2011 Sea Lettuce Harvest Pilot Project Report

April 2012

PEI Department of Environment, Labour and Justice
and the
PEI Department of Fisheries, Aquaculture and Rural Development

EXECUTIVE SUMMARY

This report summarizes the outcomes of a pilot sea lettuce harvest project conducted in Prince Edward Island, Canada during the summer of 2011.

The harvest of sea lettuce has been discussed as a possible means to reduce or eliminate anoxic events in PEI. Although this practice has been attempted in other areas, there is limited information available that would help guide this activity on PEI. This pilot was conducted to determine: (1) the effectiveness and efficiency of a sea lettuce harvest on PEI, (2) the harvest intensity required to impact sea lettuce populations, (3) the harvest intensity required to prevent anoxic events from occurring and (4) the environmental impacts resulting from the harvest.

Two levels of harvest intensity were planned. A single harvest was completed in the Covehead Bay estuary between June 27th and July 2nd, 2011. Two harvests, separated by a two week interval, were completed in the Mill River estuary; from July 11th to 20th and from August 6th to 8th, 2011. In addition, a single harvest was carried out in the Hills River (July 8 – July 9) to determine the impact of sea lettuce harvest on shellfish resources.

A monitoring program was conducted to determine the amount of sea lettuce harvested through the pilot, the degree to which sea lettuce populations are impacted by harvest, the re-growth rate of sea lettuce after harvest, impacts on water quality (anoxic events and dissolved oxygen levels) in harvested estuaries, impacts on aquatic life within the harvest zone (by-catch, shellfish survival, and finfish community composition), impacts on sediment quality and impacts on sediment disruption. The full monitoring program was conducted in Covehead Bay and Mill River estuaries, as well as in a reference site, the Wheatley River estuary. In Hills River, only by-catch, sediment quality and harvested volumes of sea lettuce were monitored.

The project was successful in harvesting a total of 64.8 tonnes of sea lettuce from Covehead Bay, 29.9 tonnes from Hills River and a total of 146.2 tonnes (99.9 tonnes on the first harvest, 46.3 tonnes on the second harvest) from Mill River. All harvested sea lettuce was either spread on agricultural land or composted.

Only small reductions in sea lettuce density were observed in the Mill River as part of the July 11th to 20th harvest. It was unclear whether this decline was due to the harvest or was a result of anoxic conditions. All other changes in sea lettuce density observed during the project were attributed to the onset of anoxic conditions. The monitoring program was intermittent, with some gaps that made tracking the cause of changes difficult. Results of the shellfish survival and sediment quality were conclusive only of the existing eutrophic/anoxic conditions in the estuary and did not demonstrate any impact from the harvest activity. Some changes in estuary floral and faunal composition may have been linked to harvest however these were more likely due to seasonal changes in community structure.

The amount of sea lettuce harvested through this project was insufficient to prevent anoxia from occurring in all three harvested estuaries. Additional and more frequent harvests would have been required to prevent anoxia. Even if this intensity of harvest can be achieved it is not certain that anoxia can be prevented as there may be a large standing crop of sea lettuce remaining in un-harvestable areas of the estuary (in areas < 0.6 m and > 1.6 m – 3 m in depth).

The effectiveness of harvesting submerged versus floating sea lettuce mats could not be adequately assessed by this project, as weather conditions in the summer of 2011 were not conducive to producing floating mats. It is thought that there is so much sea lettuce biomass present in PEI estuaries that a harvester may have to target submerged, actively growing sea lettuce to insure that the biomass does not reach a level that would result in anoxia. It is suggested that earlier harvests, conducted prior to reaching peak biomass and the onset of senescence (floating mats), may provide the time required to carry out the very intense harvest required to prevent anoxic events.

The pilot project was expensive; costs of $581/hr for the sea lettuce harvest and $322/tonne of harvested sea lettuce were incurred. Many inefficiencies were identified that could be addressed in any future work in order to reduce costs. These include having closer sites for offloading, which also have no severe drop-off, suitable depth and shelter from wind. The company operator should provide additional support equipment, such as a truck for moving the conveyor, a mooring for the harvester and a boat to access the moored harvester. Additional efficiency could also be achieved if the truck used to move the conveyor could also haul harvested sea lettuce from the site.

Harvest operators should work with the tides, instead of by a strictly 8–5 schedule and harvesting should be suspended in adverse weather conditions. A transport barge would make harvest more efficient by enabling the very slow harvester to continuously harvest. Compaction of the sea lettuce on the harvester may also be beneficial, enabling the harvester to work for longer periods before offloading. A modification of the harvester's cutter head to a take up reel, similar to hay balers' could also improve efficiency (by 40% based on estimation) as would modifications that would make adjusting the shore conveyors jack up legs and conveyor angle easier.

Projected harvest costs were estimated from the cost reductions and increased efficiencies that were considered. The operator has indicated that project costs would about $250/hour in the future. With harvest efficiencies inproved to 7 tonnes per hectare (not considering sailing times to oofload sites) this amounts to a projected harvest cost of $45 to $62 per tonne.

The projected harvest efficieincies and estimated sea lettuce volumes indicate that a single harvester would be required to manage sea lettuce populations in just one to two estuaries. Harvest costs are dependent on estuary size and projected harvest costs are provided for several estuaries with known issues with anoxia and/or sea lettuce. Harvest costs of $73,000 to $124,000 are estimated for the main branch of Mill River, $48,000 to

$81,000 for Hills River and $58,000 to $98,000 for Covehead Bay. It was estimated that it would cost between $2,000,000 and $3,400,000 to harvest all impacted estuaries on Prince Edward Island and that 12 – 14 harvesters would be required.

All harvested sea lettuce from this pilot was either spread on agricultural land or used for producing compost. Preliminary assessment of land spreading indicated that this practice provided some benefit to fields however the applied lettuce had a tendency to clump up, killing the grass beneath, indicating that chopping is required. Land application is also restricted by the timing of sea lettuce harvest and the need apply to forage crops after a first cut so the value to farmers and willingness to pay for harvested sea lettuce may be limited. Compost is is labour intensive to produce and the amount that can be charged for the finished product is fairly low, so there is little ability for composters to pay for harvested sea lettuce, especially if a similar product could be obtained at no cost from other sources.

Currently, there are few options to sell harvested sea lettuce to produce a value added product in order to offset the cost of harvesting to make it a sustainable activity. The production of biogas from sea lettuce is used as a practical example. With potential returns of between $11 and $53 per tonne of sea lettuce (not including biogas production costs) this activity would not cover all harvest costs.

The cost/benefit relationship of sea lettuce harvest would have to be carefully weighed against the alternative; the costs associated with reducing nutrient inputs to the point where anoxic events no longer occur.

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1. INTRODUCTION

Excessive growth of sea lettuce (*Ulva lactuca* L.) has become a serious issue in PEI in the last 3 - 4 decades. Many Island estuaries are full of sea lettuce during the summer months. With growth rates >30% per day (Sharp *et al*. 2003) sea lettuce biomass can increase almost exponentially with plants doubling their size in just a few days. Sea lettuce is also known to experience several periods of growth, die back and re-growth during the summer (Sharp *et al*. 2003; ELJ unpublished data) so the total amount of sea lettuce that is produced in any particular estuary can be quite large.

Problems associated with the heavy growth of sea lettuce include:

- Loss of aquatic habitat.
- Death of shellfish due to smothering.
- Thick mats of sea lettuce on shorelines resulting in odours and the disruption of activities such as swimming and boating.
- Large daily fluctuations in dissolved oxygen levels as large amounts of sea lettuce produce oxygen during the daytime and consume oxygen at night.
- Depletion of dissolved oxygen in the water as sea lettuce decomposes.
- Anoxic events.
- Death of aquatic life (shellfish, other invertebrates and fish).
- Enrichment of the bottom sediments with organic matter - *"black mayonnaise"*

The Island's sea lettuce issue can only be solved by addressing the root cause of the issue; the nutrient load from human activities. Even if nutrient reductions were to begin immediately, it would be at least 5 – 10 years before any impact on sea lettuce growth would be observed (Jiang and Somers 2009). Many Islanders feel that this is too long to wait for improvements in the sea lettuce situation.

The harvest/removal of sea lettuce from heavy growth areas of estuaries has the potential to be an effective mitigation measure in reducing the negative effects of sea lettuce growth (MacKenzie 2005). If a critical mass of the sea lettuce biomass can be removed from the system water quality may improve, anoxic events may be prevented and heavy accumulations of sea lettuce mats and organic material on shorelines, shellfish beds and sediments may be greatly reduced.

Transcon International Sales and Service is a private company which has brought a mechanical aquatic weed harvester to Prince Edward Island in order to explore the potential of sea lettuce harvest as a business opportunity. Although sea lettuce removal has been tried in other areas there are few answers available in the literature to effectively guide and plan this activity in PEI. Some basic questions need answers:

- How efficient is sea lettuce harvest under PEI conditions?
- What degree of harvest/removal effort is needed to keep sea lettuce populations in check? Once harvested will sea lettuce simply re-grow quickly requiring additional removal?

- What degree of harvest/removal effort is needed to prevent severe conditions, such as anoxic events?
- What environmental effects/impacts are achieved by the harvest activity?

During the summer of 2011 a pilot sea lettuce harvest project was carried out in PEI to determine if removal is an effective way to mitigate the issue of excessive sea lettuce growth in PEI's estuaries. This report describes the pilot harvest that was carried out, the outcomes of this work and the results of a monitoring program which documented the environmental effects of the harvest.

2. PROJECT DESCRIPTION

2.1. Harvest Activity

To determine the level of harvest required to prevent anoxic events two different levels of harvest intensity were planned; a single harvest for one estuary and two harvests, separated by one to several weeks, for a second estuary. Estuaries considered for harvest under the pilot had issues with abundant sea lettuce growth and anoxia, water depths suitable to the operational depth of the harvester (0.45 m to 1.83 m) (Transcon personal communication April, 2011), nearby offload sites that did not require significant site preparation for use, no nearby shellstock resource or fishery and landowners/operators willing to accept the harvested sea lettuce for either land spreading or composting. For the initial stages of the project a request by Transcon to have a location close to the company's home base in Charlottetown was also considered.

The matrix used for site selection is shown in Appendix A. The final selection of sites was made by the project Steering Committee (see Acknowledgements). The two sites chosen were Covehead Bay and Mill River. Both sites have problems with sea lettuce and have experienced anoxic events, although Covehead Bay has had less frequency of these events than some other estuaries (ELJ unpublished data). Covehead Bay had the proximity to Charlottetown requested by the operator and both sites had a committed community watershed group with local landowners willing to accept the harvested sea lettuce. Both estuaries also had offload sites, although neither site was very close to the harvest area. A third estuary site, the Hills River estuary, was subsequently added per a request from the PEISA to do a trial harvest in an area that had an existing shellfishery in order to determine the impacts of harvest on shellfish stocks. Hills River had initially been eliminated as a site for consideration due to having a viable oyster fishery located within the potential harvest area.

A license to harvest marine plants, within predetermined areas of the three estuaries, was obtained from Fisheries and Oceans Canada.

An Aquarius Systems 170 aquatic harvester, owned and operated by Transcon International of Charlottetown PEI, was used to carry out this project (Figure 1).
A shore conveyor was used for offloading the harvester to tandem wheeled dump trucks, single axel (1 tonne) dump trucks or slide off containers (Figure 2).

Figure 1. Aquarius 170 aquatic harvester used in project.

Figure 2. Shore conveyor and truck**.**

A single harvest was conducted in Covehead Bay between June 27th and July 2nd. The harvester was on site in Covehead Bay beginning on June 22nd; however, the period between June 22nd and June 24th was used by the operator to train new local operators using an experienced operator from Florida. Only a small portion of the work conducted prior to June 27th was considered to be productive harvest time.

A single harvest was carried out in Hills River on July 8th and 9th, while two harvests were carried out in the Mill River estuary. The first harvest was carried out in Mill River from July 11th – July 20th and the second between August 4th and August 6th.

2.2. Monitoring Program

A monitoring program was designed to determine the impacts of the harvest activity. The full monitoring program was carried out in two of the three harvested estuaries (Covehead Bay and Mill River). Wheatley River was used as a reference site for comparison for all monitoring except CAMP sampling where the Trout/Stanley River was used as a reference site. The reference estuaries had similar characteristics to the harvested estuaries. The monitoring program had the following components:

- General observations
- Biomass of sea lettuce harvested
- Changes in sea lettuce cover and density in harvest zone
- Impacts on aquatic life in harvest zone
    - By-catch
    - Shellfish growth and mortality
    - Community Aquatic Monitoring Program (CAMP)
- Water Quality
    - Dissolved oxygen levels
    - Occurrence of anoxic events
- Sediment quality
- Sediment disruption

A short description of the methodology used is included in the following sections. Since the Hills River was a short trial used to determine the effect of harvest on shellstock resources, a significant impact on the sea lettuce population or water quality was not expected. Hills River was not included in the monitoring program other than recording the amounts of sea lettuce harvested, sediment conditions and by-catch sampled.

3. MONITORING METHODS

3.1. Biomass of Sea Lettuce Harvested and Harvest Efficiency

The biomass of harvested sea lettuce was estimated using the recorded number of harvester loads (Appendix B).

Three loads of sea lettuce, from which excess water had been allowed to drain, were weighed during the project. From these values it was estimated that a harvester load weighed approximately 2.7 metric tons (6000 lbs). The volume harvested was estimated from the dimensions of the harvester's bed and was about 15 m^3 (530 cu. ft). Biomass values were used to assess harvest efficiency.

3.2. Changes in Sea Lettuce Cover and Density

Initially, it was assumed that sea lettuce standing crop and changes in standing crop following harvest could be quickly and easily monitored using visualization of bottom coverage. Unfortunately, this methodology could not be used to determine the overall effect of harvest on sea lettuce biomass. Rather than leaving bare swaths or patches on the bottom it was apparent that the harvester left a significant amount of sea lettuce behind after each harvest pass (Figure 3). This was due to some lettuce being left below the “cutting” head of the harvester, but also because the paddle wheels used for propulsion disturbed large quantities of sea lettuce on each side of the machine as it passed through an area. Disturbed sea lettuce settled back over the newly harvested area in the wake of machine. Other than occasional areas with bare patches of bottom showing it was often difficult to determine where the machine had harvested. The approach of using percent cover to quantify differences in sea lettuce coverage was abandoned in favour of a more labour intensive assessment of sea lettuce density in harvest and reference sites.

Figure 3. Sea lettuce remaining in harvester wake.

Three sites each were chosen from representative areas of Covehead Bay, Mill River and Wheatley River (Figures 5 - 7). These sites were in effect a box of approximately 1,000 m^2, located in shallow areas (< 1.5 m in depth) of each estuary which had been previously identified as having >80% sea lettuce coverage prior to harvest. On each sample date 3 replicates were randomly chosen within this box, avoiding sites that had been previously sampled. A 0.25 m^2, 0.5 m high aluminium quadrat (Figure 4) was tossed overboard and all sea lettuce within were harvested by hand by snorkelling. The collected sea lettuce was cleaned, rinsed free of sediment and placed into a 5 L plastic graduated cylinder which had been drilled with numerous small holes to allow the escape of water. A wooden plunger was used to compress the sea lettuce until most excess water was pressed out. The volume of sea lettuce (in ml) was recorded and converted to m^3. Median values were used to estimate biomass and comparisons were made using the non-parametric Kruskal-Wallis test.

Figure 4. 0.25 m^2 quadrat used to sample sea lettuce density.

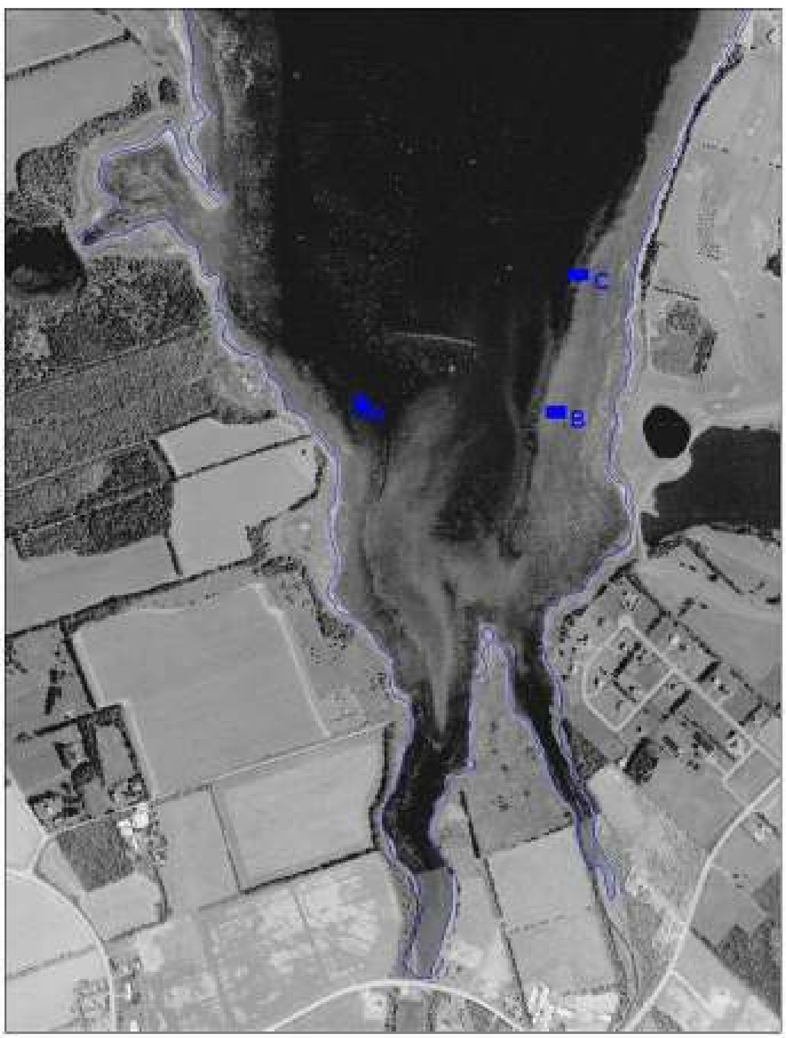

Figure 5. Ulva sampling sites in Covehead Bay.

These sites were sampled five to six times per estuary beginning in early July until mid September. The data (Appendix C) was analyzed and presented graphically using Systat 10.

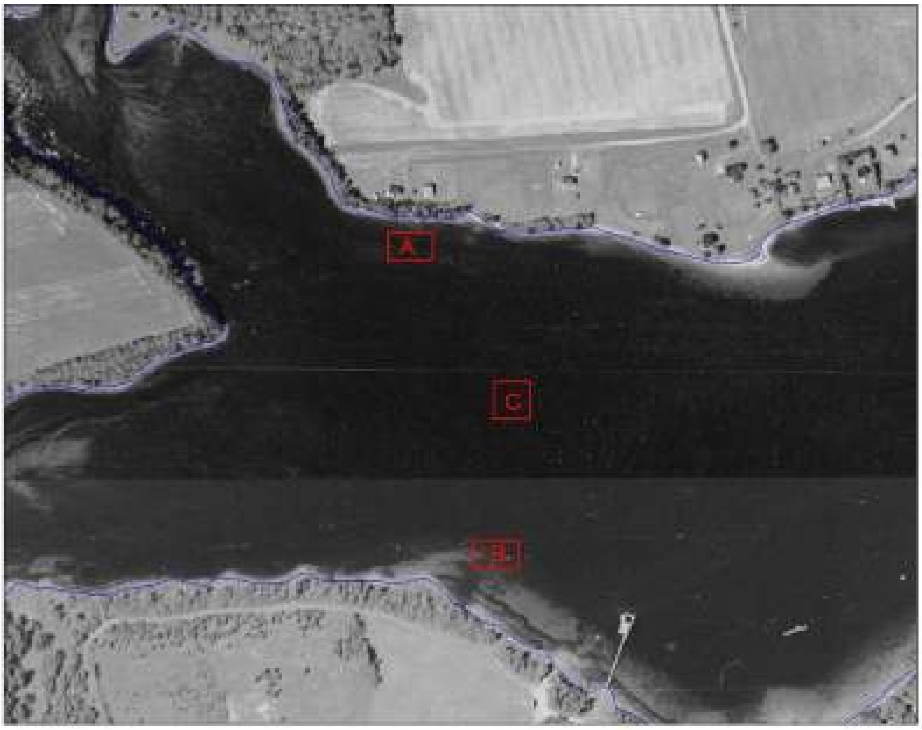

Figure 6. Sea lettuce density sample locations in Mill River.

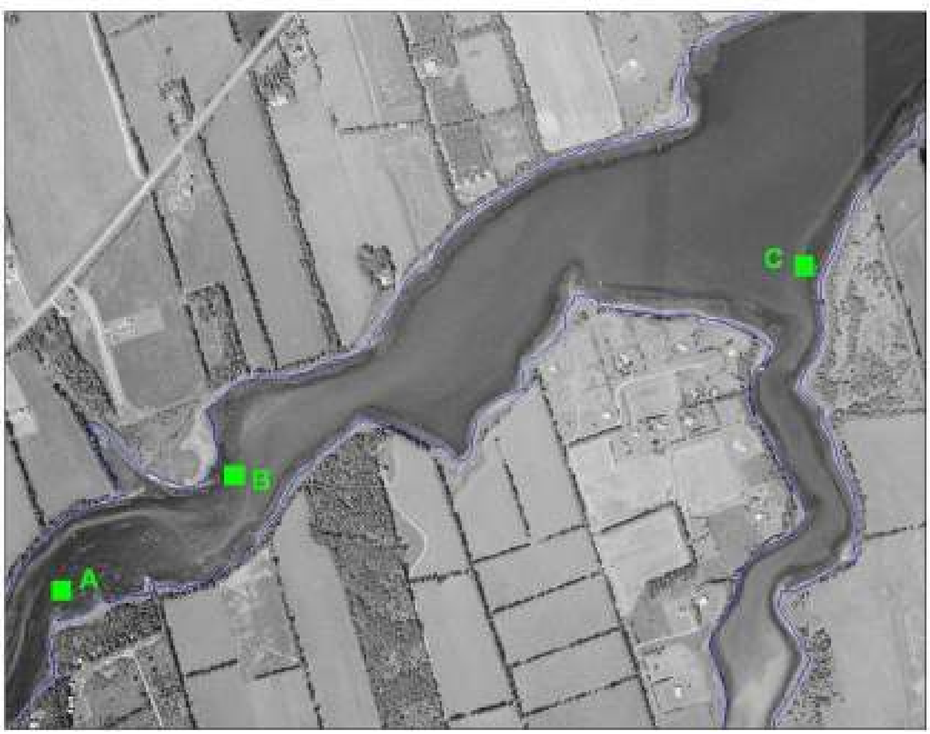

Figure 7. Sea lettuce density sample locations in Wheatley River.

3.3. Impacts on Aquatic Life in Harvest Zone

3.3.1. By-Catch

Random samples of the harvested sea lettuce were checked for the presence of by-catch (fish and invertebrates) during the harvest operation in each of the three harvested estuaries (Appendix D). In Covehead Bay, the assessors originally tried counting by-catch on the conveyor belt as the sea lettuce was offloaded. This method was ineffective, as by-catch was covered by sea lettuce and was not visible. The speed of off loading also made it dangerous for the assessors to try and count and record by-catch. Data collected in this manner was not used in the final by-catch tally. For the remainder of the project in Covehead Bay, two people sorted through a large pile of harvested lettuce for approximately 20 minutes each. This was estimated to be a volume of about 1.13 m^3 per count.

In the Hills and Mill Rivers, one fish crate of sea lettuce (approximately 0.07 m^3) was randomly collected from the off load conveyor during each day's harvest and sorted. By-catch sorting in the Mill and Hills took two people approximately 45 minutes to 1 hour to complete even though < 10% of the volume of sea lettuce checked in Covehead Bay was being sorted. Consequently, the by-catch results from Covehead Bay are not considered comparable to those from Hills River and Mill River.

Fish and invertebrates present were identified using keys provided by DFO's CAMP.

The data (Appendix D) was analyzed and presented graphically using Excel 2003.

