Journal of Applied Phycology (2006) 18: 351–359
DOI: 10.1007/s10811-006-9044-8

Changes in the brown seaweed *Ascophyllum nodosum* (L.) Le Jol. plant morphology and biomass produced by cutter rake harvests in southern New Brunswick, Canada

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Key words: *Ascophyllum*, rockweed harvest, habitat, invertebrates, cutter rake, management

Abstract

Shoots and clumps of shoots of the commercial brown seaweed *Ascophyllum nodosum* ("rockweed") add to the benthic complexity of the intertidal environment, providing an important habitat for invertebrates and vertebrates. To protect the structure of this habitat, management plans for the rockweed harvest of southern New Brunswick include restrictions on gear type and exploitation rates limited to 17% of the harvestable biomass. However, owing to physical and environmental factors, the harvest is not homogeneous, creating patches of exploitation ranging from 15 to 50%.

A direct relationship existed between clump vulnerability, weight and length in a controlled harvest at 50% exploitation within 8 m by 8 m plots. At this exploitation rate, the gear rarely impacted clumps below 50 g or 60 cm in length. Clumps larger than 300 g and 130 cm were reduced by up to 55% of their length and 78% of their biomass. The overall impacts of the harvest on intertidal habitat is however of short duration as biomass recovers after a year of the experimental harvest. The rapid recovery is mostly due to a stimulation of growth and branching of the suppressed shoots of the clumps. Some harvested plots showed biomass even higher than initial levels, suggesting an increase in productivity at least during the first year after the harvest.

Introduction

The brown seaweed *Ascophyllum nodosum* (L.) Le Jol. ("rockweed") dominates the rocky intertidal of the Atlantic shores of Nova Scotia and New Brunswick, Canada. The rockweed plant is an assemblage (clump) of dichotomously branching dominant shoots and basal or suppressed shoots arising from a common holdfast and floated by vesicles (Cousens, 1984; Sharp, 1986). The buoyant biomass creates a dense canopy as the tide rises. The high density of branching and suppressed shoots in a clump and the distribution and biomass of clumps in the intertidal create also a complex habitat for invertebrates and fishes during the tidal cycle (Rangeley & Kramer, 1998).

Ascophyllum nodosum's economic value as a raw material for fertilizer, animal fodder and alginate led to its commercial harvest in the Maritimes in 1959 (Sharp, 1986). Harvesting techniques have ranged from simple knives to sophisticated and expensive vessels with hydraulically driven suction cutters (Sharp et al., 1995). Although over the past 15 years the rockweed harvest of the Maritimes has expanded in quantity and extent, the harvesting technique has evolved from harvesting machines to manual cutter rakes (Ugarte & Sharp, 2001).

The cutter rake is attached to a 3 m pole and is equipped with sharp tooth-shaped blades held in a rake-head protected by three guides (Figure 1A). The shoots are cut by the blades and the tines of the rake gather the cut shoots while the guides prevent the blade from contacting the substratum. Harvesters work during the falling and rising tides, with vessel having a 4 to 6 t capacity (Figure 1B). The rake is drawn through the

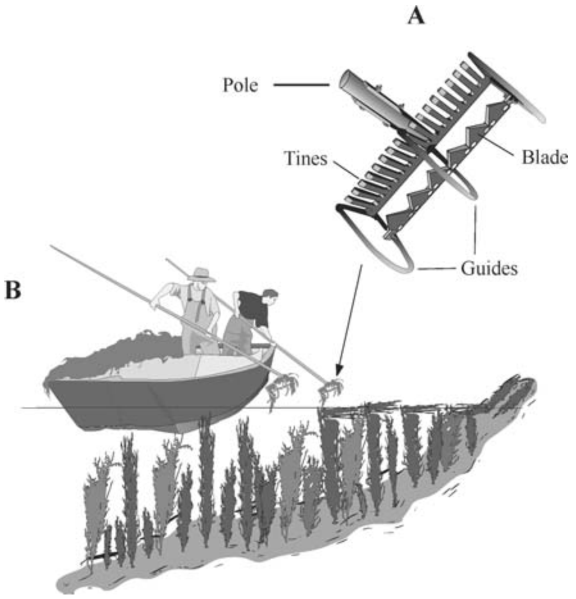

Figure 1. Harvest method of *Ascophyllum nodosum* in southern New Brunswick, Canada. (A) The manual cutter rake (B) Harvesting *Ascophyllum nodosum* from a 6 to 7 m vessel with 4 to 6 ton capacity on the falling and rising tide.

floating canopy at a 45 to 60 degree angle. Once the harvester reaches the rockweed bed, the vessel moves up and down the intertidal zone with the tide and along the bed with the wind and current. The harvester can choose areas of the bed to harvest but cannot directly control the cutting height of the clumps.

