Assessment Methods for Reclamation of Permanent Marshes in the Oil Sands: Handbook and Video

Prepared by The Bayley Lab at the University of Alberta, B-217, Dept. of Biological Sciences, University of Alberta, 11455 Saskatchewan Drive, Edmonton, Alberta

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Note that the accompanying video may be viewed online at the following URL: http://youtu.be/NXCyCY2mkRI

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EXECUTIVE SUMMARY

This handbook describes tools used to assess and monitor the health or condition of reclaimed marshes in the oil sands region. It will guide users through the sampling methods, laboratory procedures, and data calculation steps necessary for measuring health indicators of permanent wetlands located on or adjacent to reclaimed land affected by oil sands mining. The four performance indicators, which estimate health by integrating several field measurements into an index score, are the 1) Stress Gradient Index (**SGI**); 2) Submersed & Floating Aquatic Vegetation Index of Biological Integrity (**SAV-IBI**); 3) Wet Meadow Index of Biological Integrity (**WM-IBI**); and 4) Marsh Condition Index (**MCI**). The first three performance indicators can either be used individually to estimate the environmental or plant community condition within a wetland, or they can be integrated into a final MCI score providing an overall estimation of wetland health. A video on sampling procedures for each performance indicator is available at the following URL, http://www.youtube.com/watch?v=NXCyCY2mkRI.

The SGI measures eight physical-chemical indicators derived from basic hydrological, water quality and sediment quality parameters, which collectively represent the maximum variation measured across the range of reclaimed and natural wetlands in the Boreal Plains Region. This environmental variation reflects a gradient from high quality reference wetlands to wetlands physically disturbed by oil sands operations to oil sands process-affected wetlands, which have been contaminated by oil or other pollutants. The two plant-based performance indicators (SAV-IBI and WM-IBI) measure attributes of the indicator plant community that have a known sensitivity to the underlying environmental gradient summarized in the SGI. The performance indicators have established scientifically-derived criteria that can be used for regulatory purposes to inform reclamation certification of wetlands. Likewise, they can aid wetland management and conservation by monitoring conditions of reclaimed wetlands (i.e. improving, declining, no change), identifying remediation opportunities to improve environmental structure or enhance vegetation succession, and managing the effects of oil sands activity on wetlands adjacent to reclaimed land.

The performance indicators provide several options or tools that offer standardized monitoring and assessment methods and criteria for managing wetlands, which will provide more accurate and comparable evaluations of wetland reclamation practices and outcomes in the oil sands region. These tools are simple to use and, if implemented correctly, yield consistent and reproducible assessments. Thus, these performance indicators provide important tools to consistently and scientifically evaluate reclamation success and identify adaptive management opportunities based on these outcomes. These tools can operate under the normal range of climatic variability, but sampling should be postponed in the case of events such as extreme droughts or flooding, as changes in physical and chemical structure and resultant shifts in plant community structure may influence the performance indicator scores.

The performance indicators provided in this handbook are designed to evaluate permanent marshes on reclaimed open pit mining leases in the Boreal Plains Region. We recommend that future research is done to expand the application of these performance indicators to include in-situ mining sites. Similar performance indicators have been developed for permanent marshes in the northern prairies (Aspen Parkland and Boreal Transition Zone) regions, although the individual metrics and thresholds differ.

Keywords: Marshes, reclamation, oil sands, monitoring and assessment, environmental indicators, reference condition approach, wetland health, floristic quality index, oil sands process-affected water

CHAPTER 1. Introduction

This handbook describes how to use several tools that were developed to assess and monitor the health of reclaimed marshes in the oil sands region. It will guide users through the sampling methods, laboratory procedures, and data calculation steps necessary for measuring health indicators of permanent marshes located on or adjacent to reclaimed open pit mining land. The four performance indicators described in this handbook are the 1) Stress Gradient Index (**SGI**); 2) Submersed & Floating Aquatic Vegetation Index of Biological Integrity (**SAV-IBI**); 3) Wet Meadow Index of Biological Integrity (**WM-IBI**); and 4) Marsh Condition Index (**MCI**). The first three performance indicators can either be used individually to estimate the environmental or plant community condition within a wetland, or they can be integrated into a final MCI score providing an overall estimation of marsh health (Fig. 1.1). A video on sampling procedures for each performance indicator is available at the following URL, http://www.youtube.com/watch?v=NXCyCY2mkRI.

Methods for measuring each performance indicator are based on scientifically defensible approaches that have passed rigorous peer review and have been published in scientific journals (i.e. Rooney & Bayley, 2010; 2011a; Raab & Bayley, 2012; Wilson *et al.*, 2013a; Wilson *et al.*, 2013b). Providing a standardized suite of tools will enable biologists from various sectors, such as industry, consultants, environmental monitoring agencies and government to perform regulatory and management activities. The performance indicators have established scientifically-derived thresholds and limits that can be used for regulatory purposes to inform reclamation certification of wetlands. Likewise, they can aid wetland management and conservation by tracking the conditions of reclaimed wetlands (i.e. improving, declining, no change), identifying remediation opportunities to improve environmental structure or enhance vegetation succession, and managing the effects of oil sands activity on wetlands adjacent to reclaimed land. Although the performance indicators offer several options or tools for monitoring, they all provide standardized monitoring and assessment methodologies and criteria, which will provide more accurate and comparable evaluations of wetland reclamation practices and outcomes. These tools are simple to use and, if implemented correctly, yield consistent and reproducible assessments. Thus, these performance indicators provide important tools to consistently and scientifically evaluate reclamation outcomes and identify adaptive management needs and opportunities. The three performance indicators (and the summary Marsh Condition Index) will contribute to an outcome-based approach for evaluating marsh reclamation and adaptive management in the oil sands region.

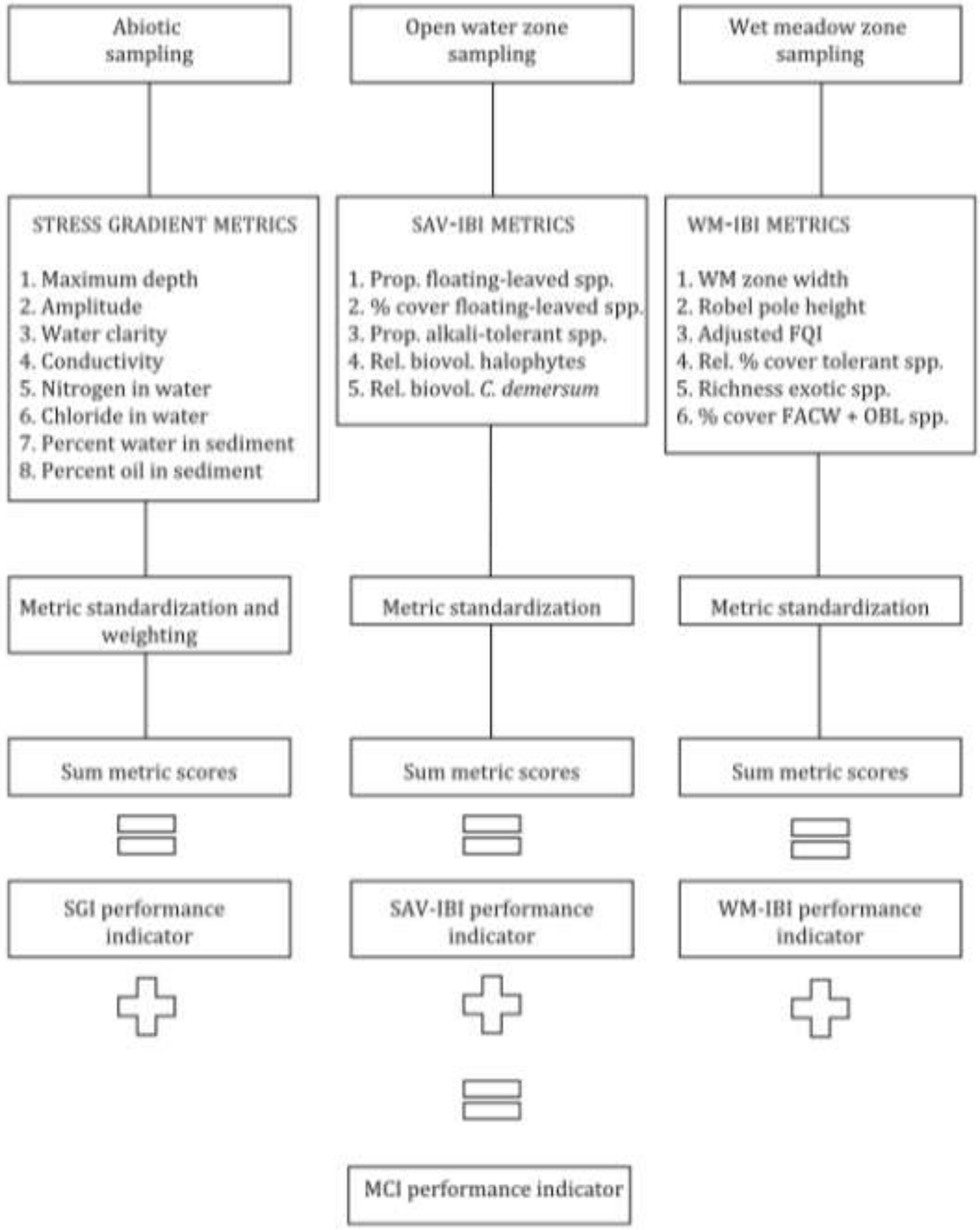

Figure 1.1. Steps necessary for calculating each of the four performance indicators in this handbook.

1.1. Oil sands surface mining and wetland reclamation

The oil sands surface mineable area is a 475,000 ha area located within the Boreal Plains Region in Alberta, Canada. Although 64% of this area supports wetland vegetation, it is estimated that reclaimed land will have 36% less wetland area (Rooney *et al.*, 2012). Land reclamation will consequently lead to a massive-scale landform transformation amounting to a net loss of ~30,000 ha of wetlands on currently approved mines. While peatlands will be inevitably lost as a result of open pit mining, there is an opportunity to replace them with other wetland types such as natural and self-sustaining marshes.

Wetland reclamation refers to the construction of wetlands on disturbed land where they did not formerly exist or where their previous form has been entirely lost (Alberta Environment, 2008). The majority of wetlands destroyed or disturbed by oil sands mining processes are peatlands such as fens and bogs. Peatland reclamation, however, faces challenges that include altered topography, geotechnical instability, water scarcity, and elevated salinity and contaminants, which bog and fen-like vegetation cannot tolerate (Pouliot *et al.*, 2012; Rezanezhad *et al.*, 2012). Elevated salinity results from open-pit mining and bitumen extraction processes, as well as leaching from saline aquifers, recycling of tailings waters, and deposition of marine shale overburden (Purdy *et al.*, 2005; Trites & Bayley, 2009b). Although naturally sub-saline and saline wetlands (i.e. conductivity of 500-2000 and > 2000 µs/cm respectively) are scarce in the Boreal Plains, marshes are more likely to be sustained on the post-mining reclaimed landscape than peatlands, as some marsh plants are tolerant of elevated salinities and contaminants (Stewart & Kantrud, 1972; Hammer & Heseltine, 1988; EPA, 2000). Furthermore, a greater amount of knowledge and research exists on marsh construction and restoration than on other wetland types, and marshes often form opportunistically on the post-mining landscape (Alberta Environment, 2008). Reclaimed marshes will likely be able to support similar vegetation species as natural sub-saline marshes (Purdy *et al.*, 2005; Trites & Bayley, 2009b; Rooney & Bayley, 2011b; Raab & Bayley, 2013).

1.2. Marshes and marsh characteristics

Marshes are a class of mineral wetlands that have shallow fluctuating water. The water balance is moderated by precipitation, surface runoff, surface water inflow, groundwater discharge, evapotranspiration, groundwater recharge and seepage (National Wetlands Working Group, 1997). They are distinguished from other mineral wetlands by the presence of less than 25% woody plants and at least 5% graminoid vegetation (Alberta Wetland Classification System). Marshes may surround an open water zone of shallow open water wetland class. Marshes tend to have circumneutral to alkaline water due to the presence of dissolved minerals, and in Alberta they are generally eutrophic with high productivity and decomposition rates.

Relatively permanent marshes and shallow open water wetlands (Class V in Stewart & Kantrud, 1971) contain water for the entire year in the majority of years, and those in the Boreal Plains generally have three distinct vegetative zones: the open water zone (OW), of the shallow open water class the emergent marsh zone (EM), equal to the deep wetland zone in the Albert Wetland Classification System, and the wet meadow marsh zone (WM), equivalent to the combined shallow wetland and wet meadow zones in the Alberta Wetland Classification System. (Fig. 1.2). Marsh vegetation zones are delineated by changes in vegetative forms and communities along a gradient in elevation (Spence, 1982). Submersed aquatic vegetation (SAV) and floating aquatic species inhabit the OW zone and comprise the biological indicators in the SAV-IBI. The EM zone consists of the marsh fringe area nearest to the edge of the open water and is characterized by cattails and rushes. The plant community in the EM zone was found to be an unsatisfactory indicator of marsh condition (Raab & Bayley, 2012) and was consequently not used as a performance indicator. The WM zone makes up the remaining marsh area between the outer edge of the EM zone and the upland boundary. Sedges and hydrophytic grasses are dominant in the WM zone. The WM-IBI measures plant condition based on wet meadow plant community structure and sensitivity to stress.

Figure 1.2. Typical zones present in shallow open water wetlands and marshes in the Boreal Plains Region.

1.3. Environmental monitoring and assessment tools

Environmental monitoring and assessment is an essential component of wetland conservation. Monitoring programs can be used to audit and regulate environmental practices such as ecosystem disturbance, remediation, and reclamation. They also aid in informing environmental planning and management by highlighting the effects of open pit mining on reclaimed land and adjacent disturbed land, and inferring causes of impairment and opportunities for adaptive management. The performance indicators in this handbook are designed to evaluate whether wetland reclamation is progressing towards the development of self-sustaining wetlands, supporting vegetation communities that are similar in structure to healthy reference marshes in the region. Although higher trophic levels are not evaluated in this handbook, monitoring other organisms is also recommended. Similar performance indicators can be developed for other organisms including invertebrates and birds. Vegetation, however, contributes to the structure of marshes and the habitat necessary to support wildlife.

Each performance indicator uses standardized scientific methods to facilitate uniform and consistent monitoring and assessment practices. The condition or health of a site can be easily evaluated by following the instructions in this handbook to measure the specific metrics comprising each indicator and calculate their corresponding scores. We recommend that these performance indicators should be implemented as part of regulatory monitoring, evaluation and management of wetlands on reclaimed land.

1.4. Performance indicators for reclaimed marshes in the Boreal Plains

It is difficult to measure everything in an ecosystem to discern whether it is healthy. Just as economists use economic indicators to predict the stock market, biologists use ecological indicators to estimate the health of an ecosystem and to predict its progress towards a re-established, functioning system similar to reference ecosystems. In terms of monitoring reclaimed landscapes, performance indicators estimate the ecological performance of the replaced landscape.

Eight physical-chemical indicators are measured in the SGI, which collectively represent the maximum environmental variation measured across the range of reclaimed (reclaimed from open pit or mined substrates) and natural wetlands in the Boreal Plains Region. This environmental variation reflects a gradient from high quality reference wetlands to those physically disturbed by oil sands operations to oil sands wetlands affected by soils or liquids from the extraction process (called process-affected wetlands). The two plant-based performance indicators (SAV-IBI and WM-IBI) were developed based on the popular Index of Biological Integrity approach that measures and compares biological condition across a gradient of human activity (Karr, 1981). The SAV-IBI and WM-IBI measure attributes of each plant community that are sensitive to the underlying environmental gradient summarized in the SGI. The measured attributes that collectively make up each performance indicator are known as "metrics." Although the IBIs measure metrics from different indicator communities, the same approach is used in both the SAV-IBI and WM-IBI (Fig. 1.4).

Performance indicators were developed by sampling existing oil sands and reference marshes that were similar in size, depth, and salinity (Rooney & Bayley, 2011a; Raab & Bayley, 2012). Three categories of marshes (n = 63) were sampled: undisturbed reference marshes (REF, n = 38), oil sands reference marshes (OSREF, n = 12), and oil sands process-affected marshes (OSPA, n = 13). The suite of reference and oil sands marshes together was used to capture the entire gradient of disturbance due to oil sands surface mining. REF marshes defined the reference condition or the natural range of variation among permanent marshes across the Boreal Plains, including fresh, subsaline, and saline marshes. REF marshes were sampled between northwest Alberta and central Saskatchewan and in isolated pockets of the Boreal Transition Zone near Edmonton, Alberta; they were located in naturally forested areas, with only small amounts of forestry or agriculture within 2 km of their open water boundaries (Rooney & Bayley, 2010). OSREF and OSPA marshes were sampled on previously mined land at Syncrude Canada Ltd. and Suncor Energy Inc. and were categorized based on their exposure to process-affected materials. OSREF sites were exposed to some oil sands-related disturbances but were free of tailings contamination. In contrast, OSPA sites were exposed to contamination from liquid tailings and process-affected waters and soils.

1.5. Limitations of performance indicators

Although the performance indicators in the Boreal Plains have not been validated against temporal and climatic variability, Wilson *et al.* (2013a) found that a vegetation IBI yielded consistent scores in dry and wet years in permanent marshes in the Aspen Parkland Region of Alberta, which overlaps the southern part of the boreal forest. Marsh vegetation responds rapidly to seasonal and longer-term fluctuations in water levels, undergoing cycles of drawdown and regeneration, degeneration and open water phases over several consecutive years. Extreme fluctuations in water levels are known to shift plant structure and composition within a wetland (Wilcox *et al.*, 2002; van der Valk, 2005) and desiccate or flood out vegetative zones. Monitoring should be postponed in years where natural disturbances like extreme drought or flooding affect the ability to sample vegetation or monitor the performance indicators. Monitoring should then resume when vegetation communities have recovered from the effects of flooding or drought and typical vegetative zones have re-established (typically 1-3 years after a return to typical precipitation levels).

Although similar monitoring approaches are widely used throughout North America, the performance indicators provided in this handbook are designed to evaluate the condition of marshes and shallow open water wetlands on or near reclaimed open pit mining leases in the Boreal Plains, Alberta. They should <u>not</u> be used to assess other wetland types (i.e. peatlands), marshes in other regions, or intermittent marshes (marshes that do not retain their surface water throughout the year). We recommend continuing research to expand the application of these performance indicators to include in-situ mining sites. Similar performance indicators have been developed for permanent marshes in the northern prairies (Aspen Parkland Region), although the individual metrics and thresholds differ (Wilson *et al.*, 2013a).

1.6. Summary of this handbook

Methods for measuring, calculating, and integrating metrics in the SGI are summarized in Figure 1.3 and will be described in detail in Chapter 2. Chapters 3 and 4 provide detailed methods for measuring the SAV-IBI and WM-IBI, respectively (Fig. 1.4). When integrated into the Marsh Condition Index (MCI), the three individual performance indicators provide an estimation of the overall environmental and vegetation conditions as discussed in Chapter 5. Chapter 6 explains how the performance indicators have established scoring criteria with which to define a healthy marsh, determine reclamation certification benchmarks and evaluate reclamation outcomes. Chapter 7 discusses monitoring timelines and adaptive management; Chapter 8 discusses the advantages and limitations of each performance indicator; lastly, Chapter 9 and 10 respectively describe the attributes of existing reclaimed marshes and their implications.

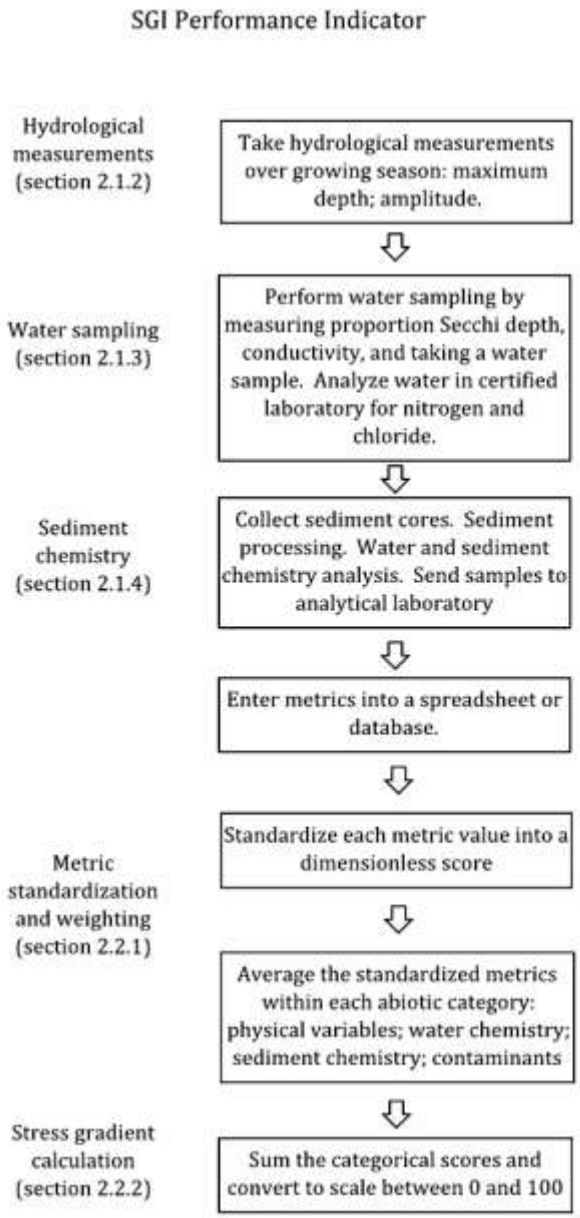

Figure 1.3. General field methods, laboratory procedures, and office steps for calculating the stress gradient index (SGI) performance indicator.

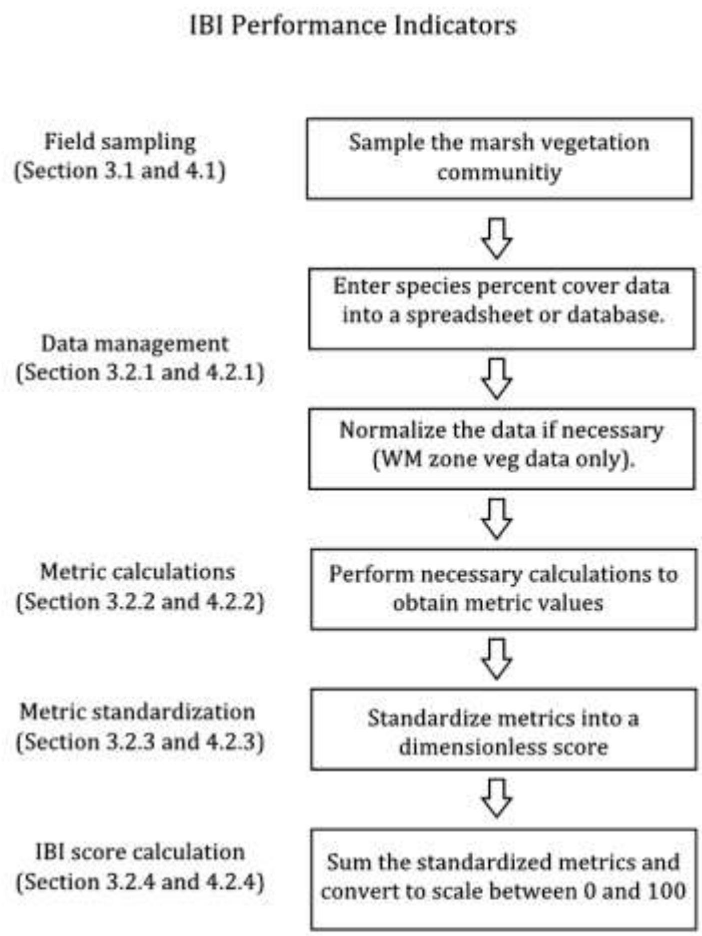

Figure 1.4. General field methods and office steps for calculating IBI (Index of Biological Integrity) scores for the submersed and floating aquatic vegetation and wet meadow zones in the marsh

CHAPTER 2. Stress gradient index performance indicator (SGI)

The Stress Gradient Index (SGI) provides an estimation of environmental condition by measuring basic hydrological, water quality, and soil indicators. SGI metrics were chosen from 52 initial environmental parameters suspected of influencing plant community health (Rooney & Bayley, 2010). In brief, a multivariate statistical technique called Principal Components Analysis (PCA) was used to select parameters that represented the most variation within datasets grouped by water chemistry, sediment chemistry, physical attributes, and contaminants. See Rooney and Bayley (2010) for a more detailed discussion on SGI development, including a comparison of scoring and weighting systems.

The eight metrics in the SGI are listed below along with a description of their expected response to abiotic stressors due to oil sands mining. Each metric was scored on a scale between 1 and 5, whereby 1 represents low stress and 5 represents high stress.

Maximum water depth

Maximum depth was estimated by taking several measurements in the center of a wetland and determining the deepest point. Reclaimed marshes tended to be deeper than reference marshes, which could potentially limit SAV growth especially at depths > 1.5 m. Maximum depth was positively correlated with stress; thus, shallower marshes are given lower stress scores and deeper marshes are given higher stress scores.

Water amplitude

Amplitude is defined in the context of this handbook as the seasonal difference in maximum and minimum water levels. Although seasonal drawdown is important for vegetation regeneration, permanent reference marshes tended to have lower amplitudes than many reclaimed marshes, possibly due to bathtub-like morphologies in reclaimed landscapes. This metric is positively correlated with stress such that sites with greater amplitude have higher stress scores.

Proportion of Secchi depth

The proportion of Secchi depth estimates the relative depth of light penetration in the water column. Lower light penetration due to higher mineral turbidity often leads to reduced SAV abundance (Bayley *et al.*, 2012). Mean turbidity in reclaimed marshes (40.92 mg/L) was much higher than in reference marshes (2.10 mg/L). Proportion of Secchi depth is negatively correlated with stress such that marshes with clearer water are given lower stress scores.

Conductivity

Cation and anion concentrations are expected to accumulate during oil sands extraction processes and are higher than in many reference marshes. Conductivity is positively correlated with stress.

Total nitrogen (TN) in the water

Although elevated nitrogen may be a stressor in other regions, marshes in the Boreal Plains are naturally eutrophic (Bayley *et al.*, 2012). Therefore, nitrogen deficiencies are more likely to occur in reclamation marshes (Rooney & Bayley, 2010). Higher Total Nitrogen is negatively correlated with stress.

Chloride (Cl^-) in the water

In naturally saline and sub-saline wetlands of the Boreal Plain, the dominant anion is usually sulfate, but in oil sands process affected wetlands chloride can be an important anion. Therefore, higher chloride is positively correlated to stress.

Percent water in the sediment

Percent water in wetland sediments is strongly related to the amount of sediment organic matter. A high percentage of water is expected in the sediment of reference marshes relative to reclaimed marshes due to the accumulation of organic material over long periods of time. Thus, a higher percentage of water in the sediment is negatively correlated with stress.

Percent oil in the sediment

Contamination from open pit mining and bitumen extraction processes can increase oil concentrations in sediments of reclaimed wetlands. Clearly, increasing oil content in the sediment reflects higher stress scores.

2.1. Stress Gradient Index (SGI) field and laboratory methods

This section describes field and laboratory sampling methods necessary for calculating SGI scores (Fig. 1.3). Field methods are demonstrated in the video available online at http://www.youtube.com/watch?v=NXCyCY2mkRI. Field personnel are required to follow the safety guidelines specific to the mine company and leasehold where field sampling will take place. These safety guidelines always require the use of personal protective equipment (PPE), including hard-hats, reflective stripes, CSA green triangle boots, safety glasses, and life jackets at all times during sampling. A list of field sampling and safety equipment is provided in Appendix 1; however, please contact each company to learn of all necessary safety requirements on their leasehold.

Field data collected for the SGI includes hydrological measurements, water characteristics, and sediment chemistry. The eight metrics in the SGI are 1) maximum water depth; 2) water amplitude; 3) proportion of Secchi depth; 4) conductivity; 5) total nitrogen in the water; 6) chloride concentration; 7) the percentage of water in the sediment; and 8) the percentage of oil in the sediment. It is best practice to standardize the time of year at which sampling takes place, since water characteristics such as depth, clarity, and ion concentrations will vary seasonally. During previous field sampling, maximum depth was measured at the beginning of the ice-free season (late May to early June) and water and sediment sampling was performed during peak vegetation biomass in late July or August (Rooney & Bayley, 2010). Water amplitude measurements were recorded from ice-off to peak vegetation biomass, the period over which precipitation inputs and evapotranspiration are the greatest (Keil, 1993) and may fluctuate. Field and laboratory procedures should be followed carefully. Longer laboratory procedures and increased costs for chemical analysis make the SGI the most laborious and costly performance indicator described in this handbook.

2.1.1. Outline of sampling timeline of field and lab procedures for the SGI

1. Record maximum depth of wetland and install staff gauge – *beginning of May*.
2. Record water levels at least every two weeks – *duration of ice-free growing season*.
3. Measure proportion of Secchi depth and conductivity *in situ*; collect a water sample – *mid-July to late-August.*
4. Send water samples to certified limnological laboratory for analysis of TN and Cl.
5. Collect three sediment cores – *mid-July to late-August.*
6. Perform laboratory pre-processing of sediment cores.
7. Analyze a sediment sub-sample for percent water content.
8. Send sub-sample to an analytical laboratory for analysis of percent oil content.

2.1.2. Hydrological measurements

Maximum depth

If a bathymetric map of the site is not available, the deepest point in the wetland can be located by taking frequent depth measurements from a boat as you make transects across the OW zone. Several quick depth measurements should be made while kayaking through the wetland to estimate the maximum depth of the wetland. More measurements should be taken for larger marshes.

Amplitude

Amplitude was defined as the seasonal difference in maximum and minimum water levels: Amplitude $= maximum\ depth - minimum\ depth.$ Usually, maximum depth occurs at the beginning of the ice-free season and the minimum depth occurs in August due to high evaporation (Fig. 2.1). However, changes in water levels do not always follow this pattern (Fig. 2.1), as high summer rainfall patterns can increase water depth in mid-summer and certain wetlands (like that depicted in panel b of Fig. 2.1) receive continuous inputs of shallow ground water via seepage. Site visits to record water depth should be attempted during the course of the season and especially after high rainfall events. If the SGI is being used in consecutive years, the amplitude needs to be measured each season.

An easy and inexpensive way to monitor fluctuations in water levels is to install a staff gauge in the OW zone of a marsh. A staff gauge is a large and visible measuring stick that is hammered vertically into the sediment of the open water zone. Alternatively, a field technician can install an electronic water level logger (e.g., HOBO U20 Water Level Logger) and retrieve it at the end of summer to download its data. Use of any loggers should follow the manufacturer's guidelines, including installation of stilling wells and reference barometers if required. The following paragraphs describe steps for measuring water level using a staff gauge.

Install staff gauges at the beginning of the ice-free season in the open water zone where it is visible from the shore and is easy to read with binoculars. During installation, ensure that the staff gauge is secure and will not become dislodged over the sampling season. Staff gauges left throughout the winter will likely experience ice heaving and thus should be re-secured at the beginning of each year. Use a post-leveler to confirm that the staff gauge is vertical. Record water level measurements from the shoreline at least once every two weeks for the duration of the sampling season (see example datasheets in Appendix 2). If staff gauges are left in wetlands over several years (re-secured in each spring), trends in amplitude can be used for future amplitude measurement in later monitoring years unless the physical structure of the marsh is altered.

Water level fluctuations recorded by the staff gauge can be calibrated to represent fluctuations in maximum marsh depth. To do this, calculate the difference between the initial depth of the staff gauge and the depth at the deepest point in the wetland; add this difference to each staff gauge water level reading. For example, if the deepest point of the wetland is 40 cm on May 1, and the staff gauge is installed at a depth of 30 cm on the same day, adding 10 cm to all subsequent staff gauge measurements will reflect the changes in maximum depth.

