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An evaluation of the mortality of the brown seaweed *Ascophyllum nodosum* (L.) Le Jol. produced by cutter rake harvests in southern New Brunswick, Canada

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Abstract *Ascophyllum nodosum* (rockweed) landings in the Atlantic Maritime provinces of Canada totalled 36,500 wet tonnes in 2009. Due to the relative slow growth, stochastic recruitment, and the importance of habitat protection, strict harvest regulations are in place in the region to maintain the integrity of this resource. Special harvesting rakes have been designed to cut the plants and not to dislodge the clumps and their holdfasts from the substratum. However, for various reasons, close to 6% of the biomass harvested annually contains holdfast material. This proportion is closely monitored by the province as it is assumed to represent clump mortality. However, due to the complex structure of *A. nodosum* clumps, this relationship with mortality is not simple. A study was carried out to evaluate the real impact of this detachment on the *A. nodosum* population of southern New Brunswick in 2004. The structure of harvested *A. nodosum* clumps with associated holdfast material was analyzed and compared to non-harvested clumps from the same harvest area. Results showed that when a rake strips a clump, it only detaches 17.4% of the holdfast surface, leaving 36.8% of the plant biomass and 80.3% of the shoot density intact. An analysis of storm-cast material from the same study area showed a similar effect in the clump structure, although the incidence of holdfast in the detached biomass could be as high as 30%. Due to the high biomass detached each year by coastal storms in New Brunswick, their impact on the *A. nodosum* resource is 21 times higher than the annual harvest.

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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 lateral, dichotomous, and basal shoots in a clump and the distribution and biomass of clumps in the intertidal also create a complex habitat for invertebrates and fishes during the tidal cycle (Rangeley and Kramer 1998).

Harvesting practices and management regulations for the harvest of rockweed in the Maritime region have changed drastically during the last 13 years, mostly influenced by the groundfish collapses of the early 1990s and strong environmental concerns by different stakeholders (Ugarte and Sharp 2001; Sharp and Bodiguel 2002). Environmental concerns will continue influencing marine resource management in Canada, especially when the harvested resource is also a habitat (Rangeley 1994; Rangeley and Davis 2000). 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).

Although it has been demonstrated that the current harvest technique produces minimum changes in the habitat architecture (Ugarte et al. 2006), a portion of the biomass harvested contains clumps with holdfast. This proportion is assumed to have a direct relationship with clump mortality and has been monitored as "holdfast incidence" from the commercial landings of rockweed since 1996 in New Brunswick, by both the harvesting company and the provincial department of fisheries (NBDAFA). Current regulations restrict the holdfast incidence in the harvested biomass to 10%. Although this measure is part of the precautionary approach to protect the resource and the habitat, it was not clear if this percentage restriction was adequate as we lacked field data to establish a good correlation between the holdfast incidence and the rate of natural mortality. In most commercial brown seaweed species, mortality is relatively easy to determine if a single shoot emerges from the holdfast and no regeneration occurs from the residual tissue after harvest as in several kelp species. Mortality of *A. nodosum* has been well documented and measured at the germling stage (Vadas et al. 1990; Viejo et al. 1999; Dudgeon and Petraitis 2005). However, as the plant grows and coalesces with adjacent individuals creating the complex clump structure, mortality becomes a more difficult parameter to estimate.

The aim of the present study was to quantify the impact of the *A. nodosum* clump dislodgement produced by the harvest and compare it to natural events such as storms that periodically affect the rockweed population of southern New Brunswick.

Material and methods

Study site

The information for this study was collected in 2004 in a study area of seven harvesting sectors within harvesting area B (Ugarte and Sharp 2001), the most productive of the three harvesting areas in southern New Brunswick (Fig. 1). The sectors in the study area produce 41.5% of the landings for area B, and they have shown a consistently high holdfast incidence since 1996.

