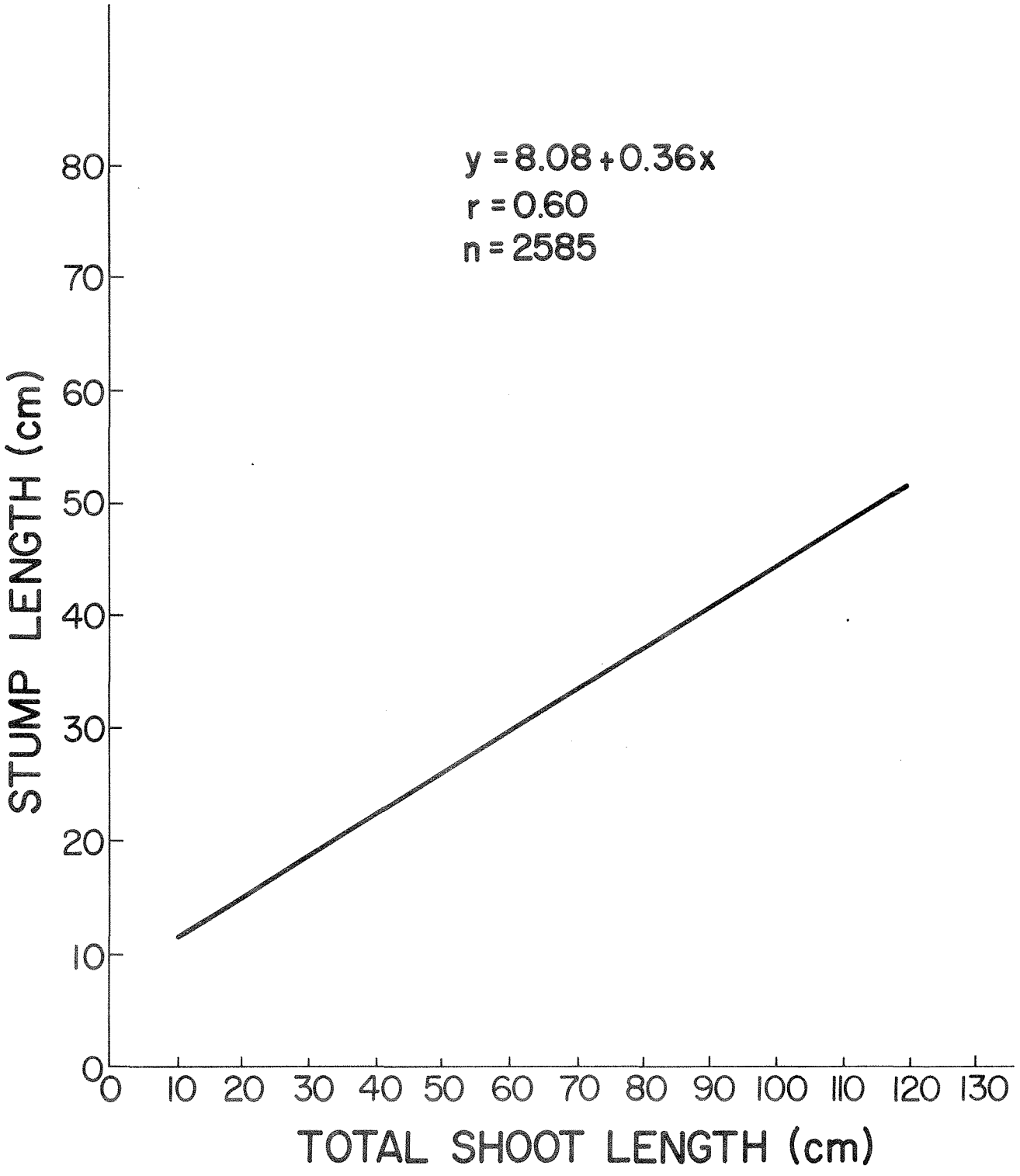

Figure 11. The relationship of total shoot length to stump length. $y = 8.08 + 0.36\ x$ defines the line and .6 is the correlation factor.