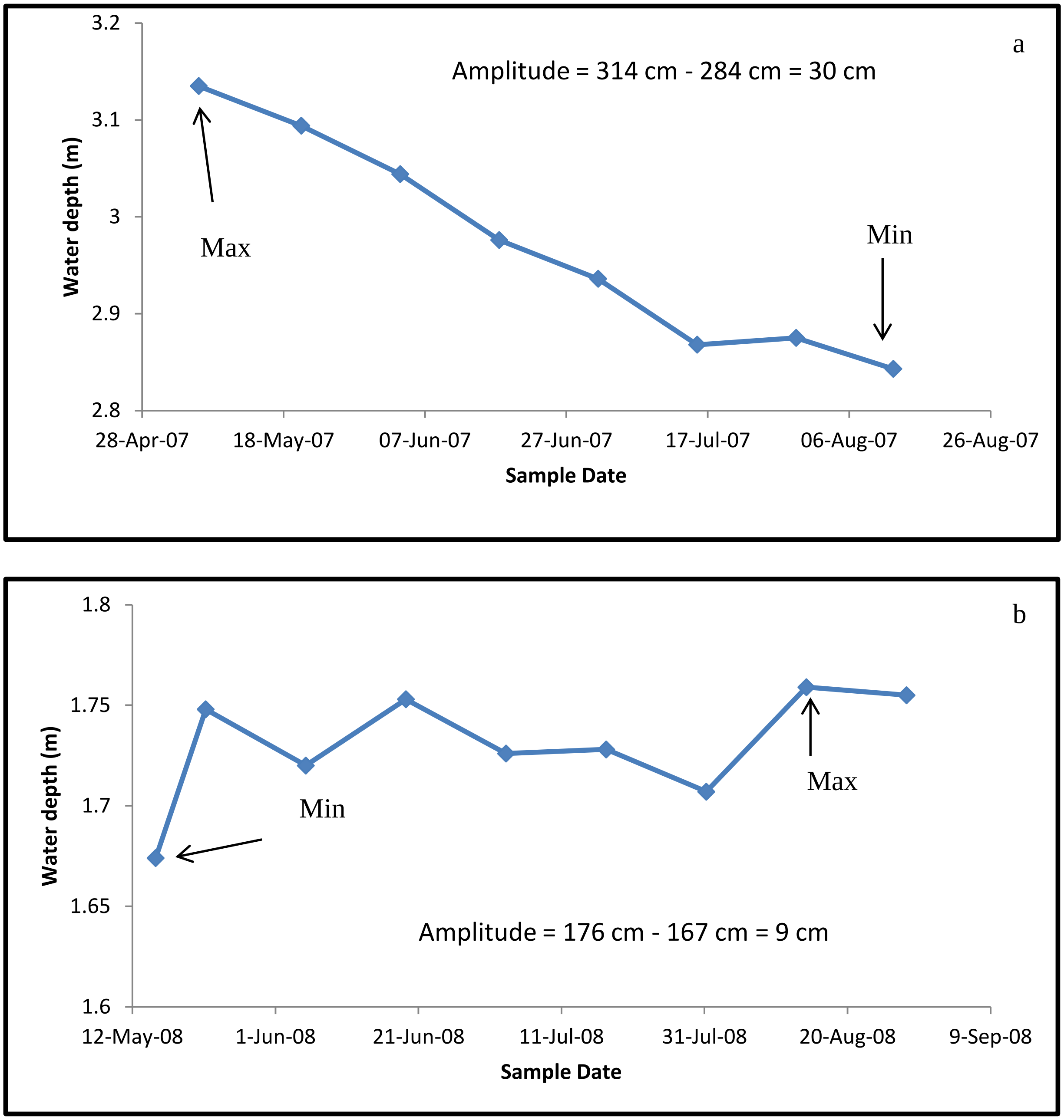

Figure 2.1. Measured water depth in two reclaimed marshes from May-September. Panel a: OSREF site named Deep Pond. Panel b: OSREF site named S-pit. Maximum and minimum depths used to calculate seasonally amplitude are shown. A pattern like that of panel b indicates seepage inputs of groundwater to the wetland.

2.1.3. Water sampling

Proportion of Secchi depth

Secchi disks are 10 cm in diameter and have alternate black and white wedges on the top of the disk (Fig. 2.2). Proportion of Secchi depth estimates the relative clarity of the water. Secchi depth should be measured from a boat or kayak at the same location where maximum depth was measured. Remove sunglasses or safety glasses before reading Secchi depth measurements to ensure consistency of visibility. After dropping the anchor on the sunny side of the boat, measure the water depth on the shady side of the vessel to avoid glare and interference from the anchor disturbing the sediment. Lower the Secchi disk into the water until it disappears. Record this depth as the "Secchi down" depth. Lower the disk further into the water until it is well out of sight and then slowly raise it until the disk is visible again. Record the depth at which the Secchi disk reappears as the "Secchi up" depth. Note that the Secchi down depth often exceeds the Secchi up depth slightly because of the eyes ability to follow the disk while it is being lowered. Averaging the "Secchi up" and "Secchi down" depths yields the mean Secchi depth. Divide the mean Secchi depth by the total depth of the water column to obtain the proportion Secchi depth:

$$\text{Proportion Secchi depth} = \frac{(Secchi\ up\ depth\ +\ Secchi\ down\ depth)}{2\ \text{(total depth of water column)}}$$

Figure 2.3 illustrates how Secchi depth estimates water clarity using light penetration as a proxy measurement.

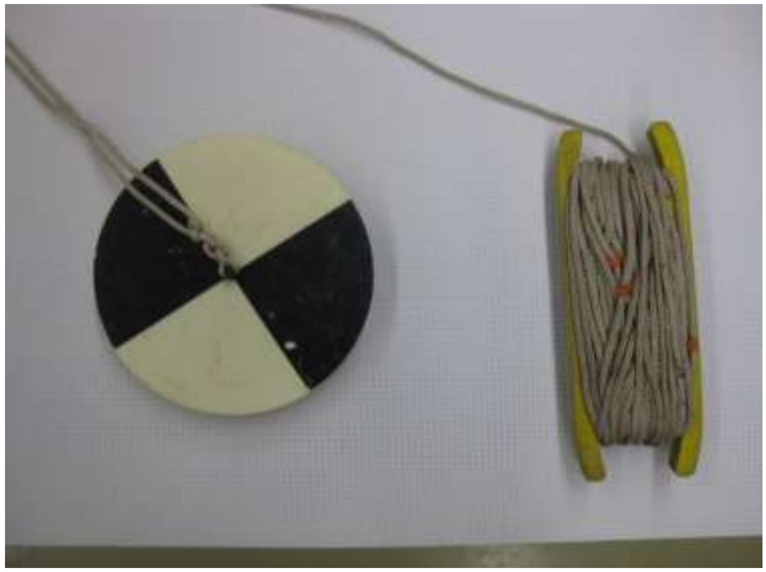

Figure 2.2. Example of a 10 cm Secchi disk used to estimate water clarity.

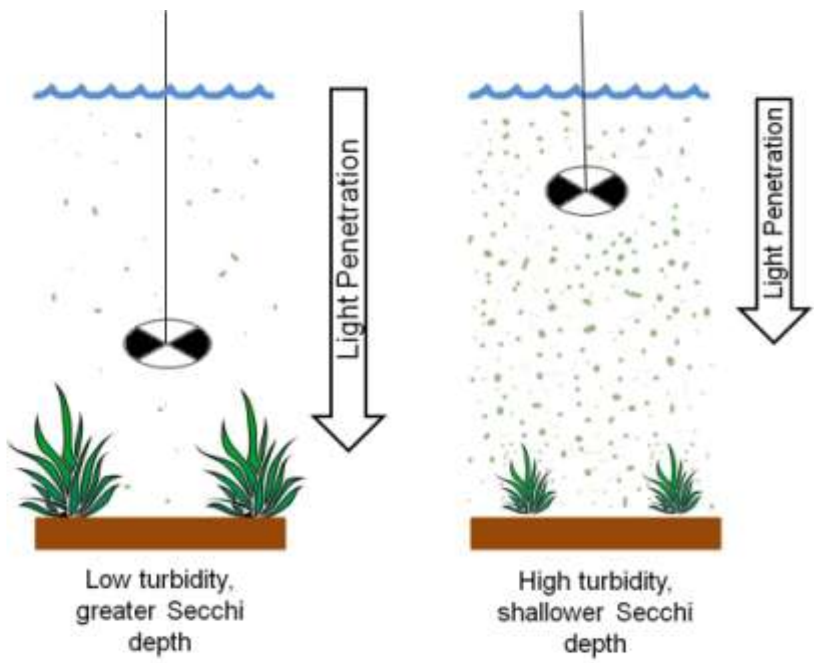

Figure 2.3. Schematic of Secchi disk measurements. Higher turbidity will lead to less light penetration and shallower Secchi depths.

Conductivity

Use a handheld conductivity probe and field meter to measure conductivity such as a HACH HQ 40d portable meter with an IntelliCAL conductivity probe. Take conductivity readings in microsiemens per cm at 25 degrees Celsius at the deepest point in the wetland before collecting the water sample. Readings should be taken at least 20 cm below the surface of the water, but be sure the probe is not touching the sediment. When using a handheld probe, ensure that the reading stabilizes before you record the measurement.

Water chemistry - Nitrogen and Chloride concentrations

Follow the sampling protocol required by the laboratory that will analyze your samples. Before going out in the field, wash the sampling bottle in a 10% HCl acid bath, rinse it five times with distilled, de-ionized water (e.g. Milli-Q water purification system, by Millipore Corporation), and dry it in a drying oven or other warm, dust-free environment.

One 0.5 to 1 L water sample needs to be collected at each site for analysis of nitrogen and chloride content. Water samples should be taken at the deepest point in the wetland. Use an integrated water sampler to collect a sample of the water column, but be careful not to disturb the sediment. A water sampler for wetlands can be constructed out of a cylindrical acrylic tube that is open at one end and has a small hole drilled in the centre of the other end (Fig. 2.4). Wear non-powdered latex or vinyl gloves while collecting a water sample to avoid chloride contamination from contact with human skin. Prior to collecting the sample, rinse the sample bottle, bottle cap, and water sampler three times by submerging them into the wetland. Then, lower the water sampler vertically with the open end down, and plug the small hole at the top of the tube with a finger to create suction. Take care to avoid contaminating the water sample by disturbing the sediment bottom with the sampler. If the sediment becomes disturbed, move to a new undisturbed sampling location to take a fresh sample. Once the sampler is submerged, lift it out of the water and immediately invert it while still blocking water from pouring out the small hole with a finger. Let the water stream out of the integrated sampler from the small hole and into a sample bottle. This method is clearly portrayed in the companion video (http://www.youtube.com/watch?v=NXCyCY2mkRI)

In wetlands that have a maximum water depth of less than 50 cm, collect the water sample directly into the acid washed sample bottle by removing the cap and lowering the bottle upside down, into the water. Once entirely submerged, turn the bottle upright and allow it to fill with water from beneath the surface. Put the bottle cap back on beneath the water's surface. You want to ensure surface water isn't used to fill the bottle as the surface tension will concentrate organic materials like pollen or dust, and could misrepresent the average water conditions beneath the surface.

Figure 2.4. Example of an integrated water sampling tube. A sampling tube like the one shown can be constructed out of a clear acrylic tube (left inset) that is open at one end (bottom right inset) and has a small hole drilled into the centre of other end (see top right inset).

Label each sample bottle with the site name, date and sampler's initials. Store the water sample in a cooler on ice or refrigerate at 4 degrees Celsius and submit it to an analytical laboratory within 24 hours. Otherwise, field pre-processing steps will be required to preserve the water sample in the field. Information about sample pre-processing should be obtained from the analytical laboratory.

2.1.4. Sediment chemistry

Sediment cores are collected along three evenly spaced transects around the wetland in the centre of the emergent zone (Figure 4.2). If there is no emergent zone present, extract cores at the edge of the open water. You can construct a sediment corer out of a 5.72 cm diameter acrylic tube and a plunger made from a fitted rubber stopper attached to a threaded metal handle (Fig. 2.5).

Sharpen the edges of the acrylic tube to aid in cutting through fibrous or organic material. First clear away any above ground vegetation or litter. Place the plunger and the tube flush with the sediment surface (Fig. 2.6). Push the tube 15-20 cm into the sediment while keeping the plunger steady on the surface (Fig. 2.6). The plunger seals the tube, creating suction. A knife may be necessary to cut through floating mats or fibrous peat. Once the corer has penetrated 15-20 cm below the surface, pull the tube straight out while holding the plunger at the surface (Fig. 2.6). Place a sample collection jar under the corer as you remove it if the sediment is flocculent. Extrude the excess sediment until only a 10 cm core remains and put the core into a labeled glass jar (Fig. 2.7). Do not store sediment cores in plastic bottles as hydrocarbons in the plastic could contaminate the sample. Combine all three cores from around the wetland into the same glass container to obtain a composite sample and store it in a cooler on ice for transportation and freeze it until pre-processing.

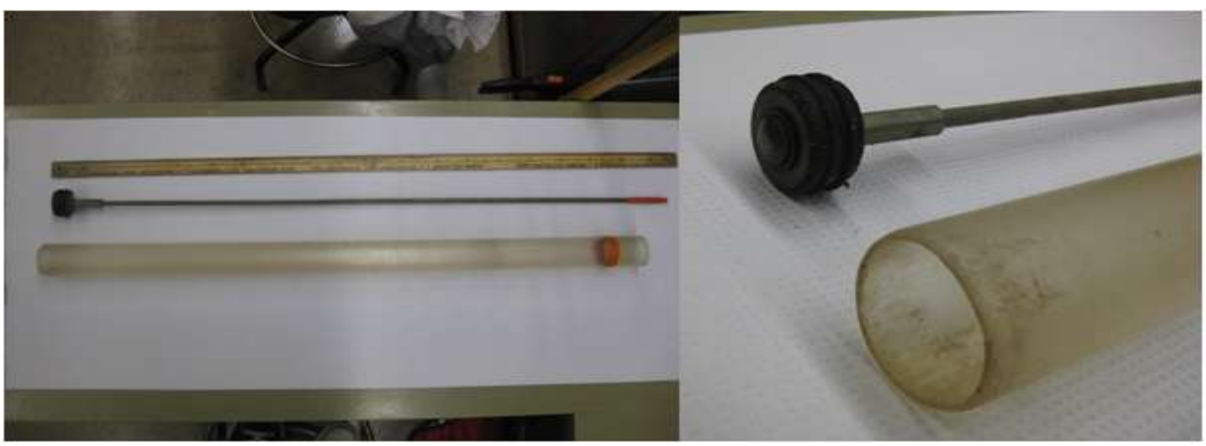

Figure 2.5. Example of a sediment corer. This corer was constructed out of an acrylic tube 5.72 cm in diameter and a plunger made from a fitted rubber stopper attached to a threaded metal handle. The acrylic tube has sharpened edges to aid in cutting through fibrous material.

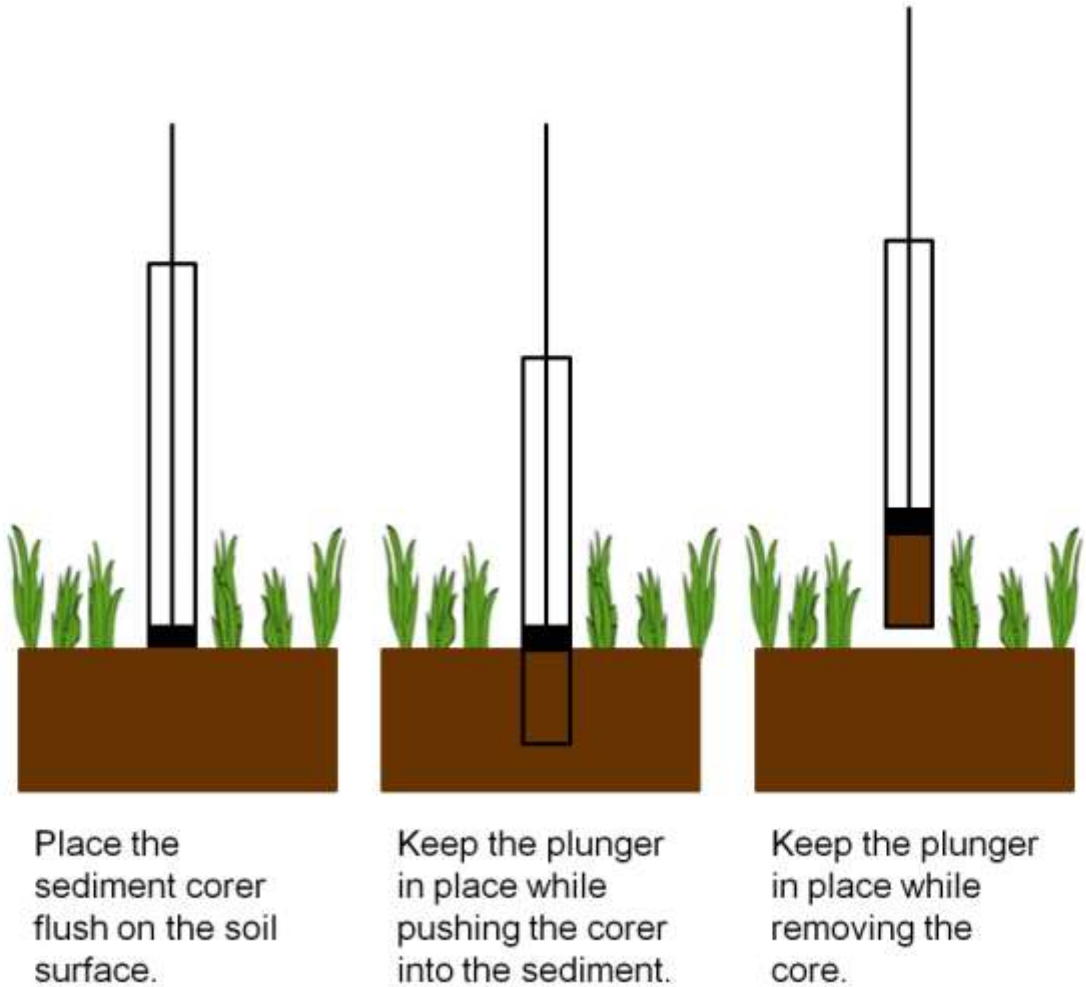

Figure 2.6. Sediment core extraction procedure. Cores are extracted from the middle of the emergent zone at three locations around the wetland and combined into a composite sample. Note that is first cleared away to obtain a clean sediment sample.

Figure 2.7. Example of extruding excess sediment during sediment sampling.

2.1.5. Sediment preparation and analysis in the laboratory

Sediment pre-processing requires homogenization of the composite sediment sample. Place the sample in a bowl and thoroughly mix it with a spatula or pestle (Fig. 2.8). Use clean and dry laboratory equipment to avoid contamination.

Once the sample is homogenized, put a sub-sample in a clean glass container and send it to an analytical laboratory for analysis of percent oil content. The Syncrude Research Laboratory, for example, measures oil content using refluxing toluene in a soxhlet extraction apparatus (Syncrude, 2006). Refer to the specific analytical laboratory to find out the size of the sample required for analysis.

Weigh another sediment sub-sample of approximately 50 g on a labeled weigh-boat for analysis of percent water. Record the exact initial (wet) weight of the sample (see data sheet in Appendix 2). Then put the sub-sample in a drying oven at 60° C and dry it to a constant weight, typically for 48 hours. After the sample has dried, weigh the sample again and record its dry weight. The percent water content in the sediment can be determined using the following equation $\frac{\left(\text{wet weight (g)} - \text{dry weight (g)}\right)}{\text{wet weight (g)}}\ x\ 100$

Figure 2.8. Soil homogenization and weighing procedures carried out during sediment processing.

2.2. Office calculations: calculating the SGI score

Once field data has been collected, laboratory analysis has been completed and water and sediment chemistry results have been received, the compilation of SGI metrics and data entry begins. The staff gauge data sheets, *in situ* water chemistry data sheets, and laboratory results of water and sediment chemistry analyses should contain all the necessary data. The following metrics should be recorded into a spreadsheet for each site: maximum water depth, water amplitude, proportion of Secchi depth, conductivity, total nitrogen (TN) in the water, chloride (Cl) in the water, percentage of oil in the sediment, and percentage of water in the sediment.

2.2.1. Metric standardization and weighting

To integrate the eight metrics into the SGI score, each metric needs to be standardized into a unitless score and weighted as shown in the steps below.

Steps for standardizing and weighting metrics in the SGI

1. Standardize all eight metrics into a unitless score.
    a. Determine the stress score bin that each metric value corresponds to in Table 2.1. Each metric will be converted to a score between 1 and 5.
2. Average the scores within each abiotic category as described below. This step weighs each abiotic category equally.
    a. Water chemistry score = the average score of conductivity and TN in the water.
    b. Sediment chemistry score = the percent water in the sediment score.

c. Physical score = the average score of maximum depth, amplitude, and proportion Secchi depth.

d. Contaminant score = the average score of percent oil in the sediment and Cl^- in the water.

Table 2.1. SGI scoring table.
Use this table to assign the corresponding bin number (1-5; highlighted in gray) to each of the eight metrics. After standardizing the metrics, average the metric scores within each abiotic category, add the four scores together, and convert them to a scale between 0 and 100. Secchi depth only has 3 possible scores, since data distribution was skewed towards sites with a maximum proportion of 1. Lower stress scores indicate healthier conditions.

Abiotic category	Metric stress score bins				
	1	2	3	4	5
Water chemistry					
Conductivity (µs/cm at 25°C)	0 - 544	545 - 868	869 - 1641	1642 - 2458	> 2458
Total nitrogen (µg/L)	> 3754	2523 -3754	1797 -2522	1339 -1796	0 - 1338
Sediment chemistry					
Percent water in sediment	> 86	72 - 85	48 - 71	32 - 47	0 - 31
Physical variables					
Maximum depth (cm)	50 - 68	69 - 89	90 - 131	132 - 175	> 175
Amplitude (cm)	0 - 13	14 - 17	18 - 22	23 - 28	> 28
Proportion of Secchi depth	—	—	0.80 - 1	0.58 – 0.79	0 – 0.57
Contaminants					
Percent oil in the sediment	0 - 0.15	0.16 - 0.27	0.28 - 0.34	0.35 - 0.45	> 0.45
Chloride (mg/L)	0 - 3	4 - 12	13 - 50	51 - 157	> 157

2.2.2. SGI calculation

To calculate the SGI, scores of the four abiotic categories need to be summed and scaled to generate a final SGI score between 0 and 100 (Fig. 1.3).

Steps for calculating SGI scores

1. Sum the four scores together to get the final SGI on a scale between 4 and 20.

2. Use the equation below to convert the SGI scores to a scale between 0 and 100. A score of 0 represents the least amount of stress, whereas a score of 100 represents the highest amount of environmental stress.

$$\frac{(\text{SGI score} - 4) * 100}{20 - 4}$$

The SGI is an indicator of environmental conditions in a marsh: lower scores reflect conditions similar to reference sites and are an indication of better health; in contrast, higher scores reflect a deviation from the reference condition and indicate impaired health. Thresholds were derived for each performance indicator that define criteria required to meet standards of a healthy marsh, which will help measure and communicate the performance of reclaimed marshes and will aid regulators in determining when a marsh should be certified as reclaimed. Three approaches were explored to quantitatively set SGI thresholds. The one selected is the simplest approach: SGI scores that fall below 1 standard deviation (sd) of the mean score for reference marshes (REF mean + 1 sd = 52; Fig. 2.9) are considered to be within the acceptable range of reference conditions. A cutoff of 1 sd was chosen because it reflected natural breaks observed in the data and produced similar thresholds as the other approaches used (see Wilson & Bayley, 2012). Since the SGI encompasses 8 environmental variables, one parameter with high stress can be offset by the other parameters and should not preclude a site from achieving a low SGI score. For instance, although the 39 REF marshes that were sampled ranged in salinity from fresh to saline, only 6 of these sites had stress scores above 1 sd of the reference mean. It is not surprising that current oil sands marshes generally have higher stress scores, as most of them either developed opportunistically on the landscape or were not designed to be healthy functioning marshes. Achieving a stress score below 52 is a realistic short-term goal that will increase the likelihood that reclaimed marshes will support healthy biological communities.

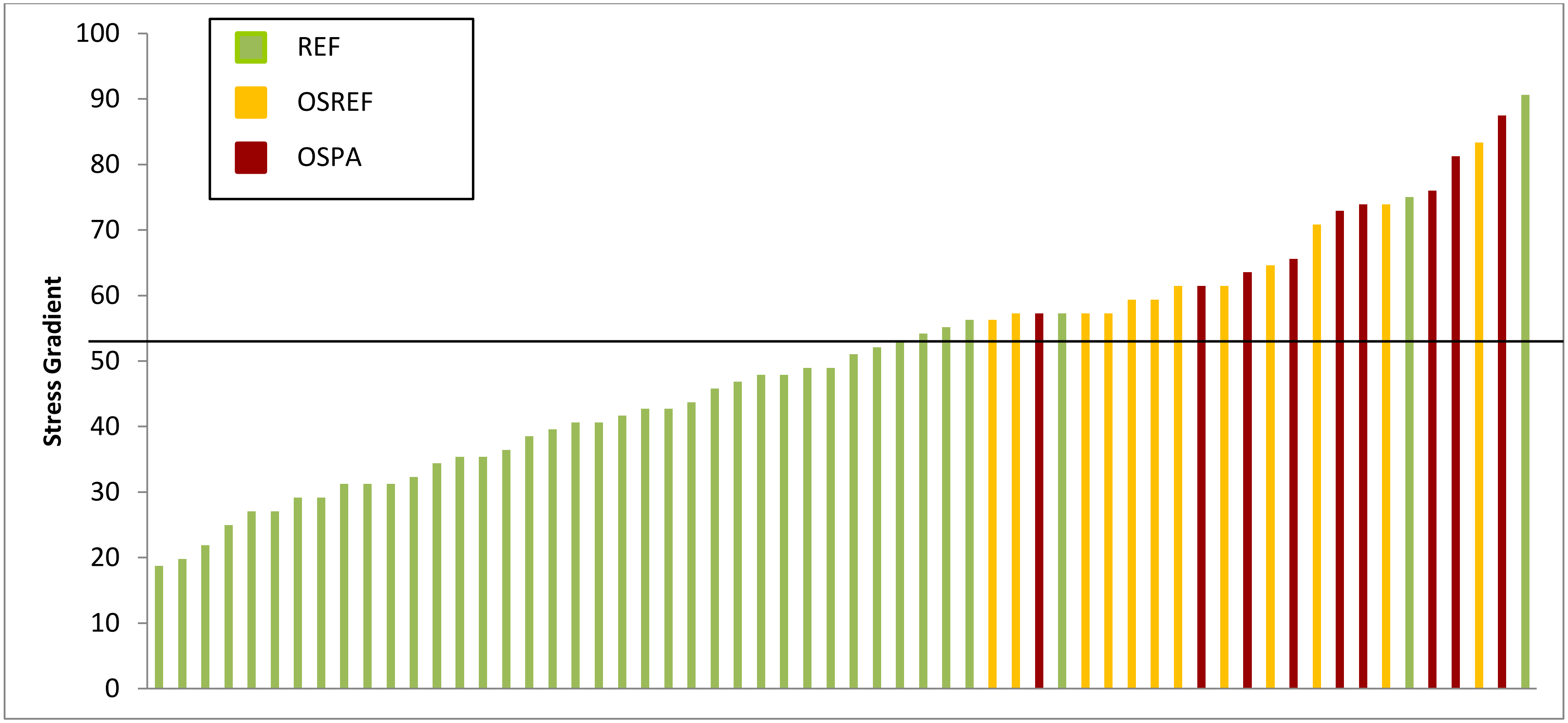

Figure 2.9. Distribution of SGI sites, grouped by reference (REF), oil sands disturbed (OSREF), and oil sands process-affected (OSPA) sites.
The threshold of 52 defines the criteria needed to meet healthy conditions similar to reference wetlands. The threshold was set as 1 sd above the mean of REF sites.

CHAPTER 3. Submersed and floating aquatic vegetation index of biological integrity (SAV-IBI) performance indicator

After testing over 60 SAV metrics against the SGI using linear regression (listed in Appendix 5-1), five metrics were included in the SAV-IBI that measured the sensitivity of open water vegetation community to the underlying gradient of environmental conditions. These five metrics are 1) the proportion of floating-leaved species; 2) the percent cover of floating-leaved species; 3) the proportion of alkali-tolerant species; 4) the relative biovolume of halophytes; and 5) the relative biovolume constituted by *Ceratophyllum demersum*. The five SAV metrics represent community- and species-based measurements of the submersed and floating plant community. Rooney and Bayley (2011a) describe the methodology used to develop and test the SAV-IBI in greater detail. In brief, metrics with significant ($\alpha \leq 0.05$), linear relationships to the SGI were assessed for redundancy. In cases where two significant metrics were strongly correlated (Pearson's $R \geq 0.6$), only the most sensitive metric was retained.

Some metrics are positively correlated with stress (e.g. the presence of halophytes) while other metrics are negatively correlated with stress (e.g., the relative biovolume of *C. demersum*). The scoring of metrics is adjusted appropriately at a later stage in IBI calculation (see Table 3.1). First, each of the five metrics retained in the SAV-IBI is described below along with its expected correlation with stress.

Proportion of floating-leaved species

The proportion of floating species is calculated as the number of floating species divided by the total species richness. Floating-leaved species include both free-floating and rooted plants with leaves that float on the water's surface. A complete list of floating species is provided in Appendix 3-2. Lower proportions of floating species may indicate less established vegetation characterized by a few dominant dispersers (Rooney & Bayley, 2011a). The proportion of richness of floating species is negatively correlated with stress; hence, values of the proportion of total richness contributed by floating-leaved species that are nearer to 1 indicate higher quality wetlands, whereas values nearer to 0 indicate impaired wetlands.

Percent cover of floating-leaved species

Percent cover of floating-leaved species measures the average surface area of a 1 m^2 quadrat that is covered by floating-leaved species. Higher percent cover of floating species reflects increasing productivity (Rooney & Bayley, 2011a). The percent cover of floating species is also negatively correlated with stress, i.e., percentages nearer 100 indicate healthier wetlands.

Proportion of alkali-tolerant species

The proportion of alkali-tolerant species is calculated as the proportion of the total species richness constituted by alkali-tolerant species. A complete list of alkali-tolerant species is presented in Appendix 3-1. Alkali-tolerant species are expected to be more abundant in sites disturbed by alkaline overburden and tailings (Rooney & Bayley, 2011a). The proportion of alkali-tolerant species is positively related to stress; thus, sites with higher proportions of alkali-tolerant species within their communities indicate impairment of wetlands.

Relative biovolume of halophytes

Relative biovolume is defined as the biovolume of a given species or species group relative to the total sample biovolume; the relative biovolume of halophytes thus refers to the percentage of the total samples volume of plant material constituted by salinity-tolerant species. In other words, biovolume is analogous to percent cover in the wet meadow vegetation measurements. Halophytes are plants that survive and maintain productivity in saline water. A list of halophytes is presented in Appendix 3-1. The relative biovolume of halophytes is positively correlated with stress.

Relative biovolume of *Ceratophyllum demersum*

The only species-specific metric used in the SAV-IBI, *C. demersum*, was a dominant species in nearly two thirds of all reference marshes (Rooney & Bayley, 2011a). *C. demersum* produces allelopathic chemicals that inhibit growth of cyanobacteria and blue-green algae outbreaks (Gross *et al.*, 2003). Hence, this metric is negatively correlated with stress.

3.1. Submersed and floating aquatic vegetation sampling methods

Field sampling for the **SAV-IBI** takes place in the open water zone of the wetland from a shallow-bottomed watercraft such as a kayak or small canoe (Fig. 1.4). Since SAV grows optimally in depths from 50 cm to 150 cm (Bayley, unpublished data) sampling should take place within this depth range. Generally SAV does not grow at deeper depths (> 175cm) due to light limitation (Bayley, unpublished data) and aquatic and emergent vegetation overlap where depths are shallower. Aquatic vegetation sampling occurs between late July and mid-August to coincide with the peak biomass and fruit production. Sampling of submersed and floating aquatic vegetation takes 2-3 hours, depending on the size of the wetland. Field data sheets are provided in Appendix 2. If the depth of the wetland is less than 50 cm, or if there is no SAV present in the wetland, open water vegetation should not be sampled. Demonstrations of sampling procedures can also be found in the accompanying video available at the following URL: http://www.youtube.com/watch?v=NXCyCY2mkRI.