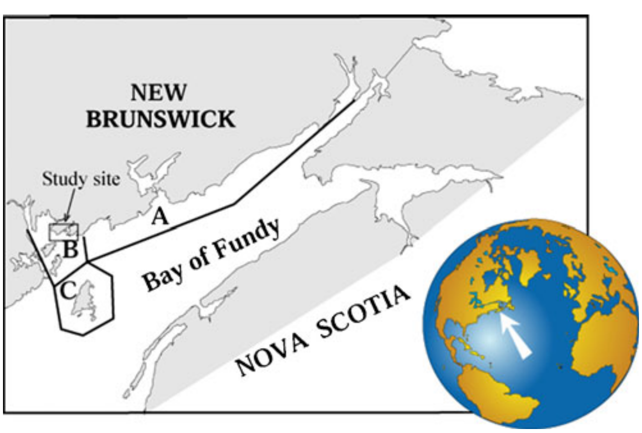

Fig. 1 *Ascophyllum nodosum* harvesting areas and study site location in southern New Brunswick, Canada

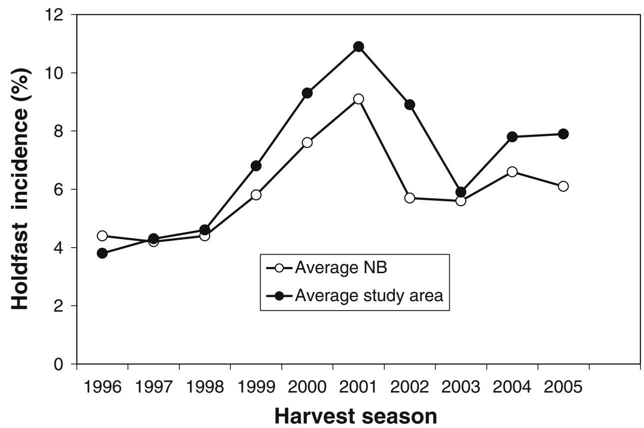

Fig. 2 Historical holdfast incidence in the landings of rockweed in southern New Brunswick

Holdfast incidence

Holdfast incidence has been quantified by the company since 1996 (a year after the harvest started) by sampling the harvested biomass at all the landing sites in southern New Brunswick. A pre-determined number of harvesters are assigned to each landing site, and they land material from a specific set of harvesting sectors. The accurate origin of landed material is supported by a harvesting log completed by the harvester that reports the sectors harvested daily (Ugarte and Sharp 2001). When a container from a landing site reaches the drying field, three 5-kg samples are haphazardly taken, and clumps with holdfasts are carefully separated from the samples, so as not to break or tear off the clumps as they were removed, counted, and wet weighed to 0.1 g. The biomass of plants with holdfasts is then compared to total weight of the sample, and an average percentage of the holdfast incidence for that particular landing site is then obtained.

Structure of the harvested and non-harvested clumps

During 2004, the same clumps with holdfasts obtained from the study area for holdfast incidence analysis were kept and taken to the lab for their structure analysis. To maintain consistency in weight in the sampled material, special care was taken in sampling only loads of material harvested within 7 h before arriving in the drying field, as they showed no reduction on biomass humidity during that period.

Samples were also taken directly from the study area to compare the clump structure of the natural population (control) to those dislodged in the harvest. Thirty-meter transects were laid parallel to the shore in the mid-portion of the rockweed bed; Ten 50×50-cm quadrats were randomly placed along the transects. All the clumps inside

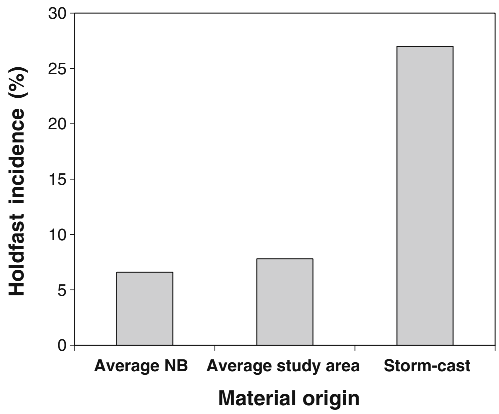

Fig. 3 Holdfast incidence in the biomass of rockweed calculated from three biomass sources in 2004; harvested from the study site, from the whole province, and from storm-cast material in southern New Brunswick

