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The Basin Head Irish Moss (*Chondrus crispus)* Population Abundance and Distribution 1980 to 2008

L'abondance et la répartition de la population de la mousse d'Irlande (*Chondrus crispus)* de Basin Head de 1980 à 2008

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ABSTRACT

The Basin Head strain of *Chondrus crispus* has unique characteristics including frond morphology, reproductive stage and growing habit distinctive from the open coast populations. These fronds are held in place by an association with Blue Mussel (*Mytilus edulis*) forming clumps of fronds and contiguous patches of clumps. The population is concentrated in a 500 m section of the northern arm of the Basin Head lagoon. There were early reports of this population in the 1960's. However, it was not until 1980 that two assessments defined a bed of 160,000 m^2 , equivalent to 127 to154 t of standing crop. Twenty years later the area was estimated at 60,000 m^2 and a biomass of 46.8t. A significant reduction in cover was observed in 2003 and this decline continued until less than 1 t of the biomass was present in 2008. Transfers of *C. cripsus* to other estuaries in PEI enhanced the growth rate compared to control fronds in Basin Head. This suggested that growing conditions in Basin Head were sub optimal for the species. The eutrophication of the basin over the past 30 years and decreasing water quality were suggested as potential reasons for the decline of the *C. crispus* population. Extensive blooms of *Ulva* spp. develop in the early summer and in the late summer breakdown of tissues leads to areas of anoxia and poor water quality. It is recommended that grow out experiments be conducted in the lagoon to test this hypothesis for the decline of *C. crispus* biomass.

RÉSUMÉ

La souche de *Chondrus crispus* de Basin Head possède des caractéristiques uniques, notamment une morphologie fronde, une étape de reproduction et une habitude de croissance distinctes des populations du littoral. Ces frondes sont tenues en place par une association avec la moule bleue (*Mytilus edulis)* formant des grappes de frondes et de groupes de grappes avoisinantes. La population est concentrée dans une section de 500 m du bras du nord de la lagune de Basin Head. On rapportait la présence de cette population dès 1960. Cependant, c'était seulement en 1980 que deux évaluations ont défini un lit de 160 000 m^2 et une biomasse de 127 à154 t. Vingt ans plus tard, la zone est estimée à 60 000 m^2 et à une biomasse de 46,8 t. Une réduction importante du couvert a été observée en 2003 et ce déclin s'est poursuivi jusqu'à ce que moins de 1 t de la biomasse ait été présente en 2008. Les transferts de *C. cripsus* à d'autres estuaires à l'Île-du-Prince-Édouard ont amélioré le taux de croissance comparativement aux frondes témoin dans Basin Head. Cela laisse supposer que les conditions d'élevage dans Basin Head étaient sous-optimales pour l'espèce. On a émis l'hypothèse selon laquelle l'eutrophisation du bassin au cours des 30 dernières années et le déclin de la qualité de l'eau étaient les raisons possibles expliquant la diminution de la population du *C. crispus*. La prolifération intensive d'*Ulva* spp. a lieu au début de l'été, et par la fin de l'été, la dégradation des tissus mène à des zones d'anoxie et de faible qualité de l'eau. On recommande la réalisation d'expériences de croissance dans la lagune pour mettre à l'essai cette hypothèse concernant la diminution de la biomasse du *C. crispus*.

INTRODUCTION

Basin Head is a shallow 59 hectare lagoon that has reached its present structure following significant geographical changes in the last 230 years (Sharp et al. 2003). During this time a unique population of *Chondrus crispus* Stackhouse (Irish Moss) developed in the northern arm of the Basin (Figure 1). *Chondrus crispus* is a red seaweed that is normally a component of the shallow subtidal and lower intertidal of rocky open coasts (Pringle and Mathieson 1986). It is commercially valuable for the extractive phycolloid carrageenan used as a food additive for viscosity control.

The special characters of the Basin Head population are frond morphology, reproductive stage and growing habit. The plant has broad flat fronds compared to narrow dichotomous branching fronds of the open coast (Figure 2).

Chondrus crispus has a triphasic life cycle and open coast types have three isomorphic macroscopic frond types: male, female and tetrasporic. The gametophyte phase and tetrasporic phases are normally in a 40:60 ratio of either phase. Basin Head has a population that is over 99% gametophytic and these fronds are rarely reproductive.

The open coast form is attached to the rocky substrate by an encrusting holdfast giving rise to a dense cluster of fronds. The Basin Head population exists on muddy bottom held in place by the weight and byssal threads of *Mytilus edulis,* the blue mussel. This population has not as yet been proven to be genetically distinct when compared to six other conspecific morphotypes (Chopin et al. 1996). Fronds are a dark red to brown colour throughout the year. Open coast forms change colour from red and purple in the winter to green and yellow in the mid to late summer.

The origins of this population are unknown; it may have been isolated as a result of the physical changes in the Basin in the past 230 years. Physical, chemical and biological conditions of the Basin could have selected for traits of the gametophyte life stage. While this population was known locally, it was not investigated until the 1970s with the interest in mariculture for the phycolloid carrageenan (Murchison 1977). Basin Head *Chondrus* was transferred to on-land tank culture and to a number of marine sites around PEI (McCurdy 1980; Craigie and Shacklock 1995; Judson et al. 1987; Chopin et al. 1999).

Basin Head became a candidate for Marine Protected Area status owing in part to this special marine plant population. A research program was initiated to provide up to date information on the status of the Basin in 1999 (Sharp et al. 2003). Subsequently a monitoring program was developed and operated with some variability between 2000 and 2008. During this time a significant decline in the *Chondrus* population was observed by direct and remote sensing techniques. This paper brings together information collected over 28 years on the status of the *Chondrus* bed and examines potential reasons for its decline.

METHODS

i) History 1979-1999

<u>Area and Cover</u>

McCurdy in 1980 calculated the total area of the Basin occupied by *Chondrus* by measuring the width of the northeast arm and in June surveyed 801 parallel transects one meter apart. On these transects, 372 randomly chosen pairs of coordinates were examined for presence or absence of *Chondrus* and other macrophytes in June. The proportion of positive to total observations was the cover index for the bed. A second survey of 240 transects in August used 189 coordinates to survey plant cover. A positive observation was defined as 100% cover as the criterion of *Chondrus* under the coordinate. The total water area of the arm measured by transects was multiplied by the cover index of *Chondrus* to calculate the area of the bed.

A similar survey was completed by Judson et al. (1987) but it was restricted to a 500 m section of the arm. Twenty-six transects were established across the bed and 102 coordinate points were observed for presence or absence with 100% cover as the criterion for a positive observation in July and August. The bed area was calculated as in McCurdy (1980) as a portion of the total water area of the arm.

A study completed in July and August 1999 examined 24 parallel transects in the arm spaced 25 m apart (Figure 3) (Sharp et al. 2003). At 5 m intervals on each transect, the cover of macrophytes was estimated within 1 m^2 quadrats. The area of the bed was assumed to be the portion of transects with a minimum of 10% *Chondrus* cover. The water surface of the arm was not calculated in 1999 but total area of the bed was based on an interpolation of cover between transects (Figure 3).

<u>Biomass</u>

A circular tube 30 cm deep with an area of 0.25 m^2 was used for sampling *Chondrus* biomass in 1980 (McCurdy 1980). It was pushed into the substrate only in positions where *Chondrus* cover was 100%. A total of 111 samples were taken, 76 from May to June and 35 were removed in mid August. All biomass was separated into *Chondrus* and non *Chondrus* material. The sample was washed and shaken then weighed to the nearest 1 g.

A similar sampling procedure was used by Judson et al. (1987). However, this sampling did not exclude areas that did not have 100% *Chondrus* cover. The sample was taken at the coordinate with a positive observation of *Chondrus* cover. However, the quadrat could also include some area that was not *Chondrus* cover. A total of 24 samples of biomass were taken on 24 transects.

Biomass was sampled with a steel box quadrat 50 cm by 50 cm by 50 cm deep in 1999 (Sharp et al. 2003). All plant biomass was removed by hand into a net bag, dewatered and separated into marine plant species and dominant fauna and wet weight for each species was recorded to the nearest 0.1 g. Twenty quadrats were placed within areas with a minimum of 10% *Chondrus* cover near the center of each transect.

In all the above studies, the total biomass was calculated as a multiple of the area in m^2 times the mean wet biomass m^{-2} of the bed.

ii) Recent Surveys 2000-2008

<u>Area and Cover</u>

A single Cessna airplane was the platform for aerial photography from 2000 to 2008 with the exception of 2001. In 2001, a remote camera was tethered to a weather balloon but problems controlling the balloon led to its failure to produce reliable photos.

The plane flew in a series of overlapping spiral loops over the Basin Head estuary. This allowed photographs to be taken almost perpendicular to the land below. It also allowed the photos to be taken from the plane at a low ground speed to reduce motion blur. Photos were taken from a height of 150 and 300 m in the early spring before the growth of (sea lettuce) *Ulva*, *Entromorpha, Chadophora* and (eel grass) *Zostera* obscured the *Chondrus* bed (Table 1). At that time, the *Chondrus* usually stands out from the sand mud bottom as dark brown to purple patches in the mussel beds to which they are attached.

The photos were processed in Photoshop©; the series of photos of the seaweed bed were placed in layers on a map outline of the Basin. Since most of the photos were taken on an oblique angle, each one was aligned to the map by digitally distorting the layer to fit the shoreline on the map. The *Chondrus* cover was selected from the image and was placed on a separate layer with a distance scale. This layer was desaturated (made into a black and white image) and saved as a JPEG file. It was opened in an image analysis program (ImageJ©) and the area was calculated with the imbedded routine.

After 2005, the validity of the assumptions regarding identification of *Chondrus* in the air photos. A resurvey of the original 24 transects that were within the portion of the bed that was sampled in all four years assessed cover every 5 m. A second series of ground truth efforts began in 2006 with underwater photo transects (Table 2). A lead line marked at 5 m intervals was stretched across the arm and the diver took still photographs at each mark. These photos and positions were compared to the same location on the air photo to test the assumptions of the earlier interpretation.

The survey of macrophyte cover on seven transects established in 1999 (#s 16-22) was repeated in July/August 2008 to further ground truth air photos.

<u>Biomass</u>

Once researchers were aware the cover of the bed had changed between 2000 and 2005, a re-sampling was necessary but the biomass remaining needed conservation. The bed was resampled in 2006 using the same methods as in 1999, but only 13 samples were removed from the bed to conserve the remaining stock.

Comparisons of biomass densities between 1980, 1987, 1999 and 2007 were restricted to those samples that were on transects that traversed the portion of the bed that was common to all four years.

<u>Condition Indices and Photography</u>

Over the history of the study, underwater photography has been a cornerstone of the program. Prior to detection of a specific problem with *Chondrus* in the Basin, it was used primarily to document methods, general habitat and illustrations for reports. These photos were examined first to ground truth air photos and second to evaluate the condition of *Chondrus* clumps and fronds.

A condition index was developed in 2008 in conjunction with digital pictures of *Chondrus* fronds. Fifteen to twenty fronds were haphazardly removed from the substrate in May, June, July and August from the substrate and placed on a photo grid where one digital picture was taken prior to evaluation of condition. The condition index consisted of evaluation of grazing damage, tissue erosion or necrosisn and new growth on a scale of 1 to 10. Colour, epiphytes and faunal biofouling was evaluated descriptively or by presence or absence observations.