Steps for sampling submersed and floating aquatic vegetation in mid-summer

1. Bring necessary equipment, including PPE, field data sheets, a small boat, boat safety gear, anchor, floating quadrat, rake, plant identification guides, plant press, and sorting tray.
2. Paddle across open water zone in a random fashion until reaching a suitable spot to drop the first quadrat (Fig. 3.1).
3. Anchor the boat and drop the floating quadrat on the side opposite the anchor.
4. Identify the species of all floating vegetation in the quadrat and estimate their percent cover.
5. Sweep the rake through the water column inside the quadrat to collect all SAV species.
6. Load the SAV from the rake onto a sorting tray and estimate the relative biovolume (in percent) of each species.
7. Repeat steps 3-6 until 10 quadrats have been sampled.

3.1.1. Arrangement of quadrats

Open water vegetation sampling includes floating and submersed aquatic vegetation (SAV), both of which are sampled from a 1 m^2 floating quadrat deployed from a watercraft such as a kayak. To sample the OW vegetation community, paddle along a series of transects crossing the OW zone (Fig. 3.1). The goal is to distribute the 10 quadrats semi-randomly, such that the entire wetland is covered and the entire range of depths within the 50-150 cm range that is present within the wetland are represented among the 10 quadrats. Check the depths periodically, while paddling across the OW zone. At any point along each transect that lies between 50 and 150 cm of waterdepth, you can lower the anchor to secure the boat and deploy the floating quadrat to take a sample.

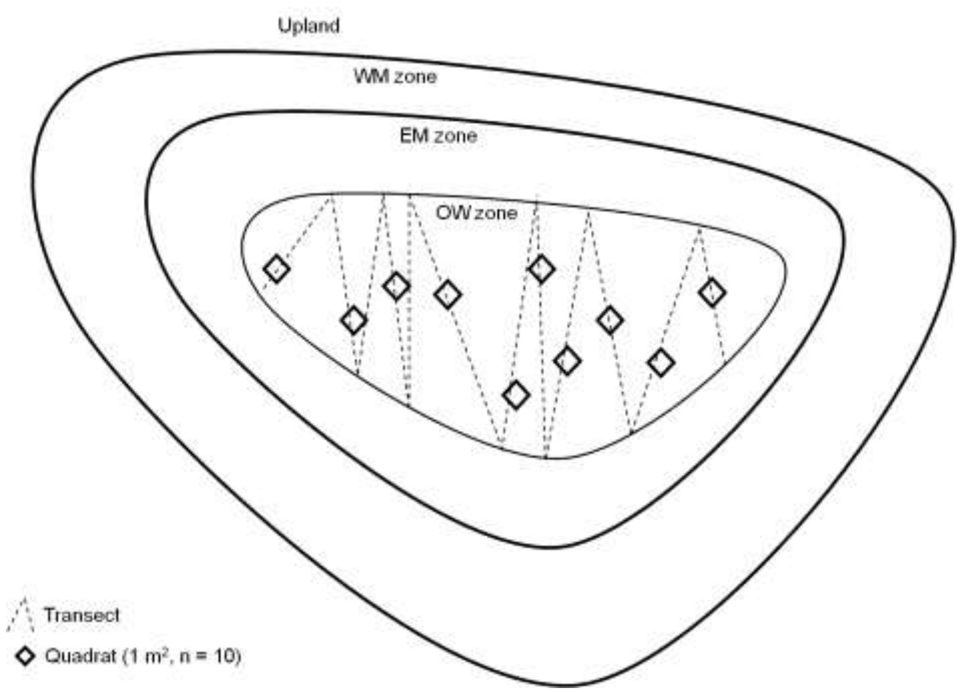

Figure 3.1. Sampling the open water (OW) vegetation communities from a boat, WM is wet meadow zone, EM is emergent zone.

3.1.2. Quadrat-level sampling

It is necessary to estimate the percent cover of floating aquatic species and relative biovolume of SAV species in each quadrat. See Appendix 3 for a species list of floating and submersed aquatic species. Once a quadrat location has been selected, anchor the boat and deploy the quadrat on the opposite side of the anchor so that it is floating on the surface of the water, parallel to the vessel. Identify all floating species within the quadrat and estimate the percent cover of each species relative to the total surface cover within the quadrat. Also estimate the non-vegetated open water cover to ensure that you have accounted for 100% of the quadrat.

Next, sample the SAV community by sweeping a rake systematically through the water column beneath the quadrat. If it is too difficult to sample the entire area defined by the floating quadrat, you can alternatively use a rake that is 50 cm in breadth to take two 1 m long drag-samples across non-overlapping regions of the water column as this will cover the same sample area as sampling within a 1 m^2 quadrat. Pull the rake out of the water and place the collected SAV on a sorting tray; separate the SAV species into piles. Estimate the relative biovolume of each species. The relative biovolume is the percentage of total biovolume constituted by each species. For species that cannot be identified in the field, assign them a collection ID, and collect and press a sample to take back to the laboratory and identify. Field and laboratory procedures for collecting and pressing plants can be found at the University of Alberta Herbarium's website (URL: http://vascularplant.museums.ualberta.ca/documents/Plant_Collection_Handbook.pdf). Follow herbarium field procedures to ensure proper preparation of specimens for identification. Pull up the anchor and paddle to the next transect (Fig. 3.1).

3.2. Office calculations: calculating the SAV-IBI score

Unknown SAV species collected in the field can be identified in a herbarium using identification keys such as the Flora of Alberta (Moss & Packer, 1983). Taxonomic names should be updated according to the International Taxonomic Information System (ITIS, http://www.itis.gov/). If a specimen cannot be identified to the species-level, identify it to the lowest possible taxonomic level. Once these samples are identified, their proper names should be recorded on both hardcopy and digital versions of the dataset. Although the actual identity of an unknown species may not be determined, it will still be included when calculating total species richness for proportional metrics.

3.2.1. Data preparation and management

In contrast to the SGI, the plant-based performance indicators require no waiting for laboratory analysis (Fig. 1.4). However, data preparation and management are necessary to carry out calculations. In this section, users are guided through all the steps for calculating an SAV-IBI score, and provided with example formulas for calculations performed in Microsoft Excel®. As with the SGI, metrics need to be standardized so that they can be integrated into a single IBI score. Each individual metric is thus standardized before being integrated and scaled to yield a plant condition score between 0 and 100, where 0 represents the lowest plant condition and 100 represents the highest condition (Fig. 1.4).

As a pilot project, a database for the SAV-IBI was also built in Microsoft Access®. This database provides an automated process for calculating the SAV-IBI score. An example screenshot of the database form is shown in Appendix 4. Using a database allows users to simply transcribe the field data into a form, after which metric scores and standardizations are automatically calculated using built-in queries. This pilot database was found to significantly reduce the amount of office work, increase efficiency and organization, and reduce the potential for human error. Furthermore, online databases could act as a data repository where monitoring information could be shared among users within one central location. The authors are willing to provide advice to create a web portal database for this purpose.

Preparing the data for metric scoring

1. Check that the field data sheets are filled in completely and correctly. This should be done before leaving the field and again back in the lab once unknown species are identified.
2. Once the data has been quality assured and controlled (QA/QC'd), enter the information electronically into either: a) an electronic spreadsheet[1] as explained in the following steps or b) an online database or web portal if it is available. Appendix 4 presents examples of forms and spreadsheets.
3. Open up a new worksheet, and type in the following headers: site name, sampling date, sampler's initials, coordinates, species code, and headers for each of the 10 quadrats sampled (i.e. Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10).

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[1] Step 3 onward provides specific instructions for data management and calculations performed in Microsoft Excel® spreadsheets, although the formulas can be adapted to other spreadsheets and databases.

4. For each floating-leaved and SAV species found at a site, enter its species code and percent cover or relative biovolume, as shown in Appendix 4. Total percent cover of floating species will range between 0 and 100 for each quadrat, whereas the relative biovolume of SAV species within each quadrat will always sum to 100% because it is a relative measure. Species not found in a quadrat should be marked as having zero percent cover in that quadrat. Species codes for floating and SAV are provided in Appendix 3 (Table A3-1). Ensure that each species name is up to date according to the ITIS website. Enter all species including those that were only identified to the genus level.
5. Copy and save this worksheet as a new file. Modification to the data will be made to the new file so that the raw data is retained.
6. In the new file, label a new column with the header "AVG species cover" to the right of the data. Enter the formula "=Average(X*i*:Y*i*)," where X*i*:Y*i* represents the range in columns X to Y for the species in row *i*. This formula will calculate the average percent cover of each species across each of the ten quadrats.

3.2.2. Metric calculations

The following sub-section explains how metrics can be calculated electronically in Microsoft Excel®. Use Appendix 3 to look up metric attributes including vegetation form and alkali-tolerance for each species that was found during sampling.

Steps for calculating open water vegetation metrics

1. Type in the headers "veg form," "alk tol," and "halophyte" in three blank cells to the right of the data. Use the species groups listed in Appendix 3 (A3-1) to assign vegetation forms (i.e. fl = floating spp. or sub = submersed spp.), alkali-tolerance group (i.e. "yes" for alkali-tolerant spp. and "no" for non-alkali-tolerant spp.), and halophyte group (i.e. "yes" for halophyte spp. and "no" for non-halophyte spp.).
2. Enter the attributes of each species into the empty cells. If a species is not listed in Appendix 3, try to find out its characteristics using resources such as the USDA PLANTS database (http://plants.usda.gov/java/) or the Flora of Alberta (Moss & Packer, 1983). Note that a few species can have both floating and submersed leaves, but its vegetation form is labeled according to where it was found during sampling. This should be clear from field notes if the data forms provided in Appendix 2 are used.
3. In an empty cell, enter the formula "=COUNTIF(X*i*:X*j*,"=fl")," where X*i*:X*j* is the range of values in column X ("veg form") for species in rows *i* to *j*. This formula counts the number of floating species found at a site.
4. Below this, enter the formula "=COUNT(X*i*:X*j*)," where X*i*:X*j* represents the range of values in column X (use any column with numerical values) for species in rows *i* to *j*. This formula calculates the total species richness. As above, a species with both floating and submersed forms are counted only once when tallying total species richness.

5. The following equation calculates the proportion of floating-leaved species:

$$\text{Proportion of floating spp.} = \frac{\text{No.of floating spp.}}{\text{Total species richness}} \text{ x } 100$$

   To complete this calculation in Excel, enter the formula "=X*i*/X*j*", where X*i* is the cell containing the number of floating-leaved species and X*j* is the cell containing the total species richness.

6. In another empty cell, enter the formula "=SUMIF(X*i*:X*j*,"=fl", Y*i*:Y*j*)," where X*i*:X*j* is the range of values in column X (header = "veg form") for species in rows *i* to *j*. Y*i*:Y*j* is the range of values in column Y ("AVG Species Cover") for species in rows *i* to *j*. This query filters by the criteria of floating-leaved species and sums the average percent cover of floating-leaved species.
7. In another empty cell, enter the formula "=SUMIF(X*i*:X*j*,"=yes",Y_i:Y_j)," where X*i*:X*j* is the range of values in column X ("halophyte") for species in rows *i* to *j*. Y_i:Y_j is the range of values in column Y ("AVG Species Cover") for species in rows *i* to *j*. This query sums the average relative biovolume of halophyte species in the column "AVG Species Cover."
8. In another empty cell, enter the formula "=COUNTIF(X*i*:X*j*,"=yes")," where X*i*:X*j* is the range of values in column X ("alk tol") for species in rows *i* to *j*. This formula counts the number of alkali-tolerant species at a site.
9. Calculate the proportion of alkali tolerant species using the following equation:

$$\text{Proportion of alkali-tolerant} = \frac{\text{No.of alkali tolerant spp.}}{\text{Total species richness}} \text{ x } 100$$

To complete this calculation in Excel, enter the formula "=X*i*/X*j*", where X*i* is the cell containing the number of alkali tolerant species and X*j* is the cell containing the total species richness.

10. Determine the relative biovolume of *C. demersum* by finding the cell containing the average species cover (header = "AVG species cover") of "ceradem." No further calculations are needed. (Clarification on calculations can be found in Appendix 4)

3.2.3. Metric standardization

Metrics need to be standardized because they cannot be added together until they are of a common unit or unitless (Fig. 1.4). Metrics in the SAV-IBI were standardized using the continuous reference range approach. Rooney and Bayley (2011a) present the scientific reasons why this method was chosen out of the several approaches that were evaluated. In the continuous reference range approach, metrics are standardized relative to the natural variation found in reference sites, or the reference condition. Reference values for each metric, which are provided in Table 3.1, were obtained during the IBI development phase and represent the natural range of variation found in the Boreal Plains. Use Equation 1 to standardize metrics that are negatively correlated with stress, and use Equation 2 if the metric is positively correlated with stress. Thus, all metric scores will align such that larger scores indicate healthier wetlands.

$$\text{Equation 1:}\quad \frac{(\text{Observed metric value} - \text{mininimum reference value})}{(\text{Maximum reference value} - \text{minimum reference value})} \text{ x } 100$$

Table 3.1. Reference values used to standardize metrics in the SAV-IBI.
Use Equation 1 for metrics negatively correlated with stress and Equation 2 for metrics positively correlated with stress.

Metric	Relationship to stress	Minimum reference value	Maximum reference value	Equation
Proportion of floating species	Negative	0	0.67	Eq. 1
% cover of floating species	Negative	0	93	Eq. 1
Proportion alkali-tolerant spp.	Positive	0	1	Eq. 2
Relative biovolume of halophytes	Positive	0	100	Eq. 2
Relative biovolume of *C. demersum*	Negative	0	100	Eq. 1

Steps for standardizing open water vegetation metrics

Note that zeros are shown in the following calculations for illustrative purposes only. Although a minimum reference value of zero clearly has no influence on calculations in this section, not all performance indicator metrics have the same minimum reference value.

1. Proportion of floating-leaved species (richness metric)

Use the following equation to standardize the proportion of floating-leaved species, where 0 is the minimum and 0.67 is the maximum proportion of floating-leaved species found at reference marshes:

$$= \frac{(\text{proportion of floating spp.} - 0)}{(0.67 - 0)} \text{ x } 100$$

2. Percent cover of floating-leaved species (percent cover metric)

Use the following equation to standardize the percent cover of floating-leaved species, where 0 percent is the minimum and 93 percent is the maximum percent cover of floating-leaved species found in reference marshes:

$$= \frac{(\text{Percent cover of floating spp.} - 0)}{(93 - 0)} \text{ x } 100$$

3. Proportion of alkali-tolerant species

Use the following equation to standardize the proportion of alkali-tolerant species, where 0 is the minimum and 1 is the maximum proportion of alkali-tolerant species found at reference marshes. Since there is a positive correlation between relative biovolume of alkali-tolerant species and stress, this metric is inversely scored.

$$= 100 - [\frac{(\text{Proportion of alkali-tolerant spp.} - 0)}{(1 - 0)} \text{ x } 100]$$

4. Relative biovolume of halophytes

Use the following equation to standardize the relative biovolume of halophytes, where 0 is the minimum and 100 is the maximum biovolume of halophytes found at reference marshes. Since there is a positive correlation between the relative biovolume of halophytes and stress, this metric is inversely scored.

$$= 100 - [\frac{(\text{Relative biovolume of halophytes} - 0)}{(100 - 0)} \text{ x } 100]$$

5. Relative biovolume of *Ceratophyllum demersum*

Use the following equation to standardize the relative biovolume of *C. demersum*, where 0 is the minimum and 100 is the maximum relative biovolume of *C. demersum* found at reference marshes:

$$= \frac{(\text{Relative biovolume } C. demersum - 0)}{(100 - 0)} \text{ x } 100$$

3.2.4. SAV-IBI score calculation

To integrate the metrics into a performance indicator score, add the five standardized metrics together to obtain the SAV-IBI score and scale it between 0 and 100. Higher scores represent better health and lower scores reflect impairment.

Steps for calculating the SAV-IBI

1. Sum the five metric scores together to yield the unadjusted SAV-IBI score for the site.

2. The maximum sum of metric scores we observed in reference sites was 475. Thus, for integration purposes, if a site ever exceeds 475, then give it a SAV-IBI score of 100, as it exceeds the best quality, healthiest wetland we observed during IBI development. Otherwise, use the following equation to convert the SAV-IBI score to a scale between 0 and 100, where 475 is the maximum observed score and 0 is the minimum observed score:

$$\frac{(\text{SAV-IBI score} - 0) * 100}{(475 - 0)}$$

The SAV-IBI can be used to determine the biological condition of a marsh (Fig. 3.2), whereby lower scores represent impaired biological condition and higher scores represent healthy conditions. The threshold for defining a healthy open water community was determined using the same method as the SGI. However, unlike SGI scores, higher SAV-IBI scores represent better health; thus, the threshold was set at 1 sd below the reference mean, which equaled a SAV-IBI of 37 (Fig. 3.2). Reference sites tended to have SAV-IBI scores above 37, whereas oil sands marshes had SAV-IBI scores below 37. Like with the SGI, professional biologists and regulators can use this threshold as the criterion that reclaimed marshes are required to meet before they are deemed ready for reclamation certification. As mentioned earlier for the SGI, the majority of oil sands marshes existing in 2007 and 2008 either developed opportunistically on the landscape or were not designed to develop into healthy, functioning marshes. A SAV-IBI score of 37 out of 100 is a relatively low threshold to strive for and the authors of this handbook believe that it can be realistically achieved.

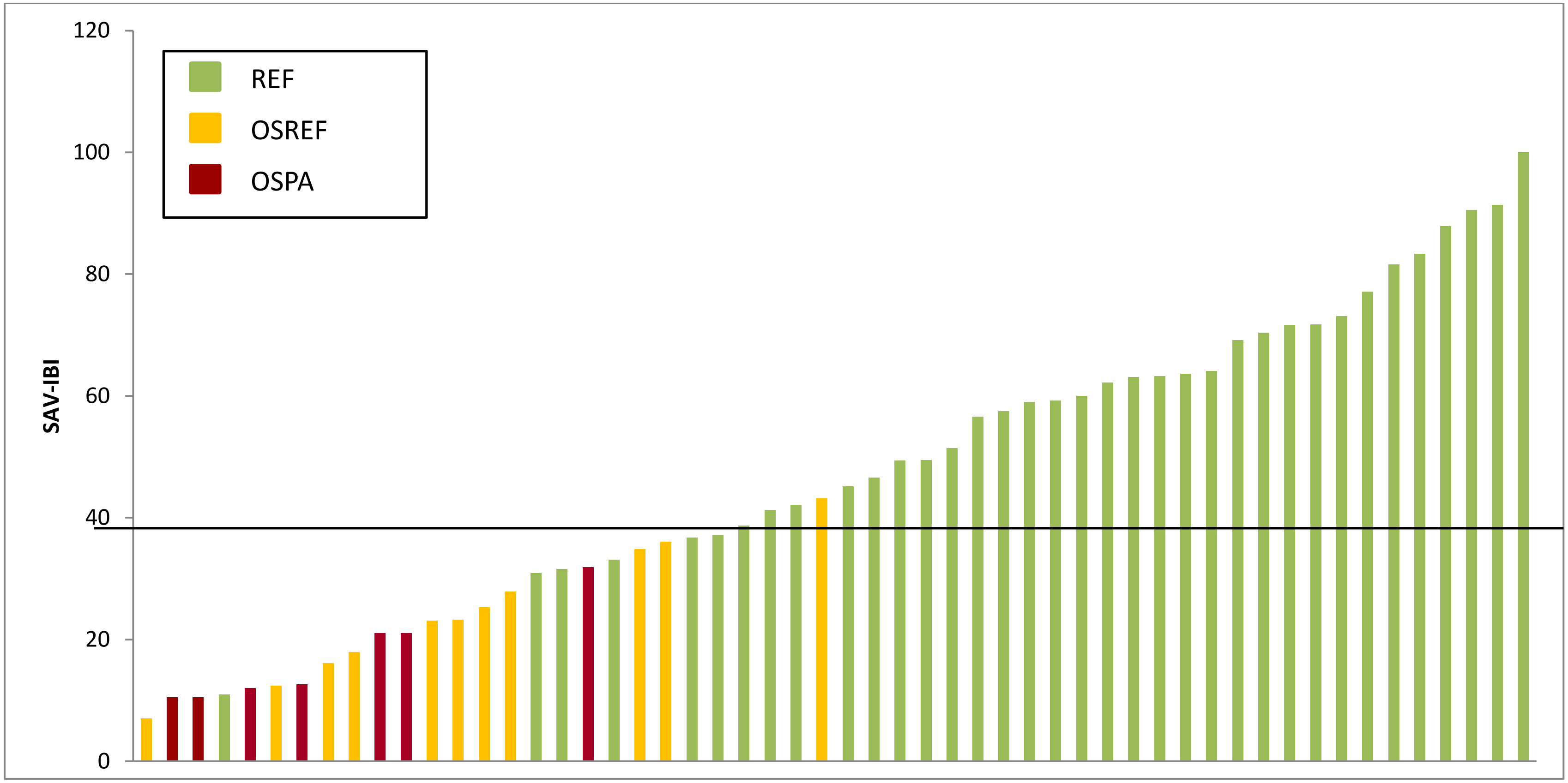

Figure 3.2. Distribution of SAV-IBI scores along reference (REF), oil sands disturbed (OSREF), and process-affected (OSPA) marshes.
The threshold of 37 defines the threshold defining healthy open water vegetation. Any sites that scored a 0 on the SAV-IBI were removed from this figure.

CHAPTER 4. Wet meadow index of biological integrity (WM-IBI) performance indicator

After testing over 40 WM vegetation metrics against the SGI using linear regression (Appendix 5-2), six metrics were included in the WM-IBI that measured the sensitivity of wet meadow vegetation community to the underlying gradient of environmental conditions. These six metrics are the 1) wet meadow zone width; 2) Robel height (as a proxy for above-ground biomass); 3) adjusted floristic quality index (adjusted *FQI*); 4) relative cover of stress-tolerant species; 5) richness of exotic species; and 6) percent cover of facultative wetland (FACW) + obligate (OBL) species. Each of the six metrics measured in the WM-IBI is described below along with its expected direction of correlation with stress. Similar to the SAV-IBI, sites that have a high WM-IBI score have a low stress. Thus metrics with positive correlations to stress are inversely scored, such that with adjusted WM-IBI scores higher values correspond to healthier wetlands (Table 4.1).

Wet meadow zone width

The wet meadow (WM) zone lies between the emergent (EM) zone and the upland boundary and is sedge- and grass-dominated. Oil sands marshes tend to have narrow WM zones due to steep shoreline slopes, whereas reference marshes have gentler slopes and wide wet meadow zones (Raab & Bayley, 2012; Wilson & Bayley, 2012). This metric is negatively correlated with stress; i.e., the stressed marshes with narrower WM zones are less healthy.

Robel pole height

This technique was first published by Robel *et al.* (1970) as a quick and easy way to estimate biomass in grasslands based on a visual obstruction method. Raab *et al.* (2013) adapted the Robel technique to the WM zone of wetlands because it is non-destructive and saves time over traditional methods of measuring biomass. Aboveground biomass and Robel pole height were strongly correlated, suggesting the Robel height is a reasonably good proxy for biomass (Fig. 4.1 R^2 = 0.68). Although Robel height cannot be used in vegetation taller than 1.5 m in height, it is appropriate for almost all vegetation in the WM zone. Robel height is expected to decrease with stress because plant growth is higher/denser in healthy marshes.

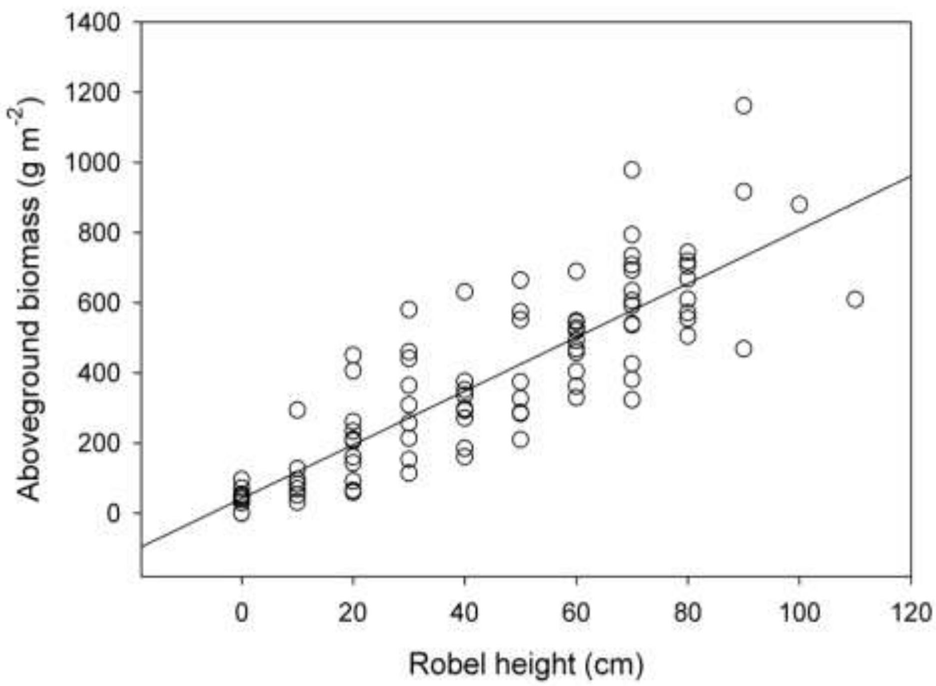

Figure 4.1. Correlation between Robel height and aboveground biomass in the WM zone sampled in 2008 (n = 96, R^2 = 0.68, p <0.00001). Adapted from Raab et al. 2013.

Percent cover of facultative wetland (FACW) + obligate wetland (OBL) species

FACW and OBL species are adapted to semi-aquatic ecosystems and are commonly found in wetlands such as marshes (http://plants.usda.gov/wetinfo.html). This metric sums the percent cover of all species adapted to hydric conditions and is therefore negatively correlated with stress.

Richness of exotic species

This metric measures the number of species found that are exotic or introduced to the region (i.e., non-native, but not necessarily invasive weeds). Exotic species were confirmed using the US Department of Agriculture PLANTS database (http://plants.usda.gov) and the Flora of Alberta (Moss & Packer, 1983). A compiled list of exotic species is provided in Appendix 3. The richness of exotic species is positively correlated with stress and thus inversely scored.

Adjusted floristic quality index (adjusted *FQI*)

The adjusted FQI estimates the ecological conservatism, or habitat sensitivity, of a plant community (Miller & Wardrop, 2006). In the FQI approach, coefficients of conservatism (*CC*) values rank each species based on their sensitivity to disturbance on an ordinal scale from 0 (exotic or disturbance-associated species) to 10 (sensitive species with specific habitat requirements). The *CC* value is the median value assigned to each species by eight expert botanists in Alberta. The adjusted *FQI* is calculated as the relative mean *CC* value of a site weighted by its relative proportion of native species:

$$\text{adjusted FQI}=\frac{\text{mean } CC}{10} \text{ x } \frac{\sqrt{\text{No. native sp.}}}{\sqrt{\text{No. of total sp.}}} \text{ x } 100$$

Appendix 3 provides *CC* values for a comprehensive list of marsh species found in the Boreal Plains Region. For more details on the floristic quality assessment method, see Wilson *et al.* (2013b). The adjusted *FQI* is negatively correlated with stress; thus, higher *FQI* values indicate healthier marshes.

Relative cover of stress-tolerant species

This metric is calculated as the proportion of total percent cover constituted by stress-tolerant species. Stress-tolerant species are defined as species with *CC* values less than or equal to 3. The proportion of stress-tolerant species is positively correlated with environmental stress and higher proportion of stress-tolerant species indicates degraded marshes.

4.1. Wet meadow vegetation field sampling methods

Wet meadow vegetation sampling takes place in the WM zone of the marsh, in the herbaceous layer. Wet meadow vegetation should be sampled between late July and the end of August during peak above-ground biomass. This coincides with flower and seedhead development for most marsh plants. Sample field data sheets can be found in Appendix 2. Although a field biologist with strong plant identification skills is required to sample the WM plant community, field sampling methods cost relatively little and can be performed fairly rapidly (2-3 hours). See Appendix 1 for safety equipment necessary for field sampling in the oil sands. Demonstrations of WM field sampling design and methods can also be viewed at the following URL: http://www.youtube.com/watch?v=NXCyCY2mkRI.

Steps for sampling wet meadow vegetation

1. Conduct wet meadow vegetation sampling during peak summer biomass in late July and the end of August.
2. Determine three equidistant transects around the wetland using imagery or a Geographical Information System (GIS). Print an aerial image of the marsh and upload its location to a Geographical Positioning System (GPS).
3. Pack necessary equipment, including aerial photographs, PPE, field data sheets, measuring tape, quadrat, Robel pole, plant identification guides, and a plant press (See Appendix 1 for equipment list).
4. After arriving at the site, identify the first transect using landmarks on the aerial photograph or by GPS.
5. Identify the upper and lower boundaries of the WM zone. Measure and record the wet meadow width from the outer edge of the EM zone to the upland edge (see Wet meadow zone delineation).
6. Walk to the middle of the WM zone and place a quadrat adjacent and parallel to the transect.
7. Estimate and record the aboveground biomass in the wet meadow by measuring the Robel pole height.

8. Arrange the vegetation around the perimeter of the quadrat (rooted inside quadrat = included; rooted outside = excluded). Identify all species inside the quadrat and estimate their percent cover (including non-vegetative cover).
9. Record all species on data sheets, including unknown species that are given a collection number.
10. Collect any unknown specimens in a plant press and double check their collection numbers are recorded on the data sheet.
11. When finished quadrat sampling at that location, walk five paces away from and perpendicular to the transect and deploy the quadrat again.
12. Repeat steps 7 to 10 for the second quadrat on that transect.

When finished sampling the 1st transect, repeat the process for the remaining two transects. Thus when finished sampling in these small marshes, there are 3 transects per wetland and 6 quadrats per wetland.

4.1.1. Wet meadow zone delineation

Boundaries of marsh zones can be distinguished based on dominant vegetation forms and species (Fig. 1.2). The EM zone, when present, lies between the open water zone and the WM zone and contains dominant species such as *Typha latifolia*, *Scirpus* spp. and *Sparganium* spp. The EM zone is typically flooded throughout the summer with water at or above the sediment surface. The WM zone may have surface water in the spring or after a heavy rainfall, but water levels will commonly drop below the surface by mid-summer. The wet meadow-upland boundary is characterized by a change in relative dominance from hydrophytic to terrestrial vegetation and can be confirmed by digging a soil pit if the boundary is not clear based on vegetation characteristics alone. Wetlands have hydric soils that formed due to saturation, flooding, or ponding long enough to develop anaerobic conditions (Natural Resources Conservation Service, 1998). More information about hydric soils is provided by the United States Department of Agriculture (URL:http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/use/hydric/). Although WM vegetation can move up and down with the moisture gradient, we strictly define the WM zone based on its dominant vegetation forms (i.e. grasses and sedges).

In some cases, one or both of the EM and WM zones may be absent, even in reference sites. If the EM zone is absent, carry out WM sampling as usual. However, if there is no WM zone at the first transect, rotate all three transects until the first transect intersects a WM zone (maintaining the 120° spacing with the other two transects). If the second and/or third transect has no wet meadow zone after performing this rotation, however, then zeros should be assigned to the WM zone width, Robel height, and its quadrat species composition. In other words, the first transect must always pass through some WM habitat but the remaining transects might not in wetlands that are steep sided or highly impaired.

