ECOLOGICAL ASSESSMENT OF IRISH MOSS (*Chondrus crispus*) IN BASIN HEAD MARINE PROTECTED AREA

Photo: Bob Semple (DFO)

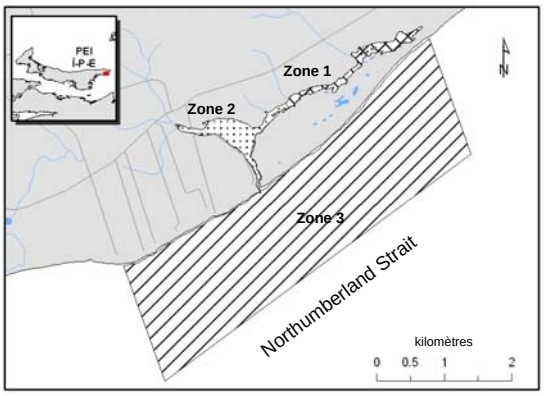

Figure 1. Basin Head Marine Protected Area

Context :

Basin Head Marine Protected Area (MPA), comprised of several management zones, was established in October 2005 under the statutory authority of the Oceans Act. The objective of the MPA designation is to protect and conserve a distinct form of Irish moss (Chondrus cripus) and its habitat found in Basin Head. This form is held on the bottom by the byssal threads of mussel, is significantly broader than the normal type of Irish moss, reproduces almost exclusively through asexual fragmentation, and is located primarily in the MPA zone 1. Regulations under the Oceans Act are in place to manage activities in Basin Head. These include a general prohibition against the disturbance, damage, destruction or removal of any living marine organism or any part of its habitat within zone 1 of the MPA. In addition to the regulations, an Operational Management Plan is in place to provide guidance in the monitoring, enforcement and compliance for Basin Head to meet its conservation and management objectives.

As early as 2005, monitoring in Basin Head indicated a change in abundance and condition for this distinctive seaweed. The specific cause(s) for the changes are currently unknown. Oceans and Habitat Management has sought Science advice regarding the potential cause(s) of decline of Irish moss within Basin Head. A meeting of the science advisory process was convened to review the status of Irish moss in Basin Head, review factors which may be contributing to the reported declines, and to consider possible research and management actions. The advice would be used to guide management actions in support of the conservation and management objectives of the MPA.. The meeting took place in Moncton (NB) November 26-27, 2008. Participants at the meeting were from DFO Gulf and Maritimes regions, academia, provincial government and the Basin Head Advisory Board.

SUMMARY

- The form of Irish moss found in Basin Head lagoon is distinct because it does not attach to the bottom but is held by byssal threads of mussels, is found almost exclusively in the non-sexual reproductive stage and replicates by fragmentation.
- Conditions in Basin Head lagoon have produced and sustained this distinct form for decades.
- There has been a large decline in the bed area, proportion cover, density, and biomass of Irish moss in Basin Head lagoon over the period of study, 1980 to 2008.
- Estimates of biomass, which were 110 t in 1980, are at the lowest value of just over one (1) tonne in 2008.
- Possible actions to mitigate the decline of Irish moss would depend upon the factors which are most likely to contribute to the sub-optimal conditions for the Irish moss in Basin Head lagoon.
- The cumulative effects of inputs of nutrients into the basin with subsequent annual green algal blooms and poor water quality are considered to be important contributory factors to these sub-optimal conditions for Irish moss.
- The recent invasion of green crab and its intensive predation on blue mussels which anchor the moss, is considered an important stressor to the Irish moss population and the Basin Head ecosystem.

INTRODUCTION

Basin Head, Marine Protected Area, was established in 2005 under the *Oceans Act* mandate. It is a shallow marine lagoon located on the eastern tip of Prince Edward Island (Fig. 1). The Basin Head MPA covers an area of 22.77 km^2, including the outer coastal area. The Basin Head lagoon watershed is relatively small (17.5 km^2), with several small streams entering the north face of the lagoon. The lagoon itself is approximately 3.8 km in length and covers 0.60 km^2. The lagoon is comprised of a 0.5 km channel connecting to the ocean, a 0.24 km^2 main basin and a narrow channel (referred to as the northeast arm) that extends 2.9 km parallel to the coast behind the dune system (Fig. 2).

The Basin Head lagoon is shallow with a mean depth less than one metre with deeper sections found in the main basin and in the channel to the ocean. The Basin Head Irish moss bed is located in the northeast arm of the lagoon (Fig. 2), in less than one metre of water. The northeast arm is well flushed, with currents reaching 0.5 to 0.8 m s^{-1} in minimum water depths of 40 cm. Sandy substrate dominates in the center of the northeast arm and eelgrass (*Zostera*) fringes the shallows.