3.3.2. Shellfish Growth and Mortality

The direct impact of the activity on shellfish was monitored by placing cages with oysters inside the harvest area of Covehead Bay and Mill River and in the corresponding high density sea lettuce growth area of the reference estuary, Wheatley River (Figures 8, 9 and 11). Three sites were setup in each of the two harvest areas and the reference area. At each site a Vexar™ oyster bag with 25 oysters was deployed, along with an oyster rack with another 25 oysters (Average length = 57mm). The oyster rack was the optimal experimental design, as the top of the rack was open, most closely representing the natural interaction with the environment. The Vexar™ bag was used to ensure there would be shellfish to evaluate at the end of the trial; however, this style cage may be more susceptible to smothering by sea lettuce than the bottom rack. A surface buoy was deployed at each site, but was not attached to the cages to ensure that no tampering occurred with the monitoring station. The cages were deployed at the end of June and collected in late September. Growth rates and mortality were recorded (Appendix E).

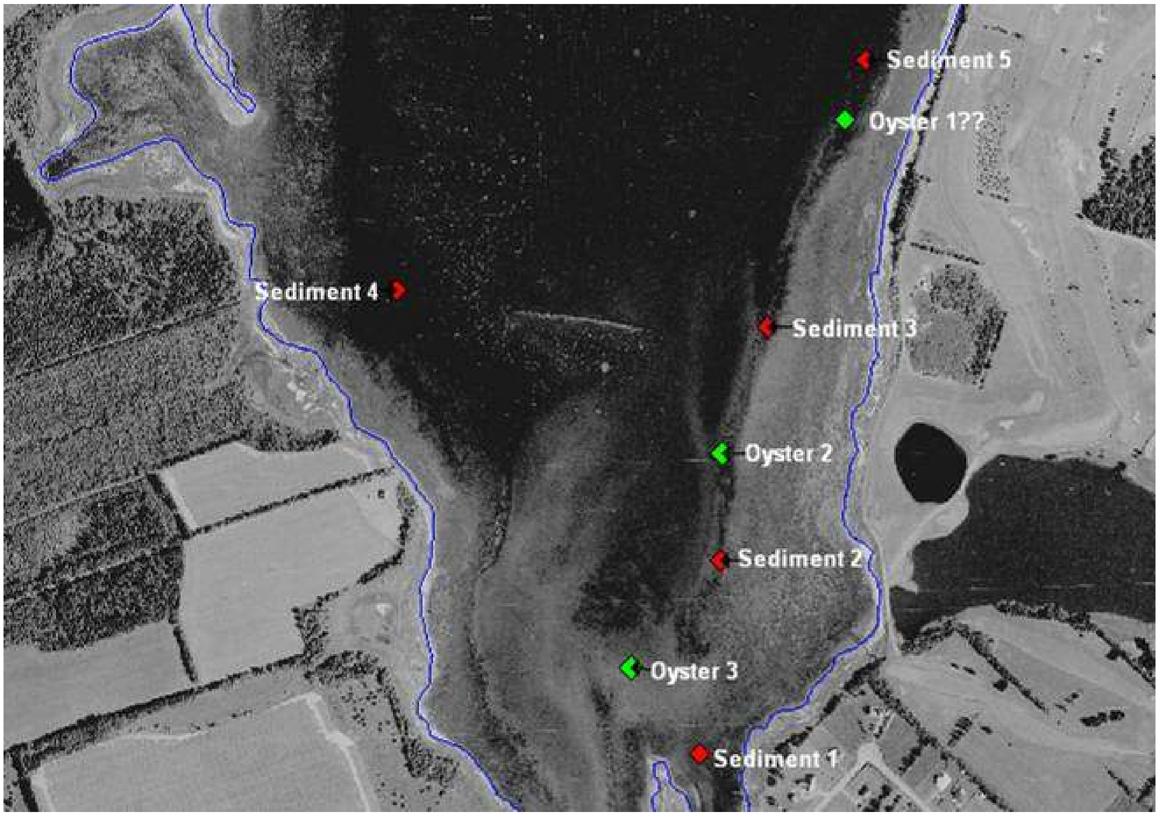

Figure 8. Shellfish survival and sediment sample locations in Covehead Bay.

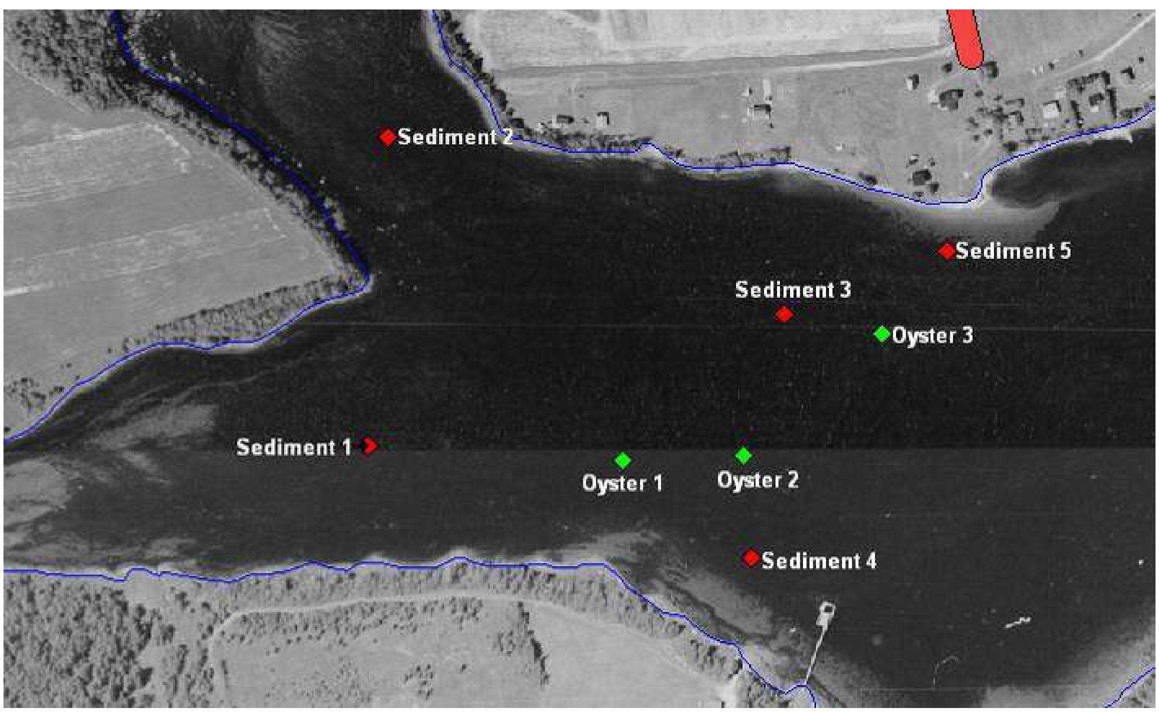

Figure 9. Shellfish survival and sediment sample locations in Mill River.

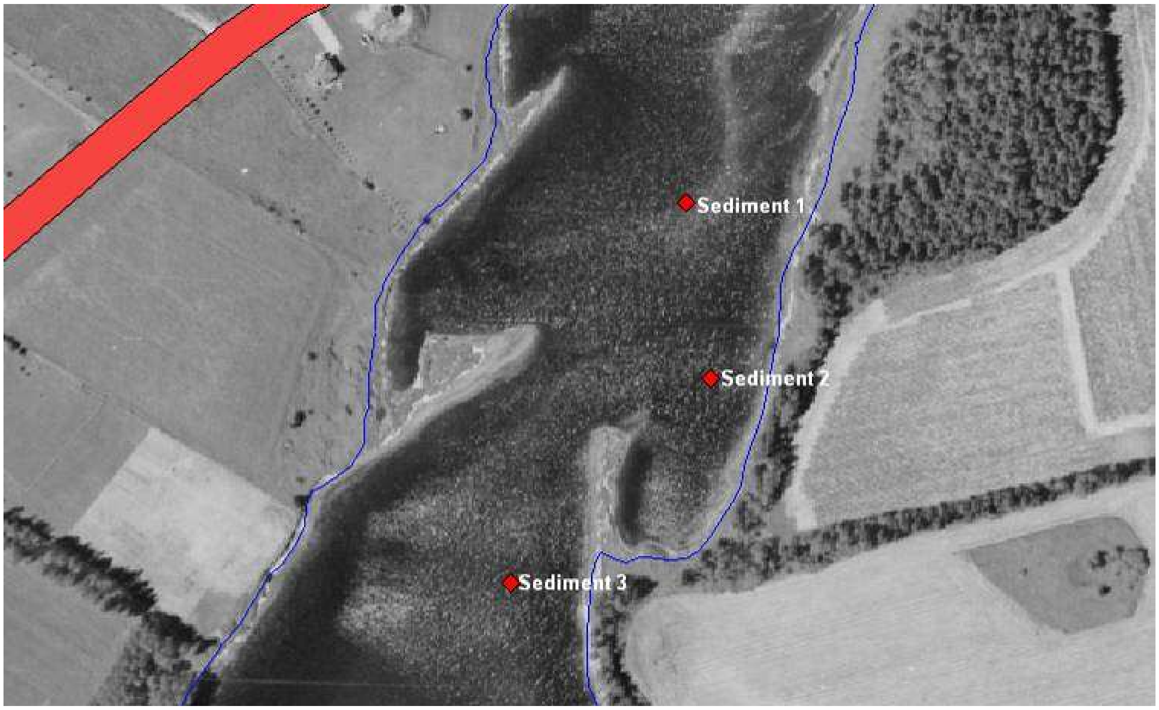

Figure 10. Sediment sample locations in Hills River.

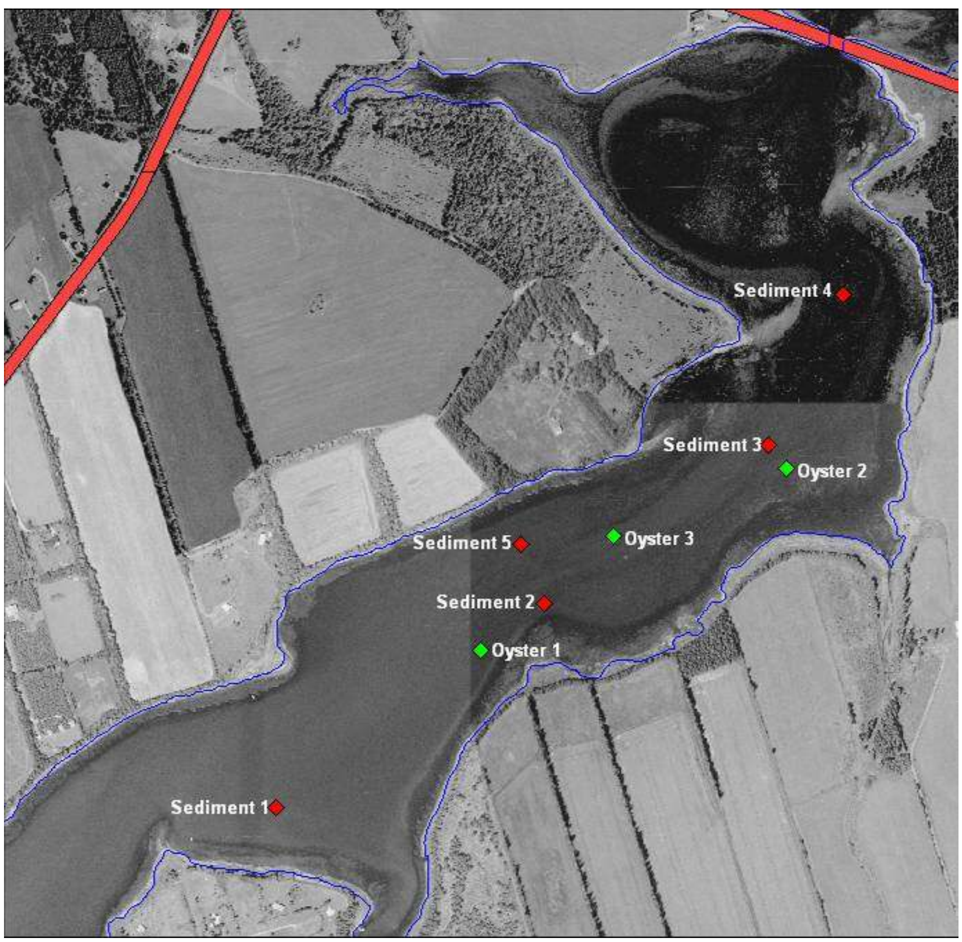

Figure 11. Shellfish survival and sediment sample locations in Wheatley River.

3.3.3. Community Aquatic Monitoring Program (CAMP)

CAMP was developed by DFO as a cooperative program for the assessment of estuarine health. Fish and invertebrates are collected by beach seining over an area of approximately 225 m^2. Six sites in each estuary are seined in each estuary in June, July and August. All fish and invertebrates captured are identified, counted and released. Sea lettuce and eel grass coverage within each beach seine area is estimated as one of six categories (0 = 0%, 1 = < 25%, 2 = 25 – 5-%, 3 = 50 – 75%, 4 = 75 – 100% and 5 = 100%).

Figure 12. CAMP sites in Mill River.

Figure 13. CAMP sites in Covehead Bay.

CAMP sampling began in Mill River in 2004 and in Covehead Bay in 2011. The six existing CAMP sites in each estuary were sampled (Figures 12 -13); however, only 1 site in each estuary was found within the harvested area (Site # 1 – "Resort" in Mill River and Site # 1 – "Golf Course") in Covehead Bay. The Trout/Stanley River was used as a reference estuary, rather than the Wheatley River, since it was an existing estuary for the DFO program and had data for comparison going back to 2004. Trout River was sampled on June 9th, July 6th and August 4th. Covehead Bay was sampled on June 22nd (1 week prior to harvest), July 20th (2 weeks following harvest) and August 18th, while Mill River was sampled on June 23rd (2.5 weeks prior to harvest), July 21st (immediately following the first harvest) and August 19th (2 weeks following the 2nd harvest).

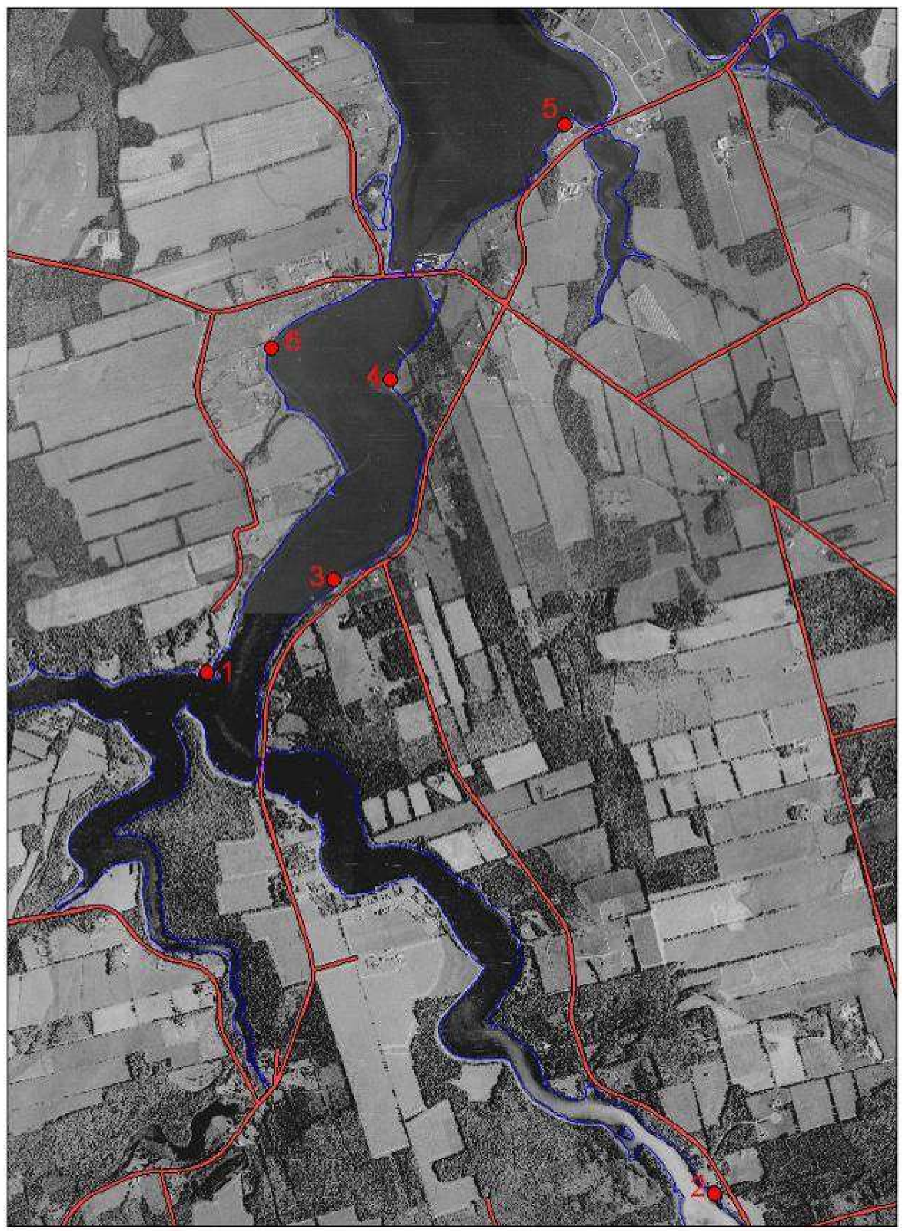

Figure 14. CAMP sites in Trout River.

3.4. Water and Sediment Quality

3.4.1. Dissolved Oxygen Levels and Anoxic Events

Dissolved oxygen was monitored using a YSI-85 multi-meter. Measurements were taken both at the surface (0.3 m depth) and bottom (0.3 m from bottom) in all sites where water depth exceeded 1 m. At sites where depth was < 1 m a single mid depth reading was taken. This monitoring was carried out periodically and sites were co-located with the sea lettuce volume sites (Figures 5 - 7). Sampling was initiated by early July, prior to the start of the harvest, and continued into late August. Additional parameters collected included tidal stage, water temperature and salinity. The data (Appendix C) was analyzed and presented graphically using Systat 10.

ELJ keeps an annual record of anoxic events for PEI. This information is gleaned from staff observations as well as calls and other input from the general public. Information from anoxic events recorded for Covehead Bay, Hill River, Mill River and Wheatley River was used in this project.

In addition, a daily log of conditions within the estuary was kept in the Mill River. The appearance of the water, presence of odours and amount of sea lettuce were recorded in a daily log (Appendix F). This information was collected by a volunteer local resident and was collated by the ELJ. A similar weekly log, kept by staff of FCBB, for Covehead Bay, was also used to track anoxic events.

3.4.2. Sulfides in Sediments

Sulfides in bottom sediments were measured to determine the overall health of the benthic environment. Measuring free sulfides in benthic environments can give an indication of the oxic condition of these sediments. The sampling followed protocols developed by FARD. A total of five sites were sampled in the two harvest areas (Covehead Bay and Mill River) (Figures 8 and 9), as well as the reference area, Wheatley River (Figure 11). Each of these sites was sampled in triplicate in early July, mid August and late September (Appendix G). In addition, three sites were sampled in Hills River (Figure 10) in early July when the river appeared to be going anoxic.

Figure 15. Sampling bottom sediments with Ekman grab.

3.4.3. Sediment Disruption

The harvest activity has the capacity to disrupt sediments which could be re-deposited on sensitive downstream habitats. ELJ staff kept a record of the details of visible sediment plumes produced (size, appearance) during times when they were on site.

4. RESULTS

4.1. General Observations

The operational depth of the harvester was given as 0.45 m to 1.83 m by the equipment operator (Transcon personal communication April, 2011). In practice, harvest in shallow areas was limited by bottom conditions as very soft or muddy conditions caused plumes of sediment to be released (Figure 16), generally as a result of the paddle wheels used for propulsion on the harvester. Operation in depths over 1.2 m was limited when poor visibility (cloudy or turbid conditions) made seeing the bottom difficult for the operator. The actual operational depth during this project was 0.6 m – 1.6 m.

Figure 16. Sediments disturbed by paddle wheels.

The harvester was equipped with a cutting head (Figure 17). Generally aquatic weed harvesters of this type are used for harvesting rooted aquatic plants in freshwater systems. The cutting head shears off this vegetation below the surface and at the edges of the cutting swath. Sea lettuce is not rooted or strongly attached to the bottom. The cutting head is therefore not really necessary to harvest sea lettuce.

During harvest it was noted many times that the “cutting” head has to pass very close to the bottom to harvest submerged sea lettuce. Despite this, some sea lettuce on the bottom was not harvested, as the cutting head simply passed over it. Some observers indicated that the cutters should be removed to facilitate the pick up of the un-attached sea lettuce.

It has also been suggested that runners on the cutting head would help to keep it off of the bottom; however, having the head run into the bottom was not really an issue when the visibility was good.

Figure 17. Harvester cutting head.

4.1.1 Covehead Bay

The harvest in Covehead Bay was carried out between June 27th and July 2nd, 2011. The estimated area harvested during this time (19.9 ha) is shown in Figure 18. Floating mats of sea lettuce were targeted as this is the standard operational practice in Florida, per the training operator.

During the Covehead Bay harvest there were only a few days when significant amounts of floating sea lettuce were present. On June 27th floating mats in the Auld's Creek branch and south eastern portion of the estuary were harvested. Homeowners along the lower Auld's Creek indicated that 'this area was all cleaned up" at this time. ELJ staff noted that there were still significant amounts of sea lettuce in this area of the estuary immediately after harvest (Figure 20), although homeowners indicated that sea lettuce was not visible from shore.

Dense floating mats of sea lettuce were also present on June 30th on the western shore of the estuary. One large mat extended from the mouth of Cass's Creek downstream to a small marsh (Figure 19). On all other days smaller amounts of floating lettuce were available for harvest, with the remainder of the harvest time spend harvesting submerged lettuce. On most harvest days access to floating lettuce was limited by shallow water as the floating mats tended to be windblown along the shoreline and were not accessible.

Figure 18. Area harvested in Covehead Bay from June 27 to July 2.

Figure 19. Dense floating mat of sea lettuce.

Figure 20. Sea lettuce present on bottom after harvest near mouth of Auld's Creek, June 29 2011.

Weather during the month of June may have played a role in the absence of floating lettuce. There were numerous cloudy and windy days which seemed to have the effect of lowering growth rates and keeping the sea lettuce submerged. A number of local homeowners commented that there seemed to be less sea lettuce present during June 2011, than in previous years.

Harvest of dense floating mats of lettuce was observed to be a very efficient use of harvester time. Full harvester loads (2.7 tons or 15 m^3) could be completed in as little as 15 minutes in these areas, representing a harvest rate in excess of 10 tons/hr. In contrast, harvest rates in areas of submerged lettuce were in the range of 30 to 40 minutes per load (not including sailing time) representing a harvest rate of (3.6 to 5.4 tons/hr).

There was some evidence that sea lettuce populations in the upper estuary were starting to decline during the period of harvest. Bacterial mats were recorded in Auld's Creek on June 28th (Figure 21) and on June 30th black anoxic sediments were present in Cass's Creek causing harvest to be suspended in this area due to the presence of silt plumes (Figure 16). Both areas showed 100% coverage of sea lettuce and no indication of decaying lettuce the previous week (ELJ staff).

During the Covehead Bay harvest the offloading location was the concrete slipway located off the entrance to the Stanhope Golf Course (Figure 18). This site was located approximately 1.3 km from the middle of the harvest area. Sailing time to and from the upper estuary harvest sites was about 15 to 20 minutes, on average. This greatly reduced the harvest efficiency of the machine. On June 28th, the harvester was operating along the shoreline by the Stanhope Golf Course. The travel time to and from the harvest area was greatly shortened (< 10 minutes) during this time. The amount of sea lettuce harvested on June 28th was the highest amount recorded at Covehead Bay (Table 2) despite there being little floating lettuce accessible to the machine at this time.

Figure 21. Bacterial mats growing on bottom in Covehead Bay, June 28, 2011.

