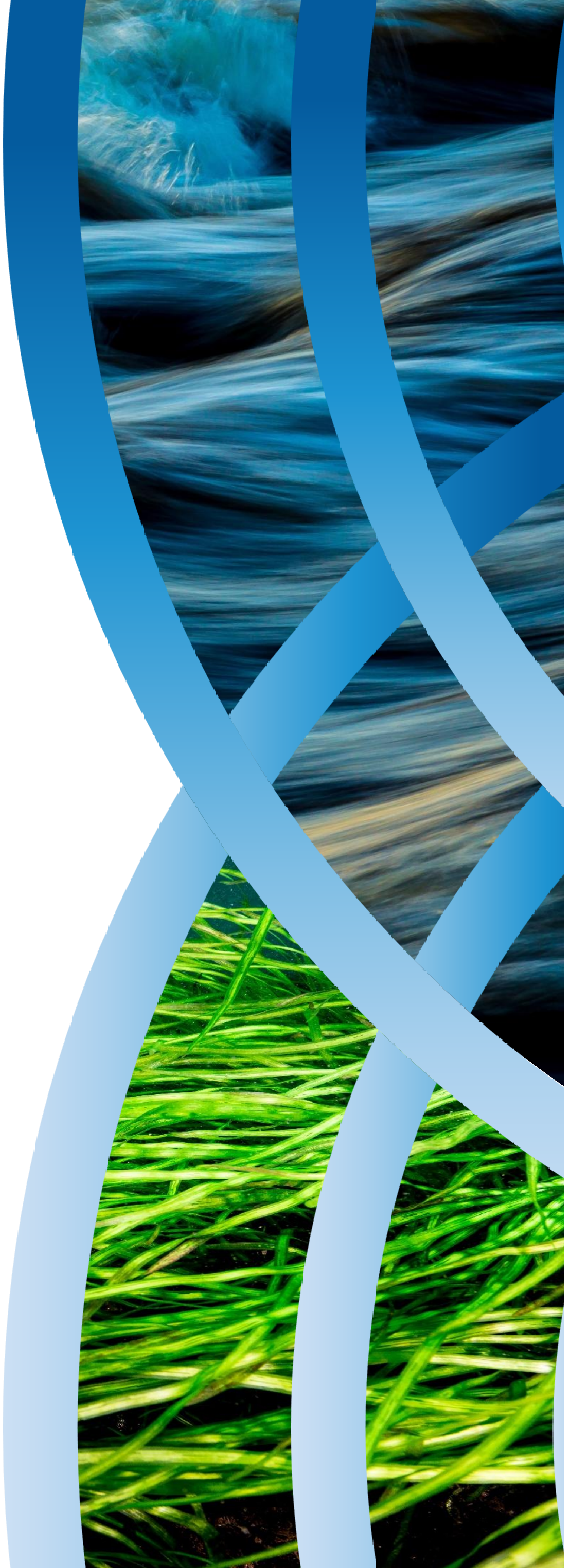
Fisheries and Oceans Canada
Pêches et Océans Canada

Marine Environmental Quality Guideline

Assessing the Trophic Status of Southern Gulf of St. Lawrence Estuaries



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Executive summary

This Guideline provides advice for assessing the trophic status of upper estuaries in the southern Gulf of St. Lawrence. Many of these systems, particularly in Prince Edward Island, receive high external nitrate loads that come primarily from row crop agriculture. Nutrient enrichment can lead to eutrophication, which can result in the loss of eelgrass beds, reduced biodiversity, and greater fluctuations in dissolved oxygen concentrations. In highly eutrophic estuaries, anoxic events may also occur.

Dissolved oxygen is recommended as an indicator of estuarine trophic status. Monitoring of dissolved oxygen should occur in the inner estuary from July to September and the collected data should be used to calculate the dissolved oxygen metric, Eutrophic Time. A Eutrophic Time of 35% is recommended as a management target to maintain or restore the trophic health of estuaries. The target supports the protection of eelgrass, a species ecologically significant in maintaining ecosystem structure and function, and the broader goal of overall health for estuarine ecosystems in the region.

Introduction

Globally, nutrient enrichment is among the most significant environmental concerns in coastal ecosystems. The ecological response is often **eutrophication**[*], the rapid growth of algae and other primary producers, which can lead to degraded fish habitats and reduced biodiversity.[46,1,29,14] **Estuaries** in the southern Gulf of St. Lawrence (sGSL) are typically small, shallow and have a limited tidal range, making them susceptible to nutrient enrichment which is a major **stressor** in these systems.[9] Although the **cumulative effects** from various human activities can contribute to nutrient loading, in Prince Edward Island (PEI) for example, where eutrophication is most severe, intensive row-crop farming in the upper watershed is the predominant source. [26] Impacts from excessive nutrients include the loss of eelgrass (*Zostera marina*) beds, an **ecologically significant species**, and extreme fluctuations in **dissolved oxygen** (DO) concentrations, sometimes resulting in anoxic conditions.[9] Marine Environmental Quality (MEQ) measures, such as this voluntary Guideline, are meant to serve as ecosystem-based management tools to support efforts to address marine stressors and are intended for use by relevant regulatory authorities and environmental stewards. This Guideline is intended to support assessment and monitoring of estuarine **trophic status** and does not, in itself, establish regulatory requirements or obligations. It presents instructions for monitoring, evaluating and reporting the trophic status of estuaries using DO as an indicator to support efforts that reduce **external nutrient loading** in estuaries. This Guideline can also be applied to healthy estuaries to facilitate early detection of increases in nutrient loading and associated changes in trophic status, allowing for timely implementation of best management practices or regulations before further degradation occurs to stay consistent with the precautionary approach principle outlined in the *Oceans Act*.

Estuaries in the southern Gulf of St. Lawrence

Most estuaries in the sGSL are river-fed estuaries with once or twice daily tides that flow into lagoons or coastal bays before reaching the Northumberland Strait or the sGSL.[39,23] Estuaries in the sGSL drain from the provinces of PEI, New Brunswick's (NB) east coast, and Nova Scotia's (NS) Northumberland coast and west coast of Cape Breton Island. While the surface area of estuaries in the sGSL can reach up to 13,570 square kilometers, most are smaller. The estuaries included in the research study used to develop this Guideline range in size from 17 to 386 square kilometers and are relatively shallow, with depths between 1 and 5 meters (Figure 1).[9]

[*] Bolded terms are defined in the glossary at the end of this document.