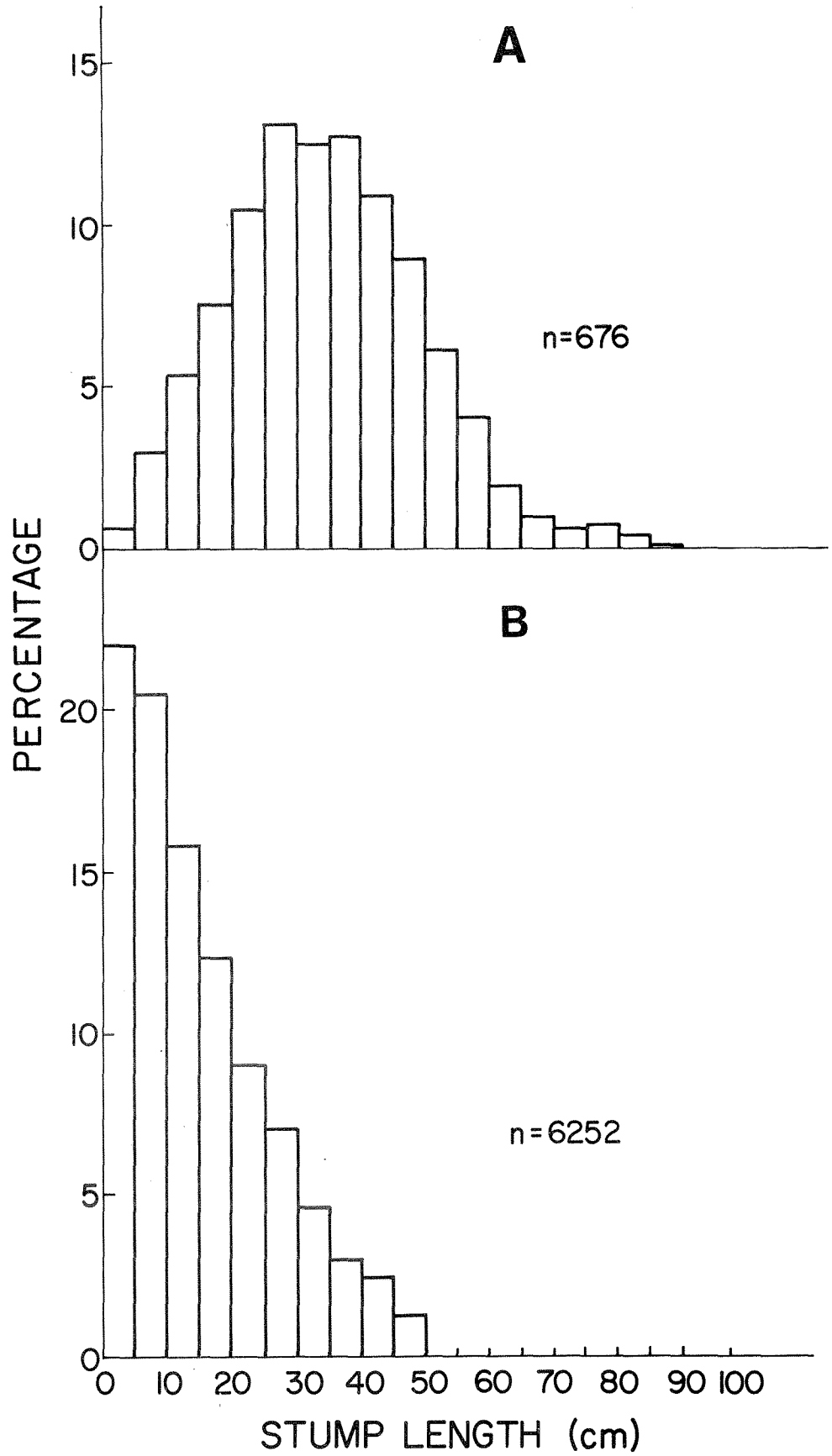

Figure 12. Length distribution of stumps with evidence of 1978 harvest; b) without evidence of 1978 harvest.

