



**CUMULATIVE IMPACTS ASSESSMENT IN THE NORTHUMBERLAND STRAIT:**  
LINKING LAND USE, SEDIMENT AND NUTRIENTS WITH STREAM AND ESTUARINE HEALTH

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*Research conducted 2012-2016*

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## WHY DID WE DO THIS RESEARCH?

Estuaries and coastal areas have tremendous ecological importance, as they are among the most productive and diverse biological systems on the planet. They are depositional zones for sediment and contaminants, and changes in nutrients can lead to an explosion of plant growth. Estuaries and coastal areas have enormous social and economic value. Shellfish aquaculture, fisheries, and tourism are highly dependent on the functional and aesthetic integrity of estuarine and coastal ecosystems.

Public concern about the environmental health of the Northumberland Strait developed around the time of the construction of the Confederation Bridge (1993-1997), when significant declines in fishery yields of lobster, rock crab, scallops and herring were being reported. In response to these concerns, the Minister of Fisheries and Oceans commissioned a working group that conducted public consultations and recommended measuring nutrient and contaminant inputs into marine waters from the adjacent watersheds.

The Northumberland Strait Environmental Monitoring Partnership (NorSt-EMP) was created as part of Canadian Water Network's Canadian Watershed Research Consortium. For the first time, representatives from five federal government departments, provincial government departments from Nova Scotia, New Brunswick and Prince Edward Island (PEI), First Nations, academia, industry, environmental organizations, and watershed groups came together to improve Cumulative Effects Assessment (CEA) in the region. Research was developed in consultation with the NorSt-EMP members that focused on understanding the impact of nutrients, sediments and contaminants from land-based activities on the estuaries and bays of Northumberland Strait on fish and fisheries, invertebrates and submerged aquatic vegetation, with a specific focus on eelgrass (*Zostera marina*) and sea lettuce (*Ulva* species).

## WHAT DID WE DO?

Cumulative Impacts Assessment (CEA) is an approach that considers all past, present and future human impacts on a defined component of the environment to facilitate environmental management and decision making. CEA requires an understanding of the relationship between stressors such as sediments or nutrients and the biological endpoint of interest. A stressor can be any substance or condition that exerts an adverse effect on a valued ecosystem component. Value can have an array of meanings, such as economic value, ecological value, value to Indigenous Peoples etc., but reflects the organism, endpoint or ecosystem component that we deem most important to protect.

These elements combine to form a CEA framework, i.e., a conceptual and numerical model that establishes quantitative relationships between stressors and biological responses of the valued ecosystem component. However, often we do not know specific pathways, and where we do, there is a lack of quantifiable relationships between the stressor and valued ecosystem component responses. The focus of this research was to identify valued ecosystem components, monitor them, and establish quantifiable pathways between the stressors and the valued ecosystem components.

The specific objectives of this research were to:

- Advance methods for the quantification of land-based stressors
- Develop a suite of monitoring tools for estuarine integrity that are sensitive to environmental quality, temporally and spatially feasible, and economically realistic
- Advance CEA in the Northumberland Strait through the development of stressor-based models of estuarine impacts
- Contribute to the ongoing viability of NorSt-EMP

