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Executive Summary

The review of the Wood Buffalo ecological integrity monitoring system focused on indicators in the Peace Athabasca Delta (Freshwater and Wetland) but extended beyond this focus to remotely sensed measures in the Forest indicator and an overall assessment of the program. In general, the duration and quality of the data collected was excellent. Because of some of the issues at stake, the park has been reluctant to draw conclusions from the data available. Here, we provide clear thresholds and some detailed background analyses of the characteristic features of these vast and dynamic ecosystems.

Operational reviews and the standards to which programs are compared are described in the Consolidated Guidelines for Ecological Integrity Monitoring in Canada’s National Parks.

The Freshwater Indicator is currently assessed on the basis of a single measure (Contaminants in waterbird eggs). We provide thresholds and assessments for three more, including River Discharge, River Water Quality and Freshwater Macroinvertebrates. The revised assessment of this indicator would remain in good condition. The amount and quality of water in the PAD is central to the Strategic Environmental Assessment that is currently being undertaken with regards to the delta. They are also the subject of some advanced research by ECCC and other partners. We are committed to assessing ecological integrity based on current evidence but open to improving our monitoring in light of this research.

The Wetland indicator is currently assessed as being in fair condition. Our recommended changes in Muskrat, Water extent and Marsh birds would likely revise this assessment to good condition. We also provide detailed analyses of Bison data for the park, which is considered to be in fair condition in comparison to the period following wolf control.

The Forest indicator has received less attention in recent years and we recommend a consolidation of the various measures of landscape change. We strongly recommend that the fire component of such a landscape measure use the standard Area Burned Condition Class approach, which yields one of the best condition scores of any fire-prone park in the system. We also recommend that a combination of moose surveys, wildlife camera data and automatic recording units for bird song would provide a more engaging and representative assessment of forest condition.

In sum, Wood Buffalo National Park represents a productive and diverse assemblage of northern boreal species and processes. This review will put the park in a position to engage its indigenous knowledge holders, work with partners and report to Canadians on the ecological integrity of this outstanding national park.
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Introduction

Wood Buffalo National Park (WBNP) contains dynamic ecosystems that are strongly influenced by bottom up processes such as flooding and fire and top down processes such as wolf predation. The ecosystems are also influenced by the spread of non-native plant species and disease. WBNP has a long history of applied research and monitoring to understand how these and emerging stressors affect ecosystems. Moreover, much of the research and monitoring was implemented in collaboration with locals, stakeholders, and universities because of its regional importance. Long-term ecological data are relatively rare and very valuable and WBNP should be commended for steadily improving the robustness of each measure.

In December 2014, a petition was sent to the World Heritage Committee to include WBNP on the List of World Heritage in Danger. The Monitoring and Ecological Information Division (MEI Division) has been requested to support the field unit in the preparation of a mission from UNESCO that will examine this petition. For this purpose the MEI Division reviewed the ecological integrity monitoring program of the park and analyzed data on vegetation, muskrats, water extent and waterfowl in the Peace Athabasca Delta area in relation to the influence of flow regulation and oil sands development and extraction activities.
Reviews of the EI Indicators

**Forest Indicator**

To be comprehensive, an ecosystem indicator needs to track change in the main drivers and biodiversity components that are currently or can be potentially affected by the main EI issues in a park. The following major forest ecosystem drivers, components and issues have been identified during discussions with representatives of the resource conservation service of Wood Buffalo National Park:

1) The major drivers of the natural disturbance regime in the park at the landscape scale are fire, followed by climate and insect outbreaks. These drivers are mainly affected by climate change. In the past, fire was affected by management practices (e.g. fire suppression), and the effect of climate on the fire regime was likely obscured in past decades.

2) Moose is a major browser in the park, and the species is known to affect plant communities when it reach high density during a long period of time. The population is currently regulated by first nations hunting and predation, mainly from Wolf, and apparently haven’t never reached very high density in the past. In turn, Moose could regulate the population dynamics of the Wolf, although this relationship have not yet been studied in details in the park.

3) Bison is also an important browser in the park. However, Bison spend a significant proportion of time in other ecosystems, and their influence on the natural dynamics of the forest is uncertain. This influence is suspected to be relatively low and likely less significant than the influence of Moose at the forest ecosystem level. Bison abundance is influenced notably by bovine disease (TB, brucellosis, and anthrax) and is likely regulated by wolf predation.

4) Snowshoe Hare is another browser, but its influence on plant community’s dynamics is likely relatively localised, and last only a few years during high density period of the population cycle. Nevertheless, Snowshoe Hare regulate the population dynamics of some birds of prey as well as of medium sized carnivores, such Pine Marten, Fisher, and Lynx. These carnivores are important furbearer species for the traditional and ongoing pelt harvest by indigenous people.

5) Main key forest plant species, i.e. species that define the plant community, are Black and White Spruce, Aspen, and Jack pine. The abundance and distribution of these species are mainly determined by fire and possibly insects. Moose browsing will affect these key species only when the population reach a very high density during a relatively long period of time (a few decades).

6) Site action plan have not been established in WBNP, so no population & distribution objectives for species at risk (SAR) have been set so far. Two SAR will potentially be listed as a high priority in the park, i.e. Wood Bison and Woodland Caribou. The role of these species as drivers of the natural dynamics of the forest ecosystem is uncertain and/or likely low. Therefore, integrating the status of these species in the EI condition assessment would not provide meaningful information.

7) Main EI issues are related to the effects of climate change on the main drivers of natural disturbance. Human activities associated with oil sands development outside the park are likely to have limited impact on the forest ecosystem of WBNP. Habitat fragmentation resulting from
landscape change outside are not likely to have an important effects on the animal community of the forest ecosystem, given the large size of the park.

The current forest indicator of WBNP includes the following measures:

1) Plant Productivity and Growing Season Change
2) Fire Frequency
3) Forest Insects and Diseases
4) Snowshoe hare
5) Forest Composition

Two of main drivers of natural disturbance in the park, i.e. fire & insects, are directly measured by “Fire Frequency” and “Forest Insects and Diseases”. The third driver, climate, and the EI issue related to climate change, is also covered by these two measures, as well as by “Plant Productivity and Growing Season Change”.

Table 1: Overview of Forest Indicator

<table>
<thead>
<tr>
<th>Measure</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>Current Value</th>
<th>Status</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Productivity and Growing Season</td>
<td>33</td>
<td>66</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>Good</td>
<td>Stable</td>
</tr>
<tr>
<td>Green Up Date</td>
<td>Apr. 2</td>
<td>Apr. 17</td>
<td>May 18</td>
<td>June 2</td>
<td>May 2</td>
<td>Good</td>
<td>Stable</td>
</tr>
<tr>
<td>Brown Down Date</td>
<td>Sept. 17</td>
<td>Oct. 4</td>
<td>Nov. 6</td>
<td>Nov. 23</td>
<td>Oct. 10</td>
<td>Good</td>
<td>Stable</td>
</tr>
<tr>
<td>Large Integral NDVI (productivity)</td>
<td>1302</td>
<td>1524</td>
<td>1968</td>
<td>2190</td>
<td>1606</td>
<td>Good</td>
<td>Stable</td>
</tr>
</tbody>
</table>

Comment: Productivity and growing season are healthy in comparison to 2001-10 baseline

| Fire frequency (% departure from historic) | -        | -        | 33%      | 67%      | 3.7%          | Good   | Stable|

Comment: Currently in ICE the park is reporting fair condition based on a non-standard fire frequency threshold.

| Forest Insects and diseases (% of park affected) | -        | -        | 1%       | 10%      | 1.06%         | Fair   | N/A   |

Comment: Incorporate into Landscape Change measure.

| Snowshoe hare (hare/ha)                | 1        | 2        | -        | -        | 2.08          | Good   | N/A   |

Comment: Relevant and sustainable measure. Not reviewed in this study.

| Forest Composition (SD from previous)  | Mean-2SD | Mean-1SD | Mean+1SD | Mean+2SD | -              | N/A    | N/A   |

Comment: Placeholder thresholds. Recommend replacement with Landscape Change measure incorporating fire frequency and insect/disease damage.
Monitoring the dynamics of the Snowshoe Hare population is relevant, given the predator-prey relationships this species have with many other species. It is a key animal species of the boreal forest in the park, as any disruption of the hare population cycle would affect the population dynamics of a significant number of predators, including some furbearer species harvested by local first nation communities.

WBNP was created to represent two different natural regions, i.e. The Northern Boreal Plains and The Southern Boreal Plains and Plateaux. The measure “Forest composition” will help assess the level of the representivity of the park to these natural regions. Any modification in the drivers of the natural disturbance regime could lead to a change in the composition and age structure of the forest ecosystem over the long term. This change could lead, in turn, to a modification in the abundance and distribution of native species in the park. This type of landscape measure is common to many parks as it provide information and message on the EI condition of the forest ecosystem that are easily understood by managers and general public. However, the main available source of information describing the forest composition in the park comes from Landsat imagery that can only provide relatively coarse cover type classification with no detailed information on the age structure. Cumulative mapping of forest fires would provide information over the long term, but this mapping will only be informative after a few decades of monitoring. Setting meaningful thresholds on this measure would also require a better understanding of influence of natural disturbance on forest composition although traditional ecological knowledge (TEK) from local communities could possibly provide some insights. For these reasons, the MEI division recommends to remove the Forest composition measure from the monitoring program of WBNP until more informative and comprehensive forest cover classification is available in the park.

In general, the selected measures cover many of the significant drivers and biodiversity component of the forest ecosystem. Nevertheless, four out of five measures are based on remote-sensing, and Fire Frequency, Forest Insects and Disease, and Forest Composition are all essentially metrics that are derived from a forest land cover change product. This indicator therefore lacks field measurements which usually provides more detailed information at a different scale than landscape change measures.

For instance, Moose is not represented in this indicator, although it is a major driver and biodiversity component of the forest ecosystem. Moose management in WBNP is a sensitive issue due to the first nation traditional hunting regulated by treaty rights and agreements with local communities. Subsistence hunting have been practiced by first nations since long before WBNP was created, and the effects of this harvest on wildlife population can be considered as part of the natural dynamics of the park ecosystems. Tracking change in moose demography is expensive in a park the size of WBNP. Engaging local Aboriginal groups in research and monitoring programs is one of the action related to the key strategy “Towards a shared vision” presented in the park management plan. If the park does not have the capacity to implement a formal monitoring project, information on the trends of the moose population could possibly be obtained from hunters. This can also be an opportunity to integrate TEK from local communities in thresholds establishment for a moose status measure.
At least two other field-based measures could be considered for this indicator. For instance, change in the bird community could be related to change in forest composition, and possibly to insect outbreaks events. Forest bird community could be tracked using Automated Recording Units (ARU) methodology, similar to the approach used to monitor the bird community in the Wetland indicator. Also, wolf occurrence and occupancy could be monitored using wildlife cameras. Both ARU and cameras could be deployed along the road network of the park, although it provides access only to a limited proportion of the territory. Basically, camera traps could be set along wildlife trails located near access road. Some other species, such as black bear, moose, bison and lynx could eventually be detected with these cameras. ARU units for birds could also be set on some of the camera sites to increase field work efficiency. The MEI division can assist the resource conservation service of the park in developing the monitoring questions and sampling design for these two measures if help is needed.

Integrating new measures in the program will depend on the relative priority of the issues related to birds, moose and wolf in comparison with the other issues covered by the existing measures. Adding new measures in the indicator will imply to rearrange the suite of measures in order to comply with the “5 measures per indicator” standard of the program. This could be done by removing a measure or merging measures together. For instance, Fire Frequency and Forest Insects & Diseases could be merged into one composite measure called Landscape change. This modification could provide the opportunity to include 2 new measures in the indicator. Also, moose and wolf measures could possibly be merged in a measure called “Moose-Wolf dynamics”.

The comprehensiveness of the EI condition assessment of the forest ecosystem would therefore be enhanced if the indicator includes the following suite of measures:

1) Landscape change
2) Snowshoes hare
3) Moose-Wolf dynamics
4) Bird community
5) Plant Productivity and Growing Season Change

Reviewed by Claude Samson, with revisions by Paul Zorn and Wanli Wu
**Freshwater Indicator**

The Freshwater indicator for Wood Buffalo National Park is comprised of 5 monitoring measures (Table 2): 1. Contaminants in colonial waterbird eggs, 2. Freshwater macroinvertebrates, 3. Lake ice phenology, 4. River discharge, and 5. River water quality. The measures with updated assessments (2/5) indicate a Freshwater indicator that is in Good condition with a Stable trend. New macroinvertebrate and water quality assessments will become available within the 2016/17 fiscal year at which time the assessment for WBNP’s Freshwater indicator should be updated.

Table 2: Overview of the Freshwater indicator

<table>
<thead>
<tr>
<th>Measure</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>Current Value</th>
<th>Status</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contaminants in colonial waterbird eggs</td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
<td>0.35 μg/g</td>
<td>Good</td>
</tr>
<tr>
<td>Freshwater macroinvertebrates</td>
<td>33</td>
<td>66</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>Good</td>
<td>N/A</td>
</tr>
<tr>
<td>Lake ice phenology</td>
<td>Mean-2sd</td>
<td>Mean-1sd</td>
<td>Mean+1sd</td>
<td>Mean+2sd</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>River discharge</td>
<td>33</td>
<td>66</td>
<td>-</td>
<td>-</td>
<td>93</td>
<td>Good</td>
<td>Stable</td>
</tr>
<tr>
<td>River water quality</td>
<td>65</td>
<td>79</td>
<td>-</td>
<td>-</td>
<td>68</td>
<td>Fair</td>
<td>Stable</td>
</tr>
</tbody>
</table>


Comment: Partnership with the Regional Aquatic Monitoring Program. Data available from 2003 to 2013. Trend analysis on data compiled for the park still to be completed. Composite measure with Simpson equitability and %pollution-sensitive measurements.

Comment: A new monitoring measure for the park based on Radarsat2 imagery. MEI has incorporated WBNP’s needs for this measure into the Radarsat2 annual tasking schedule. As data becomes available this measure will be updated.

Comment: Partnership with the Water Survey of Canada. Six water flow stations exist within the park area although only 3 provide consistent data. Composite measure with water flow magnitude, duration, timing, frequency, flashiness, freeze-up flow, and break-up flow.

Comment: Partnership with Environment Canada through the Joint Oilsands Monitoring Program. This measure will be updated pending the current analysis from Environment Canada.

As per the “Consolidated Guidelines for Ecological Integrity Monitoring in Canada’s National Parks” (Parks Canada, 2011) indicators of ecological integrity should be developed such that they produce information that is credible, sustainable and useful. This brief review will discuss WBNP’s Freshwater indicator in this context.

**Credible**

Ecological integrity indicators should represent major aspects of ecosystem biodiversity, key processes, and stressors (Table 3). The biodiversity of the Freshwater ecosystem is represented in WBNP’s monitoring program through the Freshwater Macroinvertebrate measure. Benthic
Macroinvertebrates are key contributors to lower trophic levels in freshwater ecosystems and play a vital role in food web dynamics. Key processes of the Freshwater ecosystem are represented by River Discharge and Lake Ice Phenology measures. River discharge is associated with the hydrological processes of the Peace-Athabasca Delta that effect water quantity, flooding, and habitat amount for freshwater species. Lake ice phenology is sensitive to climate change and may indicate potential responses to global warming. Stressors are represented by Contaminants in Colonial Waterbird Eggs, River Discharge and River Water Quality. These measures are sensitive to potential hydrological alteration from regional-scale resource development including the W.A.C. Bennett Dam on the Peace River. These measures are also sensitive to potential changes in freshwater pollutants such as heavy metal and organic and non-organic contaminants that may occur through oil sands development.

Table 3: Representation of the measures to the ecological integrity of the Freshwater indicator.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Biodiversity</th>
<th>Key Processes</th>
<th>Stressors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contaminants in colonial waterbird eggs</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Freshwater macroinvertebrates</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake ice phenology</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>River discharge</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>River water quality</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sustainable

Based on WBNP’s costed monitoring plan (2014) the average annual cost to implement the ecological integrity monitoring program for the Freshwater indicator is 38 person days and $3675. This represents approximately 1/3 of the total program in terms of field unit staff time and 10% in terms of fixed costs. This level of investment is appropriate for the Freshwater indicator given the higher costs associated with other measures within the park’s monitoring program (ie, bison productivity). The Freshwater indicator is considered to be operational sustainable and capable of generating consistent data into the long term.

Useful

Monitoring measures are useful when they are supported by comprehensive study designs with sufficient sample sizes to detect changes with low error rates. Study designs for all Freshwater measures were developed in association with park partners. The park has effectively engaged partners ensuring the park’s monitoring program takes advantage of regional-scale monitoring efforts from other agencies. Freshwater Macroinvertebrates, River Discharge, and River Water Quality all represent measures that are implemented in association with partners and larger-scale monitoring programs. Contaminants in Colonial Waterbird Eggs is also conducted with partners but currently the sampling is limited to two sites which may be insufficient to incorporate spatial variability at the scale of the park. Lake Ice Phenology has the potential to generate useful information but is currently nonoperational until sufficient Radarsat2 imagery is acquired.
Overall, WBNP’s Freshwater indicator is successful in meeting the national consolidated guidelines for monitoring. It contains 5 measures that possess protocols, thresholds and the ability to provide meaningful status and trend assessments. Although some measures are at the early stage of development this indicator is well positioned to provide information that is credible, sustainable and useful. A potential gap is that freshwater ecosystem biodiversity is currently represented by Freshwater Macroinvertebrates only. No high level trophic species or community (ie, piscivorous fish) is represented within the program. High level trophic species, such as a top predator, are considered to be umbrella species that are useful in assessing cumulative effects within an ecosystem. However, monitoring high level trophic species are often labour-intensive and expensive and may be beyond the park’s capacity for this indicator. If the Lake Ice Phenology measure ends up becoming non-operational due to the lack of consistently available Radarsat2 data then WBNP should consider replacing this measure with one that focuses on the abundance and distribution of a representative high trophic level species (ie, lake trout).

Recommendation: In the event that Lake Ice Phenology becomes non-operational the park should investigate adding a new measure that focuses on a high level trophic freshwater species (ie, lake trout). Adding a new measure such as this will require a careful examination in the compromise between sampling method, site selection, sample size, cost and level of effort. If an affordable solution can be found this would be a beneficial addition to the park’s monitoring program.

Reviewed by Paul Zorn
**Wetland Indicator**

The Peace-Athabasca Delta (PAD) occupies a large portion of WBNP and has historically been subject to large-scale flooding events. Since the building of the Bennett Dam in 1968, there is concern that the water flow control could affect the frequency, duration, and severity of floods. The influence of flooding has been analysed as part of the review of three measures, i.e. PAD Vegetation Change, Muskrat Abundance, and Bison Productivity & Abundance. Consistent with the current understanding of ecological processes we found that floods reduced the distribution of tall shrubs and then the distribution of tall shrubs increased with time since last flood and over time generally. Similarly, the distribution of non-native thistle species decreased during floods and then increased with time since flood and over time generally. Muskrat relative abundance increased dramatically after floods and then declined for two years following floods. Floods were thought to affect bison two ways: first high rates of mortality have been observed as bison fell through ice but bison are also thought to be able to simply move out of the PAD to other regions; and second increased shrub cover from lack of floods was thought to reduce the amount of high quality available to bison. We found the bison population growth rates were lower in the Delta during flood years but could not definitively determine why growth rates decreased during floods (e.g. adult mortality vs emigration). Floods did not significantly affect yearling survival rates and but we found a marginal increase in the growth rates of other bison populations during floods. While WBNP might tweak methods used to assess the status of each measure, data collection methods to date are generally sound, measured at the appropriate scale, respond to stressors, and can be used to assess the Wetland Indicator for state of the park reporting.