Harvest efficiency was also affected by tidal conditions during the week of harvest. Between June 27th to July 2nd there was a period of near diurnal spring tides with a reported range (at the nearest reference station) of 0.2 to 1.0 m (http://www.waterlevels.gc.ca/cgi-bin/tide-shc.cgi). During this period high tides were in the very early morning with the low tide level being recorded by midmorning to midday as the week progressed. The lowest tides of the week were recorded on June 29th and 30th (0.2 m). Incidents of grounding were associated with the low tides. The solution to this problem was to push the conveyor out further into deeper water, but because the site was a boat slip there was a significant drop off in depth instead of a gradual decrease. On several occasions, particularly on June 30th, the end of the conveyor was in such deep water that the offloaded lettuce would simply float rather than being carried up the conveyor.

The docking issue was also compounded by the operator not having a truck on site, which could move the conveyor into (and out of) deeper water as the tide level changed. Eventually a method was developed which used the tandem wheeled dump truck, on site to haul the lettuce away, to push and raise the conveyor using the box of the truck. On days when only a smaller single axel dump truck was available this method did not work, as the truck did not have a high enough box to push the conveyor.

It was clear that the conveyor used is best suited to situations where water levels remain constant. The conveyor is equipped with a cable and pulley system and jack up legs that can raise and lower the conveyor boom and configure it to suit a particular offload site. Unfortunately, this set up was cumbersome to use when it had to be adjusted very frequently. Some observers suggested that the conveyor be converted to a hydraulically operated system.

4.1.2 Hills River

Hills River was reported to have water quality conditions that indicated anoxia on both July 4th and July 6th just days prior to the start of harvest in the estuary. The observed conditions included a slight grey discoloration of the water along with odours. It was windy and rainy at the time making it difficult to determine the source; however, it appeared that most of the odour was coming from the very shallow upper area of the estuary, just above the area harvested later in the week. Dissolved oxygen readings taken in the affected area were near 0% saturation on the bottom and 85% on the surface in 1 m of water. Despite this anoxia there was plenty of sea lettuce available for harvest by July 8th. No sea lettuce density measurements were made in the Hills River.

A single harvest was carried out in Hills River on July 8th and 9th. The estimated area harvested during this time is shown in Figure 22**.** Both floating and submerged sea lettuce was harvested. There were a few days of warmer sunny weather immediately preceding this harvest which caused the lettuce to be floating and raised off of the bottom slightly. Since the goal of this harvest was to determine the impact on shellstock resources the "cutting" head harvester was lowered to near the bottom during harvest.

The area harvested was recorded by the operator, but was likely underestimated. Observations made by ELJ staff who were monitoring the work indicated that the harvest covered a larger area than was indicated by the operator. The maps used to record harvest locations lacked reference points such as roads, trees and buildings. As a result the drawings used to represent harvested areas may have been somewhat inaccurate. It is estimated that the actual area harvested was twice the size of the area indicated by the operator. These estimated harvest areas are shown in Figure 22.

The offload site for the harvest activity was a beach access in the upper river that was located near the lower end of the harvest area (Figure 22). During the harvest the typical sail to the harvest area was 500 to 750 m and required only 5 or 10 minutes to complete on average. Tides during the harvest were neap with a range of only 0.3 to 0.4 m at the nearest reference site (http://www.waterlevels.gc.ca/cgi-bin/tide-shc.cgi). This required less moving of the conveyor to accommodate docking. The site also had a gradual drop off. Operators had, by the time of the Hills River harvest, become very efficient at moving the conveyor. During the Hills River harvest multiple trucks (up to 3) were available to haul the sea lettuce and there was never any down time waiting to offload the harvester even though the harvested sea lettuce was being trucked some considerable distances.

Figure 22. Area harvested in Hills River on July 8 and 9.

4.1.3 Mill River

The first harvest in the Mill River was carried out between July 11 and July 20, 2011. The areas harvested are shown in Figure 23. During this time only submerged sea lettuce was harvested. The weather during the harvest was generally cloudy and windy. Wind and rain curtailed harvest activities on more than one day. The cloud and rain had the effect of keeping the sea lettuce very close to the bottom within the harvest area. The sea lettuce also appeared to be less whole and more shredded in appearance than the lettuce harvested in Covehead Bay or Hills River. As a result, the harvester had to operate more slowly and carefully in order to not get too close to the bottom.

The offload site used for the first Mill River harvest was a beach access (Figure 24) located about 1.6 km from the centre of the harvest area. This required sailing times of 20 - 25 minutes, on average, to and from the harvest area. This greatly reduced the harvest efficiency (Table 1). Spring tides were present during this harvest with tidal ranges of up to 0.9 m a day at the closest reference station. This was not a factor in slowing harvest efficiency because operators had become efficient at moving the conveyor with the tides using the truck box as previously described, although the harvester did become grounded while docking with the conveyor on one occasion.

Figure 23. Area harvested in Mill River between July 11 to 20.

The second harvest in Mill River was conducted between August 4th and 6th (Figure 24). Again, very little floating sea lettuce was present and only submerged or bottom sea lettuce was harvested. Turbid conditions were present on the 4th which made seeing the bottom difficult, slowing the progress of the harvest. Some blackened sea lettuce was present at this time. By August 6th the upper estuary was experiencing an anoxic event. This event greatly reduced the harvest efficiency as the sea lettuce population began to collapse.

The offloading site used for this harvest was a beach access located about 750 m from the center of the harvest area (Figure 24). This required sailing times of about 10 minutes to and from the harvest areas. Once again tides were a factor. During this harvest the operator had no mooring available for the harvester. Overnight high tides left the harvester high and dry and the operator had to wait until the tide levels came up enough to float the harvester off the shore. While this did not affect the overall efficiency of the machine, valuable harvest time was lost and equipment such as trucks had to stand idly by at financial cost to the project.

Figure 24. Mill River harvest area showing launch area.

Figure 25. Harvest location in Mill River between August 4 to 6.

4.2. Biomass of Sea Lettuce Harvested

A summary of the biomass of sea lettuce harvested in each of the three estuaries is shown in Table 1. The Hills River harvest was the most efficient in terms of time (tonnes/hr), while the Mill River Harvest was the most efficient in terms of area harvested (tonnes/ha). This was because the Mill River had repeat harvests over the same area.

Table 1. Sea Lettuce Harvest Summary.

Estuary	Harvest Dates	Total Harvest (metric tonnes)	Harvest Time (hrs)	Sail Time (to & from loading site / load) (hrs)	Avg. Harvest Time /ton (hrs)	Total Area Harvested (ha)	Harvest Rate (tons/ha)
Covehead Bay	June 22 – July 2,	64.8	34.00	0.33	1.67	19.9[2]	3.12
Hills River	July 8 -9	29.9	12.00	0.20	2.49	6.0[2]	5.0
Mill River (1)	July 11 – July 20	99.9	58.75	0.42	1.71	16.64	6.0
Mill River (2)	Aug 4-6	46.3	24.50	0.18	1.89	17.25	2.7
TOTALS		240.9	129.25			56.37	

1 – Harvest amounts on June 23 and 24^{th} were not counted because this was slower than normal due to training being carried out. In addition harvest times are not available.

2 - Harvest Area Estimated by ELJ staff

4.2.1. Covehead Bay

A daily record of the sea lettuce harvest carried out in Covehead Bay is shown in Table 2. The operator did not keep a daily map of the harvested areas; however, ELJ staff were on site and were able to indicate the approximate area harvested in Covehead Bay.

Table 2. Harvest Summary: Covehead Bay, June 23 to July 2.

Date	Truck Loads	Harvester Loads	Tonnes (est. from harvester loads)	m^3 (est.)	Harvest Area	Harvest Time	Harvest Efficiency		Harvest Efficiency	
							T/hr	T/ha	m^3/hr	m3/ha
June 23	na	1	2.7	15	na	na				
June 24	na	2	5.4	30	na	na				
June 27	na	4	10.8	60	na	4	2.7	na	15	na
June 28	na	6	16.2	90	na	8	2.0	na	11.3	na
June 29	na	5	13.5	75	na	8	1.7	na	9.4	na
June 30	na	3	8.1	45	na	8	1.0	na	7.6	na
July 1	na	2	5.4	30	na	4	1.8	na	7.5	na
July 2	na	1	2.7	15	na	2	1.4	na	7.5	na
TOTALS		24	64.8	360	19.9*	34	1.7	3.3*	9.2	18.1*

* estimated using the estimated harvest area

There was some confusion in the amounts of sea lettuce being harvested in Covehead Bay. Initially, the operator indicated that the amount of sea lettuce being harvested was being reported as truck loads. It later became apparent that the reported amounts actually reflected harvester loads. Harvests on June 23rd and 24th were considered to be training time and were not included as productive harvest time (Table 1).

Harvesting was most efficient on days when floating lettuce was harvested (June 27th) or when the sail time to the harvest area was shortened (June 28th). Harvest efficiencies were lowest on June 29th and 30th when there were issues with docking the harvester due to low tides. This was a particular problem on June 30th when a large floating mat of lettuce was present on the west side of the estuary. Difficulties with the low tides compounded by not having a tandem wheeled dump truck on site to efficiently move the conveyor resulted in very low harvest efficiencies on that day. Harvest efficiencies on July 1st could have been slightly higher if a truck for hauling the sea lettuce had been on site. The harvester had to wait for a truck to arrive in order to offload the first load (July 1 was a holiday).

4.2.2 Hills River

The harvest in Hills River was free of some of the issues encountered at other sites. The harvest area was a relatively short sail to the offloading site and there were no issues with the conveyor and docking of the harvester at the site. The weather also cooperated. Both days of harvest were relatively warm and sunny. Some sea lettuce was floating and the lettuce was lifted off the bottom making it easier for the machine to pick it up. There was a breakdown of equipment on July 8th that did have some impact on harvest efficiency (Table 3). Although the down time was not counted as productive harvest time it did prevent the operator from conducting a single long day of harvest. It is assumed that long days would be more efficient than several short days.

Table 3. Harvest Summary: Hills River, July 8 – July 9.

Date	Truck Loads	Harv-ester Loads	Tonnes (est. from harvester loads)	m^3	Harvest Area	Harvest Time	Harvest Efficiency		Harvest Efficiency	
							T/hr	T/ha	m^3/hr	m^3/ha
July 8	3	7	18.9	105	3.2	7	2.7	5.9	15.0	32.8
July 9	1	4	10.8	60	2.8	5	2.2	3.8	12.0	21.4
Totals	4	11	29.7	165	6.0	12	2.5	5.0	13.5	27.5

4.2.3 Mill River – First Harvest

Harvest efficiencies in the Mill River were very similar from day to day (Table 4). This likely reflects the degree to which the operators had become familiar with the operation of the equipment. The harvest times were noticeably longer than in Hills River. This was mostly due to the much longer sailing times to and from the harvest area. The sea lettuce harvested in the Mill River was also much closer to the bottom and was more difficult to harvest so this may have had some impact on harvest times compared to Hills River.

Table 4. Harvest Summary: Mill River, July 11 to July 20.

Date	Truck Loads	Harvester Loads	Tonnes (est. from harvester loads)	m^3	Harvest Area	Harvest Time	Harvest Efficiency		Harvest Efficiency	
							T/hr	T/ha	m^3/hr	m^3/ha
July 11	4	5	13.5	75	3.70	8.0	1.7	3.6	9.4	20.3
July 13	2	3	8.1	45	2.90	4.5	1.8	2.8	10.0	15.5
July 14	1	2	5.4	30	4.04	3.5	1.5	1.3	8.6	7.4
July 15	2	3	8.1	45	2.78	4.75	1.7	2.9	9.5	16.2
July 16	2	5	13.5	75	5.27	8	1.7	2.6	9.4	14.2
July 18	5	7	18.9	105	5.44	11	1.7	3.5	9.5	19.3
July 19	4	6	16.2	90	4.63	9.5	1.7	3.5	9.5	19.4
July 20	4	6	16.2	90	7.82	9.5	1.7	2.1	9.5	11.5
Totals	24	37	99.9	555	36.85 16.64[1]	58.75	1.70	2.7 6.0[1]	9.41	15.1 33.4

1 – Values for the total area harvested rather than the area harvested on a daily basis

Table 5. Percentage of area previously harvested – Mill River.

Date	Harvested Amount (T)	Area Harvested (ha)	Harvest Efficiency (T/ha)	Percentage of Area Previously Harvested (%)
July 11	13.5	3.7	3.6	0%
July 13	8.1	2.9	2.8	0%
July 14	5.4	4.0	1.3	40%
July 15	8.1	2.8	2.9	90%
July 16	13.5	5.3	2.6	60%
July 18	18.9	5.4	3.5	86%
July 19	16.2	4.6	3.5	59%
July 20	16.2	7.8	2.1	64%
Daily Totals	99.9	36.6	2.73	
Totals	99.9	16.6	6.0	

The impact of harvesting the same areas multiple times is apparent from the Mill River results. Although daily sea lettuce yield averaged 2.7 T/ha the overall yield for the total area in which harvest was covered was much higher at 6.0 T/ha. At this rate of harvest it is clear that harvest does not remove all lettuce from a particular site after just one pass and that enough sea lettuce remains to justify subsequent harvest passes for the same area. The results may also indicate that sea lettuce is quickly replaced by either growth or accumulation and that continuous harvest may be necessary.

The areas harvested daily are shown in Figures 26 - 33. A cursory analysis of the percentage of areas previously harvested and how many times harvested is shown in Table 5. This does not shed much light on the daily differences in sea lettuce yield; however, areas harvested on back to back days may have had slightly lower harvest efficiencies overall.


Figure 26. Area harvested in Mill River on July 11.


Figure 27. Area harvested in Mill River on July 13.

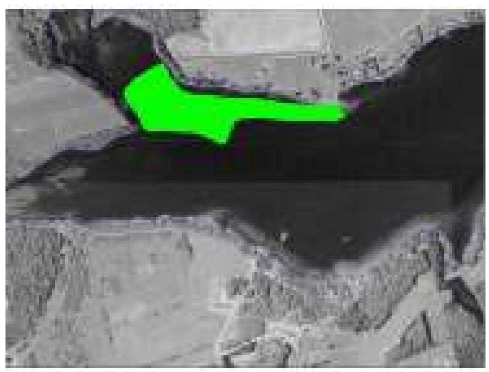
Figure 28. Area harvested in Mill River on July 14.

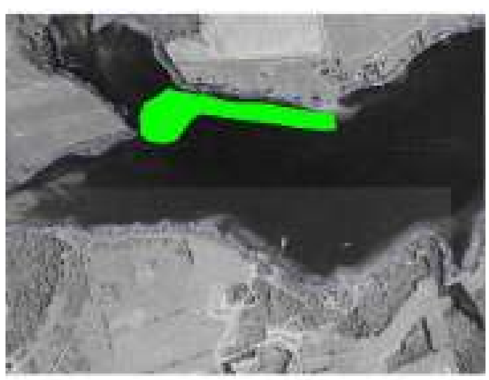
Figure 29. Area harvested in Mill River on July 15.

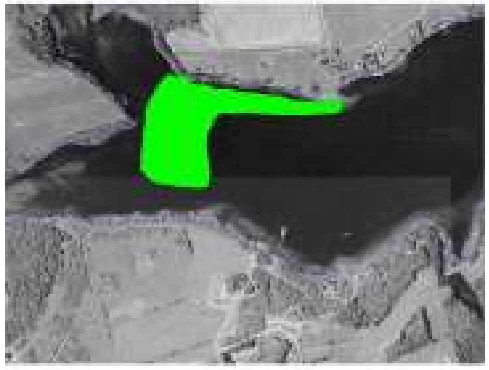

Figure 30. Area harvested in Mill River on July 16.

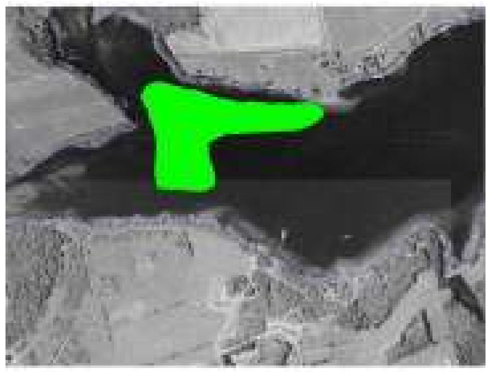

Figure 31. Area harvested in Mill River on July 18.

Figure 32. Area harvested in Mill River on July 19.

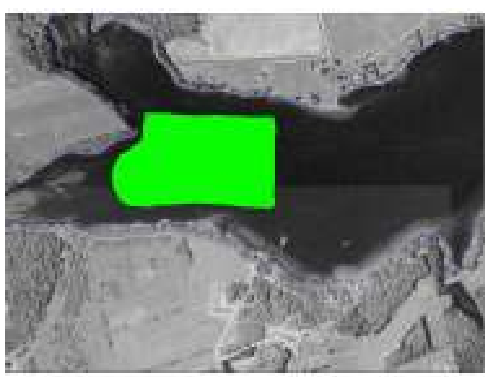

Figure 33. Area harvested in Mill River on July 20.

4.2.4 Mill River – 2nd Harvest

The efficiency of the 2nd harvest closely matched the first harvest in terms of T/hr harvested. This is surprising considering the much shorter sail times (10 minutes vs. 25 minutes) for the offload site used for this harvest. The sea lettuce population in the estuary was collapsing at the time of harvest because the estuary was experiencing an anoxic event (see below). This is also indicated by the decreasing yield of harvest by the end of the three day harvest period. By August 6th there was not much sea lettuce available to harvest in the estuary. Despite this, the sea lettuce yield for August 4th (5.0 T/ha) was among the highest recorded for the Mill and Hills Rivers and was just below the 5.9 T/ha recorded in Hills River on July 8th. This is a testament to the need to have nearby offloading sites to make the most efficient use of harvester time.

Table 6. Harvest Summary: Mill River, August 4 to August 6.

Date	Truck Loads	Harvester Loads	Tonnes (est. from harvester loads)	m^3	Harvest Area	Harvest Time	Harvest Efficiency		Harvest Efficiency	
							T/hr	T/ha	m^3/hr	m^3/ha
Aug. 4	7	7	18.9	105	3.8	9.5	2.0	5.0	11.1	27.6
Aug. 5	5	5	13.5	75	5.1	7.0	1.9	2.6	10.7	14.7
Aug. 6	5	5	13.5	75	16.3	8.0	1.7	0.83	9.4	4.6
Totals	17	17	45.9	255	25.2 17.3	24.5	1.9	1.8 2.6	10.4	10.1 14.7

4.3. Sea Lettuce Coverage/Density

Sea lettuce density was measured to determine the impact of harvest on the sea lettuce population. It was also intended to determine how quickly the sea lettuce population returned, either through new growth or accumulation from other areas.

4.3.1. Inter-Estuary Comparison

The volumes of sea lettuce measured during the project for each estuary are shown below in Figure 34.

Sea lettuce biomass of about 12 tonnes/ha have been found in other Island estuaries in the past during peak growth seasons (ELJ unpublished data). This equates to about 67 m^3/ha using the values determined by the current study. No results approached this level in the sampling conducted for the pilot harvest study (Figure 34). During 2011, anecdotal evidence suggests that there was not as much sea lettuce biomass present in the early summer as in recent years. Staff of ELJ, FARD and DFO, shellfishers, members of community watershed groups and other members of the public all agreed that there less sea lettuce present in the early summer of 2011 than in the past several years.

Lower amounts of sea lettuce were likely a result of weather conditions. Relatively wet and cold weather was present in June of 2011 and may have contributed to slower growth rates of sea lettuce. CAMP results for the Mill and Trout Rivers confirmed that lower water temperatures were present in 2011 than in previous years. Data from Environment Canada and provincially operated weather stations indicate that there were just 1248 growing degree units (GDUs) in the May to August period of 2011 compared to 1272.4 GDUs for the 30 year climate average using a 5° C base. There were just 692.9 GDUs in the same period of 2011, compared to 726 GDUs for the 30 year climate average using a 10°C base (Gwen Vessey, PEI Department of Agriculture and Forestry, January 2012). The exact relationship between GDUs and sea lettuce growth is not known. It is assumed that lower GDUS would result in less sea lettuce growth.

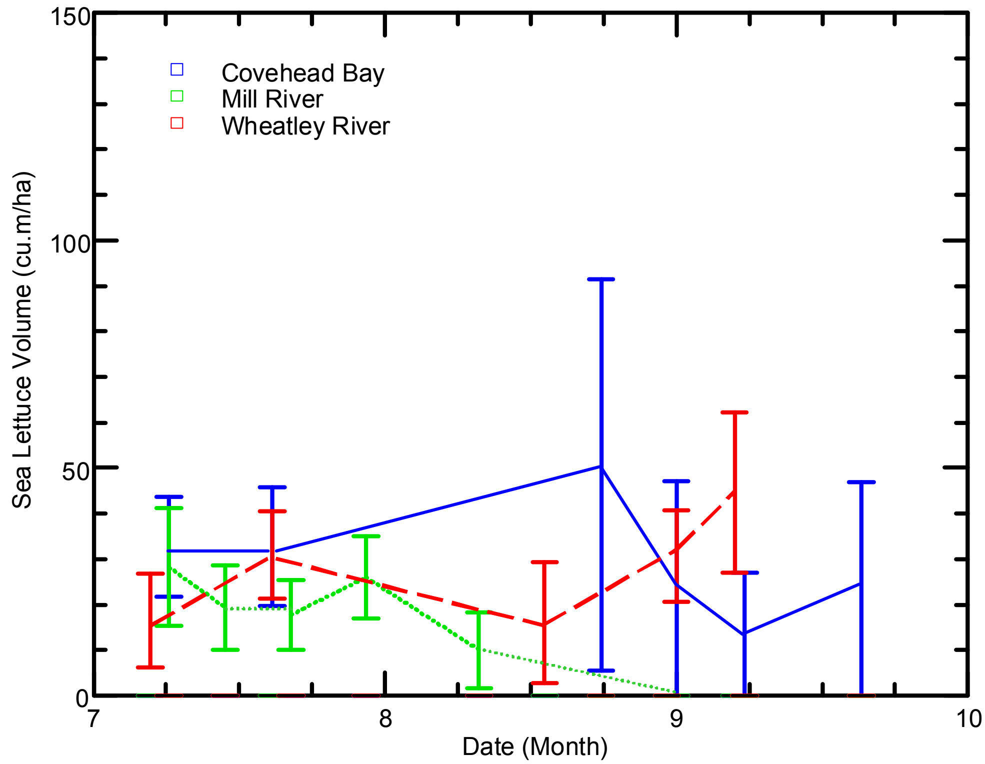

Figure 34. Volumes of sea lettuce measured in Covehead Bay, Mill River and Wheatley River.

Having less sea lettuce present during the early summer was likely the major factor in the delay of the onset of anoxia in many estuaries during 2011. In 2009 and 2010 anoxic events were reported as early as mid June with most historically anoxic estuaries displaying anoxic conditions by mid July. In 2011, anoxia was not reported until late July or early August.

There were four sample periods where direct comparison of results for at least 2 of the 3 studied estuaries could be made (Table 7). Due to the very fast rates of growth and decline observed for PEI sea lettuce populations, any more than a few days in the difference between the sample dates for the test and reference sites would provide results which were not comparable.

All three estuaries were sampled in the 3 day period of July 6^{th} to July 8^{th}. Wheatley River had significantly less sea lettuce than either Mill River (Table 7) (Kruskal-Wallis test, U test statistic = 66.0, p = 0.024, df = 1) or Covehead Bay (Table 7) (U test statistic = 69.5, p = 0.010, df = 1) during this period while Covehead Bay and Mill River had values which were statistically the same (Kruskal-Wallis test, U test statistic = 75.5, p = 0.374, df = 1). This was despite Covehead Bay having 64 tonnes of sea lettuce harvested from this site a week previous to this sample being taken.

Table 7. Sea Lettuce Volumes from 3 comparable sample dates.