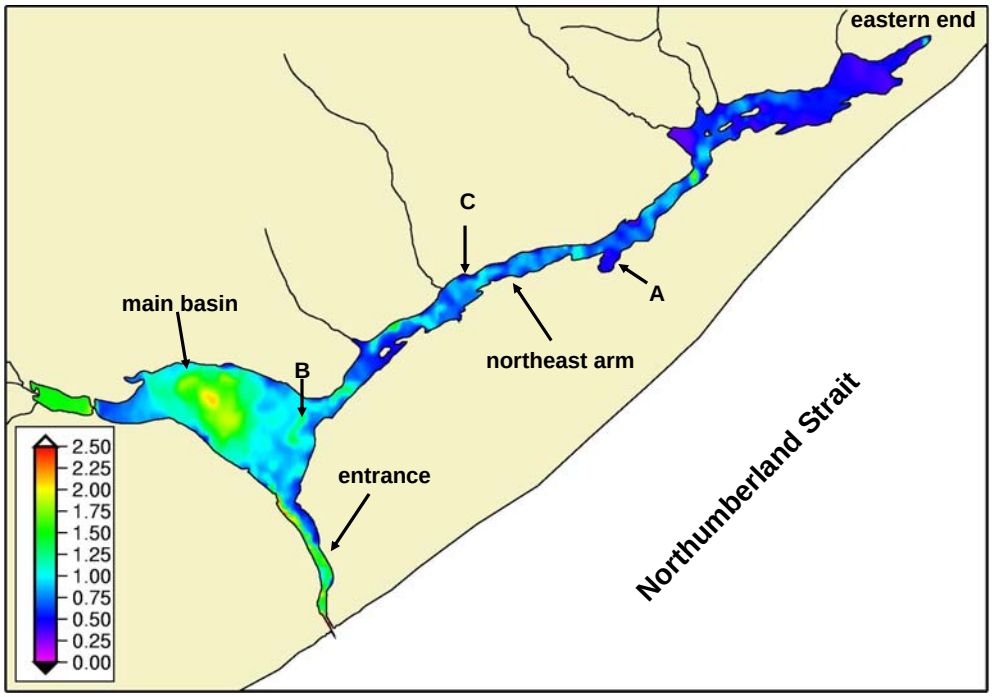

Figure 2. Bathymetry (m), geographic features, and sampling locations of Basin Head lagoon referred to in text.

Chondrus crispus (Irish moss) is a temperate red alga, ranging from Long Island NY to Labrador. Irish moss is primarily harvested for extracting carageenan which is used in a variety of food, cosmetic and health related products as a thickening or stabilizing agent. The optimal temperature for growth is between 10º and 15ºC. *Chondrus crispus* can tolerate a wide range of salinities (10 - 58 ppt), however, growth is significantly reduced below 30 ppt. Water movement is important for the removal of metabolites and for nutrient exchange.

Irish moss normally has a life cycle consisting of three phases: male, female and a spore-producing phase. All phases are similar in size and shape. The primary mode of reproduction is by the sexual production of spores that then form small plants. The second and usually minor process is vegetative or non-sexual, where parts of the plant break off and attach to a hard substrate.

The distinctive characteristics of the Basin Head Irish moss include reproductive stage, frond morphology, and growing habit. Basin Head Irish moss is found almost exclusively in the non-sexual reproductive stage, reproducing by fragmentation. The Basin Head seaweed has broad flat fronds compared to narrow dichotomous branching fronds of the plant in the open coast (Fig. 3). It maintains a dark red to brown coloration throughout the year, while the open coast type exhibits colour changes from red to yellow to green through the seasons.

Unlike the open coast form of Irish moss which attaches to the rocky substrate by an encrusting holdfast, the Basin Head Irish moss form does not produce a holdfast, rather being held on mud bottom by the weight and byssal threads of the blue mussel (*Mytilus edulis*). The individual fronds can be very large (up to 0.5 kg wet weight). The Basin Head plant has not been shown to be genetically distinct when compared to other conspecific morphotypes.

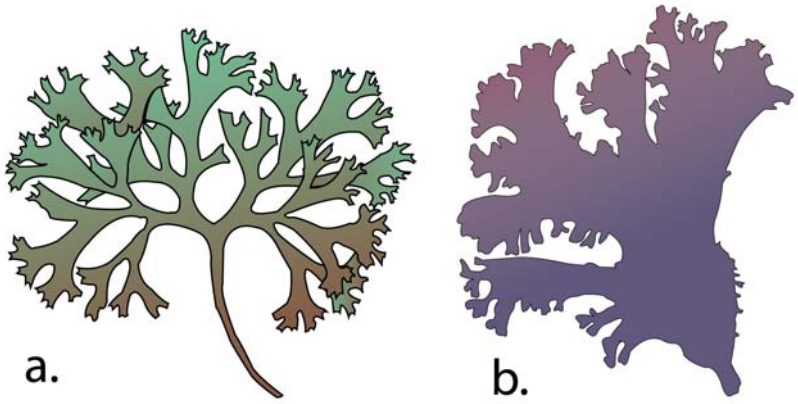

Figure 3. Comparative morphology of Irish moss (Chondrus crispus): a) open coast plant from the shallow waters around Prince Edward Island, b) distinct broad morphology of plant found in Basin Head.

The conditions for growth and survival of Irish moss in Basin Head lagoon are sub optimal. Optimal temperatures for growth between 10 and 15ºC are generally exceeded by early July in the lagoon. Salinity in the lagoon varies widely between 9 and 30 ppt depending on tidal ranges and rainfall. Sufficient nitrate and phosphate levels for growth are available in the lagoon all summer. The dark pigmentation of Irish moss fronds confirms a high level of tissue nutrients in this more than adequate supply situation. The region in the lagoon where the Irish moss bed has persisted is a high point of currents, second only to the main entrance to the lagoon. The decline in oxygen levels during the summer are a result of increasing temperatures, as well as degradation and decay of organic material that is not adequately flushed from the lagoon. The build up in particulate organic matter noted by a number of observers also suggests inadequate removal of this material. Ultimately particulate matter will reduce exchange of metabolites at the surface of the plant and reduce light energy reaching the plant.

ASSESSMENT

Changes in abundance, distribution, condition and growth

Abundance of Irish moss in Basin Head was measured in 1980, 1987 and annually during 1999 to 2008. The limits of the bed have been defined by the presence or absence of fronds along transects or by interpretation of air photos. Area occupied represents the total area of the distribution of Irish moss. Cover (%) is the ratio of sampled points with Irish moss to all sampled points. The methods for estimating the area occupied by Irish moss and the percent cover varied over the study period, 1980 to 2008. Density (weight per unit area) was estimated by collecting all Irish moss contained within a circular or square sampling frame of 0.25 m^2 standard area pressed into the substrate. The total biomass in all studies was calculated as a multiple of the area of the bed (m^2) and the mean wet density (g m^{-2}).