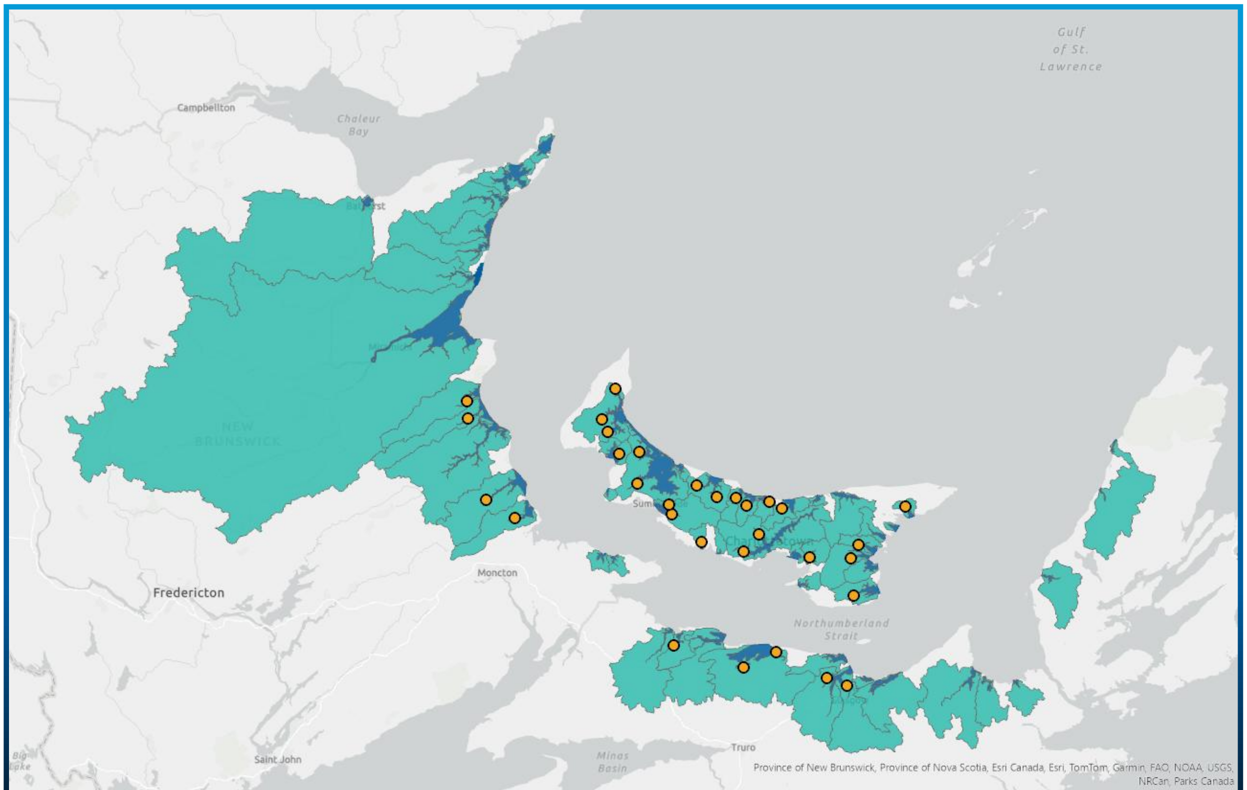

Figure 1: Estuaries of the southern Gulf of St. Lawrence with a surface area greater than 5 km^2 and their watershed. Watersheds are shown in green and estuaries in blue. Estuaries included in the Coffin et al.[9] study are identified with an orange circle. Credit: G. Lacour, DFO.

Their shallow nature, small tidal ranges, and limited freshwater input create a well-mixed transition zone between freshwater and saltwater. These conditions also reduce the capacity for nutrient dilution and export, making estuaries particularly vulnerable to nutrient enrichment. For this Guideline, estuary boundaries are defined by salinity levels in their uppermost areas where freshwater dominates (less than 0.5 PSU) and by their outermost geographical points, where they open into larger bays or where fresh and salt water fully mix in the sGSL or the Northumberland Strait.[9]

Sources of nutrients and release to the environment

The cumulative effects of human activities such as the burning of fossil fuels, urban development, fertilizer use and wastewater discharge significantly increase external nutrient loading in coastal ecosystems.[1] Land use in sGSL watersheds varies: NB and NS are mainly forested, while PEI has intensive row-crop farming which results in higher nutrient loading, driven by fertilizer use and the biological fixation of nitrogen by legumes.[26,9,33] Due to the province's sandy soils and fractured sandstone bedrock, excess nutrients leach into groundwater and eventually into rivers and estuaries.[26] Eutrophication, the ecological response to nutrient enrichment, is the accelerated growth of algae and other primary producers. This ecological process can happen naturally, but it is accelerated when human activities introduce excess nutrients, particularly nitrogen and phosphorus, into water bodies.[1,17] In saltwater ecosystems, nitrogen is typically in shorter supply relative to the biological demand, making it the limiting nutrient. While nitrogen is generally considered the primary driver of eutrophication in these environments, phosphorus can also play a contributing role under certain conditions.[46,29]

In PEI, nitrogen, mainly in the form of nitrate, makes up the majority of nutrients entering estuaries from rivers.[12] A study has shown that more than 95% of the nitrate entering estuaries in the Northumberland Strait region, including PEI and parts of NB and NS, comes from PEI (Figure 2).[47] Significant increases in nitrate concentrations in recent decades coincide with an increase in agricultural land use.[4,2] In 2024, agriculture represented over 35% of the total land area, and more than 80% in some watersheds.[32,25] Agriculture accounts for over 90% of nitrate loading in estuaries, with potato farming contributing around 60%.[26] Beyond ecological concerns, nitrate levels that sometimes exceed Canada's drinking-water guidelines have been recorded in freshwater sources.[28,24]