Wood Buffalo National Park’s Wetland indicator consists of five measures:

1) Marsh Birds and Amphibians
2) Water extent in the Delta
3) Muskrat abundance
4) Bison Productivity & Abundance
5) Vegetation Change in the Peace-Athabasca Delta

The level of comprehensiveness of this indicator is relatively high, as it cover major biodiversity components (vegetation communities, birds, amphibians, muskrats, and bison), as well as a main driver i.e. water retention/regulation. The absence of monitoring of the whooping crane and their breeding habitat seems like an important omission however, as this species is one of the Outstanding Universal Values justifying the UNESCO status, and an endangered species under the Canadian SARA. The main stressors also appear to be well captured within the measures, i.e. climate change (water extent and vegetation change), invasive species (vegetation change), and water retention/regulation (water extent). Water contamination is also another stressor but it is addressed in the freshwater indicator. The indicator also includes a mix of small scale field measurements and landscape remote-sensing metrics, which cover a variety of scale and contribute to enhance the comprehensiveness of the condition assessment.
Table 4: Overview of the Wetland indicator

<table>
<thead>
<tr>
<th>Measure</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>Current Value</th>
<th>Status</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marsh Birds and Amphibians (missing reference species)</td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Poor</td>
<td>1 spp</td>
<td>Poor</td>
<td>N/A</td>
</tr>
<tr>
<td>Comment: Recommend including waterfowl but excluding amphibians.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>More specific thresholds have been developed in light of long-term data.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water extent in the delta (Maximum coverage for given year)</td>
<td>33.36%</td>
<td>43.50%</td>
<td>63.79%</td>
<td>73.97%</td>
<td>45.00%</td>
<td>Good</td>
<td>Stable</td>
</tr>
<tr>
<td>Comment: First time that this measure has been assessed. A strong monitoring measure that has been consistently implemented for a 20 year period.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muskrat abundance (Maximum # of houses/basin in past 8 years)</td>
<td>42</td>
<td>84</td>
<td>-</td>
<td>-</td>
<td>200</td>
<td>Good</td>
<td>N/A</td>
</tr>
<tr>
<td>Comment: First time that this measure has been assessed. Combines known cycle with thresholds based on the 75th percentile (T2) of counts in the last 43 years.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bison abundance and productivity</td>
<td>33</td>
<td>66</td>
<td>-</td>
<td>-</td>
<td>60</td>
<td>Fair</td>
<td>N/A</td>
</tr>
<tr>
<td>Bison abundance</td>
<td>2262</td>
<td>3554</td>
<td>6139</td>
<td>7431</td>
<td>2200</td>
<td>Poor</td>
<td>Down</td>
</tr>
<tr>
<td>Calf survival</td>
<td>20.6%</td>
<td>50.6%</td>
<td>70%</td>
<td>70%</td>
<td>Good</td>
<td>Stable</td>
<td></td>
</tr>
<tr>
<td>Comment: Though ICE currently lists this measure as in Good condition on the basis of calf productivity, overall numbers are down. Thresholds for both are provided here.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation change in the Peace Athabasca Delta</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>25</td>
<td>17</td>
<td>Fair</td>
<td>Down</td>
</tr>
<tr>
<td>Comment: Current measure is based on invasive plants only. Analyses for tall shrubs are provided but thresholds would take further work.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The main shortcoming of this indicator is that all the monitoring measures are constrained into one area. The PAD is a defining feature of the park, a RAMSAR site of international importance, and a key reason for the UNESCO World Heritage designation for the park. However, it represents a minority of the wetland ecosystem of the park. This choice of focusing the monitoring on this area of the park is understandable given the limits on resources and the size of the park. Interpretation of the EI condition of the wetland ecosystem would have to be nuanced given this bias, and words of caution will have to be provided when presenting the results of monitoring in the state of the park report and management plan.

The program could be modified to reduce this bias. At least one measure, the Bison Productivity & Abundance, could be extended beyond the range of the PAD. We also recommend to implement a remotely sensed measure that would quantify the wetland surface area, by
wetland type for the entire park. This would give some insight into the status of wetlands as a whole for the park. This measure would have to be merged however with the vegetation change measure to comply with the program standards on the number of measure in an indicator.

Reviewed by Jesse Wittington, with revisions by Dan Kehler and Claude Samson.
Detailed measure review

Plant Productivity and Growing Season Change

**Monitoring Questions**

1) Is the two-year average in Green Up Date for WBNP April 17 (T2) or earlier?
2) Is the two-year average in Brown Down Date for WBNP November 6 (T3) or later?
3) Is the two-year average Large Integral NDVI for WBNP 1968 (T3) or higher?

*For simplicity, monitoring questions refer to the specific threshold that is likely to be crossed first.

**(Interim) Thresholds**

<table>
<thead>
<tr>
<th>Metric</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Up Date</td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Fair</td>
</tr>
<tr>
<td>Brown Down date</td>
<td>April 2</td>
<td>April 17</td>
<td>May 18</td>
<td>June 2</td>
</tr>
<tr>
<td>Large integral NDVI</td>
<td>1302</td>
<td>1524</td>
<td>1968</td>
<td>2190</td>
</tr>
</tbody>
</table>

*Thresholds based on a “Standard Deviation Interval” approach using values from 2000 to 2010 as the baseline period.

**Sampling frequency**

Annual

**Status & Trends Assessment Method**

Status: Comparison of most recent two-year average to established thresholds.
Trend: Generalized linear model.

**Review Summary**

This measure extracts plant phenology metrics from daily NDVI values generated from the MODIS satellite. The selected metrics for use in this measure are green up date, brown down date (which collectively gives trends in growing season length), and large integral NDVI (which estimates total plant productivity throughout an entire growing season). These data are made freely available through the USGS Phenology Toolbox and, therefore, represent a low cost monitoring measure for the park. Data are currently available from 2000 to 2012. Data for additional years will become available as imagery is processed and made accessible from the USGS Phenology toolbox database. Thresholds are based on standard deviation intervals from 2000 to 2010 which was selected as the baseline period. Initial assessments rate this measure as in Good condition with a Stable trend. The assessments, however, should be viewed as tentative due to a change in satellite processing method from USGS that began in 2008.

**Recommendations:**

1) WBNP follow up with MEI to ensure that this measure be reviewed again once USGS updates their Phenology Toolbox with re-processed post-2008 data.

Reviewed by Olivier Bérard, with revision by Paul Zorn

**Rationale of the measure**

Plant Productivity and Growing Season Change is a remote sensing based measure that uses the MODIS satellite to estimate daily NDVI (Normalized Difference Vegetation Index). NDVI, through multi-spectral reflectance, estimates leaf area and plant biomass. Change in plant productivity is a sensitive measure of climate change and can affect vegetation community composition, forage
quality for wildlife, and habitat availability. Daily NDVI values are used to generate a “NDVI curve” for each growing season for each year. During spring, as snow and ice melts and plants emerge, new plant growth will cause NDVI values to increase above zero. As the growing season progresses daily NDVI values will plateau in summer as vegetation reaches maximum productivity and full leaf expression. As autumn approaches plants begin to lose their leaves and become photosynthetically unproductive, at which point, NDVI values decrease down to zero once again as winter occurs. These characteristics of the NDVI curve are used to extract 3 field measurements for this monitoring measure. These field measurements are:

1. **Green Up Date**: The date in spring at which daily NDVI values begin to consistently increase.
2. **Brown Down Date**: The date in fall at which daily NDVI values finish decreasing and approach zero.
3. **Large Integral NDVI**: The total sum of daily NDVI values across an entire growing season which represents total plant productivity for that year.

**Protocol and sampling design**
This measure uses the North American Carbon Program (NACP) database¹ and is accessed through the USGS Phenology Toolbox for ArcGIS (Talbert et al., 2013). This database provides pre-processed NDVI raster files that have been used to generate phenology metrics including green up date, brown down date, and large integral NDVI (among others). These data are currently available for North America from 2000 to 2012. Additional years of data will become accessible on an ongoing basis as NACP and USGS make them available. These data are available at no cost. The protocol (still to be developed) uses Zonal Statistics functions within ArcGIS to extract the relevant phenology metrics on a pixel-basis for a given park and indicator and summarizes the results. An example of data from the USGS Phenology Toolbox for WBNP is shown in figure 1).

**Identification of Spatial Targets**
For Wood Buffalo, this Forest monitoring measure focuses on forest patches that are not recently burned (within 20 years) and have a minimum size of 56.25ha which corresponds to a 3x3 MODIS pixel cluster. Fire polygons were acquired from the Fire Management Division of the Natural Resource Conservation Branch in National Office and patch size was calculated from the available Jensen land cover map (2003). The minimum patch size ensures that measure values are based on “pure forest” pixels only and are not influenced by a mix of forest and non-forest pixels from the Landsat-based Jensen map. The focus on unburned areas controls for the potentially confounding effect of forest fire on the NDVI signal. Other potential forest stand disturbances (e.g., insect outbreaks) can also be incorporated into the identification of spatial targets if this data becomes available. If additional forest stand disturbances are to be incorporated then the spatial targets will need to be updated and a new set of Zonal Statistics will have to be recalculated for each year within the time series (approximately 1 or 2 days work).

¹ https://daac.ornl.gov/NACP/nacp.shtml
Table 5: Proposed Thresholds of the Plant Productivity and Growing Season Change measure.

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Fair</td>
</tr>
<tr>
<td></td>
<td>mean-2sd</td>
<td>mean-1sd</td>
<td>mean+1sd</td>
<td>mean+2sd</td>
</tr>
</tbody>
</table>

**Thresholds**

Proposed thresholds for this measure follow a “standard deviation interval” approach (Table 5). The tentative (see Status and Trend Assessment section) baseline period for establishing mean and SD values is from 2000 to 2010. Since annual weather (i.e., warmer than normal spring temperatures) can influence plant phenology and increase inter-annual variability it is proposed that this measure focus on two-year moving averages in phenology metrics for determining Status.

**Monitoring questions**

1. Is the two-year average in Green Up Date for WBNP April 17 (T2) or earlier?
2. Is the two-year average in Brown Down Date for WBNP November 6 (T3) or later?
3. Is the two-year average Large Integral NDVI for WBNP 1968 (T3) or higher?

**Status and Trends Assessment**

USGS Phenology Toolbox data were applied to WBNP’s Forest indicator for each year between 2000 and 2012 as per the description above. Grand mean and standard deviations values from the 2000 to 2010 baseline period were extracted and used to define tentative thresholds for each field measurement. These thresholds and current value are below. The most recent two year average (2011 and 2012) for all three metrics are within initial thresholds and, therefore, the current status of this measure is assessed to be in Good condition (Table 6).

Table 6: Status assessment of the Plant Productivity and Growing Season Change measure. (Current value based on 2011/2012 average.)

<table>
<thead>
<tr>
<th>Metric</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>Current Value</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Up Date</td>
<td>Apr. 2</td>
<td>Apr. 17</td>
<td>May 18</td>
<td>June 2</td>
<td>May 2</td>
<td>Good</td>
</tr>
<tr>
<td>Brown Down Date</td>
<td>Sept. 17</td>
<td>Oct. 4</td>
<td>Nov. 6</td>
<td>Nov. 23</td>
<td>Oct. 10</td>
<td>Good</td>
</tr>
<tr>
<td>Large Integral NDVI</td>
<td>1302</td>
<td>1524</td>
<td>1968</td>
<td>2190</td>
<td>1606</td>
<td>Good</td>
</tr>
</tbody>
</table>
Trends in each of these 3 field measurements for WBNP are shown in figure 2. During analysis of this data a curious pattern emerged in all phenology values starting in 2008 (grey area marked in figure 2). Olivier Bérard (Monitoring and Ecological Information, Parks Canada) contacted USGS and it was discovered that beginning in 2008 a change was made in the image processing algorithms used to extract phenology metrics from daily MOSIC NDVI values. This change in algorithm results in an underestimate of NDVI in Northern Canada compared to the algorithm used prior to 2008. This change creates a bias in the trend analysis for this measure. The bias generates a declining trend in Large Integral NDVI, an increase in Green Up Date, and a decline in Brown Down Date. All of these results are counterintuitive to what one would expect due to global warming. Parks Canada has notified USGS of this bias and they inform us that they will reprocess and update their phenology database such that this bias is removed. Once the re-processed data are available the data will be reanalyzed (contact Paul Zorn).

In the interim, in order to accommodate the bias in changing algorithms for phenology processing, separate trend analyses using generalized linear models (GLM) were generated for pre-2008 and post-2008 in R3.2.0. Trends in all three metrics from 2000 to 2007 and 2008 to 2012 were not significant (Table 7). The current trend in this measure, therefore, is stable.

Table 7: Trend assessment of the Plant Productivity and Growing Season Change measure.

<table>
<thead>
<tr>
<th>Period</th>
<th>Metric</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>P-Value</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 to 2007</td>
<td>Green Up Date</td>
<td>-1.381</td>
<td>1.466</td>
<td>0.382</td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Brown Down Date</td>
<td>-1.524</td>
<td>1.383</td>
<td>0.313</td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Large Integral NDVI</td>
<td>-13.35</td>
<td>24.62</td>
<td>0.607</td>
<td>Stable</td>
</tr>
<tr>
<td>2008 to 2012</td>
<td>Green Up Date</td>
<td>-3.20</td>
<td>2.179</td>
<td>0.238</td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Brown Down Date</td>
<td>-0.70</td>
<td>2.479</td>
<td>0.796</td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Large Integral NDVI</td>
<td>14.30</td>
<td>36.46</td>
<td>0.721</td>
<td>Stable</td>
</tr>
</tbody>
</table>

Recommendations
- WBNP follow up with MEI to ensure that this measure be reviewed again once USGS updates their Phenology Toolbox with re-processed post-2008 data.

List of Reviewed References

Figure 1: Average large integral NDVI for WBNP for 2000 to 2012
Figure 2: Trends for WBNP's Forest indicator for Green Up Date, Brown Date, and Large Integral NDVI. Areas in grey (2008 and later) represent values after a change in satellite image processing method from the USGS.
Fire Frequency

Revised Monitoring Questions
Is the Area Burned Condition Class (ABCC) for Wood Buffalo National Park ≥67% during the last 5 years?

Thresholds
ABCC: (Fair) = 33%, (Poor) = 67% (see below)

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABCC (%)</td>
<td>33</td>
<td>33</td>
<td>67</td>
<td>67</td>
</tr>
</tbody>
</table>

Sampling frequency 5 to 10 years

Status & Trends Assessment Method
1) Status is assessed through direct comparison of current ABCC values to established thresholds.
2) Trend is assessed by determining the direction of change in ABCC between two periods in time (ΔABCC) (see below).

Review Summary
The method relies on burn mapping using remote sensing methods based on Landsat™. ABCC has been applied to WBNP for every year between 1995 to 2015 using available satellite imagery. ABCC for 2015 is assessed to be in Good condition with a Stable trend.

Recommendations:
1) Formally adopt an ABCC method for this measure and update associated information on ICE.
2) Work with the MEI and Fire Management sections of National Office to update ABCC for WBNP using newly acquired Landsat™ imagery. Contact Paul Zorn to follow up on this recommendation.

Reviewed by Paul Zorn

Rationale of the measure
The importance of fire to the forest ecosystem in Wood Buffalo National Park is well known. The park managers propose a measure based on annual area burned. However, the standard approach in Parks Canada to monitor the effects of fire on forest composition is the Area Burned Condition Class (ABCC) method (Parks Canada, 2010a). This method uses updated fire mapping to calculate area burned which is then compared to a reference fire regime for an area. This comparison generates an Area Burned Departure value which is then used to calculate an ABCC value for a park. ABCC is a standardized metric for monitoring fire in forest ecosystems for which protocols and thresholds are already in place (Parks Canada, 2010a).

Thresholds
ABCC is a measure based on the proportion of an area (ie, a national park) under different Area Burned Departure (ABD_{final}) levels. This approach uses standardized thresholds that are used by all parks that implement this method (Parks Canada 2010a, p. 11; Table 8).
Table 8: Thresholds of the Fire Frequency measure.

<table>
<thead>
<tr>
<th>Condition Class</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td></td>
<td>33%</td>
<td>67%</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Monitoring question**

Is the Area Burned Condition Class (ABCC) for Wood Buffalo National Park ≥67% during the last 5 years?

**Protocol and sampling design**

A standardized national protocol (Parks Canada, 2010a) for ABCC is already in place and should be formally adopted by WBNP within ICE. The protocol uses satellite imagery (Landsat TM) to census the entire park to produce updated fire mapping. The approach for fire mapping uses standard multi-spectral remote sensing methods based on the Normalized Burn Ratio and is described in Perrakis & Zell (2008). Since fire mapping is based on a census of satellite pixels for the whole park issues pertaining to sampling design are not relevant.

**Status and Trends Assessment Method**

The status and trend assessment method for ABCC are described on page 11 of the National Fire Monitoring Guide (Parks Canada 2010a; Table 9).

Table 9: Status and trends assessment method for the ABCC.

This method has been applied to WBNP in 2009 (Parks Canada 2010b, p. 15). At that time, recently frequent large wildfires contributed to an ABDfinal value of 31% and an ABCC of “good”. Fire mapping for WBNP has been recently updated by Darrel Zell (2015) using LandsatTM (figure 3). Since 2009 there has been a large increase in the annual area burned within the park (figure 4). With this updated fire mapping the application of the ABCC protocol indicates that between 1995 and 2015 a total of 1,316,240ha were burned within the park (table 8). The expected area burned based on a 63 year reference fire cycle (Parks Canada 2010b, p. 15) is 1,367,037ha which yields an ABDfinal value of 3.72% and an ABCC condition of “Good”. Since the ABCC calculated in
2009 for Wood Buffalo was Good (31%) (Parks Canada 2010b, p. 15) and the updated value in 2015 was also Good (3.72%) the trend of this measure is Stable.

Table 10: Updated ABCC calculations for Wood Buffalo National Park, covering the 1995-2015 period.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RFRA</td>
<td>A (ha)</td>
<td>rFC (yrs)</td>
</tr>
<tr>
<td>Park</td>
<td>4,101,141</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>MP (yrs)</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>eAAB (ha)</td>
<td>65,097</td>
</tr>
<tr>
<td></td>
<td>eAB (ha)</td>
<td>1,367,037</td>
</tr>
<tr>
<td></td>
<td>aAB (ha)</td>
<td>1,316,240</td>
</tr>
<tr>
<td></td>
<td>ABD (%)</td>
<td>-3.72</td>
</tr>
<tr>
<td></td>
<td>ABCC</td>
<td>GOOD</td>
</tr>
</tbody>
</table>

**Recommendations**

1) The Forest Composition measure should formally adopt an ABCC approach to implementing this measure and reflect this change by updating the information on ICE.

2) The Monitoring & Ecological Information (MEI) and Fire Management sections of National Office should collaborate on updating the fire mapping for WBNP to make this measure operational into the future.

Figure 3. Area burned per year in Wood Buffalo National Park between 1995 to 2015.
Figure 4. Total annual area burned (ha) in Wood Buffalo National Park between 1995 to 2015.

**List of Reviewed References**


Contaminants in colonial waterbird eggs

**Proposed Monitoring Question**
Has the mercury content in Ring-billed Gull eggs from Mamawi Lake remains below \( \leq 0.5 \, \mu g/g \) (fresh wet weight, fww) during the last five years?