It is important to understand that the size and distribution of the WM zone may also change inter-annually due to varying precipitation, climate, water levels, and other factors such as hydrological connections. In years with extremely high precipitation, the WM zone may become completely flooded out, leading to the death of vegetation and a corresponding, temporary absence of a WM zone. In cases where flooding or dried soils has affected the WM plant community, then the WM zone should not be sampled as it will result in misleading WM-IBI scores. Resume sampling the plant community once it has recovered and water levels are moderate. Moderate fluctuations in water levels are normal for wetland communities and the IBI approach can accommodate these movements in species (Wilson *et al.*, 2013a).

4.1.2. Transect and quadrat arrangement

Marsh vegetation is sampled along three transects situated equidistantly, radiating from the center of the wetland (Fig. 4.2). The location of these transects can be determined using aerial photography or a Geographical Information System (GIS) prior to going out in the field. To randomly identify transects, choose a number between 1 and 360 using a random number generator; this number will represent the degrees from north. Draw the first transect along this angle outward from the centre of the wetland. Draw the subsequent transects 120° apart from each other so that all 3 transects are equidistant. Geographical coordinates can be uploaded directly to a GPS. Otherwise, take note of physical landmarks on an aerial photo so that transect locations can be identified in the field. After arriving at the first transect, measure the WM zone width with a surveying tape measure[2]. Take the GPS coordinates at the boundaries of each transect for future reference. This process is visually depicted in the companion video (http://www.youtube.com/watch?v=NXCyCY2mkRI).

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[2] If you are sampling for both the WM vegetation and Stress Gradient in the same year, then this is a good opportunity to collect the sediment cores along each transect in the middle of the EM zone.

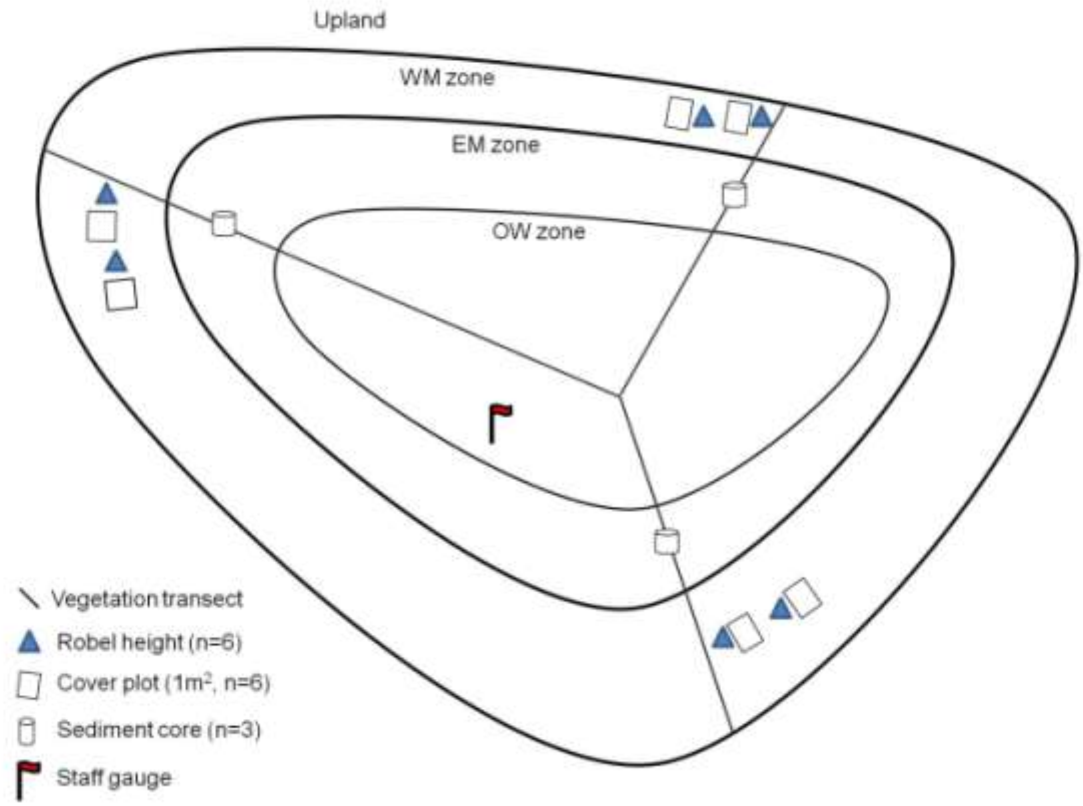

Figure 4.2. Sampling design for wet meadow vegetation. Transects radiate outwards from the center of the wetland. Wet meadow width is measured along each transect. Robel height and quadrats are sampled at two locations adjacent to each transect. Sediment cores for the SGI can be collected at this time if desired.

4.1.3. Quadrat-level sampling

Quadrats are placed in the centre of the WM zone adjacent to the transects (Fig. 4.2). Two quadrats are sampled along each of the three transects, totaling six quadrats per marsh (Fig. 4.2). Sampling in the center of the WM zone reduces the within-plot heterogeneity and prevents accidental sampling of transitional areas between vegetation zones. Power analysis has shown that six quadrats is sufficient to characterize the WM vegetation in the relatively small Boreal Plains marshes used to develop this method (Raab & Bayley, 2012).

To perform quadrat sampling, stand on the right side of the transect in the middle of the zone and parallel to the shoreline; gently throw the quadrat forward so that it lands one and a half arms-lengths away from the transect in a semi-random position. Quadrats should be roughly parallel to the shoreline. Brush out any vegetation that is rooted outside the quadrat and move in any vegetation rooted inside the quadrat as shown in Figure 4.3.

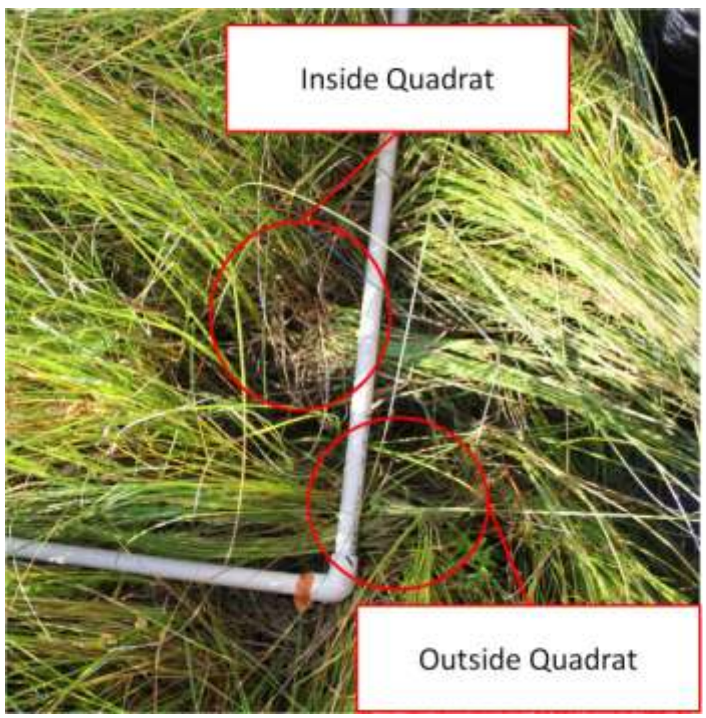

Figure 4.3. Example of rearranging vegetation at the edges of the quadrat boundary. Vegetation rooted inside the quadrat should be brushed inside the perimeter of the quadrat; vegetation rooted outside the quadrat should be brushed out.

Next, total aboveground biomass is estimated using the Robel pole technique. The details on developing and testing this method are published in (Raab *et al.*, 2013). The Robel pole is a 1.5

m pole marked with alternating 10 cm-wide red and white bands (Fig. 4.4). Attached to the Robel pole is a 4 m string with a 1.5 m stick at the other end (Fig. 4.4). Peg the Robel pole into the ground at the edge of the quadrat. Have one person hold the Robel pole vertical while the other person takes the other end and walks away perpendicular to the transect until the connecting string, as it passes directly over the center of the quadrat, is taut (Fig. 4.5). As one person holds the Robel pole vertical, the other person looks over the top edge of the stick and identifies the lowest bar that is visible on the Robel pole (Fig. 4.5). Record the Robel pole measurement as the height of the lowest band that is entirely visible.

Figure 4.4. Example of the Robel pole method, a visual obstruction technique used as a proxy measurement of biomass.

Figure 4.5. Example of reading Robel height.
This field biologist is pointing to the lowest band on the Robel pole that is visible (in this example, the lowest visible white band) to the other biologist (not shown).

Quadrat sampling requires the identification of each species and an estimation of their percent cover. Species cover is defined as the percent area of the quadrat occupied by each species and non-vegetative material (i.e. bareground, organic matter), as shown in Figure 4.6. To estimate the cover of each species, use the following modified Braun-Blanquet abundance-cover scale (Wikum & Shanholtzer, 1978): 0.1%, 0.5%, 1%, 5%, 10%, 15%, 20%, 25%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, or 100%. For example, a species covering 10% of the quadrat has a cover equal to 0.1 m^2. Any plants that are too small or young to identify are lumped together as ‘seedlings/forbs’. Total species cover may be greater than 100% due to overlapping herbaceous layers, although values in excess of 100% should be double checked to ensure they do not reflect data entry errors. The vegetation may be gently pushed aside to find smaller herbs underneath the taller graminoid layer. Appendix 3 provides a list of species found in the Boreal Plains

Region. Use the plant guidebooks listed in Appendix 6 to identify plant species, and update their taxonomic names using the ITIS (URL: http://www.itis.gov/).

Figure 4.6. Overhead view of a wet meadow quadrat used to estimate species richness and composition.

Collect voucher specimens of species that could not be identified in the field in a plant press. Assign each specimen a collection ID (e.g. *Carex* spp. 1, *Carex* spp. 2, unknown mint 1). Collection specimens should possess as many identification features as possible, including roots, stems, leaves, flowers and fruits. Write down descriptive morphological and habitat characteristics such as the number of leaves, flower colour, soil conditions, elevation, slope, aspect, soil texture, and drainage conditions. Field and laboratory procedures for collecting and pressing plants can be found at the University of Alberta Herbarium's website (URL: http://vascularplant.museums.ualberta.ca/documents/Plant_Collection_Handbook.pdf). Follow herbarium procedures to ensure proper preparation of specimens for identification.

After sampling is completed in the first quadrat, walk five paces away from the first quadrat (staying perpendicular to the transect) and place the second quadrat. Repeat quadrat sampling. Then walk to the next two transects to repeat vegetation sampling. Wet meadow vegetation should be sampled from a total of 6 quadrats per wetland (2 quadrats per transect, 3 transects per wetland; Fig. 4.2).

4.2. Office calculations: calculating the WM-IBI score

Once field work is completed, any unknown voucher specimens should be identified and then entered electronically. If a plant cannot be identified to species-level, identify the specimen to its genus level. These unidentified species can be entered with the rest of the raw data. Identification keys are listed in Appendix 6.

4.2.1. Data preparation and management

The remainder of Chapter 4 outlines steps for completing data management, metric calculations, standardizations and WM-IBI calculations (Fig. 1.4). Example formulas for Microsoft Excel® will take users through all necessary data management and calculation steps for calculating a WM-IBI score. As with the SAV-IBI, a database would reduce the amount of time spent in the office and increase the value of a wetland monitoring program by allowing open storage and sharing of information in a single repository.

Steps for preparing data for calculating wet meadow vegetation metrics

1. Check the field sheets to ensure that all necessary information has been filled out, including species names and their percent cover.
2. Once the field data sheets have been quality assured and controlled (QA/QC'd), enter the information electronically in 1) an electronic spreadsheet[3] as explained in the following steps or 2) an online database form.
3. Open a new worksheet. Enter the site-level data, including the site name, sampling date, GPS location, sampler's initials, habitat descriptions, additional comments, and wet meadow widths for the three transects (e.g. headers = "width T1," "width T2," "width T3").
4. Calculate the average WM width of the three transects. Type in the header "AVG width" into a new column and use the equation "=AVERAGE(X*i*:Y*i*)," where X:Y represents the range of values in columns X to Y for the site in row *i*.
5. Log transform the average WM width by entering the formula "=LOG(X*i* +1)",where X*i* is the cell containing the average WM width.
6. Save the file. Open a new worksheet, and type the following column headers in the first row: "site name", "sampling date", "sampler's initials", "Robel Q1," "Robel Q2," "Robel Q3," "Robel Q4," "Robel Q5," and "Robel Q6". Enter the Robel height measured at each quadrat.
7. Calculate the average Robel height by entering the formula "=AVERAGE(X*i*:Y*i*)," where X*i*:Y*i* represents the range of values in columns X to Y for the site in row *i*.

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[3] Like with the SAV-IBI, the following steps for calculating metrics contain example formulas using Microsoft Excel®.

8. Save the file. Open another new worksheet, and type the following headers in the first row: “site name”, “sampling date”, “sampler’s initials”; “species codes”, “Cover Q1,” “Cover Q2,” “Cover Q3,” “Cover Q4,” “Cover Q5,” and “Cover Q6”.
9. Enter the species codes of each new species found at the site and its percent cover in each quadrat. Record species not found in a quadrat as having zero percent cover. Species codes are provided in Appendix 3. Ensure that species names are up to date according to the latest taxonomic name in the ITIS database (URL: http://www.itis.gov/).
10. Copy and save this worksheet as a new file. Modification of the data will only be made to the new file so that the raw data is retained.
11. The data now needs to be normalized so that total species cover of each quadrat sums to 100%. Sum the percent cover in each quadrat by typing the formula “=SUM(X*i*:X*j*),” where X*i*:X*j* represents the percent cover values in column X (Q1, Q2, etc.) for species in rows *i* to *j*.
12. Normalize the percent cover in each quadrat by dividing the percent cover of each species by the total percent cover in the quadrat. Enter the formula “=X*i*/X*j*100*,” where X*i* is the cell value to be normalized and X*j* is the cell with total percent cover calculated in step 11. Click and drag this formula across the range of empty cells until all percent cover data have new normalized values. Use new headers to indicate the normalized quadrat data (e.g. “Norm Cover Q1” etc.).
13. Copy the normalized data into a new worksheet and save the file. Calculate the normalized average cover of each species across all quadrats by entering the formula “=Average(X*i*:Y*i*),” where X*i*:Y*j* represents the range of values in columns X to Y for the species in row *i*.

4.2.2. Metric calculations

The six metrics included in the WM-IBI were chosen from an initial suite of over 40 community- and species-level metrics derived from the plant community in the WM zone. Although EM zone metrics were also tested, they were found to be relatively poor predictors of abiotic stress and were subsequently excluded. As with the SAV-IBI, the final six metrics in the WM-IBI were selected to maximize sensitivity to the SGI and minimize redundancy with other metrics. Raab and Bayley (2012) tested the vegetation metrics individually against the SGI using linear regression, whereby metrics with higher R^2 values signified greater metric sensitivity to oil sands mining. As with the SAV-IBI, when a pair of metrics were strongly correlated (Pearson's $R > 0.6$), the metric with the weaker relationship to the SGI scores was discarded. The final six metrics included one vegetation structure metric: the WM zone width; a productivity metric: the Robel height; and four community-based indicators of habitat quality: the adjusted FQI (*FQI'*), the relative cover of tolerant species, the richness of introduced species, and the percent cover of FACW and OBL species. Use Appendix 3 to look up *CC* values and the native statuses. Note that some metrics have been modified since Raab and Bayley's (2012) publication after new sites were added in 2009. Although metrics should not be modified henceforth, regressions and scatter plots between the SGI and individual plant metrics should be tested periodically to ensure that their sensitivity to disturbance is maintained over time. This will be especially important as reclamation design for marshes improves. A sub-set of the candidate metrics that were sensitive to the SGI is provided in Appendix 5.

Steps for calculating the wet meadow vegetation metrics

1. Type the headers "CC value," "stress-tol status," "nat status," "wetl ind status" into four new columns.
2. Enter the attributes of each species into the empty cells. Use Appendix 3 to look up and enter *CC* values, native statuses, and wetland indicator statuses. Note that if a species is found that does not have a listed *CC* value it needs to be omitted from metric calculations. If the native status or wetland indicator status is not provided in Appendix 3, try to find these attributes out using resources such as the USDA PLANTS database (URL: http://plants.usda.gov/java) or the Flora of Alberta (Moss & Packer, 1983).
3. Sum the percent cover of facultative wetland + obligate species. Enter the formula "=SUMIF(X*i*:X*j*, "=yes", Y*i*:Y*j*) where X*i*:X*j* represents the values in column X(= "wetl ind status") and Y*i*:Y*j* is the average percent covers in column Y (= "AVG species cover").
4. Count the richness of exotic species by entering the formula "=COUNTIF(X*i*:X*j*,"=exotic"), where X*i*:X*j* represents the values in column X (= "native status") for species in rows *i* to *j* meeting the criteria of exotic species.
5. Count the richness of native species by entering the formula "=COUNTIF(X*i*:X*j*,"=native"), where X*i*:X*j* represents the values in column X (= "native status") for species in rows *i* to *j* meeting the criteria of native species.
6. To calculate the mean *CC* value, enter the formula "=AVERAGE(X*i*:X*j*)," where X*i*:X*j* represents the values in column X (= "CC value") for species in rows *i* to *j*.
7. Calculate the adjusted FQI using the following equation:

$$\text{adjusted FQI} = \frac{\text{mean } CC}{10} \text{ x } \frac{\sqrt{\text{No. native sp.}}}{\sqrt{\text{No. of total sp.}}} \text{ x } 100$$

The adjusted *FQI* can be calculated by entering the formula "=X*i*/10*(Y*i*/Z*i*)*100", where X*i* represents the mean *CC* value, Y*i* represents the number of native species richness, and Z*i* represents the number of total species.

8. Calculate the total species cover by adding the header "veg status" and entering coding (i.e. "yes", "no") to use as criteria that will identify vegetative species from non-vegetative material. Enter the formula "=SUMIF(X*i*:X*j*, "yes", Y*i*:Y*j*)", where X*i*:X*j* represents the range of values in column X (= "veg status") for species *i* to *j*. Y*i*:Y*j* represent the range of values in column Y (= "Avg Species Cover") for species *i* to *j*.
9. Sum the percent cover of stress-tolerant species by entering the formula "=SUMIF(X*i*:X*j*,"<=3", Y*i:*Y*j*)," where X*i*:X*j* is the *CC* values less than or equal to 3 in column X (header = "CC value") for species in rows *i* to *j* that meet the criteria of having a *CC* values equal to or less than 3. Y*i:*Y*j* is the average percent cover (= "AVG Species Cover").
10. To calculate the relative percent cover of stress-tolerant species, enter the formula "=X*i*/Y*i*", where X*i* represents the percent cover of stress-tolerant species and Y*i* represents the total species cover.

4.2.3. Metric standardization

As with the SAV-IBI, metrics are standardized using the continuous reference range approach. If the metric's relationship to stress is negative, (see Table 4.1) then use Equation 1 to standardize the metric. If the relationship to stress is positive, (see Table 4.1) then use Equation 2. Table 4.1 provides the maximum and minimum reference values.

$$\text{Equation 1: } \frac{(\text{Observed metric value} - \text{mininimum reference value})}{(\text{Maximum reference value} - \text{minimum reference value})} \text{ x } 100$$

$$\text{Equation 2: } 100 - [\frac{(\text{Observed metric value} - \text{minimum reference value})}{(\text{Maximum reference value} - \text{minimum reference value})} \text{ x } 100]$$

Table 4.1. Reference values used to standardize metrics in the WM-IBI using either Equation 1 for metrics negatively correlated with environmental stress, or Equation 2 for metrics positively correlated with stress.

Metric	Relationship to stress	Minimum ref value	Maximum ref value	Equation
Wet meadow zone width ($\log_{10}$ m)	negative	0.86	1.85	Eq. 1
Robel pole height (cm)	negative	4.5	77	Eq. 1
Percent cover of FACW + OBL species	negative	36	91	Eq. 1
Richness of exotic species	positive	0	2	Eq. 2
Adjusted FQI score	negative	20	53	Eq. 1
Relative cover of tolerant species	positive	0	1	Eq. 2

Steps for standardizing wet meadow vegetation metrics

1. WM zone width

Use the following equation to standardize the $\log_{10}$ transformed average wet meadow zone width, where 0.86 m is the minimum and 1.85 m is the maximum log-transformed WM width found in reference marshes:

$$= \frac{(\log_{10}\ (\text{WM width} + 1) - 0.86)}{(1.85\ -\ 0.86)} \text{ x } 100$$

2. Robel pole height

Use the following equation to standardize Robel height, where 4.5 cm is the minimum and 77 cm is the maximum Robel height found in reference marshes:

$$= \frac{(\text{Robel height} - 4.5)}{(77\ - 4.5)} \text{ x } 100$$

3. Percent cover of facultative wetland and obligate species

Use the following equation to standardize the percent cover of facultative wetland and obligate species, where 0.36 is the minimum and 0.91 is the maximum percent cover of facultative wetland and obligate species found in reference marshes.

$$= \frac{(\text{Percent cover of FACW \& OBL} - 36)}{(91 - 36)} \text{ x } 100$$

4. Richness of exotic species

Use the following equation to standardize the introduced species metric, where 0 is the minimum and 2 is the maximum richness of introduced species found in reference marshes. The richness of introduced species is positively correlated with stress and thus scored inversely:

$$= 100 - [\frac{(\text{Richness of introduced species} - 0)}{(2 - 0)} \text{ x } 100]$$

5. Adjusted FQI

Use the following equation to standardize the adjusted FQI, where 20 is the minimum and 53 is the maximum floristic quality score found in reference marshes:

$$= \frac{(\text{adjusted FQI} - 20)}{(53 - 20)} \text{ x } 100$$

6. Relative cover of stress-tolerant species

Use the following equation to standardize the stress-tolerant species metric, where 0 is the minimum and 1 is the maximum square root of relative cover of stress-tolerant species found in reference marshes. Since there is a positive correlation between the relative cover of stress-tolerant species and the degree of stress, its values are inversely scored.

$$= 100 - [\frac{(\text{Relative cover of tolerant species} - 0)}{(1 - 0)} \text{ x } 100]$$

4.2.4. WM-IBI score calculation

After each metric has been standardized, the metric scores are summed together to obtain an unadjusted IBI score. WM-IBI scores are then converted to a continuous ordinal scale between 0 and 100, where 0 represents the most degraded plant condition and 100 represents the best plant condition.

1. Sum the five metric scores together to yield the unadjusted WM-IBI score for the site.
2. Use the following equation to convert the WM-IBI score to a linear scale between 0 and 100:

$$\frac{(\text{WM-IBI score} - (-139))*100}{495 - (-139)}$$

where -139 represents the minimum observed score during WM-IBI development, and 495 represents the maximum observed score during WM-IBI development. If a site is found that is below the minimum or above the maximum observed score, then that site can be assigned a 0 or 100, respectively. This will constrain the scores for future sites between the bounds of 0 and 100.

The WM-IBI estimates the condition of the wet meadow vegetation community (Fig. 4.7), whereby lower scores represent less healthy wet meadow communities and higher scores represent healthier communities with higher biological integrity. Just as with the SAV-IBI, the threshold defining a healthy wet meadow community was derived as 1 standard deviation below the mean of reference marshes. This threshold occurred at a WM-IBI score of 66 (Fig. 4.7). Reference sites tended to have WM-IBI scores above 66, whereas oil sands marshes tended to have impaired wet meadow communities reflecting WM-IBI scores at or below 66.

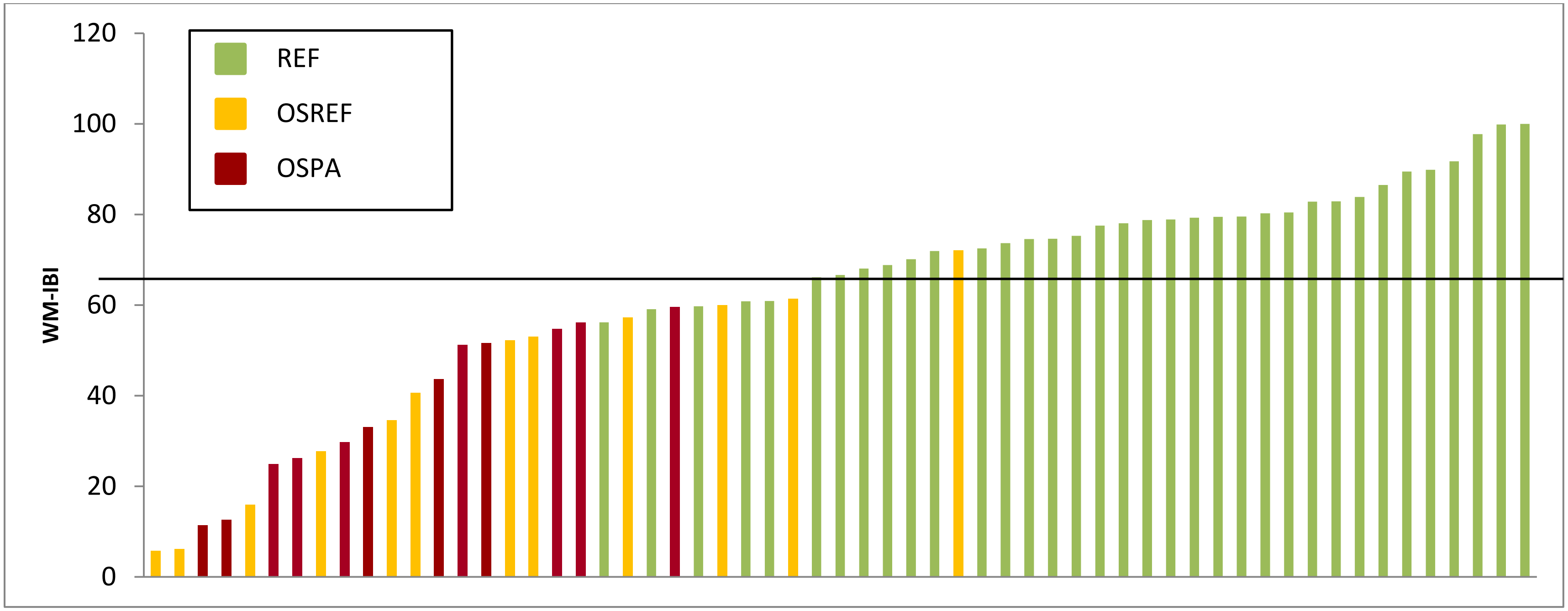

Figure 4.7. Gradient in wet meadow vegetation condition along reference (REF), oil sands disturbed (OSREF), and process-affected oil sands (OSPA) sites.
The threshold of 66 (mean WM-IBI of reference wetlands – 1SD) is the threshold defining healthy conditions as those similar to reference wetlands. Any sites that scored a 0 on the WM-IBI were removed from this figure.

CHAPTER 5. Performance indicator: the marsh condition index (MCI)

If permanent marshes are one of several ecosystems being evaluated on oil sands leaseholds, it would be useful to synthesize all 3 tools (SGI, SAV-IBI, and WM-IBI) into a single score representing overall marsh health. Given the variety of landforms on reclaimed land, a single index score ensures that the monitoring for marshes is simple and straightforward. For the SGI, higher scores represent poorer environmental conditions. Conversely, higher scores in the two IBIs indicate higher biological integrity or healthier conditions. Thus, SGI scores need to be inverted so that high SGI scores and the plant-based IBI scores can be added together into the MCI. Use the following equation to calculate a MCI score:

$$\frac{(100 - \text{SGI score}) + \text{WM-IBI score} + \text{SAV-IBI score}}{3}$$

For example, if a marsh has a SGI score of 60, a WM-IBI score of 45 and a SAV-IBI score of 35, then its MCI score is $[(100 - 60) + 45 + 35]/3 = 40$. Assuming that all three performance indicators are counted equally, the MCI score for this example is 40. As with the other three performance indicators, a threshold defining a healthy marsh was set by 1 sd below the reference mean MCI score (Fig. 5.1). In the above example, the marsh is in poor condition because its score lies below the threshold of 54. We chose to weigh the three performance indicators equally, but arguments could be made to weigh them unequally. Further study would be required to do that.

The marsh condition index is a useful tool for certification but does not provide as much information to improve reclamation success over time as the individual performance indicators. They (the SGI, WM-IBI, SAV-IBI) and the metrics used provide guidance on what can be done to improve reclamation success. If the MCI is used, all the individual tools should be measured in the same year to avoid differences due to climatic variability and responsiveness of individual metrics.

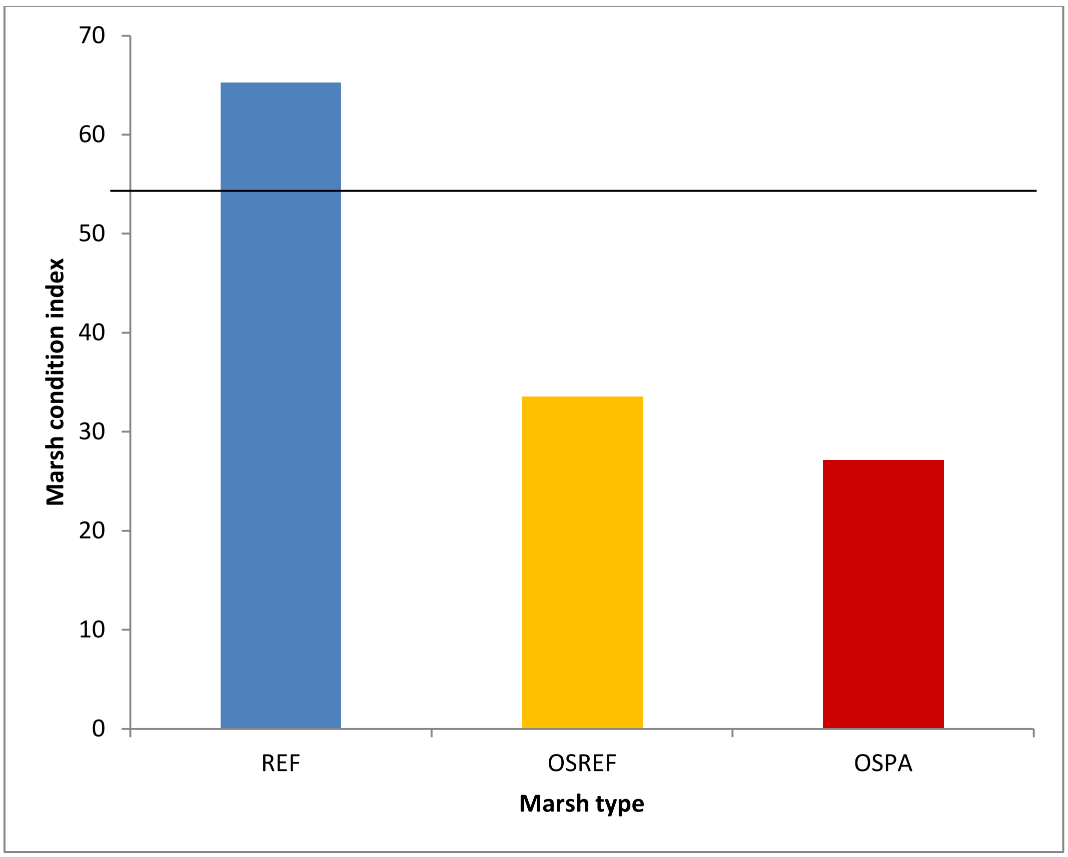

Figure 5.1. Mean marsh condition score plotted by marsh type based on sampling between 2007 and 2009. The threshold criterion for the MCI is 54 out of 100, meaning that marshes with MCI scores higher than 54 are healthy. The threshold is based on the mean MCI of reference sites minus 1 SD.

CHAPTER 6. Implications of establishing criteria to define healthy marshes

To make performance indicators meaningful in the context of reclamation policies and practices, it is necessary to define what a healthy marsh is. Criteria for performance indicators provide realistic benchmarks of health that marsh reclamation can strive to achieve. These criteria also define ecological benchmarks against which marsh reclamation can be evaluated. Criterion for each performance indicator were defined by thresholds set at 1 standard deviation below or above the mean of reference marshes as explained in Chapters 2-4. Threshold scores for each performance indicator are provided in Table 6.1 and are the final values that can be used to determine if a site is similar to reference sites. If a site meets or surpasses the criteria for all three individual performance indicators as captured in the MCI, then the reclaimed marsh has approached reference conditions. A site can meet the MCI (as defined by the reference sites) and still be below the threshold for an individual performance indicator. For example if a site has relatively healthy biotic communities despite a “failing” stress index, it can be considered healthy. Preferably a site will meet the threshold for all three performance indicators and if a site fails to meet the criterion of one or more performance indicators, it either needs more time to improve or requires intervention.