the quadrat were individualized by tying the shoots with tape and then removed by carefully scraping under the holdfast. Clumps were immediately stored in a plastic bag, kept cool, and taken to the lab for analysis on the same day. Total length (to 0.1 cm), wet weight (to 0.1 g), holdfast area (to 0.1 mm), and number of shoots emerging from the holdfast were measured from each clump. To determine the holdfast area, an ink impression of the holdfast base was made on a piece of paper; this impression was digitized, and the holdfast area was measured with NIH image analysis program. This study was conducted between July and August 2004 to minimize bias due to changes in the clump biomass during summer time (Ugarte et al. 2006).

A summer storm in August 2004 gave us the opportunity to collect and analyze the biomass detached (storm cast) from the same study area. Due to the geographic configuration of the study area (relatively closed embayments) and the short time (12 h maximum), the collection was made after the storm; we are certain that most of the cast material came from the study area. Samples were haphazardly taken by tossing a 50×50-cm quadrat on the cast material along the shore. All the cast material lying underneath the quadrat was collected, and the holdfast incidence from this naturally detached biomass was calculated as per the harvested material. The clump structure, weight, and holdfast area were then calculated from the separated clumps with holdfasts.

Landing data used in this study were obtained from Acadian Seaplants Limited daily harvest records.

Statistical analysis

Statistical differences in length, weight, number of shoot, and holdfast area among the different populations (har-

Fig. 4 Frequency (**a**) and average clump length (**b**) calculated from three biomass sources within the study area; harvested, non-harvested, and storm-cast material (*vertical bars* are ±2 standard errors)