**Thresholds (recommended by Environment Canada)**
Toxicity thresholds (mercury content) for the Ring-billed Gull are currently under review. Environment Canada recommends \( 0.5 \, \mu g/g \) (fresh wet weight, fww) as a precautionary threshold indicating increase of mercury in this species eggs, and \( 2.0 \, \mu g/g \) (fww) as a warning threshold approaching levels which may cause avian reproductive impairment.

<table>
<thead>
<tr>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Fair</td>
</tr>
<tr>
<td>Mercury content ( (\mu g/fww) )</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Status & Trends Assessment Method**
The metric for this measure is the mean adjusted mercury content (in micrograms per gram, fresh wet weight) supplied by Environment Canada (Craig Hebert). Analyses of changes in mercury content between years should use a general linear model.

**Review Summary**
1) Eggs of two colonial species (Ring-billed Gull and Common Tern) were sampled at two sites, Mamawi Lake and Rocky Point, but the latter site was only sampled once, in 2009, and thus is omitted from this summary.

2) Ring-billed Gull eggs \( (n=10/\text{year}) \) had been collected at Mamawi Lake in 2009, 2012, 2013 and 2014. The egg content has been analysed by Environment Canada. The results showed fluctuations in the mercury content between years, with the individual eggs approaching the lower threshold of \( 0.5 \, \mu g/g \) in 2012. Only some eggs approached to this threshold.

3) The mercury content was higher in the eggs of Common Tern, likely reflecting a slightly higher trophic level of this species, and some tern eggs exceeded the lower thresholds in 2009, although the mean values dropped below \( 0.3 \, \mu g/g \) in 2013. Eggs of this species were not collected every year because nesting was less predictable, and nests were harder to find and access in flood years. Then perhaps the analysis should be restricted to years when eggs of both RBGU and COTE are collected.

4) The mean mercury values, \( 0.08-0.25 \, \mu g/g \) in Ring-billed Gull and \( 0.21-0.37 \, \mu g/g \) in Common Tern, remained below the proposed lower threshold and the status of “Contaminants in Colonial Waterbirds” measure is Good regardless of whether both species or only Ring-billed Gull are used in the analysis.

**Recommendations:**
1) Limit this measure to Ring-billed Gulls from Mamawi Lake; if both species can be sampled consistently in future years then Common Tern may be reinstated.

2) Use a general linear model to report on trends in this measure.
**Detailed review**

**Rationale of the measure**

Monitoring contaminants in gull and tern eggs is a useful tool for gaining insights into local environmental conditions because gulls and terns are integrators of processes occurring at lower levels in the food web and their eggs are generally formed using local food sources (Hebert, Norstrom, & Weseloh, 1999, Hebert, et al., 2013). Therefore, the chemical composition of the egg will reflect the chemical characteristics of the region in the vicinity of the breeding colony (Hebert, Norstrom, & Weseloh, 1999, Hebert, 2009), including level of contaminants, such as mercury. Mercury in bird eggs is primarily comprised of methylmercury which biomagnifies in organisms occupying higher trophic positions (Scheuhammer, Meyer, Sandheinrich, & Murray, 2007). In highly contaminated areas, when methylmercury is transferred from the mother to her eggs, and it can reach concentrations associated with impaired reproduction in wild birds, e.g., Common Tern (*Sterna hirundo*) (Fimreite, 1974) and other colonial waterbirds (Scheuhammer, Meyer, Sandheinrich, & Murray, 2007). Indirectly, this measure also reflects on mercury level in fishes and other freshwater organisms, and interlinks with the River Water Quality measure.

**Thresholds**

Thresholds for this measure are based on mercury levels in fresh gull and tern eggs, and have been developed in cooperation with Dr. Craig Hebert (Environment Canada). Two benchmarks of 0.5 µg/g and 2.0 µg/g were identified; the former value is precautionary, indicating elevated content of mercury in eggs of these species; the latter approaches concentrations which may cause avian reproductive impairment (Scheuhammer et al. 2007). The benchmarks were adjusted for fresh egg wet weight. Thus the status of contaminants in the Ring-billed Gull eggs will be assessed against the following criteria: if mercury content adjusted for fresh wet weight exceeds 2.0 µg/g then the status is “Poor”; values between 0.5 and 2.0 µg/g indicate a cause for concern and the status is “Fair”; contents below 0.5 µg/g suggest acceptable level of mercury content and the status is “Green” (Figure 5).

**Monitoring questions**

Monitoring mercury levels in Ring-billed Gull eggs advances our knowledge on reproductive fitness of this population, but also improves understanding of freshwater ecosystems health in Wood Buffalo National Park. The main monitoring question: “Was the mercury content in Ring-billed Gull eggs from Mamawi Lake ≤ 0.5 µg/g (fresh wet weight in the last five years?” could be rephrased to reflect on the presence of heavy metals in aquatic ecosystems of the park, i.e., “Have mercury levels increased in aquatic food chains of Mamawi Lake (or Wood Buffalo National Park) in the last five years?”. The second question “Have mercury concentrations exceeded levels which may cause avian reproductive impairment (2.0 µg/g, fresh wet weight)?” will alert park managers to unacceptably high mercury contents in colonial waterbirds and likely other aquatic organisms.
Protocol and sampling design

This measure is a cooperative project between Parks Canada and Environment Canada, and most of the conceptual and analytical work was done by Dr. Craig Hebert (Environment Canada). The gull and tern egg sampling at Mamawi Lake and adjacent sites in and around the park is a part of the EC project designed to evaluate increasing concerns of the environmental impacts of industrial development in this region, in particular from the production of synthetic crude oil in the Athabasca oil sands (Hebert et al. 2011).

Wood Buffalo National Park currently has no protocol describing this measure, and the following is extracted from Dr. Hebert’s publications.

Freshly laid eggs (i.e., eggs with no embryonic development) are collected from two locations in Wood Buffalo National Park: Mamawi Lake (58.596N, -111.469 W), and Rocky Point (58.908N, -111.579W). Sampling at Rocky Point occurred only once, in 2009. At both these locations, 10 eggs were collected from each of two species: Ring-billed Gull (Larus delawarensis) and Common Tern (Sterna hirundo) (Hebert 2009, Hebert et al.2011, Hebert, et al. 2013). After collection, eggs are transported to the National Wildlife Research Centre (NWRC) in Ottawa, ON. There the eggs are opened and the contents (yolk and albumen) are homogenized. Individual homogenized samples are stored frozen (-40°C) in the National Wildlife Specimen Bank. Individual samples were used for mercury analysis as well as for stable nitrogen isotope (15N/14N) analysis; stable nitrogen isotope level provide an indication of organism trophic

Figure 5. Assessment of mercury content according to the thresholds for the Contaminants in Colonial Waterbirds measure, Wood Buffalo National Park.
position (Hebert et al. 2013). Therefore, the positive relationship between stable nitrogen isotope values and mercury levels was expected (Hebert C., 2009).

Environment Canada/Dr. Hebert uses analysis of variance (ANOVA) to test for intersite and species differences in mercury concentrations; these are followed by Tukey’s HSD test for unequal sample sizes (Hebert, Weseloh, Macmillan, Campbell, & Nordstrom, 2011). Parks Canada is also interested in determining trends once sufficient data will have been accumulated; PCA will use a general linear model. If eggs of Common Tern can be reliably sampled on annual basis then the metric may change and weighed averages based on annual trophic levels of both species (determined from stable nitrogen isotope contents) may be used in calculations.

Bibliography


(Reviewed by Michael Patrikeev and Wanli Wu)
River Water Quality

Proposed Monitoring Question:
Two monitoring questions are possible, based on the calculation method:
1) Is the average WQI across the three large rivers in WBNP >= 80, and has it changed over the last seven years?

(Interim) Thresholds

<table>
<thead>
<tr>
<th>Water Quality Index</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Fair</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>80</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Sampling frequency
- Annual: 12 samples/year at 3 sites
- Bimonthly: sampling minimum recommended.

WQI will be assessed on the pooled results from the previous year’s water samples. It is recognised that contaminant data, because of analytical costs, may not be available for all samples.

Status & Trends Assessment Method
Status is based on a Generalized Additive Model. The most recent assessment possible is for 2014 where the condition is Fair.

Trend is based on a simple linear regression of the past seven years. The current trend for 2008-2014 is Stable.

Review Summary
1) Water Quality is a high profile issue and lots of data have been and continue to be collected. Additionally, several large research programs have aimed to understand the dynamics of water quality in the region, including a current one undertaken under the auspices of the Joint Oil Sands Monitoring Program.
2) Despite the historical data and research, the assessment of water quality is still preliminary. ECCC has used the three main park sites as part of their CESI reporting.
3) There are several outstanding issues that are not resolved, notably assessing the high values of metals, and developing a useful approach for assessing potential organic contaminants (i.e. hydrocarbons).

Recommendations:
1) We recommend using the CESI parameters and thresholds in the interim.
2) Further development of this measure will be required once the most recent research is completed and synthesized. A revised set of parameters and more appropriate thresholds will be needed to better understand the actual water quality conditions in the park.
3) In the future, we also recommend the calculation of WQI without the F1 component as it imposes a heavy penalty for a single exceedance of each parameter, no matter the magnitude.

Reviewed by Wanli Wu, Dan Kehler, Stephen McCanny
Rationale for the measure

Two of the largest rivers of Alberta, the Peace River and Athabasca River, flow through WBNP and form the Peace Athabasca Delta at their confluence. The Slave River (80% from of flow comes from Peace River) carries water to the Great Slave Lake.

There is a rich history of water quality monitoring by Environment Canada (now Environment and Climate Change Canada) in the park, with the majority of the data coming from three sites: Peace Point on the Peace River, Athabasca river at 27 Baseline, and Fitzgerald on the Slave River (the park boundary is the thalweg of the Slave River). The time series begins in 1967, and the program was expanded in 1989 with additional sites and parameters. The monitoring program was initially established largely to assess general water chemistry and potential changes in nutrients due to point source inputs in upstream reaches (Glozier et al. 2009).

In 2011 water quality monitoring was done under the auspices of the Joint Oilsands Monitoring Program (JOSM), a partnership between the Alberta and federal government, with funding from the oil and gas sector. This program has recently evolved, with the province of Alberta reclaiming oversight of most monitoring, though water quality monitoring remains a joint province-ECCC responsibility. Under JOSM, surface water quality monitoring was expanded by

1) the establishment of several new sites in or near the park (Table 11)
2) Adding organics to the list of parameters monitored (approximately 143 parameters, mostly Polyaromatic Hydrocarbons; PAHs)
3) At the three long term sites (M9, M11a and M12), YSI sondes were deployed that collect hourly data on water temperature, pH, turbidity, specific conductance, and dissolved oxygen. These data are retrieved monthly.
4) At the three long term sites (M9, M11a and M12), passive samplers were deployed to collect data on PAHs, using a semi-permeable membrane (SPMD). This data is obtained monthly and should prove more reliable at detecting infrequent or low concentration compounds.

Most of the new sites were added to provide a reference, as they are not directly downstream of the oil sands, but may run through the same geological formations (K. Pippy pers. Comm.), and hence experience similar levels of metals, nutrients and turbidity.

We recommend developing a water quality index (WQI) for each of the long term sites for which sampling is anticipated to continue, following guidelines established by the Canadian Council of Ministers of the Environment (CCME). Developing a WQI has two stages: parameter selection and threshold selection. The advantages of the WQI approach is that it uses a recognized standard approach for integrating data across multiple water quality parameters, and many thresholds have been adopted by the CCME. The disadvantages are:

1) the parameter selection entirely drives the results of the WQI; if you monitor only parameters that regularly fail, you will report poor water quality, and vice versa. Hence, the parameter selection must be carefully considered to present a meaningful result;
2) CCME thresholds may not be relevant to all freshwater systems, leading to the need for developing site specific thresholds.
Table 11: Surface water quality monitoring sites in or near Wood Buffalo National Park

<table>
<thead>
<tr>
<th>Site</th>
<th>Site code</th>
<th>Data</th>
<th>In the park?</th>
<th>Data available</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIRCH RIVER BELOW ALICE CREEK</td>
<td>BI1</td>
<td>2011-</td>
<td>Yes</td>
<td>~ feeds into Lake Claire</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~ Monthly samples during open water, plus one sample in February</td>
</tr>
<tr>
<td>QUATRE FOURCHES ON SOUTHERN MAMAWI LK CHANNEL</td>
<td>QU1</td>
<td>2012-</td>
<td>Yes</td>
<td>b/w lake Mamawi and lake Athabasca</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~ Monthly samples during open water, plus one sample in February</td>
</tr>
<tr>
<td>RIVIÈRE DES ROCHER BELOW LITTLE RAPIDS</td>
<td>M10</td>
<td>2012-</td>
<td>No</td>
<td>On slave river, adjacent to park</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~ Monthly samples during open water, plus one sample in February</td>
</tr>
<tr>
<td>LOWER BUCKTON CREEK</td>
<td>BU2</td>
<td>2013-</td>
<td>Yes</td>
<td>Tributary to McIvor. There is a 2nd site on this creek about 8km south of park</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~ Monthly samples during open water, plus one sample in February</td>
</tr>
<tr>
<td>MCIVOR RIVER</td>
<td>MC1</td>
<td>2013-</td>
<td>No</td>
<td>~ 2 km south of park boundary.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~ Monthly samples, plus, in the last few years: YSI sonde and passive samplers</td>
</tr>
<tr>
<td>ATHABASCA RIVER AT 27</td>
<td>M9</td>
<td>1989-</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~ Monthly samples, plus, in the last few years : YSI sonde and passive samplers</td>
</tr>
<tr>
<td>PEACE RIVER AT PEACE POINT</td>
<td>M12</td>
<td>1967-1976; 1989-</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~ Monthly samples, plus, in the last few years : YSI sonde and passive samplers</td>
</tr>
<tr>
<td>SLAVE RIVER AT FITZGERAL</td>
<td>M11a</td>
<td>1960-1967, 1989-</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~ Monthly samples, plus, in the last few years : YSI sonde and passive samplers</td>
</tr>
</tbody>
</table>

Water quality is a high profile issue in the Athabasca river, due to the various upstream industries, most notably the extraction of petroleum products from the oil sands, but also including pulp and paper mills, municipal effluent, agriculture, and forestry. A number of studies have examined the park water quality data time series (Alberta Environment 2009, Environment Canada 2009), and identified potential issues related to varying analytical methods and high sediment load.

The three main sites have been used by ECCC is part of the reporting for the Canadian Ecological Sustainability Indicators (CESI) (Julie Boyer, pers. Comm.). As such, we recommend using the same parameters and thresholds in the interim. Both ECCC (e.g. Environment Canada 2009) and MEI recognize that there are issues with the parameters and guidelines used for CESI. The reports being prepared for the Reactive Monitoring Mission (Sept 2016) by ECCC may provide some additional guidance, or the ECCC water quality group (led by Nancy Glozier) have indicated their willingness to help select a new set of parameters and guidelines to better reflect the water quality at Wood Buffalo National Park.

Application of CCME guidelines to waters with a high sediment load is not ideal. Development of a site-specific threshold for total metals, nutrients, and the presence and abundance of organic
and non-organic contaminants of concern would provide a better assessment of risk to aquatic life. ECCC is currently field testing methods to monitor contaminants using passive samplers, which are deployed for monthly periods, as well as through biological sampling (e.g. invertebrates).

**Thresholds**

Interim annual WQI thresholds are suggested based on CCME’s WQI values categories (CCME, 2001; Tables 12 and 13).

Table 12: Interim water quality parameters and thresholds. Most metals have a threshold that is a function of hardness, where hardness is measured as mg [CaCO3]/L.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lower threshold</th>
<th>Upper threshold</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Arsenic</td>
<td>NA</td>
<td>5</td>
<td>UG/L</td>
</tr>
<tr>
<td>Total Copper</td>
<td>NA</td>
<td>2 μg/L for hardness &lt; 90 mg 0.2<em>e^{0.8545</em>ln[hardness]-1.465} μg/L for hardness &gt; 90</td>
<td>UG/L</td>
</tr>
<tr>
<td>Dissolved Chloride</td>
<td>NA</td>
<td>150</td>
<td>MG/L</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>NA</td>
<td>1</td>
<td>MG/L</td>
</tr>
<tr>
<td>Ammonia</td>
<td>NA</td>
<td>0.02</td>
<td>MG/L</td>
</tr>
<tr>
<td>Total Nickel</td>
<td>NA</td>
<td>e^{0.76*ln[hardness]+1.06} μg/L</td>
<td>UG/L</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>NA</td>
<td>0.05</td>
<td>MG/L</td>
</tr>
<tr>
<td>Total Lead</td>
<td>NA</td>
<td>e^{1.273*ln[hardness]-4.705} μg/L</td>
<td>UG/L</td>
</tr>
<tr>
<td>pH</td>
<td>6.5</td>
<td>9.0</td>
<td>PH UNITS</td>
</tr>
<tr>
<td>Total Zinc</td>
<td>NA</td>
<td>7.5 μg/L for hardness ≤ 90 7.5 + 0.75*(hardness-90) for hardness &gt; 90</td>
<td>UG/L</td>
</tr>
</tbody>
</table>

Table 13: Interim thresholds for the River Water Quality measure.

<table>
<thead>
<tr>
<th>Water Quality Index</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>65</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Monitoring questions**

We proposed the following monitoring question:

Is the average WQI across the three large rivers in WBNP >= 80, and has it changed over the last seven years?
Protocol and sampling design

Recommended sampling frequency:

In the past, water quality samples were collected 4 to 12 times annually in the three fixed WQ sites of the three large rivers in the PAD. In 2009, EC recommended “consistent sampling frequency of 8X per year with sampling distributed among the three hydrological seasons; 2 in Spring/Summer (May – July), 2 during fall (August – October) and 4 during the longer winter period (November – April).” (EC 2009). If the current stated level of monitoring (12x per year) at the three main sites is maintained, this objective is met. In reviewing the recent data collected under JOSM, the sampling does not always follow this scheme, with replicate samples being taken in certain months, and no data in some months. However, the minimum of eight samples/year is mostly met.

Status and trend assessment

Status:

The CCME WQI value is calculated for each river in each year. The average across all three rivers is the actual metric being assessed. We recommend using a Generalized Additive Model to remove some of the year-year variation caused by sampling (A rolling 3-year average is a simpler alternative).

![Figure 6: Status of average WQI for Wood Buffalo National Park. The fitted line is from a Generalized Additive Model.](image)

Trend

A simple linear model is used over the last seven years to assess change in the average WQI value.
Figure 7: Trend in the average WQI for Wood Buffalo National Park over the last seven years. The fitted line is from a general linear model.

The results for the period 2008-2014 are a slope of -1.6 (SE = 1.5), with a p-value of 0.345, hence not significant.

Figure 8: WQI results by river for Wood Buffalo National Park. The fitted line is a local smoother.

List of Reviewed References


River Discharge

Revised Monitoring Questions
Is the mean Stream Flow Index (SFI) across water stations associated with Wood Buffalo National Park greater than 0.66?

(Interim) Thresholds

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor</td>
<td>Fair</td>
<td>Good</td>
<td>Fair</td>
</tr>
<tr>
<td>Field measurements (quantile)</td>
<td>0.025</td>
<td>0.1</td>
<td>0.9</td>
<td>0.975</td>
</tr>
<tr>
<td>Measure (Mean SFI)</td>
<td>0.33</td>
<td>0.66</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Sampling frequency: Annual

Status & Trends Assessment Method
Status Assessment: Direct comparison of current values for field measurements and SFI to established thresholds.
Trend Assessment: Standard generalized linear model.