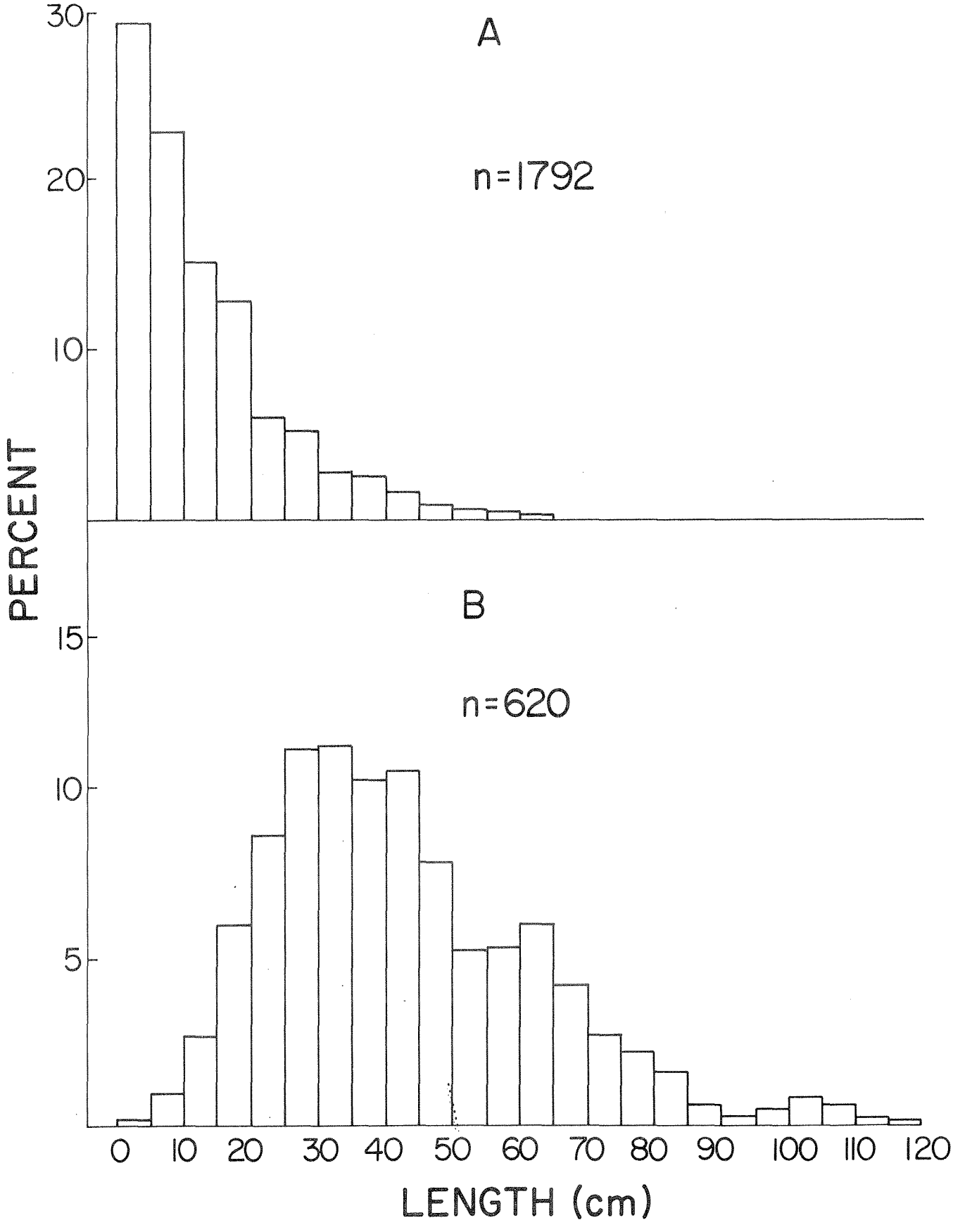

Figure 13. a) Length distribution of stumps not harvested in 1978; b) mechanically harvested in 1978. Controlled harvest site.

of 7.9 between mechanically cut and hand cut was significant. Hand-cut stumps below 20 cm were 46.8% of the stump population. The mechanically harvested population had only 22.1% of freshly cut stumps below 20 cm in length. It is important to note that only 20.4% of the total shoot population was above the mean cutting height of the mechanical cutter prior to harvest.

Holdfast Sampling

An average of 16.1 ± 8.4% by weight of the handraked harvest consisted of shoots attached to holdfasts. The number of holdfasts averaged 1.2/kg. Every holdfast had primary shoots associated with it, therefore, more than one shoot was removed with the holdfast. Basal shoot material results from breaking plants close to the holdfast (less than 1 cm). Basal shoots consisted of 25.0 ± 8.2% by weight of the sampled harvest. There was an average of four shoots attached to each basal tissue unit. These shoots included the full range of the shoot population from young normals of 2 cm to large, many-branched shoots up to 75 cm. The mechanical harvest sampled at the Wood's Harbour extraction plant consisted of 1.9 ± 1.1% by weight of shoots attached to holdfasts.