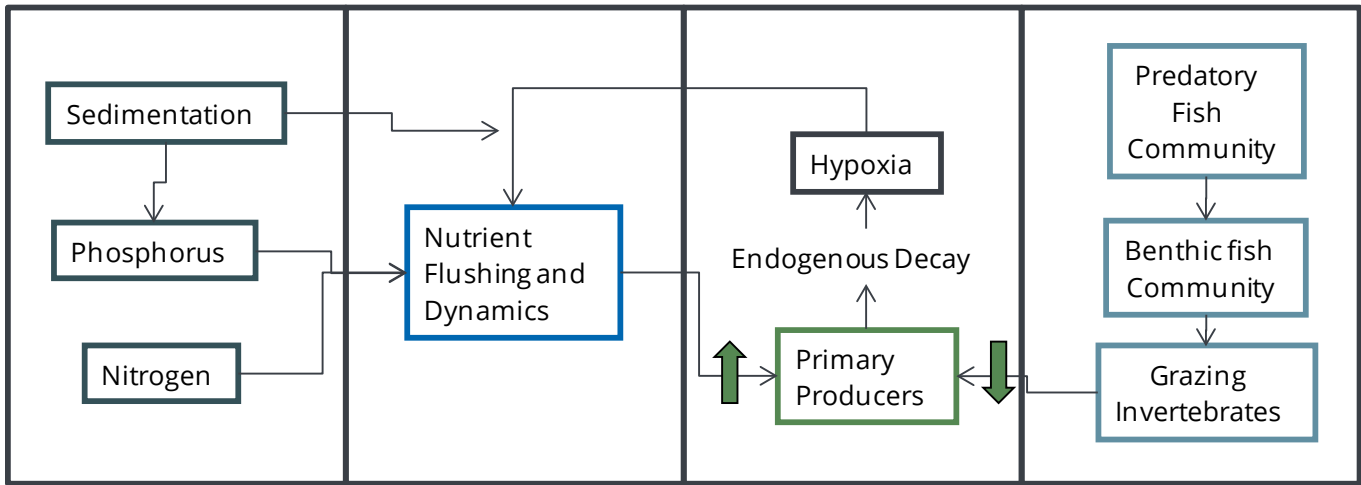


Figure 1. Potential, pathways of response between nutrient, sediments and the biological response variables that form the basis of the cumulative impacts assessment framework examined.

The valued ecosystem components defined by NorSt-EMP included plants, invertebrates, fish and fisheries. The marine plant eelgrass (*Zostera marina*) was named as a species of concern due to its known ecological function in estuaries and observed declines in the region. Fish and fisheries, while highly valued, were already being assessed in an existing Community Aquatic Monitoring Program (CAMP). Invertebrates were included because they are critical to the fish community. Oxygen was included because it responds to nutrient addition and is critical for all life in the estuary. Chlorophyll and other micro algae also respond directly to nutrients and alter light penetration that can in turn affect eelgrass. Micro algae are also essential for shellfish aquaculture. This study focused on oxygen, micro algae, invertebrates and eelgrass.



Figure 2. The geographical zone and estuaries chosen for the study encompassed the area south of a line drawn from Neguac, New Brunswick in the west and Margaree, Cape Breton in the east. The zone included all of PEI. Study sites were chosen from Nova Scotia, New Brunswick and PEI to provide even distribution around the Northumberland Strait. The widest possible range of impacts were included in site selection, and included minimally to maximally impacted estuaries with regards to agricultural land use. Different locations were chosen for different aspects of the study, as shown in this figure.

# THE CHALLENGES OF ENVIRONMENTAL MONITORING IN ESTUARIES

An estuary is a semi-enclosed area where fresh water flowing from the land mixes with seawater. Some define the uppermost part of an estuary by the salinity of the water, while others define it by the uppermost influence of the tide. Since salinity has the greatest influence on the biota living in a water body, this research considered the upper end of an estuary to be where the salinity is on average more than double that of the incoming fresh water. Similarly, the outer extent of an estuary is not always clearly defined. In this research, the outer boundaries were defined by clear geographic features such as discontinuities in the coastline and full mixing of salt and fresh water.

Estuaries are defined by a gradient of fresh to salt water. This has important implications for monitoring and assessment, as stressors that arise from land may highly impact conditions at the upper end, but have virtually no impact at the mouth. The variation in salinity within an estuary provides a major challenge when comparing, monitoring and managing estuaries. This is typically the case when there are significant nutrient and sediment inputs from land. The most impacted part of the estuary is in about the first 10% of the estuary area and impacts can persist to 50% of the estuary area. To simplify comparisons between estuaries, environmental sampling was stratified based on the area of the estuary (see Figure 3).