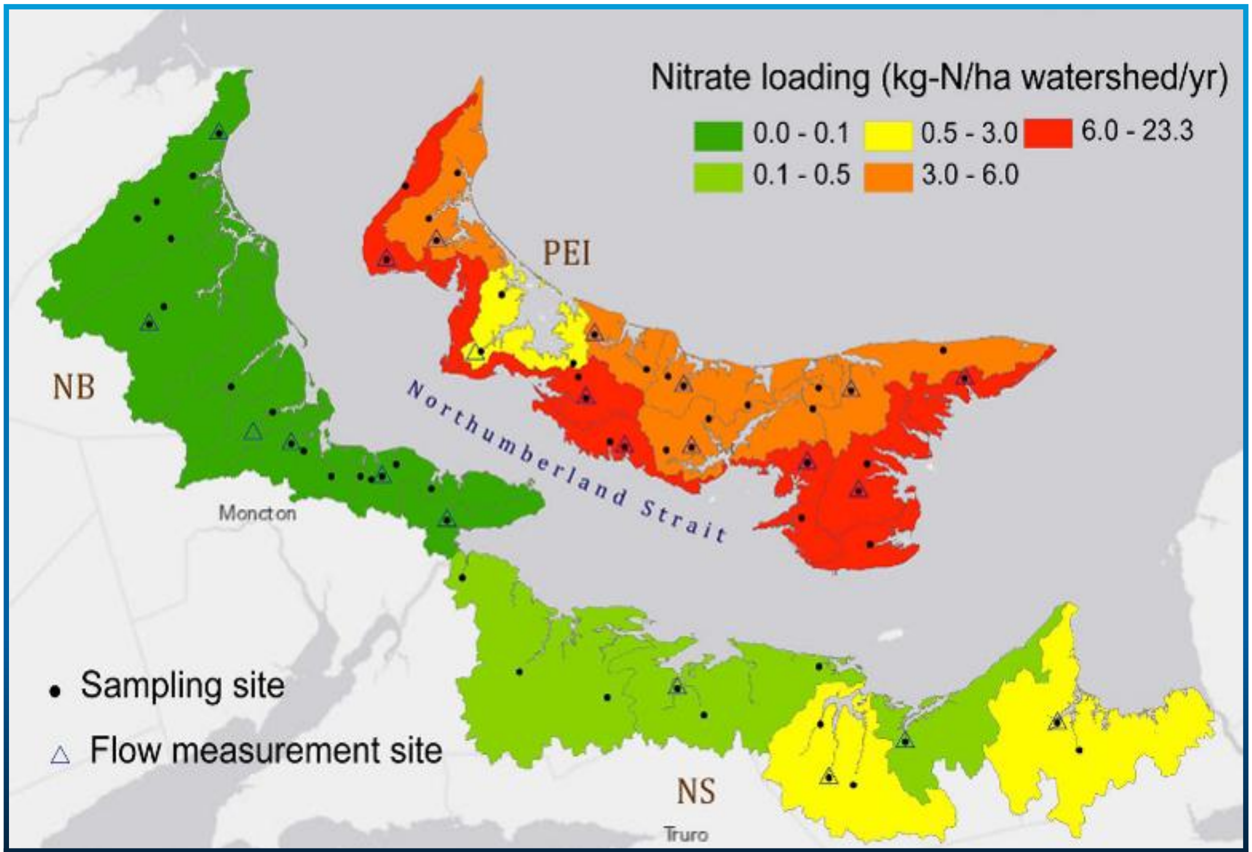

Figure 2: Measured nitrate-N loading in watersheds in the Northumberland Strait Environmental Monitoring Partnership study area in 2012. Adapted from van den Heuvel et al.[47]

In addition to external nutrient inputs, eutrophication is also driven by nutrients released from organic matter in sediments, referred to as **internal nutrient loading**. For example, in one eutrophic PEI estuary, internal nutrient loading accounted for up to 69% of nitrogen and 98% of phosphorus.[11] As a result, mitigating external nutrient sources may not reduce eutrophication in the short term because of internal nutrient loading. Despite this lag in ecosystem response, reducing external nutrient inputs remains a key management strategy, and this Guideline aims to support those efforts. Reducing internal nutrient loads is more complex than reducing nutrients coming into estuaries, and requires strategies that are not covered by this Guideline.

Impacts on marine species

Healthy eelgrass.
Credit: M. Boudreau, DFO.

Eelgrass covered with *Ulva* spp. in the upper estuary of Mill River, Prince Edward Island.
Credit: M. Boudreau, DFO.

When eutrophication occurs in deeper waters, the growth of primary producers is often dominated by phytoplankton.[42] In shallower coastal areas, excess **primary production** is usually dominated by large blooms of macroalgae that can smother seagrasses and degrade the important ecosystem functions these species provide.[46,3,41,48]

Eutrophication poses a serious threat to eelgrass, the dominant seagrass species in coastal and estuarine areas of the western North Atlantic.[3] Eelgrass is vital to coastal ecosystems: it stabilizes sediments to reduce erosion, sequesters carbon, provides food for invertebrates and migratory birds, and creates structural habitat that offers shelter, spawning sites, and nursery grounds for fish. Due to its critical role in ecosystem structure and function, severe disturbances to eelgrass can have greater ecological consequences than comparable disturbances to most other species within this community. For these reasons, Fisheries and Oceans Canada (DFO) has recognized eelgrass as an Ecologically Significant Species, a designation meant to help define ecosystem objectives, such as the current Guideline, intended to protect the ecosystem.[20] Eelgrass requires sunlight to thrive and typically flourishes in areas with low turbidity and moderate nutrient concentrations. However, nutrient-rich environments encourage the growth of macroalgae, such as *Ulva* species, which can create dense mats that block sunlight and smother eelgrass.[46,43,48] Nutrient enrichment also promotes excessive **epiphyte** growth, which can further reduce light availability.[43] Additionally, eelgrass may be impacted by geochemical changes that arise when eutrophication increases the presence of reduced nitrogen compounds (NH_x) and hydrogen sulfide.[49,44]

In recent decades, significant declines in eelgrass have been observed in the sGSL. Although data are limited, eelgrass coverage in the region's estuaries is estimated to have decreased by approximately 40%.[27] The main stressors contributing to eelgrass declines include sedimentation, turbidity, nutrient enrichment, aquatic invasive species, physical damage, and changes to water flow.[27,21] Recent research suggests that nutrient enrichment is the most significant stressor on estuarine eelgrass within the sGSL, especially in PEI.[48,9] Moreover, eutrophication is most prevalent in **upper estuaries**, where nutrient-rich waters coming from rivers remain for extended periods, allowing nutrients to accumulate and fuel the rapid growth of macroalgae. These eutrophic estuaries often show a gradient: upper areas are dominated by macroalgal blooms while lower areas near the mouth of the estuary are home to healthy eelgrass beds.[48]