DISCUSSION

The regenerative capacity of harvested Ascophyllum populations depends mainly on the number and growth rate of remaining apices and lateral initials. The removal of the apical tip stimulates lateral growth within 5 cm since this plant exhibits apical dominance (Moss, 1970). The age of surrounding tissues (Baardseth, 1955) appears to limit the ability to regenerate thus, the more basal a shoot is cut the fewer potential growth points and the lower the growth rate.

Khailov (1976) showed the importance of physiological age in determining the rates of gross photosynthesis and organotrophy in Ascophyllum from the Barents Sea. A peak in physiological activity occurred in tissues two years old, which corresponded to the largest biomass per tissue unit. Total thallus biomass increased with age up to seven years; the fronds were approximately 40 cm in length. Although Khailov (1976) shows linear growth diminishing with increasing biomass, it appears from the same data biomass increases exponentially with length. Thus overall growth is greater with length. However, the high mortality of very large plants discounts their contribution to standing crop. In south-western Nova Scotia, growth is more rapid; plants seven years

old are over 60 cm. It appears that cropping plants at 30 to 40 cm would give optimum yield. If the regenerative capacity of plants is reduced after seven to nine years, and mortality is greater, there is a need to cull these individuals to maintain growing vigor in the population and obtain maximum yield. The removal of the upper canopy will allow rapid growth of previously shaded shoots (R. Cousens*, pers. comm.). Cropping shoots below 30 cm in southwestern Nova Scotia offers a small gain in yield since individual shoots < 30 cm in length average less than 5 gm wet weight (Fig. 14). The biomass distribution of the entire canopy on bed rock substrates was found to peak at 30 to 40 cm above the holdfasts in sheltered areas and around 5 cm at exposed sites (Cousens, 1981). All sites in this study and the majority of harvestable areas in southwestern Nova Scotia are wave sheltered.

An average growth of 9 cm per year, as calculated from internodal length, was estimated for Ascophyllum in the Halifax area (MacFarlane, 1952). At estuarine sites in New England, monthly averages for tagged shoots ranged from 1.9 to 2.5 cm/month (Mathieson et al., 1976). Linear measurements of tagged fronds with at least one vesicle and an apical meristem were made in the present program; the values ranged from 0.7 to 1.1 cm per month for a semi-exposed site in southwestern Nova Scotia. Following removal of the frond apex, time would be required for initiation of a lateral shoot prior to full-scale growth. Continued growth of a harvested frond will then depend on the number of untruncated shoots. The number of apices remaining is a function of harvest height and intensity of harvest. The mechanical harvester was able to maintain an average cutting height above 30 cm. This height was well above the mean length of normal shoots which ranged between 11.9 to 17.3 cm. Preharvest surveys showed that only 20.4% of the shoot population was above the average cutting height. Thus, if the mechanical harvester removed 100% of all shoots above 30 cm, the majority of normal shoots would remain intact.

Prior to and following harvest, the majority of stumps at all sites were shorter than the average cutting height of the mechanical cutter. The number of stumps below this height are too great to be accounted for by harvesting alone. Natural causes of shoot severing are ice action, water motion, and herbivores. The sites studied are subject to ice cover for part of the winter. Strong tidal action in this area moves ice pans, which grind and break off shoots. Wave surge is not heavy due to short fetch; however, short, steep waves can develop, which may sever weakened shoots. The predominant herbivore in the Ascophyllum bed is Littorina obtusata. This gastropod was observed to reach densities exceeding 100/0.25 m^2. Grazing damage was frequently found at the base of shoots where the outer tissue layers were removed, leaving open wounds. This damage may lead to disease or weaken resistance to wave action. As well, some of the oldest stumps

---

*R. Cousens, Ph.D. candidate, Biology, Dalhousie University, Halifax, N.S., Canada