Area and Cover

From the earliest comprehensive study of Irish moss distribution in Basin Head lagoon in 1980, the main concentration of biomass was located in a restricted portion of the northeast arm. Between 1999 and 2008, the maximum length of bed cover was 600 m overlapping both the 1980 and 1987 distributions. The detailed map of the bed provided by aerial photography in

2000 and 2002 indicated that the bed area appeared to be dynamic with only some clumps or patches of the bed stable from year to year. Between 2000 and 2002 an area opened up in the central area of the bed, became enlarged in 2003 and was essentially devoid of Irish moss clumps by 2005. Since 2006 this section of the bed has been completely lost with the bed largely concentrated in a 200 m section of the arm.

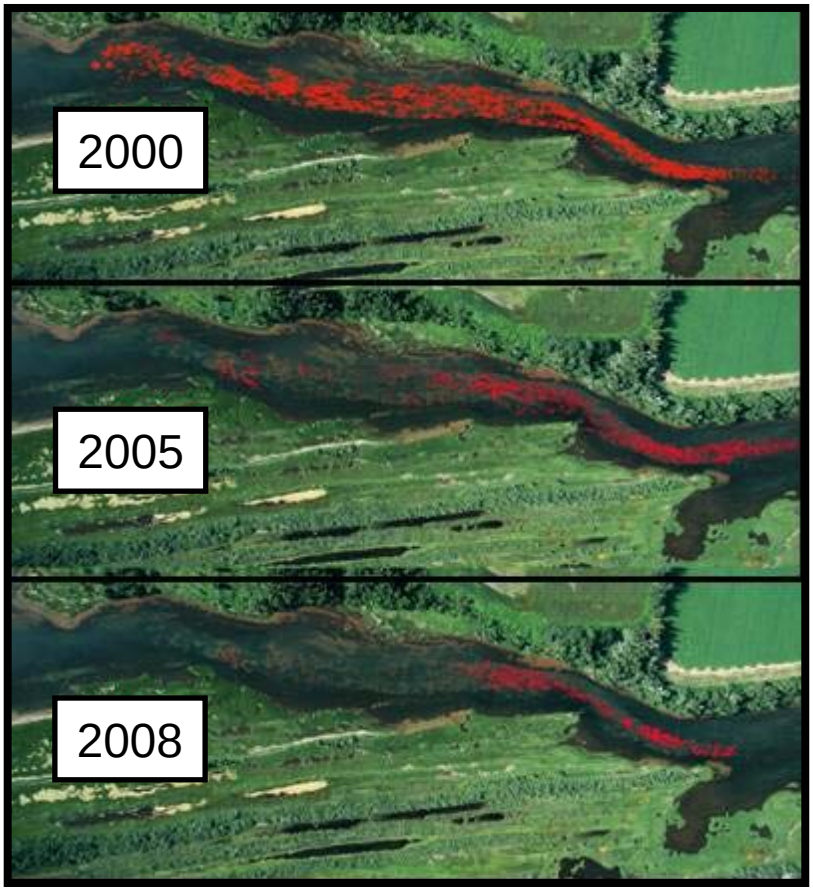

Figure 4. Aerial photographs showing distribution of Irish moss (red shading) in the northeast arm of the lagoon in 2000, 2005 and 2008. Red shading of Irish moss was added by interpretation of airphotos.

There has been a decline in the cover (%) and bed area (m^2) over the study period, 1980 to 2008. After 1999 there was a steady decline in area and cover (Fig. 5). An additional comparison of cover between 1999 and 2007 on seven selected transects showed an increasing patchiness in structure of the bed. As well, samples of Irish moss clumps from 1996 to 1999 were up to 30 cm high and usually were the coalescence of several clumps one on top of the other but by 2006 these clumps were less than 15 cm high and solitary.

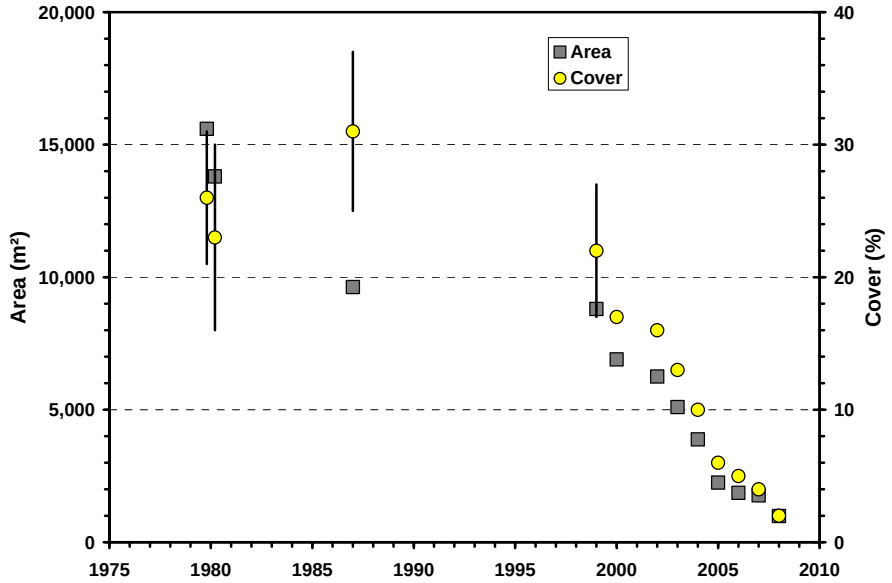

Figure 5. Area (m²) and cover (%) of the Irish moss bed in Basin Head, 1980 to 2008. There were two surveys conducted in 1980, one in June, the other in August. The 1987 data points represent estimates from sampling of only the densest portion of the bed. No information is available for 2001. One standard error bars for the mean are shown. From 2000 to 2008, cover is an absolute value, obtained by direct measure from airphotos, rather than being estimated from field sampling as in previous years.