In eutrophic estuaries, increased primary production results in increases in dissolved oxygen (DO) fluctuations: DO concentrations rise because of photosynthesis during the day (supersaturation) and decrease with **respiration** at night (**hypoxia**). As algae die and decay, oxygen concentrations can fall further, leading to hypoxic or anoxic conditions.[13,46,36,9] These fluctuations can have impacts on animal behaviour and survival. While some species may initially thrive in algae-dominated environments, worsening conditions, particularly those related to the onset of hypoxia and **anoxia**, can result in high mortality rates especially among sedentary species such as oysters, clams and mussels.[40,41,10] Fish and other mobile species often avoid these areas until oxygen levels recover. Eutrophic conditions and anoxic events can occur frequently and ultimately disrupt fish and invertebrate communities, reduce biodiversity, and drive ecosystem shifts (Figure 3).[37,41,8] For example, anoxic events were reported 117 times in PEI between 2020 and 2024.[24]

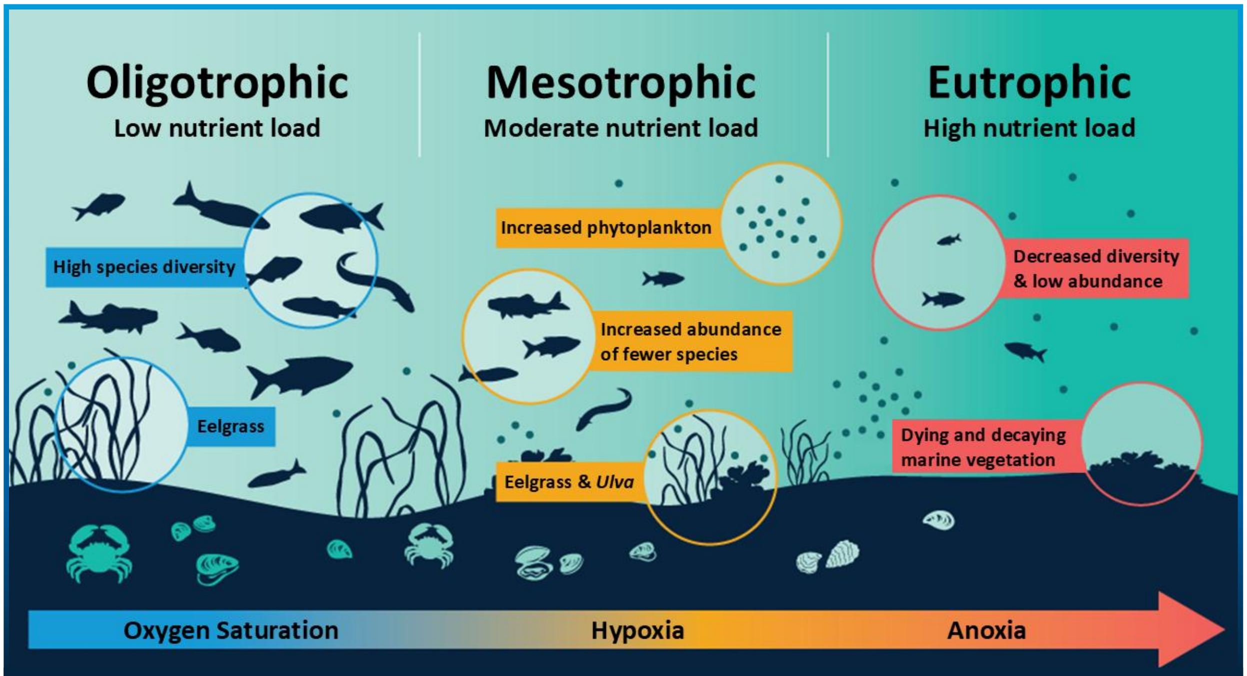

Figure 3: Continuum between trophic states showing changes in dominant marine vegetation, oxygen saturation, species diversity and species abundance. Credit: DFO.

These changes in trophic status can extend to the local economy, as shifts in fish habitats and anoxic events may negatively affect commercial fish populations and could increase mortalities in aquaculture operations.[40,14,10] Additionally, the accumulation of decaying algae can produce unpleasant sights and odours, potentially disrupting tourism and recreational activities.

Environmental quality measure development

The Canadian Council of the Ministers of the Environment (CCME) develops Canadian Environmental Quality Guidelines, including Canadian Water Quality Guidelines for the Protection of Aquatic Life. Because many factors influence an estuary's trophic status, it is not possible to establish general nutrient targets aimed at preventing coastal eutrophication across Canada. Consequently, the CCME published a framework outlining steps and considerations for establishing regional or local nutrient targets, supported by case studies.[5]

Building on this approach, efforts in the sGSL have focused on developing region-specific nutrient targets that account for local factors influencing trophic status. These targets help ensure that management measures designed to reduce external nutrient loading are tailored to regional conditions. [2,32,7,48,26] Furthermore, because nutrient enrichment results from the cumulative impacts of multiple human activities, achieving these nutrient targets requires coordinated action among regulatory authorities and stakeholders.

The *Oceans Act* provides the legislative instrument for this coordination. It not only authorizes DFO to manage, protect and foster the sustainable development of Canada's oceans and their resources, but also to establish mechanisms for **integrated management** planning. In Canada, human activities affecting marine environments fall under the jurisdiction of multiple federal and provincial authorities. While these activities are often managed individually to minimize their direct environmental footprint, the *Oceans Act* authorizes DFO to lead and facilitate the development of integrated management plans. These plans consider the cumulative impacts of all human activities on marine ecosystems and identify measures to address them through collaborative processes with relevant regulatory authorities. The Act also provides for the establishment of MEQ measures to support the implementation of integrated management plans across various spatial scales in estuarine, coastal and marine waters. MEQ measures, whether non-regulatory or regulatory, can serve as ecosystem-based management tools to maintain and improve marine environmental health by supporting efforts to address stressors from human activities.

Therefore, the *Oceans Act* provides both the legislative basis and the mechanism to develop nutrient targets and foster integrated, collaborative efforts among regulatory authorities to achieve those targets.