Growth

Over the last 28 years there have been three major transfers of Basin Head *Chondrus* to other environments. It was used as an inoculum in intensive tank culture systems at the National Research Council Laboratory in Nova Scotia. Air agitated tank culture of *Chondrus* was established as a method of aquaculture for this species in the 1970s (Craigie and Shacklock 1995). However, the tetrasporophyte produced from the gametophytic generation of Basin Head *Chondrus* was used and not the original plants because there was a requirement for lambda carrageenan, a component of tetrasporophytes.

The two other experimental transfers occurred 20 years apart in 1987 (McCurdy 1980) and in 1997 (Chopin et al. 1999). Transfers in both of these studies were of whole fronds tied to a metal screen anchoring individual fronds to the bottom. In 1980, the screen area was 0.2 m^2 and each screen held 8 plants versus 0.25 m^2 and 10 plants in 1996. The 1980 study compared the growth of Basin Head *Chondrus* with both open coast types and a special aquacultured strain T4. Plants were cleaned of epiphytes, fauna and drained wet weight recorded to 0.1 g. Basin Head fronds were transferred to 16 sites in eastern PEI estuaries and lagoons during the 1980 study. In 1996, seven estuarine sites were chosen in western PEI for out planting. Each study included deployment of control screens in Basin Head near the location of the main bed.

There were only two measurement periods in 1980: July 9 to August 6 and August 6 to 27. The 1996 transfers began in May and were monitored at most sites to the end of October at biweekly to monthly intervals. Growth of the control in the Basin was monitored until July 1997.

To investigate the cause of the decline in the Basin Head *Chondrus* bed the controlled experiment of 1996/97 was repeated in 2006. Twenty-eight fronds were tagged, weighed to within 0.1 g, placed on vinyl wire screening and anchored in the area of the established bed. The experiment began on June 20 and plants were re-measured July 4, July 19, August 2 and August 14.

The success of the 1996/97 transfers led to the development of a full scale grow out technique using mussel socking and two pilot farms were established at Freeland and Murray River, PEI. The procedures on the pilot farms were dramatically different from the simple transfer experiments. Plants were chopped into fragments either greater or less than 10 cm maximum dimension. The two fragment sizes were loaded into separate 2 m mussel socks at 500 g per sock. A minimum of 30 socks were used for each treatment. The socks were hung on longlines in the water column or placed on ground lines (Figure 4). The socks were inoculated in early July and re-weighed at the end of July and the end of August after spinning to remove excess water. Inoculum was held over the winter and re-socked and compared to material freshly transferred and chopped from the Basin.

RESULTS

Area and Cover

From the earliest comprehensive study of *Chondrus* distribution in the Basin, the main concentration of biomass was in a restricted portion of the northeast arm (Figure 5). *Chondrus crispus* has been observed in the main basin but only as isolated clumps. Each survey has defined the limits of the bed by presence or absence on transects or by direct interpretation of air photos. The 1980 survey described a bed that occupied 800 m of the arm (Figure 5). The

Judson et al. (1987) survey only seven years later defined the bed in 500 m of the arm, but this was due to their concentration on the harvestable biomass only. Our surveys between 1999 and 2008 estimated the total length of the bed was 600 m, overlapping both the 1980 and 1987 surveys (Figure 5). It is not clear why the bed defined by Judson et al. (1987) was determined to be much smaller than other surveys. However, this survey was the preparation for a significant harvest and therefore was likely only concerned with the part of the bed with the greatest cover and a high density of biomass rather than its maximum extent.

The overall trend in the area of the bed since 1980 has been a decline but there was little change in the estimates of area between 1987 and 1999 despite the difference in lineal measurement (Figure 6). After 1999, there was a steady decline in area and cover. Until 2000, surveys depended on transverse transects across the arm for estimation of cover using the point intercept method. The degree of error depended to a large degree on the number of transects. The water area of the arm occupied by the *Chondrus* bed was derived from length and width measurements. This calculation could be impacted by tidal level but this was not defined by McCurdy (1980). Aerial photography improved both the calculation of total arm area and the determination of cover. This method was very effective when the bed was coalesced and had a high density of biomass. However, as the bed became more diffuse after 2004 it was more and more difficult to differentiate the *Chondrus* clumps from clumps of mussels or wood debris, as both appeared as dark blue or black in colour. The cover estimate was a direct ratio of the area of the arm at the low tide mark (section established in 2000) (Figure 5) and the interpreted cover of *Chondrus*. Relative to this bench mark cover was directly related to the area of the bed (Figure 6).

The differences in *Chondrus* cover between 2000 and 2002 suggested that the distribution within the northeast arm was dynamic. A minority of clumps or patches of the bed were stable from year to year (Figure 7). Between 2000 and 2002, an area opened up in the central area of the bed. This open area became enlarged in 2003 and was essentially devoid of *Chondrus* clumps by 2005 (Figure 7). The interpretation of air photos was becoming more difficult by 2005 and this data was reinterpreted after ground truthing efforts of 2005/06. The resurvey of all 24 transects in 2005 confirmed that the center section of the bed was limited to a few patches of *Chondrus* compared to the previous contiguous cover (Figure 8) The photo of 2006 fully confirmed the loss of this section of the bed. It was noted that a diffuse new region of the bed appeared in 2004 to the east of Foul Bay. This was an area considered part of the original bed described in 1980 and 1987. However, by 2006, this new area was gone and the bed was largely concentrated in a 200 m section of the arm to the west of Foul Bay (Figure 7).

An additional comparison of cover was possible between 1999 and 2007 on seven selected transects (Figure 9). These transects cross the only area of significant *Chondrus* concentrations in 2007. In general *Chondrus* was patchier and lower in cover on these seven transects compared to 1999 (Figure 9).

Cover was an indication of abundance, but there was some difficulty in interpreting cover as measured on individual transects in terms of the calculation of total biomass for the bed. The cover on these seven transects crossing the densest part of the bed based on point intercept were 0.21 and 0.29 in 1999 and 2007, respectively. Considering the overall change in area of the bed it was a surprising result. The explanation was in the change of clump size over time; *Chondrus* may cover the bottom but the individual clumps are smaller. Photographs of clumps from these two years illustrated the diminished size and biomass (Figure 10). *Chondrus crispus* clumps in 1996-1999 were up to 30 cm high and usually were the coalescence of several clumps one on top of the other to the point where they smothered the bottom and created their own anoxic sediment footprint. By 2006, these clumps were less than 15 cm high and mussels were easily seen holding this residual biomass together.

Biomass

The biomass density was not significantly different between 1980 and 1999 from transects across the same region of the bed (Figure 11).

All studies sited used biased selection for positive *Chondrus* cover. Selection of biomass samples in the 1987 survey stands out as resulting in very skewed distribution of biomass samples above 1000 g (Figure 12).

The concentration of the 1987 survey in the densest part of the bed (the highest cover index 31%) more so than any other survey may have resulted in much higher biomass values than surveys using a broader definition of the bed limits as in 1999 and 1980.

The maximum estimated biomass of the bed was 154 t in June 1980 and was supported by a second estimate of 127 t in August 1980 (Figure 13).

The total bed area in 1987 was lower than in 1980, but the total biomass was similar to 1980 due to a much higher average biomass density 10622 $\pm$ 756 g m^{-2} in 1987 versus 7500 $\pm$ 1400 g m^{-2} in 1980 (Figure 13). The drop in estimated total biomass in 1999 was due to a significant reduction in the bed area from that determined in 1980 (Figure 6). Subsequent estimates of the total biomass until 2005 utilized the same biomass density values as in 1999; thus the perceived reduction in total biomass was directly related to the change in total area. It was not until 2006 that re-sampling the same regions of the bed updated the estimate of average biomass and the combination of area reduction and significantly lower biomass density fully described the reduction in total biomass to slightly over 1 t in 2008 (Figure 13).

Condition of *Chondrus*

The morphology of *Chondrus crispus* as discussed in the introduction is very plastic. Early descriptions of the Basin Head strain defined three types of morphology: spriggy, narrow branches with numerous apices forming ball like clumps; foliose, wide thick thalli with few apices; normal, broad thalli, numerous apices, rubbery texture (McCurdy 1980). These plants were in general described as healthy with little evidence of grazing and few epiphytes.

The photos of clumps in the densest part of the bed in 1996 have all the characteristics of healthy Basin Head *Chondrus* (Figure 14). Plants of the “normal” type have a smooth surface and rounded tips with dark red colour. The fronds photographed in 2008 were more similar to the “spriggy” type but also had eroding edges and broken edges (Figure 14).

Prior to 1999, several hundred kilograms of Basin Head *Chondrus* were transferred to five locations in PEI. In all locations where growth was positive, the plant changed morphology to more the spriggy type or closer to the open water morphology yet was still larger and broader (Figure 15).

We began to note a change in the “healthy” state of Basin Head *Chondrus* in the spring of 2005. Plants had a ragged appearance that at first appeared to be grazing damage. Large dense clumps were less abundant and in some areas of the bed there was only small residual clumps attached to mussels (Figure 16).

The tips of fronds were eroded and there were very few and small apices (Figure 17). The basal portion of the plant appeared unchanged but there were few broad rounded apices.

Necrosis was not clearly defined and degrading, white or rotting tissues were not observed. The index of erosion was slightly higher in the beginning of the summer (Figure 18). The grazing index was similarly slightly less in August (Figure 19).

Incidence of epiphytes increased during the summer as did the number of fronds with bryozoan cover.

The major problem with indices was the lack of any previous data for comparison. They do not demonstrate any degradation over the summer. The abundance of new apices or in general signs of growth averaged 4.5, 6 and 6 out of 10 in June, July and August, respectively. This does not describe the quality of the growth; whether the apices are broad or narrow. However photographic records of apices are generally of small and narrow blades (Figure 20).

McCurdy (1980) noted that Basin Head plants planted on screens for transfer to other locations and on control screens in the Basin had apices with a ragged appearance and suggested that net growth was slow due to fragmentation at this time. Unfortunately there were no pictures available of these plants.

Growth

Fronds transferred in 1980 grew well during the July growth period at most sites but in general did poorly in the August growth period. The growth rates of Basin Head *Chondrus* outside of the Basin were higher than in the Basin (Figure 21). When comparing the growth rate during the June/July period, at all the grow out sites, the lowest growth per day occurred in the control fronds in Basin Head 1980 experiments.

Basin Head *Chondrus* transplants in 1996/97 were monitored for longer periods and more frequently than the earlier experiments (Chopin et al. 1999; McCurdy 1980). Plants grown on screens in the region of the arm starting in May 1996 until July 1997 grew at or above 1% during the first year peaking in the September to October 1996 period (Figure 22). Over the winter, growth dropped and did not recover in 1997. This decline may be related to plant size (Figure 22). Plants may have begun to fragment over 400 g and these tissues were lost in the summer.

In comparison, plants out planted in Freeland, a very open environment within Malpeque Bay, grew at or near 2% per day with the exception of the end of August (Figure 23). The morphology of these plants was much different than those maintained in Basin Head. New apices were narrower and more abundant than on the broad Basin Head form (Figure 15). Freeland out plants reached a maximum of 195 g, less than half the maximum size in Basin Head. The frond growth was increasing in the last growth period, September 9 to October 31, similar to those in the Basin (Figure 23).

In 2007, out plants at Basin Head did not grow in size over the experiment. Fronds had a growth rate in wet weight of less than 1% d^{-1} until the late July peak then the rate rapidly declined in August (Figure 24). While this decline was not observed in 1996/97 it was consistent with the poor August growth in the 1980 study (McCurdy 1980). Fronds were eroding and fragmenting during August 2007.