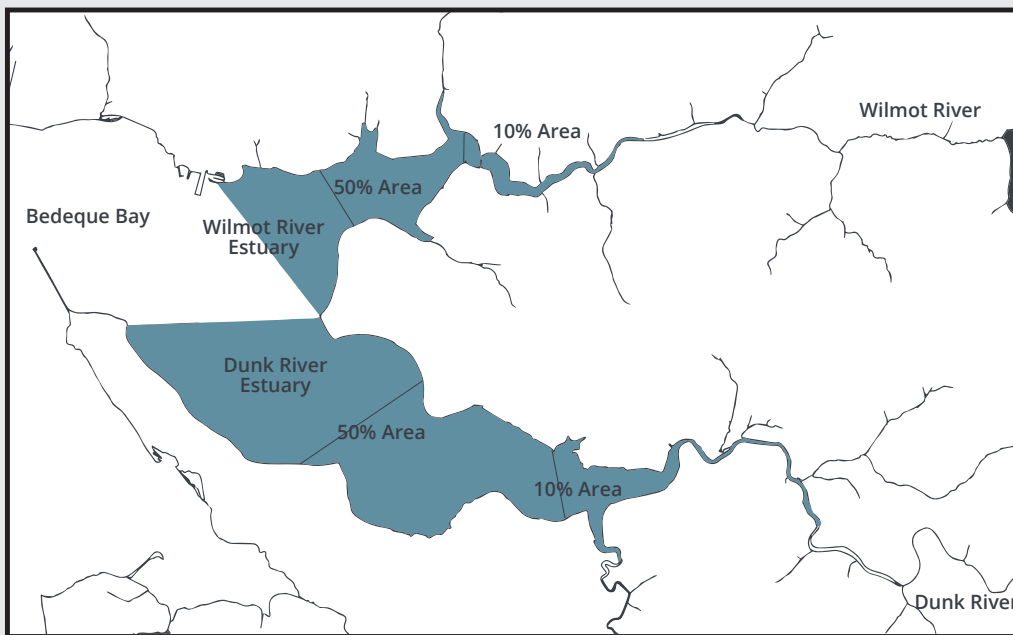


Figure 3. An example of the delineation of estuaries using the Wilmot River and Dunk River estuaries near Summerside, PEI.



# WHAT DID WE FIND?

## NITROGEN LOADING

Nitrogen has often been considered the primary driver of estuarine effects. Results from a two-year stream survey found that over 95% of the nitrogen in the Northumberland Strait originates from PEI (Figure 4). A model was used to assess nutrient sources in PEI. This model used data for nitrogen entering the aquifer from different crops and considered other activities such as septic tanks, as well as the population and land use in each watershed. The model suggests that the largest component of nitrogen loading comes from agriculture and that the dominant crop for nitrogen contribution was potatoes (Figure 5).