In southern New Brunswick regulations restrict gear type and the exploitation rate is limited to 17% of the harvestable biomass in order to protect the structure of this habitat (Ugarte and Sharp, 2001). However, owing to physical and environmental factors, the harvest is not homogeneous, resulting in patches of exploitation ranging from 15 to 50% (DFO, 1999).

The present paper examines the length and biomass structure of *Ascophyllum. nodosum* clumps immediately before and after a harvest and recovery in experimentally harvested plots. To date experimental harvests using various gear types have only examined shoots, and clump length and density (Ang et al., 1993; Lazo & Chapman, 1996).

Methods

The study area was located in Harvesting Area B, which produces the highest landing of the three harvesting areas in the northern shore of the Bay of Fundy in southern New Brunswick, Canada (Figure 2). A closed site (previously non-harvested) located at Green Point, inside Area B, was the location of the experimental harvest (Figure 2). This site was semi-exposed, with a boulder substratum, 15°–30° slope and 100% rockweed cover.

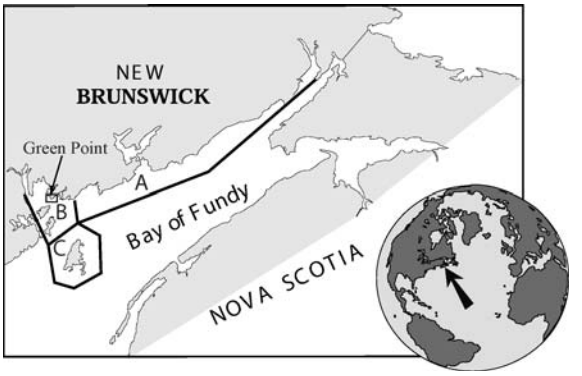

Figure 2. Ascophyllum nodosum harvesting areas and study site location in southern New Brunswick, Canada.

During the summer of 2001 the population structure of rockweed in Harvesting Area B was determined by sampling 16 sites within this area. All clumps were removed from fifteen 0.25 m^2 randomly-placed quadrats without evidence of harvest, along a 30 m transect set in the middle of the rockweed zone at each site. Clumps were bagged and immediately refrigerated (5 °C) and analyzed within two days. The total length, wet weight and number of shoots were measured in 1,196 clumps. From these, 482 clumps were randomly selected, dissected into 10 cm segments from base to tip and the wet weight of each segment measured to 0.1 g.

To measure the impact of the harvest on the population structure, five plots (8 m × 8 m) were permanently marked with rock anchors in the middle of the rockweed zone located at the Green Point study site (Figure 2). Thirty quadrats (each 0.125 m^2) were evenly spaced along five parallel transects in each plot. All clumps in a quadrat were tagged using permanent tags (Sharp and Tremblay, 1985). A total of 1,256 clumps was tagged at the start of the experiment but only 1,137 (90.5%) provided reliable data throughout the experiment. Three plots were randomly selected as treatments and two as controls. Each tagged clump was measured for length to 0.1 cm using a flexible tape. The wet weight (accurate to 0.1 g) for each clump was measured using a low-profile base electronic scale (Acculab VI-600). The clump was carefully piled inside a tared

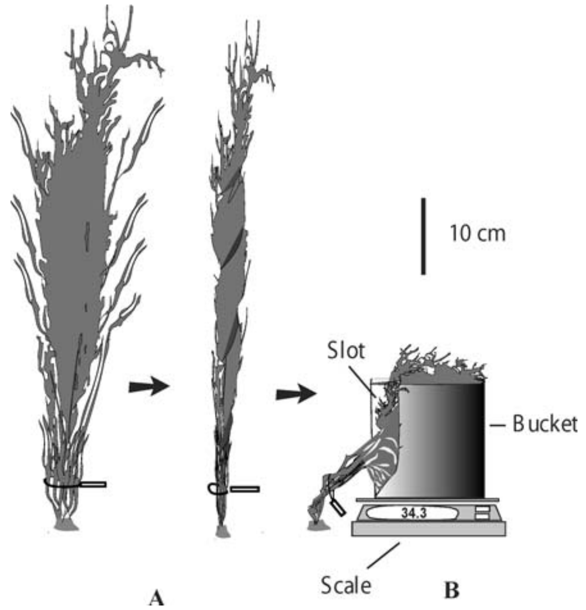

Figure 3. Measurement of *Ascophyllum nodosum* clump weight. (A) Twisting the clump, (B) Rolling the clump inside a tared bucket over a low-profile base scale.