The procedures used to grow out *Chondrus* in a farm setting were dissimilar to the screens but yielded some relevant information. When plants were cut to place in socks, two sizes of fragments were chosen. The larger plant fragments (>10 cm) grew at a higher rate than the smaller fragments (< 10 cm) through June and July (Figure 25). The smaller fragments had more of the tissue cut per unit weight and, therefore, required more tissue repair prior to producing apices. The larger plant retained more undamaged apices and, therefore, grew more rapidly. A similar result occurred when socks were restocked with new and old (1 year) inocula. The old inoculum was not cut but just reloaded in the socks at the required density. The new material had been recently cut into fragments and required repair of tissues prior to re-growth (Figure 26).

This relates to the natural situation in the Basin where sources of erosion, breakage or grazing of tissue require recovery prior to initiation of apices. If frond apical erosion increased then the productive capacity of the individual fronds would remain suppressed.

DISCUSSION

Differences in methods, purpose and assumptions among studies spanning 28 years impacted on the ability to make conclusions regarding the changes in the Basin Head *Chondrus* bed. The apparent decline in the estimated area of the bed estimated between 1980 and 1987 could have been the result of the different assumptions employed regarding the limits of the bed in the arm in these two studies. The 1980 study had clear evidence of *Chondrus* biomass from parallel transects to set the limits to the bed. The 1987 survey had a much different goal, to outline an area for a significant commercial harvest. Therefore, the survey was restricted to the area most likely to be economically viable for harvest. The 1999 estimate of the area was similar to the value calculated in 1987. It was dependant on the limits set by transects with interpolation between transects. If we accept our calculation of 46.8 t for total biomass in 2000, there was a 50% reduction from 1987 estimates and a 65% reduction from 1980. It is reasonable to assume the negative environmental conditions in this habitat were prevailing for at least 28 years. Therefore, the bed biomass was most likely in decline when it was assessed in 1999. After the 1987 harvest, 78 t of residual biomass was left to recover over 12 years and it did not. The decline in cover and total biomass for the past 9 years was more rapid suggesting that when we first started monitoring this bed it was already well into a decline.

The change in the patchiness of the bed between 2000 and 2002 was at first attributed to annual dispersion or aggregation of clumps plus growth of biomass in new parts of the bed. A macrophyte that is not attached to the bottom is essentially “drift” seaweed. It is expected that fronds will fragment upon reaching a maximum size. As well, clumps of fronds once reaching a critical size are susceptible to movement by tidal currents and wind events. During ice break up large sections of the bed could be displaced. As we observed the basin over several years we found clumps of *Chondrus* in areas to the east and west of the main bed that seemed to support this dynamic movement.

The first observation of major changes in the bed in the spring of 2005 followed the storm surge event of the fall 2004. This event caused significant damage to the ocean entrance to the Basin, destroying some of the adjacent dune structure and the protective wharves. It was a flushing event in the Basin raising the water level throughout the Basin and increasing the water circulation in the arm over the short term. Although we expected some dispersion of the bed from this event, we anticipated a recovery over the next year or two but we were proven wrong.

The drop in abundance or lack of recovery of biomass was not due to a single factor but the effects of episodic or cumulative anthropogenic environmental factors. Since there were no observations of environmental health between 1980 and 1999, we can only infer changes from trends in the rest of PEI estuaries and watersheds. The primary change was the continual increment of nutrient loading of the watersheds and the steady increase of nitrates in streams and brooks feeding the estuaries (Raymond et al. 2002). The nitrate levels implicated in observations of anoxia were usually above 0.4 mg l^{-1} (opp cit). In 1999, nitrate was above 1.0 mg l^{-1} at the head of the Basin where there was the major input of freshwater from the watershed; this has continued to be the dominant source of nitrogen (Sharp et al. 2003). Phosphate levels were highest (>0.2 mg l^{-1}) at the head of the northeastern arm where annually there is a major degradation of accumulated green algal tissue. Ammonium levels increase above 5 uM at the end of summer and act as another N source for green algae capable of pulse uptake.

The watershed of the Basin was and is now utilized primarily by agriculture. During this period, a potato processing facility was developed adjacent to the main freshwater stream for the Basin. This facility may have added some process wash water with residual agrichemicals periodically into the Basin. More importantly, with its development, the assimilative capacity of the marsh at the head of the Basin was reduced by infilling adjacent to the stream. The Fisheries Museum was developed in this era and its use increased during the 1990s. Sewage loading from the museum was reduced in recent years by tank storage and regular pump out for remote dumping. There were increasing episodes of unpredictable high fecal counts in the Basin until it was permanently closed to shellfish harvesting (Chris Craig, Environment Canada, pers. comm.).

The very high nutrient loading of the Basin waters is expressed in the colour of *Chondrus*. In the Basin, *Chondrus* has a very dark red to purple colouring throughout the year. This colouration is a function of the amount of stored nutrients N and P, which were two to three times greater in the Basin plants than in plants that were transferred out of the Basin (Chopin et al. 1999). The total P in tissue quickly dropped in all the new environments, while it was maintained at high levels throughout the summer in the Basin. Tissue nitrogen dropped in the Basin plants by 50% between May and June, but levels in fronds transplanted to Freeland were 80% lower over this period. In an open water population of *Chondrus,* it is a normal cycle for tissue nutrients to become depleted in summer as ambient nutrients decline. The colour of these plants transforms from red to yellow and green where the plant is fully exposed to sunlight. Growth declines by the end of June but recovers in the fall when nutrients increase in coastal waters (Sharp 1987). The nutrients in the Basin waters do not drop significantly over the summer and the decline in August growth may due to increasing stress from other factors. Water temperatures reach their maximum during August and may exceed physiological limits for the species.

Our hypothesis is that the cumulative effects of inputs of nutrients and perhaps agrichemicals into the Basin with subsequent annual green algal blooms and low water quality are the fundamental reason for the decline of this special population. The degree of negative impacts of algal blooms in the basin on water quality depend on the flushing of both whole living fronds or fragments and the degradation products soluble and particulate from the system. When we examined the Basin every spring, it appeared it had flushed itself of green algal mats. However, the head of the arm and to a lesser extent the head of the main basin was a dead zone, with very organic sediments and a water column that was anoxic every year. *Ulva* growth exploded in the spring exceeding 50% per day and the biomass peaked by July in most years followed by degradation in August to September. Recent data suggest that the production of *Ulva* has increased in the main basin of the lagoon later in the summer, and it has become an attached population in the arm (Sharp et al. 2008). Since the Basin requires from one to six days for turnover it is not surprising that the water quality can become very poor. At low tide, during periods of slow flushing, water temperatures can become elevated. As well, strong rain events during this time will reduce salinity significantly. Slow flushing would also contribute to low oxygen levels particularly when *Ulva* spp. are degrading in the Basin late in the summer (Sharp et al. 2003). The lack of growth of *Chondrus* in the Basin during August in the 1980 study may point to a seasonal cycle of very poor conditions in the Basin even 28 years ago.

Further evidence of poor environmental quality was that Basin Head *Chondrus* grew better in environments outside of the lagoon with few exceptions in all years of out planting. The environments ranged from lagoons similar to Basin Head such as South Lake to more oceanic environments like Freeland in Malpeque Bay. It is possible that this could be due to changes in morphology that accelerate growth rates. In “normal” *Chondrus crispus* dichotomous branching is typical and as the plant develops the number of apices increase exponentially with the number of dichotomies (Sharp 1987). The growth form of Basin Head *Chondrus,* while basically dichotomous, has such broad branching that the growth potential is less than open ocean fronds. When removed from the Basin Head environment, highly dichotomous branching develops and contributes to the potential for increased growth rates compared to the Basin. This has been confirmed and described as placing more of the biomass into a higher per unit surface morphology (Kubler and Dudgeon 1997). However, there were a range of morphological types in the Basin some with more dichotomization than others. It would be anticipated that the spriggy type would dominate if morphology was the only issue in promotion of growth rate. The increased dichotomization is a growth response to more optimal conditions.

Ulva/Enteromorpha blooms are both an indication of eutrophication and a potential negative physical factor. Increasing turbidity in the Basin as an indirect result of *Ulva* blooms could reduce the growth rate of *Chondrus* by reducing light levels. However, *Chondrus* does survive in shaded under stories of other macrophytes. The very shallow waters in the arm of the Basin (less than 1 m) are unlikely to limit the growth rate at the photo flux density of optimal light conditions at 70 $uEm^{-2}s^{-1}$. Limited periods of low light may occur after rain events on the watershed cause increased suspended solids in the lagoon. However, the area of the bed is on normal low tides less than 40 cm deep and the plants may even reach the surface on extreme tides. Light levels in the arm of the Basin were 1.5 to 4 times higher than four other estuarine sites in eastern PEI in 1980 (McCurdy 1980). There is an unknown issue of whether the settlement of organic sediments on fronds will reduce the ability to exchange metabolites or nutrients.

The Basin Head lagoon has steadily increasing water temperature during the summer rising to over 20ºC by July, sub optimal temperatures for *Chondrus*. *Chondrus crispus* can grow and survive in a wide range of temperatures but reaches an optimum between 10 and 15ºC at 3% per day (Fortes and Lüning 1980). It can maintain 1% d^{-1} growth at 25ºC; however, the Basin temperatures can reach 28ºC in late August. Sustained maximum temperature that can be survived for two weeks by open coast *Chondrus* plants was 27ºC (Lüning et al. 1986). The Basin Head strain has survived for decades in this environment but temperatures in the Gulf of St. Lawrence have on average increased in recent years (J. Chasse, Department of Fisheries and Oceans, pers. comm.). This is the input water for the Basin and normally the major cooling factor for the basin (Sharp et al. 2003).

At the minimum end of the temperature spectrum, *Chondrus* is a perennial and survives exposed to winter water temperatures. Intertidally it can be frozen in severe weather events but then there can be damage to plasma membrane as it is essentially a sub tidal species (Dudgeon et al. 1990). Winter bleaching of fronds and necrosis of tissue has been observed within its normal range when exposed during the low tide to temperature of -20ºC. Normally the

Basin Head *Chondrus* bed is not exposed to freezing temperatures and the currents prevent total freezing of this part of the Basin.

High levels of freshwater inflow can reduce the salinity at some stations to 9 ppt during the summer. While *Chondrus* can tolerate a wide range of salinities (10 - 58 ppt), its optimal growth occurs around 30 ppt (Craigie and Shacklock 1995). Growth rate is reduced by 75% in lower salinities (Laycock et al. 1981). Salinities in the *Chondrus* bed vary with the state of the tide, flushing rates and freshwater drainage from the watershed. Over a tidal cycle, the salinity normally ranges from 30 ppt to 15 ppt (Sharp et al. 2003).

In Basin Head, *Chondrus* is under environmental stresses and is more susceptible to diseases and parasites. Knowledge of infectious diseases of *Chondrus* is derived largely from tank cultivation of stains. A green spot or green rot disease was described from tank culture causing holes in mature parts of plants (Craigie and Correa 1996). A pathogenic strain of bacteria were isolated from healthy fronds and found in necrotic tissue. We have not observed the development of holes similar to these in mature portions of Basin Head *Chondrus*. Holes could heal or lead to fragmentation of the frond.

Acrochaete operculata a green algal pathogen is virulent in the sporophytic generation but the gametophyte is resistant (Bouarab et al. 2001). The Basin Head strain is largely gamethophytic and therefore resistant.