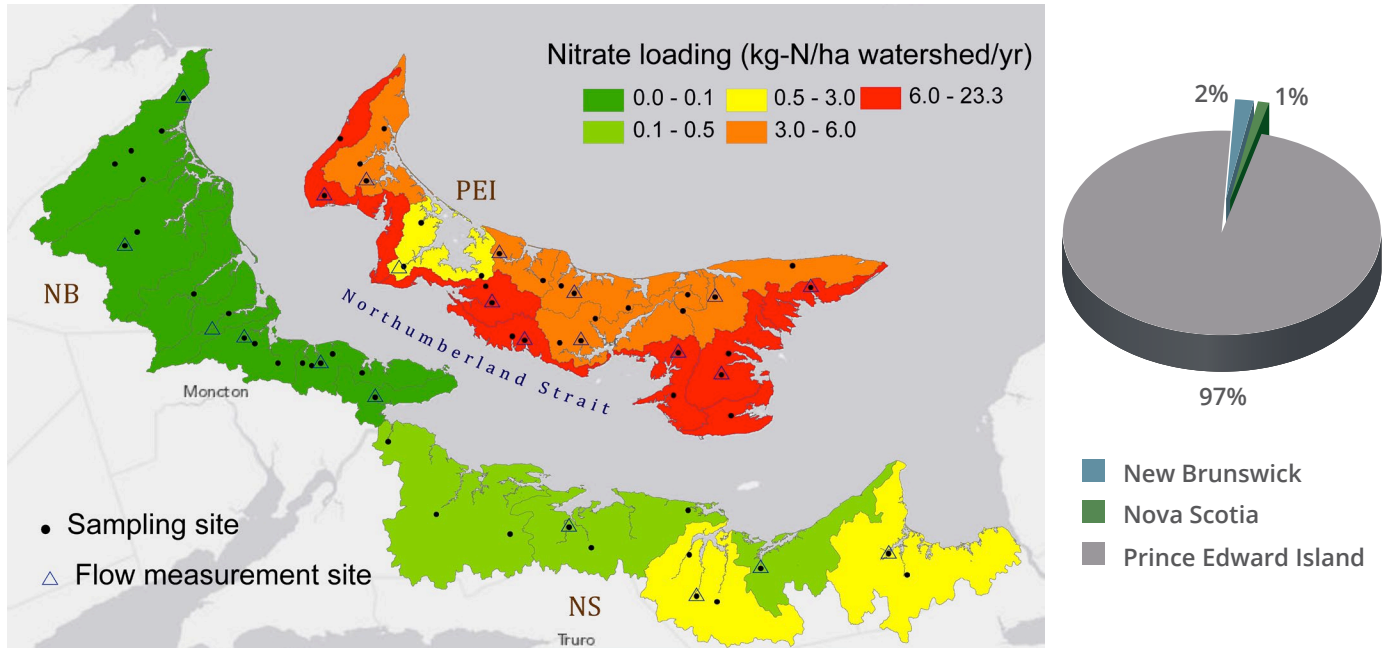


Figure 4. Measured nitrate-N loading in watersheds in the study area in 2012. Pie graph shows the proportion of nitrate-N coming from each province.

## SEDIMENT

Sediment, unlike nitrogen, which is relatively constant through the year, is primarily related to rain events and is highly episodic. This creates sampling challenges as entire rain events must be captured in order to fully quantify the sediment load. Sediment and water flow were monitored over a two-year period in six watersheds of varying land use intensity in the region. Evaluation was restricted to the time of bare and unfrozen soil, from May to December. As expected, watersheds with more agricultural land use were more susceptible to erosion and showed higher sediment loads.

Two technologies for quantifying suspended sediments were evaluated, including optical sensors that measure the scattering of light by sediment particles, and acoustic doppler current profilers that measure the backscatter of sound by suspended sediments. While both technologies are suitable to capture the type of continual data required to quantify sediment loads, both have challenges in calibrating the response to provide sediment concentration. As

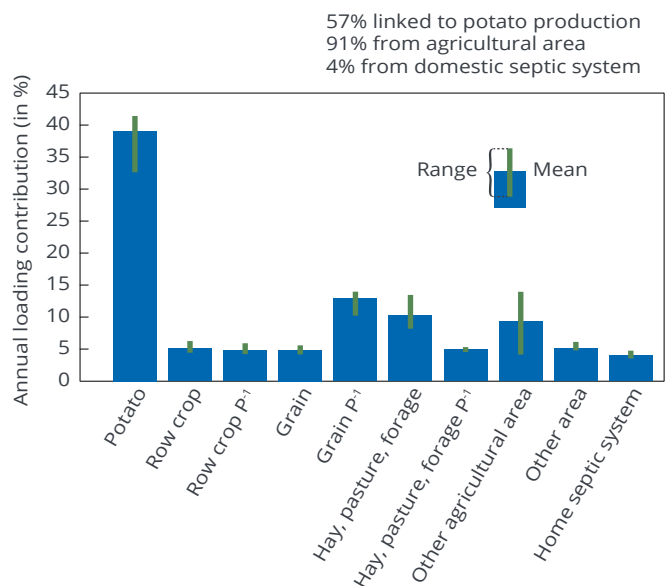


Figure 5. Modelled contribution of different human activities and agricultural crops to nitrogen loading on PEI. P<sup>-1</sup> after the crop indicates that potatoes were the crop during the previous year.