Biomass

In 1987 the survey covered only the densest part of the bed and therefore yielded the highest estimate of cover and density. Results from four studies (1980, 1987, 1999, 2006) indicate that average density (g m^{-2}) was not significantly different between 1980 and 1999. The drop in estimated total biomass in 1999 (60 t) from 1980 (128 to 154 t) was due to a reduction in the area of bed in 1999 (8,800 m²) relative to 1980 (13,800 to 15,600 m²) (Fig. 5, 6). Estimates of the total biomass for 1999 to 2004 used a fixed density estimate of 7.5 kg m^{-2} derived from sampling in 1999; thus the change in total biomass reflects only the change in total area. In 2006, re-sampling the same regions of the bed indicated that the estimate of density (1.6 kg m^{-2}) was significantly less than in 1999. The 2006 value was applied to the 2005 to 2008 data series. The continuous reduction in total biomass to slightly over one tonne in 2008 is explained by the combination of reduced area of the bed and significantly lower mean density from that of 1999 (Fig. 6).

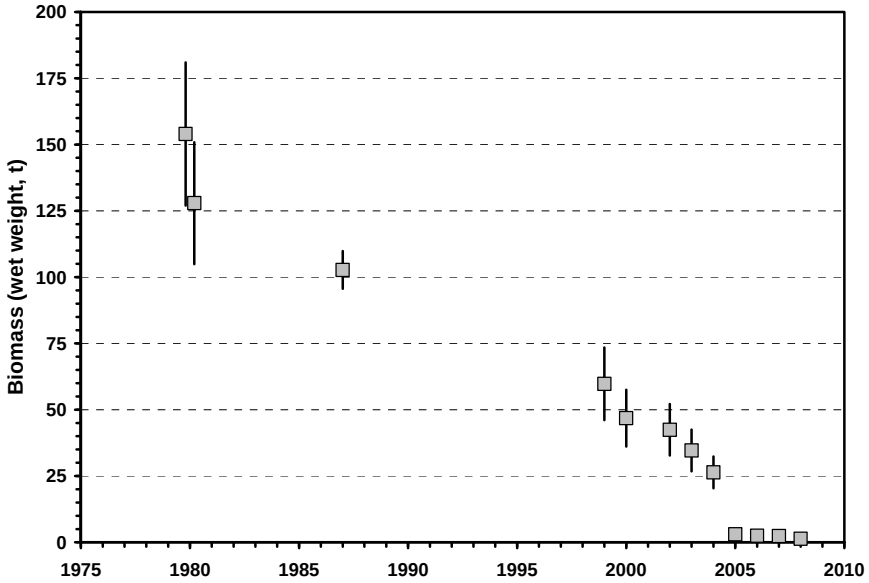

Figure 6. Total estimated biomass (wet weight, t) of Irish moss in the Basin Head bed, 1980 to 2008. Points for the two surveys in 1980 are offset to reduce overlap. One standard error bars for the mean are shown.

Condition and growth

The morphology of Irish moss is very plastic. Within the northeast arm of Basin Head, three types have been described: spriggy, (narrow branches with numerous apices forming ball like clumps), foliose (wide thick thalli with few apices), and normal (broad thalli, numerous apices, rubbery texture). These three types were present in the bed in 1999.

"Healthy" plants show little evidence of grazing or tissue erosion and few epiphytes. Changes in the "healthy" state of Basin Head Irish moss were first noted 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 were only small residual clumps attached to mussels. Fronds photographed in 2008 were more similar to the "spriggy" type but also had eroding and broken edges.

Overall, Irish moss transplanted to other sites grew better than in Basin Head lagoon itself. Lower growth in July in Basin Head lagoon was also documented in 1980 when biomass of Irish moss was high (Fig. 7).

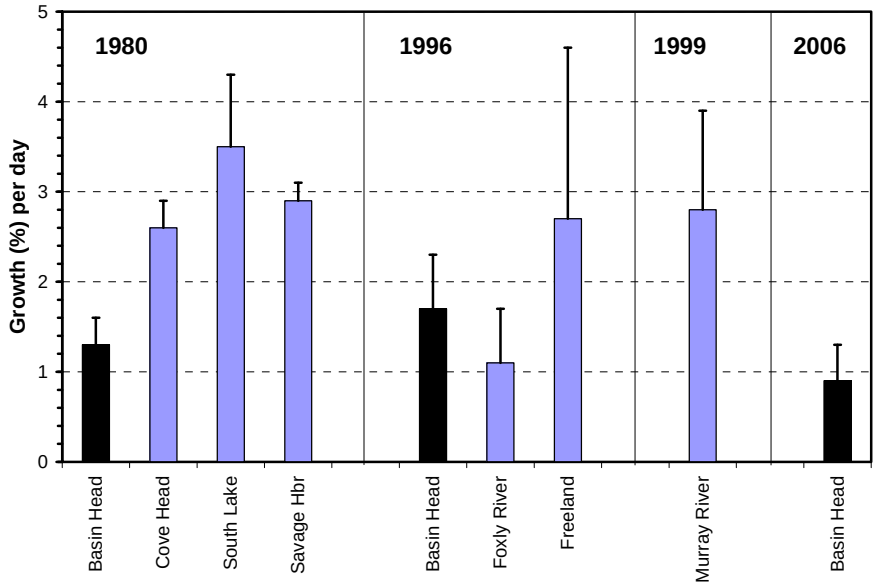

Figure 7. Comparative growth rate (% per day) during the month of July of Chondrus fronds within Basin Head lagoon and for those out planted from Basin Head in 1980, 1996, 1999 and 2006. One standard error bars are shown.