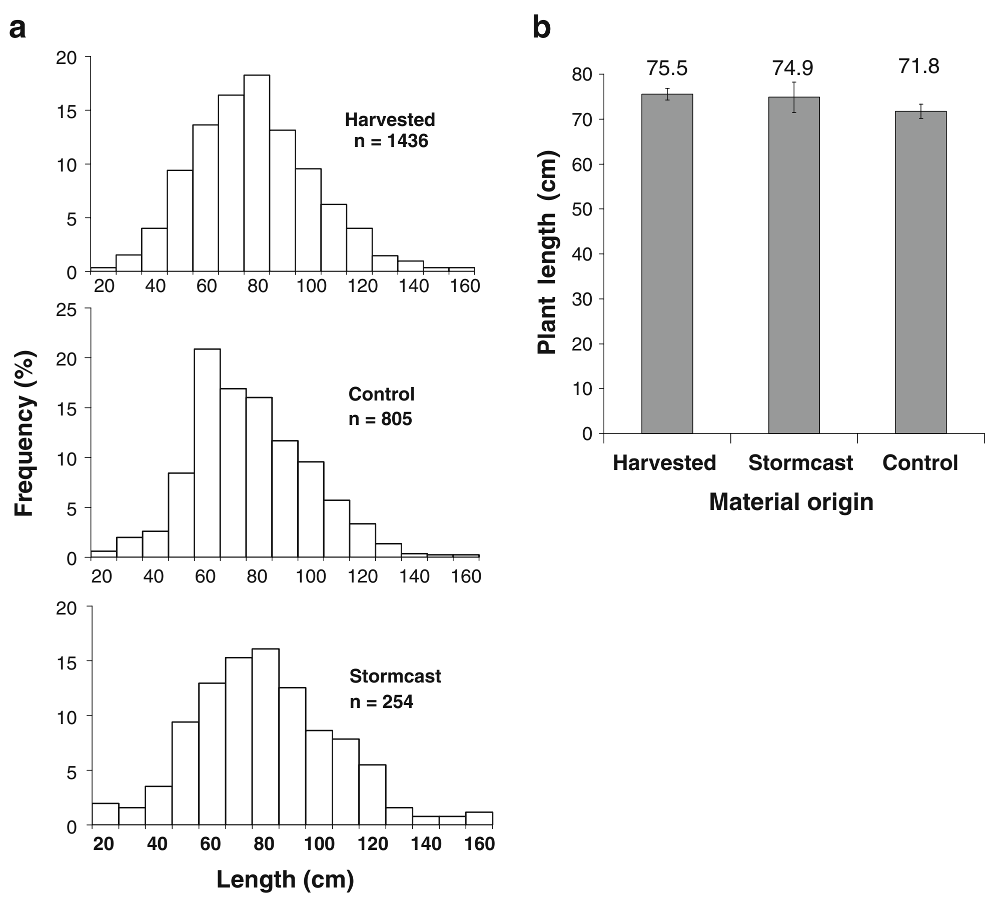

Table 1 Paired comparison of variables from three different rockweed material origin

Variable		Harvested	Control	Storm cast
Length	Harvested		ns	ns
	Control		*p*<0.001	ns
	Storm cast			
Weight	Harvested			ns
	Control		*p*<0.001	*p*<0.005
	Storm cast			
No shoots	Harvested			*p*<0.001
	Control		*p*<0.001	*p*<0.001
	Storm cast			
Holdfast area	Harvested			*p*<0.001
	Control			*p*<0.001
	Storm cast			

ns difference with a $p<0.016$

vested, field (control), and storm cast (natural perturbation)) were performed using the Kolmogorov–Smirnov test, incorporating the Bonferroni correction (Sokal and Rohlf 1995). The analysis was performed using the software Statistica 6.0.

Results

Holdfast incidence

The holdfast incidence in the harvested biomass varied from a minimum of 4.3% at the beginning of the harvest in 1996 to a maximum of 9.2% in 2001 and fluctuated around 6% subsequently (Fig. 2). The holdfast incidence in study area sectors, with the exception of the first 3 years, was always higher than the province average, peaking in 2001 at 11.1% (Fig. 2).

The storm-cast biomass collected in August 2004 in the study area had a holdfast incidence of 27%, compared to 7.8% for the harvest in the study site and 6.6% for the province as a whole for that year (Fig. 3).

Clump structure

A total of 1,436, 805, and 254 clumps from harvested, non-harvested, and storm-cast material, respectively, were analyzed during this study.

Average clump length of harvested, storm-cast, and control clumps were 73.5, 74.9, and 71.8 cm, respectively (Fig. 4). This difference was not significant ($p>0.016$; Table 1).