Statistics (L sea lettuce / m^2 bottom)	Dates								
	July 6 – July 8			July 19 to July 21			August 30 – August 31		
	WR	CB	MR	WR	CB	MR	WR	CB	MR
# of Cases	9	9	9	9	9	9	9	9	9
Minimum Value	0.4	1.8	1.0	2.0	1.8	0.8	2.0	0.4	0
Maximum Value	3.6	5.2	5.2	4.4	5.0	3.0	4.4	6.4	0
Median	1.4	3.4	2.4	2.8	2.6	1.6	2.8	0.6	0
Mean	1.6	3.3	2.8	3.1	3.3	1.8	3.1	2.2	0
95 % CI of Mean (upper)	2.4	4.0	3.7	3.8	4.2	2.3	3.8	4.0	0
95% CI of Mean (lower)	0.9	2.5	1.9	2.4	2.3	1.2	2.3	3.1	0
Standard Error of Mean	0.3	0.3	0.4	0.3	0.4	0.2	0.3	8.0	0
Standard Deviation	1.0	1.0	1.2	0.9	1.2	.07	0.9	2.4	0

In the sample period between July 19th and July 21st there was statistically no difference between sea lettuce volumes measured in Covehead Bay and Wheatley River (Kruskal-Wallis test, U test statistic = 43.5, p = 0.790, df = 1). The Mill River had statistically lower volumes than either Covehead Bay (Kruskal-Wallis test, U test statistic = 69.5, p = 0.010, df = 1) or the reference site in Wheatley River (Kruskal-Wallis test, U test statistic = 10.0, p = 0.007, df = 1). Harvest in the Mill River had just been completed prior to this sample date.

In the sample period between August 30th and August 31st Mill River had no sea lettuce recorded within the sample plots established for the project (Figure 34, Table 7). There was some sea lettuce noted in other harvested areas of the upper Mill River outside of these plots (estimated 25% - 50% coverage); however, these areas were not sampled. There was no statistical difference between the measured volumes in either Covehead Bay or Wheatley River on August 31 (Kruskal-Wallis test, U test statistic = 24.0, p = 0.142, df = 1), even though Covehead Bay had a much wider variation in results.

The sample dates for Covehead Bay and Wheatley Rivers also corresponded on September 6th and 7th (Figure 34). Covehead Bay had significantly lower volumes of sea lettuce present than Wheatley River during this period (Kruskal-Wallis test, U test statistic = 4.5, p = 0.001, df = 1). Covehead Bay also had an anoxic event recorded at about this time.

4.3.2. Covehead Bay

Sea lettuce volumes were sampled in Covehead Bay six times during 2011; twice during July, August and September (Figures 35 and 36). Sampling was not carried out prior to harvest beginning in Covehead Bay on June 27th as it had been initially planned to conduct visual bottom coverage surveys only. Sampling was not evenly distributed and there was a large gap in sampling between July 19th and August 23rd (Figure 35 and Figure 36).

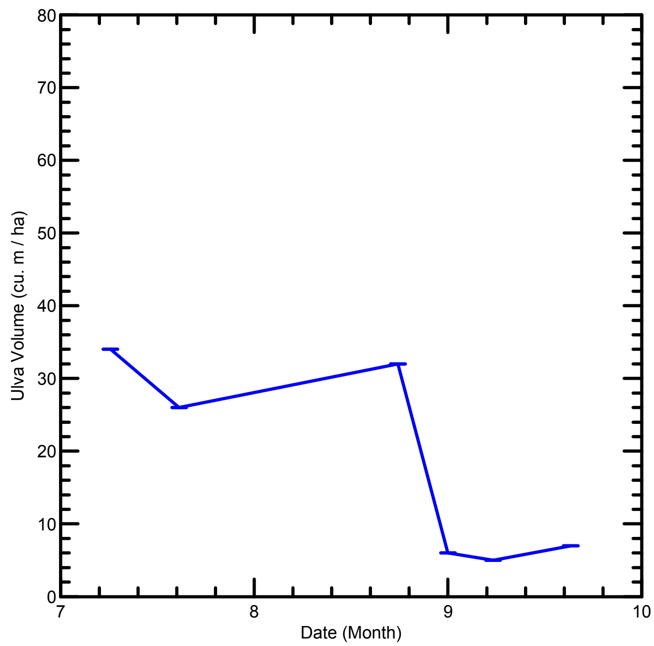

Figure 35. Median values and trends for sea lettuce volumes for Covehead Bay.

Sea lettuce volumes were statistically similar on the July 8th, July 19th and August 23rd sample dates (Figure 35). The lowest values were recorded on August 30th and during both September sample dates (Figure 35). Plot A had similar sea lettuce volumes for all sample dates (Figure 36) (Kruskal-Wallis test, U test statistic = 6.56, $p = 0.225$, df = 1) while both Plot B (Kruskal-Wallis test, U test statistic = 15.42, $p = 0.009$, df = 1) and Plot C (Kruskal-Wallis test, U test statistic = 11.44, $p = 0.049$, df = 1) had significant declines over the sampling period (Figure 36).

Periods of anoxia are known to correspond to declines in sea lettuce population in Island estuaries (ELJ unpublished data). Due to a large gap in monitoring, an anoxic event which occurred in Covehead Bay on August 1st was not captured by sampling; however, an anoxic event first recorded on September 6th may be indicated by the decline in sea lettuce density that were noted between August 31st and September 7th. The results from the sea lettuce monitoring program indicate that this anoxic event may have been more severe on the upper and eastern areas (Plots B and C) than on the western side (Plot A) of the bay.

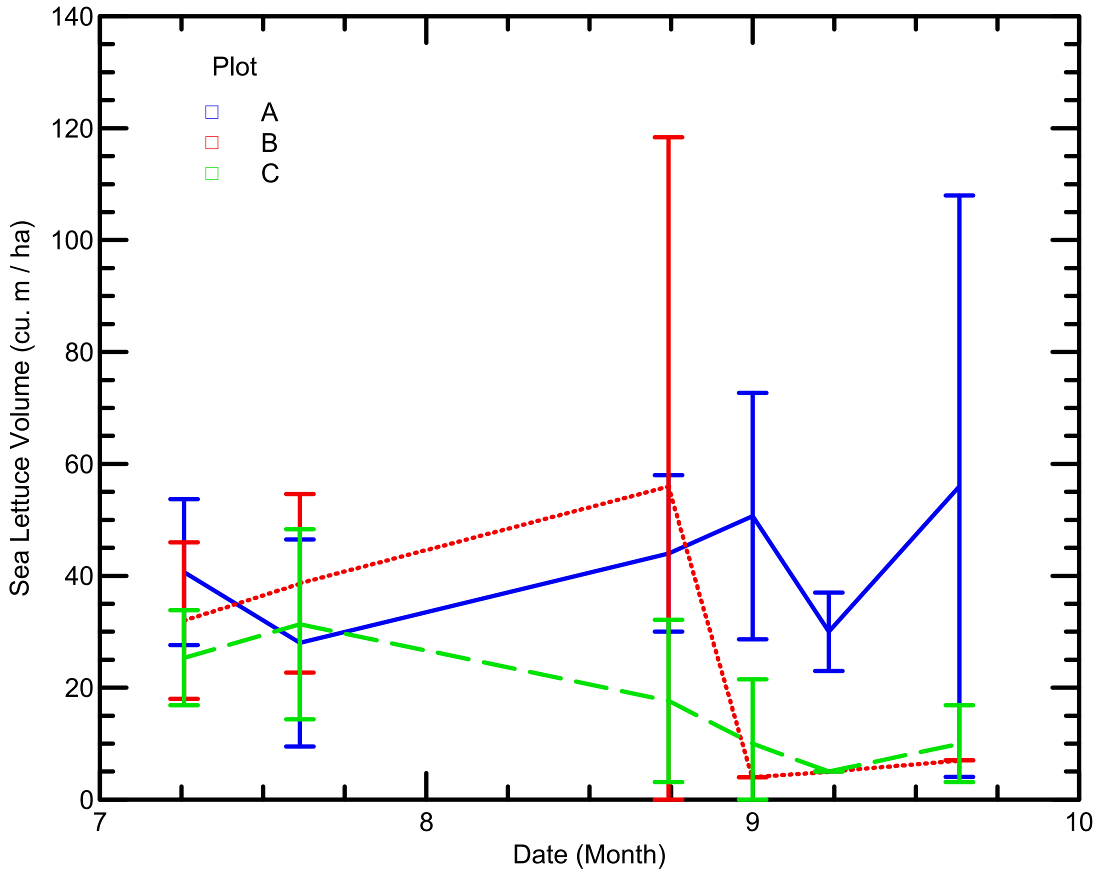

Figure 36. Sea lettuce volumes and trends by station in Covehead Bay.

4.3.3. Mill River

Sea lettuce was sampled in the Mill River weekly during July and the twice during August 2011 (Figures 37 and 38). Sampling was abandoned after the end of August as a complete collapse of the sea lettuce population had been noted on August 31st.

The highest volumes of sea lettuce in Mill River were recorded at the earliest sample date, July 8th, prior to the first harvest in the estuary (Figure 37). The volumes of sea lettuce sampled were lower on July 14th and July 21st (during and just after the first harvest was completed respectively); however, only the July 21st results were significantly different than the July 8th results (Kruskal-Wallis test, U test statistic = 63.5, p = 0.041, df = 1). During this time sea lettuce volumes declined in both plots A and B but increased slightly in Plot C (Figure 38). The decline noted in plots A and B was significant for the July 8th and July 14th sample dates (Kruskal-Wallis test, U test statistic = 32.0, p = 0.025, df = 1). The area of the estuary in which Plot C was located was not harvested until July 20th (Figure 33).

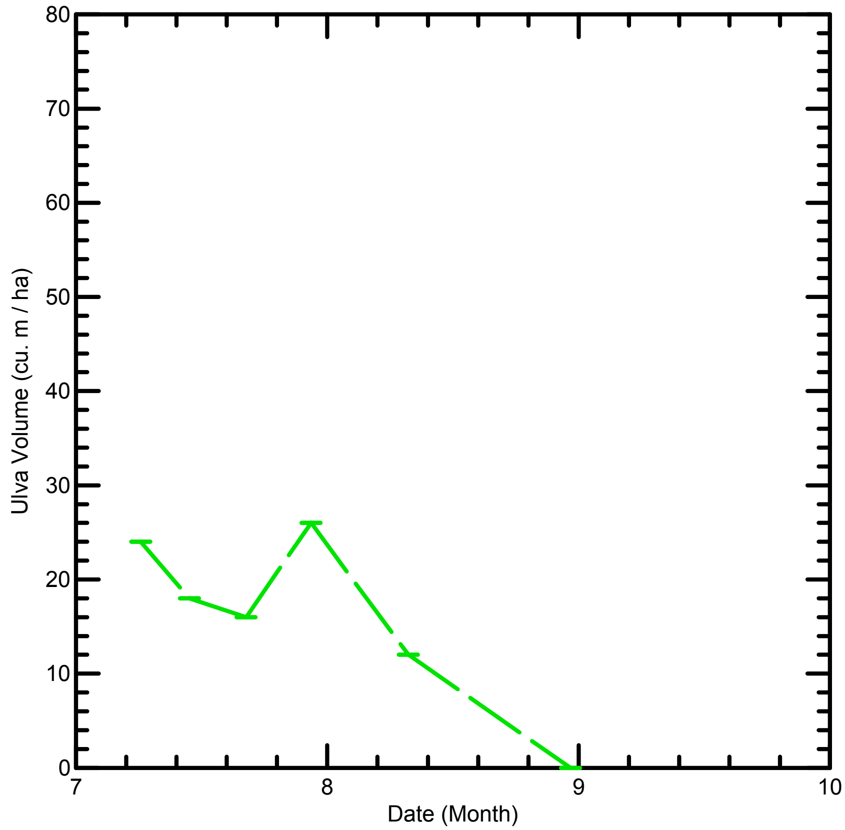

Figure 37. Median values and trends for sea lettuce volumes in Mill River.

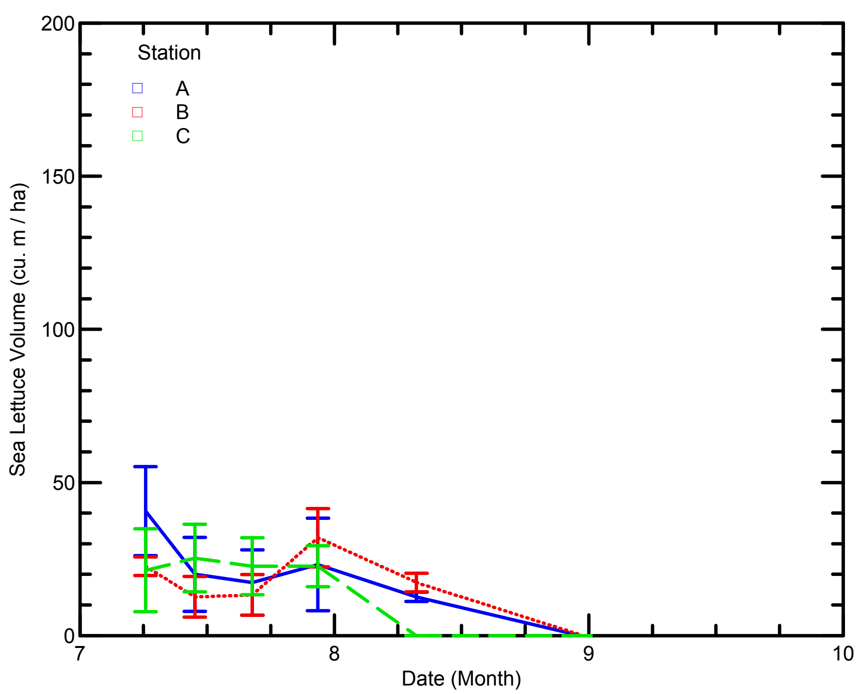

Figure 38. Sea lettuce volumes and trends by station in Mill River.

Sea lettuce volumes recorded on the July 29th were statistically similar to those recorded on July 8th (Kruskal-Wallis test, U test statistic = 45.5, p = 0.657, df = 1), July 14th (Kruskal-Wallis test, U test statistic = 24.0, p = 0.144, df = 1) and July 21st Kruskal-Wallis test, U test statistic = 18.5, p = 0.051, df = 1) (Figure 38). By August 10th sea lettuce volumes were significantly lower than those recorded on both July 8th (Kruskal-Wallis test, U test statistic = 74.5, p = 0.003, df = 1) and July 29th (Kruskal-Wallis test, U test statistic = 75.5, p = 0.002, df = 1). Although this was after the 2nd harvest conducted in Mill River an anoxic event had also been recorded, beginning on August 5th (see below). No sea lettuce was recorded in Plot C, in the center of the estuary, on August 10th as the sea lettuce at this location was reported to have the 'consistency of jello' on that date. No sea lettuce was recorded within any of the 3 sample plots on the August 30th sample date. This sample date followed a second anoxic event, which began about August 12th.

4.3.4. Wheatley River

Wheatley River was sampled on five sample dates during 2011; twice during July and August and once in September (Figures 39 and 40). Sampling was not evenly distributed and there was a month long gap in sampling between July 19th and August 17th.

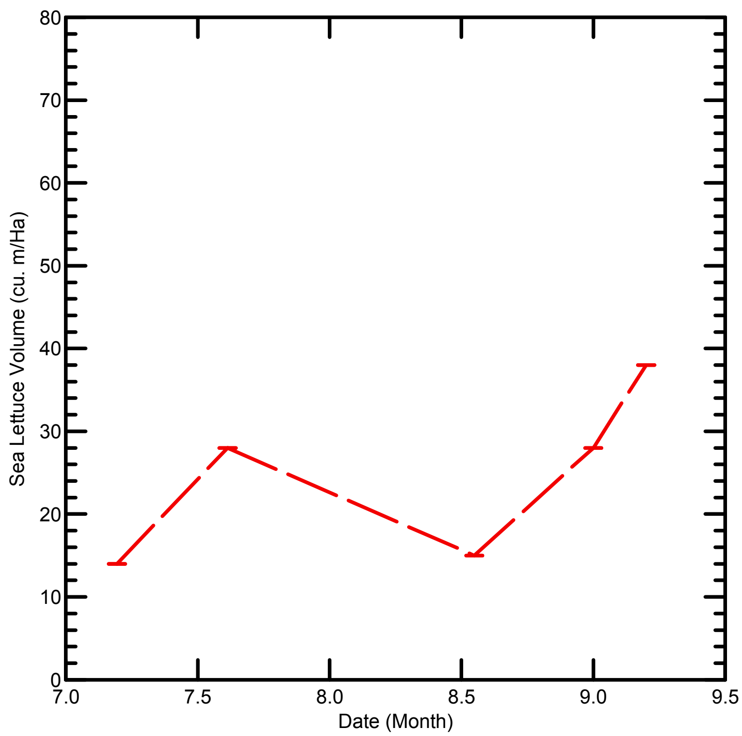

Figure 39. Median values and trends for sea lettuce volumes measured in Wheatley River.

Sea lettuce volumes were highest on the September 6th sample date. Sea lettuce volumes were the lowest on the July 6th and August 17th sample dates, and these dates had statistically similar values (Figure 39). Values recorded for July 19th and August 31st were higher, but statistically similar to each other as the sea lettuce population first increased, declined and then increased once again (Figure 39).

There was little difference between the volumes of sea lettuce collected between the three plots in Wheatley River (Figure 40). Plot B had very low values on the August 17th sample date.

Anoxic events recorded in the Wheatley River on August 1st and August 22nd could not be related to a corresponding decline in sea lettuce density. There was a gap in sea lettuce sampling between July 19th and August 17th and, except for the results recorded at Plot B on August 17th, all sites showed only a slight decline or increasing sea lettuce densities between August 17th and September 6th.

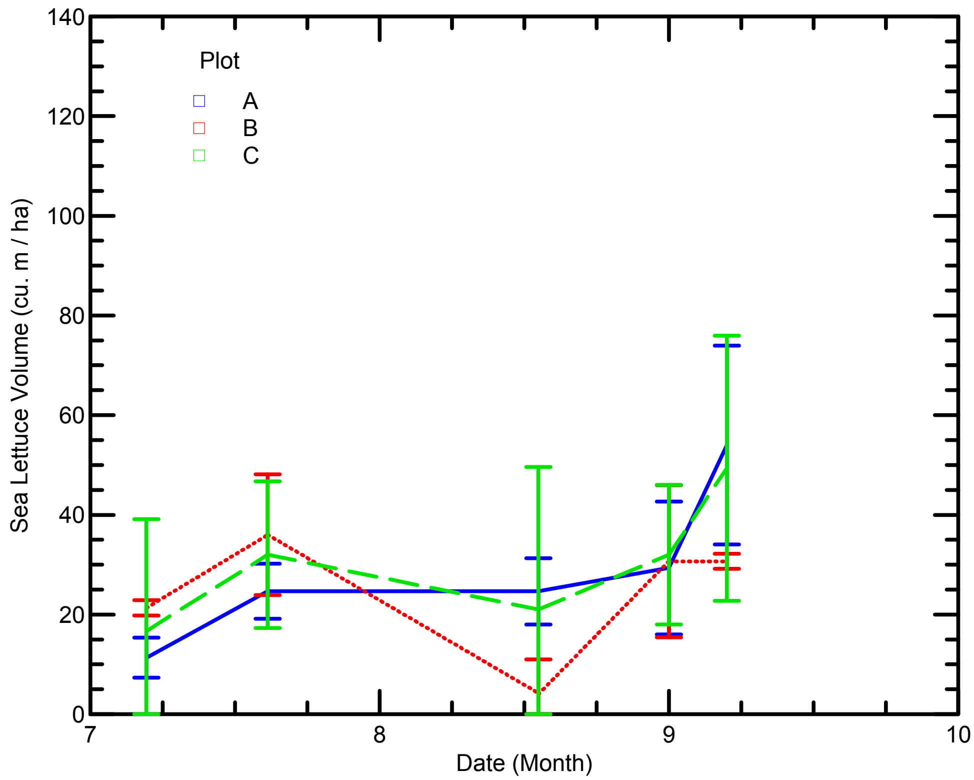

Figure 40. Sea lettuce volumes and trends in Wheatley River.

4.4. Impacts on Aquatic Life

4.4.1. By-Catch

4.4.1.1. Covehead Bay

As previously indicated the methodology for recording by-catch was different between Covehead Bay and the Hills and Mill Rivers. As a consequence the results between these estuaries are not comparable.

The by-catch recorded in Covehead Bay is shown below by species (Figure 41). By-catch by date is shown in Appendix D. A total of 104 individuals (fish and animals) were recorded.

The species with the greatest number of individuals captured was the fourspine stickleback, with 46 individuals of various sizes recorded in by-catch sampling. A total of 11 grass shrimp, mummichog and sea stars were recorded as well as 9 cunner and 5 sand shrimp.

Only 7 eel grass plants were reported; however, assessor notes indicated that there was a 'fair amount' of eel grass present in the sampled truck load on June 27th. Harvest during this day was conducted in the upper part of the estuary in and around the mouth of Auld's Creek. A large eel grass bed had been noted in this area prior to the start of the project and the harvester did avoid this area; however, it was noted that there was some live eel grass present in much of the area near the confluence with Auld's Creek and along the eastern shoreline of the bay. This was despite these areas having 80- 100% sea lettuce coverage.

The by-catch samples also included 1-4 individuals of each of the following species: three spine stickleback, winter flounder, smooth flounder, silversides, rock crab and sea star. No ninespine or blackspotted stickleback were observed in the by-catch sampling; however, one *Gasterosteus sp*. YOY (stickleback, young of the year) was recorded.

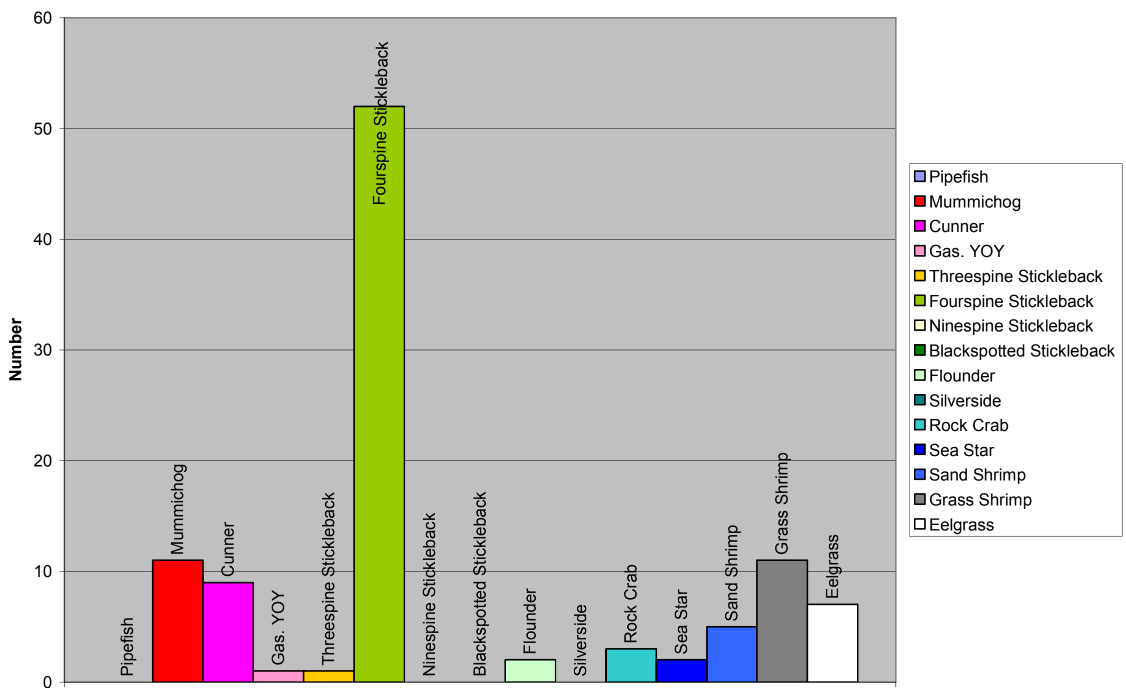

Figure 41. By-catch by species in Covehead Bay.

By-catch sampling was carried out on 5 of the 8 harvest dates in Covehead Bay. These dates can be separated by the sea lettuce "target". On June 27th and 30th floating sea lettuce was targeted for harvest, while on June 28th submerged sea lettuce was targeted. On June 23rd and 24th both floating and submerged sea lettuce was harvested.