In cultivation experiments, larger frond fragments grew at a higher rate than the smaller fragments through June and July because the former retain more undamaged apices and therefore grow more rapidly. This relates to the natural situation in Basin Head lagoon where plants suffering from erosion, breakage or grazing of tissue require recovery prior to initiation of apices. If the degree of these impacts increases then the productive capacity of the individual fronds may be suppressed.

Factors which may be affecting the abundance, structure and distribution of Irish moss in Basin Head

Several factors have been suggested as contributing to the decline in abundance.

Macroalgal blooms

When Basin Head was being considered as a candidate for Marine Protected Area (MPA) status, *Ulva* (sea lettuce) blooms and associated areas of anoxia were listed as one of the threats to Irish moss, particularly at the head of the northeast arm. Macroalgal blooms are a recognized symptom of eutrophication of shallow coastal waters. The negative effects of macrophyte blooms can be more extensive and persistent in semi-closed water bodies like Basin Head. Foliose green algae are essentially nutrient sponges and respond to favourable conditions by rapid increases in biomass. This biomass ultimately becomes self-limiting; the algae dies and biodegrades rapidly which can lead to many problems including decreased aesthetics, lowered water quality and creation of anoxic events or persistent dead zones. In addition, the thallus of *Ulva* is sheet-like and as production increases it can grow unattached forming layers or mats in the water column. The shade effect of these layers can reduce the productivity of macrophytes below the canopy.

There have been annual blooms of *Ulva* (predominantly *Ulva lactuca* and to a lesser extent *Ulva intestinalis)* in Basin Head lagoon since at least 1980. The biomass accumulation begins in the spring in the areas with the least water movement (head of the northeast arm and the head of the main basin of the lagoon). As the summer progresses the biomass of green alga becomes an increasing component of the macrophyte cover of the substrate in all areas of the lagoon. At the time of peak accumulation in mid-summer large floating mats of *Ulva* are seen moving with the current. Tidal flushing of the lagoon clears the majority of green algal biomass by the fall of each year and only very eroded and fragmented pieces remain.

From 2001 to 2008, growth rate of *Ulva* and other green algae was assessed at two sites; site A is adjacent to the main part of the Irish moss bed in the northeast arm, and site B at the entrance to the northeast arm (Fig. 2). The growth rate of *Ulva* reached a maximum at site A in late May in most years followed by a rapid decline in June. There were notable differences in the magnitude of the spring peak between years. Summer growth rates generally averaged less than 20 % d^{-1}. In 2007 and 2008, the pattern changed with July growth exceeding 38 % d^{-1} with a third pulse of growth (60% d^{-1}) in August of 2008 that exceeded the spring peak. The growth in 2007 and 2008 was both sustained for a longer time period and at a higher rate than in the early 2000s (Fig. 8).

It is unclear if the increased abundance of *Ulva* in Basin Head lagoon is contributing to the declines in Irish moss. Reduced growth rates of Irish moss resulting from reduced light levels as a direct result of *Ulva* blooms can be discounted based on the very shallow waters of the northeast arm and the strong currents which characterize the majority of the bed and which would preclude buildup of *Ulva* mats at the surface. However, the degradation of *Ulva* mats and the release of fine particulate matter from the head of the northeast arm has been documented passing over the Irish moss bed. These may have effects on light transparency. *Ulva* blooms are an indication of eutrophication and this may be more relevant to Irish moss growth and or survival in Basin Head lagoon.

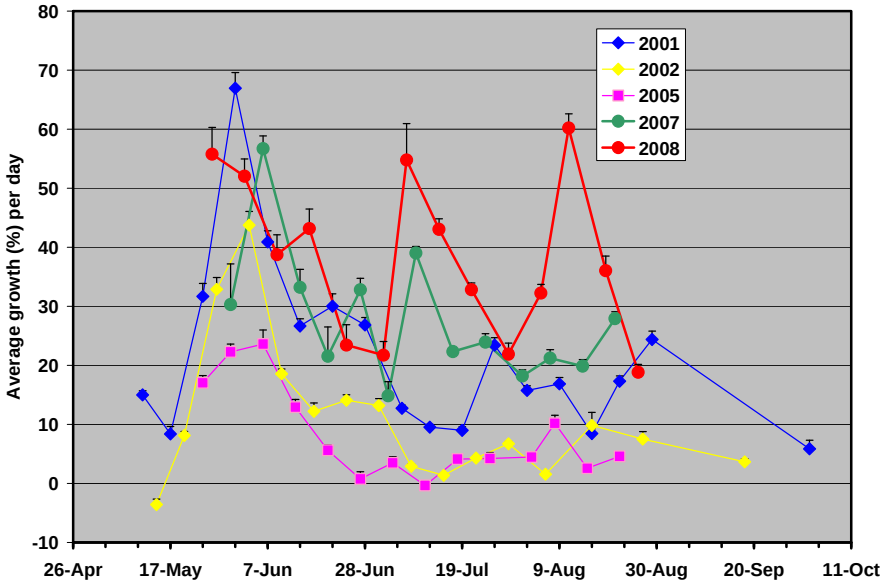

Figure 8. The average growth (%) per day in surface area of Ulva lactuca discs held at site A in the northeast arm of Basin Head, 2001 to 2008. One standard error bar (upper range) is shown.

Eutrophication and environmental quality

The cumulative effects of nutrient inputs into the basin with subsequent annual green algal blooms and low water quality are also hypothesized to contribute to the decline in Irish moss.