particle size varies with the geology and soils of the watershed, the most accurate calibration method was to directly measure suspended sediment concentrations during one or more rainfall events using automated samplers. This has important implications for monitoring, as it implies that particle size should be measured for streams being monitored. Because it is challenging to compare between streams, the best option may be to compare a stream to itself over extended periods of time, or as land use and land-use practices evolve.

Mathematical algorithms that simulate human learning (i.e., fuzzy-logic) were used to develop models to predict sediment concentrations based on the data collected in all six systems. These models did not provide good predictive power until a watershed-specific vulnerability index that incorporates land use and soil characteristics was added to the input variables. The research showed that these models can be predictive even across watersheds and have great potential as a tool for quantifying sediment loads to estuaries.

In order to monitor the biological impacts of sediment, brook trout eggs were placed into plastic incubators that were buried in the gravel of three streams that varied in degree of agriculture and sediment load and their hatching success was monitored. Hatching and growth of the brook trout showed no relationship with sediments in the rivers, but had a positive relationship with temperature. Brook trout often place their eggs in areas of groundwater upwelling that provides warmth, oxygen and flow to mitigate impacts of sediment in the stream. The spawning behavior of this species makes it adaptable to the range of PEI conditions, which is likely why it is still a very widely distributed species despite elevated sedimentation due to land-use.

### OXYGEN LEVELS

Typically the growth of sea lettuce (*Ulva* species) and micro algae dominate estuaries where nutrient enrichment occurs. Ultimately the mass of sea lettuce reaches a level at which it will shade itself, or it may be shaded by algal growth in the water column. With the warm water temperatures in late July or August, the plant biomass starts to decompose, and bacteria that facilitate decomposition consume the oxygen in the water column. The result is a partial loss of oxygen (hypoxia) or complete loss of oxygen (anoxia) that can prove fatal to invertebrates and fishes (Figure 7). Anoxic events occur in over 20 estuaries in PEI on an annual basis. Less is known about the oxygen status in New Brunswick and Nova Scotia estuaries.

Oxygen in an estuary can change dramatically with light and dark cycles or the stage of the tide. It also changes with depth, and will tend to increase closer to the mouth of the estuary with fully mixed seawater. The patterns of variability in an estuary make it nearly impossible to consistently capture the oxygen profile in an estuary by periodic measurement. However, oxygen logger technology has recently become substantially less expensive and these instruments were chosen as the primary tool for monitoring oxygen in 16 estuaries at the 10% area mark, one-half a meter from the bottom.



Figure 6. Macroalgae (*Ulva* species) proliferation in an estuary (left photo) the decomposition of which leads to periods of anoxia often resulting in white turbid conditions in an estuary (right photo).

The example shown in figure 7 contrasts oxygen in the Kildare estuary, one of the worst sites for hypoxia, with Tatamagouche, an estuary that did not show hypoxia. This shows anoxia in the Kildare estuary starting in late July that unexpectedly persisted as late as November. From these data, metrics of accumulated hypoxic hours, minimums, maximums, means and accumulated high oxygen hours were derived for all of the estuaries monitored. Low dissolved oxygen was found to be very strongly correlated with the residence time (flushing) in the estuaries examined. The correlation with nitrogen load was not as strong as for residence time. Overall, it was concluded that oxygen measured using loggers was an exceptionally good monitoring endpoint since unlike all other endpoints it incorporates both low oxygen (due to the respiration and decomposition of plants) and high oxygen or supersaturation (due to photosynthesis from both microalgae and macroalgae).