Review Summary
River Discharge is currently an underdeveloped measure. Little information is available on ICE that describes the park’s approach for this measure. Supplemental information provided by the park suggests an intention to follow an IHA (Indicators of Hydrological Alteration) approach (Richter et al., 1996) using available water flow data from the Water Survey of Canada for three stations: Peace River at Peace Point (07KC001), Athabasca River below McMurray (07DA001), and Slave River at Fitzgerald (07NB001). The IHA approach identifies 64 individual parameters (field measurements) representing 5 major groups of hydrologic attributes. There is a concern that this is too cumbersome for assessment purposes and an alternative approach based on a Stream Flow Index currently used by Atlantic Region national parks is proposed.

Recommendations:
1) Base the River Discharge measure on a Stream Flow Index approach similar to other parks across the country. This approach is particularly used in Atlantic Canada.
2) For WBNP, a Stream Flow Index based on 7 field measurements is suggested. These 7 metrics represent the 5 major groups of hydrologic attributes (Richter et al., 1996), as well as, predictors of ice-jam flooding events for the Peace-Athabasca Delta (Beltaos 2014).
3) MEI will prepare an R script that extracts all 7 field measurement variables from standard daily flow data available online from the Water Survey of Canada. Contact Paul Zorn for more information.

Rationale of the measure
This is a relatively underdeveloped measure. Little information is provided on ICE regarding monitoring questions, thresholds, etc. From the information provided by the park it seems as though the intention is to base this measure on “Indicators of Hydrologic Alteration (IHA)” (Richter et al., 1996), however, details on how IHA is to be applied for WBNP’s condition monitoring program are not described.
The concept of IHA for this measure is appealing because it is comprehensive and has been shown to be effective at detecting impacts on the flow regimes of aquatic, wetland and riparian ecosystems (Richter et al., 1996). IHA is based on the following 5 groups of hydrologic attributes:

1. Magnitude of monthly water conditions
2. Magnitude and duration of annual extreme water conditions
3. Timing of annual extreme water conditions
4. Frequency and duration of high and low pulses
5. Rate and frequency of water condition changes

These five groups are comprised of 32 parameters, each of which is tabulated using measures of central tendency and dispersion, to form 64 “indicators” (or field measurements using PCA’s terminology) (Richter et al., 1996). While a River Discharge measure composed of 64 field measurements is certainly comprehensive it poses significant problems from an operational perspective. One of these problems relate to thresholds. Parks Canada’s monitoring guidelines requires that all field measurements possess thresholds in order to clearly determine the status and trend of the measure. For River Discharge, trends of interest include both declines (ie, drought) and increases (ie, floods). Therefore, each field measurement will require 4 thresholds—a declining yellow and red threshold and an increasing yellow and red threshold. In short, 256 (64*4) thresholds will need to be established to make this measure consistent with national guidelines. Another concern with a 64 field measurement approach relates to potential difficulty with interpretation and communication of monitoring information. The quantitative combination of 64 values to determine the overall value of the River Discharge measure will be a complicated process (ie, it will have many parameters) which may make it difficult to communicate and understand from the perspective of partners and stakeholders. Also, the higher the number of field measurements the greater than chance that some, due to random variability or sampling / measurement error, will cross a threshold. So it may be that a measure based on 64 field measurements presents an inconsistent or mixed message pertaining to the status and trend of River Discharge for the park.

For reasons such as these it is recommended that WBNP adopt a “limited IHA” approach such as the one adopted by several Atlantic Region national parks (eg, Fundy, Kejimkujik, Terra Nova, Prince Edward Island, Gros Morne). These Atlantic Region parks refer to their limited IHA approach as a Stream Flow Index (SFI). The SFI contains the same 5 groups of hydrological attributes as the IHA but represents each group with only 1 field measurement each instead of 32 parameters. The SFI, therefore, only contains 5 field measurements instead of 64 (table 12; for more information on SFI, see the Stream Flow measure for Kejimkujik on ICE).

Since SFI contains fewer parameters than IHA but still represents the primary hydrological attributes used to describe river discharge the SFI is considered to be a good trade-off between a monitoring measure that is comprehensive and operational.
In addition to these primary hydrologic attributes, WBNP may also wish to consider additional field measurements that are particularly sensitive to ice-jam flooding in the Peace-Athabasca Delta (PAD). Hydrologic recharge of the PAD from period ice-jam flooding is an important ecological process of WBNP and is something that has been shown to have been affected by climate change and water flow regulation (Beltaos 2014). Specifically, increased flow levels at the time of freeze-up and reduced flow levels at the time of ice breakup have been shown to be key parameters that positively affect the probability of ice-jam floods (Beltaos 2014, Beltaos et al. 2006). For this reason it is suggested that WBNP add 2 field measurements to its SFI (Table 14). The recommended River Discharge measure for WBNP, therefore, is a Stream Flow Index (SFI) with 7 field measurements all of which are derived from existing daily water gauge data.

Table 14: Proposed field measurements for the Stream Flow Index.

<table>
<thead>
<tr>
<th>Hydrological Attribute</th>
<th>Field Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Magnitude</strong></td>
<td>1) Mean daily flow [unit = m$^3$/s]</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>2) Minimum average flow for 30-day period [unit = m$^3$/s]</td>
</tr>
<tr>
<td><strong>Timing</strong></td>
<td>3) Julian date of annual minimum flow [unit = Julian date]</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>4) Number of high flow pulses greater than x3 mean flow [unit = #]</td>
</tr>
<tr>
<td><strong>Rate of Change</strong></td>
<td>5) Richard-Baker Flashiness Index (difference in daily flow divided by sum of daily flow) [unit = relative index]</td>
</tr>
<tr>
<td><strong>Freeze-Up Level</strong></td>
<td>6) Mean monthly flow for November and December [unit = m$^3$/s]</td>
</tr>
<tr>
<td><strong>Break-Up Level</strong></td>
<td>7) Mean monthly flow for April and May [unit = m$^3$/s]</td>
</tr>
</tbody>
</table>

**Site Selection for Wood Buffalo**

Six river discharge stations were identified as affecting the ecological integrity of the park and candidates for this measure (figure 9). These six stations are:

1. 07DA001: ATHABASCA RIVER BELOW FORT MCMURRAY
2. 07DD001: ATHABASCA RIVER AT EMBARRAS AIRPORT
3. 07KE001: BIRCH RIVER BELOW ALICE CREEK
4. 07KF015: EMBARRAS RIVER BREAKTHROUGH TO MAMAWI LAKE
5. 07KC001: PEACE RIVER AT PEACE POINT
6. 07NB001: SLAVE RIVER AT FITZGERALD
In order for a river discharge station to be used for this measure it must be consistently operational and provide timely and useful information. Even though they may be well located to inform the Freshwater indicator for the park, stations must provide sufficient information to calculate each of the 7 field measurements within the SFI. In order to assess the suitability of each of these 6 stations a detailed review of data quantity and quality was undertaken. The results of this review are as follows:

07DA001: ATHABASCA RIVER BELOW FORT MCMURRAY (Accepted)

- Data consistently available 1957. Missing values are uncommon. Where missing values do occur all 7 SFI metrics can be calculated with minimal bias.

07DD001: ATHABASCA RIVER AT EMBARRAS AIRPORT (Rejected)

- Data are only available between 1971 and 1984. The station has been non-operational since 1984. SFI metrics cannot be calculated with data from this station.

07KE001: BIRCH RIVER BELOW ALICE CREEK (Temporarily Rejected)

- Data is available from this station since 1967. However, this station appears to be either malfunctioning, not calibrated with other stations in the region, or collects data in some other unit of measurement. Typical values from the 5 other stations in the region range from 500 to 5000 m$^3$/s whereas values from the Birch River station range from 0.5 to 100 m$^3$/s (orders of magnitude lower). It is assumed that these very low values are not normal for this river. If data quality issues from this station can be resolved then it can be used for this measure, however, until such time this station is temporarily rejected from use.

07KF015: EMBARRAS RIVER BREAKTHROUGH TO MAMAWI LAKE (Rejected)

- Data are available since 1987, however, for every year of operation approximately 2/3 of all days have missing values. In some cases the number of missing values within a year approaches 100%. Data are consistently too sparse to calculate SFI metrics.

07KC001: PEACE RIVER AT PEACE POINT (Accepted)

- Data consistently available 1959. Missing values are uncommon. Where missing values do occur all 7 SFI metrics can be calculated with minimal bias.
Figure 9. Location of 6 candidate river discharge stations for use in WBNP's ecological integrity monitoring program.

07NB001: SLAVE RIVER AT FITZGERALD (Accepted)

- Data consistently available 1953. Missing values are uncommon. Where missing values do occur all 7 SFI metrics can be calculated with minimal bias.
Based on available data from water flow stations in the region only 3 of 6 have sufficient data for use in WBNP’s monitoring program. If data issues associated with the Birch River station can be resolved then data from this station should be added to this measure. For the time being only data from the 3 accepted stations are used within this report. These 3 stations are:

1. 07DA001: ATHABASCA RIVER BELOW FORT MCMURRAY
2. 07KC001: PEACE RIVER AT PEACE POINT
3. 07NB001: SLAVE RIVER AT FITZGERALD

**SFI Implementation**

This section describes the results of calculating SFI trends for each station based on the identified 7 field measurements (Table 15). All analyses and charts were conducted using R3.2.0.

**07DA001: ATHABASCA RIVER BELOW FORT MCMURRAY**

Values per year for all 7 SFI metrics for station 07DA001 are shown in figures 10 and 11. The number of days per year with missing values (“Missing Values”) is also shown to help with interpretation. A standard generalized linear model (GLM) was used to assess linear trends over time for each metric. All metrics show a small, significant ($P<0.2$) decrease since 1957 with the exception of Frequency which has shown no change.

**07KC001: PEACE RIVER AT PEACE POINT**

There has been no consistent trend across the 7 SFI metrics for station 07KC001 (Table 15). Three metrics have increased since 1959 (Duration, Timing, and Freeze Up Flow), one metric has decreased (Frequency), and three are stable (Magnitude, Rate of Change, Break Up Flow). This seemingly random pattern is what one would expect due to natural variation. The trends for each metric are shown in figure 12 and 13.

**07NB001: SLAVE RIVER AT FITZGERALD**

Trends in SFI metrics for the 07NB001 station are summarized in Table 15. Similar to the station on Peace River there are no consistent trends across metric. Three metrics have been stable since 1953 (Frequency, Freeze Up flow, Break Up Flow), two have decreased (Magnitude, Rate of Change), and two have increased (Duration, Timing). Note that the metric “Frequency”, which measures the number of flow pulses per year (x3 mean annual flow), is N/A because a pulse has never occurred at this station since its establishment in 1953. Trends for each metric for the Slave River station are shown in figures 14 and 15.
Table 15: GLM results of trend analysis for the Stream Flow Index metrics in three sites

<table>
<thead>
<tr>
<th>Metric</th>
<th>07DA001 (Athabasca)</th>
<th>07KC001 (Peace)</th>
<th>07NB001 (Slave)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>Std.Err</td>
<td>P Value</td>
</tr>
<tr>
<td>Magnitude</td>
<td>-2.17</td>
<td>1.02</td>
<td>0.038</td>
</tr>
<tr>
<td>Duration</td>
<td>-0.66</td>
<td>0.26</td>
<td>0.013</td>
</tr>
<tr>
<td>Timing</td>
<td>-1.57</td>
<td>1.14</td>
<td>0.173</td>
</tr>
<tr>
<td>Frequency</td>
<td>0.0077</td>
<td>0.0075</td>
<td>0.310</td>
</tr>
<tr>
<td>Rate of Change</td>
<td>-6.9E-05</td>
<td>3.6E-05</td>
<td>0.062</td>
</tr>
<tr>
<td>Freeze Up Flow</td>
<td>-1.74</td>
<td>0.51</td>
<td>0.001</td>
</tr>
<tr>
<td>Break Up Flow</td>
<td>-3.47</td>
<td>2.01</td>
<td>0.091</td>
</tr>
</tbody>
</table>
Figure 10. Trends in SFI metrics for station 07DA001 Athabasca River.
Figure 11. Trends in SFI metrics for station 07DA001 Athabasca River.
Figure 12. Trends in SFI metrics for station 07KC001 Peace River.
Figure 13. Trends in SFI metrics for station 07KC001 Peace River.
Figure 14. Trends in SFI metrics for station 07NB001 Slave River.
Figure 15. Trends in SFI metrics for station 07NB001 Slave River.
Thresholds

An attractive element to the recommended SFI approach is that it has been adopted by several national parks throughout the country. As such, standards are already in place for thresholds, monitoring questions, protocol, etc. For thresholds, it is recommended that WBNP adopt the same approach as other parks that monitor SFI (see, for example, the Stream Flow measure for Kejimkujik on ICE).

This approach is a two-step process that first establishes thresholds for each field measurement and then rolls up the field measurements into a SFI value (table 16). The approach is as follows:

Step 1—Field Measurement Thresholds

Historic baseline data is used to establish thresholds based on quantiles of 0.025, 0.1, 0.9 and 0.975. These quantiles contain 80% and 95% of historic values. For WBNP, baseline river discharge data are available from 3 water gauge stations since the 1950’s. These stations are: Peace River at Peace Point (07KC001), Athabasca River below McMurray (07DA001), and Slave River at Fitzgerald (07NB001). Baseline data from these three stations show trends that are relatively stable over time (annual variability over a fairly stable long term mean). While some SFI metrics show a trend that is significantly greater than zero the magnitude of these trends is small. Therefore it is recommended that the entire existing baseline time series for each station be used to establish initial thresholds. Field measurement thresholds should be calculated separately for each of the 3 flow stations used for WBNP’s monitoring program.

Step 2—Calculating SFI Values

Once thresholds are established for each of the 7 field measurements then current values are compared to each threshold. Field measurements that rate a “poor” are assigned a value of 0, those rated “fair” are assigned a value of 0.5, and those rated “good” are assigned a value of 1. The average of these values across all 7 field measurements is the SFI score for that water flow station (3 stations total for WBNP). The average of SFI values across the 3 stations represents the Mean Stream Flow Index score for the park and is the measure value that is entered into ICE. The thresholds for SFI values represent the bottom third of values (0.33) and the upper third of values (0.66).
Table 16: Summary of thresholds for field measurements and the Stream flow Index.

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>0.025</td>
<td>0.1</td>
<td>0.9</td>
<td>0.975</td>
</tr>
<tr>
<td>Field measurements (quantile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measure (Mean SFI)</td>
<td>0.33</td>
<td>0.66</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Monitoring questions**

“Is the mean Stream Flow Index (SFI) across water stations associated with Wood Buffalo National Park greater than 0.66?”

**Protocol and sampling design**

Since this measure is based on data mining existing water station data from the Water Survey of Canada the protocol and sampling design are straightforward. MEI will prepare a script in R that will extract all 7 field measurements from the time series of daily water flow data that is downloaded from Water Survey of Canada. This will easily consolidate all the necessary information needed to make this measure operational. Once the field measurements per station per year are extracted it is a simple matter of comparing future values to the thresholds and apply the SFI as outlined in table 16. Contact Paul Zorn for more information on the R script.

**Status and Trends Assessment**

The assessment method for this measure is simple and straightforward. For status assessments the current value is compared to the established threshold and the corresponding status is assigned. For trend assessments the majority of the trend direction for each metric should be assigned to the SFI. If there is no clear majority then trend is considered “Stable”.

Note that for “Frequency” the threshold has been changed to a uni-directional threshold with T1 and T2 values only. This is because 0.025 and 0.1 percentile values for Frequency for all stations were zero based on baseline data.

The current status and trend assessment based on current 2014 values are shown in Tables 17 and 18. The River Discharge measure for Wood Buffalo National Park in 2014, therefore, is Good and Stable.
Table 17: Status and trends assessments of Stream Flow Index in three sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Metric</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>Value (2014)</th>
<th>Metric Status</th>
<th>Score</th>
<th>SFI Status (Score)</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>07DA001</td>
<td>Magnitude</td>
<td>422.0</td>
<td>451.4</td>
<td>769.2</td>
<td>867.7</td>
<td>576.7</td>
<td>Good</td>
<td>1</td>
<td>Good (0.93)</td>
<td>Decreasing</td>
</tr>
<tr>
<td></td>
<td>Duration</td>
<td>99.6</td>
<td>105.8</td>
<td>186.8</td>
<td>214.0</td>
<td>164.5</td>
<td>Good</td>
<td>1</td>
<td>Decreasing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Timing</td>
<td>3</td>
<td>15</td>
<td>364</td>
<td>364</td>
<td>364</td>
<td>Poor</td>
<td></td>
<td></td>
<td>Decreasing</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>Good</td>
<td>0.5</td>
<td></td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Rate of Change</td>
<td>0.0140</td>
<td>0.0146</td>
<td>0.0224</td>
<td>0.0315</td>
<td>0.0148</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Decreasing</td>
</tr>
<tr>
<td></td>
<td>Freeze Up Flow</td>
<td>156.1</td>
<td>180.9</td>
<td>348.8</td>
<td>378.2</td>
<td>217.6</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Decreasing</td>
</tr>
<tr>
<td></td>
<td>Break Up Flow</td>
<td>349.8</td>
<td>449.7</td>
<td>1091.8</td>
<td>1322.9</td>
<td>870.3</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Decreasing</td>
</tr>
<tr>
<td>07KC001</td>
<td>Magnitude</td>
<td>1353.3</td>
<td>1510.3</td>
<td>2501.5</td>
<td>2970.3</td>
<td>1668.7</td>
<td>Good</td>
<td>1</td>
<td>Good (0.93)</td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Duration</td>
<td>328.0</td>
<td>375.4</td>
<td>1386.8</td>
<td>1471.9</td>
<td>916.1</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Increasing</td>
</tr>
<tr>
<td></td>
<td>Timing</td>
<td>6</td>
<td>16</td>
<td>352</td>
<td>364</td>
<td>255</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Increasing</td>
</tr>
<tr>
<td></td>
<td>Rate of Change</td>
<td>0.0060</td>
<td>0.0062</td>
<td>0.0136</td>
<td>0.0145</td>
<td>0.0137</td>
<td>Fair</td>
<td>0.5</td>
<td></td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Freeze Up Flow</td>
<td>652.2</td>
<td>932.2</td>
<td>1854.1</td>
<td>1973.0</td>
<td>1330.9</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Increasing</td>
</tr>
<tr>
<td></td>
<td>Break Up Flow</td>
<td>1567.9</td>
<td>1838.7</td>
<td>3536.0</td>
<td>4372.2</td>
<td>2694.9</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Stable</td>
</tr>
<tr>
<td>07NB001</td>
<td>Magnitude</td>
<td>2595.3</td>
<td>2720.3</td>
<td>4313.4</td>
<td>5062.1</td>
<td>2966.4</td>
<td>Good</td>
<td>1</td>
<td>Good (0.93)</td>
<td>Decreasing</td>
</tr>
<tr>
<td></td>
<td>Duration</td>
<td>579.9</td>
<td>766.8</td>
<td>2295.5</td>
<td>3070.9</td>
<td>1824.0</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Increasing</td>
</tr>
<tr>
<td></td>
<td>Timing</td>
<td>15</td>
<td>37</td>
<td>344</td>
<td>360</td>
<td>315</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Rate of Change</td>
<td>0.0054</td>
<td>0.0066</td>
<td>0.0208</td>
<td>0.0289</td>
<td>0.0220</td>
<td>Fair</td>
<td>0.5</td>
<td></td>
<td>Decreasing</td>
</tr>
<tr>
<td></td>
<td>Freeze Up Flow</td>
<td>1642.7</td>
<td>1790.7</td>
<td>2884.5</td>
<td>3890.1</td>
<td>1941.0</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Break Up Flow</td>
<td>2343.4</td>
<td>2597.1</td>
<td>4521.6</td>
<td>5100.9</td>
<td>3239.7</td>
<td>Good</td>
<td>1</td>
<td></td>
<td>Stable</td>
</tr>
</tbody>
</table>
Table 18: Overall Stream Flow Index condition and trends assessment.