High nutrient loading of the lagoon waters is expressed by the very dark red to purple colouring of Irish moss in Basin Head lagoon throughout the year. In open water populations of *Chondrus,* tissue nutrients decrease in summer as ambient nutrients decline resulting in a transformation of the colour of these plants from red to yellow and green. Although the nutrients in lagoon waters drop over the summer, stored nutrients are maintained in Basin Head plants at levels 2 to 3 times higher than in plants transferred out of the lagoon. High tissue nitrogen content is associated with brittleness of the plant which can lead to excessive fragmentation and loss. Observed negative growth rates of Basin Head moss in August are also associated with increasing stress from other factors such as high temperature.

In the absence of environmental monitoring between 1980 and 1999, inferences on changes in Basin Head lagoon were derived from trends in other PEI estuaries and watersheds. The primary change over this time period is the continual increment of nutrient loading of the watersheds. Nitrate levels implicated in observations of anoxia are usually above 0.4 mg l^{-1}. 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 and this has continued to be the highest input location. Phosphate levels were highest (>0.2 mg l^{-1}) at the head of the northeast arm where annually there is a major degradation of accumulated green algal tissue.

Weekly sampling for water temperature, salinity, dissolved oxygen, chlorophyll and dissolved inorganic nutrients was conducted between April and August, 2001 to 2008 at up to 13 stations in Basin Head watershed. Some of the variability in the measurements of these parameters can most likely be explained by the state of the tide during sampling. Seasonal values for key parameters from the station located within the Irish moss bed (site C) are within the range of values sufficient for Irish moss growth: salinity 15 to 30 ppt, temperature 15ºC to 25ºC in July and August, dissolved oxygen 5 to 14 mg/l, nitrogen as nitrate generally less than 0.3 mg/l. Nitrate levels in particular at site C have generally decreased over the period 2001 to 2008. Nitrate inputs (concentrations) have also generally declined at the freshwater sites. However tissue nitrogen levels remain high in the lagoon, originating from ammonia pulses in late summer.

Potential sources of nutrients to the lagoon include a number of land use and industrial activities. The assimilative capacity of the marsh at the head of the lagoon has been reduced by infilling. There have been episodic and unpredictable high fecal coliform counts in the lagoon. All these are cumulative stress factors to the ecosystem of the lagoon.

Water circulation patterns

The tides affecting the Gulf of St. Lawrence come mainly from the Atlantic Ocean through Cabot Strait. The tidal range in the area of Basin Head is around 1.8 m. The Eastern Northumberland Strait (ENS) has a mean occurrence of ice of 100 to 105 days per year. By mid-February the ENS is covered with ice 100% of the time. The area usually has ice present until the second week of April. The presence of sea ice can protect shorelines from erosion during storms.

Sea Surface Temperature (SST) in the area off Basin Head has been slightly increasing since the mid 1990's with a more noticeable change since 2002 (Fig. 9). Because this is the water

present at the mouth of the lagoon and entering at each tidal cycle, it is expected that these changes could also have affected the temperatures in Basin Head lagoon. The SST changes are observed in Northumberland Strait and around PEI.

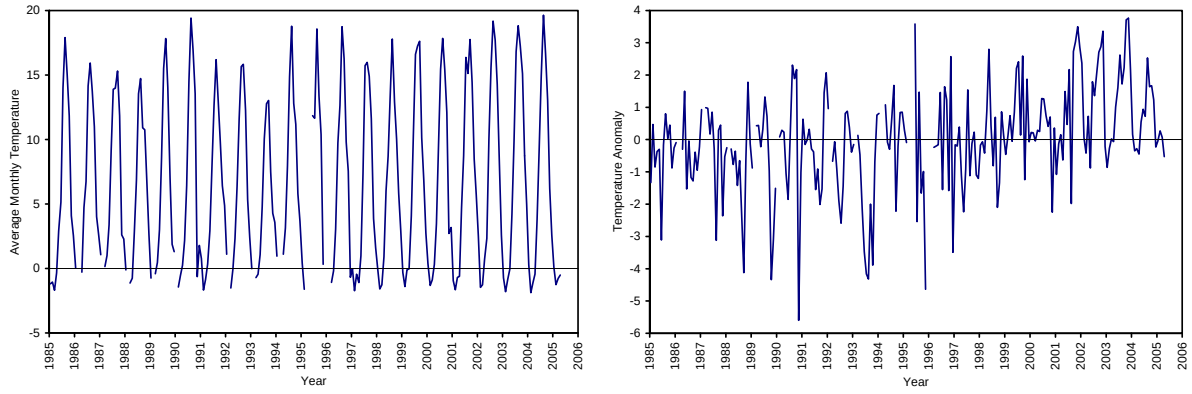

Figure 9. Monthly average sea surface temperature (SST left) and temperature anomaly (right) of the waters offshore of Basin Head.

Tidal currents into Basin Head lagoon reach a maximum of around 1.4 m s^{-1} between the breakwaters at the entrance. High currents are also observed in the northeast arm which contains the Irish moss bed (Fig. 10). The main basin typically has slower currents than the rest of the lagoon and surface currents are stronger than the ones closer to the bottom.