Table 6.1. Thresholds defining a healthy marsh for each performance indicator. These thresholds can be used as criteria to monitor the health of marshes and evaluate reclaimed marshes ready for certification. A marsh should consistently meet the criteria of all three performance indicators over time before being certified. All values are relative to a scale out of 100.

Certification requirements	SGI	SAV-IBI	WM-IBI	MCI
Pass	< 52	> 37	> 66	> 54
Fail	≥ 52	≤ 37	≤ 66	≤ 54

Biological integrity of wetlands typically decreases with increasing abiotic stress which causes failures to meet threshold benchmarks for each individual performance indicator (Fig. 6.1 and 6.2). Marshes in the upper left quadrant of each graph meet the criteria for both the IBI and the SGI. Marshes in the lower right quadrant of each graph miss the criteria for both the IBI and the SGI. Marshes in the upper right quadrant of each graph meet the criterion for the respective plant community IBI but miss the criterion for the SGI. This suggests that plant communities in those sites may be tolerating higher amounts of stress. The lower left quadrant represents marshes that meet the SGI criterion but fail to meet the IBI threshold. This may represent communities which have not had time to respond to improved environmental conditions or have become dominated by invasive plants.

The SAV-IBI threshold was relatively low because there was a high variability in health among reference marshes (Fig. 6.1) however the OW communities at existing oil sands marshes were not compositionally similar to reference marshes. And since dissimilarities in OW community composition coincide with changes in environmental stress, OS marshes were consequently in poorer condition. In contrast to the high variance in the SAV reference community, the plant community in the WM-IBI plot had low variability among reference sites and high variability among reclamation sites (Fig. 6.2). This dichotomy in variability between reference and reclamation sites suggests several things. Wet meadow communities of reference marshes had relatively similar plant community composition and health, and high variability among reclamation sites suggests that stress tolerant invasive species and invading upland species may be a concern. Proper marsh design and construction also play an important role in wet meadow health. Achieving biological integrity similar to reference sites is a realistic target for wet meadow communities as indicated by several oil sands marshes that have achieved healthy biotic conditions.

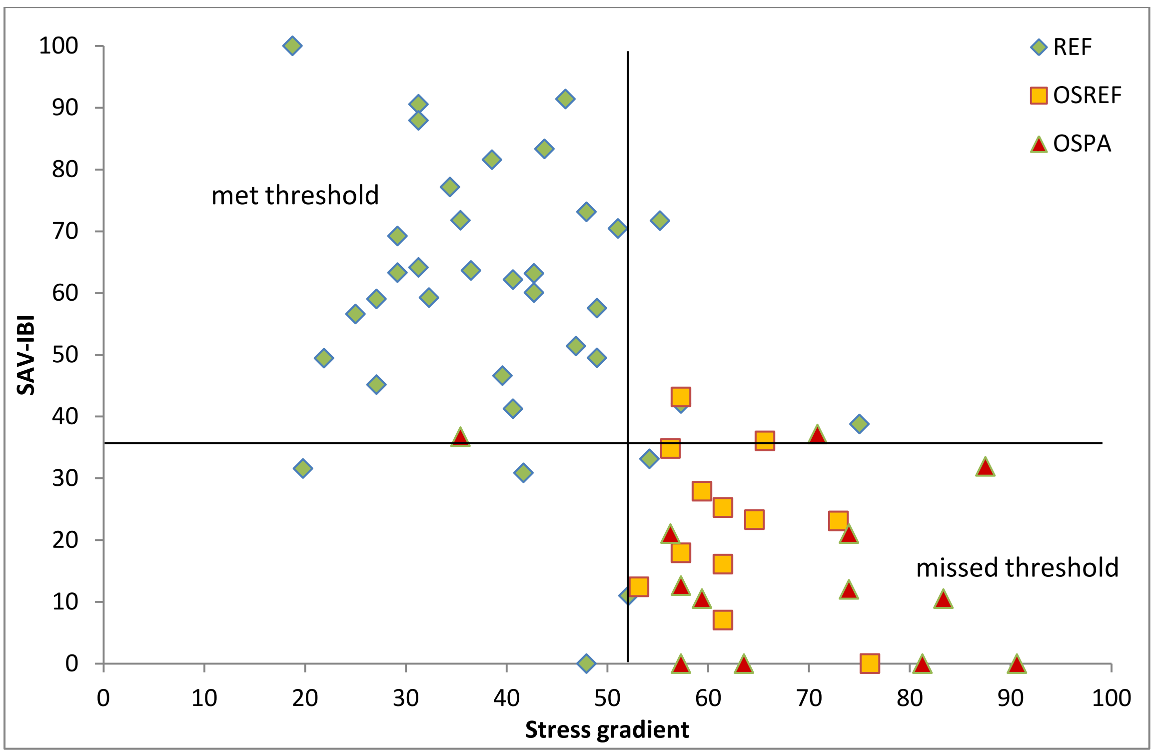

Figure 6.1. Recommended thresholds necessary for meeting SAV-IBI and SGI criteria. Note that although the reclaimed marshes in the upper right quadrant have already met the necessary criterion for the open water plant community, their abiotic conditions still fall below benchmarks.

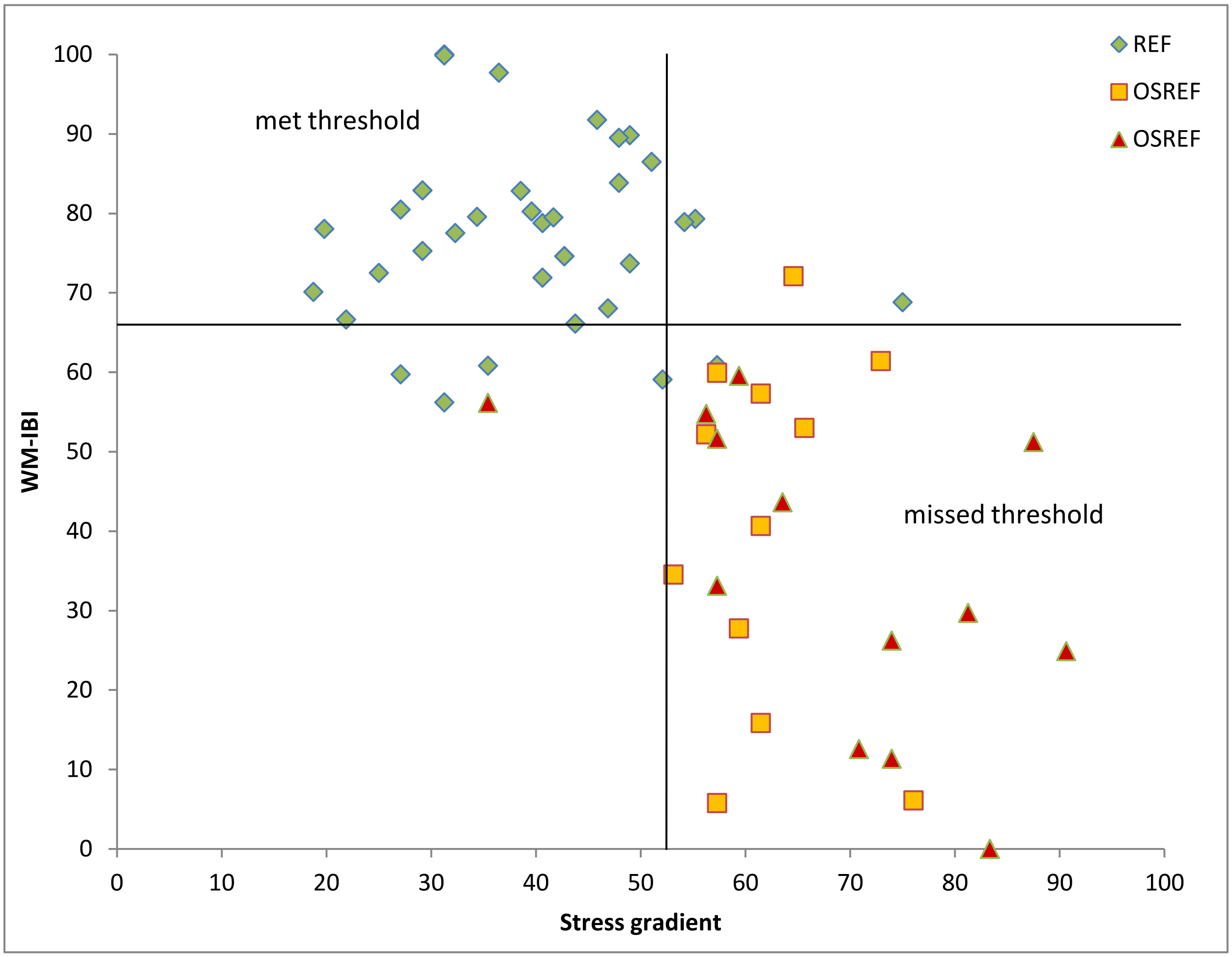

Figure 6.2. Recommended thresholds necessary for meeting WM-IBI and SGI criteria. Note that although the reclaimed marshes in the upper right quadrant have already met the necessary criterion for the wet meadow plant community, their abiotic conditions still fall below SGI benchmarks.

The MCI is convenient because it integrates the three performance indicators into a single, simple marsh score. However, the MCI can reduce and mask information, thereby making it less clear as to why a marsh is either succeeding or failing. For example, assessments based on the MCI makes it easier to obtain a passing score for a “healthy” marsh because a failing score for one performance indicator can be offset by a passing score for another. Using all three indicators individually offers more comprehensive information in that it highlights which elements of the marsh are healthy and which are not. A downside of using the performance indicators separately is that it is more cumbersome and less appealing than a single score from a management perspective, especially considering that marsh reclamation is only one portion of the reclamation landscape. There are advantages and disadvantages to using the performance indicators separately and in combination, and a final decision should be based on management and regulatory objectives.

CHAPTER 7. Monitoring timeline and adaptive management

Reclaimed marshes require several years for abiotic conditions to improve. We recommend calculating SGI scores in the first 3-5 years to establish baseline abiotic conditions against which to compare future evaluations. In the first several years, reclaimed marshes may naturally recruit marsh vegetation from neighbouring habitats, although recolonization depends on dispersal ability and proximity to source marshes (Galatowitsch & Van der Valk, 1996). Planting may be done to facilitate establishment of desirable plant communities (Mitsch *et al.*, 1998). After initial vegetation settlement and maturation, we encourage monitoring abiotic and biological condition every 2-4 years using one or more performance indicator. Using the same performance indicator will ensure that evaluations are consistent over time and will allow comparison among sites. The timeline below outlines a suitable monitoring protocol from initial reclamation to certification.

Timeline for monitoring marsh condition over time

- *Initial abiotic assessment.* Measure the SGI 3-5 years after the reclaimed marsh is constructed. This initial evaluation provides the baseline abiotic conditions against which future conditions are compared to.
- *Initial vegetation assessment.* Plant monitoring and assessment 5-7 years after construction. Vegetation settlement and maturation requires several years. This process can be facilitated by planting or may occur via natural recruitment from nearby wetlands.
- *Consistent monitoring over time*. The SGI should be measured every 2-4 years after the initial SGI assessment and the IBIs should be monitored in the same years as the SGI after vegetation maturation.
- *Adaptive management*. If a site does not show biological improvement over time, it may be impaired by underlying abiotic conditions or by a biotic response to a variety of causes. Examination of individual metrics in the performance indicators will aid in inferring causes of impairment and providing directions for intervention.
- *Final evaluation for reclamation certification.* We recommend that marshes must meet the criteria set for the three performance indicators (i.e. the MCI) before a reclaimed site is approved for certification. Due to the long durations and the massive scale of oil sands projects, as well as the long time frame for plant communities to recover, it may take years before a marsh approaches reference conditions and is ready for reclamation certification.

7.1. Adaptive management approach to marsh reclamation: multiple uses of the performance indicators

Plant communities are known to respond to abiotic conditions. The established relationship between biotic responses of the IBIs and abiotic drivers measured in the SGI can help infer causes of biological impairment. Monitoring both abiotic and biotic conditions every 2-4 years can aid in pinpointing potential drivers of impairment and provide guidance for intervention and adaptive management. For example, Figure 7.1 illustrates a hypothetical site where improving abiotic conditions (lower SGI scores) coincides with improving wet meadow condition (increasing WM-IBI scores). In this hypothetical case, the marsh is on the right trajectory towards healthy and successful marsh reclamation. In the hypothetical case shown in Figure 7.2, both the SAV-IBI and SGI scores in the hypothetical marsh are in poor condition and there is no indication that the marsh is improving. Inspection of the individual IBI and SGI metrics may help elucidate which characteristics may be causing elevated stress and whether planting, weeding or fertilizing might expedite a biological response to abiotic stressors.

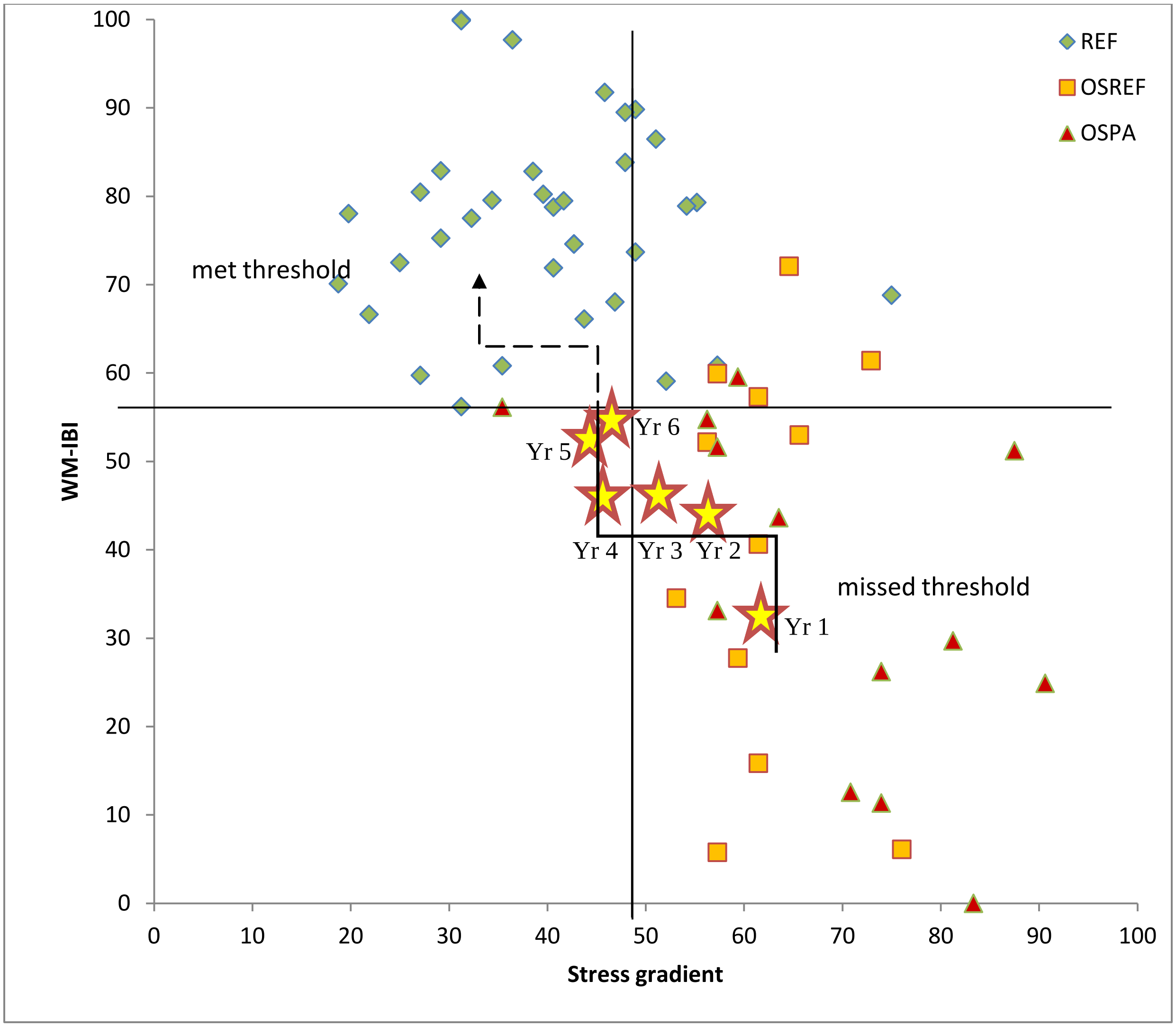

Figure 7.1. Example of monitoring changes in WM vegetation condition over time. The trajectory (shown by the arrow) of the hypothetical marsh (the star) exemplifies a marshes natural improvement over time. Using more than one assessment tool can help improve the resolution of marsh evaluation and aid in adaptive management. In this example, improving abiotic conditions coincides with a healthier wet meadow vegetation community.

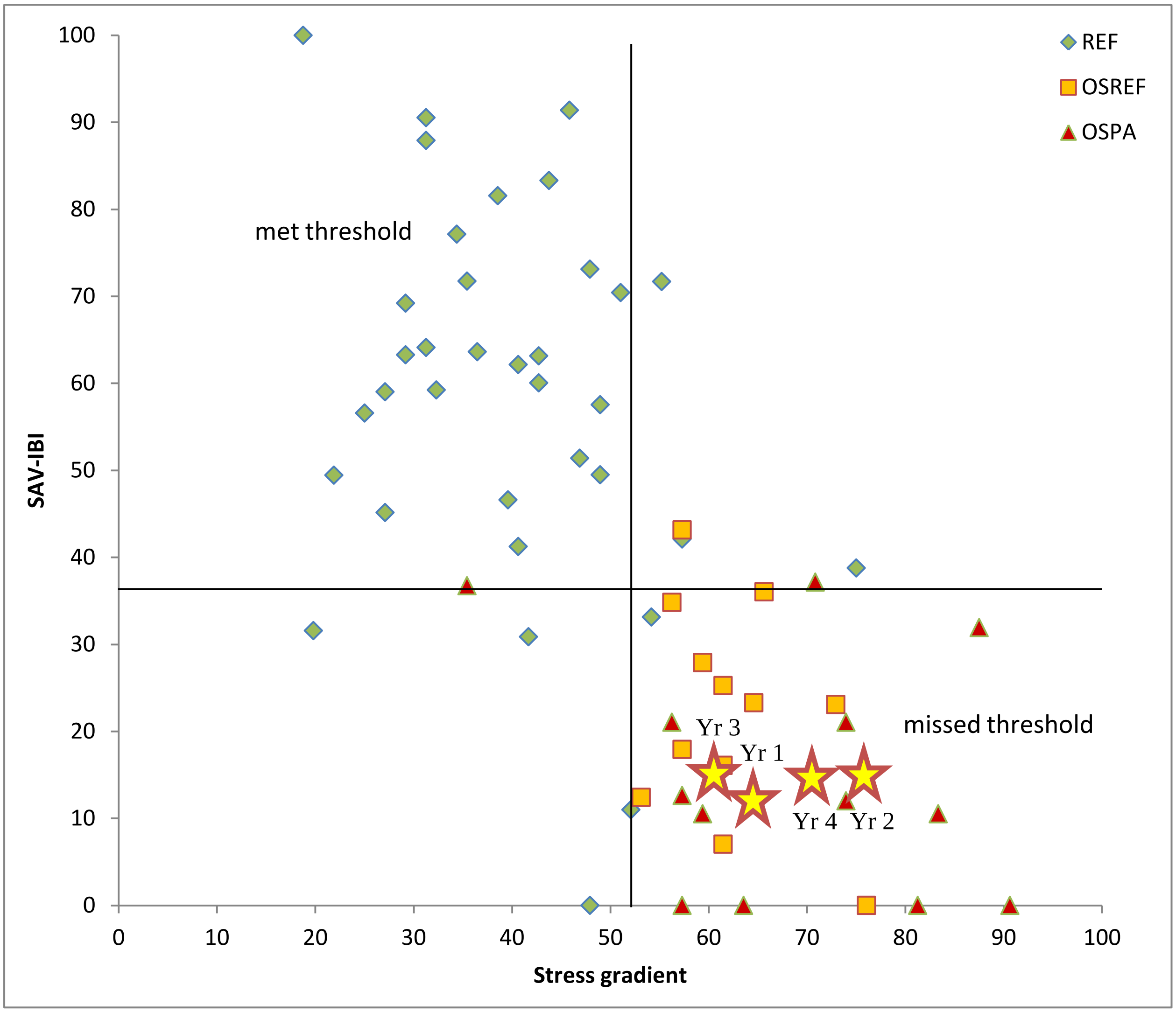

Figure 7.2. Example of monitoring changes in SAV vegetation condition over time.
Figure 7.2. Example of monitoring changes in submersed aquatic vegetation condition over time. Both the SAV-IBI and SGI demonstrate a lack of improvement. Intervention and adaptive management may thus be required to improve the trajectory of this marsh towards successful reclamation. Closer inspection of individual metrics may help elucidate causes of impairment.

Existing reclamation marshes that were used to develop the performance indicators either formed opportunistically on leaseholds or were often constructed without the intention of being healthy, functioning marshes similar to their natural counterparts. If one objective of reclamation in the oil sands is to design healthy marshes, it may be important to consider the whole suite of biological metrics that are sensitive to abiotic stress for marsh construction planning and design. Although each plant-based IBI incorporates several metrics, a larger suite of candidate metrics was also sensitive to the SGI. Many of these metrics were eliminated due to statistical redundancy, although they may be important for marsh design. Appendix 5 contains a list of all the vegetation metrics that had a significant relationship to the SGI. Consideration of a broader suite of metrics may also be important for maintaining a diversity of wetland habitats on the landscape supporting differing species compositions. Likewise, metrics found to have little to no relationship to altered environmental conditions, such as total biodiversity, may not provide adequate information about health as generally assumed.

The range of stresses that oil sands marshes are exposed to may change over time as marsh reclamation improves the physical design characteristics (this topic will be discussed in Chapter 9) and technology develops ways to cope with salinity and contaminants such as naphthenic acids and polycyclic aromatic hydrocarbons. As the physical and chemical stresses change over time, flexibility exists to modify some of the metrics in each IBI. These performance indicators were developed under a short time frame of three years. One important next step will be to implement a testing phase for these performance indicators that will test their functionality and adaptability over larger ranges of climate variability and across newly constructed sites designed to be healthy reclaimed marshes.

CHAPTER 8. Advantages and limitations of the performance indicators

The three performance indicators are useful for: 1) standardizing methods for monitoring and regulating reclamation practices and outcomes; 2) tracking the trajectory of reclaimed marsh health over time; 3) establishing criteria that define what a healthy marsh is and to use as a tool to aid in certifying reclaimed marshes; and 4) identifying potential drivers impairing marsh ecosystem recovery. Despite the numerous advantages and rigorous science involved in developing the performance indicators, there are certain limitations that need to be considered before using these tools in all conditions. First, the performance indicators are calibrated to evaluate oil sands marshes in the Boreal Plains ecozone. They should not be used to assess marshes in other regions, other types of marshes (those without permanent water), or other types of wetlands (e.g. peatlands) exposed to different kinds of disturbances. See Wilson & Bayley (2012) for an example of how similar performance indicators were developed independently for permanent marshes in the Aspen Parkland in Alberta.

The precision of all three performance indicators may be influenced by extreme changes in water levels and hydroperiod. Such variability can alter zone structure and plant communities (Van der Valk & Davis, 1978; van der Valk, 2005). Neither IBI will be useable if their respective vegetation communities have been severely altered by extremely high or low water levels. Furthermore, water chemistry metrics will be influenced by evapoconcentration and dilution resulting from extreme changes in water levels. In circumstances where extreme natural flooding or drought makes it either impossible to perform sampling or will likely compromise the accuracy of the marsh assessment, sampling should be postponed until water levels have returned to moderate levels with the typical vegetation zones. Notwithstanding this precaution, the performance indicators should be fairly robust against a moderate range of natural variation. IBI tools in the Aspen Parkland region yielded consistent scores under relatively variable inter-annual precipitation (Wilson *et al.*, 2013a).

A standardized and comprehensive plan for monitoring and assessment of reclaimed aquatic and terrestrial ecosystems is necessary in the oil sands regions in Alberta. Wetlands provide a critical hydrological and ecological linkage in the Boreal Plains. Plant communities provide structural habitat for fauna and assist in wetland functions such as decomposition and nutrient cycling; they are a fundamental biological component of marshes and an important indicator of ecosystem condition and provide for traditional uses for Aboriginal communities. For example, in the Aspen Parkland of Alberta, Rooney and Bayley (2012) found that wetland birds, invertebrates and marsh plant communities were found to be sensitive to the same environmental stressors. In the Boreal Plains, however, the ability of plant-based indicators to predict the health of higher trophic organisms has not yet been tested. If the health of other organisms of higher trophic levels is a priority, tools may need to be developed using other biological indicators. Samples of macroinvertebrates in all oil sands and reference sites were collected with Dr. Jan Ciborowski but have not analyzed and incorporated into an IBI thus far.

Advantages of performance indicator assessment tools for monitoring reclamation marshes

The three performance indicators offer numerous advantages that encourage their application as standardized tools in the oil sands area of Alberta:

- They provide a rapid assessment tool that has been developed, tested and calibrated to uniquely monitor reclaimed marshes in the oil sands region.
- They provide standardized evaluations and thresholds that can be applied consistently across industry.
- They provide a scientifically validated method for measuring wetland condition.
- They help to assess whether a marsh is ready for reclamation certification.
- They can aid in inferring causal abiotic stressors affecting biological and habitat integrity.
- They can aid in making recommendations for marsh improvements and future reclamation practices and design.
- They can be updated and adapted as new information becomes available.

Limitations of performance indicator assessment tools for monitoring reclamation marshes

- Their use is limited to permanent marshes (Class 5) in the oil sands region.
- They are not appropriate to use during events such as extreme drought or extreme flooding which destroys the vegetation communities.

- Sampling timelines are restricted to the short growing season in the Boreal Plains.
- They are based only on abiotic and plant-based indicators that may not be representative of the health of other trophic levels, such as invertebrates, birds, and mammals.

CHAPTER 9. Attributes of existing reclamation marshes

The marshes on oil sands leases either formed opportunistically or were built as relatively small-scale experiments. Several shallow lakes were also built as part of the reclamation landscape. Although there has been extensive research on the ecology of existing wetlands by various research groups (Bayley, Ciborowski, Foote and others), no systematic large-scale pilot project to optimize permanent marsh wetland design has been undertaken by the oil companies. Thus it is not surprising that most of the existing reclaimed marshes evaluated using these performance indicators are in relatively poor condition. Wetlands that formed opportunistically were no healthier than those that were actively constructed.

Here we will briefly summarize the data on reclaimed marshes on Suncor and Syncrude leaseholds that were used to develop the three performance indicator tools. Performance indicator scores for all oil sands and reference marshes are found in Appendix 7. In general, OSPA marshes that were exposed to process affected water (either a single or continual exposure) were in poorer condition than oil sands wetlands that experienced only physical disturbance. That is, the oil sands “reference” wetlands (OSREF) were on soils that had been physically disturbed or constructed, but were not directly subject to water or soil contamination by hydrocarbons, metals and various other contaminants. However, all oil sands wetlands were subject to varying amounts of elevated salt from the mining of saline soils. All of the oil sands wetlands were older than 7 years of age and the mean age of the reclamation sites was 16 years. Age or time since formation (or construction) did not make a difference to the health of the sites.

The poorest quality marshes, which had MCI scores of less than 54, included all reclaimed marshes we sampled. Of these, sixteen marshes were contaminated by process-affected water (OSPA marshes) and twelve were exposed to physical disturbance and salt contamination (OSREF marshes). Some OSREF sites such as Bills Lake and Crane Lake, which are considered to be relatively healthy by the oil sands industry failed to meet the MCI criterion of 54 out of 100. This is likely because they were constructed for other purposes and few have the shallow slopes required for healthy wetlands.

Most reference marshes met the criterion for good health; those in the best condition (> 54 out of 100) included Miquelon 23, CL 4C, CL South, CLWP 68, Youngs, Birchbay, Lac La Biche REF5, Lac La Biche REF7, CL WEST and OGS 1. These reference marshes were spread across the entire Boreal Plains region, from northwest Alberta to Saskatchewan to discontinuous patches of boreal plains ecoregion just east of Edmonton. The reference marshes with a marsh condition score below the threshold of 54 were Miquelon 3, Lasaline 1, Hay 2, and Julien Lake. These sites failed to pass the threshold due to poor SAV communities or high stress levels. Reference marshes represent the reference condition or the natural range of variation in the abiotic conditions and vegetation communities and were found to be distinctly different from most reclaimed sites.

SGI scores

When using SGI scores as calculated in Chapter 2 where higher scores indicate higher stress, one of the oil sands marshes met the criteria for a healthy marsh, which had to have a stress score of less than 52. Only Cell 44, an OSPA site, had healthy abiotic conditions relative to the SGI threshold. This suggests that the majority of sites were exposed to stressful abiotic conditions. This is particularly true of OSPA marshes (n=16, see Appendix 7). Some reclaimed marshes had intermediate SGI scores near the threshold, including Golden Pond, OSREF 4, Cell 46, Suncor Natural, Bills Pond, Peat Pond, Shallow Pond, 4 MCT and 1 MCT. Golden Pond, OSREF 4 and Shallow Pond had low amounts of oil contamination. Cell 46, Suncor Natural and Bills Lake had high oil contamination despite supposedly being unexposed to process-affected water; nevertheless, all three sites had conductivity and salinity levels similar to reference marshes. 1 MCT and 4 MCT had high exposure to process-affected waters (oil and salts), but had physical characteristics similar to reference marshes, such as maximum depth and amplitude. Marshes with the lowest stress scores were Seepage, Mike's Pond, Jans' Pond, Test Pond 9, Saltmarsh and East Toeberm. Due to the low stress scores (better abiotic conditions), some of the marshes had plant communities that met the thresholds established by the WM-IBI and SAV-IBI thresholds (see below).

SAV-IBI Scores

SAV-IBI scores were above the threshold of 37 in Bill's Lake, suggesting that it supported relatively healthy OW plant communities. The open water vegetation health at Demo and

Cell 44 were both on the threshold, and would need little effort or time to meet the criteria. This suggests that managers can build relatively healthy SAV communities even in marshes that receive process-affected waters. Nevertheless, the remainder of the OSPA and OSREF sites generally had poor OW plant community condition in spite of the relatively low threshold (>37 out of 100) due to high variability among reference marshes. In addition, 5 reference marshes (Miquelon Lake 3, Hay 2, Hay River 3, Hay River 2, and CW Ref 5) had SAV-IBI scores below the threshold for healthy marshes. All five of these reference marshes contained high proportions of alkaline-tolerant species similar to reclaimed marshes. Although alkali-tolerant communities with low IBI scores do occur naturally, we believe it is a realistic objective to create marshes that meet the threshold for the SAV-IBI, considering the wide range of corresponding conditions considered as healthy (i.e. any score from 38 to 100).