<table>
<thead>
<tr>
<th>Station</th>
<th>SFI Status</th>
<th>SFI Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athabasca River Below Fort McMurray (07DA001)</td>
<td>0.93</td>
<td>Decreasing</td>
</tr>
<tr>
<td>Peace River at Peace Point (07KC001)</td>
<td>0.93</td>
<td>Stable</td>
</tr>
<tr>
<td>Slave River at Fitzgerald (07NB001)</td>
<td>0.93</td>
<td>Stable</td>
</tr>
<tr>
<td><strong>OVERALL SFI</strong></td>
<td><strong>0.93</strong></td>
<td><strong>Stable</strong></td>
</tr>
</tbody>
</table>

**Recommendations**

1) Adopt a modified Stream Flow Index (SFI) instead of the suggested “Indicators of Hydrologic Alteration” (IHA) approach described on ICE. The SFI contains the same major groups of hydrologic attributes as the IHA but has far fewer parameters and, therefore, is more operational. SFI is already used by several national parks across the country, particularly in Atlantic Canada.

2) Modify the 5 parameter SFI used by other parks by adding 2 additional field measurements: Freeze-Up Level and Break-Up Level. These 2 field measurements have shown to be useful predictors of the occurrence of ice jam floods in the PAD.

**List of Reviewed References**


**Freshwater Macroinvertebrates**

**Proposed Monitoring Question**
Do the key aspects of benthic invertebrate diversity (Simpson equitability and % EPT) for the current monitoring year exceed the 33rd or 66th percentiles of previously observed communities?

**Thresholds**
Using a baseline of 2003-2012, we established thresholds for the top and bottom thirds of observed values for Simpson equitability, the tendency for a community to be represented by equally abundant species, and the percentage of individuals from pollution-sensitive orders (mayflies, stoneflies and caddisflies) for Ekman grab samples from the bottom of three sites in the Athabasca river delta. The field measurement thresholds were:

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Poor</strong></td>
<td>0.11</td>
<td>0.17</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Equitability (on a scale of 0-1)</strong></td>
<td><strong>Fair</strong></td>
<td><strong>Good</strong></td>
<td><strong>Fair</strong></td>
<td><strong>Poor</strong></td>
</tr>
<tr>
<td><strong>% pollution-sensitive</strong></td>
<td>0.21%</td>
<td>1.10%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Sampling frequency**
Annual

**Status & Trends Assessment Method**
Field measurement assessments are converted to a scale of 0-100 and averaged to determine the status of the measure. Trend should be assessed through a generalized linear model on data ranging back over the last 10 years.

**Review Summary**
1) The Regional Aquatic Monitoring Program (RAMP, 2014) assesses hydrology, water chemistry, benthic invertebrates and fish populations in the Lower Athabasca River, including the Athabasca Delta. Our data come from this regional program and focus on three sites in the delta: Big Point Channel, Fletcher Channel and Goose Island Channel.
2) Four to five Ekman grab samples were pooled to produce samples with an average of 2800 individuals and 22 taxa. Individuals were identified to the lowest identifiable taxon.
3) Simpson equitability was calculated according to the RAMP 2013 Technical report.
4) Average values for the parameters across the three sites were available from 2003-2013 – data was not collected in 2006.
5) Thresholds were based on percentiles, instead of standard deviations, for the baseline period of 2003-2012 because of a non-normal distribution.
6) Equitability and % EPT in 2013 were among the highest values observed at these locations and the measure value was calculated as 100.

**Recommendations:**
1) Maintain communication with the Regional Aquatic Monitoring Program and stay apprised of changes in sample locations and techniques.
2) Develop R script for calculating field measurement values.

(Reviewed by Stephen McCanny)
**Detailed review**

**Rationale of the measure**

Benthic invertebrates represent a broad testing ground for the integrity of aquatic ecosystems. (Rooke and Mackie, 1982). With a quick sediment sample or net sweep, a range of chemical and biotic sensitivities can be probed. Though sample identification is a specialized field, benthic invertebrates are one of the most consistent measures across national parks monitoring freshwater ecosystems. The diversity of benthic invertebrates, especially those that are known to be sensitive to water quality, is particularly valuable for integrating environmental quality over long periods of time rather than representing its state at the time of sampling.

For this measure we have chosen not to use the CABIN probability ellipse to identify test samples that depart from reference benthic communities (Bailey and Reynoldson, 2004). Reference conditions are often difficult to establish for a National Park. Environment and Climate Change Canada scientists often seek communities from National Park streams to determine reference conditions for streams that are more exposed to development. In the case of Wood Buffalo, our samples are taken downstream from oil sand development. The Peace Athabasca Delta also does not offer the typical wadeable stream habitat with rocky, shallow bottoms. They are instead deep and muddy. The best reference condition in the circumstance is a long term baseline from the same test sites. Though advanced techniques in examining benthic invertebrates with more comprehensive sampling regimes are being developed by Environment and Climate Change Canada scientists (Gibson et al. 2015), it will take time to convert this research into usable monitoring measures. We recommend single parameters as components of a benthic measure rather than an all-encompassing difference in community composition as they are easier to calculate and communicate.

The three sample locations, Fletcher Channel, Big Point Channel and Goose Island Channel are outside the park but immediately adjacent to it in the delta where the river ends in Lake Athabasca. The sites are exposed to the same Athabasca River water that infuses most of the Peace-Athabasca delta. The Regional Aquatic Monitoring Program (RAMP, 2014) that tracks environmental conditions arising from the oil sands extraction industry on the lower Athabasca River has recently begun sampling one more site in the Athabasca river delta near the Embarras River. This site could be included in this measure once its effect on baseline conditions is better understood.

**Thresholds**

The thresholds for the two field measurements were chosen on the basis of 33rd and 66th percentiles of the baseline data. This approach avoids the difficulties of large standard deviations based on skewed distributions.

**Monitoring questions**

*Do the key aspects of benthic invertebrate diversity (Simpson equitability and % EPT) for the current monitoring year exceed the 33rd or 66th percentiles of previously observed communities?*
The monitoring question aims to divide the known distribution of observed communities into high, medium or low equitability or % EPT (the percentage of individuals from the reliably sensitive insect orders: Ephemeroptera, Plecoptera and Trichoptera). High equitability in the context of a river delta means less domination of the sample by single taxa such as oligochaete worms or chironomid fly larvae. High % EPT is quite modest in this context, as mayflies, stoneflies and caddisflies are not as abundant in deep river sediments as in rocky streams. Nonetheless, both field measurements are signs of benthic invertebrate community health. These values are converted to a scale of 0-100 based on their thresholds and averaged together to give a single measure condition.

The nine year baseline for this measure is superior to that of most National Park benthic monitoring programs. It occurs, however, entirely during a period of oilsands development. This measure reports only on the relative health of the invertebrate community and not on its departure from a pristine state.

It is notable that the measure value is based on the most recent samples from the test sites. Some thought could be given to using smoothing to select a value representative of the last couple of years. Given the current length of the data set it is recommended to work from a single annual value at this time.

Bibliography


Ice Phenology

Revised Monitoring Questions

Has the date of lake-ice on and lake-ice off changed by more than 1SD from baseline values?

(Interim) Thresholds

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
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<td>mean-1sd</td>
<td>mean+1sd</td>
<td>mean+2sd</td>
</tr>
<tr>
<td>Lake-Ice Off</td>
<td>mean-2sd</td>
<td>mean-1sd</td>
<td>mean+1sd</td>
<td>mean+2sd</td>
</tr>
</tbody>
</table>

Sampling frequency: annual

Status & Trends Assessment Method

Status Assessment: Direct comparison of current two-year average to thresholds. Trend Assessment: Generalized linear mixed model (GLMM) with Lake-Ice On/Off Date as the response variable, Year as the fixed effect variable, and annual image classification error rate as the random effect variable.

Review Summary

Lake ice phenology has the capability of being an ecologically important and low cost measure for WBNP’s Freshwater indicator. Data access is potentially an issue as Radarsat2 orders have to be tasked and the possibility of conflicts exist with other Radarsat2 users. The protocol developed by the Canadian Centre for Remote Sensing is a peer reviewed and valuable method if it can be operationally sustainable.

Recommendations:

1. Ensure MEI has incorporated WBNP’s Radarsat2 image acquisition needs into the annual image tasking schedule with the Canadian Space Agency.
2. Consider investigation of archived imagery to determine if historical values in lake ice phenology can be collected to inform initial thresholds. Contact Paul Zorn for more information.

(R Reviewed by Olivier Bérard with revisions by Paul Zorn)

Rationale of the measure

Lake ice phenology measures the timing of lake ice on/off across years. Lake ice phenology is sensitive to global warming such that the length of lake ice-free periods within the park is expected to increase. Loss of ice cover and increased duration of ice-free conditions may have wide-ranging effects on the limnology of northern lakes. Longer ice-free conditions will increase wind-induced mixing and change the albedo of lake surfaces leading to increased water temperature and increased UV penetration into the water column. These changes may have a number of significant ecological impacts such as (Vincent et al., 2013):

- increased radiant heating of the water column
increased rates in aquatic primary production,
shifts in water temperature stratification and timing and magnitude of nutrient mixing,
increased tissue damage on aquatic plants and animals from bright UV radiation,
changes to algal community structure and planktonic:diatom ratios,
increased eutrophication and deep water oxygen depletion, and
impairment of coldwater fish oxythermal habitats.

This measure relies upon synthetic aperture radar (SAR) satellite imagery from Radarsat2. As a remote sensing-based measure data on lake ice phenology can provide WBNP with very meaningful monitoring information on the ecological integrity of its Freshwater indicator at low cost.

Protocol and sampling design

Lake Ice On/Off is a CCRS (Canadian Centre for Remote Sensing) developed and tested protocol. It has been extensively peer reviewed and published (Geldsetzer et al., 2010). Parks Canada, led by Jean Poitevin, worked with PCI Geomatica to develop a software add-on to be able to automate this protocol. This should substantially improve the feasibility and sustainability of implementing this protocol in the future. More information on this PCI add-on will be distributed when it becomes available. In the short term, the primary action item was to ensure that WBNP’s Radarsat2 data needs were adequately incorporated into the ongoing tasking schedule of this satellite through the Canadian Space Agency. MEI has facilitated the coordination of the Radarsat2 tasking schedule for Wood Buffalo with the park staff. Two appropriate AOI (Area of Interest) has been identified in the PAD during the last summer (10 by 10 square km each) (figures 16, 17 and 18). Image acquisition for WBNP began in September 2015.

The protocol uses daily Radarsat2 quad-polarization imagery, supplemented by LandsatTM, acquired during spring and fall to classify lake ice cover. Lake ice is considered to be “off” when the proportion of open water to lake ice is >90%. Similarly, lake ice is considered to be “on” when the proportion of lake ice to open water is >90%. The accuracy of lake ice classification using Radarsat is known to be affected by wind speed and fetch length. Therefore, during windy periods (as determined by the closest available weather station(s)), imagery for some days may not be used for lake ice analysis which leads to variable frequency within years for which data are used to assess Lake Ice On/Off Date. For years where daily imagery are not available the mid-point between the date of imagery when the ratio of lake ice to open water is below 90% and the date of imagery when the ratio is above 90% is used to estimate phenology for that year. Due to the spatial resolution of the satellite imagery used lakes that are sampled through this protocol should be a minimum of 1ha in size.

Thresholds

Initial thresholds for this measure are proposed to be based on a “standard deviation interval” approach such that T1 = mean-2sd, T2 = mean-1sd, T3 = mean+1sd, and T4 = mean+2sd. An obvious limitation is that WBNP does not possess historical data on lake ice phenology and so past trends are unknown. Placing these thresholds in an appropriate ecological context,
therefore, will be difficult. Unfortunately, this is a common limitation of many new monitoring measures throughout Parks Canada. It may be possible to investigate historical lake ice phenology values using a combination of archived optical and SAR satellite imagery or aerial photography. WBNP may wish to consider an investigation of available archived remote sensing data to see if any historical information exists to guide to establishment of initial thresholds for this measure.

**Monitoring questions**

Has the date of lake-ice on and lake-ice off changed by more than 1SD from baseline values?

**Status and Trends Assessment**

Status assessments for this measure should be based on comparing a two-year average to the established thresholds. Since it is normal to have occasional warm years comparing annual values may create a measure with high inter-annual variability and unnecessary changes in status. Using two-year averages will reduce these effects.

Trend assessments should be based on a generalized linear mixed model (GLMM) analysis with Lake Ice On/Off Date as the response variable, Year as the fixed effect variable, and annual image classification error rate as the random effect variable. Incorporating this random effect variable will account for differences in lake ice classification accuracy across years.

**Recommendations**

1) Ensure MEI has incorporated WBNP’s Radarsat2 image acquisition needs into the annual image tasking schedule with the Canadian Space Agency.

2) Consider investigation of archived imagery to determine if historical values in lake ice phenology can be collected to inform initial thresholds. Contact Paul Zorn for more information.

**List of Reviewed References**


Figure 16. Location of 2 areas of interest in WBNP for Radarsat acquisition.

Figure 17. Northern area of interest in WBNP for Lake Ice Phenology.
Figure 18. Southern area of interest in WBNP for Lake Ice Phenology.
**Marsh Birds and Amphibians**

**Revised Monitoring Questions**
The following questions are proposed:

1) Bird community: “Did the average relative abundance and occupancy rate of >3 Waterbirds species per group differ from the expected range of variability during the last 5 years?”

2) Amphibian community: “Did the average relative abundance and occupancy rate of the 2 amphibian species differ from the expected range of variability during the last 5 years?”

**Thresholds**
The thresholds should be established by the statistical distribution of the relative abundance (birds) or occupancy rate (amphibians) from a baseline (see detailed review). Expected range of variability should be defined by ±1 SD around the mean.

**Sampling frequency**
Annual

**Status & Trends Assessment Method**
The status of each species should be determined based on the combination of the average relative abundance and occupancy rate over a 5 year period in relation to the baseline, i.e.

<table>
<thead>
<tr>
<th>Relative abundance</th>
<th>Occupancy rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; -1 SD</td>
<td>Poor</td>
</tr>
<tr>
<td>± 1 SD</td>
<td>Fair</td>
</tr>
<tr>
<td>&gt; +1 SD</td>
<td>Poor</td>
</tr>
</tbody>
</table>

The status of the bird community should be based on the 70th percentile approach, i.e. the status of the 7th species out of 10 ordered from Good to Poor EI (see detailed review). The status of the amphibian community should be based on the status of the 2 amphibian species included in the measure, i.e.

<table>
<thead>
<tr>
<th>Boreal Chorus Frog</th>
<th>Wood Frog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Poor</td>
<td>Fair</td>
</tr>
</tbody>
</table>

The status of the measure should be determined by the following rules:

<table>
<thead>
<tr>
<th>Status of the Amphibian community</th>
<th>Status of the Bird community</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Poor</td>
<td>Fair</td>
</tr>
</tbody>
</table>

The EI trends in the relative abundance and occupancy rate should be determined for each species. Significant trend will be assigned a score of -1 (declining) or +1 (improving), while non-significant trends will be assigned a score of 0 (stable). The within and between group average should be used to determine the overall trends of the measure (see detailed review).
Review Summary

1) Monitoring the abundance diversity and distribution of amphibians and birds in wetlands was implemented in Wood Buffalo National Park (WBNP) mainly to track the effect of changes in the hydrology and water quality related to human activities associated with the oil sand developments outside the park, as well as changes to wetland habitat due to flow regulation and climate change.

2) The measure should focused on the most common waterbird species, as they are considered the most representative species, and are likely to provide more accurate and less variable information than uncommon species. A total of 20 species are suggested to be part of the measure, i.e. the 10 most common non-waterfowl species observed from the Automated Recording Unit (ARU) monitoring project, and the 10 most common waterfowl observed from the Breeding Population and Habitat Survey.

3) Two species of amphibians, the Boreal Chorus Frog and Wood Frog, were commonly observed with the ARU protocol and could be included in the measure.

4) The reference period to set thresholds varied among the waterfowl species (n=10 species), depending if a significant long term trends was observed between 1959-2014. The reference period for other birds (n=10 species) and for amphibians (n=2 species) will be the first 5 years of the project (started in 2014), assuming that the abundance of the species will be relatively stable.

5) The protocol and sampling design used to monitor waterfowl have been field-tested since 1956 and proven to be adequate to track long term change in bird abundance. The efficiency of the ARU protocol to detect presence and estimate relative abundance is still under evaluation, but the results obtained so far are encouraging, given the number of species identified.

6) One shortcoming of this measure is the relatively high weight of the Amphibian species group on the status and trend of the measure. The inclusion or exclusion of the amphibians in the same measure as waterbirds depends on the level of concerns that managers and stakeholders have regarding the conservation of frogs in the park.

Recommendations:

1) Change the name of the measure to “Waterbirds and Amphibians Status” to clarify which species are included in the bird community;

2) Focus on the most common species of each group of species;

3) Monitor change in the abundance and occupancy of waterfowl species with the information obtained from the Breeding Population and Habitat Survey instead of the ARU protocol;

4) Establish the EI status and trend of the measure based on the relative abundance and occupancy rate of group of species (Waterfowl, Non-Waterfowl bird species and Amphibians);

5) Consider dropping the Amphibians group from the measure if the level of concern regarding their conservation in the park is not too high;

6) Conduct a pilot project or consult bird experts to determine if a shorter recording duration and a larger number of recording period would improve species detection probability and the precision of abundance estimate.

7) Perform a power analysis once the data from 2015 will be available to determine the statistical power of the current ARU sampling design.

Reviewed by Claude Samson, with revision by Michael Patrikeev
**Detailed review**

**Rationale of the measure**

Monitoring the abundance diversity and distribution of amphibians and birds in wetlands was implemented in Wood Buffalo National Park (WBNP) mainly to track the effect of flow regulation of the Peace River and of change in water quality related to the oil sand developments outside the park. However, no list of species of interest (beside some Species at Risk and some species associated with human activities) nor precise field parameters and status assessment approach have yet been defined for this measure.

**Selection of species to be included in the measure**

A. **Birds**

Originally the measure focus on “Marsh” bird species, but it implicitly include “Waterbirds”, i.e. according to the Ramsar Convention definition, “species of bird that are ecologically dependent on wetlands” (Wetlands International 2010; see list of families in Appendix 1). A pilot project was implemented in 2014 to test the efficiency of Automated Recording Units (ARU) to detect the presence and estimate the relative abundance of birds and amphibians. A total of 73 bird species as well as 3 amphibian species were identified during this project, and 30 bird species from that list are in waterbird families (Tables 19 & 20). Although some waterfowl species have been detected by the ARU, the efficiency of this methodology to monitor specifically this group of species in WBNP is remains to be assessed. However, the waterfowl of the Peace-Athabasca Delta (PAD) is being monitored since 1956 by the US Fish & Wildlife Service and the Canadian Wildlife Service as part of the Breeding Population and Habitat Survey (BP&HS) (http://www.fws.gov/birds/surveys-and-data/population-surveys.php; see also Zimpfer et al. 2015), and this survey can provide accurate information on the waterfowl abundance, as well as historical data that can be used to set thresholds.