plastic bucket with a vertical slot to weigh it as close to the holdfast level as possible (Figure 3). As the aim of this measurement was to quantify changes of clump weight after the harvest, the small portion of the clump biomass close to the holdfast and outside the bucket (Figure 3) was considered constant before and after the harvest. To avoid variations, all weight measurements during the study were done by one trained person. Variation due to desiccation was avoided by measuring the clumps within an hour of being exposed. In addition, 30 suppressed shoots in three size classes (10–20, 21–40 and 41–60 cm) were individually tagged in each plot to evaluate their response to harvesting. The use of the scale was difficult in the lower size class so their initial weight (pre-harvest) was obtained through a regression with their length. The relation was highly significant ($p < 0.001$, $n = 350$) with $R = 0.93$ in this small unbranched class (Ugarte, unpublished data).

To determine the rockweed biomass in the study site, fifteen 0.25 m^2 quadrats were randomly sampled along a 10 m transect set in the middle of the bed. These data were used to determine the biomass removal needed to reach the target 50% exploitation rate in the experimental harvest. A commercial harvester with a conventional cutter rake then harvested the required biomass in each treatment plot. The tagged clumps were re-measured for length and weighed immediately after the harvest. The clumps were re-measured three times during the first year of the experiment: October 2001, April 2002 and August 2002. Another measurement was carried out in August 2003, two years after the harvest. Mean differences were compared using *t*-tests. Biomass values were log transformed.

Results

Length and biomass structure of rockweed clumps

The distribution of biomass within a clump changes with the total length of the clump. At smaller size classes the biomass is proportionately closer to the bottom (Figure 4). Fifty percent of the biomass is within the lower half of the plant up to the 90 cm length class. In the 130 cm length class 50% of the biomass is distributed in the upper one third of the clump (Figure 4).

Clump length is normally-distributed and ranges from 12 cm to 143 cm, with a mean of 74.5 cm (SD ± 27.6 cm) (Figure 5). Clump weight varied from 1.0 g to 765.3 g, with a mean of 68.2 g (SD ± 112.2). 83% of the clumps in the stand are under 100 cm; however, they only contribute 50.8 % of the total weight. The remaining 17.1% of the clumps over 100 cm contribute 49.2% of the stand biomass (Figure 5).

Effect of harvest on clump length and biomass structure

The impact of the harvest increased with clump size. Length was significantly reduced ($p < 0.01$) in those clumps over 70 cm. Clumps over 90 cm and 130 cm lost 35% and 45% of their original length, respectively (Figure 6A). The rake did not reduce the length significantly in those clumps under 60 cm ($p > 0.01$) (Figure 6A).

A more dramatic effect of the harvest was evident when measuring the clump biomass. The biomass of clumps in the 90.1–99.0 cm category was reduced by 56.5%. Clumps over 130 cm lost 78% of their biomass. However, as with length, those clumps below 70 cm were not reduced in biomass ($p > 0.05$) (Figure 6B).

Biomass recovery

The mean clump biomass of unharvested rockweed increased in the fall due to vegetative and reproductive growth. Wet weight reached a peak by late April when receptacles had a high water content. Clump weight