Trophic status indicator derivation

Extensive research has been carried out to identify the causes of severe eutrophic conditions in the sGSL, especially in PEI, and to identify strategies to address them. This research, which helped overcome many of the challenges to understanding estuarine response to nutrient enrichment, includes:

- creating nitrogen loading criteria for PEI estuaries,[2]
- modelling external nitrate loading in estuaries and linking it to various land-use activities, including agricultural practices,[32,26] and
- developing tools to monitor estuarine trophic status through the Northumberland Strait Environmental Monitoring Partnership.[47,7,48]

The identification of trophic status indicators has been an integral part of this research, as they are key to developing nutrient targets that are needed to effectively manage human activities contributing to external nutrient loading. Although nutrient loading is the key driver of trophic status and often used as an indicator, its presence alone does not guarantee eutrophication will occur. The length of time water remains in the estuary before being replenished (**water residence time**) also determines the severity of eutrophication because it affects both nutrient retention and renewal of oxygen rich waters. Other factors that can influence an estuary's response to nutrient loading include the climate of the region, freshwater input, the shape of the estuary, the type of seabed and tidal patterns.[9]

Various trophic indicators were tested or considered for assessing trophic status' of sGSL estuaries and due to their limitations were not selected (Table 1).[9]

Table 1: Trophic indicators considered for assessing trophic status' of southern Gulf of St. Lawrence estuaries and their limitations.

Trophic indicator	Limitations
Chlorophyll as an indicator of phytoplankton biomass	Not suitable for shallow estuaries where primary production occurs both in the water column (e.g., phytoplankton) and on the bottom (e.g., macroalgae).
Benthic primary production (e.g., macroalgae)	Difficult and costly to measure at large spatial scales for regional monitoring.
Eelgrass coverage as a percentage of available habitat	Eelgrass responses are indirect effects of nutrient-driven algal growth. Impacts on eelgrass can take a long time to become visible. Most estuaries in the region lack sufficient historical eelgrass data for reliable monitoring.

To serve as an effective indicator of trophic status, several criteria had to be met: the indicator had to be biologically meaningful, cost-effective, and easy to measure. Most importantly, the indicator needed to respond directly to nutrient changes so that shifts in the stressor would produce noticeable changes in the indicator. The researchers found that continuous monitoring of DO met these criteria. DO shows changes in primary production (e.g. algae growth) caused by nutrient enrichment by capturing the full range of oxygen fluctuations due to photosynthesis, respiration, and decomposition, making it an effective measure of eutrophication.[9]

After measuring DO concentrations in different estuaries, researchers explored metrics to best reflect oxygen changes and capture symptoms of eutrophication. A composite variable was created from two metrics: the percentage of time DO concentrations dropped below 4 mg/L or rose above 10 mg/L. This variable is called **Eutrophic Time** (ET). Coffin et al. also calculated two **predictor variables** for each estuary: **nitrate-N** external loading and water residence time, which together determine the severity of eutrophication. Researchers observed a strong correlation between ET and these two predictor variables.[7,9] Notably, this relationship can be used to determine the nutrient load reductions (i.e. nutrient targets) required to mitigate eutrophication in individual estuaries.[9]

DO data were collected in sGSL estuaries from 2013 to 2020, through the Northumberland Strait Environmental Monitoring Partnership, the DFO Science sector, and the PEI Department of Environment, Energy and Climate Action. These data were used to calculate the ET for 32 estuaries, with many estuaries monitored for multiple years. ET values for these estuaries were ranked in order, along with their dominant vegetation (Figure 4). Along this spectrum, estuaries with low nutrient impacts or ET are dominated by eelgrass, but around 0.35 or 35% ET, the dominant vegetation shifts to *Ulva* species. The researchers suggested that an ET target of 35% could be used to prioritize the protection of eelgrass.[9]

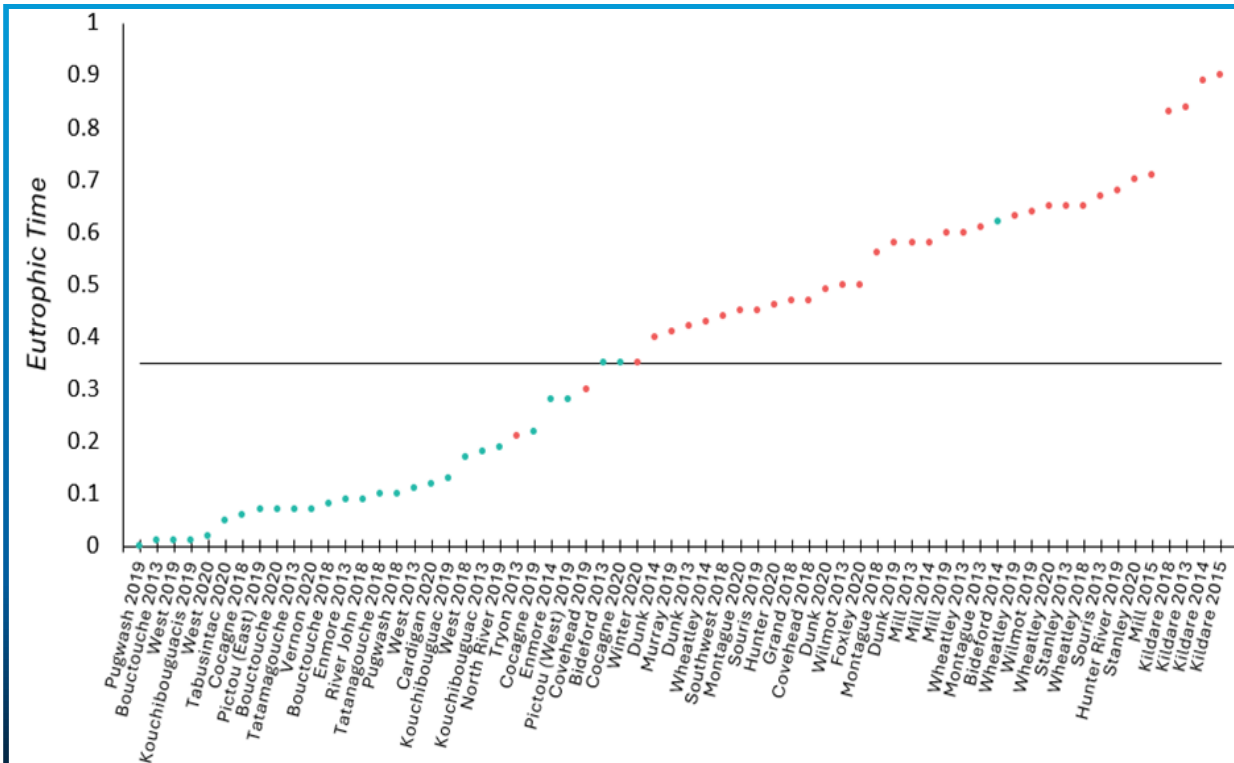

Figure 4: Eutrophic Time at each site for each year sampled. Sites are presented in ascending order for Eutrophic Time and are coloured according to dominant vegetation with eelgrass-dominated estuaries indicated by green and Ulva spp.-dominated estuaries by red. Adapted from Coffin et al.[9]