The measure should focused on the most common bird species, as they are considered the most representative species, and are likely to provide more accurate and less variable information than uncommon species. A total of 20 species are suggested to be part of the measure (table 22), i.e. the 10 most common non-waterfowl species observed from the ARU monitoring project, and the 10 most common waterfowl observed from the BP&HS. It should be noted that species were grouped in generic waterfowl class in 2 cases, i.e. Goldeneye spp. and Scaup spp., as these species could not be distinguished during the aerial survey. The waterfowl group include 5 dabbler and 5 diver species.

Such representation should provide a comprehensive overview of the evolution of waterbirds in wetlands of WBNP. Nevertheless, the list of non-waterfowl birds is still preliminary, as it was established based on only one year of data. This list should be revised after 5 year of monitoring, to confirm which non-waterfowl species are the most common wetland birds.

Originally, three SAR (Tree Swallow, Canada Warbler, and Yellow Rail), as well as 3 species associated with disturbance or human activity (European Starling, House Sparrow, American Crow) were proposed to be included in the measure. However, 5 of these species are not considered waterbird species, and the only wetland bird species, the Yellow rail was not
common enough to be considered as representative of the bird community. Given the purpose of the EI condition monitoring program, none of these species should be included in the proposed measure.

B. Amphibian

Three species of amphibians have been detected during the ARU monitoring project in 2014 (table 23). Two species, the Boreal Chorus Frog and Wood Frog, were relatively common, with chorus of various size found in near 50% of the sites. In comparison, a single individual of the third species, the Canada Toad, was detected in one site. Assuming that the Canada Toad is rare in the park, the species have not been included in the measure. This decision should be reviewed after 5 years of monitoring, once more information on the abundance and occurrence of Canada Toad in the park will be available.

Thresholds

The thresholds should be established by the statistical distribution of the relative abundance (birds) or occupancy rate (amphibians) from a baseline. Expected range of variability should be defined by ±1 SD around the mean.

Baseline for the non-waterfowl birds and amphibians could be established only after some years of monitoring. Typically, 5 years of data are required to provide sufficient information on the interannual variability to set thresholds, assuming that the species abundance do not show a significant trends through time.

The reference period varies among the waterfowl species, depending on whether the long term trends was observed or not between 1959 and 2014. Long term trends was analysed with a generalized linear model (GLM) fitted with a negative binomial distribution (function glm.nb() of MASS package in R). Year was used as fixed effect on the abundance of birds, and effects was considered significant at p<0.1. No significant trend was observed between 1956-2014 in four species (American Coot, Bufflehead, Canvasback and Northern Shoveler; see figure 19). A significant increasing trend was detected in one species (Canada Goose), while a significant declining trend was detected in the remaining 5 species (American Wigeon, Goldeneye spp., Scaup spp., Mallard, and Northern Pintail; see figure 20). For those species, a more detailed analysis will be required to determine if a specific period could be used as a baseline. Since the impact of human activities on the breeding activities of waterfowl in the PAD area is likely to have begun with the completion of the dam in 1968, the data prior to that event could be considered for setting the threshold. However, a trend analysis should be conducted to determine if the population of these species was relatively stable during that period. If a significant trend was detected, a longer or different period should be considered. If no satisfying period could be found, the species could possibly be replaced by another in the list.

Monitoring questions

The status of the waterbirds groups and of the amphibians will be determined separately, and the results will be roll-up in a composite measure (See Status and Trends Assessment Method section below). The status of waterbirds and amphibians will be determined by the number of species for which abundance and occupancy rate are different from the expected range of
variability. Therefore, two monitoring questions are required, and the following statements are suggested:

1) Bird community: “Did the average relative abundance and occupancy rate of >3 Waterbirds species per group differed from the expected range of variability during the last 5 years?”

2) Amphibian community: “Did the average relative abundance and occupancy rate of the 2 amphibian species differed from the expected range of variability during the last 5 years?”

Protocol and sampling design

The protocol and sampling design used by the US Fish & Wildlife Service and the Canadian Wildlife Service to monitor waterfowl have been field-tested since 1956 and proven to be adequate to track long term change in bird abundance. A single stratum (no. 20) cover the PAD area, and 67% of the surface area of this stratum is located in the park (see figure 21). Assuming that waterfowl distribution is relatively similar between the 2 areas, trends in the bird abundance in the stratum should be relatively representative of trends of the bird abundance in the park. However, any major landscape change occurring within the stratum area outside the park should be considered in the interpretation of the trends.

The efficiency of the ARU protocol to detect presence and estimate relative abundance is still under evaluation, but the results obtained so far are encouraging, given the number of species identified. With a few exceptions, most bird species are detected equally well and their number is equally estimated by either recording devices or by field observers, and ARU are considered advantageous in situations where the number of experienced observers is limited and where access is difficult (Venier et al. 2011).

The long duration of the recoding period (up to 3 months) could generate a large amount of data, and the analysis cost of the whole data set is prohibitive for the needs of the monitoring program. Recordings collected in early-May and June are sufficient to obtain a representative sample of the bird community. The ARU could nevertheless be used to detect the presence of some rare SAR, such as the Yellow Rail. Subsampling have been established by randomly selecting four 10-minute recordings per site (two at dawn, and two at dusk), separated by at least two weeks. This sampling effort have been established by the available budget for species identification. The consultant hired to identify the species have suggested using a shorter recordings duration (3 minutes) and increase the number of periods per site to 3 to improve detection with similar costs for transcription. A pilot project should be done to test this idea, although it would be a significant difference with the standardized protocol used by other national parks, and the Canadian Wildlife Service. Also, the statistical power of the current design have not been determined yet, and a power analysis should be performed after the data from 2015 will be available.

The ARU sampling design have one main shortcoming however, i.e. the lack of stratification or of any major criteria related to waterbirds and amphibian habitat requirements. Indeed, the sampling sites were selected based on accessibility, on the traditional importance of the area to
local indigenous people, especially egg-collecting, and on maximisation of spatial coverage. Sites were also co-located with vegetation transects and muskrat abundance estimation sites to reduce access costs of the monitoring program. In the case of the waterbirds and amphibians, tracking changes through time is more important than estimating the population size within the PAD area or than comparing the abundance between species, so the lack of stratification in the sampling design is less critical.

**Status and Trends Assessment Method**

A. **Waterbirds status**

Since waterfowl species are not tracked with the same protocol as the non-waterfowl species, a separated status assessment should be performed for each group. The assessment of the EI status of the Waterbirds include the following steps:

1) The status of a species is established based on the average relative abundance and average annual occupancy rate over a 5 year period (see table 23). Annual occupancy rate of non-waterfowl species is defined as the proportion of sites occupied by the species during a given year. Annual occupancy rate of waterfowl species is arbitrarily defined as the proportion of years during which the relative abundance was >50 individuals over the preceding 10 years.

2) In each group, species are ordered by their EI status from Good to Poor. The 70th percentile approach is applied to determine the EI status of a group, i.e. the status of the 7th species determine the status (see table 24 for some examples).

3) The status of the Waterbirds species is based on the status of the 2 groups of species (table 25).

B. **Amphibians status**

The assessment of the EI status of the Amphibians include the following steps:

1) The status of a species is established based on the average relative abundance and average annual occupancy rate over a 5 year period (see table 23). Annual occupancy rate of amphibian species is defined as the proportion of sites occupied by the species during a given year.

2) The status of the Amphibian species is based on the status of the Wood Frog and Boreal Chorus Frog (table 26).

C. **Status roll-up approach**

The status of the measure is determined by the status of the Waterbirds and Amphibian species (table 27). In summary, the measure is based on the status of 22 species, i.e. 10 waterfowl species, 10 non-waterfowl species, and 2 amphibian species. The status of the measure will be Poor if both the average relative abundance AND occupancy rate of at least 36% of the species, i.e. ≥3 waterfowl species, ≥3 non-waterfowl species, and 2 amphibian species, differ from the expected range of variability during a 5 year period of assessment.
D. Trend assessment

Determining the trend in EI of a composite measure is complex and involves the following steps for this measure:

1) Determine if the trend in relative abundance and occupancy is significant at p<0.2 over the period of assessment. Trend is generally analyzed with a generalized linear mixed model.

2) Assign a value of -1 or +1 to significant trends if the parameter respectively move away from or approach a Good EI condition. Assign a value of 0 to trends that are not significant. When a parameter is already in Good EI, any significant trends should be interpreted according to the mid-value between the “two-tailed” thresholds.

3) Sum the value of abundance and occupancy trends to determine the overall trends of each species. The sum will vary from -2 (high EI decline) to +2 (high EI improvement). Contradictory trends (-1 vs +1) will cancel each other, and will result as a “no overall trends”.

4) Calculate the average overall trends within each group.

5) Calculate the average overall trends between groups of waterbirds.

6) Calculate the average overall trends between the Waterbirds groups and the Amphibian group.

7) The trends in EI of the measure will be judged as “Stable” if the average between -0.6 and +0.6. If the average is <-0.6, the trends of the measure will be considered as “Declining”, and it will be considered as “Improving” if the average is >+0.6.

E. Relative weight of each group

One shortcoming of this measure is the relatively high weight of the Amphibian species group on the status and trend of the measure. Indeed, amphibians account for 50% of the status and trend, but represent 9% of the number of species considered in the measure. One way to balance the relative weight of each species would be to pool the status of all species and apply the 70th percentile approach to the list of 22 species. The trends could also be established with the average of overall trends of all the species, not within and between groups. However, this approach would be relevant only if most of the species are affected by the same stressor. Most bird species are migratory and most of the species in the waterfowl group are hunted during their fall migration. Amphibians are likely to be affected differently by climate change than birds. Thus each group are facing different issue that could influence their EI status. Assessing the status and trends of different groups would facilitate the interpretation of the change in EI of the wetland indicator.

Waterbirds community contains a large number of species in the park, and including 2 amphibians species add an unnecessary level of complexity to a measure that is already relatively comprehensive. The inclusion or exclusion of the amphibians in the same measure as waterbirds depends on the level of concerns that managers and stakeholders have regarding the conservation of frogs in the park. If this concerns are high enough, the establishment of a stand-alone measure for amphibians could be considered. However, this modification would require to eliminate another measure, or to merge 2 other measures in the indicator to comply with the program standards.
Recommendations

In conclusion, the MEI division recommends the following modifications to improve the quality of the measure:

1) Change the name of the measure to “Waterbirds and Amphibians Status” to clarify which species are included in the bird community;
2) Focus on the most common species of each group of species, and exclude SAR and species associated with human activities as originally proposed;
3) Monitor change in the abundance and occupancy of waterfowl species with the information obtained from the Breeding Population and Habitat Survey instead of the ARU protocol;
4) Establish the EI status and trend of the measure based on the relative abundance and occupancy rate of species grouped according to the taxonomy, conservation issue and source of information;
5) Consider dropping the Amphibians group from the measure if the level of concern regarding their conservation in the park is not too high;
6) Conduct a pilot project to determine if a shorter recording duration and a larger number of recording period would improve species detection probability and the precision of abundance estimate.
7) Perform a power analysis once the data from 2015 will be available to determine the statistical power of the current ARU sampling design.

List of Reviewed References


Table 19: List of wetland bird species detected in 2014 with the ARU protocol. Species were ranked according to their relative abundance and occupancy rate.

<table>
<thead>
<tr>
<th>Species</th>
<th>Relative abundance</th>
<th>Occupancy</th>
<th>Total rank</th>
<th>Final rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(nb of birds/site)</td>
<td>(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sora</td>
<td>2.75</td>
<td>93.3</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>Red-winged Blackbird</td>
<td>3.42</td>
<td>93.3</td>
<td>58</td>
<td>2</td>
</tr>
<tr>
<td>American Bittern</td>
<td>1.28</td>
<td>93.3</td>
<td>56</td>
<td>3</td>
</tr>
<tr>
<td>Northern Shoveler*</td>
<td>0.53</td>
<td>73.3</td>
<td>54</td>
<td>4</td>
</tr>
<tr>
<td>American Coot*</td>
<td>2.25</td>
<td>73.3</td>
<td>52</td>
<td>5</td>
</tr>
<tr>
<td>Wilson's Snipe</td>
<td>0.75</td>
<td>66.7</td>
<td>50</td>
<td>6</td>
</tr>
<tr>
<td>Green-winged Teal*</td>
<td>0.44</td>
<td>66.7</td>
<td>48</td>
<td>7</td>
</tr>
<tr>
<td>Alder Flycatcher</td>
<td>1.36</td>
<td>66.7</td>
<td>46</td>
<td>8</td>
</tr>
<tr>
<td>Pied-billed Grebe</td>
<td>0.94</td>
<td>60.0</td>
<td>44</td>
<td>9</td>
</tr>
<tr>
<td>Swamp Sparrow</td>
<td>0.56</td>
<td>53.3</td>
<td>42</td>
<td>10</td>
</tr>
<tr>
<td>Canada Goose*</td>
<td>0.64</td>
<td>53.3</td>
<td>40</td>
<td>11</td>
</tr>
<tr>
<td>Black Tern</td>
<td>0.78</td>
<td>53.3</td>
<td>38</td>
<td>12</td>
</tr>
<tr>
<td>American Wigeon*</td>
<td>0.28</td>
<td>53.3</td>
<td>36</td>
<td>13</td>
</tr>
<tr>
<td>Mallard*</td>
<td>0.22</td>
<td>46.7</td>
<td>34</td>
<td>14</td>
</tr>
<tr>
<td>Franklin's Gull</td>
<td>0.42</td>
<td>46.7</td>
<td>32</td>
<td>15</td>
</tr>
<tr>
<td>Yellow-headed Blackbird</td>
<td>0.97</td>
<td>40.0</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>Blue-winged Teal*</td>
<td>0.14</td>
<td>26.7</td>
<td>28</td>
<td>17</td>
</tr>
<tr>
<td>Solitary Sandpiper</td>
<td>0.08</td>
<td>20.0</td>
<td>26</td>
<td>18</td>
</tr>
<tr>
<td>Marsh Wren</td>
<td>0.64</td>
<td>20.0</td>
<td>24</td>
<td>19</td>
</tr>
<tr>
<td>Ring-necked Duck*</td>
<td>0.06</td>
<td>13.3</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>Northern Pintail*</td>
<td>0.06</td>
<td>13.3</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>Yellow Rail</td>
<td>0.03</td>
<td>6.7</td>
<td>18</td>
<td>22</td>
</tr>
<tr>
<td>Spotted Sandpiper</td>
<td>0.03</td>
<td>6.7</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td>Short-billed Dowitcher</td>
<td>0.03</td>
<td>6.7</td>
<td>14</td>
<td>24</td>
</tr>
<tr>
<td>Red-necked Grebe</td>
<td>0.03</td>
<td>6.7</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>Redhead</td>
<td>0.03</td>
<td>6.7</td>
<td>10</td>
<td>26</td>
</tr>
<tr>
<td>Lesser Yellowlegs</td>
<td>0.06</td>
<td>6.7</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>Forster's Tern</td>
<td>0.03</td>
<td>6.7</td>
<td>6</td>
<td>28</td>
</tr>
<tr>
<td>Common Loon</td>
<td>0.03</td>
<td>6.7</td>
<td>4</td>
<td>29</td>
</tr>
<tr>
<td>Common Goldeneye*</td>
<td>0.03</td>
<td>6.7</td>
<td>2</td>
<td>30</td>
</tr>
</tbody>
</table>

*Waterfowl species that will be monitored using results of the Breeding Population and Habitat Survey conducted by the US Fish & Wildlife Service and the Canadian Wildlife Service (see table 20)
Table 20: List of Waterfowl species monitored since 1956 in the Peace-Athabasca Delta area by the US Fish & Wildlife Service and the Canadian Wildlife Service as part of the Breeding Population and Habitat Survey. Species were ranked according to their relative abundance as well as their temporal occupancy rate.

<table>
<thead>
<tr>
<th>Species</th>
<th>Guild</th>
<th>Relative abundance (nb/year)</th>
<th>Temporal occupancy rate (%)*</th>
<th>Total</th>
<th>Final Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg</td>
<td>Std</td>
<td>Rank</td>
<td>Rate</td>
</tr>
<tr>
<td>Mallard</td>
<td>Dabbler</td>
<td>264.8</td>
<td>189.8</td>
<td>17</td>
<td>98.3%</td>
</tr>
<tr>
<td>Generic scaup</td>
<td>Diver</td>
<td>187.4</td>
<td>133.9</td>
<td>16</td>
<td>91.5%</td>
</tr>
<tr>
<td>Northern pintail</td>
<td>Dabbler</td>
<td>117.0</td>
<td>145.3</td>
<td>15</td>
<td>59.3%</td>
</tr>
<tr>
<td>Canvasback</td>
<td>Diver</td>
<td>83.8</td>
<td>49.6</td>
<td>12</td>
<td>71.2%</td>
</tr>
<tr>
<td>Northern shoveler</td>
<td>Dabbler</td>
<td>78.8</td>
<td>47.7</td>
<td>11</td>
<td>69.5%</td>
</tr>
<tr>
<td>American coot</td>
<td>Dabbler</td>
<td>106.4</td>
<td>180.7</td>
<td>14</td>
<td>40.7%</td>
</tr>
<tr>
<td>Canada goose</td>
<td>Dabbler</td>
<td>84.1</td>
<td>151.1</td>
<td>13</td>
<td>42.4%</td>
</tr>
<tr>
<td>American wigeon</td>
<td>Diver</td>
<td>57.3</td>
<td>38.0</td>
<td>10</td>
<td>50.8%</td>
</tr>
<tr>
<td>Bufflehead</td>
<td>Diver</td>
<td>56.3</td>
<td>31.0</td>
<td>9</td>
<td>49.2%</td>
</tr>
<tr>
<td>Generic goldeneye</td>
<td>Diver</td>
<td>48.5</td>
<td>51.6</td>
<td>8</td>
<td>30.5%</td>
</tr>
<tr>
<td>Redhead</td>
<td>Diver</td>
<td>39.2</td>
<td>32.2</td>
<td>7</td>
<td>22.0%</td>
</tr>
<tr>
<td>Mergansers</td>
<td>Diver</td>
<td>34.5</td>
<td>40.1</td>
<td>6</td>
<td>20.3%</td>
</tr>
<tr>
<td>American green-winged teal</td>
<td>Dabbler</td>
<td>32.0</td>
<td>24.2</td>
<td>5</td>
<td>16.9%</td>
</tr>
<tr>
<td>Blue-winged teal</td>
<td>Dabbler</td>
<td>25.9</td>
<td>22.4</td>
<td>4</td>
<td>10.2%</td>
</tr>
<tr>
<td>Ring-necked duck</td>
<td>Diver</td>
<td>20.6</td>
<td>17.7</td>
<td>3</td>
<td>6.8%</td>
</tr>
<tr>
<td>Gadwall</td>
<td>Dabbler</td>
<td>20.5</td>
<td>17.3</td>
<td>2</td>
<td>10.2%</td>
</tr>
<tr>
<td>Ruddy duck</td>
<td>Diver</td>
<td>9.7</td>
<td>8.0</td>
<td>1</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

*Proportion of years during which ≥50 individuals were observed

Table 21: Proposed list of species to be included in the bird community component of the Wetland Birds and Amphibian Measure, according to the source of information.