WM-IBI Scores

Given that oil sands sites (both OSPA and OSREF) were not necessarily built with the intention of creating healthy wetlands, it is not surprising that most oil sands marshes have poor biological conditions. For the reclaimed marshes to achieve the adequate threshold for the wet meadow marsh community, a wet meadow vegetation community <u>must</u> be present, and that community has to have an IBI score greater than 66. Some sites had extremely poor wet meadow zones mostly consisting of bare ground with little vegetation at all. Test Pond 9, East Toeberm, OSREF 1, Demo Pond, S Pit and Golden Pond all had WM-IBI scores of less than 20 (see Appendix 7). Although Golden Pond had a SGI score that almost met acceptable conditions, it had one of the worst WM-IBI scores. This suggests that reclamation designs for this site did not attempt to incorporate a healthy wet meadow zone, which requires shallow slopes that are intermittently flooded. Planting and/or fertilizing should also be considered when plant communities are not establishing or thriving naturally. Only one marsh site met the adequate threshold for the WM-IBI. SWSS Beav, an OSREF site, had a wet meadow IBI score of 72. SWSS Beav had exceptionally wide wet meadows for a reclaimed marsh, although scores for its other plant metrics and floristic quality were low. Another site, Saltmarsh, had a relatively healthy plant community that almost met the WM-IBI threshold in spite of having high stress (high SGI score) partially due to elevated salinity. This suggests that reclamation marshes have the potential to support healthy wet meadow communities. Many freshwater marsh species are able to tolerate a range of water and substrate salinity, although salt-tolerant species may represent a higher proportion of the species composition in more saline marshes. For example, CELL 44, which had a wet meadow community nearing the threshold for the WM-IBI, had salt- and alkaline-tolerant plants such as *Triglochlin palustris*, *Juncus bufonius*, and *Plantago eriopoda* in addition to freshwater marsh species. Regardless of these positive indications from some constructed wet meadow zones, process-affected water may be a main driver impairing the health of marsh vegetation at OSPA marshes. The effect of process-affected water on marsh plants should be investigated in future experiments.

CHAPTER 10. Implications for reclamation design of permanent marshes on oil sands leases

To improve the design of permanent open water marshes on oil sands mine leases, we recommend modeling the constructed wetlands after natural reference wetlands. This should improve their capability to be self-sustaining, natural in appearance, healthy and resilient to future disturbance. In other words, we can use characteristics of natural wetlands to optimize the design of reclamation wetlands (Erwin, 1991; Hammer, 1997).

The biggest improvement in design would be to imitate the morphological characteristics of natural wetlands, including their size, depth, number and area of vegetation zones, and slope. We are not going to address remediation and construction engineering designs to achieve the proper hydrology and substrate conditions appropriate for marshes since that was beyond the scope of our study. Wetland construction and engineering designs will be addressed in a forthcoming revision of the Guideline for Wetland Establishment on Reclaimed Oil Sands Leases (Alberta Environment, 2008). We note, however, that the appropriate level of hydrologic connectivity at the landscape scale should be evaluated experimentally and follow a reference condition approach. For example, various forms of clay typically make up the impermeable substrate that retains water in most wetlands, but other substances could also be used. A large-scale experimental pilot program should be instituted to investigate substances like mature fine tailings and/or other available impermeable materials.

We will briefly mention those attributes that were part of the studies that formed the basis of this handbook. After insuring the supply of water to the constructed wetland, the physical structure is most important. The reference marshes spanned the same range of salinity as exhibited by oil sands marshes because we intentionally selected reference sites to reflect the salinity gradient found in the oil sands marshes. However, reference sites differed from oil sands sites in most morphological characteristics.

Size

Our reference marshes were located in the Boreal Plains between Northwest Alberta and Saskatchewan as well as a discontinuous portion of boreal near Edmonton, Alberta. Marshes averaged 5.5 ha in size. Although larger marshes do exist, most marshes tend to be small in size and we intentionally selected sites similar in size to marshes that formed opportunistically on oil sands leases. The oil sands reference sites averaged 4.07 ha and the oil sands process affected marshes averaged 1.34 ha in size with an average size of all oil sands sites of 2.5 ha (Table 10.1).

Table 10.1. Physical characteristics of reclamation marshes in the oil sands region.
EM = emergent zone; WM = wet meadow zone. Freshwater sites are defined as <500 µS/cm conductivity; sub-saline sites are defined as 500-2000 µS/cm; saline sites are defined as >2000 µS/cm

Site type	Total Area (ha)			Open water area (ha)			Area EM + WM (ha)			Vegetated Marsh Area % of Total		
	Median	Mean	90% CI	Median	Mean	90% CI	Median	Mean	90% CI	Median	Mean	90% CI
All REF marshes (n = 39)	3.3	5.5	1.3	0.7	2.4	1.0	2.3	3.5	0.9	80.7	76.1	5.0
Freshwater (n = 10)	6.0	6.7	6.6	1.3	3.4	1.1	4.6	4.4	0.4	83.8	79.9	3.8
Sub-saline (n = 22)	2.4	5.0	1.3	0.6	2.1	1.0	2.1	2.9	0.6	78.3	74.4	5.1
Saline (n = 7)	3.8	6.6	1.7	1.2	2.7	0.9	2.3	5.9	1.9	93.6	82.2	5.9
All OS marshes (n = 29)	1.5	2.8	1.2	0.6	1.7	1.0	0.7	1.1	0.3	58.1	53.5	5.5
OSREF (n = 13)	1.9	4.4	1.8	0.6	2.8	1.4	1.2	1.7	0.4	66.0	60.6	4.8
OSPA (n = 16)	0.9	1.4	0.2	0.6	0.8	0.2	0.5	0.6	0.1	48.5	47.6	5.8

Site type	WM zone width (m)			EM zone width (m)			EM + WM width (m)		
	Median	Mean	90% CI	Median	Mean	90% CI	Median	Mean	90% CI
All REF marshes (n = 39)	12.53	18.73	5.86	19.57	29.14	5.19	34.40	45.42	9.61
Freshwater (n = 10)	11.26	14.66	2.61	17.45	21.07	3.00	31.82	35.73	4.61
Sub-saline (n = 22)	11.48	12.16	1.48	21.09	30.52	4.32	38.38	42.68	4.58
Saline (n = 7)	27.25	55.78	13.96	13.67	39.23	10.54	33.17	67.87	21.20
All OS marshes (n = 29)	5.97	7.69	1.19	9.77	10.06	1.73	12.92	15.85	2.38
OSREF (n = 13)	7.42	9.41	1.45	9.81	11.65	2.28	18.86	19.43	2.80
OSPA (n =16)	5.19	6.10	0.82	9.77	8.60	1.02	12.55	13.65	1.79

Vegetated marsh to open water ratio

For reclaimed marshes to reflect the physical structure of reference wetlands, the area of vegetated marsh as a percent of the total wetland area should be increased. On average, reference marshes comprised 63% vegetated marsh in area and only 37% open water. In contrast, the oil sands wetlands averaged 40% marsh area and 60% open water. This difference is due to narrower bands of vegetation surrounding the open water zones in reclaimed marshes: in the reference wetlands, the wet meadow marsh width averaged 18 m, while in the oil sands marshes it averaged 8.2 m. The width of the emergent zone was also narrow in reclaimed marshes in comparison to reference marshes (Table 10.1). Note that the marsh zone is comprised of two vegetation zones: the emergent zone marsh (characterized by bulrush and cattails) and wet meadow marsh (characterized by sedges and grasses).

Slope

Part of the reason for this difference in marsh zone width is due to differences in shoreline slope. The slope of the reference wetlands was much shallower, which allowed the marsh zones to be wider. While we did not measure the slope in the oil sands region, we did measure the slope in similar reference marshes in the boreal transition zone. The boreal transition zone marshes had an average slope of 2.3 %. This is equivalent to a 43:1 slope ratio (that is for every 1 meter vertical drop in elevation there is a 43 meter horizontal run in distance) (Table 10.2). When the slope is less than 20:1, there is a significant loss of vegetated marsh area in wetlands. Although constructed marshes elsewhere in Alberta are sometimes constrained by limited available area, it is still possible to obtain a 20:1 slope by designing some of the wetland sides with very flat slopes. Slope data are based on an average taken at three transects, meaning that it is possible for there to be steeper slopes on one or two sides of the wetland providing the other sides have shallower grades. Shallow slopes are characteristics of reference wetlands and are desirable because they buffer vegetation against rapid changes in water depth, thereby increasing resilience against a wide range of precipitation and water inputs and consequently support a larger area of hydrophytic vegetation (Fig. 10.1).

Table 10.2. Example of slope (%grade) measured in reference marshes in the boreal transition zone and in constructed marshes in the Cities of Edmonton and Sherwood Park. Slope was measured 10 m from the edge of the open water to the upland. Means, medians, and 90% confidence intervals are provided.

Site type	Slope	Median %	Mean %	CI %
All Reference marshes (n = 28)	42:1	2.1	2.4	0.419
All constructed (n = 27)	8:1	12.5	11.4	1.939
Naturalized constructed ponds (n = 16)	9:1	11.8	10.4	1.569
Standard stormwater ponds (n = 11)	8:1	13.9	12.3	1.152

Depth

Generally, the maximum depth of the reference wetlands was much shallower (average = 1.09m) than reclaimed marshes (average = 1.46 m) (Table 10.3). Reference wetlands tended to be more of a flat shallow pan (possibly with a few deeper holes) rather than the bowl shape of many constructed marshes (Fig. 10.1). Reference marshes have depths that permit the growth of SAV (preferably between 50 cm and 1.5 m); thus, if a rich community of SAV is desirable, then a significant portion of the open water zone should be constructed to those depths. As a result of light limitation, the maximum depth for growth of SAV in Alberta lakes and wetlands is approximately 1.75 m, but this threshold may be shallower in turbid waters such as those more common in oil sands reclaimed marshes. Since the average deepest point in reclaimed marshes was 1.46 m, they are right at the edge of maximum tolerable depth for SAV. Given the elevated turbidity of the water in the OSPA marshes (99 mg/L), light limitation is likely a factor limiting SAV abundance and diversity in reclaimed marshes.

Table 10.3. Hydrological characteristics of reclamation marshes in the oil sands region
EM = emergent zone; WM = wet meadow zone. Freshwater sites are defined as <500 µS/cm conductivity; sub-saline sites are defined as 500-2000 µS/cm; saline sites are defined as >2000 µS/cm. Means, medians, and 90% confidence intervals are provided.

Site type	Amplitude (m)			Proportion Secchi depth			Maximum depth (m)		
	Median	Mean	90% CI	Median	Mean	90% CI	Median	Mean	90% CI
All REF marshes (n = 39)	0.17	0.19	0.01	89.00	77.74	5.27	1.12	1.09	0.11
Freshwater (n = 10)	0.16	0.17	0.01	90.00	78.10	5.09	1.22	1.20	0.10
Sub-saline (n = 22)	0.21	0.19	0.02	82.50	74.23	5.68	1.08	1.15	0.10
Saline (n = 7)	0.16	0.18	0.01	100.00	88.29	4.12	0.57	0.78	0.12
All OS marshes (n = 29)	0.25	0.23	0.02	99.00	78.68	6.56	1.36	1.46	0.18
OSREF (n = 13)	0.25	0.23	0.03	99.50	92.08	2.45	1.77	1.79	0.15
OSPA (n =16)	0.23	0.22	0.02	78.00	66.31	8.13	0.78	1.15	0.18

Soil

The substrate of most reference marshes was higher in organic matter and water content than the oil sands marshes. We found that the % C of the reference marshes was 25% in contrast to the 4.7% organic matter in the reclaimed marshes (Table 10.4). However, Trites and Bayley (2009a) have shown that marsh vegetation in oil sands marshes can accumulate organic matter at annual rates similar to those found in reference sites. An experiment is required to determine how much organic matter should be applied when constructing reclaimed marshes. Research to date has indicated that applying large quantities of peat merely leads to its decomposition, but some minimum threshold of organic matter will be required to provide suitable substrate for marsh vegetation. The nutrient content of the substrate on reference marshes is also higher than in oil sands marshes (11 times higher in TN and 2.8 times higher in TP). This suggests that N is more limiting than P in the substrate and that fertilization of the marsh soils should be considered when reclaiming and planting vegetation in constructed marshes. This should be explored with a soil fertilization study.

Table 10.4. Chemical characteristics of sediment from marshes in the oil sands region. Freshwater sites are defined as <500 µS/cm conductivity; sub-saline sites are defined as 500-2000 µS/cm; saline sites are defined as >2000 µS/cm. Means, medians, and 90% confidence intervals are provided.

Site type	**Water (%)**			**Total Phosphorus (mg/g)**			**Total Nitrogen (%)**			**Total Carbon (%)**			**Loss on Ignition (%)**		
	Median	**Mean**	**CI**	**Median**	**Mean**	**CI**	**Median**	**Mean**	**CI**	**Median**	**Mean**	**CI**	**Median**	**Mean**	**CI**
All REF marshes (n = 39)	72.50	65.21	5.04	0.876	0.950	0.073	2.39	2.02	0.21	27.16	25.56	2.74	34.91	35.76	4.79
Freshwater (n = 10)	80.80	67.67	6.21	0.812	0.813	0.055	2.67	2.18	0.21	31.00	30.03	3.00	43.97	37.52	4.12
Sub-saline (n = 22)	67.20	60.96	4.96	0.876	0.902	0.055	2.00	1.89	0.23	23.90	23.27	2.83	33.15	32.56	5.38
Saline (n = 7)	81.65	75.95	2.26	1.456	1.347	0.100	2.27	2.20	0.18	25.91	30.85	1.75	43.95	38.13	3.63
All OS marshes (n = 29)	60.00	55.00	4.13	0.297	0.329	0.031	0.11	0.19	0.05	3.14	4.81	0.90	3.41	4.81	1.12
OSPA (n = 16)	68.60	56.39	4.15	0.260	0.287	0.024	0.11	0.18	0.04	3.86	5.05	0.80	3.94	5.56	1.38
OSREF (n = 13)	59.80	53.50	4.27	0.322	0.374	0.036	0.13	0.21	0.06	2.84	4.55	1.04	3.40	4.01	0.77

Water quality

While there are large differences in nutrient concentrations in water between reference and reclaimed marshes, we do not think that water should be enriched to enhance the growth of marsh plants. Most marsh species (except for SAV) can tolerate more mesotrophic and oligotrophic conditions than what currently exists in the Boreal Plains. While we have no evidence of this, we believe that fertilization of the water may result in the increased growth of suspended and attached algae and decrease growth of marsh vegetation. A summary of the differences in water quality parameters between reference wetlands and reclaimed marshes is provided in Table 10.5.

Table 10.5. Chemical characteristics of water samples from marshes in the oil sands region. Freshwater sites are defined as <500 µS/cm conductivity; sub-saline sites are defined as 500-2000 µS/cm; saline sites are defined as >2000 µS/cm Means, medians, and 90% confidence intervals are provided. (Med. = Median)

Site type	Conductivity (µs/cm)			Chloride (mg/L)			Sulfate (mg/L)			Sodium (mg/L)			Potassium (mg/L)		
	Med.	Mean	CI	Med.	Mean	CI	Med.	Mean	CI	Med.	Mean	CI	Med.	Mean	CI
All REF marshes (n = 39)	862	1341	288	12.10	114.32	56.61	100.61	443.67	257.39	54.20	158.64	58.88	17.40	21.95	7.15
Freshwater (n = 10)	210	228	20	0.36	1.29	0.40	3.73	11.87	4.71	3.95	7.39	1.50	2.96	5.61	1.14
Sub-saline (n = 22)	890	1107	108	23.09	51.16	14.95	170.46	230.44	44.72	56.70	88.31	16.04	22.70	22.53	1.88
Saline (n = 7)	3350	3666	347	74.40	474.29	107.72	870.18	1730	557.37	490.00	595.71	96.18	4.67	43.49	16.37
All OS marshes (n = 29)	1619	2032	318	50.26	131.99	43.72	268.53	392.39	101.69	263.00	350.48	60.99	8.81	11.24	1.70
OSPA (n = 16)	2641	2938	338	99.65	224.99	54.01	187.26	505.52	131.99	603.00	546.69	58.93	14.00	12.98	1.57
OSREF (n = 13)	926	1050	99	12.16	31.25	9.42	280.90	269.82	47.17	88.40	137.91	17.87	7.02	9.35	1.82

Site type	Magnesium (mg/L)			Calcium (mg/L)			Ammonia (µg/L)			Nitrates + Nitrites (µg/L)			Total Nitrogen (µg/L)		
	Med.	Mean	CI	Med.	Mean	CI	Med.	Mean	CI	Med.	Mean	CI	Med.	Mean	CI
All REF marshes	33.62	85.61	38.76	37.40	49.69	5.68	77.00	167.46	68.10	2.00	2.77	1.08	3000	3802	818
Freshwater	8.91	9.59	0.96	28.01	27.32	1.91	70.50	125.00	28.99	2.50	2.90	0.49	2100	2359	230
Sub-saline	41.95	116.86	49.47	41.73	51.86	4.71	76.00	105.36	5.75	0.50	1.61	0.45	3225	3421	308
Saline	70.90	95.99	19.58	83.80	74.83	7.35	87.00	423.29	135.82	2.00	6.21	2.12	3920	7057	1572
All OS marshes	32.30	36.22	6.25	36.12	41.53	7.64	32.00	148.12	104.57	2.00	17.72	12.07	1690	1998	452
OSPA	35.02	40.08	8.31	34.92	41.78	9.14	35.00	247.23	4.33	4.00	29.92	0.48	1780	2443	163
OSREF	30.50	32.04	2.91	37.66	41.26	6.01	22.50	40.75	132.43	2.00	4.50	15.20	1425	1515	570

Site type	Total Dissolved Nitrogen (µg/L)			Soluble Reactive Phosphorus (µg/L)			Total Phosphorus (µg/L)			Total Suspended Solids (mg/L)			Total Dissolved Solids (ppt)		
	Med.	**Mean**	**CI**	**Med.**	**Mean**	**CI**	**Med.**	**Mean**	**CI**	**Med.**	**Mean**	**CI**	**Med.**	**Mean**	**CI**
All REF marshes	2530	2944	463	10.00	130.08	92.42	113.00	269.03	116.59	7.50	10.55	2.10	0.543	0.939	0.217
Freshwater	1785	2064	230	10.50	39.50	14.81	103.00	135.30	18.86	4.50	8.50	2.15	0.203	0.208	0.016
Sub-saline	2740	2887	176	7.50	44.95	32.71	117.00	176.77	43.30	7.75	11.23	2.10	0.605	0.729	0.075
Saline	3900	4382	892	13.00	527.00	180.24	135.00	750.00	229.26	9.00	11.36	2.26	2.134	2.553	0.248
All OS marshes	1390	1732	338	2.00	6.20	4.04	36.00	63.28	17.70	10.00	69.91	40.92	1.132	1.405	0.202
OSPA	1570	2082	145	3.00	9.42	0.81	48.00	81.77	7.32	12.00	120.54	55.55	1.541	1.808	0.216
OSREF	1280	1352	425	1.50	2.71	5.18	28.00	43.25	22.36	5.75	15.07	4.39	0.763	0.801	0.061

Summary

Most of the existing marshes in the oil sands were not constructed with the purpose of forming part of the closure landscape, but were rather designed to test individual experimental factors, such as the toxicity of process-affected sediments or tailings water. Other wetlands have opportunistically formed on reclaimed landscapes in areas of low drainage. When oil companies begin to build permanent marshes on their leaseholds, they should set up an experimental program to optimize the best design and planting strategy to maximize habitat value and resilience. These should include a range of sizes with a least some of them with ~60% of the total area as vegetated marsh and < 40% open water by area. The marsh should have shallow slopes rather than a bowl shape (Fig. 10.1). The slope should be a minimum of 20:1 to increase the wet meadow width and buffer against fluctuations in water levels due to climate variability. The average depth of open water should be < 1 m so that SAV species receive adequate light. These brief recommendations stem mainly from the morphological attributes of reference marshes that were sampled and may aid in the development of an experimental permanent marsh design in the oil sands.

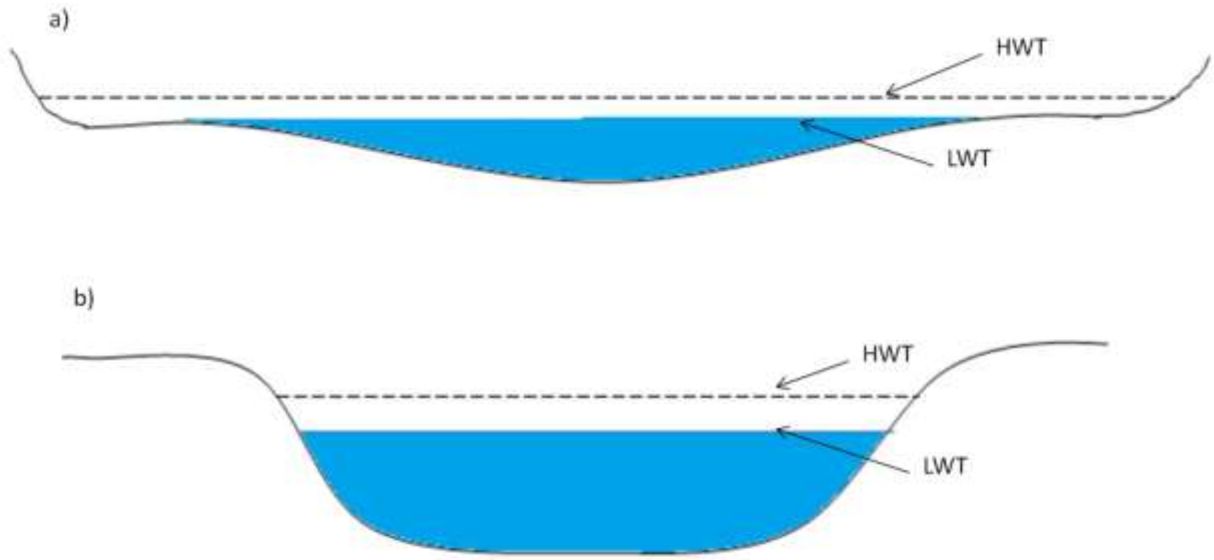

Figure 10.1. Schematic depicting observed differences in shoreline slope between reference and reclaimed marshes.
Slopes in natural reference wetlands (a) are generally more gentle than in oil sands wetlands (b), which tend to have bathtub-shaped basin morphology. Note that the distance between the high water table (HWT) and the low water table (LWT) is the region where the wet meadow zone is typically located.

GLOSSARY[4]

Amplitude – Defined as the seasonal difference in maximum and minimum water levels: Amplitude $= maximum\ depth - minimum\ depth.$ Maximum depth usually occurs at the beginning of the ice-free season, and the minimum depth occurs during August due to high evaporation.

Biological condition (integrity) – the ability to support and maintain a balanced, integrated, adaptive biological system having the full range of parts (genes, species, and assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics, and metapopulation processes) expected in the natural habitat of the region (Karr, 1991; Karr & Chu, 1999).

Biovolume – The volume of organic material relative to the total sample volume.

Disturbance – a change in the minimal structure caused by a factor external to the level of interest (Pickett *et al.,* 1989). In this handbook, the minimal structure is the interaction between the physicochemical environment and the biological structure of vegetation communities. Oil sands processes and reclamation land materials are the external factors causing the disturbance. Rather than a before and after scenario to measure disturbance, the effect of disturbance in the oil sands is measured against the undisturbed "reference condition."

Emergent zone – the marsh fringe area nearest to the edge of the open water and characterized by cattails and rushes.

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[4] Definitions were adapted from the following two sources unless otherwise noted:

1. Raab, D., 2010. Reclamation of wetland habitat in the Alberta oil sands: Generating assessment targets using boreal marsh vegetation communities. M.Sc. Thesis. University of Alberta. Canada

2. Ciborowski, J. J. H., A. Grgicak-Mannion, M. Kang, R. Rooney, H. Zeng, K. Kovalenko, S. E. Bayley, A. L. Foote, 2012. Development of a regional monitoring program to assess the effect of oil sands development of wetland communities. Cumulative Environmental Management Association, Fort McMurray, Alberta. CEMA Contract No. 2010-0029 RWG.

Facultative wetland species – Plant species usually occurring in wetlands under normal conditions, but occasionally found in non-wetlands.

Floristic Quality Index (adjusted FQI) – The adjusted FQI estimates the ecological conservatism, or habitat sensitivity, of a plant community (Miller & Wardrop, 2006).

adjusted FQI= $\frac{\text{mean } CC}{10} \text{ x } \frac{\sqrt{\text{No.native sp.}}}{\sqrt{\text{No.of total sp.}}} \text{x } 100$

Gradient – a change in ecological conditions relative to a change in the degree of disturbance. The slope yields the rate of change along the measured gradient.

Indicator – the physical, chemical or biological components (e.g. water quality, soil, vegetation indicators) that are monitored to estimate ecological condition or health. Biological indicators are often further defined by their taxonomic group (e.g. invertebrates, amphibians, plants) or community (i.e. open water vegetation community). Multiple metrics or attributes of the indicator being monitored are measured against criteria to define the health or condition of a test site. In the context of this handbook, indicator is short for performance indicator. See **stress gradient**, **submersed and floating aquatic vegetation IBI**, and **wet meadow vegetation IBI**.

Index of biological integrity (IBI) – A multi-metric index indicating the ability of a habitat to support and maintain a balanced, integrated, adaptive biological system having the full range of elements expected in a region's natural habitat (Karr, 1991; Karr & Chu, 1999). The plant-based IBIs are performance indicators of biological integrity, condition or health.

Marsh - Marshes are a class of mineral wetlands defined by having minimal or no peat accumulation. Marshes can be distinguished from other mineral wetlands by the presence of more than 25% of the wetland area covered by herbaceous or woody vegetation and periodic or persistent standing water or slow-moving surface water which is circumneutral to alkaline and generally nutrient-rich (National Wetlands Working Group, 1997).

Marsh Condition Index (MCI) – The integrated score of the SGI, the SAV-IBI and the WM-IBI, representing an overall estimation of wetland health.

Metric - an individual measure or attribute measured for each performance indicator.

Obligate wetland species – Species nearly always occurring in wetlands under natural conditions

Oil sands process-affected (OSPA) wetlands – wetlands on oil sands leaseholds that were subjected to both physical and chemical disturbance, by exposure to oil sands process water or substrate. These materials can be highly saline and can contain naphthenic acids, polycyclic aromatic hydrocarbons, and heavy metals. This disturbance could have occurred as a discrete single event or as continuous disturbance, such as the case where some wetlands receive seepage water from nearby tailings facilities. OSPA sites were sampled and used to examine existing conditions of reclamation sites and to define characteristics of wetlands presumed to be in poor condition or health.

Oil sands reference (OSREF) wetlands - wetlands on oil sands leaseholds that were subjected only to physical disturbances, such as gravel extraction or impoundment, or formed opportunistically on materials that were not considered process-affected.

Performance indicator – The four tools in this handbook used to measure the performance or health of reclaimed wetlands.

Reclamation – to stabilize the terrain, assure public safety, and recreate habitat on a land surface that has been altered, disturbed, damaged, or degraded. In reclamation, the replaced habitat is often fundamentally different from the historical or pre-disturbance habitat. The Environmental Protection and Enhancement Act of Alberta defines reclamation as:

(i) the removal of equipment or buildings or other structures or appurtenances;

(ii) the decontamination of buildings or other structures or other appurtenances, or land or water;

(iii) the stabilization, contouring, maintenance, conditioning or reconstruction of the surface of land;

(iv) any other procedure, operation or requirement specified in the regulations;

Reference Condition – the range of variation in physical, chemical, and biological characteristics observed in a large sample of natural wetlands exposed to minimal human influences. The reference condition was used to define the range of characteristic that represents wetlands in good condition or health.

Reference site – a site that represents natural physical, chemical and biological conditions in the region and that was used with other reference sites to represent the reference condition.

Robel pole height – A method was adapted to wetlands to measure the visual obstruction of a banded 1.5 m pole as a proxy for biomass.

Saline wetland – wetlands with water conductivities greater than 2000 µs/cm.

Shallow open water wetland – mineral wetlands that contain surface water with depths up to 2 m for most or all of the year and have less than 25% herbaceous or woody vegetation (National Wetlands Working Group, 1997).

Staff gauge – a graduated scale attached to a vertical pole that is placed in a water body and used to measure water levels from the shoreline.

Stress gradient indicator (SGI) – a performance indicator that measures the physicochemical conditions of a test site based on physical, water, sediment and contaminant indicators.

Submersed aquatic and floating aquatic vegetation (SAV) – vegetation that inhabits the open water area of a wetland and comprises both floating and submersed vegetation forms.

Submersed aquatic and floating aquatic vegetation IBI (SAV-IBI) – a performance indicator that measures the biological integrity of a site based on open water vegetation indicators.

Subsaline wetland – wetlands with water conductivities equal to or greater than 500 µs/cm.

Threshold – the criteria necessary to meet the definition of a healthy wetland for that performance indicator. This may be a moveable target and should be adapted as reclamation marsh design improves or if climate and/or other conditions change.

Wet meadow vegetation Index of Biological Integrity (WM-IBI) – a performance indicator that measures the biological integrity of a site based on wet meadow vegetation indicators.

Wet meadow zone - the marsh area between the emergent marsh fringe and the upland boundary. Dominant vegetation includes sedges and hydrophytic grasses.

Wetland monitoring - Estimating the condition or health of wetlands using indicators and their individual metrics. Used to conserve and manage wetlands, measure the success of reclaimed wetland designs, inform land use planning and management, improve wetland engineering and design, collect scientific information, and provide education to the public.

APPENDIX

Appendix 1. Sampling equipment and timelines

A 1-1.Equipment list for sampling each performance indicator.

PPE is Personal Protection Equipment.

SGI	WM-IBI	SAV-IBI
PPE	PPE	PPE and safety tickets
Staff gauge	GPS measure	Boat/paddles
Rubber mallet	Long tape measure	Anchor
Meter stick	Robel pole	1 m^2 floating quadrat
Post level	1 m^2 quadrat	Rake
GPS	Field guides	Meter stick
Binoculars	Plant press	Tray
Pencil	Hand lens	Field guides
Clipboard	Trowel	Plant press
Data sheets	Knife	Hand lens
Boat/paddles	Data sheets	Data sheets
Anchor with anchor rope	Pencil	Pencil
Secchi disc (10 cm diameter)	Clipboard	Clipboard
Latex vinyl gloves		
Clean, labeled water sample bottle		
Integrated sampling tube		
Conductivity meter		
Suction corer		
Knife		
Clean, labeled glass sediment sample bottle		
Cooler with ice		
Sediment corer		

Note: The use of chest-waders and rubber boots is strongly recommended when working in wetlands. When sampling on mine leases, the appropriate safety measures must be followed as dictated by the lease-holder. This likely includes use of personal protective equipment (PPE) such as hard-hats, reflective vests, and green-triangle Canadian Safety Association certified boots and life jackets. Check with the lease-holder for additional safety equipment needs.

A1-2. Sampling timeline for all performance indicators.

Month	Procedures
May	Staff gauge installation Max depth measurement Bi-weekly staff gauge readings
June	Bi-weekly staff gauge readings
July	Begin water chemistry in late July Begin water clarity measurement in late July Begin sediment sampling in late July Begin wet meadow vegetation IBI in late July
	Bi-weekly staff gauge readings
August	Finish water chemistry Finish water clarity measurement Finish sediment sampling Finish wet meadow vegetation IBI Submersed and floating vegetation IBI Bi-weekly staff gauge readings

Appendix 2. Examples of sample data sheets

Staff Gauge Data Sheet

Date/Time: ________________	Site: ______________________
Field Tech: __________________	Max Depth (m): ______________

Staff Gauge	UTM Zone: __________________
UTM E: _____________________	UTM N: _____________________

Date	Depth at Staff Gauge (m)

Comments:

Water Chemistry Data Sheet

Site: ___________________ Field Tech: ____________________ Date/Time: ____________

UTM E: ___________________ UTM N: ____________________ UTM Zone: ____________

Water Sampling

Secchi Up (cm): ________________

Secchi Down (cm): ______________

Max Depth (cm): ________________

Conductivity (μS/cm):____________

Comments:

Sediment percent water content

Lab technician: __________________________ Date: __________________

Site	Wet Weight (g)	Dry Weight (g)	% Water Content	Notes

WM-IBI Field Data Sheet

Si Site name:___________________

Fi Field sampler:________________

D Date/time:___________________

UTM Zone:___________________

Transect		T 1	T 2	T 3
Width of WM zone				
Open Water Edge	UTM E			
	UTM N			
Upland Edge	UTM E			
	UTM N			

Transect		1		2		3	
Quadrat		Q 1	Q 2	Q 3	Q 4	Q 5	Q 6
Robel height (to nearest 10 cm band)							
Species code	Collection ID and #						

SAV-IBI Field Data Sheet

Site: ______________________________ Field sampler:______________________________

Date/time:________________________________

Floating Species		% cover									
Transect/quadrat		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Species name	Collection#										
Submersed Species (SAV)		% relative biovolume									
Species name	Collection#	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10

Appendix 3. Species names, codes, characteristics, and Coefficients of Conservatism (CC) values

A3-1. Species codes, vegetation community, and alkalinity tolerance for submersed and floating plant species commonly found in boreal marshes.