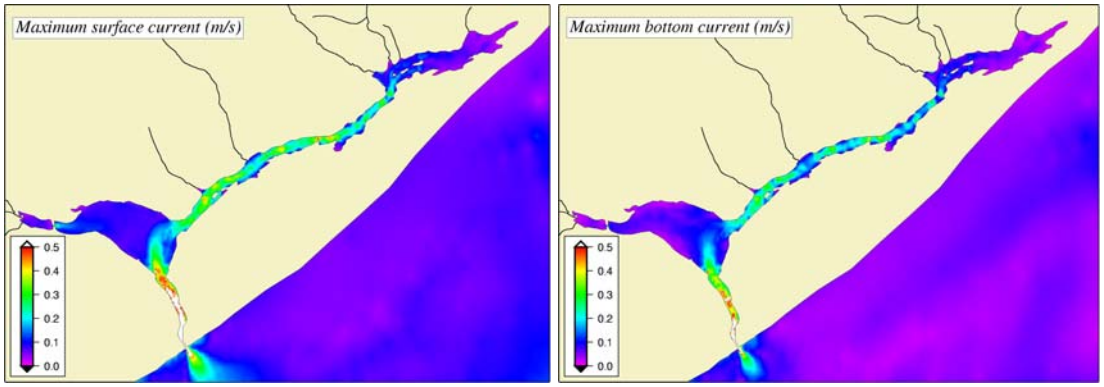

Figure 10. Average maximum surface (left) and bottom (right) water currents (m/s) in Basin Head lagoon due to the tidal constituent M2 and freshwater runoff.

Based on the "tidal prism" method and the volume and area of the lagoon, the average flushing time of the lagoon is 24.5 hours. Remote locations would take longer to flush while the entrance channel would have a shorter flushing time. The Irish moss bed is in an area which is well flushed due to the strong tidal currents.

A storm surge event on December 27, 2004 prompted further investigation on possible impacts to the Irish moss bed. Some dispersion of the bed from this event was anticipated. A macrophyte that is not attached to the bottom is essentially “drift” seaweed. Fronds are expected to fragment upon reaching a maximum size. Additionally, clumps of fronds having attained a critical size are susceptible to movement by tidal currents and wind events. The rise in water level from the storm surge was 1.2 m above the highest tide. This event caused significant damage to the ocean entrance to the lagoon, destroying some of the adjacent dune

structure and the protective wharves. This flushing event raised the water level throughout the lagoon and would have changed the water circulation in the northeast arm for the short term. There was evidence of further loss to the Irish moss bed in 2005 but the decline could not be directly linked to the storm surge event.

It is unknown if the storm surge in December 2004 produced currents and a disturbance of a sufficient force to further displace and damage the Irish moss bed in the northeast arm. Nor is there information on changes in circulation patterns within the lagoon which could explain the declines in Irish moss observed since 1999.

Other factors

Of the number of other possible factors contributing to the continuous decline in Irish moss abundance in Basin Head lagoon since 1999, several are unlikely to have contributed to the decline.

The only recorded commercial harvesting of Irish moss occurred in 1987 when 23 t were removed of an estimated abundance of 103 t. As there have not been any subsequent reported commercial removals from Basin Head lagoon, commercial harvesting is not a contributor to the decline in biomass observed over the 1999 to 2008 period.

Three pathogens of Irish moss have been identified, largely from tank cultivation of strains. A pathogenic strain of bacteria isolated from healthy fronds and found in necrotic tissue can cause green spot or green rot disease in plants in tank culture. The disease is characterized by holes in mature parts of plants. Such holes have not been noted in mature parts of moss from Basin Head lagoon but such holes could heal or lead to fragmentation of the frond. The stage of Irish moss found in the lagoon is resistant to *Acrochaete operculata*, a green algal pathogen, which is otherwise virulent to other stages of Irish moss. Finally, 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. Early stages of this parasite have not been observed when necrotic tissue would appear at the tips of the plants. Overall, moss has not been examined for these parasites or pathogens but two transplants of material to tank culture in 2007/08 exhibited good productivity and healthy fronds.

Field and laboratory experiments suggest that the presence of herbivores (snails) and scavengers (amphipods) does not seem to affect Irish moss growth in Basin Head lagoon. Irish moss is a sturdy seaweed and the presence of snails and amphipods probably serves to keep the plants clean of epiphytes more than anything else. The density of snails used in a field and laboratory experiments was similar to that observed in the wild; if artificially high densities had been used the snails may have had more of an effect on the Irish moss tissue.

Uncertainties

The accumulation of fine particulate matter on the herbivore exclusion structures in Basin Head lagoon in 2007 points to a factor potentially impacting Irish moss growth and survival. These particulates may shade or interfere with gas exchange, or indicate microscale anoxic conditions, all of which could reduce plant growth and lead to fragmentation. The particulate matter may derive from degradation of high *Ulva* growth which is driven by the high nitrogen loading in the lagoon. The impacts of pulse events from degradation of biological materials (primarily algal blooms) on water quality in the region of the moss bed are unknown. The fragmentation or

direct loss of Irish moss by the mechanisms described above need verification by laboratory and field experiments.

Green crab (*Carcinus maenas*) is an invasive species whose presence was first confirmed in 1999 in Basin Head lagoon. Direct studies in Basin Head lagoon and monitoring programs indicate that green crab have increased in abundance in the lagoon and are found in the northeast arm within the Irish moss bed. Studies have shown that green crab can be predators of blue mussel. The potential negative effects of green crab on Irish moss may be indirect and associated with predation on mussels, the latter being an essential and unique organism for the anchoring of the Irish fronds.

The essential role of mussels in the anchoring, stability and recruitment of Irish moss in Basin Head lagoon is well documented. All anchored Irish moss in the lagoon are associated with mussel clumps. As this form of moss replicates almost exclusively by fragmentation, the attachment of drifting fragments presumably depends upon the contact of these with mussel and attachment with the byssal threads. Intense predation on mussels by green crab would reduce the anchoring opportunities for fragmented moss. Adverse environmental conditions also could be a limiting factor in mussel byssal thread production which attaches the moss to the mussels. Similarly, anoxic conditions or poor water quality which could lead to mussel mortality would result in detachment of Irish moss clumps from the bottom making them susceptible to displacement out of northeast arm and the lagoon. These functional relationships require further research.