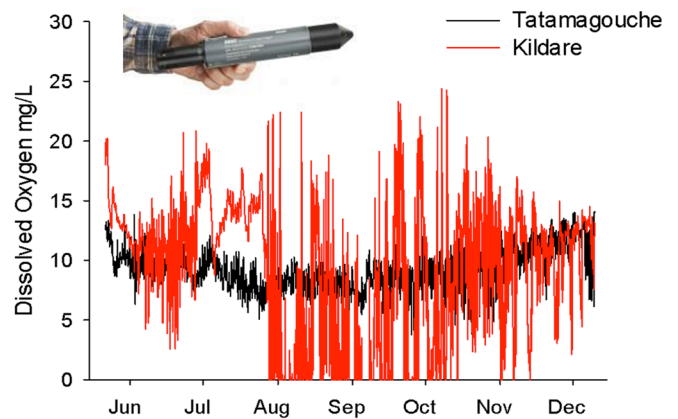


Figure 7. Dissolved oxygen in Tatamagouche (low impact) and Kildare (high impact) estuaries in 2013. Kildare shows high variability ranging from extended periods of low oxygen alternating with periods of oxygen supersaturation. Inset shows a dissolved oxygen optical logger.

## ALGAE GROWTH

Blooms of algae have long been used as an indicator of nutrient enrichment. A number of methods were compared, including the use of optical chlorophyll sensors, laboratory chlorophyll analysis, direct counting of chlorophyll containing cells using a flow cytometer and identification of algal and bacterial species using genetic sequencing. Optical sensors that would have provided the most rapid and economical analysis did not function well in estuaries. Both chlorophyll-based and cell-counting methods were also not particularly predictive of each other. Genetic methods to examine algal communities have great potential, but more research needs to be completed in order to understand these responses. Overall, the nutrient loading to an estuary was not strongly predictive of laboratory chlorophyll measurement, making it a lower priority as an endpoint and dissolved oxygen may be a better tool. Sampling of estuaries in mid to late August could provide a good basis of comparison between estuaries.

## INVERTEBRATES

Many invertebrates in an estuary are epibenthic, meaning they live and depend on the plant material in the estuary for habitat, while others dwell in the sediment. Thus both the presence of plants and low oxygen would be expected to influence the invertebrates. Sixteen estuaries were evaluated for the invertebrates living on plants and in sediment. There was substantial variability in the invertebrate communities across estuaries; they were either dominated by amphipods or snails. In estuaries that undergo anoxia, amphipods were found to avoid the low oxygen by escaping on islands of floating sea lettuce carried by the tide, potentially allowing them to recolonize later. While invertebrates make good indicators of environmental conditions, an invertebrate monitoring program would be extremely work-intensive and expensive.

## EELGRASS

Two potential monitoring approaches for understanding the health of eelgrass meadows within an estuary were examined. The first approach sought to examine characteristics of the plant that relate to overall productivity and adaptive responses of the plant to stress such as above and below ground biomass and canopy height. Research on these measures was conducted in four estuaries, from the uppermost region where eelgrass was found, to the outermost reach of the estuary where the plant was present. Two estuaries in the watershed with high agricultural land use and two estuaries with low agricultural land use were chosen in PEI and New Brunswick.

Given the natural salinity gradient in any estuary, it was not surprising that plant measures varied significantly along the estuary. This variability within estuaries was so high that differences were not detected between estuaries, suggesting that averaging eelgrass health over whole estuaries is not a sensitive measure of estuarine or eelgrass health. However, monitoring particular locations within an estuary over time can potentially provide useful information. Light was found to relate best to canopy height and above ground biomass, whereas salinity had the greatest correlation with the below ground biomass.