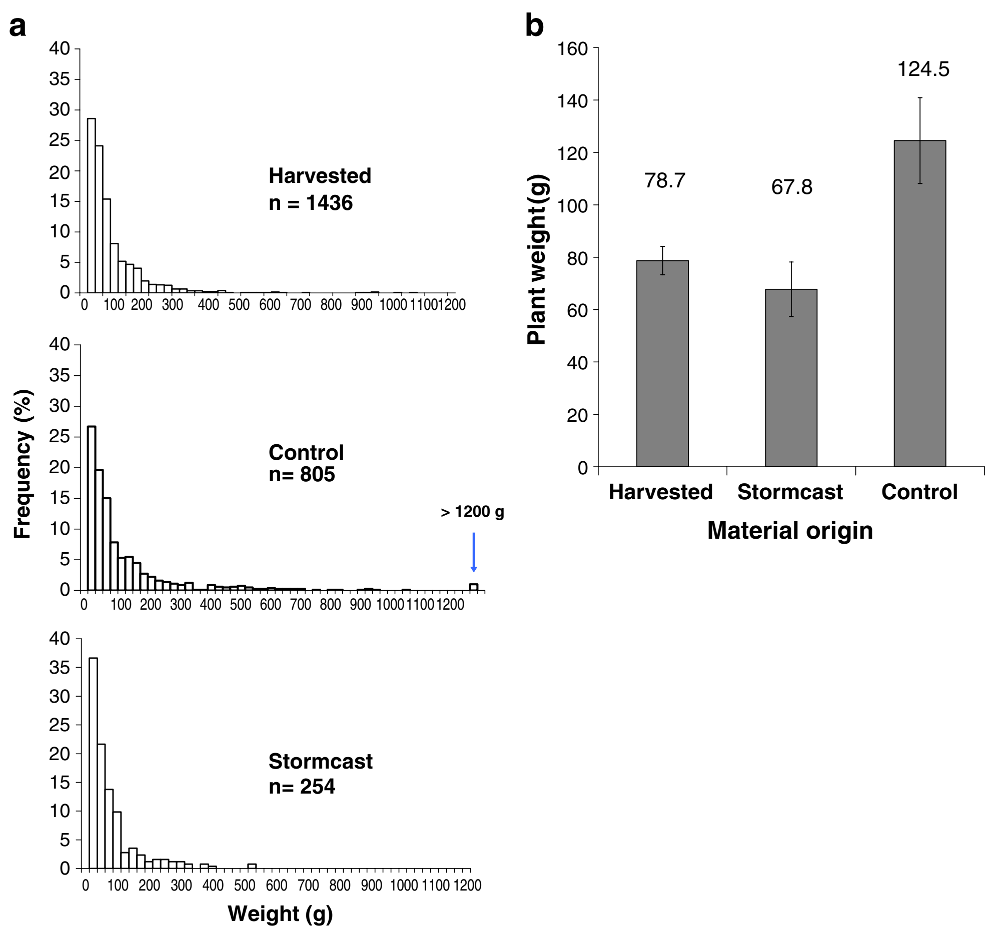

Fig. 5 Frequency (**a**) and average clump weight (**b**) from three biomass sources within the dropped considerably, non-harvested, and storm-cast material (*vertical bars* are ±2 standard errors)