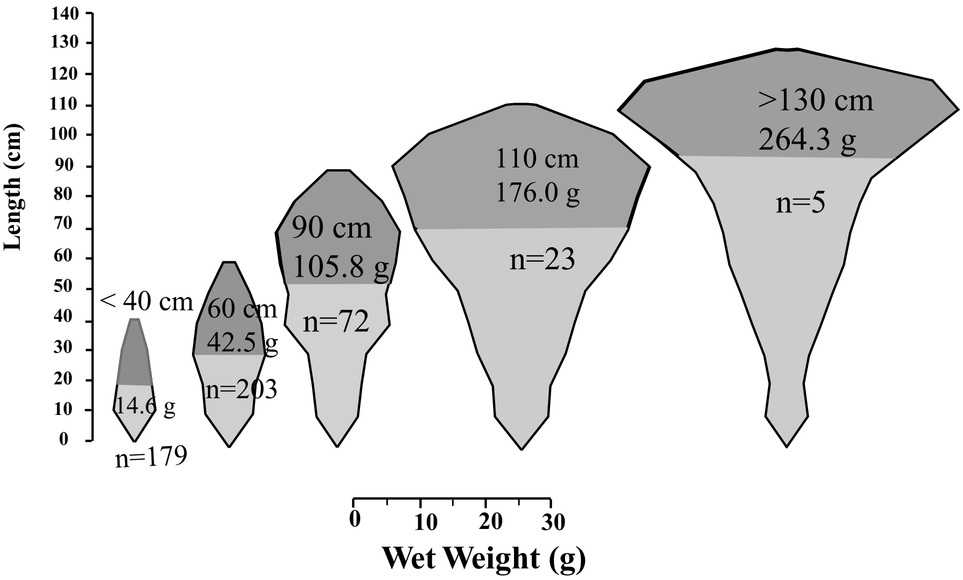

Figure 4. Mean distribution of biomass in 10 cm increments within individual *Ascophyllum nodosum* clumps of 5 size classes. The shaded areas in each size class represent 50% of the biomass.

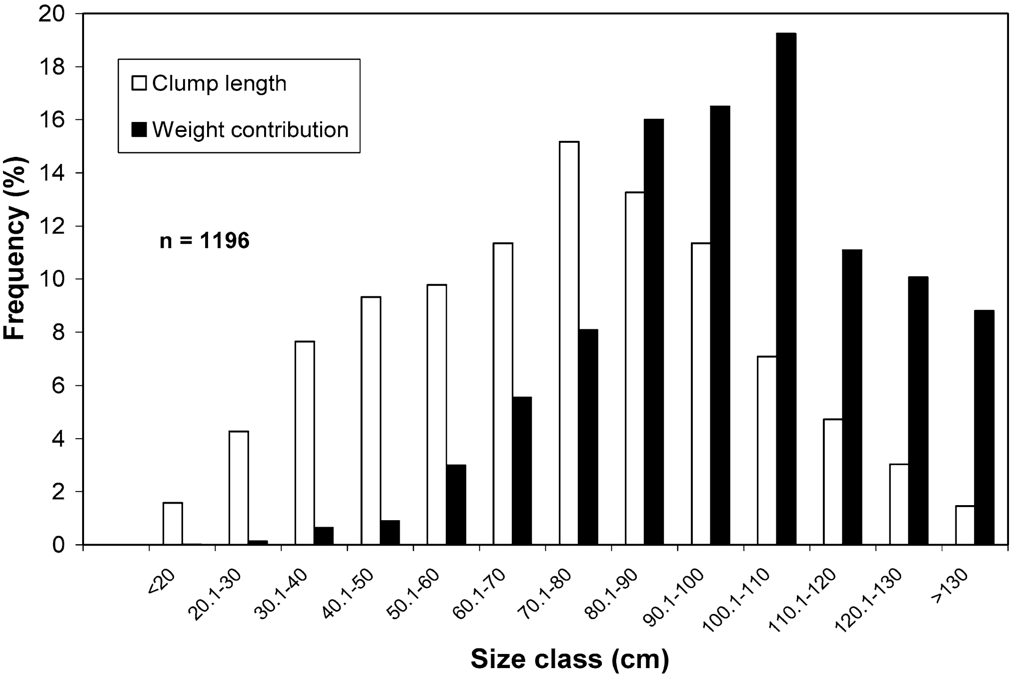

Figure 5. Length frequency and weight contribution of *Ascophyllum nodosum* clumps in study area.

dropped suddenly in mid May, after the breakdown of the receptacles and reached its previous year's level in July (Figure 7).