The second approach was the examination of eelgrass distribution on an estuary-wide scale. There are a variety of technologies being developed that can be applied to the examination of eelgrass distribution, including satellite monitoring, photography by plane or unmanned aerial vehicles, bathymetric lidar and sonar. Of all of these, only sonar has virtually no depth limitations since sound penetrates water no matter how turbid. Estuaries are perhaps the most turbid of all aquatic systems, and light penetration issues in the upper estuary will hamper all other techniques except for sonar. Sonar can also determine depth, and separate efforts to ground truth are not required. While it may have lower resolution than some of the optical techniques, sonar also offers the possibility of determining canopy height and biomass using software specifically developed for this purpose.

During 2014, sonar bathymetry and eelgrass distribution data were gathered from 14 estuaries in order to make eelgrass distribution maps. Light penetration was also measured at intervals corresponding to 10%, 50% and 100% of the area of the estuary. As expected, there is always a gradient of light penetration, with the least light in the upper estuary and the greatest light penetration closer to the mouth of the estuary. Eelgrass distribution tends to follow this light gradient, often with little or no eelgrass in the upper estuary, although this could also be the result of low salinity.

### TIDAL INFLUENCE

In addition to the physical size, shape, nutrient and sediment loading that an estuary is subjected to, the nature of the tide plays a critical role in dictating how an estuary responds to stress. As was observed with the oxygen monitoring, the more flushing from tides, the less susceptible an estuary is to the impacts of nutrients as plants, sediment, and nutrients are removed, and oxygen brought in. Flushing, or water residence time, is the main factor that makes estuaries challenging to compare. Water depth was recorded in all estuaries for at least one month, and models were created to enable tide prediction in those estuaries. The tide models, bathymetry, and freshwater flows allowed to calculation of the residence time of water in the estuary. Residence time is a crude model for estuarine flushing as it treats the estuary as one well mixed compartment - an assumption we know to be inaccurate. However, the tide and bathymetry data will allow more refined models of estuarine flushing that treat the estuary as a gradient.

Development of these predictive models will also require data about the internal re-release of nitrogen into the estuary from the decay of plant material. The lack of such data may be why oxygen was correlated better with residence time than external nitrogen load. Thus, understanding the internal load of nutrients is a future research priority. Development of more accurate models that examine the gradient of change in an estuary will also facilitate the next research question: what is the contribution of nutrients and sediment from the estuaries to coastal waters?

## SUMMARY OF NorSt-EMP MONITORING RECOMMENDATIONS

More work must be done to refine a CEA framework for nutrient and sediment loading in Northumberland Strait estuaries. However, substantial progress has been made to answer the questions that NorSt-EMP set out to answer. These have led to recommendations regarding the initial steps in a regional monitoring program for estuaries.

CONCLUSION	MONITORING RECOMMENDATION
<p><b>NUTRIENTS</b></p> <p>Further work would benefit from a nutrient monitoring program in New Brunswick and Nova Scotia that is easily publically available as it is for PEI.</p>	<p>Nitrogen and phosphorous should be monitored at least three times per year over the summer months in major streams in New Brunswick and Nova Scotia at stations close to the head of tide. Historic data should also be made available in a database.</p>