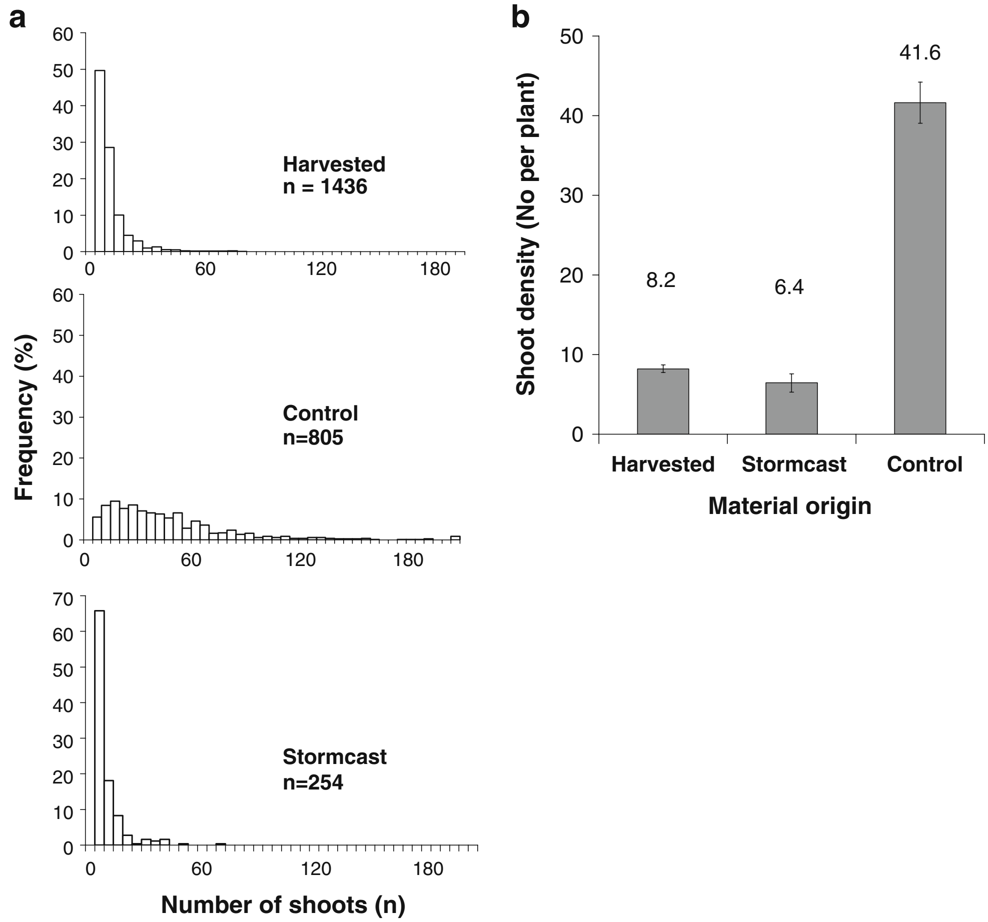

Fig. 6 Frequency (**a**) and average number of shoots per clump (**b**) from three biomass sources within the study area: harvested, non-harvested, and storm-cast material (*vertical bars* are ±2 standard errors)

Average weight of harvested and storm-cast clumps was 78.7 and 67.8 g, respectively, not significantly different ($p>$ 0.016; Table 1). However, the average weight of field-collected clumps (124.6 g) was 37% and 46%, significantly higher ($p<0.005$ and $p>0.001$; Table 1) than those harvested and naturally detached (Fig. 5).

Average number of shoots in non-harvested clumps was significantly higher ($p<0.001$; Table 1) than those from harvested and storm-cast origin, with 41.6 shoots vs 8.2 and 6.4 shoots, respectively (Fig. 6). Although the number of shoots was close in harvested and naturally detached clumps, the average was significantly different ($p<0.001$; Table 1).

The average holdfast area of the non-harvested clumps was significantly greater ($p<0.001$; Table 1) than those collected from the harvested and storm-cast material, 124 vs 21.6 and 14.9 mm^2, respectively (Fig. 7). Thus, when dislodged, the proportion of holdfast material taken by the harvest and storms was17.4% and 12.0% of the entire holdfast surface, respectively. Again, although the dislodged holdfast area was relatively similar between harvested and storm-cast material, the difference was significant ($p<0.001$; Table 1).

Discussion

Holdfast incidence in the harvested material can be the result of a friable substrate holding the rockweed clumps, a naturally damaged clump, or the condition of the harvesting tool. The latter was responsible for the 2001 peak in the holdfast incidence analysis. In fact, a dull or rusted blade can increase the holdfast incidence up to three times compared to a sharp blade (Ugarte unpublished results). After this problem was identified and corrective actions were taken, the holdfast incidence dropped considerably the year after. The low levels reached the first 3 years of the harvest have not been reached again, most probably due to the increase in landed biomass (less than 5,000 t before 1998 vs over 11,000 t after 2002; Acadian Seaplants Limited landings records) and an increase in harvesting locations with a more diverse substrata. The 6.6% holdfast incidence registered for NB in 2004 corresponded to 671 t of biomass being harvested with holdfast.

The impact of the harvest can be compared to those of natural events as follows: the total rockweed biomass for southern New Brunswick is 159,000 t (CAFSAC 1992),