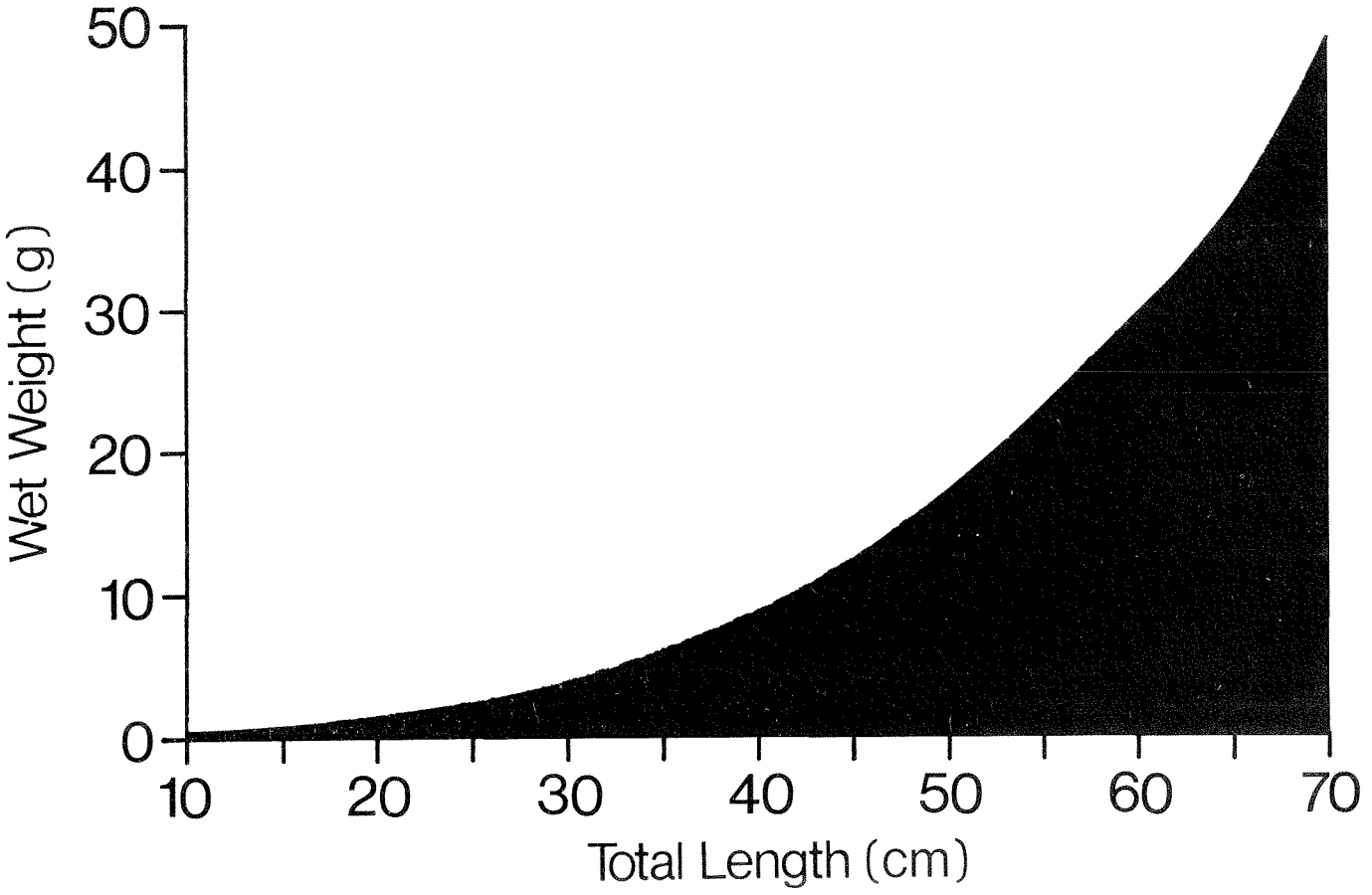

Figure 14. The total length to wet weight relationship of normal shoots from Roberts Island.

found below the average cutting height may be attributed to early hand harvesting.

In general, standing crop did relate to harvest history. Biomass in areas harvested most recently was 40 to 50% of biomass at sites harvested three to five years previously. However, at Raspberry Island (H-5), the standing crop was larger than expected for the recent harvest and high incidence of harvest observed (Figs. 6 and 7). A low intensity of harvest is a possible explanation. Four months had elapsed between harvest and biomass assessment; thus, significant growth may have occurred. The Raspberry Island site is in an area of unrestricted water flow and is remote from any run-off and therefore may offer optimal nutrient and light conditions.