<p><b>SEDIMENT</b></p> <p>Turbidity monitoring is suitable to conduct stream sediment monitoring at present. Although acoustic Doppler current profilers are more expensive, they may offer better potential in the long term. Sediment monitoring of individual streams is highly intensive, and a modeling approach was successful at relating rainfall and watershed erosional vulnerability to suspended sediment load over multiple watersheds.</p>	<p>Monitoring of at least 2 new rivers per year on PEI should be initiated in order to further validate the sediment load model and to provide a baseline for future monitoring. These streams should be monitored simultaneously with turbidity and low profile ADCPs until there is confidence in the use of ADCPs for monitoring. Model development and refinement should continue, as this offers great promise for estimating loads on a larger geographic scale.</p> <p>Rain event intensity and season should also be considered when comparing data between years, in order to improve a monitoring program's ability to detect change.</p>
<p><b>BROOK TROUT HATCHING</b></p> <p>Brook trout responded to incubation temperature but not sediment, suggesting that the selection of groundwater upwelling is a key to spawning success. This behaviour would be difficult to mimic with any monitoring technique, leading to high variability in hatching and the inability to relate this endpoint to stream sediment stressors.</p>	<p>Brook trout hatching is not recommended for use as a future monitoring technique. Efforts could be made to use salmon eggs, as this species has a different spawning strategy.</p>
<p><b>OXYGEN</b></p> <p>Oxygen should be an essential part of a CEA framework, as it can be directly related to the nutrients coming into the estuaries, incorporates plant decomposition, plant respiration and plant photosynthesis (proliferation), is critical to all organisms, and can be economically and easily measured.</p>	<p>Optical oxygen logging technology is reliable and can accumulate the temporal intensity of data that no other method could. The proposed oxygen monitoring methodology involves having one oxygen logger at the point where hypoxia is most severe (i.e., 0.5 m from the bottom within the first 10% of the area of the estuary) in order to indicate whether anoxia is present in the estuary. In order to gauge the severity, two more loggers are located at the half-way point in the total area of the estuary, with one 0.5 m from the bottom, and the other at the surface. Loggers would be set to log every hour.</p> <p>While an extended period (May until late November) provides the maximum information, it is recognized that extended monitoring is not always practical. The specific months monitored are less critical than having a consistent level of effort everywhere that oxygen is measured. The months that correlate best with the whole season dissolved oxygen parameters are July, August and September.</p>
<p><b>CHLOROPHYLL/PHYTOPLANKTON</b></p> <p>This study found weak relationships between chlorophyll and nutrient loading. In situ measurement with fluorescence meters in the highly turbid estuary environments was inaccurate. The use of plankton community and algal counts also shows potential to relate to estuarine conditions, but more work is required.</p>	<p>Annual chlorophyll monitoring would be advantageous to a monitoring program as it is a rapid and economical monitoring technique for primary productivity. While algae bloom and crash during the year, sampling at multiple times in the weeks before and after August 1 would offer the maximum probability of hitting chlorophyll peaks. Chlorophyll should be analyzed by HPLC methods. Surface sampling at the 10% and 50% estuary area is suggested.</p>
<p><b>EELGRASS</b></p> <p>As a critically important ecosystem component to estuarine biota, eelgrass should be a high priority for monitoring. Geospatial analysis of eelgrass coverage has much greater potential to be used for management purposes than measures of eelgrass growth and biomass, because the parameters examined can be linked back to external stressors on the estuary such as nutrients or sediments. Sonar, the only technique that has unlimited depth penetration, is suitable for highly turbid estuaries and is the only technique that can simultaneously determine bathymetry, eelgrass height and potentially biomass.</p>	<p>An eelgrass geospatial monitoring program should be initiated in the region for estuarine eelgrass. This can be economically and adequately performed with sonar transects of 50 to 100 m apart. It is suggested that five locations with varying human-made stressors be chosen each year on a five-year rotating basis, for a total of 25 locations in the three provinces. An additional two sites could be added and sampled every year to examine the question of year to year variability.</p> <p>Eelgrass must be co-monitored with light attenuation, nutrient inputs and flow into the estuary. At the end of the five-year period, the program should be reviewed to assess whether these variables contribute to a model predictive of eelgrass distribution.</p>

### INVERTEBRATES

Invertebrate communities respond to estuarine hypoxia. However, it would be difficult to establish numerical models relating stressor loads and invertebrate endpoints. Invertebrates were also found to have the ability to recolonize the affected areas very quickly.

Invertebrate community assessment is highly intensive with regards to the human resources and expertise required to undertake it.

It is not recommended that invertebrate sampling techniques be incorporated in monitoring at this point in time. While highly ecologically relevant, endpoints directly related to estuarine inputs that can be managed should be the first priority.



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### PHOTO CREDITS

SEAN LANDSMAN, Cover image and oyster fisherman

JESSE HITCHCOCK, Ulva and eelgrass image

MEGAN FINLEY, Figure 6 left image

KATE MACQUARRIE, Figure 6 right image