The only species present on all by-catch sample days was the fourspine stickleback. Mummichogs were captured on 3 sample dates but were not found on June 28th when only submerged lettuce was harvested. Cunner were found in harvested loads on three sample dates but not on June 27th or 30th when mostly floating lettuce was harvested. Eel grass was recorded on June 27th, 28th and 30th; however, assessors noted that this was likely due to the presence of very low tides on all of these harvest days. ELJ staff also noted that there appeared to be more floating/detached eel grass present in the harvest areas on these days than there had been earlier in the harvest. All other species found were recorded on only one or two of the by-catch sample days. Nearly all of these species were found on dates when submerged lettuce was harvested.

Assessors in Covehead Bay also indicated that there were many invertebrates, mostly snails, found in the by-catch samples. These were not recorded as there were too many to count. It was mentioned that some mussels were also found in the by-catch samples however there was no indication of how many or on which days these were found.

4.4.1.2. Hills River

The by-catch recorded in Hills River is shown below by species (Figure 42). By-catch by date is shown in Appendix D.

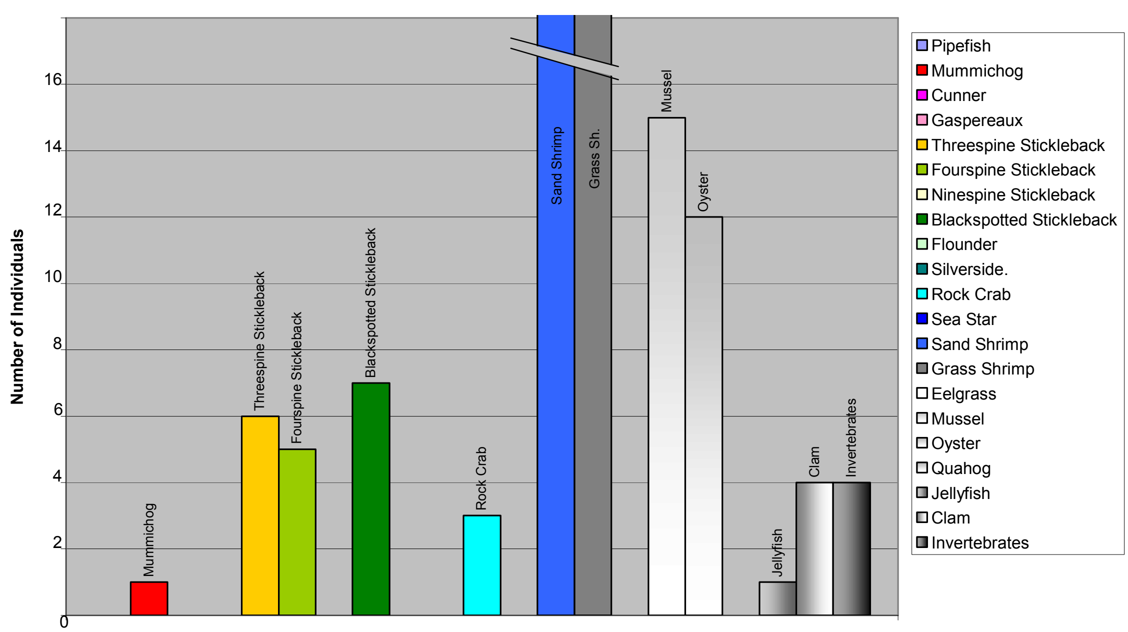

Figure 42. By-catch by species in Hills River.

In Hills River assessors provided detailed information on the number of individuals collected from by-catch samples. The two species with the largest number of individuals captured were sand shrimp and grass shrimp. Both were captured in numbers too large to count. Snails were captured as well; however their abundance was not recorded. A total of 58 other individuals were recorded. Shellfish represented the highest proportion of these 58 individuals. The area that was harvested in the Hills River had an oyster resource (enhanced public ground). Twelve oysters were captured along with fifteen mussels and 4 clams in a total of 0.02 m^3 of sea lettuce. If extrapolated to the total volume of sea lettuce harvested (165 m^3) in the Hills River the total amount of shellfish included in the harvest would have been very significant (Appendix D). Assessor notes did not contain any information on the condition or size of individuals harvested.

ELJ staff indicated that spot checks of by-catch demonstrated that oyster shell was present but that when "whole shells" were opened the harvested mussels and oysters appeared to be either dead or in very poor condition. The condition of harvested clams was not noted.

Other species collected in the Hills River included threespine stickleback, fourspine stickleback, black-spotted stickleback, rockcrab, as well as single individuals of jellyfish and mummichog. Snails were recovered in large amounts; however, these were not recorded as numbers were too large to count. Invertebrates collected and recorded in the Hills River also included both worms and various empty tubeworm cases.

4.4.1.3. Mill River

The by-catch recorded for the July 11 to July 20th harvest in Mill River is shown below by species (Figure 43). By-catch by date is shown in Appendix D.

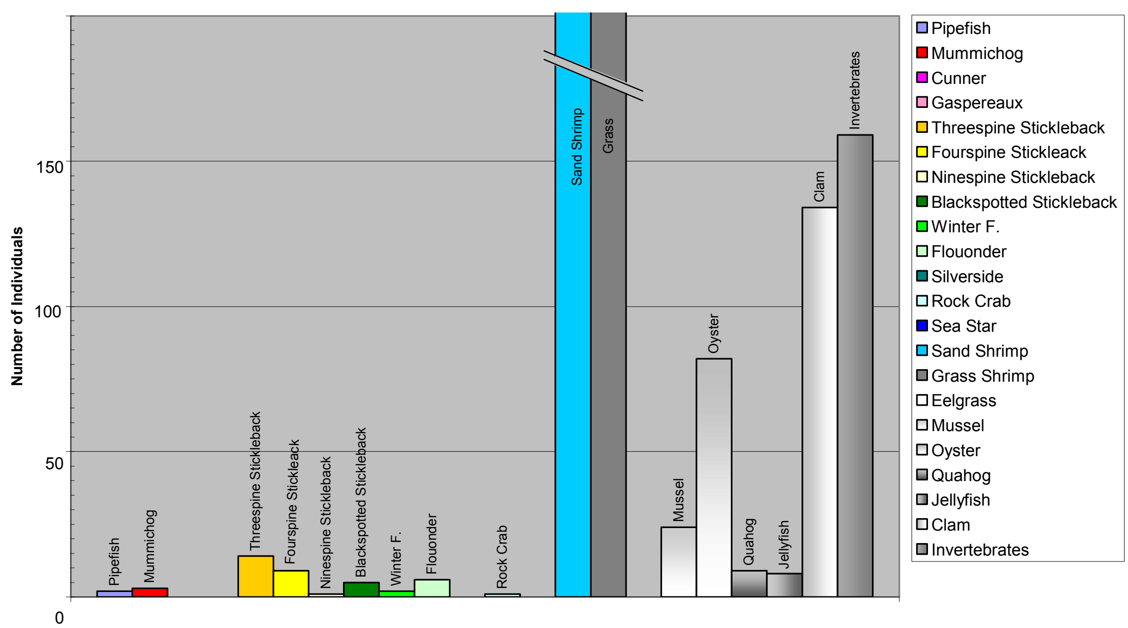

Figure 43. By-catch by species in Mill River for the July 11 to 20 harvest.

The assessors once again provided detailed information on the number of individuals collected from by-catch samples. As in Hills River the two species with the largest number of individuals captured were sand shrimp and grass shrimp. Both were captured in numbers too large to count. Snails were captured in very large amounts but numbers were not recorded. A total of 459 other individuals were recorded and shellfish were captured in the next highest number. The area that was harvested in the Mill River was not supposed to have a significant oyster resource; however, over 80 oysters were recovered from the by-catch samples during this period. There were also significant numbers of mussels (24) and clams (134) and quahogs (shell only?) (9) recorded in a total of 0.63 m^3 of harvested sea lettuce. If extrapolated to the total volume of sea lettuce harvested (555 m^3) in Mill River from July 11 – July 20th the total amount of shellfish harvested as by-catch would have been very significant (Appendix D). Observers from ELJ, as well as a shellfisher employed as an operator, noted that that these by-catch amounts included oyster and mussel shell as well as shellfish that were either dead or in very poor condition. This was not noted by the other assessors however. Assessor notes also did not contain any information on the size of individuals harvested.

Other species collected in the first Mill River harvest included threespine stickleback, fourspine stickleback and blackspotted stickleback, as well as single individuals of rock crab, ninespine stickleback and mummichog. Two pipefish were discovered in the by-catch along with some winter flounder (2) and smooth flounder (6). Snails were recovered in very large amounts; however, these were not recorded as numbers were too large to count. Invertebrates collected and recorded in the Mill River once again included both worms and various empty tubeworm cases. Eight jellyfish were also found.

Eels were not found in any of the by-catch samples. Eels of various sizes were observed on the harvester's cutting head chain on several occasions during the Mill River harvest. When eels were encountered the harvest operator would reverse the direction of the cutter head chain allowing eels to be safely returned to the water. No dead or injured eels were ever observed in the water in visual surveys of the area. One dead gaspereaux (approximately 20 – 25 cm long) was recovered from the harvest area on one of these surveys. It is not known if the harvest operation was responsible for its' death.

The by-catch recorded for the August 4th to August 6th harvest in Mill River is shown below by species (Figure 44). By-catch by date is shown in Appendix D.

The two species with the largest number of individuals captured were sand shrimp and grass shrimp. Both were captured in numbers too large to count. Invertebrates were captured in the next highest amounts. Snails were recovered in very large amounts. Larger numbers of worms were observed compared to the previous two harvests.

Significant numbers of oysters (9) mussels (10) and clams (50) were recorded in a total of 0.28 m^3 of harvested sea lettuce. If extrapolated to the total volume of sea lettuce harvested (255 m^3) in Mill River from August 4th to 6th the total amount of shellfish harvested as by-catch would have been very significant (Appendix D). Staff from ELJ, who did a single by-catch spot count on August 5th noted that that these by-catch amounts included both oyster and mussel shell as well as some shellfish that were either dead or in very poor condition. These observations were not noted by the other by-catch assessors. Assessor notes also did not contain any information on the size of individuals harvested.

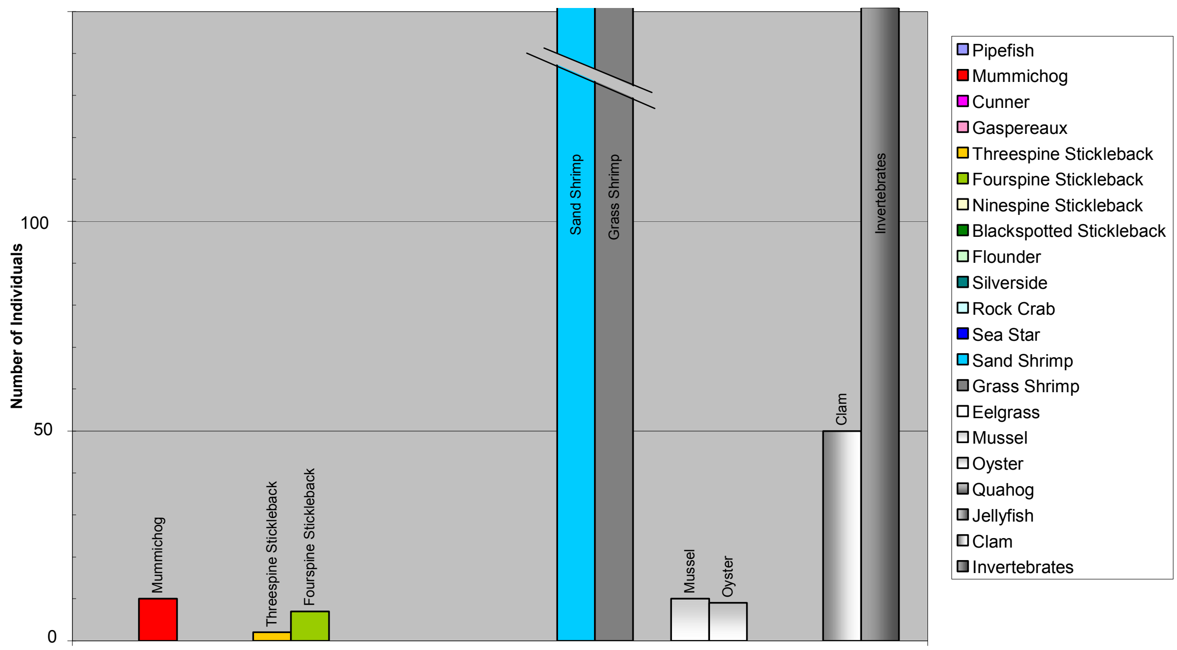

Figure 44. By-catch by species in Mill River for the August 4 to 6 harvest.

Other species collected in the Mill River included threespine and fourspine stickleback. Significant numbers of mummichog were noted during offloading operation of one harvester load on August 5th. A sampling of by-catch from this load revealed 8 mummichog in one (0.07 m^3) sample. The harvest operator indicated that significant numbers of mummichog (15-20) per minute were observed coming up in the harvest load. This was not acceptable under the terms of the harvest license from DFO. As a result the operator was asked to take precautionary measures. The harvester moved to a different area of the estuary to harvest and the cutting head chain was reversed as described for eels (above), allowing fish on the chain to swim away, when significant numbers of fish were observed coming up on the chain. This greatly reduced the number of mummichog observed in harvested sea lettuce.

4.4.2. Shellfish Survival

The majority of the oysters deployed at the three sites (Covehead Bay, Mill River and Wheatley River) did not survive. In most cases, between 0-2 oysters out of a total 25 survived. There was only one site in Covehead Bay in which high oyster survival was observed. In the bottom rack 44% of the oysters survived and 84% survived in the Vexar bag. The benthic quality in Covehead was generally better than the other two areas, which may explain the higher survival at this site. The sediments were coarser and a brown color, as opposed to a dark black fine silt/mud.

Two bottom racks (Site 3 in Mill River and Site 1 in Wheatley River) were recovered in an overturned position and the oysters were not recovered. In addition, no Vexar bag was recovered from Site 3 in Mill River. At all the sites a significant amount of sea lettuce biomass was sitting on the Vexar bags and the bottom racks.

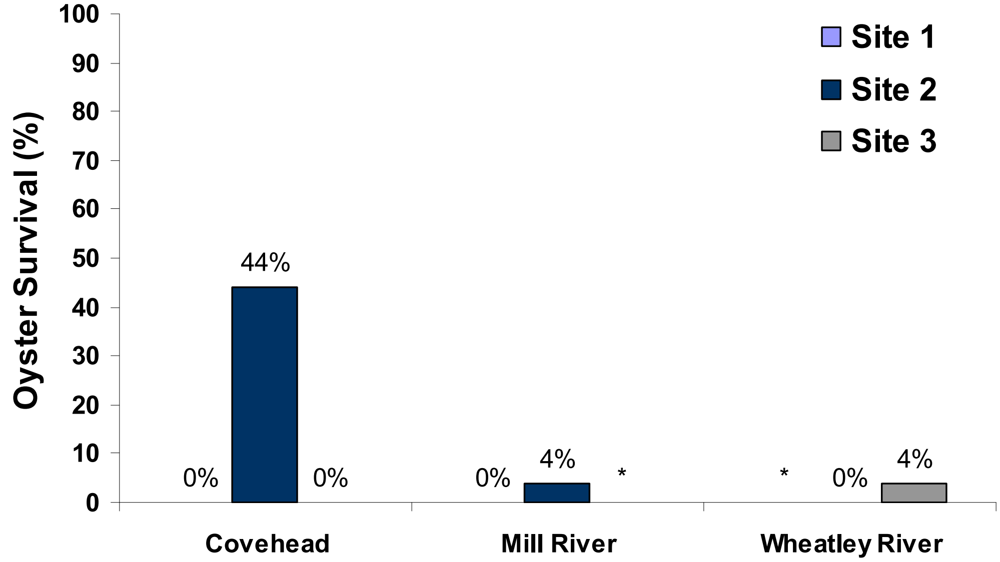

Figure 45. Oyster survival (25 oysters) in racks deployed at three sites in each of the three study areas.

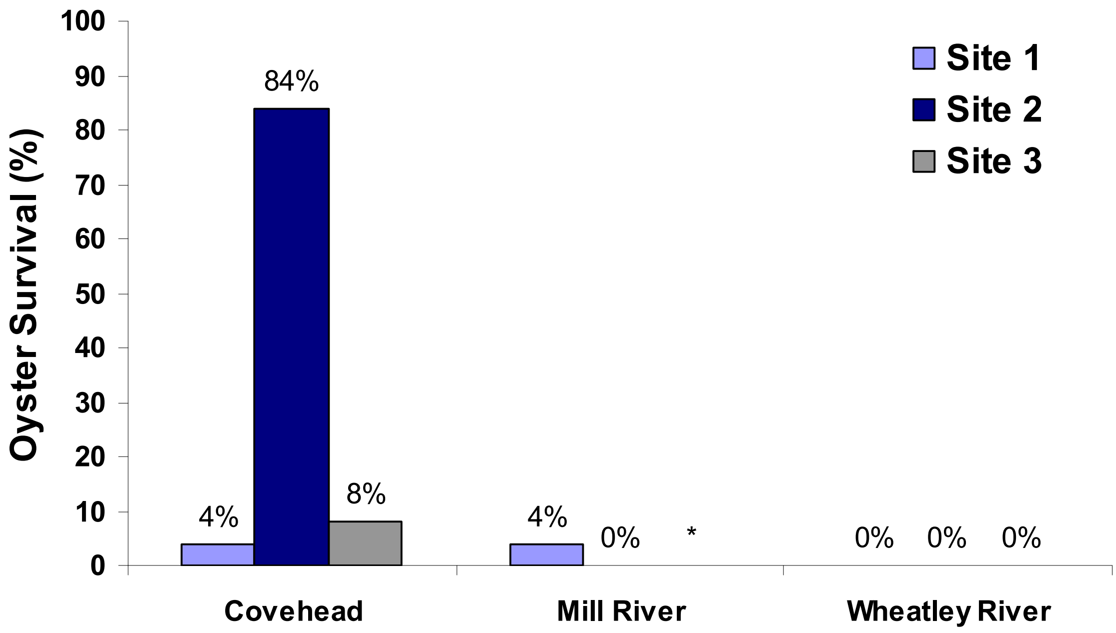

Figure 46. Oyster survival (25 oysters) in Vexar bags deployed at three sites in each of the three study areas.

4.4.3. Community Aquatic Monitoring Program (CAMP)

4.4.3.1. Floral Community

The type of vegetation found in an estuary can be a useful tool to determine health. Sea lettuce can have a large impact on the estuarine ecosystem. Generally, higher quantities of sea lettuce and lower amounts of eel grass signify a more nutrient-rich site. The vegetative community structure determined by 2011 CAMP sampling for the Trout River, Mill River and Covehead Bay estuaries is shown below in Figure 47.

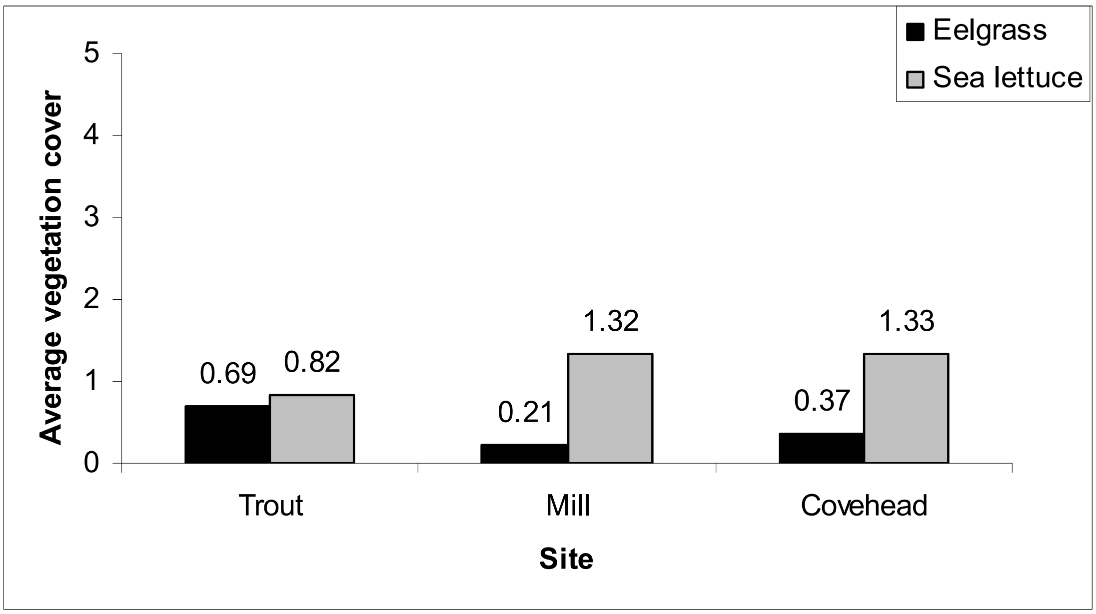

Figure 47. Average vegetation cover at CAMP sites in each estuary(averages are shown on a scale of 0 to 5, 0 = 0%, 1 = <25%, 2 = 25-50%, 3 = 50-75%, 4 = 75-100%, 5 = 100%).

These results indicate that Mill River and Covehead Bay have similar cover values for sea lettuce, while Covehead Bay has slightly more eel grass present than Mill River. This may be an indication that Covehead Bay is slightly less affected by eutrophication than the Mill River. The site used for comparison in Trout River (Site 3) has lower values of sea lettuce and higher values of eel grass which may indicate that it is less impacted by eutrophication than the two harvested estuaries although the Trout River is known to have periodic anoxic events which would suggest otherwise. As such, it may not be a comparable reference site.

The changes in sea lettuce cover in Mill River recorded during CAMP sampling are shown below in Figure 48. The sea lettuce coverage actually increased considerably between the 1^{st} (June 23) and 2^{nd} (July 21^{st}) rounds of CAMP sampling despite harvest being carried out in the area between July 11^{th} to July 20^{th}. This may reflect both a slower than normal growth rates in the spring of 2011, due to cloudy, cold weather and a failure of the harvest to reduce sea lettuce coverage. The CAMP site was however located on the shoreline in an area inaccessible to the harvester.

The decline in coverage noted by the CAMP sampling in August is consistent with the decline previously noted in the sea lettuce density sampling and could possibly be related to the harvest conducted between August 4th and 6th; however, this is impossible to demonstrate. In reality the decline is more likely related to the occurrence of anoxic events on August 5th/6th and August 15th.

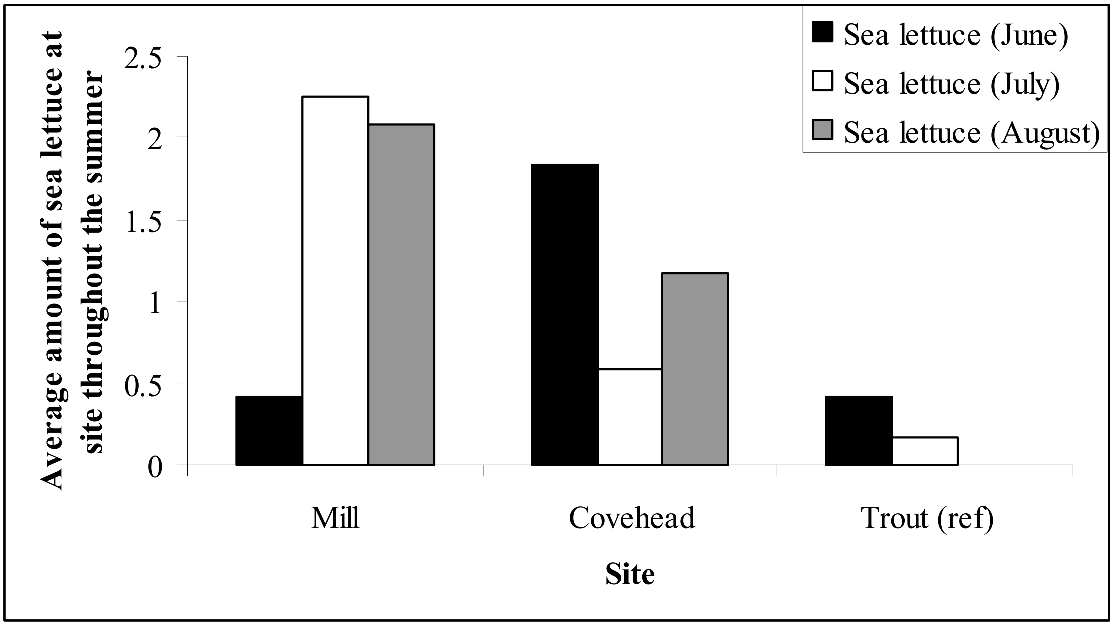

Figure 48. Average amount of sea lettuce at CAMP site within harvested area (averages are shown on a scale of 0 to 5, 0 = 0%, 1 = <25%, 2 = 25-50%, 3 = 50-75%, 4 = 75-100%, 5 = 100%).