Guidance to assess the trophic status of southern Gulf of St. Lawrence estuaries

This Guideline recommends implementing continuous DO monitoring in sGSL estuaries to assess trophic status. The monitoring approach described below is based on methods developed and validated through research reviewed by the Canadian Science Advisory Secretariat, ensuring consistency and comparability across estuaries.[9,22] It provides general guidance on monitoring, evaluating and reporting on trophic status, with detailed instructions presented in ***Annex 1 Field guide for dissolved oxygen monitoring***. Considerations are also provided for recovery challenges, adaptive management and region-specific limitations.

MONITORING

A DO logger is needed to properly measure and monitor the trophic status of estuaries. Optical DO loggers are recommended because they are affordable and can be used across many estuaries as part of a regional program; the studies supporting this Guideline used Onset HOBO® optical DO loggers. The DO loggers should be deployed in the upper 10% of the estuary area where land-derived nutrients first enter the marine environment and where nutrient impacts are usually the most severe (Figure 5). Monitoring should be done from July to September, as this is when estuaries are most likely to experience hypoxia or anoxia.

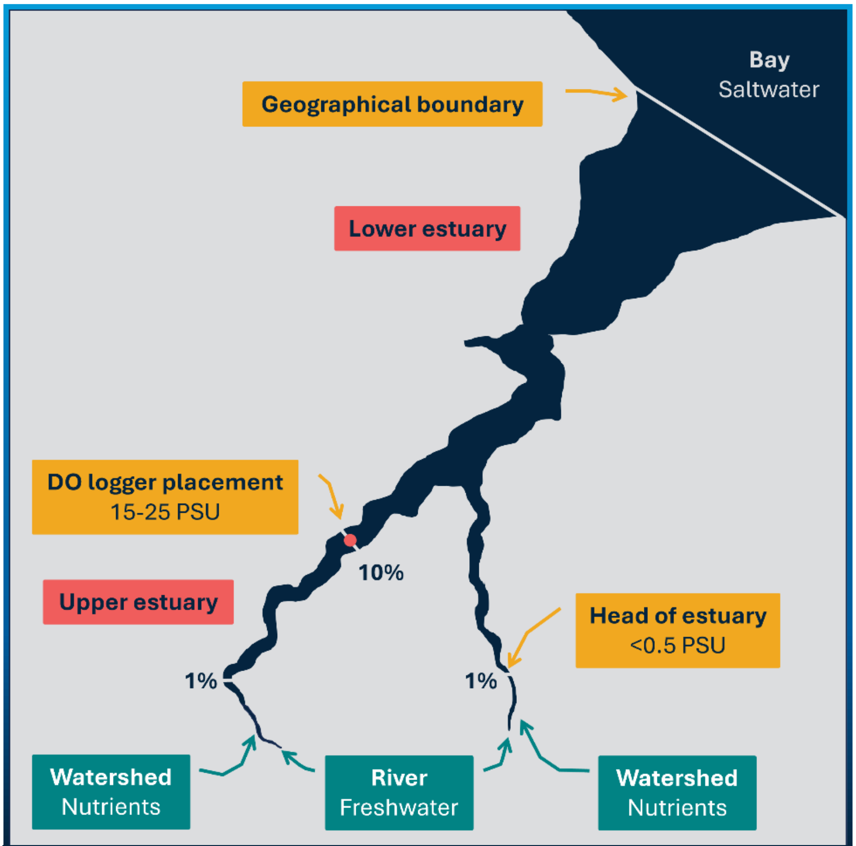

Figure 5: Estuary diagram illustrating estuarine zones and highlighting the 10% area where dissolved oxygen (DO) measurements should be collected.[16] Credit: J. Vienneau, DFO.

Estuaries should be monitored on a multi-year cycle (e.g. every three years), as annual changes may be minimal. One to two estuaries per province should be monitored annually, when possible, to account for changes from year to year.

EVALUATION AND REPORTING

Once the DO data are collected, ET should be calculated as the percentage of time DO concentrations dropped below 4 mg/L or rose above 10 mg/L during the monitored period from July to September.

A Eutrophic Time of 35% is recommended as a management target to maintain or restore the trophic health of estuaries. The target supports the protection of eelgrass and the broader goal of overall health for estuarine ecosystems in the region.

The following categories may be used to report ET values if a traffic-light approach to communicating the trophic status is preferred. These are intended as a communication tool to support interpretation of results and do not represent ecological thresholds beyond the recommended ET target:

< 30%	30%-40%	> 40%
Eutrophic Time: **Good trophic status**	Eutrophic Time: **Fair trophic status**	Eutrophic Time: **Poor trophic status**

To determine how much external nitrate reduction is needed to meet the ET target, data on nitrate loading from the watershed and water residence time are required. In 27 of the 32 estuaries studied, a model developed by Coffin et al.[9] was used to estimate the nitrate reductions needed to reach the ET target (see Table 1 in Coffin et al.[9]). These nitrate targets provide a strong foundation for developing targeted management strategies in the affected watersheds.

Efforts should be made to make the DO data publicly available. Reporting could follow the model of the public-facing water quality and quantity data on the Government of PEI's Water Registry website (https://water.princeedwardisland.ca/) which includes ET data under the Estuary Dissolved Oxygen Indicator tab.

CONSIDERATIONS

The Guideline does not predict how long it will take for estuaries in fair or poor trophic status to recover after external nitrate inputs are reduced. While reductions in these inputs are expected to lead to positive ecosystem changes over time, recovery is likely to be slow because significant amounts of nutrients may already be stored in agricultural soils, groundwater, and estuarine sediments.[51,31,11] As a result, measurable improvements in trophic status may lag behind reductions in external nitrate inputs.