In addition to the eutrophication concerns, changes in land use and agricultural practices in the watersheds may also be impacting the ecosystem. No information relative to these changes were reviewed at the meeting but the watersheds within the Basin Head drainage area are under intensive cultivation. Nutrient loading from streams in the lagoon and overall nutrient annual loading needs to be determined.

Storm surges and other environmental forcing events contribute to physical changes in Basin Head lagoon. The contribution of these episodic and potentially catastrophic events to Irish moss is unknown. Similarly, the variability in winter ice conditions within the lagoon, particularly during winters with highly variable temperature conditions which can result in frequent ice formation, breakup and movement, could physically damage the moss beds which are located in the shallow waters of the northeast arm.

CONCLUSIONS AND ADVICE

The characteristics of Irish moss in the Basin Head lagoon which make it distinctive include the almost complete dependence on asexual fragmentation for dispersion and multiplication, the dependence upon blue mussel for substrate attachment, the frond shape and the sustained seasonal colouration. It also is characterized by a low growth rate within the Basin Head lagoon. The characteristics are defined by the environmental conditions in the lagoon.

Irish moss biomass in Basin Head lagoon has declined by greater than 99% over the period 1980 to 2008 with the lowest value of just over one ton (wet weight) estimated in 2008. The precipitous decline has been observed during the intensively monitored period, 1999 to 2008. The area of the bed has also been greatly reduced.

Present conditions in Basin Head are sub-optimal for maintaining historical abundance levels of the Basin Head Irish moss form. This situation likely pre-dates 1999. Eutrophication of the

lagoon and its associated consequences including increases in intensity and spatial coverage of green alga blooms, degradation of biological material resulting in anoxic conditions in portions of the basin, production of toxic materials (hydrogen sulfide, ammonium), extensive suspended follicular material, and warm temperatures in summer, may all contribute to the stressful conditions encountered by Irish moss in Basin Head lagoon.

Although the basin is susceptible to intense storm surge events, the consequences of such events on Irish moss abundance are unknown. The absence of historical information on changes in internal basin currents, bathymetry and other physical features of the basin preclude any conclusions of the role of these factors on Irish moss abundance.

The invasion of green crab is a recent and important stressor to the Basin Head ecosystem. The unique association of Basin Head Irish moss with mussels and the potentially intensive predation by green crab on mussel appears to be an important interaction which warrants research.

The status of Irish moss in Basin Head lagoon reflects the cumulative effects of a number of repetitive stress factors. The situation is not isolated to Basin Head and is part of a wider ecosystem condition in many coastal areas of PEI.

Potential management actions

Possible actions to mitigate the decline of Irish moss would depend upon the factors which are most likely to contribute to the sub-optimal conditions for this form of Irish moss in Basin Head lagoon.

The eutrophication of the basin, most likely associated with cumulative intensive land use within the watershed, is not a positive factor for the Irish moss. Modifications in land use which would result in reduced inputs to the basin of nitrates and phosphates would reduce stress on the ecosystem but would not necessarily by themselves lead to increased biomass and bed coverage of Irish moss in the lagoon.

Invasive species such as green crab once established are difficult if not impossible to eradicate. The possibly very important indirect effect of green crab on the Irish moss in Basin Head lagoon should be a priority research activity. Field experiments, of the type conducted to address the hypothesis of herbivory on Irish moss, could be considered and depending upon the spatial scale of the experiment could result in positive growth of Irish moss within the basin.

Artificial culture of the Basin Head Irish moss is presently occurring in laboratories. The objective is to provide a source of plant material for research and potentially for transplantation back into Basin Head lagoon. Present conditions in the basin are considered sub-optimal for Irish moss growth and survival. If the stressors within Basin Head lagoon that have contributed to the decline of this moss are not identified and addressed, artificial culture for transplant would have to be a sustained effort.

OTHER CONSIDERATIONS

Effectiveness of monitoring program

The size of the Irish moss bed since 2000 has been assessed using aerial photography and digital photo interpretation. This monitoring has provided the evidence for the large decline in Irish moss in the northeast arm and when combined with field sampling provides the information required to track the annual changes in abundance, bed structure, and condition of Irish moss. Ground truth transect efforts are now required in the monitoring program due to the dispersed structure of the bed in recent years. The time of year when the losses occur is still unknown as there has not been regular seasonal replication of sampling effort. If an important period of Irish moss loss can be identified, this may provide further insight into the most important factor(s) to consider.

The monitoring program could expand the measurement of *Ulva* cover using aerial photography, supported by field sampling. Although the growth rate component is well measured in the present program, this indicator does not provide a measure of the resulting size of the bloom in the lagoon overall.

The environmental monitoring initiatives within Basin Head lagoon have to date focused on periodic single point sampling at multiple sites. The variability in many of the factors suspected of contributing to the sub-optimal growth conditions in Basin Head lagoon are associated with daily, seasonal and annual cycles which are not sufficiently characterized by the present sampling programs. With new technologies, continuous monitoring equipment could be deployed in Basin Head lagoon to measure the variations in these components on appropriate temporal scales. Sampling programs should be extended to monitor conditions in all seasons.

In addition to measuring nitrates and phosphates, consideration should be given to include ammonium as this suite of parameters would be a better indicator of the nutrient dynamic. Including ammonium monitoring would provide a better indicator of environmental stress in the Basin Head ecosystem.

The faunal monitoring program (Community Aquatic Monitoring Program) remains shoreline-based with one station within the northeast arm. No sampling of mussel or green crab demographics, abundance, and distribution occurs in the Irish moss bed. Given the certainty regarding the functional role of mussel populations in maintaining the distinct form of Irish moss in Basin Head lagoon and uncertainty regarding the impact of green crab predation on the abundance of mussels, a sampling program of quantitative indicators should be considered. For example, the sampling program could be based on quantitative analysis of digital underwater images, which is an unintrusive sampling method.

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