After the reduction in their mean biomass in early August 2001, clumps in all harvested plots showed an increase in their mean biomass (Figure 7). Here, the growth rate was higher than the control after October 2001 and until April 2002 (Figure 7). A year after the harvest in July 2002 harvested clumps had a 85% biomass recovery in plot 6, a total recovery in plot 3,

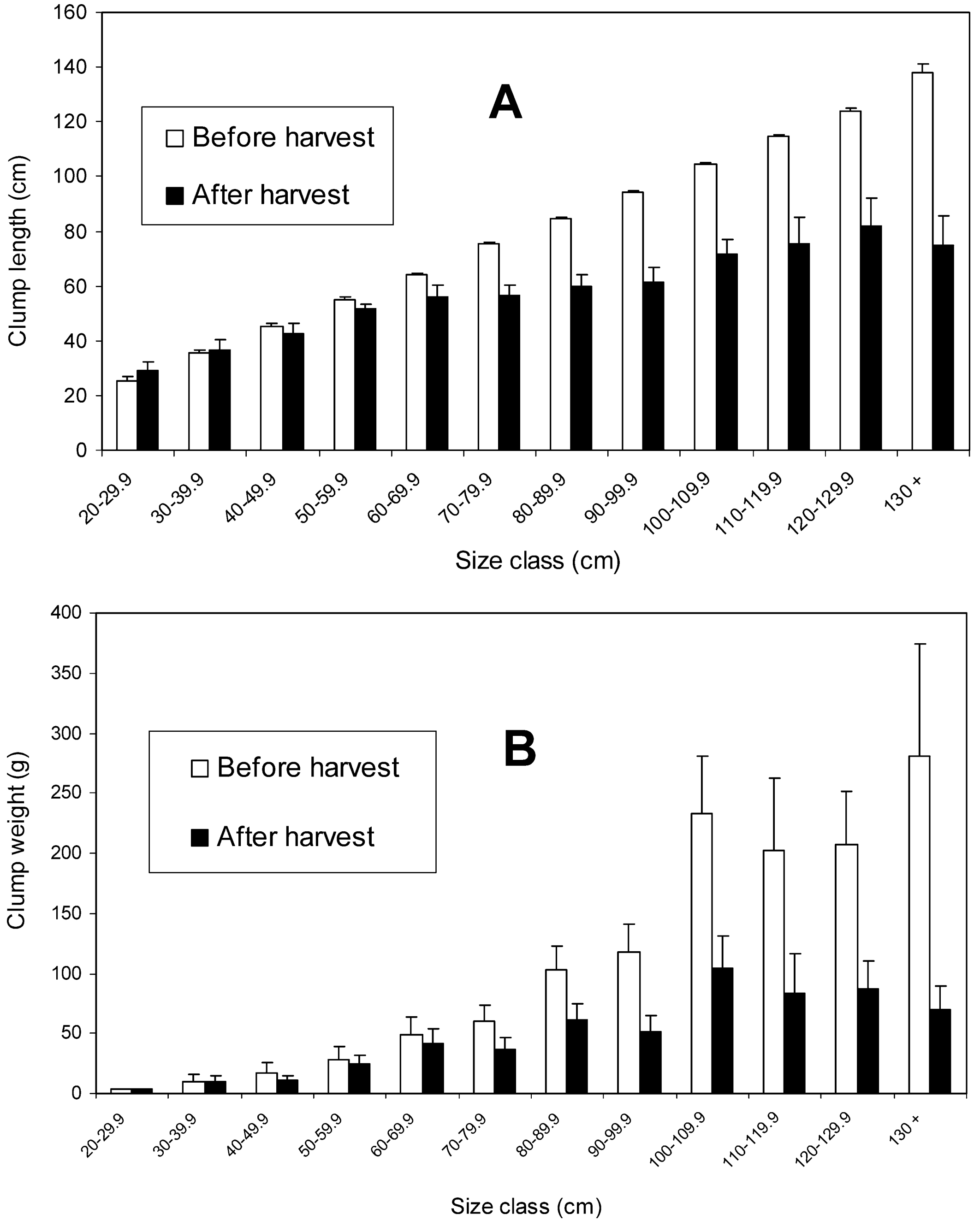

Figure 6. Changes in clump structure of *Ascophyllum nodosum* in 12 different size classes after a 50% exploitation rate harvest in experimental site at Green Point, southern New Brunswick ($N = 672$; Vertical bars are ± 2 standard errors). (A) Changes in mean length of clumps (B) Changes in mean weight of clumps.

and a 52% increase in plot 7 in comparison to the original biomass (Figure 7). By July 2003, two years after the harvest, clumps of plot 6 had totally recovered their original biomass, clumps in plot 3 had increased their original mean biomass by 22%, while those in plot 7 were down from the July 2002 biomass but still maintained a 23% increase from their original biomass. Control clumps were not significantly higher in their original mean biomass ($p > 0.05$) when re-weighed in July 2003 (Figure 7).