Updating this MEQ Guideline to reflect the latest science and evaluate the monitoring cycle will be important to maintain its relevance and scientific rigor over time. This adaptive management approach will ensure the continued improvement of the effectiveness of the Guideline in assessing trophic status.

While much of the knowledge base on eutrophication in the region is derived from studies conducted in PEI, the study by Coffin et al.[9] that informed the development of this guideline includes estuaries from across the sGSL. The ecological processes described are therefore applicable to estuaries throughout the sGSL. As such, this Guideline is not intended solely to inform management measures aimed at remediating eutrophic estuaries. It can also be applied in healthy estuaries to facilitate the early detection of increases in nutrient loading and associated changes in trophic status, allowing for the timely implementation of best management practices or regulatory measures before further degradation occurs to stay consistent with the precautionary approach principle outlined in the *Oceans Act*.

In theory, using DO as an indicator could work in other shallow estuaries across the North Atlantic with similar characteristics, such as benthic production, land-based nutrient inputs, and watershed areas. However, this approach has not yet been tested outside the sGSL. This Guideline is based on specific DO thresholds and nutrient sources unique to the sGSL region.

Conclusion

Effective marine environmental management relies on collaboration, evidence-based decision-making, and adaptive strategies to address the cumulative effects of stressors on marine ecosystems. This Guideline is intended as a tool to assist relevant regulatory authorities and environmental stewards, such as watershed groups, in assessing the trophic status of estuaries, with the goal of developing and implementing effective best management practices, and regulations when necessary, to reduce external nutrient loading through an integrated management approach. Exploring collaborations with Indigenous communities, industries, and coastal communities that may be affected by the proposed best management practices and potential regulatory measures is encouraged.

Agricultural field in Prince Edward Island. Credit: M. Coffin, DFO.

Glossary

Word	Definition
Anoxia	Complete absence of dissolved oxygen (0 mg/L) in an aquatic environment.[1]
Cumulative effects	The net result of multiple residual stressors (or pressures) from human activities acting together on an ecosystem or ecosystem component.[30]
Dissolved oxygen	Concentration of oxygen present in water that is available for uptake by aquatic organisms.[50]
Ecologically Significant Species	The identification of Ecologically Significant Species (ESS) is a tool for calling attention to a species that has particularly high ecological significance in order to facilitate provision of a greater-than-usual degree of risk aversion in management of human activities that may affect such species.[19]
Epiphytes	Plants (or algae) that germinate and root non-parasitically on other plants at all stages of their life.[52]
Estuary	Semi-enclosed coastal body of water that has a free connection with the open sea, and within which seawater is measurably diluted with fresh water derived from land drainage.[16]
Eutrophic time	Composite variable consisting of the percentage of time dissolved oxygen concentrations drop below 4 mg/L or rise above 10 mg/L.[9]
Eutrophication	A process driven by enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, leading to increased growth, primary production and biomass of algae, as well as changes in the balance of organisms and water quality degradation.[17]
External nutrient loading	Influx of nutrients entering an aquatic ecosystem from the watershed in a given period of time.[45]

Hypoxia	Dissolved oxygen concentration ranging from > 0 mg/L to 4 mg/L in an aquatic environment.[9]
Integrated management	A collaborative approach to managing human activities where all factors are considered for the sustainable use, development, and protection of areas and resources.[18]
Internal nutrient loading	The release of nutrients that are present within the estuary's sediments.[45]
Mesotrophic	Condition characterized by moderate primary production due to moderate nutrient content.[38]
Nitrate-N	Measurement of the nitrogen portion of the nitrate molecule.[6]
Oligotrophic	Condition characterized by low primary production due to low nutrient content.[38]
Predictor variable	A factor, such as nitrogen or phosphorus, that directly influences trophic status by driving changes such as algal growth and dissolved oxygen concentrations.[35]
Primary production	Synthesis of organic material from inorganic carbon through processes such as photosynthesis.[34]
Respiration	Utilization of oxygen to break down organic matter, releasing energy and producing inorganic components.[34]
Stressor	Physical, chemical, or biological factor resulting from human activities that causes adverse effects on organisms, populations, or ecosystems.[34]
Trophic status	Amount of biotic productivity in a aquatic ecosystem; in the context of eutrophication, it refers to the productivity by primary producers.[15]
Upper estuary	Freshwater-dominated section of an estuary located near its head, characterized by low salinity waters and subject to strong tidal action.[16]
Water residence time	The average time water remains in a defined region, before being replaced.[34]

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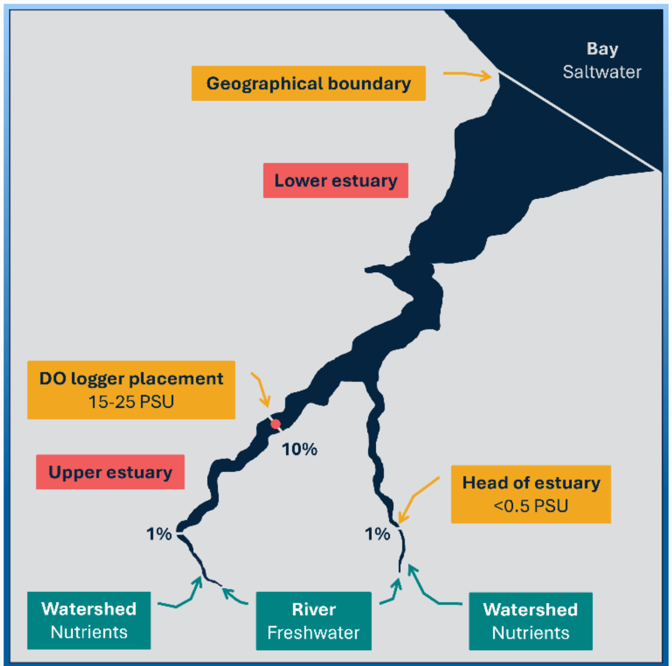
Annex 1 Field guide for dissolved oxygen monitoring



FG Figure 1: Estuary diagram illustrating estuarine zones and highlighting the 10% area where dissolved oxygen (DO) measurements should be collected. Figure credit: J. Vienneau, DFO.