The fungal parasite *Petersenia pollagaster* selectively destroys frond apices and could create the jagged edges of non apical tissues observed in fronds from Basin Head (Craigie and Shacklock 1995). We have not observed the early stages of this parasite when necrotic tissue would appear at the tips of the plants. However, since our work is largely a spring summer sampling season this process may occur earlier in the year. We have not examined the plant for these parasites or pathogens. Two transplants of material to tank culture in 2007/08 are exhibiting good productivity and healthy fronds.

In conclusion, *Chondrus crispus* in Basin Head has been living in conditions that are suboptimal for growth and at times for survival since the 1980s. A decline in any critical environmental variable parameter either episodically or cumulatively could have caused the productivity of the plant to decline further in the last nine years. This theory should be tested with strategic out planting of healthy Basin Head Strain *Chondrus* in the lagoon at different times of year and locations to determine the critical stress factors for its survival in the Basin.

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TABLES

Table 1. Series and dates of aerial photography used to map the Chondrus crispus bed of Basin Head 2000-2008.

Year	Month	Platform	Date
2000	May	Plane	May 17, 2000 3pm
2001	June	Balloon	
2002	May	Plane	May 25, 2002 3pm
2003	May	Plane	May 31, 2003 5pm
2004	May	Plane	May 17, 2004 3pm
2005	May	Plane	May 10, 2005 5pm
2006	March	Plane	March 29, 2006 4pm
2007	March	Plane	April 29, 2007 4pm
2008	April	Plane	April 17, 2008 1pm

Table 2. Dates of photo transects and transects numbers from the 1999 Chondrus crispus survey.

Year	Date	Transect numbers
2006	April 4	9, 17, 22
2006	June 13-14	9, 16,18,21,22,23
2007	Dec 5	9, 17, 22
2008	March 12	9
2008	April 30	9,11,14,15,16,17,18,20,21,21,22
2008	July 3	2,17,22

FIGURES

Figure 1. Location of the Chondrus crispus bed in the central part of the north eastern arm of Basin Head Lagoon.

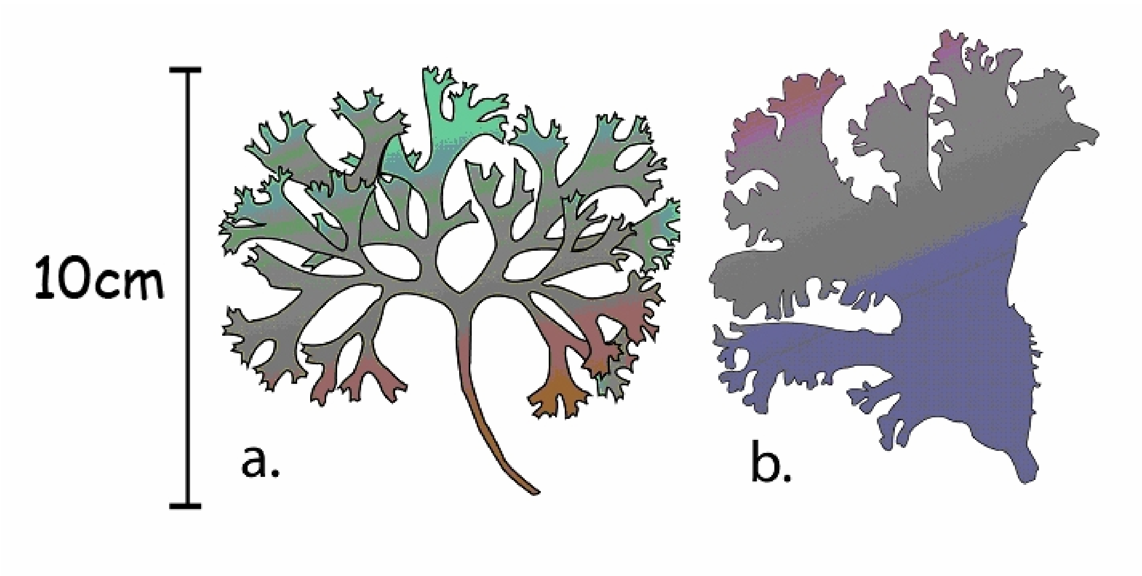

Figure 2. The morphology of Chondrus crispus at Basin Head (PEI).. a. open water form, b. Basin Head strain.

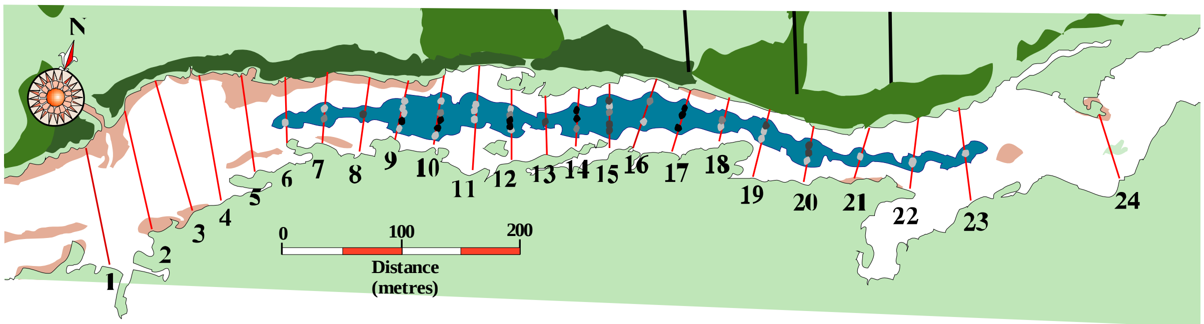

Figure 3. Location of the 24 survey transects in the 1999 survey of the Chondrus bed.

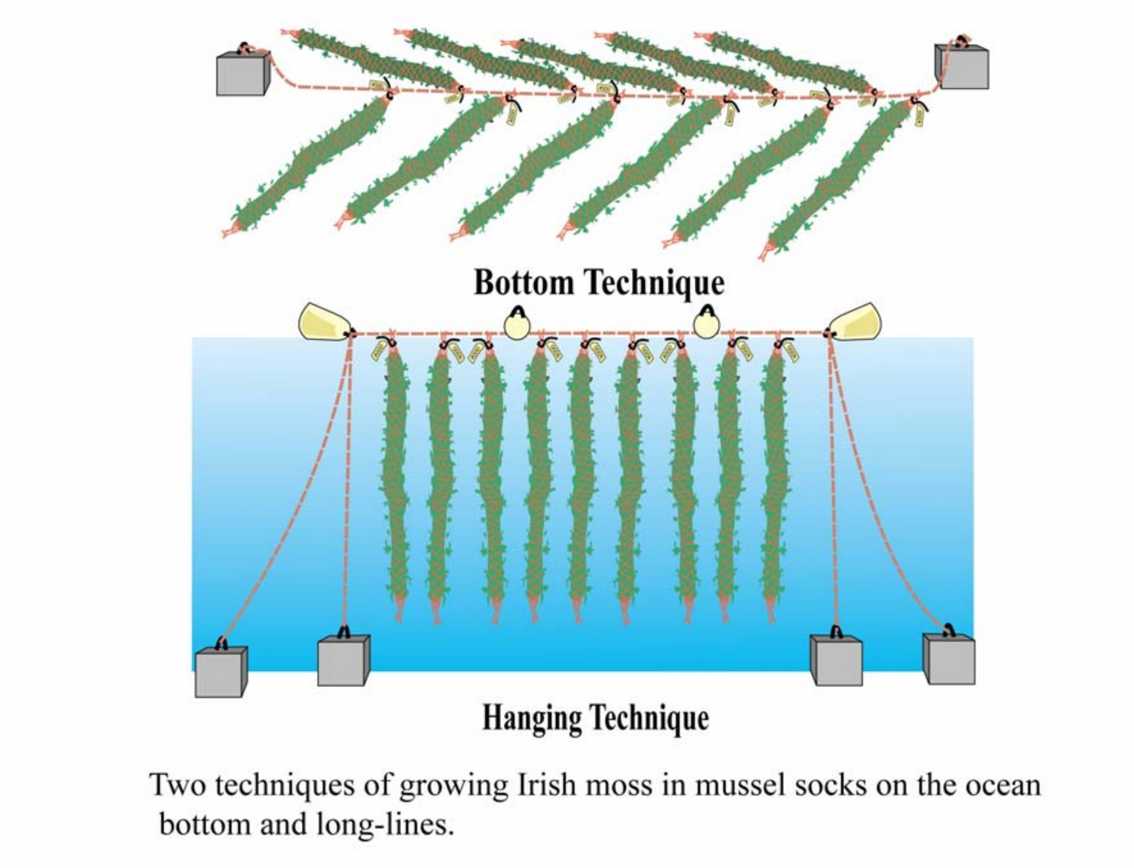

Figure 4. Methods of Chondrus crispus aquaculture using long line techniques.

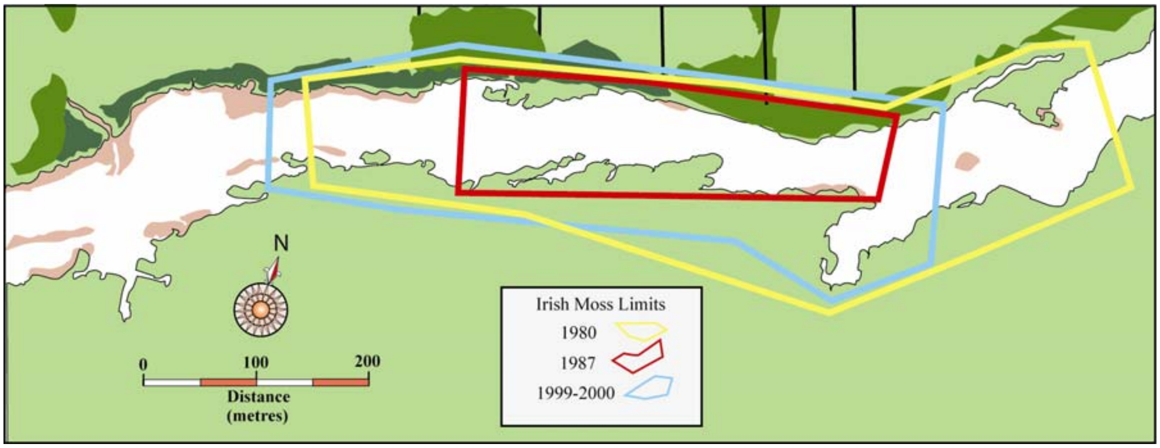

Figure 5. The limits of the Basin Head Chondrus bed as defined by McCurdy (1980), Judson et al. (1987), Sharp et al. (2003).