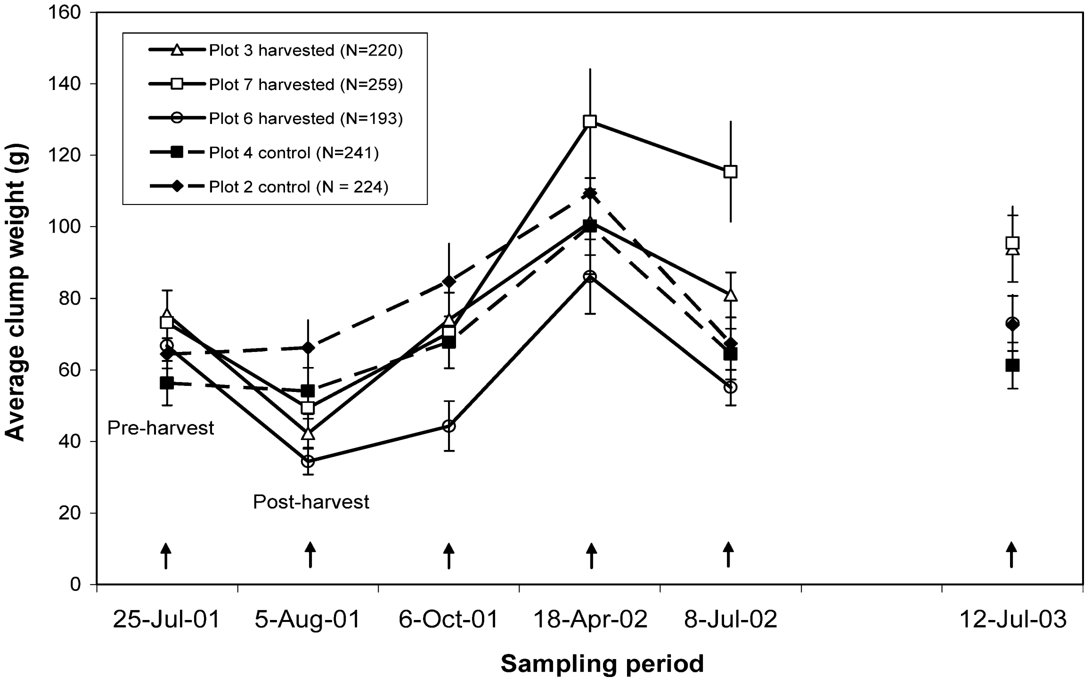

Figure 7. Seasonal changes in average clump weight of *Ascophyllum nodosum* harvested and control plots (vertical bars are ± 1 standard error).

Length recovery

There was a small but significant increase ($p < 0.01$) in clump length in the control plots between July 2001 and July 2002 (Figure 8). In July 2003, plot 2 maintained the same mean length as the previous year but in plot 4 mean clump length was reduced significantly ($p < 0.01$) from 78.2 cm to 65.4 cm.

Clumps from harvested plots reduced their mean length by 25% and 23% in plots 3 and 6 respectively and 12% in plot 7 immediately after the harvest (Figure 8). They increased their length through the year but only clumps from plot 7 showed a total recovery. Clumps from plot 6 and 3 recovered only 95% and 92% of their pre-harvest length (Figure 8). There was no variation in the length of harvested clumps during the July 2003 examination (Figure 8).

Suppressed shoots

Shoots between 21–40 cm and 41–60 cm in the harvested plots increased their biomass by 131% and 249%, respectively over the control plot shoots after the first year of the harvest (Figure 9A). There was no significant difference ($p > 0.05$) between treatment and control for shoots of the 1–20 cm class during this period (Figure 9A). In August 2003, two years after the harvest, suppressed shoots over 20 cm of initial length still showed highly significant weight differences from the control shoots. However, the mean shoot weight in the 41–60 cm category from the harvested plots showed a slower growth rate compared to the previous year. Although not as dramatic as the increase in weight, most of the suppressed shoots over 20 cm in the treatments plots had a significantly higher ($P < 0.05$) increase in length compared with the controls (Figure 9 B).