A considerable decline in sea lettuce coverage was noted in Covehead between the June 22nd and July 20th sample dates. Again this could possibly be due to harvesting activities carried out between June 27th and July 2nd; however, this cannot be proven. Harvest was completed more than two weeks prior to the CAMP sampling and a decline was not noted in the sea lettuce density sampling carried out by the project.

The Trout River site also showed a decline in sea lettuce between the June 9th and July 6th sample dates. Since no harvest was conducted in the Trout River this decline would have been due to other factors such as anoxic events. Although sea lettuce coverage was similar to that of the Mill River in June, the Trout River did not have as much sea lettuce coverage in July as either the Mill River or Covehead Bay in June or July.

4.4.3.2. Faunal Community

The changes in fish community structure noted by the CAMP sampling are noted in Figures 49 and 50. These results do not appear to show any major changes in faunal community structure that can be attributed to harvest activities carried out between July 11th and 20th and August 4th to 6th in Mill River and June 27th to July 2nd in Covehead Bay. The trends observed reflect only seasonal trends in the faunal population that have been noted by others (Finley *et al*. 2009, Schein *et al*. 2011).

No changes in faunal composition were noted that could be attributed to a negative effect of harvest activity. Sensitive species including silverside, flounder and pipefish were found in the August CAMP samples, following the completion of harvest in both harvested estuaries.

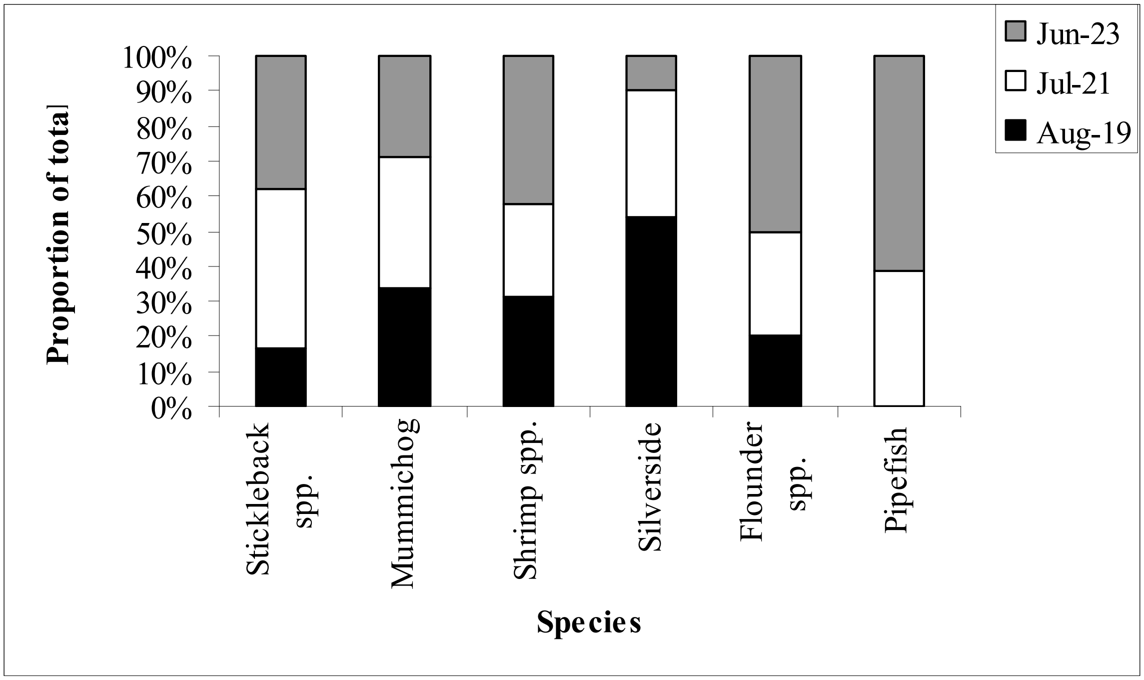

Figure 49. Faunal species proportion present on all sample dates at CAMP Site 1, Mill River.

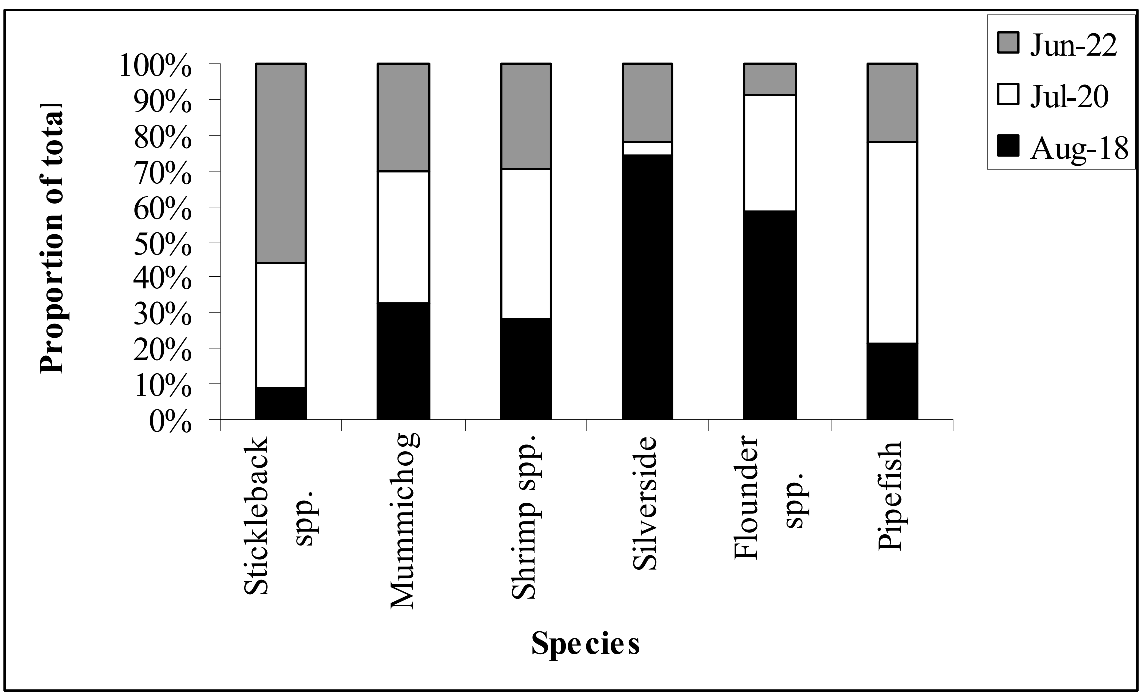

Figure 50. Faunal species proportion present on all sample dates at CAMP Site 2, Covehead Bay.

CAMP results can indicate an estuary's unique community composition. Certain species can give information concerning the health status of estuaries. Relatively higher mummichog populations may possibly be used as an indication of lower habitat quality including areas with more sea lettuce. Recent studies in multiple estuaries in Prince Edward Island (PEI) demonstrated that sites with enhanced macroalgal production, especially sea lettuce, had significantly higher mummichog densities (Finley *et al*. 2009; Schein et al. 2011). Northern pipefish, on the other hand, are generally indicative of habitats with less sea lettuce and more eel grass. In comparison to the reference site (Figure 51), it would seem that the Trout River and Covehead Bay are less impacted by eutrophication than the Mill River.

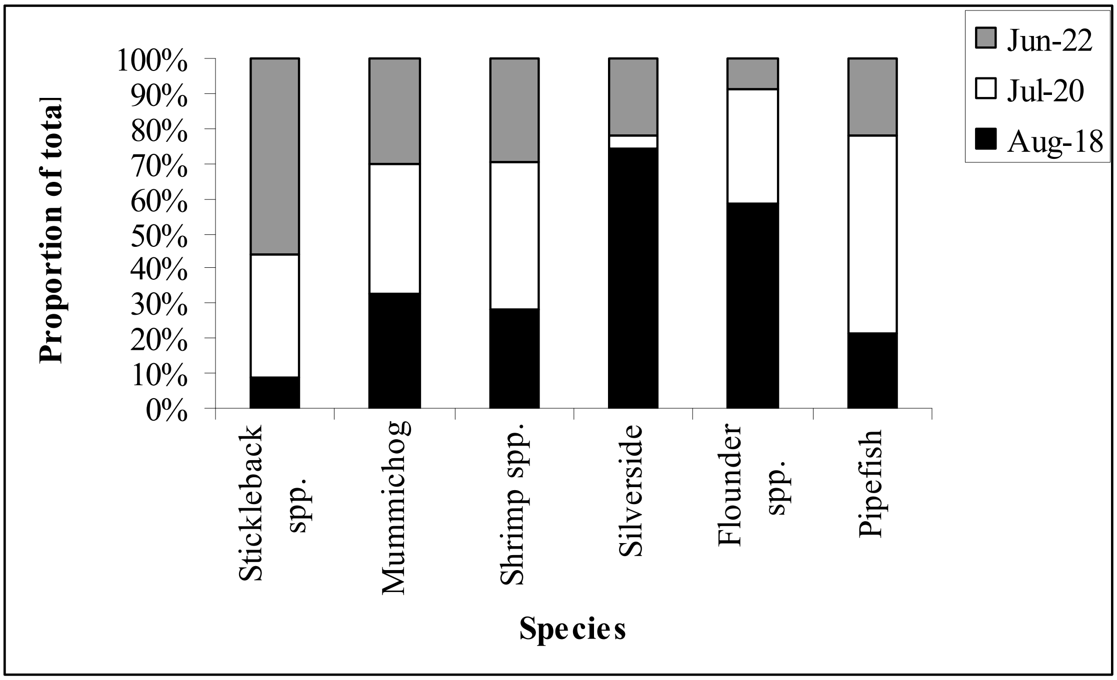

Figure 51. Faunal species proportion present at all sample dates at CAMP Site 3, Trout River.

4.5. Water and Sediment Quality

4.5.1. Dissolved Oxygen and Anoxic Events

4.5.1.1. Covehead Bay

Dissolved oxygen was measured in the upper Covehead Bay on 8 occasions between June and September 2011 (Figure 52). These were discrete samples taken, using a handheld meter, at various times from mid morning to mid afternoon during daylight hours.

The highest dissolved oxygen saturation values were recorded on July 19th with values between 134% and 138% saturation. The lowest dissolved oxygen saturation values were recorded on the September 7 sample date with values between 45% and 72% saturation recorded. Sampling was not carried out in Covehead Bay between July 19th and August 23rd, so it is not known how dissolved oxygen levels may have changed during this time.

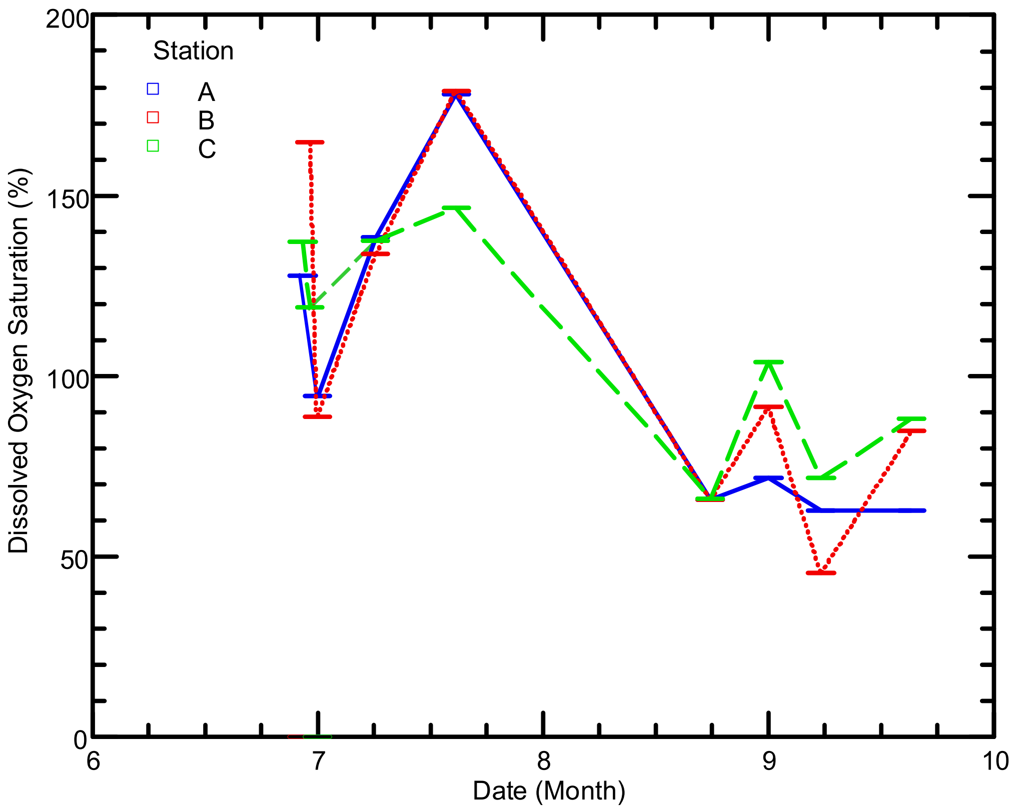

Figure 52. Median DO values and trends – Covehead Bay.

The decline in dissolved oxygen saturation values over the period of June 28th to June 30th could have been related to the time (of day) sampling. Values for June 28th and 29th were recorded in the early afternoon while those from June 30th were recorded nearly two hours earlier in the late morning. It is possible that the differences observed during these times are related to increasing dissolved oxygen levels as sea lettuce, phytoplankton and other marine plants photosynthesize as the day progresses.

A weekly log of water quality conditions in Covehead Bay was kept by staff of the local watershed group (FCBB). Although this log does not specifically record the presence of anoxia in the estuary it does ask for details on the appearance of the water, condition of sea lettuce, the presence of odours and the health of fish/shellfish that would be clues to the presence of anoxia in the estuary. This log indicates that discoloured water (cloudy green or milky white) was present on the east side of the bay adjacent to the Stanhope Golf Course on August 4th, 10th, 17th, 20th and 23rd as well as on September 3rd and 6th. This discoloration was accompanied by the presence of decaying sea lettuce on most dates and by rotten sea lettuce or rotten egg odours on August 20th, August 23rd and September 6th. Similar conditions were noted upstream at the Cass' Pond outlet at the same times. Dissolved oxygen values recorded in the upper estuary on the August 23rd sample date were in the range of 65% – 66% saturation which could indicate that the estuary had been affected by an earlier anoxic event.
Observations of discolorations and odours were recorded as part of the anoxic event tracking conducted by ELJ and indicate that anoxic events occurred in Covehead Bay

during August 1st and 2nd and again on September 6th. An additional event was also recorded in the area of the Stanhope Golf Course between September 15th and 18th. It is possible that this may have been a continuation of the event noted on September 6th.

4.5.1.2. Mill River

Dissolved oxygen was measured in the upper Mill River between 5 and 9 occasions between May and August 30th 2011. These results are summarized in Figure 53. These were discrete samples, using a handheld meter at both surface (0.3 m from the surface) and bottom (0.3 m from the bottom) locations, taken at various times from mid morning to mid afternoon during daylight hours.

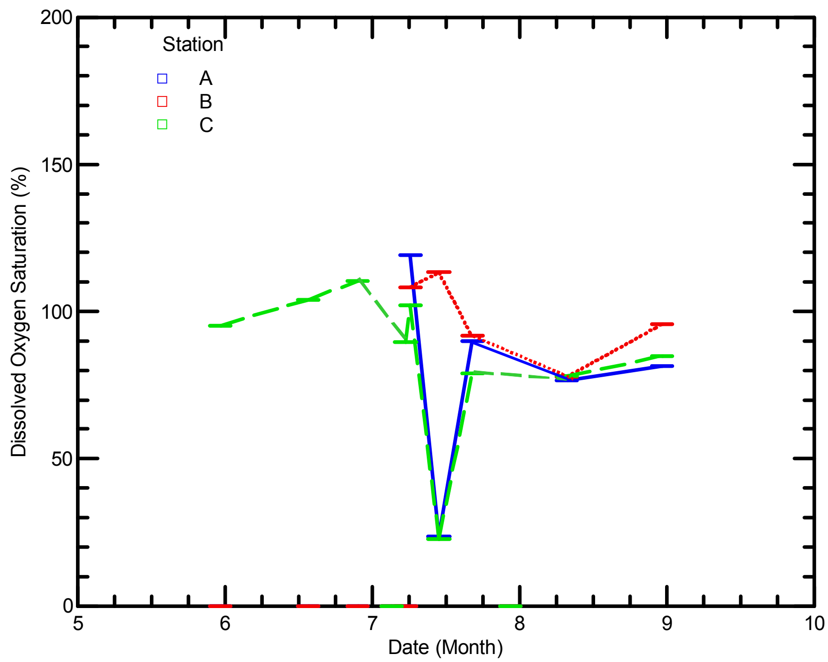

Figure 53. Median DO values and trends – Mill River.

The highest dissolved oxygen values recorded ranged between 108% and 119 % saturation on July 8th at Stations A and B. The lowest were on July 14th (stations A and C) and were 23 – 24% of saturation. The July 14th date was during the first harvest carried out in the Mill River estuary. No dissolved oxygen readings are available for the second harvest which was carried out August 4th to 6th.

A daily log of conditions on the Mill River estuary was kept by a local resident (Appendix F). Although this log does not specifically record the presence of anoxia in the estuary it does ask for details on the appearance of the water, condition of sea lettuce, the presence of odours and the health of fish/shellfish that would be clues to the presence of anoxia in the estuary. The log indicates that some discoloured water was present on July 30th and 31st and although this was not accompanied by any odours there were some dead fish or shellfish and decaying sea lettuce present that indicate poor water quality at this time. Dissolved oxygen readings are not available for this period.

The log indicates that discoloured water (cloudy green to milky white) water was present in the estuary during August 5th to 7th along with some odours, dying sea lettuce and some dead fish or shellfish. An anoxic event was confirmed to be occurring at that time by the sea lettuce harvest crew and ELJ staff that were on site on August 6th. Similar conditions were noted in the log between August 12th and 16th. During this period it was noted that there were "many" fish and shellfish either dead or in distress. The presence of anoxic conditions, indicated by a large area of milky white water and foul odours, was noted by ELJ staff who were in the area on August 15th.

4.5.1.3. Wheatley River

Dissolved oxygen was measured in the Wheatley River on 8 to 10 occasions between June and September 2011. These results are summarized in Figure 54. These were discrete samples taken at various times from mid morning to mid afternoon during daylight hours.

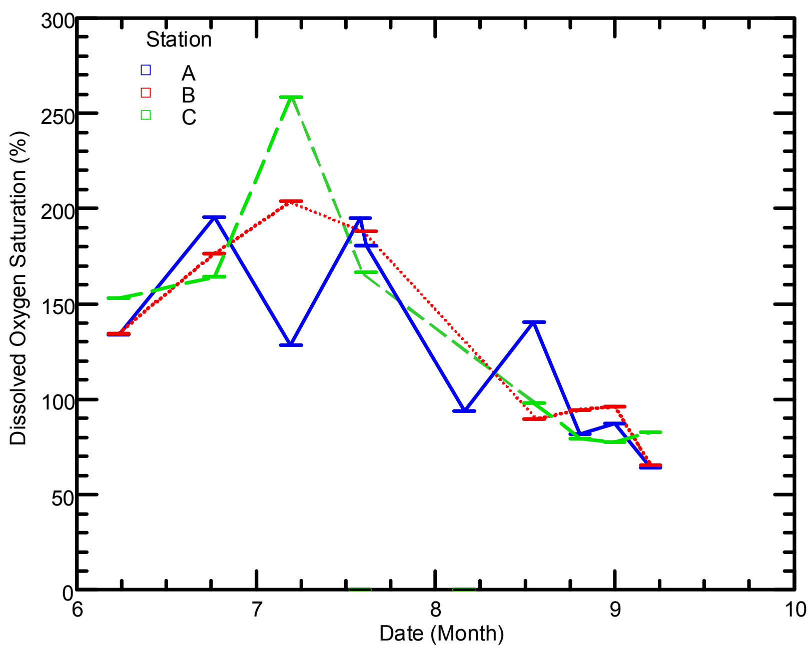

Figure 54. Median DO values and trends – Wheatley River.

During June and July dissolved oxygen levels were variable and showed periods of both increase and decline. This could be related to differences in the time of day when sampled. Values recorded during this period did not go below 129% saturation. The highest dissolved oxygen saturation value recorded (258%) was at Station C, located at the mouth of Crooked Creek, on July 6th. During August, dissolved oxygen levels were lower and ranged between a low of 78% saturation at Station C on August 31st and a high of 141% at Station A on August 17th. On September 6th recorded dissolved oxygen values were even lower ranging between 54% at Station A and 84% at Station C.

A daily log of water quality conditions was not kept in the Wheatley River. Several periods of anoxia were reported to ELJ by local residents and others over the summer months. Anoxic conditions were reported by CAMP samplers on July 26th and again on August 1st, 2011 by a member of the public. A large area of discoloured water was reported on August 1st and extended from the upper estuary to just above the Oyster Bed Bridge. No sample dates correspond directly to this reported period of anoxia; however, values recorded on August 6th were lower than those recorded on July 18th and 19th. Another anoxic event was reported by a member of the public as beginning on August 22nd and lasting for approximately 10 days. Dissolved oxygen measurements taken during this period ranged between 78% and 97% saturation.

4.5.2. Sediment Quality

Benthic sediments with sulfide measurements below 1500µM are generally considered to be oxic and relatively healthy. As measurements increase to between 1500-3000µM they are considered sub-oxic and measurements greater than 3000µM are characteristic of anoxic sediments.

Figure 55 shows the measurements taken in Covehead Bay at each of the sample times. In general, the sediments were all below the oxic level (<1500µM). There was only one measurement above 1000µM, which occurred after the harvest period. The benthic sediments in Covehead were low in free sulfides at each of the sites throughout the study. This also correlated with direct observation of the sediments. They were coarse grained and a brownish color (similar to beach sand on the north shore of PEI).

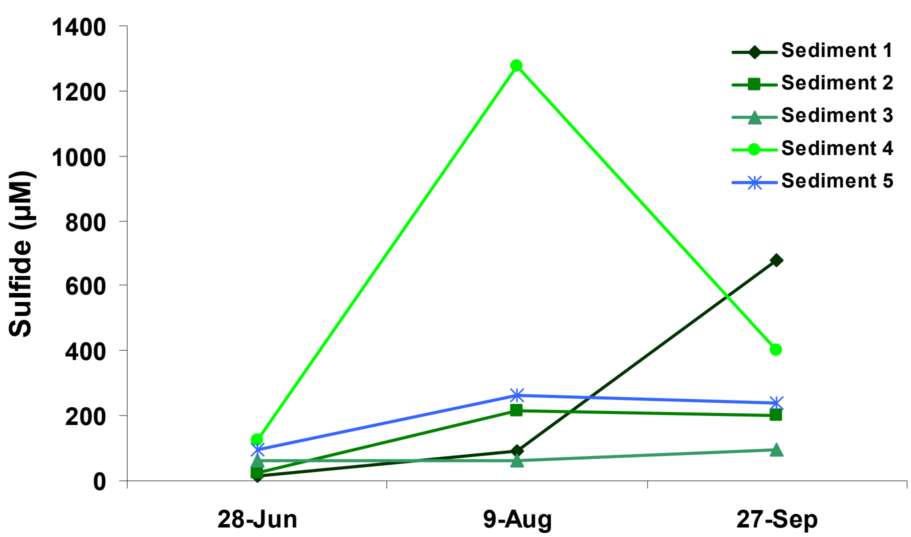

Figure 55. Sulfide results for Covehead Bay.