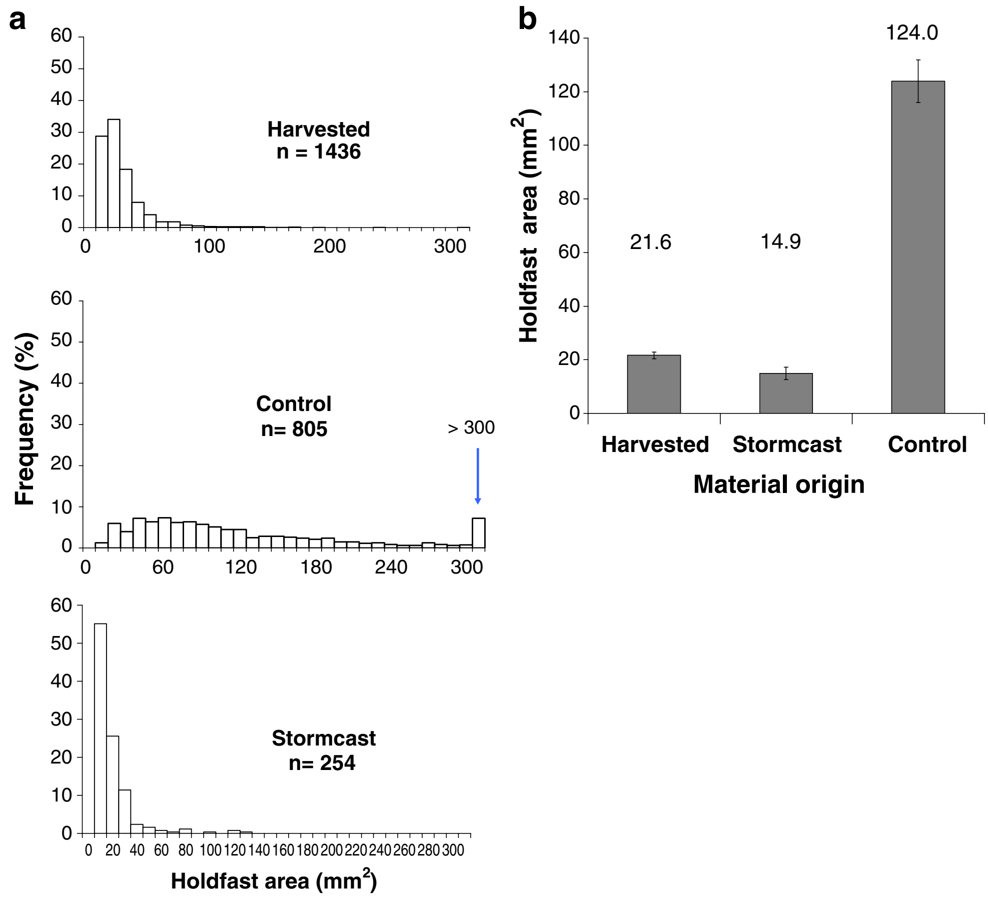

Fig. 7 Frequency (**a**) and average holdfast area (**b**) from clumps collected from three biomass sources within the study area: harvested, non-harvested, and storm-cast material (*vertical bars* are ±2 standard errors)

and from growth and production data for this seaweed in the region (Cousens 1984; Ugarte et al. 2010), a minimum of approximately 52,000 t of biomass is released as storm-cast material each year. If the average holdfast incidence of 27% found in the detached biomass in August 2004 is a normal range for these events (the author has measured holdfast incidence from storm-cast material from 2002 to 2004 in New Brunswick, with values varying between 24% and 32%), then a minimum of 14,040 t of biomass bearing holdfasts are naturally detached each year in the province, an impact 21 times larger than the harvest.

Considering that rockweed is a perennial seaweed and that recruitment is considered a poor mechanism to maintain these populations (Vadas et al. 1990; Viejo et al. 1999; Dudgeon and Petraitis 2005), alternative mechanisms must exist that prevent the decline of these populations by the cumulative effect of storms or other natural events. The small portion of the holdfast surface that is dislodged when impacted by both the cutter rake and storms is the explanatory mechanism. The portion of the clump that is affected in both cases are the largest and heaviest shoots conforming the canopy, leaving behind a large amount of meristematic tissue in the form of suppressed shoots and laterals. Once the canopy is removed, the biomass of the affected clump is rapidly regenerated as the growth of the suppressed shoots is stimulated by light (Lazo and Chapman 1996; Ugarte et al. 2006). To date, we do not have empirical data to confirm if the affected holdfast regenerates the dislodged portion, but indirect evidences of beds recovery after severe ice scouring observed in two locations of Nova Scotia (Ugarte et al. 2009) suggest that a regenerating mechanism similar to that described for other fucoids such as *Fucus vesiculosus* in Nova Scotia (McCook and Chapman 1991) and in Finland (Kiirikki and Ruuskanen 1996), where remnants of holdfasts are able to regenerate full clumps, may be also possible in *A. nodosum*.

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