Discussion

The casual observer of a recently harvested rockweed bed in southern New Brunswick cannot perceive any change in cover and biomass compared to undisturbed beds. It appears counter-intuitive that 12,000 t of biomass can be removed from the accessible resource without obvious signs. Our examination of biomass distribution in the bed and in the clumps provides an explanation. Harvesting of rockweed with a cutter rake at or below the target 17% exploitation rate will impact patches of rockweed habitat within beds. In these patches, harvesting reduces the biomass and total length of selected clumps by cutting a portion of

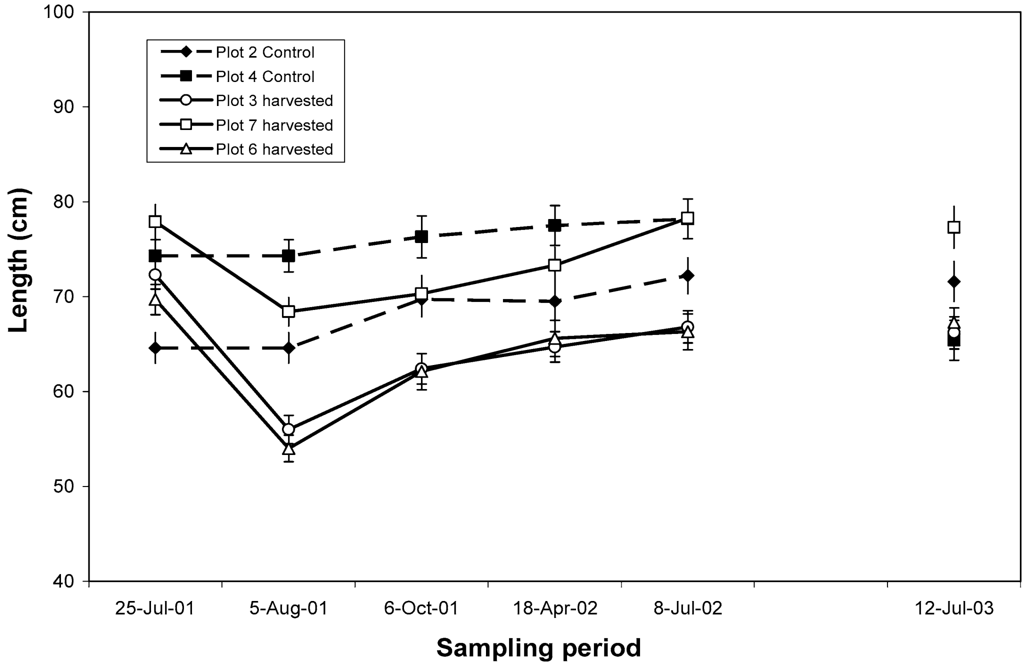

Figure 8. Seasonal changes in average clump length of *Ascophyllum nodosum* from harvested and control plots (vertical bars are ± 1 standard error).

their shoots. Due to the skewed distribution of biomass in the clump and the stand, small changes in clump length can result in localized exploitation rates of 50%. The exponential relationship between shoot length and weight shows that most of the biomass is in the distal portion of the clump. The harvester is able to direct his rake to the larger clumps that form the canopy of the stand. The diagonal, basal to distal cutting action of the rake removes the upper, heavier part of these clumps, changing significantly their complexity and spatial structure. However, the largest net change in the harvested patches is in clump biomass not length or the number of shoots. Though tedious, measuring clump biomass before and after the harvest is the best way to determine any structural change. Measuring frond length and circumference and obtaining their correlation with biomass (Cousen, 1984; Aberg, 1990) cannot be used in this case as the volume and biomass relationship is lost after the harvest.

The reduction in the complexity and spatial structure in the harvested patches could potentially affect both the abundance of associated invertebrates and the abundance and behaviour of vertebrates. The body size and abundance of metazoans in small tufted algae are affected by the size and structural variety of the algal species (Gee and Warwick, 1994; Pavia et al., 1999). Moderate changes in shape and branching within the structural units of the red alga *Gracilaria* did not affect predation on amphipods (Masterson, 1998). However, reduction in biomass within rockweed clumps can potentially affect those species most closely related to the plant surface, such as *Littorina obtusata* (Johnson and Scheibling, 1987). Micro-spatial complexity is directly affected as the amount of epiphyte biomass is reduced. Invertebrate species abundance and diversity in *A. nodosum* epiphytes is linearly related to this level of complexity (Hicks, 1980). Algal cover also affects schooling behaviour of juvenile pollock, which use it to avoid predation (Rangeley and Kramer, 1998). The behaviour of eider ducklings can be also affected by the structure of the *A. nodosum* stand (Hamilton, 2001).