In Mill River, the free sulfide measurements taken followed the same trending as in Covehead Bay, with low measurements at the beginning and end of the study. Site 3 (Figure 56) had elevated sulfides during the mid-August sampling; however, this dropped to negligible levels by late September.

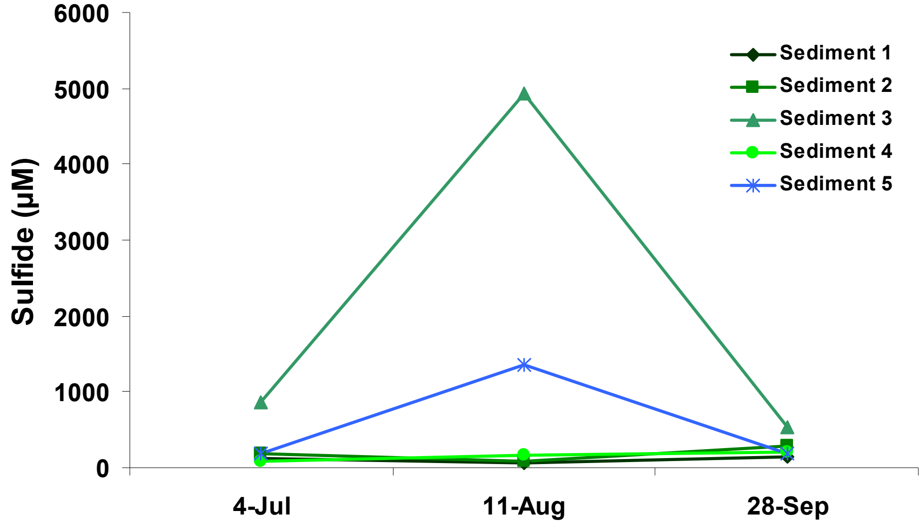

Figure 56. Sulfide results for Mill River.

Wheatley River, the reference site selected for this, study had extremely high free sulfides (<3000µM) at four of the five sites during the study (Figure 57). The sulfide levels declined significantly by the late September sampling, with all sites measuring less than 2000µM. Site 3 consistently had low measurements of free sulfides in the sediments from the early July sampling until the late September sampling.

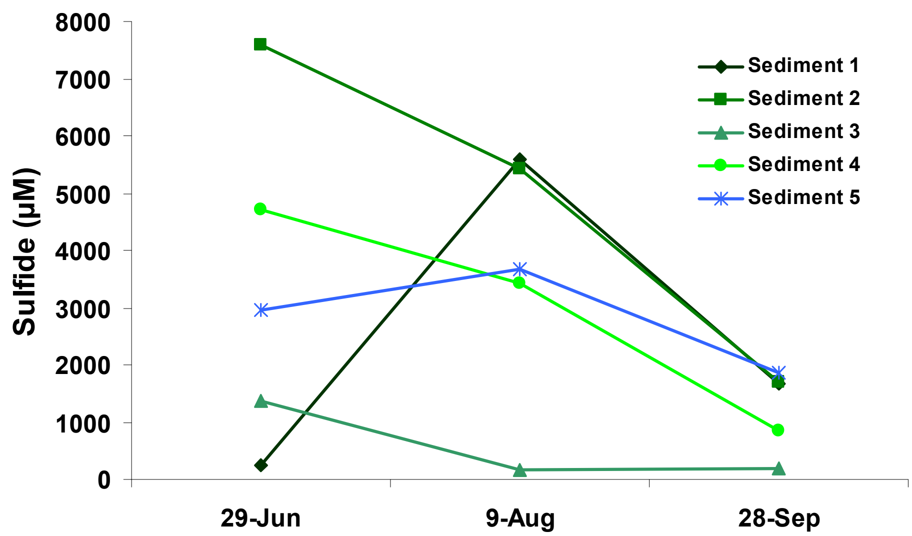

Figure 57. Sulfide results for Wheatley River.

All three study locations, regardless of whether sea lettuce harvest occurred, had low sulfide measures in the sediments in the late September sampling. Even the sites that had extremely high sulfide measurements in early summer at the reference site had low values by the late September sampling (see Figure 58).

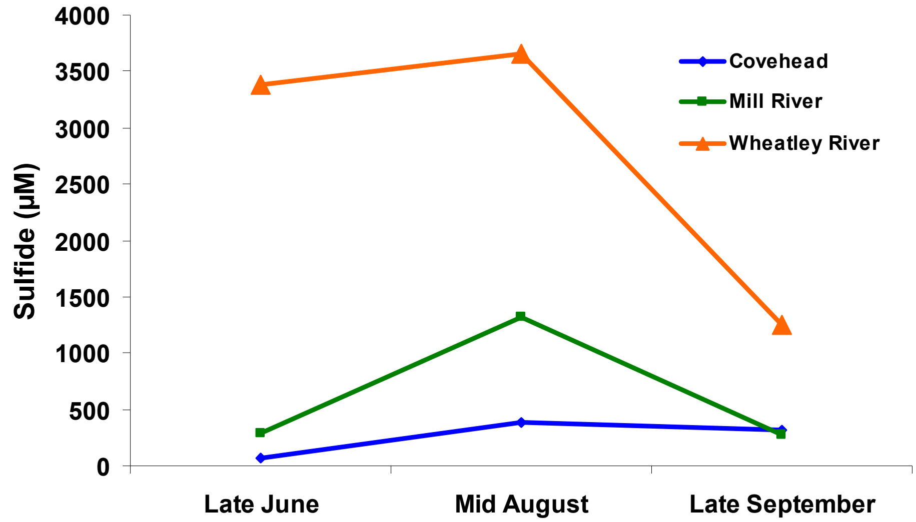

Figure 58. Sulfide results for each study area (average of 5 sites in each area, triplicate samples collected from each site).

4.6 Sediment Disruption

During harvest there was generally no issue with the disruption of sediments causing the creation of sediment plumes. Plumes which resulted in the suspension of harvest operations were noted in the uppermost harvested area of Auld's Creek, Covehead on July 27th , in Cass's Creek on July 28th and in Mill River, in the upper parts of the estuary, on August 5th and 6th. It was noted that prior to the onset of anoxic conditions in the estuary sediments (usually sand and mud) disturbed by the harvester's paddle wheels or cutting head quickly settled. It was only when the harvester began to encounter anoxic conditions that this became an issue. Rotting sea lettuce has a consistency of mayonnaise or loose jelly. This loose, black unconsolidated material is very fine and does not settle quickly.

5. PROJECT COSTS & SUSTAINABILITY

As part of the investigation of the efficiency of sea lettuce harvest, a cursory investigation of projected project costs and possible returns has been carried out.

Costs associated with this project, and included in this assessment, included the hourly rental of the harvesting equipment along with the costs associated with the trucking of the harvested material to farms and compost facilities. These costs were calculated to be approximately $75,000. This equates to a cost of $581/hour of harvest time or $322/tonne of harvested sea lettuce. This is very expensive and likely beyond the realistic ability of any group, including government, to sponsor. The cost of harvest must be lowered in the future.

Although the costs calculated here do not include costs unique to the pilot (such as project administration, day to day management, operator training or costs associated with the monitoring program) the 2011 costs are higher than those that would be incurred in the future. The operator has indicated that the hourly rate for the equipment used in this project could be in the range of $200 - $250/hour for future projects (Transcon personal communication, January 2012). This hourly rate can be achieved by spreading capital costs over a period of at least 10 or 12 weeks/season (rather than the 3 weeks in this pilot) and by achieving improved harvest efficiencies.

During this pilot, maximum harvest efficiencies occurred when floating sea lettuce was gathered at a rate of one load (2.7 tonnes) in 15 minutes. Allowing for a maximum offload time of 5 minutes/load, but no sailing time to an offload site, this is a harvest rate of 8.1 tonnes/hr. The harvest of submerged sea lettuce was less efficient than the harvest of floating sea lettuce. This was due to the slower speed at which the harvester had to operate to harvest submerged lettuce, as well as a lower density of submerged lettuce versus floating lettuce. A load of submerged lettuce took 25 – 40 minutes to harvest for a harvest efficiency of 3.6 – 5.4 tonnes /hour, allowing 5 minutes for offload, but no sailing time. The higher harvest rate (5.4 tonnes/hr) was achieved when the sea lettuce was relatively healthy and was lifting off of the bottom slightly.

Even though it has a lower harvest efficiency, it is thought that the harvest of submerged lettuce will be necessary in order to keep biomass in a severely impacted estuary at a level below that which would trigger anoxia. Therefore, it would be desirable to have the harvest rate for submerged sea lettuce comparable to the harvest of floating sea lettuce. Assuming that harvest would begin early in the season, prior to sea lettuce biomass beginning to decline, and that healthy, growing sea lettuce can be harvested throughout the season, a harvest rate of 5.0 tonnes/hr could possibly be achieved and sustained.

There are additional measures which could be taken to improve harvest efficiency above this level. The inclusion of a pick-up reel on the harvester's "cutting head" could allow the machine to harvest submerged sea lettuce an estimated 40% faster than the base rate of 5.0 tonnes/hour. This would be about 7 tonnes/hr or about 2.6 harvester loads per hour at 2.7 tonnes of harvested sea lettuce per load.

It is estimated that a device that would compact the sea lettuce by removing excess water from the lettuce as it is being harvested could increase load capacity by approximately 30% (from 2.7 tonnes to 3.5 tonnes/load). Increasing load capacity has the effect of reducing the total time required for offloading, allowing more time for harvest. With the 5 minute offload and 0 minute sailing times used in the estimates above, a small increase (3 tonne/day or 5%) in the amount of sea lettuce harvested per day could be achieved. It should be noted that the saved time would become even more significant if offload times are actually longer than the 5 minutes used in this exercise.

The biggest issue for harvest efficiency in this pilot was the time lost sailing the harvester back and forth to offload sites. Sailing times for this pilot varied between a low of 5 or 6 minutes/one way trip to a high of 25 minutes/one way trip. If sailing times can be reduced or eliminated through either using closer offload sites or a transport barge, significant improvements in harvest efficiency can be achieved. This is illustrated in Table 8, using a projected harvest efficiency of 7.0 tonnes/hr.

Table 8. Projected harvest efficiencies with various projected sail times to offload sites.

Total Sail Time	Total Time Per Load (at 7.0 tonnes/hr)	Overall Harvest Efficiency (tonnes/hr)	Harvest Efficiency Improvement (%) With Sail Times:						
			0 Minute	5 Minute	10 Minute	15 minute	20 minute	25 minute	30 minute
0	30	7.00	0.00						
5	35	6.46	8.33	0.00					
10	40	6.00	16.67	7.69	0.00				
15	45	5.60	25.00	15.38	7.14	0.00			
20	50	5.25	33.33	23.08	14.29	6.67	0.00		
25	55	4.94	41.67	30.77	21.43	13.33	6.25	0.00	
30	60	4.67	50.00	38.46	28.57	20.00	12.50	5.88	0.00
35	65	4.42	58.33	46.15	35.71	26.67	18.75	11.76	5.56
40	70	4.20	66.67	53.85	42.86	33.33	25.00	17.65	11.11
45	75	4.00	75.00	61.54	50.00	40.00	31.25	23.53	16.67
50	80	3.82	83.33	69.23	57.14	46.67	37.50	29.41	22.22
55	85	3.65	91.67	76.92	64.29	53.33	43.75	35.29	27.78
60	90	3.50	100.00	84.62	71.43	60.00	50.00	41.18	33.33
65	95	3.36	108.33	92.31	78.57	66.67	56.25	47.06	38.89
70	100	3.23	116.67	100.00	85.71	73.33	62.50	52.94	44.44
75	105	3.11	125.00	107.69	92.86	80.00	68.75	58.82	50.00
80	110	3.00	133.33	115.38	100.00	86.67	75.00	64.71	55.56
85	115	2.90	141.67	123.08	107.14	93.33	81.25	70.59	61.11
95	120	2.71	158.33	138.46	121.43	106.67	93.75	82.35	72.22
100	125	2.63	166.67	146.15	128.57	113.33	100.00	88.24	77.78

Offloading times of 5 minutes are included in the total harvest time

There is significant cost associated with the operation of a sea lettuce harvester so any significant improvement in harvest efficiency achieved by shortening or eliminating sailing times would be beneficial. Reducing sailing times may involve the construction of offloading sites that are closer to harvest areas. Construction of these sites would add cost to any project; however it is estimated that these costs could be covered by improved efficiencies in the sea lettuce harvest over a single harvest season. For example, the construction of an offload site that would reduce total sailing times for the harvester from 30 minutes (15 minutes or 1 – 1.2 km each way) to 10 minutes (5 minutes or 400 – 500 m each way) would result in a 28% improvement in harvest efficiency (from 4.7 tonnes/hr to 6.0 tonnes per hour). A project that would cost $80,000, with the longer sailing time, would be reduced to $58,000 with the reduced sail time. The $22,000 that would be saved could be used to fund offload site construction. Construction of offload sites could also be spread out over several years, as a capital cost.

A transport barge could also greatly improve harvest efficiency; however, the inclusion of a barge in harvest operations would add cost to projects, unless sailing times were very long. A transport barge is a faster and lighter piece of equipment that could sail back and forth between the harvester and the offload site, so the harvester only has to stop harvesting to offload to the transport barge. Using a transport barge, nearly continuous harvest is possible. A transport barge would add an estimated 65%- 70% to the harvest cost due to higher operational and capital costs. This cost can be completely recouped through the improvement in efficiency when sailing times exceed 40 minutes (20 minutes or 1.2 – 1.5 km each way) (Table 8). Sailing times less than 40 minutes total would result in higher harvest costs overall if a transport barge were used (Table 8). Higher hourly harvest costs associated with using a transport barge may also have to be considered if increasing the frequency of harvests is the only way to remove enough sea lettuce biomass to prevent anoxia.

The projected harvest times for selected local estuaries (those with known issues with sea lettuce and anoxia), using various sailing times and efficiencies, is given in Table 9. For this exercise, it is estimated that 75% of the estimated standing crop (9.4 tonnes/ha of 12.5 tonnes/ha) in any given estuary has to be removed in any given harvest in to keep sea lettuce populations in check and to prevent anoxic events from occurring.

It is estimated that six harvests will be required in each estuary, per season, as sea lettuce will re-grow once harvested. It is further assumed that the most plausible and feasible scenarios for harvest in these estuaries involve either a 15 minute sailing time (or less) to an offload site or the use of a transport barge. Estimated harvest costs for these estuaries are given in Table 10, using these assumptions. Values from Table 10 indicate that it would cost an estimated $2,000,000.to $3,400,000 per year to harvest the most impacted estuaries in the province. This would require 12 – 14 harvesters, with one harvester being shared between two or more estuaries.

A remaining question is if sea lettuce harvest can become a viable and sustainable enterprise. It is estimated that the cost of harvesting a tonne of sea lettuce will be between $45 and $62 per tonne, if the improved harvest efficiencies and lower harvest costs used here can be achieved. These values will now be used to determine how realistic it is to expect to recoup harvest costs through the sale or use of the harvested sea lettuce.

Sea lettuce has approximately the same nitrogen content as pig manure with the added benefit of micro-nutrients (John MacLeod, personal communication April, 2011). Although there is some risk to crops from salt and substances such as sulfide and manganese this should not be an issue as long as healthy sea lettuce is applied and recommended application rates are followed (John MacLeod, personal communication April, 2011.). The field application rates for sea lettuce recommended by the PEI Department of Agriculture are very similar to pig manure (14.5 t/ha) (Appendix H). A small field trial conducted by Agriculture Canada (Rodd *et al*. 2011) suggests that forage crop yields benefited (60% increase in yield) from the application of sea lettuce at the recommended rate. This suggests that harvested sea lettuce has approximately the same value as pig manure as a crop supplement. Although not a commodity that farmers would typically purchase, pig manure would be valued at about $6 to $12/tonne (Erica MacDonald, personal communication December, 2011). This value is well below the estimated cost of harvest.

Table 9. Estimated harvest times for selected estuaries (impacted by sea lettuce and anoxic events) with various sailing times to offload sites.

Estuary	Estimated Harvestable Area (HA)	Time To Harvest (Hours) With Sailing Time of:						
		0 Min	5 Min	10 Min	15 Min	20 Min	25 Min	30 Min
Wheatley	30	40	44	47	50	54	57	60
Southwest (main branch)	35	47	51	55	59	63	66	70
Eel Creek	8	11	12	13	13	14	15	16
Tuplin Creek	7	9	10	11	12	13	13	14
Durant Creek	10	13	15	16	17	18	19	20
Harding Creek	13	17	19	20	22	23	25	26
Long River	12	16	17	19	20	21	23	24
Montrose/Huntley	55	74	80	86	92	98	104	110
Mill River (main branch)	29	39	42	45	49	52	55	58
Long Creek	8	11	12	13	13	14	15	16
Meggison's Creek	10	13	14	15	16	17	18	19
Hills River	27	36	39	42	45	48	51	54
Mill Creek	19	25	28	30	32	34	36	38
Barbara Weit River	30	40	44	47	50	54	57	60
Indian River	29	39	42	45	49	52	55	58
Trout/Stanley River (main b	23	31	33	36	39	41	44	46
Founds River	8	11	12	13	13	14	15	16
Granville River	14	19	20	22	23	25	27	28
Anderson's Creek	5	7	7	8	8	9	9	10
Hope/Bayview River	19	25	28	30	32	34	36	38
Hunter/Clyde River	44	59	64	69	74	79	83	88
Chapel Creek	23	31	33	36	39	41	44	46
Horne's Creek	5	7	7	8	8	9	9	10
Covehead Bay	23	31	33	36	39	41	44	46
Brackley Bay	53	71	77	83	89	95	101	106
Winter River	36	48	52	56	60	64	68	72
Souris River	21	28	30	33	35	38	40	42
Dunk River	112	150	163	175	188	200	213	225
Wilmot River	88	118	128	138	147	157	167	177

Table 10. Estimated annual sea lettuce harvest costs for selected estuaries impacted by anoxic events

Estuary	15 Minute Sail to Offload Site			With Transport Barge		
	Estimated Harvest Time (hrs)	Estimated Cost (@ $250/hour)	Total Cost (6 harvests per season)	Estimated Harvest Time	Estimated Cost (@$425/hr)	Total Cost (6 harvests per season)
Wheatley	50	$12,600	$75,600	50	$21,300	$127,800
Southwest (main branch)	59	$14,600	$87,600	59	$24,900	$149,400
Eel Creek	13	$3,300	$19,800	13	$5,700	$34,200
Tuplin Creek	12	$2,900	$17,400	12	$5,000	$30,000
Durant Creek	17	$4,200	$25,200	17	$7,100	$42,600
Harding Creek	22	$5,400	$32,400	22	$9,200	$55,200
Long River	20	$5,000	$30,000	20	$8,500	$51,000
Montrose/Huntley	92	$23,000	$138,000	92	$39,100	$234,600
Mill River (main branch)	49	$12,100	$72,600	49	$20,600	$123,600
Long Creek	13	$3,300	$19,800	13	$5,700	$34,200
Meggison's Creek	16	$4,000	$24,000	16	$6,800	$40,800
Hills River	45	$11,300	$67,800	45	$19,200	$115,200
Mill Creek	32	$8,000	$48,000	32	$13,500	$81,000
Barbara Weit River	50	$12,600	$75,600	50	$21,300	$127,800
Indian River	49	$12,100	$72,600	49	$20,600	$123,600
Trout/Stanley River (main branch)	39	$9,600	$57,600	39	$16,400	$98,400
Founds River	13	$3,300	$19,800	13	$5,700	$34,200
Granville River	23	$5,900	$35,400	23	$10,000	$60,000
Anderson's Creek	8	$2,100	$12,600	8	$3,600	$21,600
Hope/Bayview River	32	$8,000	$48,000	32	$13,500	$81,000
Hunter/Clyde River	74	$18,400	$110,400	74	$31,300	$187,800
Chapel Creek	39	$9,600	$57,600	39	$16,400	$98,400
Horne's Creek	8	$2,100	$12,600	8	$3,600	$21,600
Covehead Bay	39	$9,600	$57,600	39	$16,400	$98,400
Brackley Bay	89	$22,200	$133,200	89	$37,700	$226,200
Winter River	60	$15,100	$90,600	60	$25,600	$153,600
Souris River	35	$8,800	$52,800	35	$14,900	$89,400
Dunk River	188	$46,900	$281,400	188	$79,700	$478,200
Wilmot River	147	$36,800	$220,800	147	$62,600	$375,600
Totals	**1332**	**$333,000**	**$2,000,000**	**1,332**	**$566,000**	**$3,400,000**

Unfortunately, it may be that sea lettuce has very limited value to farmers due to the constraints associated with using it. The earliest that harvested sea lettuce may be available to farmers is mid to late May or early June. By this time of year the planting of crops is well under way and farmers may not have the luxury of delaying this work in order to get a supply of sea lettuce to use as a nutrient source. Sea lettuce harvested late in the summer (mid to late June and July/August) currently have only one suitable use; as a supplementary nutrient application to forages that have already been cut. An Islandwide harvest of all impacted estuaries would likely create an excess of product to the available land area where it can be applied. Trials conducted this year indicate that the sea lettuce has a tendency to clump up and sit on top of the grass when applied, killing the grass beneath. The sea lettuce should be either chopped as it is offloaded or spreading eguipment would have to be equipped with a chopping attachment in order to effectively use sea lettuce as a soil supplement on these fields. These factors, plus the already narrow window of opportunity, may be enough to reduce the already low value of sea lettuce to farmers. Research is needed to determine if there are other ways in which sea lettuce can be used as a soil supplement.

Approximately half of the sea lettuce harvested in this pilot was used to make compost. One of the two composters will use the finished compost as on-farm soil additive while the other will package it for sale to local gardeners as “seaweed compost”. This operator has indicated that as it is labour intensive to first make and then package the compost. As the amount that can be charged for the product is fairly low, there is little ability to pay for harvested sea lettuce, especially if a similar product could be obtained at no cost from beach wrack. Compost would provide little opportunity to recoup harvest costs.

There has been a great deal of public discussion of possible added value of sea lettuce. Until these discussions proceed beyond the proof of concept phase of development, it is possible to assign only theoretical value to these uses. The following is an example.

Use of harvested sea lettuce as a feedstock for biogas production has been widely discussed. Various conflicting references to biogas potential can be found on the internet. Biogas yields as little as 17 m^3/tonne of wet sea lettuce have been reported by Japanese researchers (http://aiche.confex.com/aiche/2006/preliminaryprogram/abstract_73948.htm). Other references indicate that sea lettuce is similar in yield to manure (http://www.biowalk4biofuels.eu/wp-content/files_mf/1280303544Algae_species.pdf) (60 m^3/tonne wet weight) or forage grasses (240 m^3/tonne dry weight or approximately 36 m^3/tonne wet weight) (http://care.india.tripod.com/id26.html).

Theoretically, based on the above values, a tonne of sea lettuce could yield between 17 m^3 and 60 m^3 of biogas. Since the energy value for biogas is approximately 1.5 to 2.1 m^3 per litre of diesel fuel (medium grade) (http://www.greenpowerindia.org/Biogas.htm) one tonne of sea lettuce would be approximately equal to 8.1 litres to 40.0 litres of diesel fuel. At a current retail price of $1.32/L this represents a value of $10.70 to $52.80 / tonne of sea lettuce. This range is certainly in the ballpark of the $45 - $62/tonne harvest costs estimated here. It is important to note that this “theoretical” value for biogas produced from sea lettuce does not reflect the actual quality of the biogas produced or any costs associated with producing the biogas. Biogas would likely have to be used where it is produced as transportation and storage of the gas would be difficult and add additional cost to production. The limited usability of biogas generated from sea lettuce may make it less valuable than an equivalent amount of diesel.

Biogas production will also leave behind a waste product that would have to be dealt with at additional cost. It is possible that this waste product can be turned into something useful such as a dried pellet for use as fertilizer or an animal feed supplement. There has been some suggestion that this may produce the highest potential return for value added options. The costs associated with the production of such a pellet are not known; however, it is possible that the initial biogas production could help produce the energy required to produce a pellet.