Fl = floating spp.; SAV = submersed aquatic vegetation spp.; n = not alkali tolerant or halophyte; y = alkali tolerant or halophyte.

Species code	Latin name	Common name	Vegetation form	Alkali tolerant	Halophyte
Aquamos	Aquatic Moss		SAV	n	n
Callpal	*Calla palustris*	water arum	SAV	n	n
Caltnat	*Caltha natans*	floating marsh marigold	Fl/SAV	n	n
Ceradem	*Ceratophyllum demersum*	coontail	SAV	n	n
Charspp	*Chara* sp.		SAV	y	n
Elodcan	*Elodea canadensis*	Canada waterweed	SAV	n	n
Hippvul	*Hippuris vulgaris*	common mare's-tail	SAV	n	n
Lemnmin	*Lemna minor*	common duckweed	Fl	n	n
Lemntri	*Lemna trisulca*	ivy-leaf duckweed	Fl	n	n
Lemntur	*Lemna turionifera*	turion duckweed	Fl	n	n
Myrisib	*Myriophyllum sibiricum*	American watermilfoil	SAV	n	n
Myrispp	*Myriophyllum* spp.		SAV	n	n
Myriver	*Myriophyllum verticillatum*	whorl-leaf watermilfoil	SAV	n	n
Najafle	*Najas flexilis*	nodding waternymph	SAV	n	n
Nuphvar	*Nuphar variegata*	variegated yellow pond-lily	Fl	n	n
Polyamp	*Polygonum amphibium*	water knotweed	Fl/SAV	n	n
Potaalp	*Potamogeton alpinus*	alpine pondweed	SAV	y	n
Potacri	*Potamogeton crispus*	curly pondweed	SAV	n	n
Potafol	*Potamogeton foliosus*	leafy pondweed	SAV	y	n
Potafre	*Potamogeton friesii*	flat-stalk pondweed	SAV	n	n
Potagra	*Potamogeton gramineus*	grassy pondweed	SAV	n	n
Potanat	*Potamogeton natans*	broadleaf pondweed	Fl/SAV	n	n
Potaobt	*Potamogeton obtusifolius*	bluntleaf pondweed	SAV	n	n
Potapra	*Potamogeton praelongus*	whitestem pondweed	SAV	n	n
Potapus	*Potamogeton pusillus*	baby pondweed	SAV	n	n
Potaric	*Potamogeton richardsonii*	Richardon pondweed	SAV	n	n
Potazos	*Potamogeton zosteriformis*	flatstem pondweed	SAV	y	n
Ranuaqu	*Ranunculus aquatilis*	water buttercup	SAV	n	n
Ruppcir	*Ruppia cirrhosa*	spiral ditchgrass	SAV	n	y

Species code	Latin name	Common name	Vegetation form	Alkali tolerant	Halophyte
Sagicun	*Sagittaria cuneata*	arum-leaf arrowhead	Fl/SAV	n	n
Stucfil	*Stuckenia filiformis*	fine-leaf pondweed	SAV	n	n
Stucpec	*Stuckenia pectinata*	sago pondweed	SAV	y	y
Stucvag	*Stuckenia vaginata*	sheathed pondweed	SAV	n	n
Utrimac	*Utricularia macrorhiza*	common bladderwort	SAV	n	n
Utrimin	*Utricularia minor*	lesser bladderwort	SAV	n	n
Wolfbor	*Wolffia borealis*	northern watermeal	Fl	n	n
Wolfcol	*Wolffia Columbiana*	Columbia watermeal	Fl	n	n
Zaniaqu	*Zannichelli palustris*	horned pondweed	SAV	y	Y

A3-2. Wet meadow vegetation species list, coefficient of conservatism values, and indicator statuses.

Median coefficients of conservatism (*CC* value) and indicator status (FACW = facultative wetland; FACU = facultative upland; FAC = facultative; OBL = obligate, NO = no status) are presented for each species. *CC* values represent a species' tolerance to stress and habitat specificity and is used to calculate the floristic quality of a site, or adjusted *FQI*. These *CC* values are only appropriate for the Boreal Plains Region. Note that if a species is found that does not have a listed *CC* value, it needs to be omitted from calculation of the site's adjusted *FQI* score. Indicator status was taken from the USDA website (http://plants.usda.gov/wetinfo.html) for region 4.

Species code	Latin name	Common name	*CC* value	Indicator status
Achialp	*Achillea alpina*	Siberian yarrow	4	NO
Achimil	*Achillea millefolium*	yarrow	0	FACU
Acorame	*Acorus americanus*	sweetflag	8	NO
Actarub	*Actaea rubra*	red baneberry	6	NO
Agristr	*Agrimonia striata*	roadside agrimony	5	FACU
Agrosca	*Agrostis scabra*	ticklegrass	2	FAC
Agrosto	*Agrostis stolonifera*	creeping bentgrass	0	FAC
Alispla	*Alisma plantago-aquatica*	American waterplantain	4	OBL
Allisch	*Allium schoenoprasum*	wild chives	6	NO
Almupau	*Almutaster pauciflorus*	alkali marsh aster	6	FACW
Alnuinc	*Alnus incana*	gray alder	4	FACW
Alnuvir	*Alnus viridis*	green alder	3	NO
Alopaeq	*Alopecurus aequalis*	shortawn foxtail	4	OBL
Aloppra	*Alopecurus pratensis*	meadow foxtail	0	FACW
Amelaln	*Amelanchier alnifolia*	Saskatoon serviceberry	4	FACU
Anemvir	*Anemone virginiana*	tall thimbleweed	6	NO
Anthmon	*Anthoxanthum monticola*	alpine sweetgrass	4	NO
Arctuva	*Arctostaphylos uva-ursi*	bearberry	4	FACU
Arnicha	*Arnica chamissonis*	Chamisso arnica	5	NO
Artebie	*Artemisia biennis*	biennial wormwood	2	FAC
Astrcan	*Astragalus Canadensis*	Canada milk vetch	6	FACU
Astragr	*Astragalus agrestis*	purple milk vetch	5	FACU
Atridio	*Atriplex dioica*	saline saltbrush	5	NO
Atrimic	*Atriplex micrantha*	saltbush	0	NO
Atripro	*Atriplex prostrate*	hastate orache	0	NO
Barbort	*Barbarea orthoceras*	American yellorocket	6	OBL

Species code	Latin name	Common name	*CC* value	Indicator status
Becksyz	*Beckmannia syzigachne*	American slough grass	3	OBL
Betugla	*Betula glandulosa*	resin birch	6	OBL
Betuneo	*Betula neoalaskana*	resin birch	6	NO
Betuocc	*Betula occidentalis*	water birch	6	FACW
Betupap	*Betula papyrifera*	paper birch	4	FACU
Betupum	*Betula pumila*	bog birch	6	OBL
Bidecer	*Bidens cernua*	nodding beggarticks	3	OBL
Bromcil	*Bromus ciliatus*	fringed brome	5	FAC
Bromine	*Bromus inermis*	awnless brome	0	NO
Calacan	*Calamagrostis canadensis*	bluejoint	1	FACW
Calastr	*Calamagrostis stricta*	narrowspike reedgrass	4	NO
Calaine	*Calamagrostis stricta* ssp. *Inexpansa*	northern reedgrass	4	FACW
Callpal	*Calla palustris*	water arum	7	OBL
Callher	*Callitriche hermaphroditica*	northern water-starwort	6	OBL
Callver	*Callitriche palustris*	vernal water-starwort	5	OBL
Caltnat	*Caltha natans*	floating marsh-marigold	6	NO
Caltpal	*Caltha palustris*	marsh-marigold	6	OBL
Canamod	*Canadanthus modestus*	large northern aster	5	NO
Capsbur	*Capsella bursa-pastoris*	shepherd's-purse	0	FACU
Cardpen	*Cardamine pensylvanica*	bitter cress	5	OBL
Cardpra	*Cardamine pratensis*	meadow bitter cress	6	NO
Careaqu	*Carex aquatilis*	water sedge	2	OBL
Careath	*Carex atherodes*	awned sedge	5	OBL
Careaur	*Carex aurea*	golden sedge	4	FACW
Carebeb	*Carex bebbii*	Bebb's sedge	4	OBL
Carebru	*Carex brunnescens*	brownish sedge	6	FAC
Carebux	*Carex buxbaumii*	brown sedge	8	OBL
Carecan	*Carex canescens*	short sedge	6	OBL
Carecap	*Carex capillaris*	hair-like sedge	6	FACW
Carecho	*Carex chordorrhiza*	prostrate sedge	7	OBL
Carecra	*Carex crawfordii*	Crawford's sedge	5	FAC
Caredia	*Carex diandra*	two-stamened sedge	5	OBL
Caredis	*Carex disperma*	two-seeded sedge	6	FACW
Careebu	*Carex eburnea*	bristle-leaved sedge	7	FACU
Caregyn	*Carex gynocrates*	northern bog sedge	7	OBL
Carehel	*Carex heleonastes*	Hudson Bay sedge	9	NO
Careint	*Carex interior*	inland sedge	6	OBL
Carelac	*Carex lacustris*	lakeshore sedge	8	OBL
Carelas	*Carex lasiocarpa*	hairy-fruited sedge	6	OBL

Species code	Latin name	Common name	*CC* value	Indicator status
Carelim	*Carex limosa*	mud sedge	7	NO
Careliv	*Carex livida*	livid sedge	8	NO
Carelol	*Carex loliacea*	rye-grass sedge	7	NO
Careoli	*Carex oligosperma*	few-fruited sedge	9	NO
Carepauc	*Carex pauciflora*	few-flowered sedge	9	NO
Carepaup	*Carex paupercula*	boreal bog sedge	8	OBL
Carepel	*Carex pellita*	woolly sedge	6	OBL
Careprae	*Carex praegracilis*	graceful sedge	5	FACW
Careprai	*Carex prairea*	prairie sedge	7	OBL
Careprat	*Carex praticola*	meadow sedge	5	FAC
Careret	*Carex retrorsa*	turned sedge	5	OBL
Careros	*Carex rostrata*	beaked sedge	8	OBL
Caresar	*Carex sartwellii*	Sartwell's sedge	5	FACW
Caresax	*Carex saxatilis*	rocky-ground sedge	6	NO
Caresti	*Carex stipata*	awl-fruited sedge	5	OBL
Caresyc	*Carex sychnocephala*	long-beaked sedge	5	FACW
Caretene	*Carex tenera*	broad-fruited sedge	5	FACW
Caretenu	*Carex tenuiflora*	thin-flowered sedge	8	NO
Caretor	*Carex torreyi*	Torrey's sedge	5	NO
Caretri	*Carex trisperma*	three-seeded sedge	9	NO
Careutr	*Carex utriculata*	small bottle sedge	5	OBL
Carevag	*Carex vaginata*	sheathed sedge	5	OBL
Carevir	*Carex viridula*	green sedge	7	OBL
Carevul	*Carex vulpinoidea*	fox sedge	8	OBL
Castrau	*Castilleja raupii*	purple paintbrush	5	FAC
Ceraarv	*Cerastium arvense*	field mouse-ear chickweed	4	FACU
Chenalb	*Chenopodium album*	lamb's-quarters	0	FAC
Chencap	*Chenopodium capitatum*	strawberry blite	2	NO
Chenrub	*Chenopodium rubrum*	red goosefoot	4	OBL
Chensal	*Chenopodium salinum*	oak-leaved goosefoot	3	NO
Chryiow	*Chrysosplenium iowense*	golden saxifrage	6	NO
Chrytet	*Chrysosplenium tetrandrum*	green saxifrage	6	OBL
Cicubul	*Cicuta bulbifera*	bulb-bearing water-hemlock	6	OBL
Cicumac	*Cicuta maculata*	water-hemlock	5	OBL
Cucuvir	*Cicuta virosa*	narrow-leaved water-hemlock	6	NO
Cinnlat	*Cinna latifolia*	drooping wood-reed	6	OBL
Cirsarv	*Cirsium arvense*	creeping thistle	0	FACU
Coelvir	*Dactylorhiza virdis*	bracted bog orchid	7	FACU

Species code	Latin name	Common name	*CC* value	Indicator status
Conimac	*Conium maculatum*	poison hemlock	0	FAC
Copttri	*Coptis trifolia*	goldthread	9	FACW
Cornsto	*Cornus sericea*	red-osier dogwood	3	FACW
Coryaur	*Corydalis aurea*	scrambled eggs	1	NO
Creptec	*Crepis tectorum*	annual hawk's-beard	0	NO
Cyprpar	*Cypripedium parviflorum*	lesser yellow lady’s slipper	8	FACW
Delpgla	*Delphinium glaucum*	Sierra larkspur	5	NO
Desccas	*Deschampsia caspitosa*	tufted hair grass	4	FACW
Descsop	*Descurainia sophia*	flixweed	0	NO
Diststr	*Distichlis stricta*	salt grass	7	FACW
Dodepul	*Dodecatheon pulchellum*	saline shooting star	7	FACW
Dracpar	*Dracocephalum parviflorum*	American dragonhead	1	FACU
Drepadu	*Drepanocladus aduncus*	Drepanocladus moss	4	NO
Eleoaci	*Eleocharis acicularis*	needle spike-rush	4	OBL
Eleopal	*Eleocharis palustris*	creeping spike-rush	4	OBL
Eleoqui	*Eleocharis quinqueflora*	few-flowered spike-rush	7	NO
Elumrep	*Elymus repens*	quackgrass	0	FAC
Elymtra	*Elymus trachycaulus*	slender wheat grass	3	FAC
Chamang	*Chamerion angustifolium*	common fireweed	1	FAC
Epilcil	*Epilobium ciliatum*	northern willowherb	2	FACW
Epillep	*Epilobium leptophyllum*	narrow-leaved willowherb	7	NO
Epilpal	*Epilobium palustre*	marsh willowherb	5	OBL
Equiarv	*Equisetum arvense*	common horsetail	1	FAC
Equiflu	*Equisetum fluviatile*	swamp horsetail	4	OBL
Equihye	*Equisetum hyemale*	common scouring-rush	4	FACW
Equilae	*Equisetum laevigatum*	smooth scouring-rush	5	FAC
Equipal	*Equisetum palustre*	marsh horsetail	5	FACW
Equipra	*Equisetum pratense*	meadow horsetail	4	FACW
Equisci	*Equisetum scirpoides*	dwarf scouring-rush	5	FAC
Equisyl	*Equisetum sylvaticum*	woodland horsetail	5	FACW
Equivar	*Equisetum variegatum*	variegated horsetail	6	FACW
Erigacr	*Erigeron acris*	northern daisy fleabane	3	FAC
Erigela	*Erigeron elatus*	tall fleabane	6	NO
Erilon	*Erigeron lonchophyllus*	shortray fleabane	4	FACW
Eriphi	*Erigeron philadelphicus*	Philadelphia fleabane	4	FACW
Eriobra	*Eriophorum brachyantherum*	close-sheathed cotton grass	7	NO
Eriocha	*Eriophorum chamissonis*	russett cotton grass	7	OBL
Eriogra	*Eriophorum gracile*	slender cotton grass	7	OBL
Eriopol	*Eriophorum angustifolium*	tall cotton grass	6	OBL

Species code	Latin name	Common name	*CC* value	Indicator status
Eriosch	*Eriophorum scheuchzeri*	one-spike cotton grass	6	NO
Eriovir	*Eriophorum viridicarinatum*	thin-leaved cotton grass	7	OBL
Erysche	*Erysimum cheiranthoides*	wormseed mustard	0	FACU
Eupamac	*Eupatorium maculatum*	spotted Joe-pye weed	6	FACW
Eurycon	*Eurybia conspicua*	western showy aster	4	NO
Fragves	*Fragaria vesca*	woodland strawberry	4	NO
Fragvir	*Fragaria virginiana*	wild strawberry	1	FACU
Galetet	*Galeopsis tetrahit*	hemp-nettle	0	NO
Galilab	*Galium labradoricum*	Labrador bedstraw	7	OBL
Galitrifi	*Galium trifidum*	small bedstraw	5	OBL
Galitrifl	*Galium triflorum*	sweet-scented bedstraw	5	FACU
Gentdet	*Gentianopsis detonsa*	Northern fringed gentian	8	NO
Geumale	*Geum aleppicum*	yellow avens	3	FACU
Geummac	*Geum macrophyllum*	large-leaved yellow avens	4	FACW
Geumriv	*Geum rivale*	purple avens	6	FACW
Glaumar	*Glaux maritima*	sea milkwort	6	OBL
Glycbor	*Glyceria borealis*	northern manna grass	6	OBL
Glycgra	*Glyceria grandis*	common tall manna grass	5	NO
Glycpul	*Glyceria pulchella*	graceful manna grass	6	NO
Glycstr	*Glyceria striata*	fowl manna grass	4	OBL
Glyclep	*Glycyrrhiza lepidota*	wild licorice	4	FACU
Gratneg	*Gratiola neglecta*	clammy hedgehyssop	5	OBL
Heleaut	*Helenium autumnale*	sneezeweed	5	FACW
Helinut	*Helianthus nuttallii*	Nuttall's sunflower	4	FACW
Heralan	*Heracleum lanatum*	cow parsnip	4	FAC
Hierumb	*Hieracium umbellatum*	narrow-leaved hawkweed	2	NO
Hippvul	*Hippuris vulgaris*	common mare's-tail	5	OBL
Hordjub	*Hordeum jubatum*	foxtail barley	1	FACW
Hypemaj	*Hypericum majus*	large Canada St. John's-wort	6	FACW
Impacap	*Impatiens capensis*	spotted touch-me-not	4	FACW
Impanol	*Impatiens noli-tangere*	western jewelweed	6	NO
Isoeech	*Isoetes tenella*	northern quillwort	9	NO
Ivaaxi	*Iva axillaris*	povertyweed	3	FACU
Juncalp	*Juncus alpinoarticulatus*	alpine rush	4	OBL
Juncbal	*Juncus balticus*	wire rush	2	OBL
Juncbre	*Juncus brevicaudatus*	short-tail rush	6	OBL
Juncbuf	*Juncus bufonius*	toad rush	2	OBL
Juncfil	*Juncus filiformis*	thread rush	6	FACW
Junclon	*Juncus longistylis*	long-styled rush	5	FACW

Species code	Latin name	Common name	*CC* value	Indicator status
Juncnod	*Juncus nodosus*	knotted rush	5	OBL
Juncten	*Juncus tenuis*	slender rush	3	FAC
Juncvas	*Juncus vaseyi*	big-head rush	5	FACW
Larilar	*Larix laricina*	tamarack	6	FACW
Picemar	*Picea mariana*	black spruce	5	NO
Lactpul	*Lactuca pulchella*	common blue lettuce	4	FACU
Lactser	*Lactuca serriola*	prickly lettuce	0	FACU
Ledugro	*Ledum groenlandicum*	common Labrador tea	5	OBL
Lepiden	*Lepidium densiflorum*	common pepper-grass	0	FACU
Limoaqu	*Limosella aquatica*	mudwort	2	OBL
Linavul	*Linaria vulgaris*	toadflax	0	NO
LIstbor	*Listera borealis*	northern twayblade	9	NO
Lobedor	*Lobelia dortmanna*	water lobelia	9	NO
Lobekal	*Lobelia kalmii*	Kalm's lobelia	9	OBL
Lomarot	*Lomatogonium rotatum*	marsh felwort	8	NO
Lotucor	*Lotus corniculatus*	bird's-foot trefoil	0	FACU
Lycoasp	*Lycopus asper*	western water-horehound	5	OBL
Lycouni	*Lycopus uniflorus*	northern water-horehound	6	OBL
Lysilan	*Lysimachia lanceolata*	lanceleaf loosestrife	7	FACW
Lysithy	*Lysimachia thyrsiflora*	tufted loosestrife	6	OBL
Lythsal	*Lythrum salicaria*	purple loosestrife	0	OBL
Marcpol	*Marchantia polymorpha*	liverwort	2	NO
Matrdis	*Matricaria discoidea*	pineappleweed	0	FACU
Matrper	*Tripleurospermum perforata*	scentless chamomile	0	FAC
Melialb	*Melilotus alba*	white sweet-clover	0	FACU
Melioff	*Melilotus officinalis*	yellow sweet-clover	0	FACU
Mentarv	*Mentha arvensis*	wild mint	4	FACW
Mentspi	*Mentha spicata*	spearmint	0	NO
Menytri	*Menyanthes trifoliata*	buck-bean	7	OBL
Mononut	*Monolepis nuttalliana*	spear-leaved goosefoot	1	FAC
Muhlglo	*Muhlenbergia glomerata*	bog muhly	8	FACW
Muhlric	*Muhlenbergia richardsonis*	mat muhly	6	FAC
Myrigal	*Myrica gale*	sweet gale	7	OBL
Nastoff	*Nasturtium officinale*	water cress	0	OBL
Nymptet	*Nymphaea tetragona*	white water-lily	8	OBL
Parnpal	*Parnassia palustris*	northern grass-of-parnassus	5	OBL
Pedigro	*Pedicularis groenlandica*	elephant's-head	6	NO
Pedimac	*Pedicularis macrodonta*	swamp lousewort	6	NO
Petafri	*Petasites frigidus* ssp *frigidus*	sweet coltsfoot	5	FAC

Species code	Latin name	Common name	*CC* value	Indicator status
Petapal	*Petasites frigidus* ssp *palmatus*	palmate-leaved coltsfoot	4	FACW
Petasag	*Petasites frigidus* ssp *sagittatus*	arrow-leaved coltsfoot	4	FACW
Petavit	*Petasites frigidus* ssp *vitifolius*	vine-leaved coltsfoot	4	FAC
Phalaru	*Phalaris arundinacea*	reed canary grass	2	FACW
Phalcan	*Phalaris canariensis*	canary grass	0	FACU
Phlepra	*Phleum pratense*	timothy	0	FACU
Phraaus	*Phragmites australis*	reed	6	FACW
Physpar	*Physostegia parviflora*	false dragonhead	6	FACW
Plagsco	*Plagiobothrys scouleri*	Scouler's popcornflower	3	FACW
Planeri	*Plantago eriopoda*	saline plantain	5	FAC
Planmaj	*Plantago major*	common plantain	0	FAC
Planmar	*Plantago maritima*	sea-side plantain	6	NO
Plathyp	*Platanthera hyperborea*	northern green bog orchid	5	FACW
Poapal	*Poa palustris*	fowl bluegrass	3	FACW
Poapra	*Poa pratensis*	Kentucky bluegrass	0	FACU
Poleacu	*Polemonium acutiflorum*	tall Jacob's-ladder	7	NO
Polyamp	*Polygonum amphibium*	water smartweed	4	OBL
Polyare	*Polygonum arenastrum*	common knotweed	0	NO
Polyere	*Polygonum erectum*	striate knotweed	2	OBL
Polylap	*Polygonum lapathifolium*	pale persicaria	2	OBL
Polyper	*Polygonum persicaria*	lady's-thumb	0	FACW
Polyram	*Polygonum ramosissimum*	bushy knotweed	3	FACU
Polyviv	*Polygonum viviparum*	alpine bistort	7	FACW
Poteans	*Potentilla anserina*	silverweed	2	OBL
Potegra	*Potentilla gracilis*	graceful cinquefoil	5	FAC
Potenor	*Potentilla norvegica*	rough cinquefoil	2	FAC
Potepal	*Potentilla palustris*	marsh cinquefoil	6	OBL
Poteriv	*Potentilla rivalis*	brook cinquefoil	4	OBL
Priminc	*Primula incana*	mealy primrose	6	FACW
Puccdis	*Puccinellia distans*	slender salt-meadow grass	0	FACW
Puccnut	*Puccinellia nuttalliana*	Nuttall's salt-meadow grass	5	OBL
Ranuabo	*Ranunculus abortivus*	small-flowered buttercup	5	FACW
Ranuacr	*Ranunculus acris*	tall buttercup	0	FACW
Ranucym	*Ranunculus cymbalaria*	seaside buttercup	4	OBL
Ranugme	*Ranunculus gmelinii*	yellow water crowfoot	5	FACW
Ranuhyp	*Ranunculus hyperboreus*	boreal buttercup	7	NO
Ranulap	*Ranunculus lapponicus*	Lapland buttercup	7	OBL
Ranulon	*Ranunculus longirostris*	longbeak buttercup	4	OBL
Ranumac	*Ranunculus macounii*	Macoun's buttercup	5	OBL

Species code	Latin name	Common name	*CC* value	Indicator status
Ranupen	*Ranunculus pensylvanicus*	bristly buttercup	5	FACW
Ranurep	*Ranunculus flammula*	creeping spearwort	6	NO
Ranusce	*Ranunculus sceleratus*	celery-leaved buttercup	3	OBL
Rhinmin	*Rhinanthus minor*	yellow rattle	3	NO
Ribeame	*Ribes americanum*	wild black currant	7	FACW
Ribegla	*Ribes glandulosum*	skunk currant	6	NO
Ribehud	*Ribes hudsonianum*	northern black currant	7	NO
Ribelac	*Ribes lacustre*	bristly black currant	6	FACW
Ribeoxy	*Ribes oxyacanthoides*	northern gooseberry	4	NO
Ribetri	*Ribes triste*	wild red currant	5	OBL
Roricur	*Rorippa curvipes*	bluntleaf yellowcress	3	OBL
Roripal	*Rorippa palustris*	marsh yellow cress	3	OBL
Rosaaci	*Rosa acicularis*	prickly rose	1	FACU
Rosawoo	*Rosa woodsii*	common wild rose	4	FACU
Rubuarc	*Rubus arcticus*	dwarf raspberry	6	NO
Rubuida	*Rubus idaeus*	wild red raspberry	1	FACU
Rubupub	*Rubus pubescens*	dewberry	5	FACW
Rumecri	*Rumex crispus*	curled dock	0	FACW
Rumemar	*Rumex maritimus*	golden dock	5	FACW
Rumeocc	*Rumex occidentalis*	western dock	5	OBL
Rumeorb	*Rumex orbiculatus*	water dock	5	OBL
Rumetri	*Rumex triangulivalvis*	narrow-leaved dock	3	FAC
Sagicun	*Sagittaria cuneata*	arum-leaved arrowhead	5	OBL
Sagilat	*Sagittaria latifolia*	broad-leaved arrowhead	5	OBL
Salirub	*Salicornia rubra*	samphire	6	OBL
Saliarb	*Salix arbusculoides*	shrubby willow	5	NO
Salibeb	*Salix bebbiana*	beaked willow	2	FACW
Salican	*Salix candida*	hoary willow	6	OBL
Salidis	*Salix discolor*	pussy willow	2	FACW
Saliexi	*Salix exigua*	sandbar willow	2	FACW
Saligla	*Salix glauca*	smooth willow	4	FACW
Saliluc	*Salix lucida*	shining willow	6	FACW
Salilut	*Salix lutea*	yellow willow	5	FACW
Salimac	*Salix maccalliana*	velvet-fruited willow	5	NO
Salimyr	*Salix myrtillifolia*	myrtle-leaved willow	5	NO
Salipet	*Salix petiolaris*	basket willow	4	OBL
Salipla	*Salix planifolia*	flat-leaved willow	4	OBL
Salixpro	*Salix prolixa*	Mackenzie's willow	6	NO
Salipse	*Salix pseudomonticola*	false mountain willow	5	FACW

Species code	Latin name	Common name	*CC* value	Indicator status
Salipyr	*Salix pyrifolia*	balsam willow	6	NO
Salisco	*Salix scouleriana*	Scouler's willow	6	FACU
Saliser	*Salix serissima*	autumn willow	6	OBL
Schoacu	*Schoenoplectus acutus*	great bulrush	5	OBL
Schotab	*Schoenoplectus tabernaemontani*	common great bulrush	4	OBL
Scirces	*Scirpus cespitosus*	tufted bulrush	6	NO
Scirhud	*Scirpus hudsonianus*	Hudson Bay bulrush	7	NO
Scirmic	*Scirpus microcarpus*	small-fruited bulrush	3	OBL
Scirpal	*Scirpus paludosus*	prairie bulrush	6	NO
Scirpun	*Scirpus pungens*	three-square rush	6	NO
Scolfes	*Scolochloa festucacea*	spangletop	6	OBL
Scutgal	*Scutellaria galericulata*	marsh skullcap	5	OBL
Senecon	*Senecio congestus*	marsh ragwort	3	FACW
Seneere	*Senecio eremophilus*	cut-leaved ragwort	5	FAC
Sisymon	*Sisyrinchium montanum*	common blue-eyed grass	5	FAC
Siumsua	*Sium suave*	water parsnip	5	OBL
Smilste	*Smilacina stellata*	star-flowered Solomon's-seal	5	FACU
Smiltri	*Maianthemum trifolium*	three-leaved Solomon's-seal	7	NO
Solican	*Solidago canadensis*	Canada goldenrod	2	FACU
Soligig	*Solidago gigantea*	late goldenrod	5	FACU
Soligra	*Solidago graminifolia*	flat-topped goldenrod	5	NO
Soncarv	*Sonchus arvensis*	perennial sow-thistle	0	FAC
Soncasp	*Sonchus asper*	prickly annual sow-thistle	0	FACW
Sonculi	*Sonchus uliginosus*	smooth perennial sow-thistle	0	FAC
Sparang	*Sparganium angustifolium*	narrow-leaved bur-reed	5	NO
Spareur	*Sparganium eurycarpum*	giant bur-reed	6	OBL
Sparmin	*Sparganium minimum*	slender bur-reed	6	NO
Spargra	*Spartina gracilis*	alkali cord grass	7	FACW
Sparpec	*Spartina pectinata*	prairie cord grass	9	FACW
Spersal	*Spergularia salina*	salt-marsh sand spurry	9	OBL
Spiralb	*Spiraea alba*	white meadowsweet	5	FACW
Spirrom	*Spiranthes romanzoffiana*	hooded ladies'-tresses	8	OBL
Stacpal	*Stachys palustris*	marsh hedge-nettle	4	OBL
Stelcal	*Stellaria calycantha*	northern stitchwort	5	NO
Stelcra	*Stellaria crassifolia*	fleshy stitchwort	6	OBL
Stellongif	*Stellaria longifolia*	long-leaved chickweed	5	FACW
Stellongip	*Stellaria longipes*	long-stalked chickweed	4	OBL