<table>
<thead>
<tr>
<th>ARU monitoring project</th>
<th>Breeding Population and Habitat Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alder Flycatcher</td>
<td>American coot</td>
</tr>
<tr>
<td>American Bittern</td>
<td>American wigeon</td>
</tr>
<tr>
<td>Black Tern</td>
<td>Bufflehead</td>
</tr>
<tr>
<td>Franklin's Gull</td>
<td>Canada goose</td>
</tr>
<tr>
<td>Pied-billed Grebe</td>
<td>Canvasback</td>
</tr>
<tr>
<td>Red-winged Blackbird</td>
<td>Generic goldeneye</td>
</tr>
<tr>
<td>Sora</td>
<td>Generic scaup</td>
</tr>
<tr>
<td>Swamp Sparrow</td>
<td>Mallard</td>
</tr>
<tr>
<td>Wilson's Snipe</td>
<td>Northern pintail</td>
</tr>
<tr>
<td>Yellow-headed Blackbird</td>
<td>Northern shoveler</td>
</tr>
</tbody>
</table>
Table 22: List of Amphibian species detected during the ARU monitoring project in 2014.

<table>
<thead>
<tr>
<th>Species</th>
<th>Occupancy rate (% of site occupied)</th>
<th>Chorus size distribution*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreal Chorus Frog</td>
<td>46.7%</td>
<td>0 6 5 1</td>
</tr>
<tr>
<td>Wood Frog</td>
<td>46.7%</td>
<td>1 8 0 0</td>
</tr>
<tr>
<td>Canada Toad</td>
<td>6.7%</td>
<td>1 0 0 0</td>
</tr>
</tbody>
</table>

*1: Single individual; 3-5: Calling intensity from low (3) to high (5)

Table 23: EI status according to the relative abundance and occupancy rate.

<table>
<thead>
<tr>
<th>Relative abundance</th>
<th>Occupancy rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; -1 SD</td>
<td>Poor</td>
</tr>
<tr>
<td>± 1 SD</td>
<td>Fair</td>
</tr>
<tr>
<td>&gt; +1 SD</td>
<td>Poor</td>
</tr>
</tbody>
</table>

Table 24: Examples of EI status assessment of a group of 10 species based on the 70th percentile approach.

<table>
<thead>
<tr>
<th>Species rank</th>
<th>Case no.1</th>
<th>Case no.2</th>
<th>Case no.3</th>
<th>Case no.4</th>
<th>Case no.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>2</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>3</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>4</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>5</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>6</td>
<td>Good</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>7</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>8</td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>9</td>
<td>Fair</td>
<td>Fair</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>10</td>
<td>Fair</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>El Status</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
<td>Poor</td>
<td>Poor</td>
</tr>
</tbody>
</table>
Table 25: EI status of the Waterbirds species based on the status of waterfowl and non-waterfowl species.

<table>
<thead>
<tr>
<th>Non-Waterfowl species</th>
<th>Waterfowl species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
</tr>
</tbody>
</table>

Table 26: EI status of the Amphibian species based on the status of the Wood Frog and Boreal Chorus Frog.

<table>
<thead>
<tr>
<th>Boreal Chorus Frog</th>
<th>Wood Frog</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
</tr>
</tbody>
</table>

Table 27: EI status of the Waterbirds and Amphibian measure based on the status of Waterbirds and Amphibian species.

<table>
<thead>
<tr>
<th>Amphibian species</th>
<th>Waterbirds species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Fair</td>
<td>Good</td>
</tr>
<tr>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
</tr>
</tbody>
</table>
Figure 19: Waterfowl species included in the measure for which no significant (p>0.1) population trends was detected. Blue line indicate the long term trends according to GLM and shaded area indicate standard error on fitted values.
Figure 20: Waterfowl species included in the measure for which a significant (p<0.1) population trends was detected. Blue line indicate the long term trends according to GLM and shaded area indicate standard error on fitted values.
Figure 21: Stratum 20 of the Breeding Population and Habitat Survey in relation to Wood Buffalo National Park boundaries.
**Delta Water Extent**

**Revised Monitoring Questions**
Is the proportion of “water inundated” area within the Peace-Athabasca Delta less than 43.5%?

<table>
<thead>
<tr>
<th>(Interim) Thresholds</th>
<th>Sampling frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
</tr>
<tr>
<td></td>
<td>Poor</td>
</tr>
<tr>
<td>Proportion of “water inundated” area</td>
<td>33.36%</td>
</tr>
</tbody>
</table>

**Status & Trends Assessment Method**
Status: Direct comparison of current value to thresholds.
Trend: Generalized linear model (GLM).

**Review Summary**
Overall, this is a strong monitoring measure that has been consistently implemented since 1996. No major issues with the conceptual or operational basis of this measure have been identified. MEI updated this measure using satellite imagery from 2013, 2014, and 2015. The proportion of “water inundated” area increased in 2014 as expected due to a known flooding event that occurred that year. Thresholds were calculated for this measure using a “standard deviation interval” approach that is common throughout Parks Canada using data from 1996 to 2012 as the baseline period (which represented the existing dataset prior to this review). Using the 2015 value of Delta Water Extent this measure is assessed as being in Good condition with a Stable trend.

**Recommendations:**
1) Apply standard deviation intervals for thresholds as follows: T1 = mean-2SD, T2 = mean-1SD, T3 = mean+1SD, T4 = mean+2SD. Updated ICE with this new information.
2) Request assistance from MEI in updating this protocol next year.
3) Contact MEI (Justin Quirouette or Paul Zorn) to investigate whether missing data in 1997, 2000, and 2002 can be filled with archived Landsat imagery.

Adobe Acrobat was searched for the PAD area (Path 43, Row 19) for these missing years. Relative cloud free imagery is available for April 29, 1997; May 31, 2000; June 16, 2000; May 22, 2002; and June 22, 2002. Some of this imagery is early in the spring and lake ice is prevalent, however, it is consistent with the timing of other imagery used 1996, 1998 and 2001. The quality of this imagery is sufficient such that it is worth the effort of addressing the missing years in 1997, 2000 and 2002. It is recommended that WBNP request MEI to conduct this work in 2017/18.

Reviewed by Justin Quirouette and Paul Zorn

**Rationale of the measure**
Water extent of the Peace-Athabasca Delta (PAD) is an important measure for the park. Delta Water Extent is directly related to habitat availability for many freshwater and wetland associated species. It is sensitive to changes in water quantity due to climate change, hydrological alteration from human resource use, and periodic ice-jam flooding events. The measure is implemented through the analysis of satellite imagery and, therefore, can represent the entire PAD area at relatively low cost. Historical, archived imagery allows the park to assess past trends in water extent for the establishment of thresholds and to help interpret current status and trends.
The metric for this measure is “%Inundated” which refers to the proportion of area within the Peace-Athabasca Delta that is inundated with water. Inundated areas refer to “open water” and “flooded vegetation” classes within the protocol. For each year remote sensing methods are applied to estimate %Inundated from optical and SAR satellite imagery.

**Protocol and sampling design**

The protocol for this measure is provided in Toyra et al. (2006) and later updated in Yazbek (2011). Both of these documents are now outdated due to changes in PCI Geomatica software. If future applications of the protocol are applied by an experienced remote sensing specialist then these changes are not critical. However, the park may want to consider updating the protocol document to be consistent with current methods and software.

**Thresholds**

Thresholds on ICE use a “standard deviation (SD) interval” approach which is common across Parks Canada. Thresholds on ICE, however, only contain one lower and one upper threshold. Since this is a bi-directional measure then a total of 4 thresholds are required (lower red (T1), lower yellow (T2), upper yellow (T3), and upper red (T4)). MEI proposes that the same SD method be applied to identify all 4 thresholds (Table 28).

<table>
<thead>
<tr>
<th>Baseline period = 1996 to 2012</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule</td>
<td>Mean-2SD</td>
<td>Mean-1SD</td>
<td>Mean+1SD</td>
<td>Mean+2SD</td>
</tr>
<tr>
<td>Value(%)</td>
<td>33.36%</td>
<td>43.50%</td>
<td>63.79%</td>
<td>73.97%</td>
</tr>
</tbody>
</table>

**Monitoring questions**

Since the primary concern with this measure is a drying trend within the PAD due to climate change and hydrologic alteration the monitoring question listed here makes reference to the T2 threshold. The monitoring question is:

“Is the proportion of “water inundated” area within the Peace-Athabasca Delta less than 43.5%?”

**Status and Trends Assessment**

As part of this review MEI updated the water extent mapping in the PAD for 2013, 2014, and 2015 using a combination of Landsat Thematic Mapper and Radarsat2 (dual polarization) satellite imagery. Results from these 3 years were added to the time series of flood mapping available for the area dating back to 1996. An updated sequence of water extent mapping is shown in figure 22. The %inundated for 2013, 2014 and 2015 was 44.96%, 60.22%, 45.00% respectively. The relatively high value in 2014 is consistent with a known flooding event that occurred in the year.

The trend in %inundated over time is shown in figure 23. The time series spans the period between 1996 to 2015 with missing values in 1997, 2000, and 2002 due to excessive cloud cover. Results from a generalized linear model (GLM) trend analysis show a small but significant
decline during this time period. This relative decline is influenced by the flooding event that occurred in the late 1990’s. The parameters from this GLM analysis are below:

<table>
<thead>
<tr>
<th>Metric</th>
<th>Predictor</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Inundated (1996 to 2015)</td>
<td>Year</td>
<td>-1.2294</td>
<td>0.3255</td>
<td>0.00183</td>
</tr>
</tbody>
</table>

This decline, however, is strongly influenced by the high water extent values at the beginning of the time series in 1996 and 1998 (figure 23). After this initial period the trend is stable and not significantly different from zero (see below). If the high values in 1996 and 1998 happened to occur in the middle of the time series, instead of at its beginning, the overall trend would be stable. When reporting on recent trends of monitoring measures, MEI recommends that only the past 10 years (the current reporting period for State of the Park Report) be considered. For this measure, the trend over the past 10 years between 2005 and 2015 has been stable and not significantly different from zero (see below). Therefore, the trend for this measure is assessed as Stable.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Predictor</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Inundated (2005 to 2015)</td>
<td>Year</td>
<td>-0.5973</td>
<td>0.6502</td>
<td>0.382</td>
</tr>
</tbody>
</table>

Given the current value of this measure from 2015 the status and trend assessment for this measure is Good and Stable (Table 29)


<table>
<thead>
<tr>
<th>Metric</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>Value (2015)</th>
<th>Status</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>%Inundated</td>
<td>33.36</td>
<td>43.50</td>
<td>63.79</td>
<td>73.93</td>
<td>45.00</td>
<td>Good</td>
<td>Stable</td>
</tr>
</tbody>
</table>
**Recommendations**

Overall, this is a strong monitoring measure that has been consistently implemented for a 20 year period. No major issues with this measure have been identified. Two recommendations for the future implementation of this measure are:

- Apply standard deviation intervals for thresholds as follows: T1 = mean-2SD, T2 = mean-1SD, T3 = mean+1SD, T4 = mean+2SD. Updated ICE with this new information.
- While not a current priority the park should endeavour to update the protocol for this measure before their next SOPR.
- Contact MEI (Justin Quirouette or Paul Zorn) to investigate whether missing data in 1997, 2000, and 2002 can be filled with archived Landsat imagery.

**List of Reviewed References**


Figure 22. Time series of flood mapping in the Peace-Athabasca Delta from 1996 to 2015.
Figure 23. Annual values in %Inundated in the PAD from 1996 to 2015.
Muskrat Abundance

**Proposed Monitoring Question**
*Has the number of muskrat houses per basin exceeded the 75th percentile of long-term observations (84 houses) in the past 8 years?*

<table>
<thead>
<tr>
<th>(Interim) Threshold</th>
<th>Sampling frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum houses per basin in last 8 years</td>
<td>Poor</td>
</tr>
<tr>
<td>≤42</td>
<td>≥84</td>
</tr>
</tbody>
</table>

**Status & Trends Assessment Method**
Trend should be based on the period since 1998 as ground survey data is fairly continuous since that time. Ultimately the period of trend observation should extend back 24 years to capture several population cycles/ flooding events. The metric will not decline for a period of 8 years and is biased towards increasing trends and sudden declines.

**Review Summary**
1) This metric will indicate when population cycles have been longer than usual or when they have lower peaks.
2) The 8 year cycle length was based on literature values for the Boreal Plains ecozone.
3) The aerial survey protocol would make the measure stronger and could use thresholds based on calibration with the ground observation data.

**Recommendations:**
1) Standardize the naming of the basins in the historical data in order to allow an analysis of occupancy rate over time
2) Aerial surveys are a superior method for counting houses, as effort can be more easily standardized. However, before adopting this new approach, it is important to establish whether the measure can be reliably assessed with the existing ground-based data. The decision should also consider increased cost and long-term sustainability. One advantage of ground based surveys is that they engage local stakeholders and citizen scientists. If the aerial data become the basis of the measure, a minimum of two more years of data will be required to establish preliminary thresholds.
3) If the ground counts are continued, revise the protocol to ensure that sampling effort is standardized, and that extraneous data are not collected to increase the efficiency of the sampling.

Reviewed by Jesse Wittington, with revisions by the operational review team.
**Detailed review**

**Rationale of the measure**

As stated in ICE, there is a good rationale for using this measure:

*Muskrats play an important role in the Peace-Athabasca Delta by affecting vegetation composition of wetlands through herbivory, and providing food base for a range of key predators. Culturally, they play a fundamental role in the diet, materials, medicine, and traditional values, culture and economy of First Nations and Métis of the PAD. Traditionally, the species was trapped for food, clothing, and revenue. Today, muskrat trapping continues to provide local people with a vital connection to the land and a way to pass on traditions to younger generations.*

**Thresholds**

Use the 75th percentile of historic observations (84 houses/basin for the ground observation protocol) as the T2 threshold between fair and good condition. The measure value is calculated as the average of all basins examined. Extend this threshold back in time by using the eight year maximum number of houses/basin. This value will indicate when population cycles have been longer than usual or when they have lower peaks. Use a maximum 8 year house density that is half the value of the 75th percentile (42 houses/basin) as the T1 threshold between poor and fair.

**Monitoring questions**

The monitoring question must consider two elements of the muskrat population: abundance and cyclicity.

*Has the number of muskrat houses per basin exceeded the 75th percentile of long-term observations (84 houses) in the past 8 years?*

There are a few issues with the question as posed. First, abundance varies dramatically between flood and non-flood periods. Flooding is a significant factor in muskrat populations in the year of a flood and for two years following it (Appendix V). Second, the local cyclical pattern is difficult to determine, even with long-term fur trade data (Appendix V, Timoney 2013, p.284). Some certainty is brought to the discussion by Erb et al. (2000), who on the basis of 91 time series of fur-trade data, estimated an eight year cycle length for the muskrats in the Boreal Plains region (7.86 years with a standard deviation of 2.28). The authors relate this cycle to mink populations, vegetation and disease.

The peak population densities may be somewhat lower than pre-industrial values (J. Straka pers. comm.; Timoney, 2013) but are consistent with population declines elsewhere in Canada.

A two-tiered measure was considered with different field measurements for flood and non-flood periods. The 8 year maximum was chosen, however, to show that ecological integrity for this measure does not decline at the low end of the population cycle. It is only considered impaired if the peaks are low or far apart.
Protocol and sampling design

The strength of the ground-based muskrat abundance metric is that protocols are well established, search areas are well established, there is a long-term data set, and it involves the local community. The biggest weakness of the metric is that results may be influenced by surveyor effort and travel conditions. This has been addressed by collecting and analysing data at an individual basin level (repeated measures). The status of muskrat and identification of fluctuation events were calculated by averaging the number of muskrat houses across basins. If the number of basins surveyed changes each year, then results would be influenced by which basins were surveyed because some basins innately have higher numbers of muskrat. That said, the increase in muskrat abundance following flood events may be large enough to swamp among basin variation in abundance.

In 2013, Wood Buffalo started conducting aerial surveys for muskrat abundance (Appendix V). This is likely a much stronger measure for muskrat abundance because search effort is the same each year and there is potential to incorporate detection probability into the analysis, which could then be used to estimate abundance. Power analysis was not conducted but there may be lower year-to-year variation in abundance with the aerial survey metric and there is potential to save funds by conducting surveys every 2 years and then in years with and following flood events. The aerial survey data could be re-evaluated for efficiencies and power after collecting 5 years of data.

Summary

Muskrat are an important species to the ecology and people of Wood Buffalo National Park. The strength of the ground count data is that it is a long-term data set, designated survey areas have been delineated, and it involves the local community and citizen science. Weaknesses of this method are that search effort may vary year to year depending on travel conditions. Changes in effort could strongly influence results. However, that can continue to be mitigated by using set survey routes and tallying data on a per basin basis. An advantage of ground surveys is that they engage locals.

Aerial surveys were conducted from 2013 to 2015. These surveys explicitly quantify survey effort because the same transects are flown each year. Aerial surveys may over time be a stronger measure of muskrat abundance than ground counts. One of the main draw-backs of the aerial surveys is that they require a lot of field work coordination during a period of low capacity in the park.

In the meantime, the threshold developed for the ground surveys appear to adequately reflect the ecology of the species and the cyclic nature of the muskrat populations.

Literature Cited


**Bison Productivity**

**Monitoring Questions**
1) Is the estimate of total bison population within historical limits (3554-6139 animals), and has it changed within the last ten years?

<table>
<thead>
<tr>
<th>Metric</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance</td>
<td>2262</td>
<td>3554</td>
<td>6139</td>
<td>7431</td>
</tr>
<tr>
<td>Calf survival</td>
<td>20.6</td>
<td>50.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sampling frequency**
Abundance: ≤5 years

**Status & Trends Assessment Method**
As population count data are only collected every five years, there is insufficient data to fit a trend model. Instead, use the EI monitoring guideline recommendation for establishing the ten year trend (compare the current value to the mean of the two previous observations).

**Review Summary**
1) WBNP has a long history of conducting bison management and monitoring. In brief, the bison population minimum count has ranged between roughly 1500 and 12 000 animals since 1922 when WBNP was first formed. The bison population has been influenced by wolf control that likely led to unnaturally high bison populations, introduction of Plains bison, the introduction of brucellosis and tuberculosis, anthrax, floods, changing habitat quality, and predation. The relative importance of these factors has been well studied, published, and discussed (Carbyn et al. 1993, Joly and Messier 2000, 2004, Bradley and Wilmshurst 2005). Using the most recent survey data available at the time, Bradley and Wilmshurst (2005) found that population changes were most strongly driven by predation and less so by interactions between predation, disease, and habitat quality associated with construction of the Bennett Dam.

2) Aerial survey effort has varied considerably over time but has been relatively consistent since 2002 when permanent survey transects stratified by sub-region were established (Cortese and McKinnon 2015). Segregated counts for calf:cow and yearling:cow ratios have been conducted consistently since 1984 and have been useful for understanding mechanisms of decline given that juveniles are thought to be less susceptible to disease than adults and more susceptible to predation (Bradley and Wilmshurst 2005). Adult survival rates were estimated from 1988 – 2003.

3) Since WBNP started systematic surveys in 2002, the population increased significantly to 2005 and then decreased to the last survey in 2014. Population growth rates were not influenced by winter severity, winter temperature, or summer precipitation. During flood years, growth rates decreased in the Delta and marginally increased in other regions.
Calf:cow ratios, yearling:cow ratios and especially calf to yearling survival rates were positively correlated with population growth rates. Summer precipitation had a weak negative association with calf to yearling survival.

WBNP proposed using bison productivity as the bison metric for their EI monitoring program. While this does provide useful information, juvenile survival rates can be highly variable and the direct estimate of population size is a preferable EI Monitoring metric.

**Recommendations:**

1. Use total population estimate as the EI Monitoring metric. Continue with surveys that count bison within the survey transect strips (or distance from strip), because they enable estimates of uncertainty.

2. Other metrics like distance sampling might be considered. However, there are likely pros and cons to this method that would need to be evaluated. Some factors to consider would be the practicality of sampling large herds that straddle transects, the ability to convert historical data to distance sampling format, and compatibility with adjacent jurisdictions.