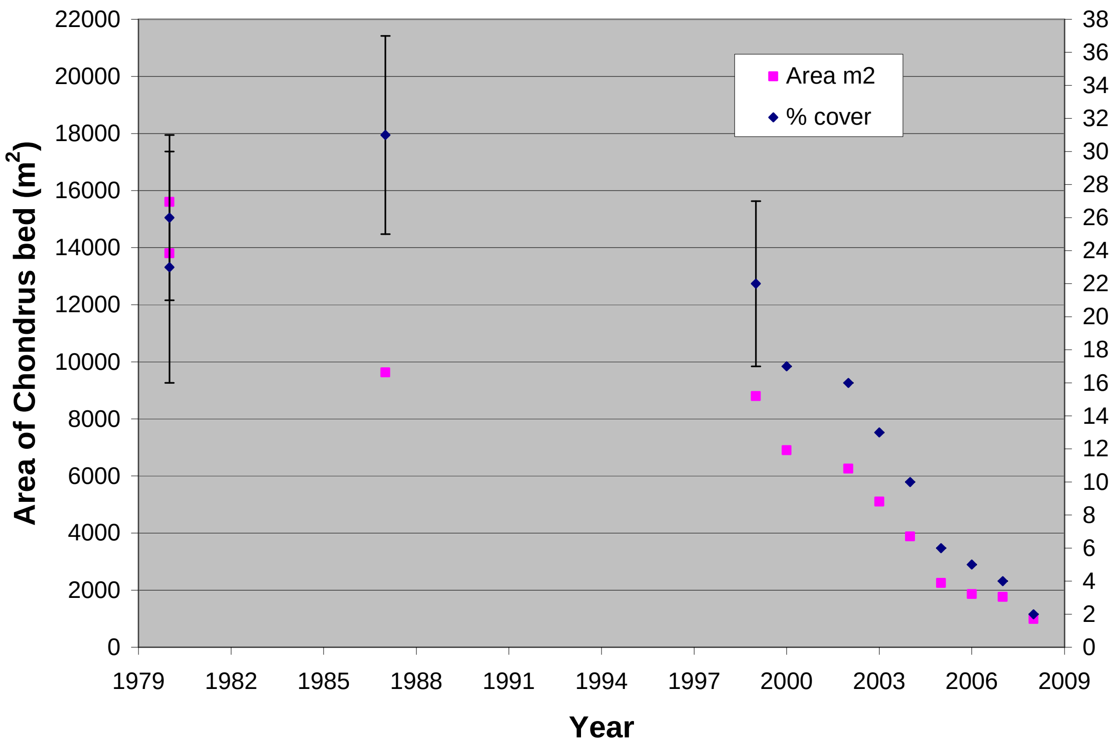

Figure 6. The area and cover of the Chondrus crispus bed in Basin Head, 1980 – 2008.

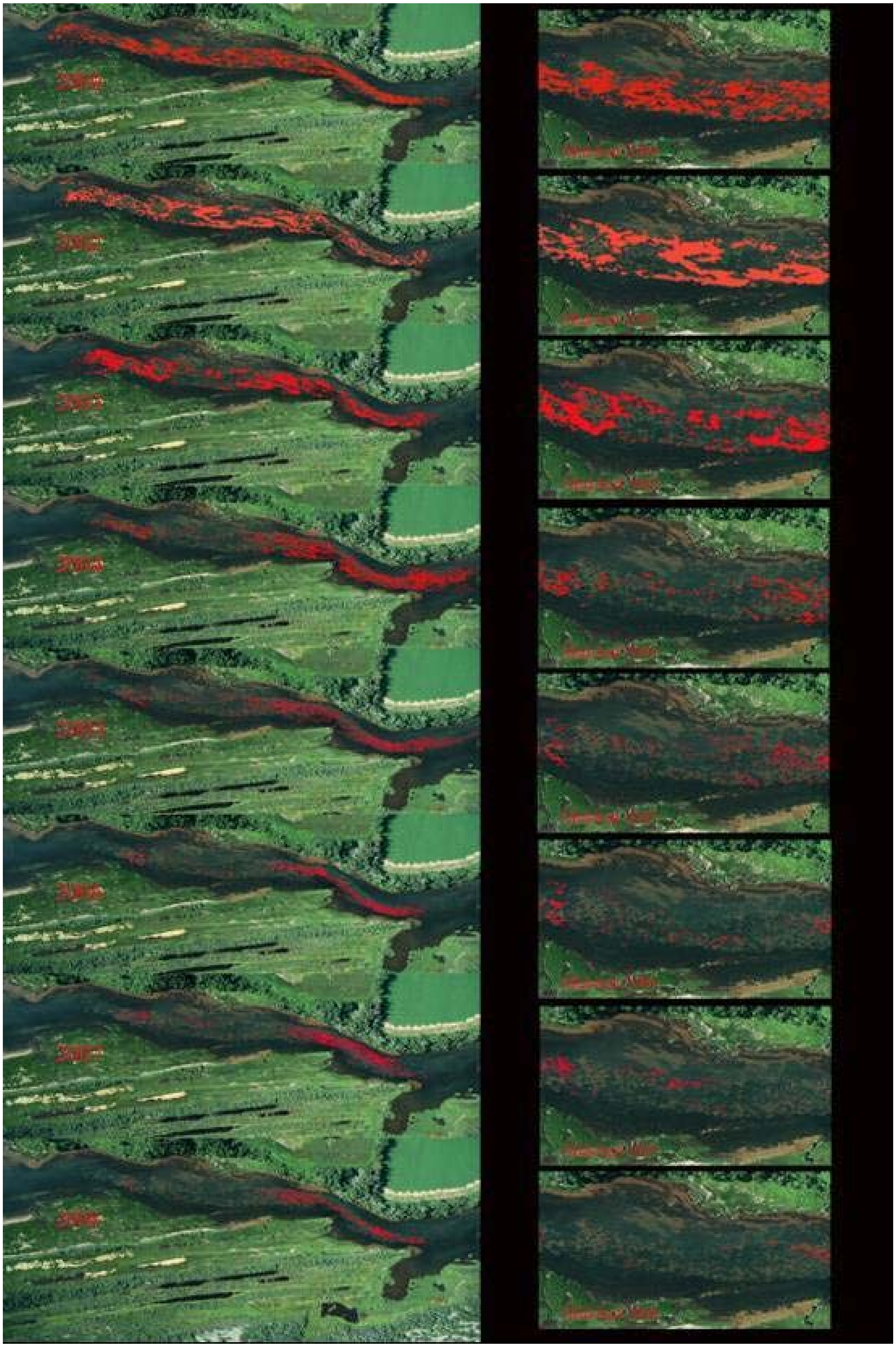

Figure 7. Air photo interpretation of Chondrus crispus (red) cover 2000-2008, insert enlargement of the central section of the bed in Basin Head.

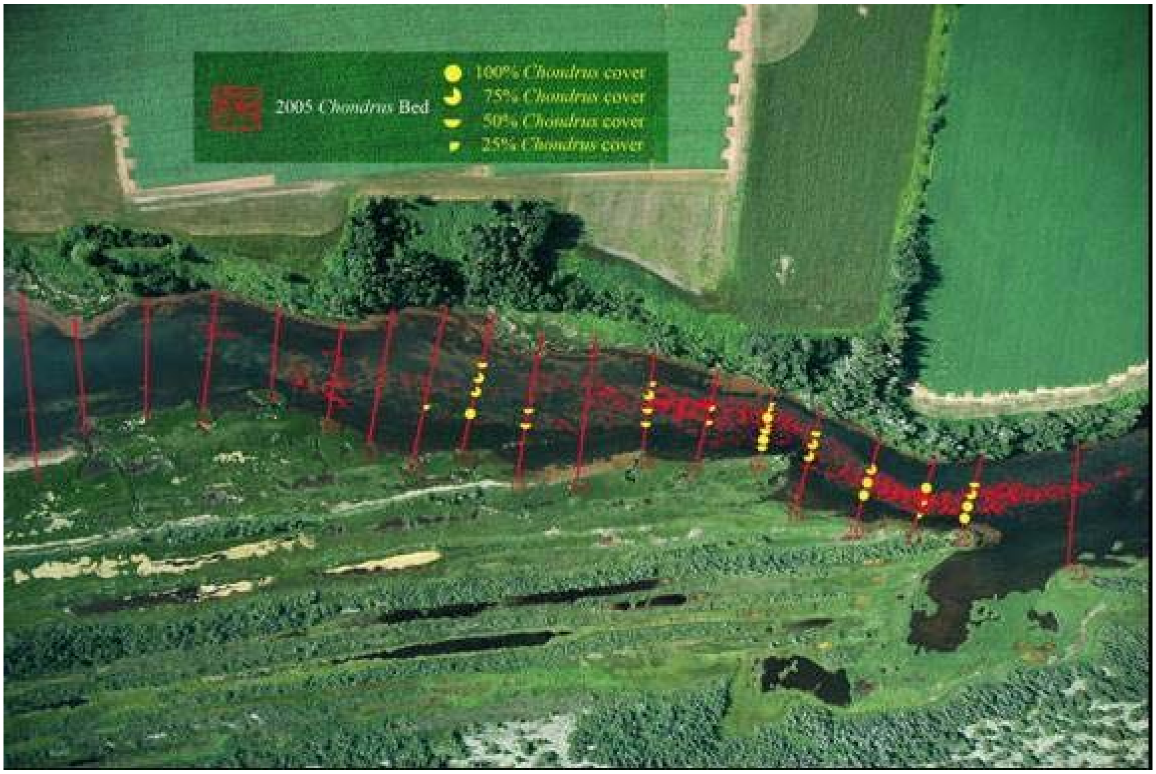

Figure 8. Ground-truth results from July 2005 resurvey of 24 original 1999 transects of positive observations of Chondrus crispus cover.

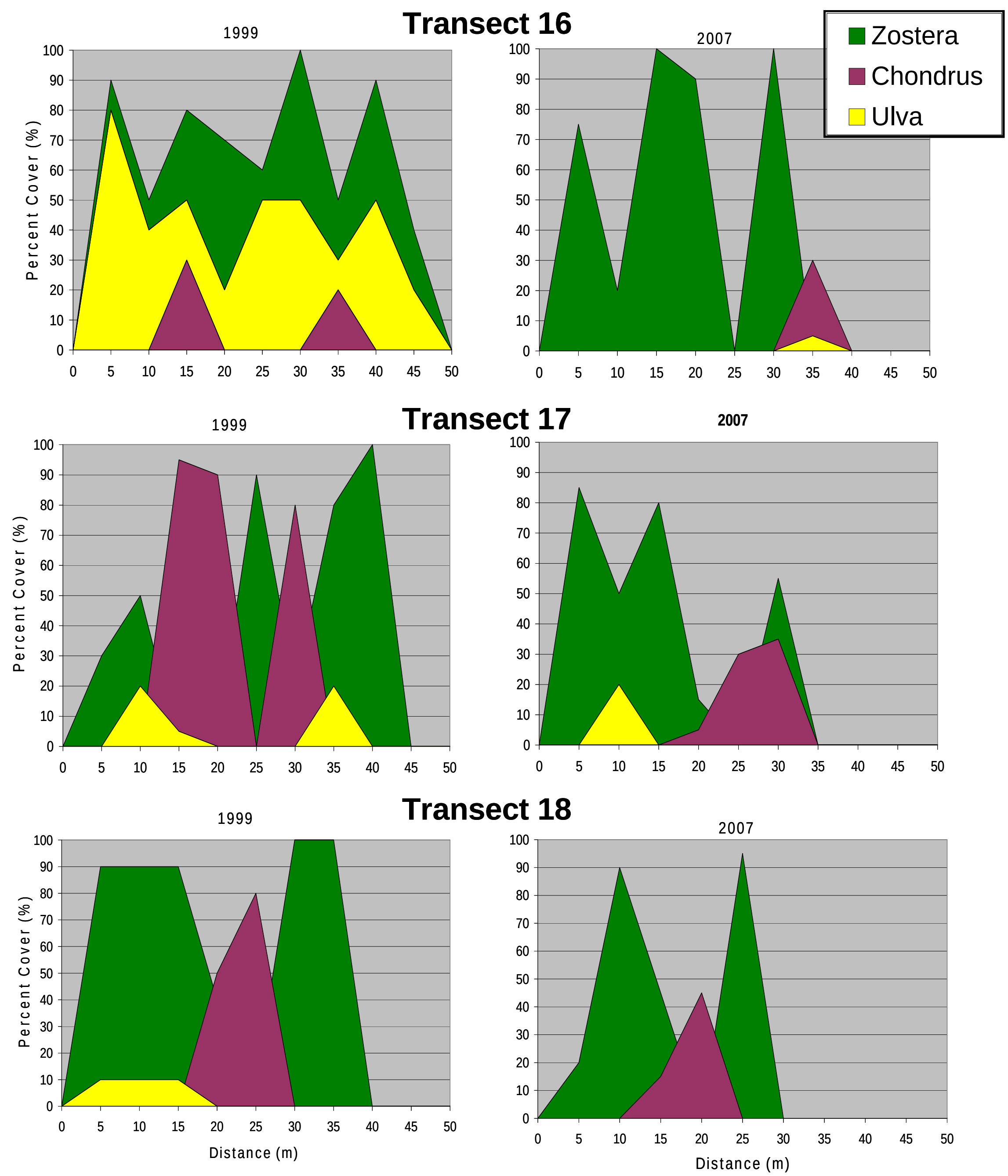

Figure 9. Macrophyte cover on seven transects surveyed in 1999 and resurveyed in 2007.