Species code	Latin name	Common name	*CC* value	Indicator status
Suaecal	*Suaeda calceoliformis*	western sea-blite	5	FACW
Sympbor	*Symphyotrichum boreale*	northern bog aster	6	OBL
Sympcilia	*Symphyotrichum ciliatum*	rayless alkali aster	4	FACW
Sympcilio	*Symphyotrichum ciliolatum*	Lindley's aster	4	NO
Symperi	*Symphyotrichum ericoides*	white heath aster	4	FACU
Sympfal	*Symphyotrichum falcatum*	white prairie aster	5	FACU
Symplan	*Symphyotrichum lanceolatum*	white panicle aster	5	OBL
Sympppun	Symphyotrichum *puniceum*	purple-stemmed aster	5	OBL
Tanavul	*Tanacetum vulgare*	common tansy	0	NO
Taralae	*Taraxacum laevigatum*	red-seeded dandelion	0	NO
Taraoff	*Taraxacum officinale*	common dandelion	0	FACU
Thlaarv	*Thlaspi arvense*	stinkweed	0	NO
Tofiglu	*Triantha glutinosa*	sticky false asphodel	7	NO
Triccli	*Trichophorum clintonii*	Clinton's bulrush	7	NO
Trifhyb	*Trifolium hybridum*	alsike clover	0	FACU
Trifpra	*Trifolium pratense*	red clover	0	FACU
Trifrep	*Trifolium repens*	white clover	0	FACU
Trigmar	*Triglochin maritima*	seaside arrow-grass	5	OBL
Trigpal	*Triglochin palustris*	slender arrow-grass	6	OBL
Typhlat	*Typha latifolia*	common cattail	2	OBL
Urtidio	*Urtica dioica*	common nettle	3	FACW
Utriure	*Urtica urens*	small nettle	0	NO
Vaccvit	*Vaccinium vitis-idaea*	bog cranberry	5	NO
Valedio	*Valeriana dioica*	northern valerian	6	FACW
Veroame	*Veronica americana*	American brooklime	4	OBL
Veroana	*Veronica anagallis-aquatica*	water speedwell	0	OBL
Veroper	*Veronica peregrina*	hairy speedwell	5	FACW
Veroscu	*Veronica scutellata*	marsh speedwell	4	OBL
Viciame	*Vicia americana*	wild vetch	3	NO
Violmac	*Viola macloskeyi*	small white violet	7	NO
Violnep	*Viola nephrophylla*	bog violet	7	FACW
Violpal	*Viola palustris*	marsh violet	6	FACW
Zizaaqu	*Zizania aquatica*	wild rice	3	OBL

A3-3. Exotic species found in the wet meadow zone of marshes and shallow open water wetlands in the Boreal Plains Region. Note that native status was taken from the USDA website (http://plants.usda.gov/java/)

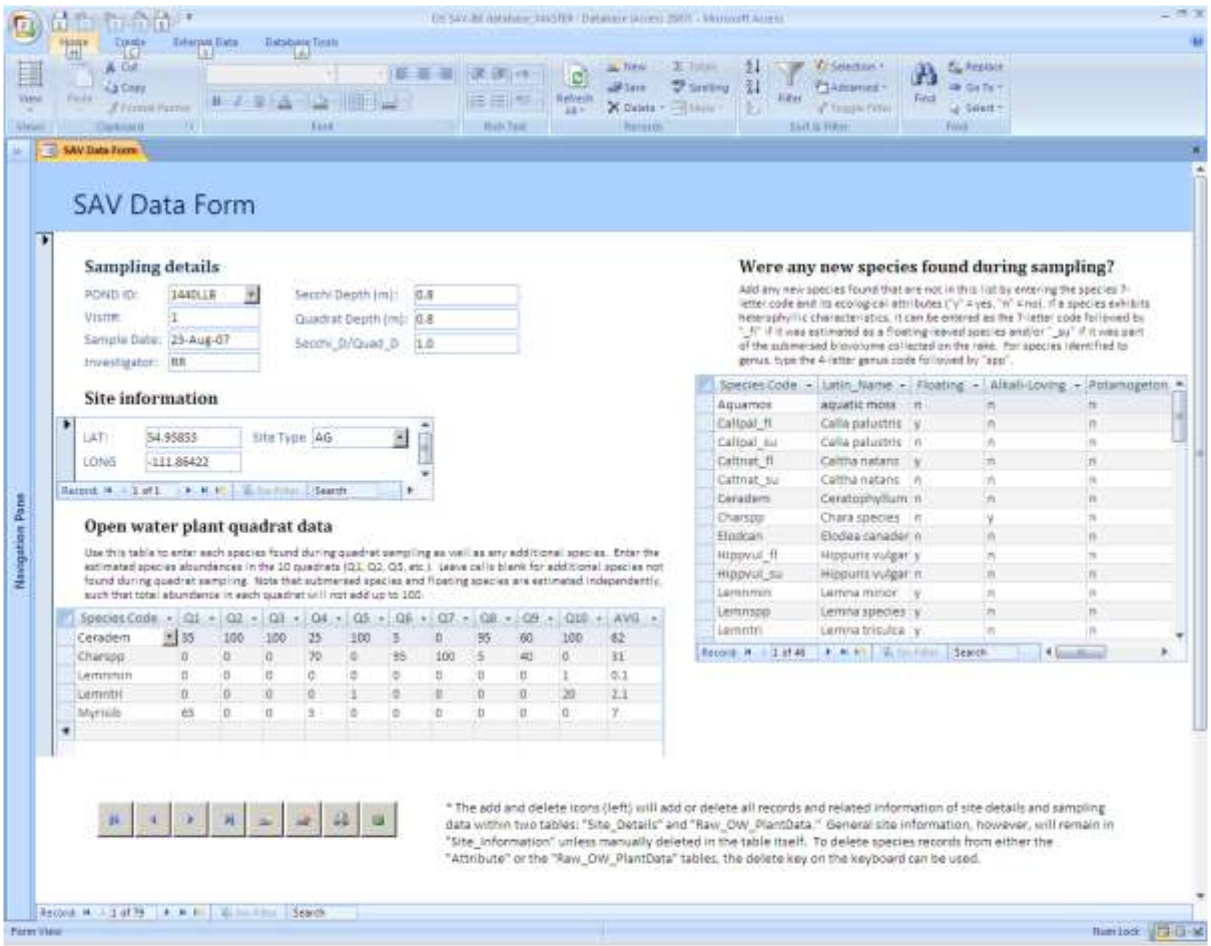
Species code	Latin name	Common name
Achimil	*Achillea millefolium*	yarrow
Agrosto	*Agrostis stolonifera*	creeping bentgrass
Aloppra	*Alopecurus pratensis*	meadow foxtail
Atrimic	*Atriplex micrantha*	saltbush
Atripro	*Atriplex prostrate*	hastate orache
Bromine	*Bromus inermis*	awnless brome
Capsbur	*Capsella bursa-pastoris*	shepherd's-purse
Chenalb	*Chenopodium album*	lamb's-quarters
Cirsarv	*Cirsium arvense*	creeping thistle
Conimac	*Conium maculatum*	poison hemlock
Creptec	*Crepis tectorum*	annual hawk's-beard
Descsop	*Descurainia sophia*	flixweed
Elumrep	*Elymus repens*	quackgrass
Erysche	*Erysimum cheiranthoides*	wormseed mustard
Galetet	*Galeopsis tetrahit*	hemp-nettle
Lactser	*Lactuca serriola*	prickly lettuce
Linavul	*Linaria vulgaris*	toadflax
Lotucor	*Lotus corniculatus*	bird's-foot trefoil
Lythsal	*Lythrum salicaria*	purple loosestrife
Matrdis	*Matricaria discoidea*	pineappleweed
Matrper	*Matricaria perforata*	scentless chamomile
Melialb	*Melilotus alba*	white sweet-clover
Melioff	*Melilotus officinalis*	yellow sweet-clover
Mentspi	*Mentha spicata*	spearmint
Nastoff	*Nasturtium officinale*	water cress
Phalcan	*Phalaris canariensis*	canary grass
Phlepra	*Phleum pratense*	timothy
Planmaj	*Plantago major*	common plantain
Poapra	*Poa pratensis*	Kentucky bluegrass
Polyare	*Polygonum arenastrum*	common knotweed
Polyper	*Polygonum persicaria*	lady's-thumb
Puccdis	*Puccinellia distans*	slender salt-meadow grass
Ranuacr	*Ranunculus acris*	tall buttercup
Rumecri	*Rumex crispus*	curled dock
Soncarv	*Sonchus arvensis*	perennial sow-thistle
Soncasp	*Sonchus asper*	prickly annual sow-thistle
Sonculi	*Sonchus uliginosus*	smooth perennial sow-thistle
Tanavul	*Tanacetum vulgare*	common tansy
Taralae	*Taraxacum laevigatum*	red-seeded dandelion

Taraoff	*Taraxacum officinale*	common dandelion
Thlaarv	*Thlaspi arvense*	stinkweed
Trifhyb	*Trifolium hybridum*	alsike clover
Trifpra	*Trifolium pratense*	red clover
Trifrep	*Trifolium repens*	white clover
Utriure	*Urtica urens*	small nettle

Appendix 4. Data management

A4-1. Screenshot of an example SAV-IBI database entry form in Microsoft Access.

Using this form, users can add and delete sites and SAV data, as well as add new species not previously stored in the database. Once the quality assured and controlled information is entered in the form, the program calculates metric values, metric scores, and IBI scores. Reports can be generated that summarize the results. We highly recommend using a database to expedite office work.



A4-2. Example of the raw SAV data (as % cover or biovolume) entered and stored in Microsoft Excel.

Pond ID	Sampling date	Sampler's initials	Species Code	Collection #	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Floating														
LASAL01	23-Aug-07	RR	Lemnmin		0	10	0	10	0	0	50	0	0	0
Submersed														
LASAL01	23-Aug-07	RR	Ceradem		0	0	0	0	0	0	0	0	0	10
LASAL01	23-Aug-07	RR	Charspp		0	0	0	0	0	0	0	40	0	0
LASAL01	23-Aug-07	RR	Myrispp	1	100	50	0	0	0	0	100	60	30	70
LASAL01	23-Aug-07	RR	Potazos		0	0	100	0	0	100	0	0	40	20
LASAL01	23-Aug-07	RR	Unknown	2	0	50	0	0	100	0	0	0	30	0

Q1, Q2, Q3, etc. stand for the percent cover of floating species or biovolume of submersed species in each quadrat. Note that relative biovolume measures should sum to 100, but percent cover measures may not if the entire surface of the water is not covered in vegetation.

A4-3. Example of the SAV data sheet after unknown species have been identified.

The unknown species at LASAL01 was identified as *Stuckenia pectinata* (Stucpec).

Pond ID	Species Code	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Avg
Floating												
LASAL01	Lemnmin	0	10	0	10	0	0	50	0	0	0	7
Submersed												
LASAL01	Ceradem	0	0	0	0	0	0	0	0	0	10	1
LASAL01	Charspp	0	0	0	0	0	0	0	40	0	0	4
LASAL01	Myrispp	100	50	0	0	0	0	100	60	30	70	41
LASAL01	Potazos	0	0	100	0	0	100	0	0	40	20	26
LASAL01	Stucpec	0	50	0	0	100	0	0	0	30	0	18

A4-4. Example of SAV data entry and management spreadsheet.

This provides the complete information needed to calculate all the SAV metrics. Assume the floating species was already normalized because there was only one species found. “Veg form” refers to vegetative form of the species and is coded as “sub” for submersed vegetation or “fl” for floating vegetation. “Alk tol” refers to alkalinity tolerance and “Pot spp” refers to whether or not the species is in the genus *Potamogeton*.

Pond ID	Species Code	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Avg	Veg form	Alk tol	Pot spp
LASAL01	Lemnmin	0	10	0	10	0	0	50	0	0	0	7	fl	n	n
LASAL01	Ceradem	0	0	0	0	0	0	0	0	0	10	1	sub	n	n
LASAL01	Charspp	0	0	0	0	0	0	0	40	0	0	4	sub	y	n
LASAL01	Myrispp	100	50	0	0	0	0	100	60	30	70	41	sub	n	n
LASAL01	Potazos	0	0	100	0	0	100	0	0	40	20	26	sub	y	y
LASAL01	Stucpec	0	50	0	0	100	0	0	0	30	0	18	sub	y	n

Richness of floating spp. = 1

% cover of floating spp. = 7

Relative biovolume of *Potamogeton* spp. = 26

Relative biovolume of alkali-tolerant spp. = 48

Relative biovolume of *C. demersum* = 1

Appendix 5. Candidate metrics in the plant-based performance indicators.

A5-1. Sub-sample of promising metrics tested during the development of the SAV-IBI.

Those metrics that had a statistically significant linear relationship to the SGI and could be incorporated into future iterations of the SAV-IBI are indicated with a "Y." Note that including metrics that have correlated errors may reduce the sensitivity of the IBI to the SGI and will inflate error in estimates of wetland condition.

Metric	F-value	R^2	p-value	Suitable for use	Mean	Range
Relative biovolume of halophytes	17.1	0.30	< 0.001	Y	15.18	100
Proportion of halophytes	16.3	0.29	< 0.001	Y	13.16	100
Proportion of alkali-tolerant species	15.5	0.28	< 0.001	Y	18.33	100
Relative biovolume of alkali-tolerant species	14.9	0.27	< 0.001	Y	20.54	100
Relative biovolume of *C. demersum*	12.5	0.24	<0.01	Y	19.05	100
Proportion of floating species	11.3	0.22	<0.01	Y	16.58	93
Relative biovolume of *Chara spp.*	9.7	0.19	<0.01	Y	7.91	100
Floating species richness	9.2	0.19	<0.01	Y	1.29	4
Relative biovolume of floating species	8.6	0.18	<0.01	Y	28.54	66.7
Proportion of *C. demersum*	7.7	0.16	<0.01	Y	48.61	100
Proportion of *Chara spp.*	5.2	0.12	0.03	Y	8.77	100
Presence/Absence of *R. cirrhosa*	4.7	0.10	0.04	Y	0.00	0
Proportion of rare taxa	3.9	0.09	0.06	N	3.63	90
Proportion of common taxa	3.9	0.09	0.06	N	96.37	90
Relative biovolume of annuals	3.3	0.08	0.07	N	0.24	9.1
Relative biovolume of *P. pusillus*	0.3	0.06	0.11	N	100.00	0
Relative biovolume of *U. macrorhiza*	2.6	0.06	0.11	N	7.36	50
Relative biovolume of carnivorous plants	2.6	0.06	0.12	N	8.06	50
Proportion of annuals	2.5	0.06	0.12	N	0.00	0.1
Proportion of perennials	2.5	0.06	0.12	N	91.50	100
Overall SAV density	2.5	0.09	0.12	N	3.11	3
Proportion of sparse leaved SAV	2.4	0.06	0.13	N	0.34	6.5
Proportion of *U. macrorhiza*	2.1	0.05	0.15	N	11.97	100
FQAI	2.0	0.05	0.17	N	7.55	15.7
Number of rare taxa	1.6	0.04	0.21	N	0.16	2

Relative biovolume of sparse leaved plants	1.4	0.03	0.24	N	1.89	25
Proportion of carnivorous plants	1.4	0.03	0.25	N	12.18	100
Relative biovolume of rare taxa	1.3	0.03	0.26	N	3.16	50
Relative biovolume of common taxa	1.3	0.03	0.26	N	96.84	50
Relative biovolume of monocots	1.1	0.03	0.30	N	50.96	100
Relative biovolume of dicots	1.1	0.03	0.30	N	43.77	100
Proportion of *Potamogeton spp.*	1.0	0.02	0.32	N	14.23	100
Proportion of monocots	1.0	0.02	0.33	N	18.70	100
Median SAV density	0.9	0.02	0.34	N	3.36	4
Shannon-Weiner evenness	0.7	0.02	0.40	N	0.45	1.0
Sum of coefficient of conservatism values	0.7	0.02	0.40	N	16.82	52
Relative biovolume of perennials	0.6	0.01	0.46	N	99.76	9.1
Proportion of *Myriophyllum spp.*	0.6	0.01	0.46	N	2.28	45.6
Presence/Absence of aquatic moss	0.5	0.01	0.47	N	0.11	1
Shannon-Weiner diversity	0.5	0.01	0.48	N	0.56	1.4
Shannon-Weiner entropy	0.5	0.01	0.49	N	1.95	3.0
Relative biovolume of *Myriophyllum spp.*	0.5	0.01	0.50	N	3.06	25
Proportion of dicots	0.5	0.01	0.50	N	81.30	100
Gini-Simpsons diversity index	0.4	0.01	0.53	N	1.65	3.9
Richness of SAV species	17.1	0.30	0.57	N	3.13	8
Shannon Entropy/Gini-Simpsons Index	16.3	0.29	0.57	N	1.13	0.4
Gini-Simpsons diversity	15.5	0.28	0.59	N	0.31	0.7
Number of species in all quadrats	14.9	0.27	0.61	N	2.76	8
Proportion of *P. pusillus*	12.5	0.24	0.63	N	7.75	98.5
Mean coefficient of conservatism value	11.3	0.22	0.64	N	3.89	5.6
Median coefficient of conservatism value	9.7	0.19	0.65	N	4.05	6
Hmax	9.2	0.19	0.66	N	0.92	2.1
Relative biovolume of *Potamogeton spp.*	8.6	0.18	0.74	N	14.71	100
Richness of SAV and floating species	7.7	0.16	0.78	N	4.39	11

A5-2. A sub-sample of the candidate metrics tested during the development of the WM-IBI.

Those metrics that had a statistically significant linear relationship to the SGI and could be incorporated into future iterations of the WM-IBI are indicated with a "Y." Note that metrics that have correlated errors may reduce the sensitivity of the IBI to the SGI.

Metric	F-value	R^2	p-value	Suitable for use	Mean	Range
Log10 wet meadow width	16.9	0.37	< 0.001	Y	26.54	62.7
Wet meadow width	10.2	0.26	< 0.001	Y	26.54	62.7
Wet meadow biomass	9.6	0.25	< 0.001	Y	578.60	748.3
Robel pole biomass	9.6	0.25	< 0.001	Y	51.48	44.5
Adjusted FQI	9.3	0.33	< 0.001	Y	40.63	30.1
Richness of introduced species	9.3	0.24	< 0.001	Y	0.66	2
Proportion of introduced species	8.4	0.22	< 0.001	Y	0.04	0.1
Average CC values	8.2	0.22	< 0.001	Y	4.15	3
Proportion of weeds	7.1	0.20	0.01	Y	0.11	0.3
%Cover of facultative wetland and obligate species	6.7	0.19	0.01	Y	56.61	84.1
Relative cover of stress-tolerant species	6.0	0.17	0.02	Y	0.31	1
Relative cover of facultative wetland and obligate species	5.8	0.17	0.02	Y	0.88	0.7
Adjusted FQI excluding exotics	5.6	0.16	0.03	Y	42.44	30
%Cover of native species	5.5	0.16	0.03	Y	60.67	72.7
WM total percent cover	5.4	0.16	0.03	Y	61.89	72.5
Proportion of stress-tolerant species	4.5	0.13	0.04	Y	0.29	1
Relative cover of introduced species	4.1	0.12	0.05	N	0.01	0.1
Relative cover of native species	4.0	0.12	0.06	N	0.97	0.2
Richness of weeds	3.8	0.12	0.06	N	1.80	6
FQI	3.7	0.11	0.06	N	14.79	25.8
Richness of stress-tolerant species	3.3	0.10	0.08	N	3.86	10
%Cover of obligate species	3.2	0.10	0.08	N	45.24	79.0
Proportion of native species	3.0	0.09	0.09	N	0.98	0.2
Average CC values excluding exotics	2.9	0.09	0.10	N	4.34	3
Proportion of facultative upland species	2.7	0.08	0.11	N	0.10	0.3
FQI excluding exotics	1.7	0.05	0.21	N	15.48	25.8
%Cover of stress-tolerant species	1.6	0.05	0.21	N	19.62	80
Proportion of facultative wetland and obligate species	0.9	0.03	0.35	N	0.76	0.6
Richness of facultative upland species	0.8	0.03	0.38	N	1.69	7

%Cover of introduced species	0.7	0.02	0.40	N	0.55	4.2
Relative cover of obligate species	0.7	0.02	0.41	N	0.69	0.9
Richness of native species	0.7	0.02	0.42	N	14.23	27
Richness of obligates	0.6	0.02	0.46	N	7.29	13
Proportion of obligates	0.5	0.02	0.48	N	0.56	0.7
Richness of facultative wetland and obligate species	0.5	0.02	0.49	N	10.57	20
Species richness	0.2	0.01	0.68	N	14.89	28

Appendix 6. Recommended field guides for plant identification

Johnson, J.D., Kershaw, L.J., MacKinnon, A., Pojar, J. 1995. Plants of the western boreal forest and aspen parkland. Lone Pine Publishing, Edmonton, Alberta.

Lahring, Heinjo. 2003. A guide to water and wetland plants of the prairies. Canadian Plains Research Center, University of Regina, Regina, Saskatchewan.

Moss, E. H. and Packer, J. G. Flora of Alberta 2nd Ed., 1983. University of Toronto Press, Toronto, Ontario.

Appendix 7. Site locations of marshes sampled and scores of marsh condition

A7-1. Locations and performance indicator scores of sites evaluated using the three performance indicators between 2007 and 2009.

REF = reference sites, OSREF = oil sands reference sites, OSPA = oil sands process-affected sites. Good condition for the SGI is < 52; for the SAV-IBI score is > 37 for the WM-IBI is > 66; and for the sum of all scores (called the MCI) is > 54. Poor condition is less than those numbers.

POND_ID	TYPE	LAT	LONG	SGI score	SAV-IBI score	WM-IBI score	MCI
1440 LAC LA BICHE	REF	54.9586	-111.8642	49	58	74	61
171 UTIKUMA	REF	55.9827	-115.1926	34	77	80	74
19 UTIKUMA	REF	56.0827	-115.5383	43	60	75	64
207 UTIKUMA	REF	56.1254	-115.7044	40	47	80	62
BARRHEAD REF4	REF	53.7169	-114.6809	22	49	67	65
BIRCHBAY	REF	53.6114	-105.8949	36	64	98	75
BLACKFOOT1	REF	53.5284	-112.7904	41	62	79	67
BLACKFOOT2	REF	53.5162	-112.8491	51	70	86	69
CL 4C	REF	58.4226	-116.5512	43	63	75	65
CL 4D	REF	58.4241	-116.5519	55	72	79	65
CL 5 (2008)	REF	58.4200	-116.5401	49	49	90	63
CL SOUTH	REF	58.4207	-116.5453	39	82	83	75
CL WEST	REF	58.4243	-116.5593	31	91	100	86
CLWP 68	REF	58.4253	-116.5499	31	88	100	86
CW REF5	REF	55.1148	-119.8518	20	32	78	63
ELK ISLAND 2	REF	53.5235	-112.9250	31	64	56	63
ELK ISLAND 2B	REF	53.5229	-112.9315	32	59	78	68
ELK ISLAND SOAP	REF	53.6058	-112.8078	25	57	72	68
GRIMSHAW REF 1	REF	56.1591	-118.2194	27	45	60	59
HAY 2	REF	59.1043	-118.0574	48	0	84	45
HAY RIVER 1	REF	59.1077	-118.0473	27	59	80	71
HAY RIVER 2	REF	59.1100	-118.0785	54	33	79	53
HAY RIVER 3	REF	59.1085	-118.0813	42	31	79	56
JULIEN LAKE	REF	54.0335	-111.2917	57	42	61	49
LASALINE 1	REF	57.0701	-111.5124	75	39	69	44

LAC LA BICHE REF 5	REF	54.6412	-111.5113	29	69	75	72
LAC LA BICHE REF 7	REF	54.6527	-111.6012	29	63	83	72
MIQUELON 1	REF	53.2460	-112.8843	48	73	90	72
MIQUELON 2	REF	53.2450	-112.8813	47	51	68	58
MIQUELON 3	REF	53.2498	-112.8782	52	11	59	39
MIQUELON 23	REF	53.2355	-112.8779	46	91	92	79
MIQUELON 36	REF	53.2334	-112.8692	44	83	66	69
OBH 4	REF	53.8771	-114.2209	41	41	72	58
OGS 1	REF	56.4078	-117.6653	19	100	70	84
YOUNGS	REF	55.1479	-117.5880	35	72	61	66
BILLS POND (2008)	OSREF	56.9989	-111.6121	57	43	60	49
CRANE LAKE	OSREF	56.9931	-111.5480	61	7	57	34
DEEP POND	OSREF	57.0797	-111.6860	66	36	53	41
GOLDEN POND	OSREF	56.9973	-111.6246	57	18	6	22
NW INTER	OSREF	57.1125	-111.6899	61	16	41	32
OSREF 1	OSREF	57.0576	-111.6952	61	25	16	27
OSREF 4	OSREF	56.9876	-111.5394	53	12	35	31
PEAT POND	OSREF	56.9937	-111.6238	59	28	28	32
S PIT	OSREF	57.1069	-111.6387	76	0	6	10
SALTMARSH	OSREF	56.9940	-111.5357	73	23	61	37
SHALLOW	OSREF	57.0811	-111.6913	56	35	52	44
SWSSBEAV	OSREF	56.9838	-111.7139	65	23	72	44
1 MCT	OSPA	56.9898	-111.5309	57	0	33	25
4 MCT	OSPA	56.9915	-111.5318	59	11	60	37
CELL 44	OSPA	56.9747	-111.7984	35	37	56	52
CELL 46 (2007)	OSPA	56.9955	-111.8015	56	21	55	40
DEMO POND	OSPA	57.0822	-111.6885	71	37	13	26
EAST TOEBERM	OSPA	57.0898	-111.6266	74	12	11	16
HISULPH (2008)	OSPA	56.9972	-111.5529	64	0	44	27
JANS POND	OSPA	56.9925	-111.5314	81	0	30	16
MIKES (2007)	OSPA	57.1117	-111.6814	91	0	25	11
MILLSEEP	OSPA	56.8930	-111.3758	74	21	26	24
SEEPAGE	OSPA	57.0999	-111.6392	88	32	51	32
SUNCORE NATURAL	OSPA	56.9804	-111.5110	57	13	52	36
TEST POND 9	OSPA	57.0843	-111.6923	83	11	0	9

Appendix 8. Performance indicator development schematics

Figure A8-1. Steps used in the development of the SGI.

Figure adapted from Rooney and Bayley (2010).

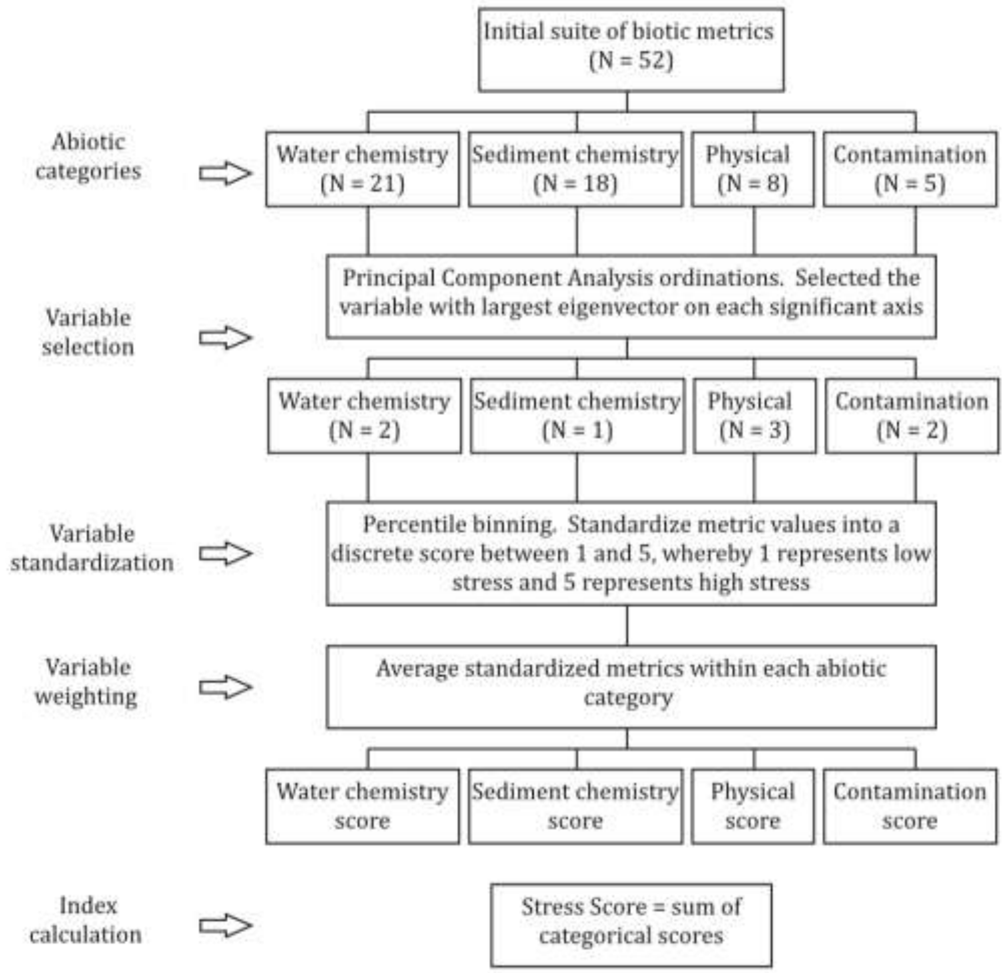
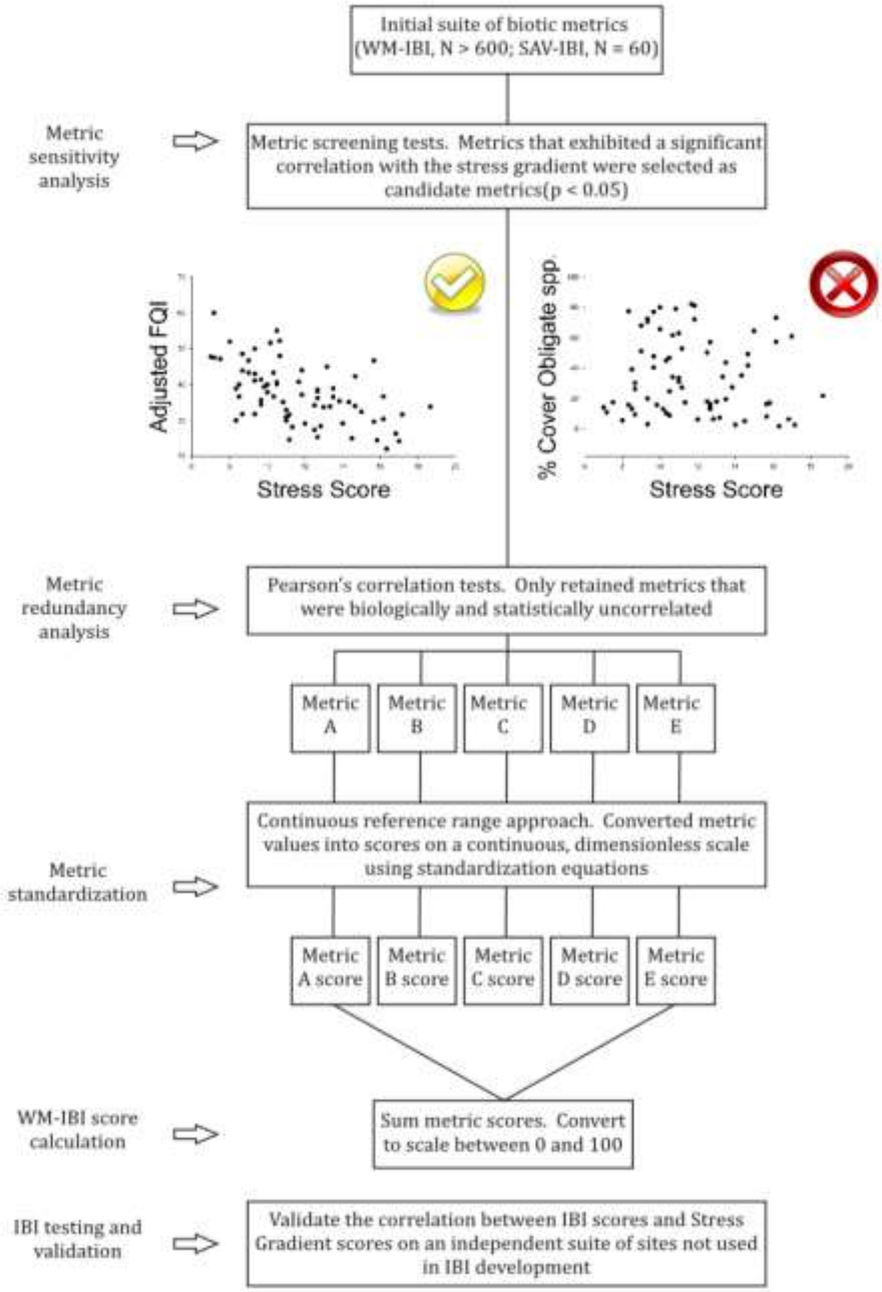


Figure A8-2. Schematic of development process used to develop the WM-IBI and SAV-IBI.

The adjusted FQI is a metric measuring the floristic quality within the wet meadow of a marsh.



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