Although the current scale of harvesting in New Brunswick does not alter shoot or clump density or bed cover, the overall structural complexity is altered. However, net changes in canopy height or complexity of clumps quickly become diluted to small differences between harvested and un-harvested stands when placed in the context of the entire bed and the intertidal landscape. The question remains whether this change in the canopy or height structure in harvested patches causes

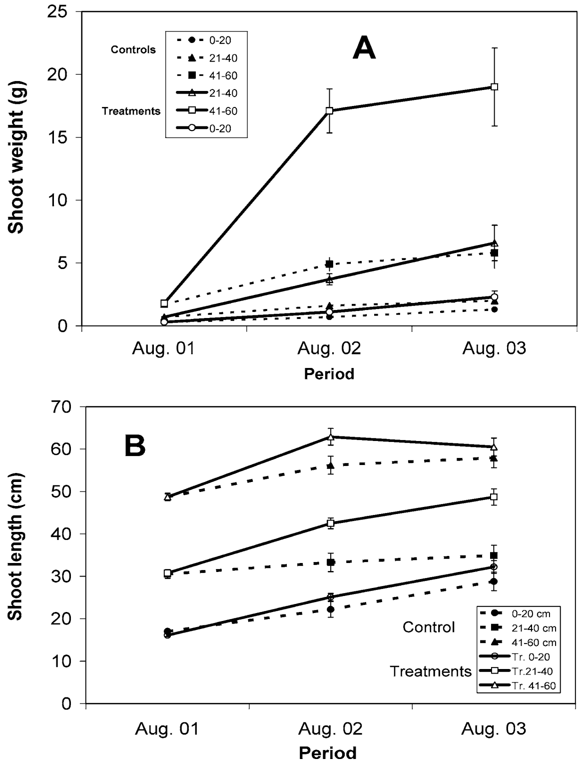

Figure 9. Changes in suppressed shoots of *Ascophyllum nodosum* after a 50% exploitation-rate harvest in experimental site at Green Point, southern New Brunswick (Vertical bars are ± 1 standard error). (A) Changes in average weight of shoot. (B) Changes in average length of shoot.

any significant reduction in the value of a stand as a habitat and whether this alters critical environmental factors for fauna. In our southern New Brunswick experiments, the structural changes produced by rockweed harvesting in the habitat are short lived as the reduction in standing crop at this scale of harvest is compensated for by the overall production during the summer and fall months. The removal of the canopy enhances growth and production by the initiation of new laterals from cut or basal shoots (Lazo & Chapman, 1996), thus redeveloping the complexity of the clump within a year.

Changes in biomass also become less significant as we move from the stand to the sector, to the harvest area, and then the coast or the bay. The change is a function of the degree of harvest, the amount of accessible rockweed compared to the total rockweed in the system and the importance of macrophyte production to the total primary production in the system.

The current quota of 12,000 t is spread over the southern New Brunswick rockweed resource and is 7.5% of the total rockweed biomass of 159,000 t (DF0, 1999). Annual production to biomass ratios of rockweed are 0.4 to 0.5 depending on the method of calculation (Cousens, 1984). According to this information, the annual productivity of rockweed in New Brunswick would range from 64,000 t to 79,500 t. Consequently, this harvest does not diminish the standing stock of rockweed as it takes 15.1% to 18.7% of annual production in southern New Brunswick.

The question of cumulative effect is very relevant. Harvesting has been most intensive in harvesting area B (Ugarte & Sharp, 2001), because of resource abundance as well as easier access to the resource both for harvesters and materials-handling issues for the company. The goal is to spread harvesting evenly between sectors as well as within sectors. The harvester expects a minimum catch-per-unit of effort in a bed and if this is not reached, he will move to another bed. The very large tidal range also prevents harvesters from remaining in one place for more than a few minutes as the tide rises or falls. Harvesters do not normally return to the same patch in the same year as their catch per unit effort could not be sustained in an area that is still recovering from harvest. The harvest within sectors is not controlled to the level of a bed and re-harvest of a patch is possible. However, in theory, at a 17% exploitation rate of the harvestable biomass, it could take 6 years before it is 100% probable that all harvested patches in a bed will be re-harvested.

Acknowledgements

The authors extend their appreciation to J. Sharp and J. Bettle for their extensive field assistance. This study was supported and entirely financed by the Department of Research and Development of Acadian Seaplants Limited.

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