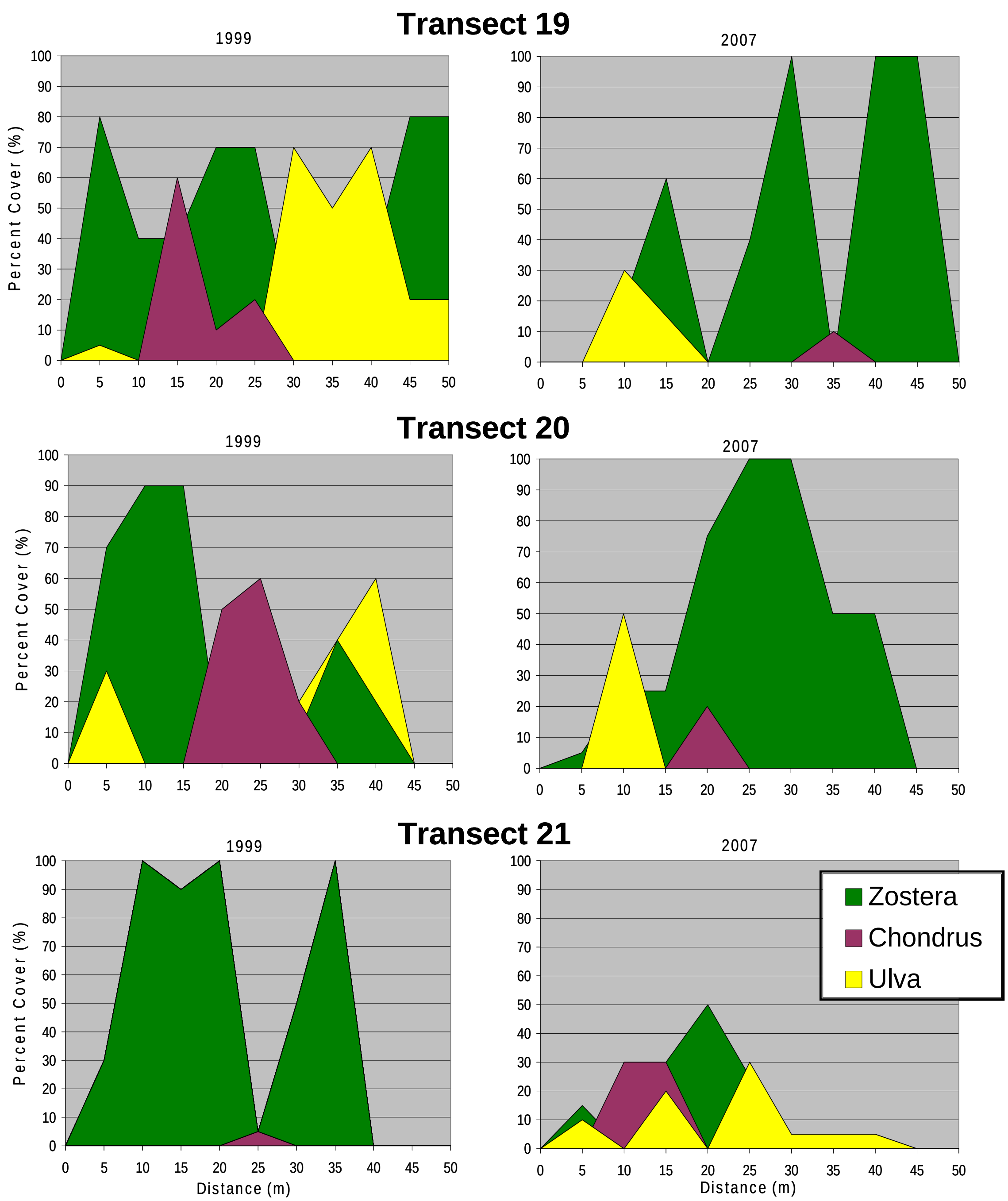

Figure 9 (continued). Macrophyte cover on seven transects surveyed in 1999 and resurveyed in 2007.

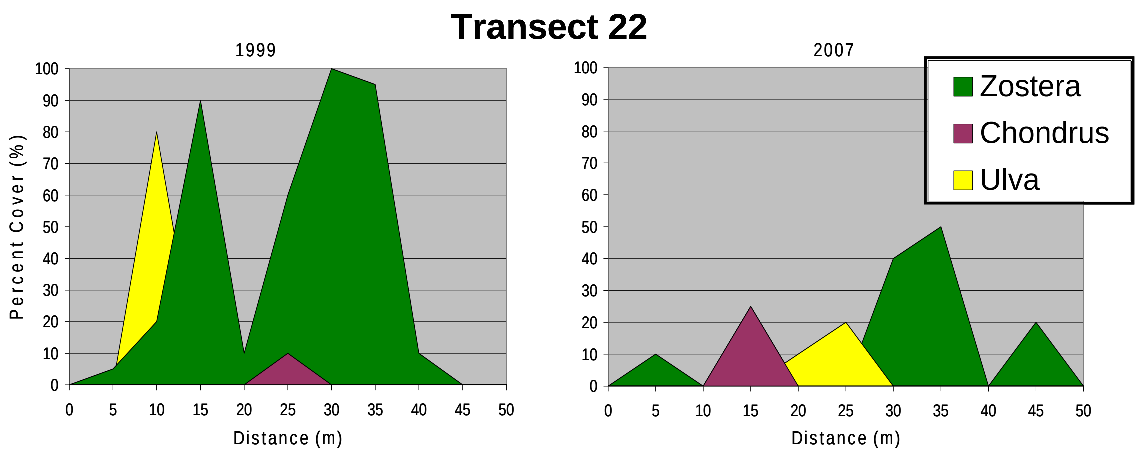

Figure 9 (continued). Macrophyte cover on seven transects surveyed in 1999 and resurveyed in 2007.

Figure 10. The density of Chondrus crispus clumps in the Basin Head Chondrus bed, 1997 and 2006.

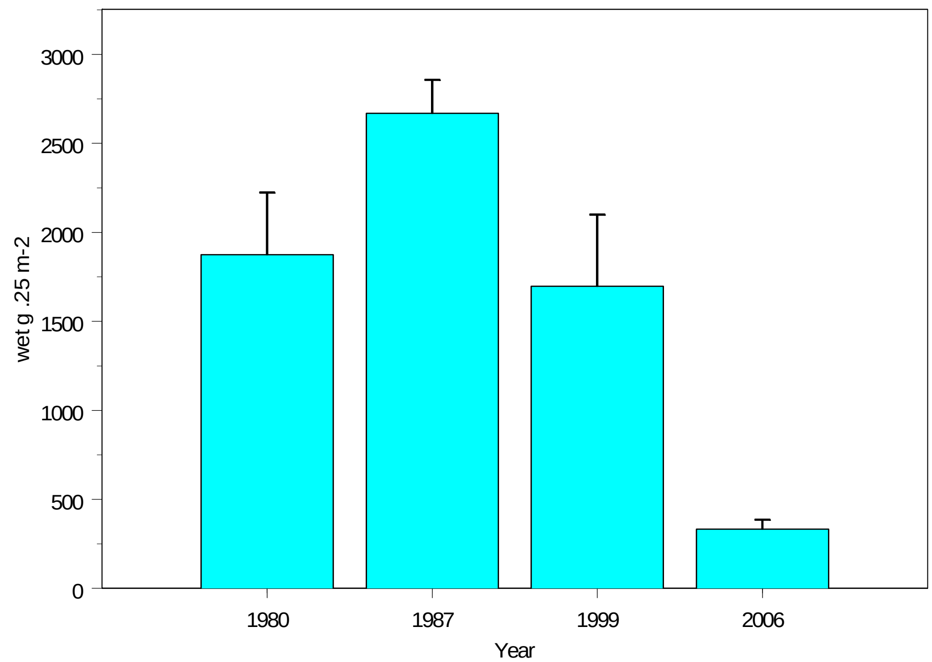

Figure 11. Mean biomass (wet g) of Chondrus cripsus from samples taken in the same region of the Basin Head Chondrus bed McCurdy (1980), Judson (1987), Sharp et al. (2003) and this study.

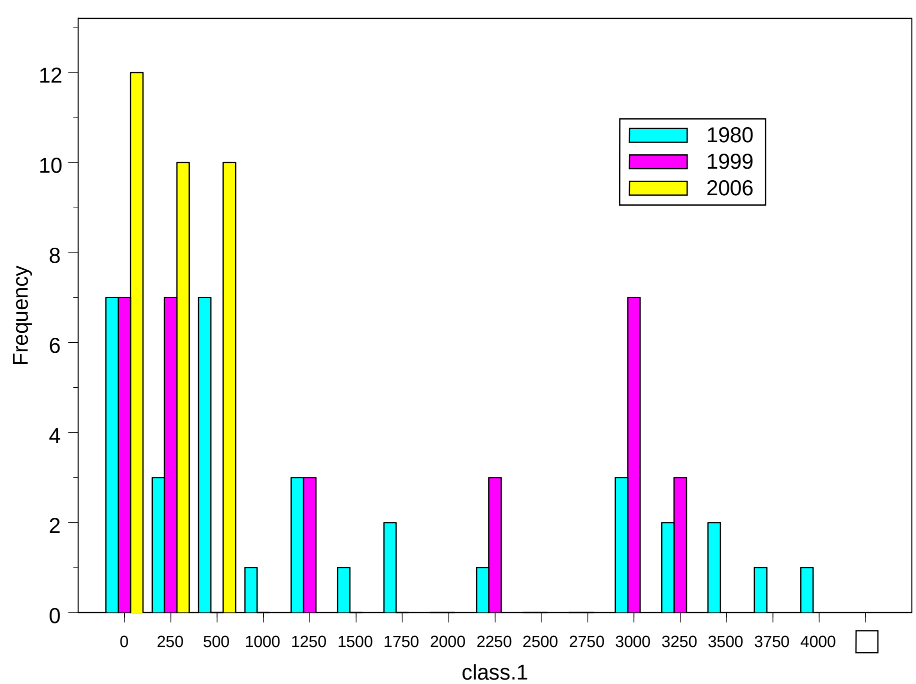

Figure 12. Distribution of Chondrus crispus sample weights (g 0.25 m^{-2}) from the same area of the Basin Head Chondrus bed.