The value of sea lettuce harvest also has to be weighed against the cost of taking other measures to improve water quality conditions in estuaries. The only real solution to issues of eutrophication is to address the root cause; the input of nutrients from human sources. Prince Edward Island has endorsed watershed nutrient planning as the way to accomplish nutrient reduction.

Although the benefit of harvesting sea lettuce from the Island's estuaries is chiefly in reducing the biomass which is causing oxygen stress on the system, the removed sea lettuce also has a nutrient component. In this case, the nutrient of interest is nitrogen. Samples taken in support of this project demonstrated that actively growing, healthy sea lettuce has a total nitrogen content of around 0.54% wet weight (Appendix H). Samples taken from the sea lettuce harvested by this project in the Mill and Hills River were around 0.3% total nitrogen (wet weight). The difference is likely due to the sea lettuce having passed its active growing phase and becoming senescent. This means that the sea lettuce harvested for Covehead Bay, Hills River and Mill River had total nitrogen amounts of about 194 kg, 90 kg and 439 kg respectively.

Nitrogen loading to various estuaries has been estimated by ELJ as part of the watershed nutrient planning process. Loads of 114 kg/day, 97 kg/day and 515 kg/day have been calculated for Covehead Bay, Hills River and Mill River. The total nitrogen removed from each estuary as a result of harvest represents just 1.7 days (0.47%) of loading to Covehead Bay, 0.92 days (0.25%) of loading to Hills River and 0.85 days (0.23 %) of loading to Mill River. This indicates that nutrient planners will have to carefully consider the costs associated with the harvest of sea lettuce if it is to be considered in conjunction with nutrient reduction as a solution. It may be that the cost to harvest sea lettuce, in amounts which are great enough to prevent anoxia from occurring, is exorbitant and would be better spent on efforts to reduce the nutrient loading. While this is a longer term solution it may end up being more cost effective than harvesting.

6. DISCUSSION

Entering this project it was proposed that some basic questions exist about harvesting sea lettuce in Prince Edward Island. These were:

- How efficient is sea lettuce harvest under PEI conditions?

- What degree of harvest/removal effort is needed to keep sea lettuce populations in check? Once harvested, will sea lettuce simply re-grow quickly requiring additional removal?
- What degree of harvest/removal effort is needed to prevent severe conditions, such as anoxic events?
- What are the environmental effects achieved by the harvest activity?

Using the results of this project these questions can now be at least partially answered.

6.1. Sea Lettuce Harvest Efficiency

This project demonstrated that mechanical harvest of sea lettuce is possible in Prince Edward Island. A total of 241 tonnes of sea lettuce was harvested from three estuaries in 129 hours of harvest time. It was apparent that harvest efficiency (tonnes/hr harvested) could have been greatly improved.

Several factors reduced harvest efficiency during this project. In both Covehead Bay and the first harvest in Mill River the offloading sites for the harvested sea lettuce were over a kilometre from the main harvest area. Harvesting in the Hills River and the second harvest in the Mill River demonstrated that closer offloading sites can improve harvest efficiency by as much as 2 to 3 times.

There were several other factors that can affect harvest efficiency that would have to be more carefully planned in any future project. Offloading efficiency could also have been greatly improved by having launch areas with suitable water depths. Shallow conditions are a factor as are steep drop offs. Offloading sites should also be located in a sheltered area as winds were a factor in inefficiencies in docking of the harvester to the shore conveyor.

Having a dedicated vehicle on site that can move the shore conveyor with the rise and fall of the tide would also greatly improve overall harvest efficiency. The greatest efficiency would be achieved if this vehicle can also be used to haul the harvested sea lettuce.

Additional support equipment that should be provided by the owner/operator would include a mooring so that the harvester does not become stranded on shore due to wind and/or falling tides. Operators should also have access to small boat, canoe or kayak that can allow them to access the moored harvester. There is often a narrow window of time in any given day or week that is optimal to harvest due to factors like tide levels, wind and condition of the sea lettuce. Any loss of time that subtracts from this time results in lost harvest efficiency.

Harvesting operations should also be attentive to working with the tides. Tides change on a daily basis and operators should be very aware of the expected tides during the planned harvests so that they can adequately plan the harvest activity. Rather than being a strictly 8 – 5 operation, harvest times may have to be adjusted to times when the tide heights are more conducive to harvest operations. This may also assist in efficient docking of the harvester to the shore conveyor. Operators could also harvest more selectively with the tides harvesting shallow areas during the higher tides and deeper areas during lower tides.

Days with windy and rainy conditions made it difficult to operate the harvester during this pilot. The weather cannot be controlled, so operators must use their best discretion to determine when to harvest. Harvesting on several short days is not as efficient as harvesting for a single long day. Harvesters must weigh the decision to begin harvest on a marginal weather day with the narrow window of opportunity for harvest that often exists.

Harvest efficiencies may also be addressed through the use of an additional piece of equipment. Aquarius Aquatic Weed Harvesters © has a transport barge available which is reported to improve harvest efficiencies by up to 90%. These barges are lighter and faster than the harvester allowing for docking in shallower areas and much faster trips to and from the offloading area. Use of this piece of equipment would mean that the harvester would never have to leave the harvest area, pausing only briefly to transfer its load to the barge. Increased harvest efficiencies would have to be scaled against the increased capital and overhead costs associated with the operation of a third piece of the equipment.

The current harvester is equipped with a cutter head which is not necessary for the harvest of sea lettuce in PEI. Some observers of the harvest operation wonder if modification to the cutter head would improve harvest efficiencies by an estimated 40%. An uptake reel similar to one used on a hay baler has been mentioned as a possible improvement. This uptake might allow submerged sea lettuce to be picked up more efficiently from the bottom without getting the cutter head close to the bottom. It is not clear how this would be attached or how it would operate or if it would simply become fouled with sea lettuce.

An additional modification may be a mechanism on the harvester which would compress or compact the harvested sea lettuce allowing it to carry bigger loads and make fewer offloading trips. It should be noted that a increase in loaded weight (from 2.7 tonnes to 3.5 tonnes) may make docking with the conveyor even more difficult in shallow areas.

The cost per hour/tonne of the pilot harvest was very high. Changes that would reduce these costs need to be implemented for any future projects. The operator has indicated that future project costs could be in the $200 - $250 per hour range. These reductions can be achieved through amortizing the capital costs over a longer period of use over the summer months (Transcon personal communication, January 2012). Overhead costs could also be reduced by reducing labour costs associated with the project. During the pilot 3 paid employees were often on site; the harvester operator, the truck driver and an operator for the shore conveyor. By combining the truck driver and shore conveyor operator duties one third of the labour costs could potentially be saved.

Overall harvest costs will remain high even with the projected cost reductions and improved efficiencies that could possibly be achieved. For example it is estimated that it could cost about $9,600 per harvest in Covehead Bay and about $12,100 for Mill River (Table 10). If as many as six harvests are required in order to prevent anoxia in each estuary this could amount to total costs of $58,000 and $73,000 per estuary (Table 10).

Harvested areas could be more accurately monitored through the use of a chart plotter that records harvest tracks. Some of these plotters have removable media or are capable of downloading data so that harvested areas can be easily mapped for very good accuracy of areas harvested. Operators would also be able to see which areas have been previously harvested and would be able to keep to areas with the highest sea lettuce densities for the best possible harvest efficiency.

6.2. Impact on Sea Lettuce Populations

The monitoring program used in this pilot had some gaps in frequency, which make it difficult to closely track changes in sea lettuce density in the three estuaries studied.

There is insufficient data to indicate if the pilot harvest in Covehead Bay had any impact on sea lettuce densities immediately following the harvest carried out from June 27th to July 2nd. No pre-harvest measurements were made, due to a change in methodology after the harvest had already started in Covehead. Covehead Bay did have sea lettuce densities which were statistically similar to those recorded in Mill River between July 6th and July 8th (prior to harvest occurring in Mill River) and to those in the reference (un-harvested) site, Wheatley River (between July 19th and 21st). This could indicate that little or no change occurred in density as a result of the harvest activity in Covehead. CAMP sampling did reveal a decline in sea lettuce following harvest in the sampled area near the Stanhope Golf Course.

Slight declines in sea lettuce density were noted in Mill River on three occasions. The first two declines were recorded in subsequent weeks (July 14th and July 21st) and followed the start of harvest on July 11th. There is a small amount of evidence that this decline could be a result of the first harvest conducted in Mill River. The area of the estuary containing Plot C was not harvested until July 20th and showed a very slight increase in densities between the July 6th and July 14th and decrease on July 21st. Sea lettuce densities in the Wheatley River (un-harvested) and Covehead Bay (un-harvested during this sample period) increased slightly or stayed relatively the same during the same period.

It is also very possible that the decline noted in the Mill River is for other reasons. Sea lettuce populations in estuaries which experience periodic anoxia are known to experience periods of increase and collapse over the summer months (ELJ unpublished data). This is likely due to a highly inter-related chain of events; some sea lettuce begins to die off and decompose causing an anoxic event and the anoxic event then cause more sea lettuce to die and decompose. Although it seems possible that the decline in density noted in Mill River in mid July is related to the harvest conducted between July 11th and 20th there is also the possibility that it was due to a decline related to the onset of anoxia. Anoxia may have been starting to occur in Mill River around July 14th, as very low dissolved oxygen readings were recorded at this time. There was some die off of sea lettuce noted in the estuary log on July 15th and 16th. Some blackened sea lettuce was also observed in the estuary on both July 20th and July 21st.

The decline noted in sea lettuce densities in Mill River during early to mid August are almost certainly due to the onset of an anoxic event at that same time. Observations made by the harvest operator during the second Mill River harvest conducted between August 4th and August 6th indicate a collapsing sea lettuce population with the onset of anoxic events. By the time harvest was halted on August 6th there was little or no sea lettuce left to harvest.

It is possible that the first harvest in Mill River helped avert an anoxic event that was threatening to begin around July 14th. Sea lettuce densities recorded in Mill River on July 29th were very similar to pre-harvest densities. Since the estuary began experiencing anoxia a week later, this density (26 m^3/ha) may have been very close to the value which resulted in anoxia. If this was the case, then the estuary should have been close to anoxia on July 6th. It is possible that the harvest conducted between July 11th and July 20th removed enough sea lettuce from the system at that time to briefly postpone anoxia from occurring.

More than two weeks elapsed between the first and second harvests conducted in the Mill River. ELJ staff noted that some floating sea lettuce was present in the upper Mill River on July 29th. Floating sea lettuce mats are generally considered to be a sign that the sea lettuce population is starting to decline. If the 2nd harvest had started sooner and/or the first harvest been more extensive in terms of amounts harvested it may have been possible to delay or avert the anoxic event which began on August 5th or 6th.

An unexpected side effect of this project was the debate over the merits of targeting floating vs. submerged sea lettuce. This project has demonstrated that the harvest of floating mats of sea lettuce can be the most efficient type of harvest. The project also demonstrated that not all populations of sea lettuce become floating. The weather conditions experienced this year worked against this practice as sea lettuce was submerged on the bottom throughout most of the harvest period. It would be interesting to see what the impact would be if a sustained harvest of floating sea lettuce could be carried out (assuming that there was a year where weather conditions cooperated).

Sea lettuce populations are starting to collapse by the time there is floating lettuce appearing. The harvest of only floating lettuce may not be sufficient to keep an estuary from becoming anoxic if there is so much sea lettuce present that the harvester could not keep up. A better practice would likely to be to harvest actively growing sea lettuce, from the bottom, earlier in the season. This would be prior to the sea lettuce population reaching peak biomass giving a cushion of time for the harvest to be completed before there is a threat of an anoxic event being triggered.

Sea lettuce populations were not tracked in the Mill River after the end of August. High densities of sea lettuce present in the Wheatley River during this time and reports of anoxia from Wheatley River and Covehead Bay, and from other areas of the province, in September, would suggest that additional harvests in early to mid September would have been necessary to prevent anoxia.

Under a “best case” scenario, enough sea lettuce could be harvested to allow a gap of time between harvests. Another scenario would be that continuous non-stop harvests would be necessary, while the “worst case” would be that no amount of harvest can keep up with growth in order to prevent anoxic events from occurring. Insufficient information was collected to determine which case may exist in the affected estuaries of PEI. If either of the first two cases is true the practice of harvest becomes much like a “mow the lawn” exercise with the time between mowings depending on how fast the sea lettuce grows and how efficient the harvest is.

All indications are that sea lettuce grows very fast in PEI and that populations can double their size in just a few days. The window of opportunity for effectively removing the sea lettuce and keeping it below the level which could trigger anoxia could be very small. As little as 3 -4 days could exist between the time there is only half enough sea lettuce present to cause an anoxia and the time where there is enough sea lettuce present. This was demonstrated by this project. In the week following the first harvest measured sea lettuce densities in the estuary closely matched those which were present prior to the harvest. This was a time when the estuary appeared to be becoming anoxic. Another week passed before the second harvest began in the Mill River. By this time, the sea lettuce was declining and an anoxic event occurred. Beginning the 2nd harvest a week earlier could have had a greater impact in either preventing or delaying this anoxic event.

It is clear that any future projects would have to be able to respond quickly to sea lettuce growth. Any delays in getting harvesting carried out could be very critical.

Finally, it is apparent that monitoring would have to be much more frequent to adequately track changes in sea lettuce density in estuaries in PEI. Weekly frequencies are recommended. It is also suggested that more sites be sampled within estuaries to give more robust results. Sea lettuce density monitoring is a labour intensive process. Increased frequency and intensity of monitoring would mean that monitoring could only be adequately carried out in a few estuaries.

6.3. Anoxic Events

It is readily apparent that the level of harvest carried out by this project was not sufficient to prevent anoxic events from occurring in any of the three estuaries measured.

Covehead Bay suffered at least two distinct anoxic events throughout the season. The first event was recorded in early August, just one month after harvest stopped.

Hills River may have experienced an anoxic event in the upper end of the estuary just prior to the harvest beginning on July 8th. The amount of sea lettuce harvested from the Hills River was small and it was not expected that it would be enough to avert anoxic events from occurring. Anoxic events were reported in the estuary on August 1st and again on August 15th.

Observations from the Mill River indicate that an anoxic event may have been threatening/averted at or around July 14th. Although harvest was continuing during this time, it is not known if the harvest had any factor in this.

The first notably anoxic conditions in Mill River were not recorded until August 6th. This is a few days later than the other two harvested rivers. It is also a few days later than some other north shore estuaries known to have periodic anoxia. These included the Wheatley River (July 26th and August 1st), Trout/Stanley River (July 26th and August 1st) and the Southwest River (Harding Creek) (August 1). Although this may indicate that anoxic conditions were somehow delayed by the harvest that occurred in Mill River, two estuaries - Winter River and Montrose River, which both have issues with annual anoxic events - were also not reported to be anoxic until later in August (August 16th and 29th, respectively).

It is apparent that more sea lettuce would have to be harvested in all estuaries to avert anoxic events. It is not known how much sea lettuce harvest this would require. There should have been a shorter interval between harvests in the Mill River, as the nearly two week period that was present was clearly too long. It has been estimated here that six harvests of sea lettuce would be needed per season in order to keep sea lettuce populations in check.

A further question that may remain is whether the current harvester, at maximum efficiency, can even harvest enough sea lettuce to prevent anoxia from occurring. The harvest of sea lettuce is limited by the operational depth of the machine which, for all practical purposes of this project, was 0.6 m to 1.6 m. Any significant sea lettuce populations that grow at depths less than 0.6 m or greater than 1.6 m (sea lettuce has been observed growing at depths > 3 m in PEI) would remain un-harvested using the current harvester. It is estimated that in the Mill River a standing crop that is at least double the volume present in harvestable areas exists in un-harvestable areas, while in Covehead Bay an equal amount of un-harvestable sea lettuce exists. While it is not known exactly what impact this remaining sea lettuce would have, it is possible that enough would still remain to trigger an anoxic event even after extensive harvest is carried out.

6.4. Environmental Impact

No impacts on dissolved oxygen levels or sediment conditions were found that could be attributed to the sea lettuce harvest activity. While the CAMP sampling may have indicated some change in vegetative cover in Covehead Bay that might be related to harvest, most changes in floral and faunal species composition may be attributed to seasonal changes which occur within estuaries. Results from the monitoring program demonstrated only that the three systems monitored were impacted to some degree by eutrophication and the occurrence of anoxic conditions.

Significant by-catch was an issue with the sea lettuce harvester. Uncountable numbers of invertebrates, including grass shrimp, sand shrimp and snails were harvested as a result of this project. Smaller, but still significant, numbers of small fish were also captured. It is not known what effect the removal of such very large numbers of invertebrates and fish would have on the aquatic system from which they are removed. Theoretically there would be some impact on food chains. It was not within the scope of this project to determine this impact.

All harvested areas were located within areas that typically undergo periodic anoxia. It is not known at this point in time how these anoxic events typically impact aquatic populations; however, cases of mortalities due to anoxic events are common on PEI. While most reports of these mortalities include fish like stickleback, flounder, eels and shellfish, such as oyster and clams, it is assumed that other species, such as invertebrates, are also affected, but are not reported. If large mortalities are expected as a result of anoxia anyway, by-catch may not be a significant consideration in determining if harvest should proceed in areas regularly impacted by anoxic conditions.

The capture of shellfish as part of sea lettuce harvest by-catch is also a concern. Shellfish were captured only when bottom or submerged sea lettuce was being harvested. Significant by-catch of shellfish could have an impact on the ecosystem as well as on the shellfishery. Most of the areas that are candidates as potential sea lettuce harvest areas are also closed areas for the shellfishery. Important activities such as the spring relay fishery could still be affected however.

There was some indication that the shellfish captured were either dead or in very poor condition; however, not all assessors indicated this in their recorded information so this cannot be said with certainty. It may be that these populations are heavily impacted by anoxia and that by-catch as a result of sea lettuce harvest would not place any additional stress on the aquatic system. The results of the oyster survival experiment conducted by this project would certainly suggest that this is the case.

It is apparent that some by-catch of important species can be avoided by actions taken by the operator. Mummichogs were captured in very large numbers on one occasion. This indicated that they may be present only at certain times and locations within the estuary. This project has demonstrated that mummichog by-catch can be avoided by moving harvest to a different area. Mummichog and eels can be returned to the water by reversing the direction of the harvester cutting head and allowing them to escape.

The results from Covehead Bay indicated that by-catch of eel grass can also be an issue. Avoidance of beds may not be sufficient to reduce or eliminate the by-catch of this important aquatic system component. Although eel grass is not present in many estuaries, such as Hills River and Mill River, which are the most severely impacted by anoxic events, eel grass does co-exist with sea lettuce in some estuaries such as Covehead Bay, which are less impacted by anoxia. It may be that the capture of some eel grass as part of a harvest undertaking is for the greater good overall and that this vestigial eel grass population is threatened by the current conditions. It was not in the scope of this project to determine what the impact of eel grass by-catch would be.

The harvest of floating lettuce may reduce by-catch. Harvest of floating lettuce is the most efficient harvest that can occur; however, large floating mats of lettuce are not always present, as was the case this year.

An additional negative impact of sea lettuce harvest is the tendency to produce plumes of sediment. Prior to the onset of anoxic conditions in the estuary any sediments (usually sand and mud) disturbed by the harvester's paddle wheels or cutting head quickly settled. It was only when the harvester began to encounter anoxic conditions that this became an issue. Rotting sea lettuce gets a consistency of mayonnaise or loose jelly. This loose, black, unconsolidated material is very fine and does not settle quickly. Once this loose black material is encountered it is recommended that harvest be stopped or that harvest be moved to another part of the estuary.

7. CONCLUSIONS

- The pilot has demonstrated that the harvest of sea lettuce in Island estuaries is possible using conventional aquatic weed harvesters. Harvest efficiencies of 1.0 to 2.7 tonnes/hr and 1.3 to 5.9 tonnes/ha were recorded. There were some inefficiencies in the work that could be addressed to make any future projects as cost efficient as possible. The following measures could increase efficiency:
    - The harvest of floating mats of sea lettuce is the most efficient way to harvest sea lettuce. Unfortunately, as demonstrated this year, there is not always floating sea lettuce available to harvest and the harvest of submerged sea lettuce may be necessary to keep ahead of large biomasses of sea lettuce in order to prevent anoxic events from occurring. The effectiveness of harvesting submerged sea lettuce was not adequately addressed by this project, as anoxia still occurred in all three harvested estuaries. Harvest should begin earlier in the season to determine if harvest of submerged sea lettuce can be more efficient.
    - Offloading sites must be located close to the harvest area in order to keep the sailing time of the harvester as short as possible. Offload sites should also be sheltered from the wind, have sufficient depth to allow ease of docking and have a relatively gentle slope to accommodate the operation of the shore conveyor.
    - If suitable nearby offload sites cannot be found a transport barge could be considered. These barges can improve harvest efficiency by up to 90%. Any improved efficiencies achieved would have to be carefully weighed against increased capital costs.
    - A truck that can move the shore conveyor with the changing tides should be on site at all times. Additional efficiencies could be achieved if this truck can also be used to haul harvested sea lettuce.
    - Harvest operations must be geared to the rise and fall of the tides.

    - Harvest operations should be curtailed when adverse weather conditions (wind and rain) exist. Harvest under these conditions is very slow and it is much more cost efficient to wait for more suitable weather conditions. Full harvest days are also much more efficient than part days.
    - Some modifications to the harvester and shore conveyor have been suggested:
        - Removal of the cutter blades on the harvester.
        - A take up reel – similar to that of a hay baler on the cutting head (estimated 40% improvement in efficiency).
        - A compactor, on the storage area of the harvester, so that loads can be bigger (an estimated 30% bigger).
        - Modification of the hand powered jack up legs and pulley system of the shore conveyor to something less manual and easier to adjust (hydraulic controls).
        - An on-board chart plotter would help indicate areas that have been harvested previously.
    - The operator must provide all necessary support equipment, including equipment such as moorings and a small boat to access a moored harvester.

- The weather was a huge factor in this year's results. Cool, cloudy conditions may have produced less sea lettuce than usual. The sea lettuce that was present by the time harvest began in Mill River was also in poor condition after having been pushed close to the bottom by wind and not having enough sunny days to cause it to rise off the bottom. More typical summer weather conditions might have resulted in better harvest efficiencies this year.

- There was only a small possible decline in sea lettuce density that may have occurred as either a result of the harvest or as a result of the onset of anoxic conditions. A much larger volume of sea lettuce would have had to been removed in order to determine how quickly sea lettuce populations can re-grow.

- The level of harvest provided by this project was not sufficient to prevent anoxic events in any of the three harvested estuaries. To prevent anoxia, additional and more frequent harvests would have to be carried out. In order to prevent anoxia, harvest may become like a "mowing the grass" activity, with harvest proceeding as sea lettuce growth dictates. Due to the very fast growth rates, this may mean that sea lettuce harvest may have to be continuous or separated by only short gaps.

- Most of the monitoring programs (dissolved oxygen levels, shellfish growth and survival, CAMP and sediment quality) carried out by this project demonstrated the eutrophic condition of estuaries and not the impact of the harvest.

- The main negative impact discovered was the relatively high by-catch of fish, shellfish and other animals, as well as the disruption of eel grass in harvested areas. The harvested estuaries are all affected by eutrophication and anoxia, so these ecosystem components may be affected even without harvest. By-catch, as a result of sea lettuce harvest, may not place any additional stress on the aquatic ecosystem.

- An additional impact with negative potential was the disruption of sediments during harvest operations. Some plumes were produced during harvest in shallow areas and during the onset of anoxic conditions. This disruption can be eliminated or reduced by avoiding areas where loose un-consolidated sediments exist.

- Even with greater harvest efficiency and lower harvest costs there are currently few options to offset the cost of harvesting in order to make it a sustainable activity.

- Planners will have to carefully consider the costs associated with the harvest of sea lettuce if it is to be considered as either in lieu of or in conjunction with nutrient reduction as a solution to anoxia. It may be that the cost to harvest sea lettuce, in amounts which are great enough to prevent anoxia from occurring, is exorbitant and that resources would be better spent on efforts to reduce nutrient loading. While this is a longer term solution, it may end up being more cost effective than harvesting.

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APPENDICES