Within the mechanically harvested sites, due to the characteristics of the harvesting machine, it was noted that areas with the greatest biomass were more frequently harvested than those with lower biomass. As well, evidence of harvest was not generally found in plants with shoots less than the 30 cm average cutting height. As a result, the clumps of plants harvested had the highest biomass even after harvest. The minimum operating depth prevents the machine from reaching the upper edges of the A. nodosum zone and in fact this zone may be avoided due to intermixing of undesirable Fucus spp.

The hand cutter-rake was found to sever shoots in the same population at two-thirds the height of the mechanical harvester. This was largely due to lack of operator control over cutting height. The cutter-rake is dragged through a clump of plants and thus cuts at a wide range of heights. Holdfast and basal shoots are removed due to the binding of shoots between the tines and ineffective cutting action. The amount of holdfast tissue removed may vary per unit harvest depending on the substrate friability. However, replacement of lost plants must be via germling settlement and competition with other species for space. The regenerative capacity of the population is thus much reduced when compared to the mechanical cutting procedure.

To realize the maximum sustainable yield (MSY) from the Ascophyllum resource, cutting height is only one parameter of harvest strategy. The intensity and frequency of harvest of harvest are two other major factors in reaching an MSY. In Europe, the harvest intensity leaves 2% of the carrying capacity, with regrowth three to six years (Seip, 1980). Long-term yield was found to increase by 40-70% when the intensity of cutting decreased from 95.5% to 88%, of the carrying capacity (Seip, 1980). The intensity of harvest in S.W.N.S. is ca. 58% of maximum standing crop (assuming a residual biomass at three sites [H-1 to H-3] harvested in 1978 of 8 kg/m^2 and a mean biomass of 14 kg/m^2 after 3-4 years).

It appears the intensity of harvesting with the mechanical cutter is well below European values and suggests a more frequent and intensive harvest is required to obtain the MSY. Catch per unit effort, however, will decrease with increased harvest frequency.

The carrying capacity of sheltered sites is greater than exposed sites in Norway (Baardseth, 1970). And in Maine, recovery from various harvesting strategies was faster in sheltered estuaries than in exposed sites (Keser, 1978). Annual production of two sites in SWNS was found to vary by a factor of 2 (Cousens, 1981). Therefore, harvesting strategy must take into account such site-specific factors as production rate and mortality rate to be effective in reaching MSY.

CONCLUSIONS

1. The mechanical cutting operation leaves a large proportion of the population undamaged and thus, permits rapid regeneration.

2. The cutter-rake, while harvesting at a reasonable height, removes a significant number of entire plants (41%).

3. The present harvest strategy is not obtaining the maximum sustainable yield.

ACKNOWLEDGEMENTS

I thank the following who were involved in field operations: Martha Goudey, Mary Mahoney, Walter Oustimovich, Eileen Sharp, and Diane Tremblay. Bob Semple and Don Jones ably assisted in data compilation and analysis.

REFERENCES

Baardseth, E. 1955. Regrowth of Ascophyllum nodosum after harvesting. Inst. for Ind. Res. and Standards. Dublin, Ireland: 67 pp.

_____. 1970. A square-scanning, two-stage sampling method of estimating seaweed quantities. Rep. No. 333, N.I.T.T., University of Trondheim, Trondheim: 41 pp.

Cousens, R. 1981. Population biology of Ascophyllum nodosum (L.) LeGalis. Ph.D. thesis, Dalhousie University. 244 pp.

Kailov, K.M. 1976. The relatioship between weight, length, age, and intensity of photosynthesis and organotrophy of macrophytes in the Barents Sea. Bot. Mar. 19: 335-339.

Keser, M. 1978. Ecological effects of harvesting on the growth of Ascophyllum and the growth dynamics of Fucus. Ph.D. Thesis, University of Maine at Orono, U.S.A.: 138 pp.

MacFarlane, C. 1952. A survey of certain seaweeds of commercial importance in southwest Nova Scotia. Can. Jour. Bot. 30: 78-97.

Mathieson, A.C., J.W. Shipman, J.R. O'Shea, and R.C. Hasevlat. 1976. Seasonal growth and reproduction of estuarine fucoid algae in New England. J. Exp. Mar. Biol. Ecol. 25: 273-284.

Moss, B. 1970. Meristems and growth control in Ascophyllum nodosum (L) LeJolis. New Phytol. 69: 253-260.

Seip, K.L. 1980. A computational model for growth and harvesting of the marine alga Ascophyllum nodosum. Ecological Modelling 8: 189-199.