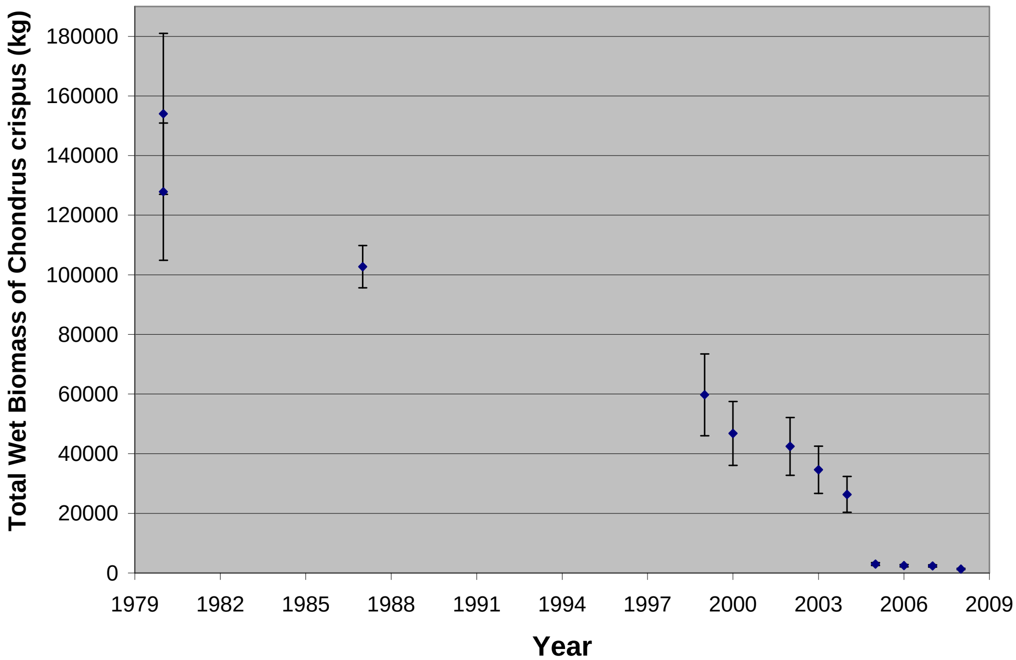

Figure 13. The total biomass estimated in the Basin Head Chondrus crispus bed between 1980 and 2008 McCurdy (1980), Judson et al. (1987), Sharp et al. (2003) and this study.

Figure 14 Morphology of Basin Head Chondrus crispus clumps and apices in 1996 and 2008.

Figure 15. Morphology of Basin Head Chondrus crispus 1-2 months after transfer to out planting sites in Malpeque Bay, PEI.

Figure 16. Top: isolated clump of Chondrus crispus, bottom: frond with poorly formed or damaged tips.

Figure 17. Damaged and eroded tips of Basin Head Chondrus crispus 2008.

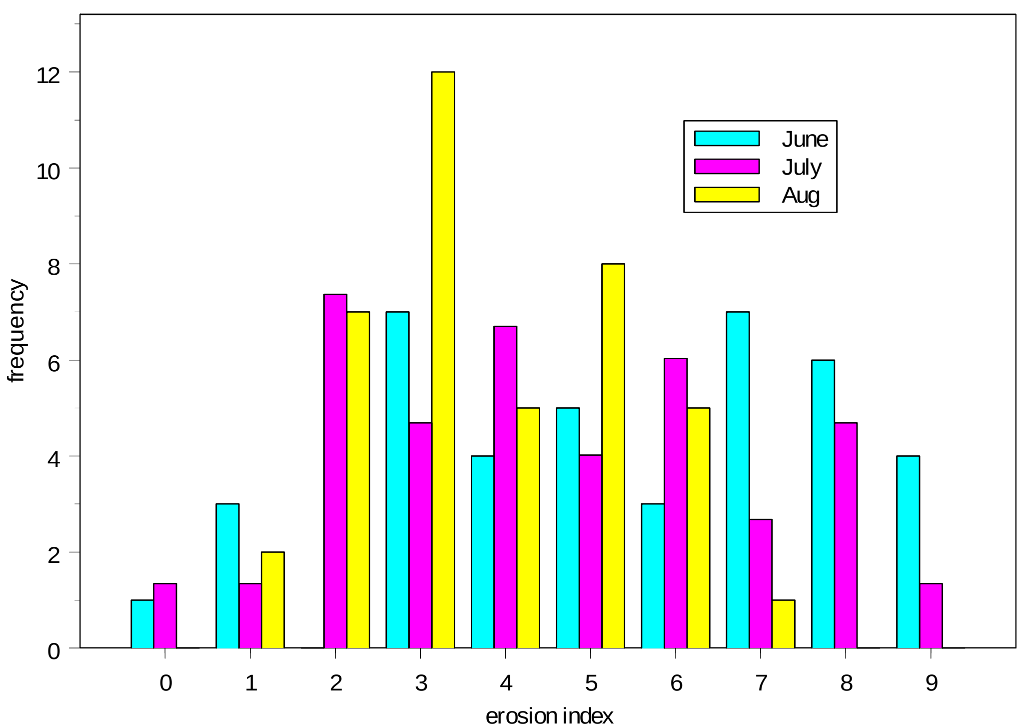

Figure 18. Index of erosion on Basin Head Chondrus fronds summer 2008.

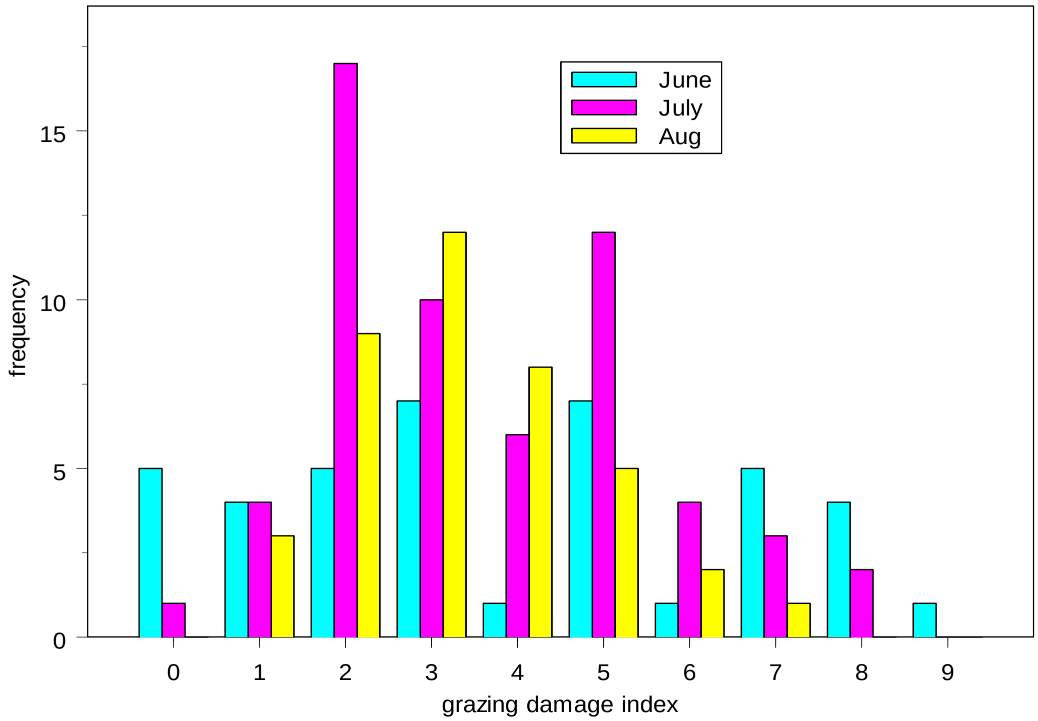

Figure 19. Index of grazing damage from Basin Head Chondrus crispus fronds summer 2008.

Figure 20. Apices of a Chondrus crispus frond August 2008.

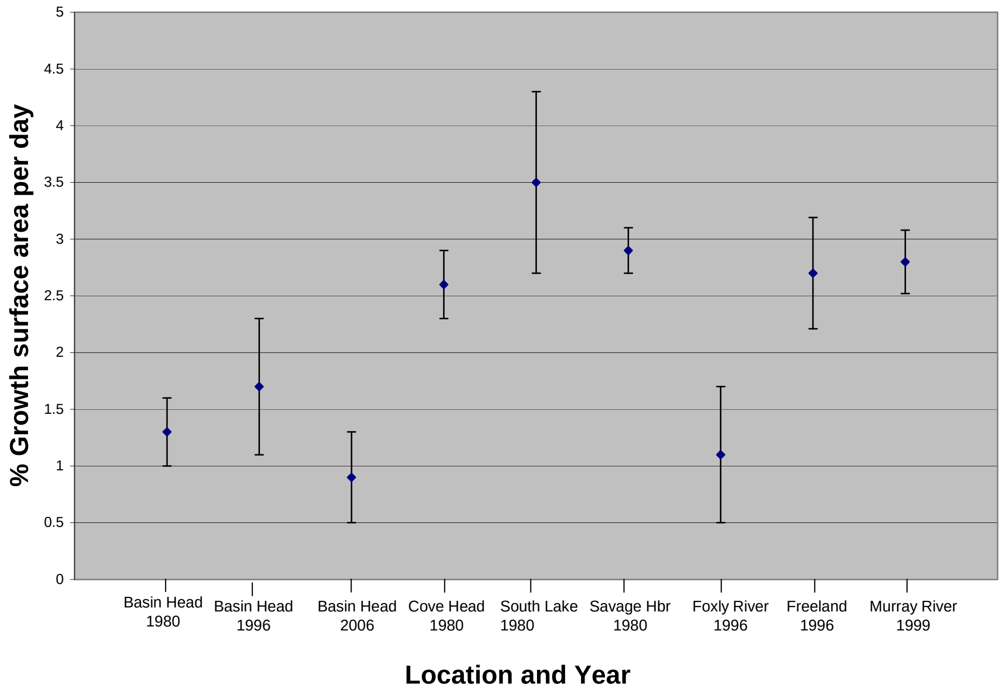

Figure 21. The growth rate of Chondrus crispus fronds out planted from Basin Head and control fronds in Basin Head. Data from McCurdy (1980), Chopin (1999), this study 2006 during the month of July.

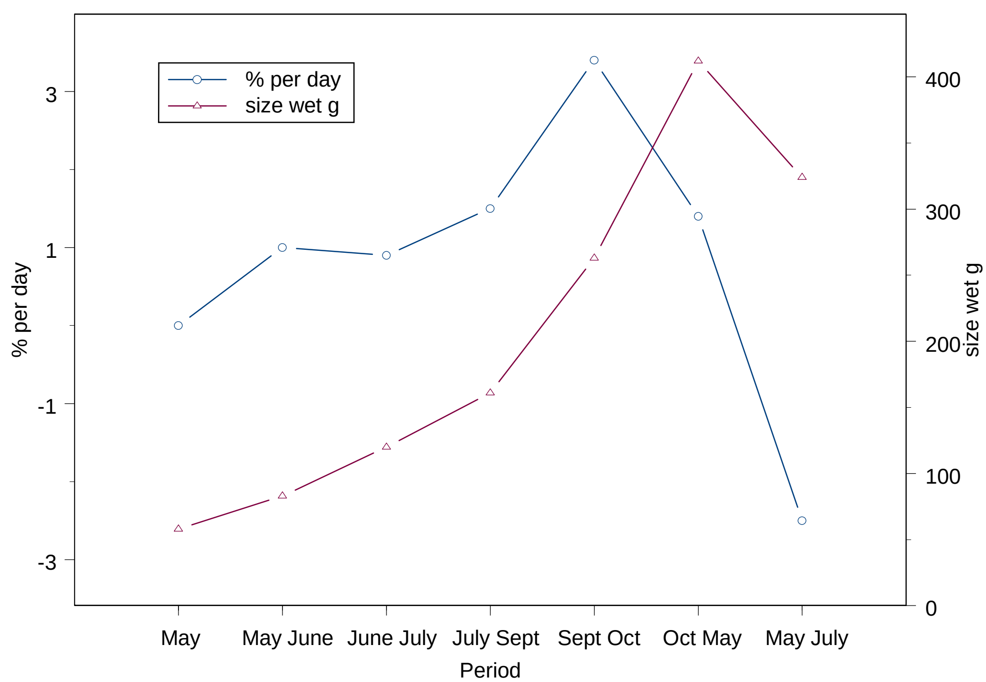

Figure 22. The growth of control Chondrus cripsus fronds in the region of the arm, 1996-1997.