LOCATION OF MONITORING

To apply this Guideline, dissolved oxygen (DO) loggers should be placed in the upper 10% of the estuary area (i.e. 10% of the total estuary area, measured from the head of tidal influence), as shown in Field Guide (FG) Figure 1. This area is defined by having salinity levels between 15-25 PSU and an average water depth of 1-2.5 meters, which is where benthic production can occur.

EQUIPMENT NEEDED

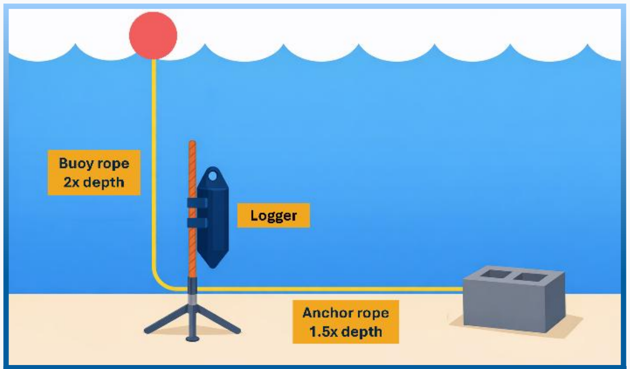
- DO loggers - Onset HOBO® optical DO loggers are recommended. Optical DO loggers were selected because they are affordable and could be used across many estuaries as part of a regional program. Find more information on the HOBO website (FG Figure 2).
- Logger stand (FG Figure 2)
- Concrete block(s) or weight(s)
- Rope measuring at least 3.5 times the water depth
- Laptop with HOBOware installed
- Waterproof shuttle with extra batteries and USB
- Cable for attaching to computers

FG Figure 2: Dissolved oxygen logger attached to a rigid rebar post on a tripod foot, to keep the equipment standing vertically in the water column, and from sinking into the sediment. Photo credit: J. Walker, DFO.

- Dry, soft cloths for cleaning and drying logger interface
- Small, soft-bristle brush (such as a tooth brush) for cleaning logger
- A scraper for cleaning logger stands
- Distilled water, if available, or tap water to rinse and clean logger (or to recalibrate as needed)
- Zip ties, to reattach logger to stand after cleaning
- Gloves
- Scissors or knife
- Extra loggers (if available) for deployment in case of a failure

LOGGER INSTALLATION AND DATA COLLECTION

Dissolved oxygen loggers should be placed approximately 0.5 meters from the estuary substrate on a stand anchored by a weight with a rope 1.5 times the water depth and attached to a surface buoy on a rope equal to twice the water depth (FG Figure 3). The DO loggers should ideally be set to record dissolved oxygen and temperature every 15-20 minutes, but hourly at a minimum, and should be deployed from July to September, as this is when estuaries are most likely to experience hypoxia or anoxia. At least 50% of the data collected during this period is needed to calculate a reliable Eutrophic Time (ET).



FG Figure 3: Dissolved oxygen logger setup on the estuary bed, anchored by a weight (concrete block) and attached to a surface buoy. Figure credit: J. Walker, DFO

DATA DOWNLOAD AND MAINTENANCE DURING DEPLOYMENT

- Data need to be downloaded and the loggers cleaned every two to three weeks to remove algae or organisms (biofouling). To reduce biofouling, copper wire guards should be placed over the sensors, when possible (FG Figure 4).
- Follow these steps to ensure that data are downloaded successfully and loggers are clean and operating properly:
    - Navigate to the marker buoy and pull the buoy and/or rope onto the boat until you reach the logger stand.
    - Loop the rope around a cleat on the boat, and then pull the stand/logger onboard. In still water, leave the weight in the water to anchor the boat from moving (if water is flowing, drop the boat anchor).

- Remove the loggers from the stand by cutting the zip ties, and clean the logger as described in the owner's manual.
- Clean any growth (biofouling) from the stand using the brush and the scraper.
- Download the data using the waterproof shuttle plugged into a laptop.
- Do not stop the logger from logging. If you get a message asking you to continue logging, click yes.
- Do not start a new file. The data file should be continuous from the time the logger is first launched until it is retrieved at the end of the season.
- View the data on the laptop by plotting the downloaded file in HOBOware to make sure that the logger has been properly launched and is collecting data.

FG Figure 4: Copper wire guard on dissolved oxygen logger to reduce biofouling. Picture credit: J. Walker, DFO.

- Make sure that the logger is still set to log every 15-20 minutes (hourly at a minimum, dependent on current data and battery availability).
- Check the status of the logger before redeploying. Before disconnecting the logger from the shuttle/computer, click on Device in the top left of the screen. Select pilStatus from the dropdown box and then select OK. A new screen will pop up. Near the bottom of the Device Details box will be the Current Status. This should say '*Launched, Logging*.' If it does not, then the logger must be re-launched prior to deployment.
- You can restart the logger right away; you do not need to set it to launch later in the day.
- Re-specify the starting date and same time intervals (i.e. 12:00, 12:20, 12:40, etc.) and relaunch the logger.
- Reattach the logger to the stand using zip ties and put the stand/logger and rope/buoy back in the water.

LENGTH OF MONITORING CYCLE

Monitoring should follow a three-year cycle, which is generally considered enough time to detect changes in water quality. However, there isn't yet a scientifically proven cycle length based on current data or recovery timelines. With recovery expected to take a long time, extending the monitoring cycle (e.g., from three to five years) may be warranted.

The information in this field guide is based on the following publications:

Coffin, M. R. S., Poirier, L. A., Clements, J. C., Dickson, E., Guyondet, T., & van den Heuvel, M. R. (2021). Dissolved oxygen as a Marine Environmental Quality (MEQ) measure in upper estuaries of the southern Gulf of St. Lawrence: Implications for nutrient management and eelgrass (*Zostera marina*) coverage. *DFO Canadian Science Advisory Secretariat Research Document* 2021/056, iv + 27 p.

Coffin, M. R. S., Knysh, K. M., Roloson, S. D., Pater, C. C., Theriault, E., Cormier, J. M., Courtenay, S. C., & van den Heuvel, M. R. (2021). Influence of nutrient enrichment on temporal and spatial dynamics of dissolved oxygen within northern temperate estuaries. *Environmental Monitoring and Assessment, 193,* 804. https://doi.org/10.1007/s10661-021-09589-8