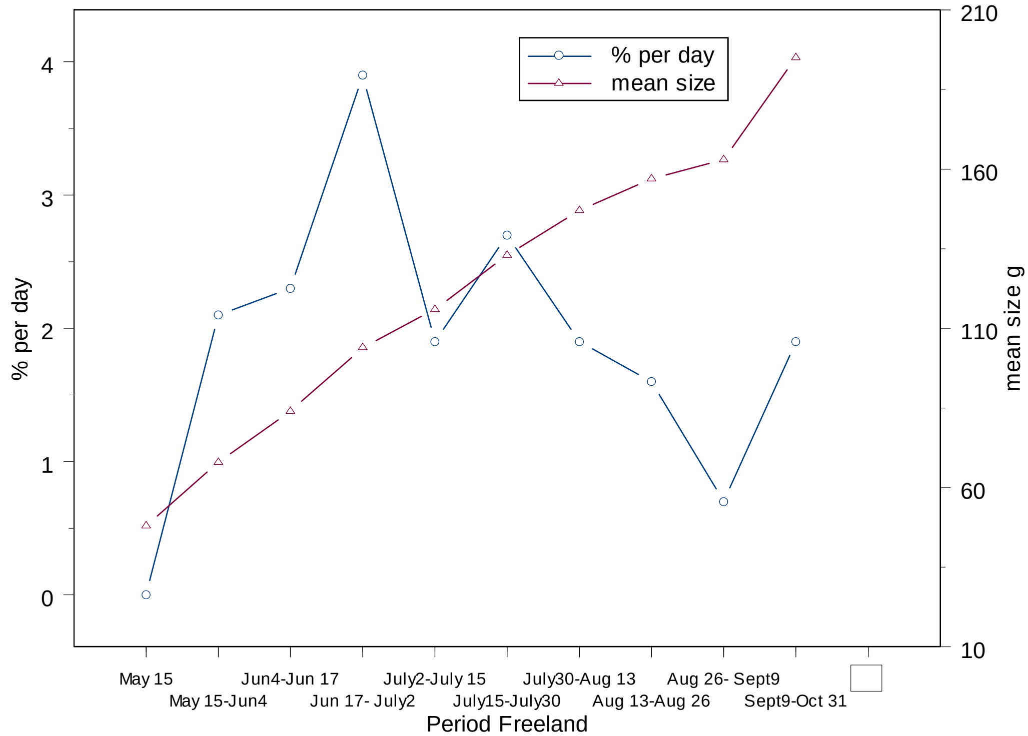

Figure 23. Basin Head Chondrus crispus fronds out planted in Freeland (PEI), 1996.

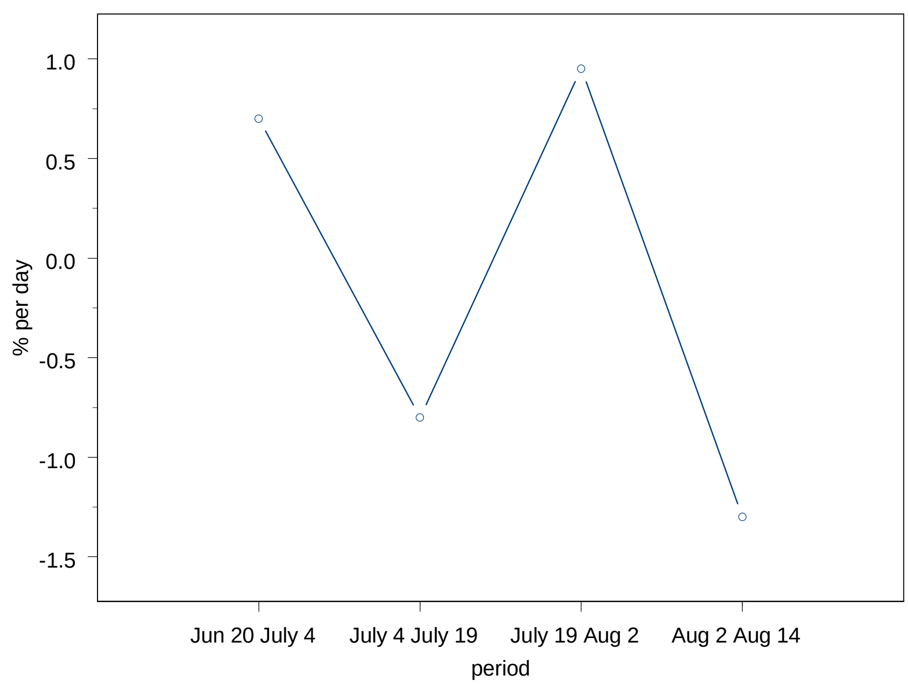

Figure 24. Growth of Chondrus crispus fronds in Basin Head, 2007.

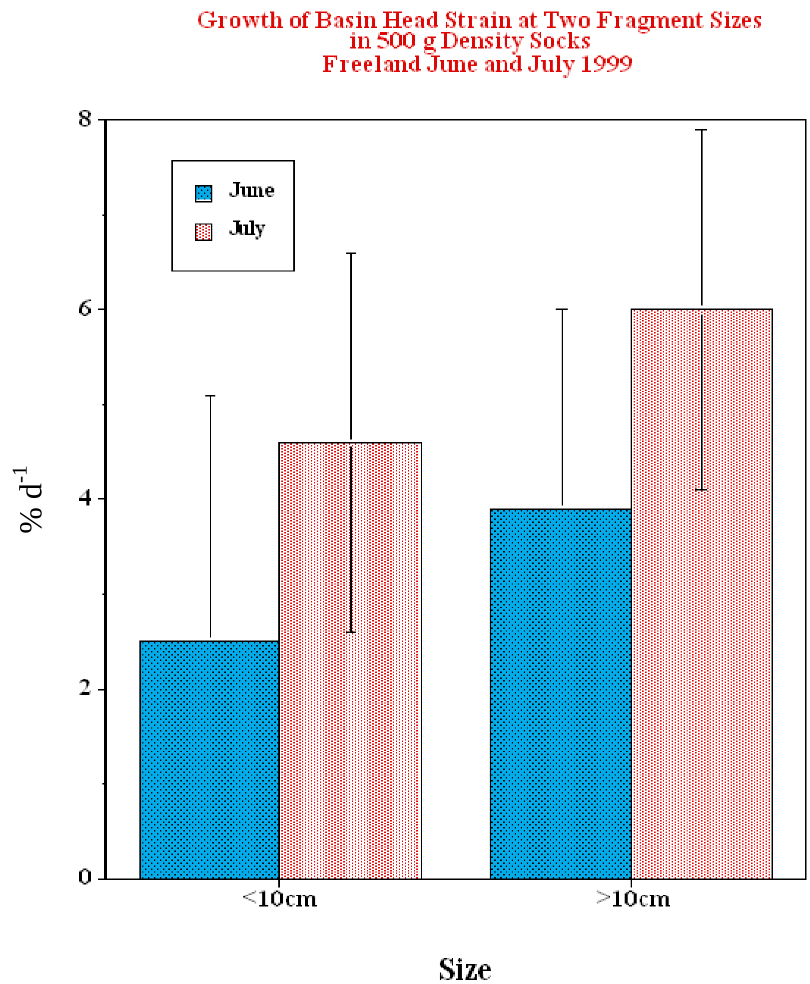

Figure 25. Growth rates of Basin Head Chondrus crispus in mussel socks loaded with two sizes of fragments, 1999.

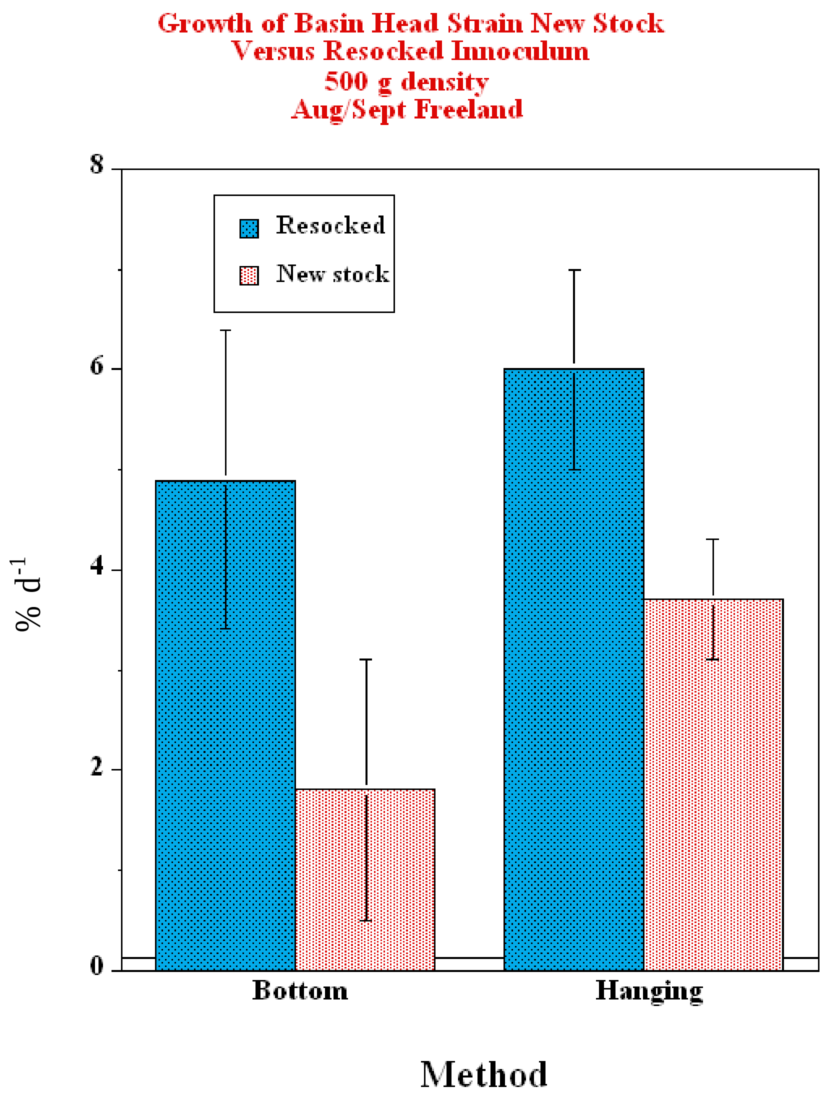

Figure 26. Growth rate of Basin Head Chondrus crispus out plants in mussel socking new stock versus resocked (1 year) inoculums.