3. Automate the analysis of the population estimates using R or similar software to ensure repeatability, and minimize errors involved with multiple manual steps in Excel.

**Detailed review**

**Rationale of the measure**

As stated in ICE, there is a good rationale for using this measure:

*The PAD supports the largest free-ranging wood bison herd in the world. Bison influence the direction and rate of change of the ecological process of succession in the PAD; disturbance favours open water, aquatics, marches and meadows, thereby bison help maintain open prairies through the process of herbivory. They are a central link in the graminoid (grasses and grass-like plants): bison: wolf food chain. Calf to cow ratios (determined through herd composition counts) are commonly used as an index of herd productivity and have a broad spectrum of applications including rate of herd increase and mortality rates. Because the data are acquired soon after the majority of calving has taken place and before the expected calf mortality influences results – the measure provides a snapshot of the herds’ current health, nutritional level and range condition. Recruitment rates may provide managers with an early warning of population decline, and early warnings should be assessed often.*

**Thresholds**

Productivity thresholds posted in ICE lack details regarding what the metric is, how it was calculated, and why those values were chosen. Similarly, it is unclear how the CI’s on the thresholds are to be used. I suspect they refer to calf to yearling survival.

We propose preliminary threshold for the population estimate using the following logic. There is limited data on population estimates for generating thresholds based on historical variability, but there is good information on the total minimum abundance. The total minimum abundance is simply the sum of observed animals, and is likely an undercount of the actual abundance. Hence, we standardized the minimum abundance data (by dividing by the mean) to generate a
standardized variance estimate. We only used data from after 1980, since previous observations were likely influenced by wolf control, and the bison introduction, and likely do not reflect natural variability. We applied the scaled variance to the recent population estimate data (minus the most recent value in 2014) and we derived thresholds based on +/- one and two standard deviations from the pre 2014 mean.

**Monitoring questions**

The following monitoring question is proposed:

1) Is the estimate of total bison population within historical limits (3554-6139 animals), and has it changed within the last ten years?

Additionally, if the park continues with the productivity monitoring, we recommend the following question:

2) Is the calf to yearling survival rate ≥50.6% and has it changed in the last 5 years?

**Protocol and sampling design**

Protocols for the classified counts and aerial surveys are very thorough and have undergone extensive reviews.

The data sets I saw for the aerial population surveys are distributed among several worksheets and excel files and thus might be labour intensive and prone to mistakes because so many calculations are required. Data were tallied across spreadsheets for each region and then for all of WBNP. This made it challenging to find and re-analyse historical data. Analyses could potentially be done much more quickly and with fewer errors if at a minimum all transect level data were in the same database or excel spreadsheet. If excel is used, drop down lists can help minimize data entry errors. If each row had the following columns such as date, region, strata, transect, number of bison in the strip, number of bison out of the strip, search area, and percent area, then I suspect things like population estimates, variance, degrees of freedom, and confidence intervals could be calculated for all data at once and summarised by region and park using pivot tables. This recommendation contains the caveat that I have not gone through the data processing and it might be more efficient than imagined.
ANALYSIS OF LONG TERM TRENDS AND STATUS

Objectives:
   b. Bison Classified Age-Sex Counts and calf to yearling survival
2. Operational Review of the Bison Measure for Ecological Integrity.

1. Long Term Trends.

Population Counts

WBNP has a long history of conducting bison management and monitoring (Figure 24). In brief, the bison population has ranged between roughly 1500 and 12,000 animals since 1922 when WBNP was first formed. The bison population has been influenced by wolf control that likely led to unnaturally high bison populations, introduction of Plains bison, the introduction of brucellosis and tuberculosis, anthrax, floods, changing habitat quality, and predation. The relative importance of these factors has been well studied, published, and discussed (Carbyn et al. 1993, Joly and Messier 2000, 2004, Bradley and Wilmshurst 2005). Bison carrying both brucellosis and tuberculosis had lower survival rates than disease-free bison (Joly and Messier 2004). However, using the most recent survey data available at the time, Bradley and Wilmshurst (2005) found that population changes were most strongly driven by predation and less so by interactions between predation, disease, and habitat quality associated with construction of the Bennett Dam. Brodie (2008) provides a good summary of how WBNP’s survival and reproductive rates compare to other bison populations in North America.

Figure 24. History of bison abundance and management in Wood Buffalo National Park (copied from ‘Bison Total Count Graphic 1900 to 2014 Based on Carbyn 31 LC.xlsx’).
Figure 25. Minimum number of bison observed on aerial surveys in Wood Buffalo National Park.

Note: Numbers prior to 2002 were adjusted for survey effort, which enabled better comparisons between survey periods.

Given the management and ecological concerns around bison, bison surveys have been conducted in Wood Buffalo National Park since the early 1900’s (Figure 2424, Figure 255). Starting in 2002, researchers started using systematic late winter aerial surveys along pre-defined routes (Figure 2626). On each survey, staff counted the number of bison occurring within 500 metres of the survey route. Constraining counts to bison within strips, enabled the calculation of population estimates with confidence intervals. Surveyors also counted bison beyond the strip and in some years extend surveys to search all open areas with high concentrations of bison. These counts were used to determine the minimum number of bison in WBNP. In several years researchers extended the survey to count bison beyond the 1 km wide strip.

The number of bison in WBNP was likely unnaturally high in the 1970’s because of extensive wolf control. The numbers declined from over 6000 individuals to 2500 in the late 1990’s. Populations throughout WBNP increased to a minimum count of 4366 in 2005 then appeared to decrease, even when accounting of uncertainty in population estimates (Figure 2727). I tested for statistically significant changes in the bison population from 2002 to 2014 using the aerial survey population estimates. I compared four models to assess whether or not there was no trend, a linear trend, or a linear increase and then a linear decrease from 2005 (segmented...
Before running the analysis, I needed to combine abundance estimates and uncertainty for the part of the Little Buffalo region (Slate River Lowlands) that was surveyed by the NWT in 2014 using distance sampling. Uncertainty around WBNP estimates were symmetrically distributed around the estimate on the nominal scale, whereas the NWT estimates and uncertainty were symmetrical on the log scale. To combine estimates and uncertainty, I randomly generated 10000 values from each distribution, combined, and then calculated confidence intervals on the nominal scale.

I conducted linear regression using the R package metaphor, which incorporates uncertainty in population estimates in the model. The best model was the segmented regression which showed the population increased by an average of 446 individuals per year from 2002 – 2005 and then decreased by an average of 644 from 2005 – 2014 (Figure 27; Table 30).

Figure 26. Flight transects for bison abundance surveys, copied from Cortese and McKinnon (2015). Note: All bison observed within a 1 km wide strip were recorded and entered to estimate density and abundance within the study area.

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>SE</th>
<th>Z</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept2005</td>
<td>5496.9</td>
<td>298.3</td>
<td>18.4</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Year.2002-2005</td>
<td>446.6</td>
<td>135.3</td>
<td>3.3</td>
<td>0.001</td>
</tr>
<tr>
<td>Year.2005-2014</td>
<td>-644.3</td>
<td>185.4</td>
<td>-3.5</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Population Growth Rates

I examined the effects of winter severity and flooding on population growth rates. I compared minimum count abundance data from the Delta to other regions because flooding might exert stronger effects on the Delta. In 1974, an early spring flood increased bison mortality rates when bison fell through the ice (Cortese and McKinnon 2015).

I calculated the population growth rate $\lambda$ as $\lambda = \left(\frac{N_t}{N_0}\right)^{1/n\text{years}}$ where $n\text{years}$ was the number of years between the previous survey ($N_0$) and the current survey ($N_t$). I used log($\lambda$) as the response variable in linear models and then compared the effects of the previous year’s summer precipitation, winter temperatures, winter severity, and flood years on population growth rates. I also included direct and interacting effects between the environmental covariates and the Delta vs Other Regions. The weather-related covariates were used because they have influenced elk demographics and migration strategies in the Rocky Mountains (Eggeman et al. 2016). I used Fort Smith Environment Canada weather data from 1974 to the present. I calculated summer precipitation as the total precipitation from May through August, mean winter temperature from November through March, and total winter precipitation from November through March. I calculated winter severity as the product of the absolute value of mean winter temperatures and winter precipitation. Flood years were 1972, 1974, 1996, 1997, and 2014. I compared models using AICc. When running models I did not propagate uncertainty in population estimates into the estimate of $\lambda$. This would likely inflate Type I error (i.e. find a significant trend when none exists).
Population growth rates were highly variable until the early 1990’s, especially for regions other than the Delta (Figure 288). This high variability could have been influenced by survey effort and lower sightability in some regions of WBNP.

The top model examining the effects of climate-related covariates on growth rates showed weak support for an interaction between Floods occurring in the spring prior to the winter survey and Region. Growth rates in the Delta were similar to Other Regions, except during Flood Years, when growth rates were slightly lower (Error! Reference source not found.29). However, the ΔAIC value was only 0.1 from the Null Model. Moreover, as growth rates declined in the Delta, they increased in other regions perhaps because bison would simply move into adjacent areas during flood years (M. Bradley pers. comm.). Because we did not include measures of uncertainty in annual growth rates, we likely over-estimated the effects of flooding. Summer precipitation, winter temperatures, and winter severity had no discernable effect on population growth rates.

![Bison Population Growth Rate](image1.png)

**Figure 28.** Bison population growth rates from 1974 to 2014. Estimates were from minimum number of animals observed, corrected for survey effort.

![Boxplot of Bison Population Growth Rates by Region and Flood](image2.png)

![Predicted Bison Population Growth Rates by Region and Flood](image3.png)

**Figure 29:** Observed (boxplot) and predicted (with 95% CI’s) bison population growth rates by region and flood years. During flood years, bison population growth rates in the Delta dropped well below growth rates for stable populations ($\lambda = 1$) while growth rates did not change in other areas of Wood Buffalo National Park.
Bison Productivity: Calf:Cow Ratios, Yearling:Cow Ratios

WBNP conducts segregated age-sex counts in shortly after calving season in June. Calf:cow ratios, yearling:cow rations, and calf to yearling survival (hereafter referred to as calf survival) are important metrics for understanding mechanisms behind changes in abundance. Bison calve in May and segregated counts occur in June. Following Bradley and Wilmshurst (2005), I calculated calf to yearling survival rates in year $t$ as:

$$CalfYearlingSurvival_t = \frac{YearlingCowRatio_t}{CalfCowRatio_{t-1}}.$$

I calculated confidence intervals for calf to yearling survival following instructions here [http://www.rit.edu/~w-uphysi/uncertainties/Uncertaintiespart2.html](http://www.rit.edu/~w-uphysi/uncertainties/Uncertaintiespart2.html), however I am not 100% certain that propagating standard errors is equivalent to propagating standard deviations. The formula I used was:

$$SE_{CalfYearlingSurvival_t} = CalfYearlingSurvival_t \sqrt{(SE_{CalfCow t-1} \div CalfCow_{t-1})^2 + (SE_{YearlingCow_t} \div YearlingCow_t)^2}.$$

The 95% CI was calculated by $1.64 \times SE_{JuvenileSurvival_t}$.

Bradley and Wilmshurst (2005) also calculated juvenile survival rates as a product of survival from pregnancy to segregated counts and survival from segregated counts in year $t-1$ to year $t$ such that $JuvenileSurvival_t = \left(\frac{CalfCowRatio_{t-1}}{PregnancyRate}\right) \times \left(\frac{YearlingCowRatio_t}{CalfCowRatio_{t-1}}\right)$. However, such a metric reduces to the YearlingCowRatio, which does not account for changes in the number of adult females from year $t-1$ to year $t$. One possible way to account for changes in the female population would be to divide the number of cows observed in year $t$ by the population growth rate $\lambda_t$. This denominator could then be used when calculating yearling:cow ratios. The JuvenileSurvival metric could be further improved by scaling the ratio of yearling to calf:cow ratios by the power of 11/12, because there are 11 months from June count dates to May calving dates (Decesare et al. 2011). Further, the manuscript Bradley and Wilmshurst (2005) incorrectly states that survival from pregnancy to calf count should be $Pregnancy / CalfCowRatio$; the correct formula which was likely used in their calculations is $CalfCowRatio/Pregnancy$. For simplicity below, I used yearling:cow ratios as a proxy for juvenile survival.

I imported data from the Excel file ‘Bison Segreation Count Analysis All Years 3 Jun 2014 LC.xlsx‘. The file contained annual calf:cow and yearling:cow ratio’s, juvenile survival (Figure 3030), as well as minimum population counts. Note that the Excel file contains an error in how calf to yearling survival was calculated for 2014 and 2015.
Figure 30. Calf:100 Cows, Yearling: 100 Cows, and Calf to Yearling survival rates and 90% CI for bison in WBNP.

I graphically examined the association between calf:cow ratios, yearling:cow ratios, and calf to yearling survival rates. I linked the previous year’s calf cow ratios, the current year’s yearling:cow ratio, and the current year’s juvenile survival rates to population growth rates estimated from the late winter population surveys. I selected population growth rate estimates with single year between surveys to match date ranges of population counts and segregated surveys. I removed the 1984 to 1985 data because staff were just learning ground survey methodology (Bradley and Wilmshurst 2005) and the 1984 survey had a lower calf:cow ratio than the 1985 yearling:cow ratio, which was biologically impossible. All three metrics and especially calf to yearling survival rates were positively correlated with population growth rates (Error! Reference source not found. 31).
Figure 31: Relative effects of calf:cow, yearling:cow, and juvenile survival rates on population growth rates. Straight gray lines and shaded areas represent predictions and 95% CI from a linear model between each demographic parameter and population growth rates. Note, uncertainty in parameter estimates were not included in the models.

I explored the effects of climate-related variables (as described above) and floods on yearling:cow proportions as well as calf to yearling survival rates from 1986 through 2015. Given that values were constrained between 0 and 1, I used beta-regression and compared 6 models using AICc. There was no effect of flood or climate related covariates on yearling:cow ratios. The top model for calf to yearling survival showed a weak negative association between summer precipitation and survival ($B_{\text{SummerPrecip}} = -0.072$, SE = 0.039, p = 0.064). The difference in AICc between this model and the null model was 1.5. This analysis likely overestimated the effects of precipitation because it did not include uncertainty in calf to yearling survival rates.

2. Bison Measure for Ecological Integrity

Thresholds as posted in ICE are 20.6 and 50.6 and likely refer to calf to yearling survival rates. It is unclear how these thresholds were derived. A plot of the survival rates against the thresholds suggest the bison are currently in “Good” condition (Figure 32).

I assessed trends in calf to yearling survival from the past 10 years. The data is constrained between 0 and 1 proportions are used and thus point towards analysis with beta-regression models. However, it is currently unclear how to incorporate levels of uncertainty around annual estimates. Therefore, I used linear regression with the R metaphor package so that estimates of uncertainty could be included in the models. The drawback of this approach is that predictions can exceed 0 and 1 (or 0 and 100%). I compared models with no change, linear change, change point in 2010, and a categorical variable for 2 periods (2005 – 2010 and 2011 – 2015). Given the big changes in rates from 2005 to 2010, there was little evidence for a statistically significant change in rates from 2005 to 2015.
Figure 32. Calf to yearling survival rates with 90% CI plotted against interim thresholds.

Literature Cited


Peace-Athabasca Delta Vegetation Change Measure

**Monitoring Questions (from ICE)**

1) What is the relative abundance of non-native species in delta meadows, and how is it changing through time?

**Thresholds (from ICE)**

- **Good:** <5% of plots have invasive species (1988 levels)
- **Fair:** 5-25% of plots have invasive species.
- **Poor:** >25% of plots have invasive species.

**Sampling frequency**

5 years

**Status & Trends Assessment Method**

Percent of plots with invasive species.

**Review Summary**

1) This is a simple and easy to calculate metric for the distribution of invasive species. However, the metric percent plots with invasive species requires that the same plots are sampled every year. Otherwise, if only some plots are sampled and there is a strong spatial gradient in the distribution of invasive species then results will depend on which sites were sampled.

2) Analysis of the vegetation plot and line-intercept data found that:

- Tall shrub cover increased over time and with time since the last flood. Tall shrub cover was highest on drier soil classes.
- Invasive thistle increased over time and increased from time since the last flood. Invasive thistle was more likely to occur on well drained soils and at sites with a deeper depth to water.
- As of 2008, 17% of the plots had invasive thistle and thus the park was in Fair and decreasing condition for invasive species.

**Recommendations:**

1) Vegetation plots are labour intensive, especially as written in the protocols. If the park is interested in just the distribution of invasive species and percent tall shrub cover, then line-intercept transects simply estimating percent cover and presence/absence of invasive species might be more efficient.

2) Consider adding percent tall shrub cover to the vegetation metric. Conversely, this metric could be used to inform management without a direct link to ICE.

**Detailed review**

**Rationale of the measure**

As stated in ICE, there is a good rationale for using this measure:

*The PAD is a dynamic ecosystem that thrives from fluctuating water levels. However, sustained and prolonged stressors such as reduced water quantity and climate warming may be altering the resilience of the vegetation community. PAD plant communities provide structure for nesting and spawning habitat, food for herbivores, and protection from predators. Should reduction and/or regulation of flow on the Peace River be mitigated in the future, this measure would capture ensuing vegetation changes*
Thresholds

As described in ICE, the thresholds are biologically based:

Thresholds were based on lowest observed abundance of invasive plants in the PAD (proportion of plots with invasive species, post-flood). In 1998, all invasive plants occurred in <5% of study plots, so this was used as a threshold between good and fair. The condition of PAD veg was declining until the ice-jam flood event in spring of 2014. Effects of this event have yet to be determined, but it may have reduced prevalence of invasive species and increased native wetland vegetation.

Monitoring questions

Good. WBNP might consider the addition of tall shrub cover as a measure or a combined measure with the invasive species. As entered in ICE:

Work is currently underway to add additional monitoring questions and thresholds related to PAD vegetation. These are 1. How is the plant community cover of the delta changing over time? (i.e. is the proportion of plots/transects covered by each of 8 community types?) and 2. How is the extent of willows changing over time?

Protocol and sampling design

Protocols as entered in ICE are good. Field methods appear labour intensive, which may be difficult to sustainable for a long term monitoring program.

Vegetation was assessed annually from 1993-1998, and at five year intervals afterwards. The data set includes information on community composition (% cover in plots), and extent of willow presence (linear transects). Past reports show that the flooding regime accounts for only a portion of variability in community composition and no single factor describes vegetation changes observed over time. The main invasive species of concern in WBNP are Canada thistle (Cirsium arvense) and perennial sow thistle (Sonchus arvensis). The spread of invasive plants is likely linked to changing climate, hydrology, and human traffic.

ANALYSIS OF LONG TERM TRENDS AND STATUS

Objectives:
   - Tall Shrub Line Intercept Transects (1993 - 2014)
   - Vegetation Plots including Tall Shrubs and Invasive species (1993 - 2008)
2) Operational Review of the Invasive Species measure for Ecological Integrity.

Below I outline analytical methods, summarise results, discuss strengths and weaknesses of the measure, and make recommendations for improvement.

1. Long-term trends in Tall Shrub and Invasive Species Distribution.

Flooding can have large effects on vegetation in the Peace Athabasca Delta (PAD). Timoney and Argus (2006) found that in general willow increase in drier areas and die back in
wet areas. The amount of die back depended on water depth and duration of flooding. However, resilience to flooding was higher for large old willows and for some species of willow. Willow in the PAD increased from the 1980’s to a peak in 1993 as a result of decreased water flows associated with the Bennett Dam, a long drying period, and wild fires. Flooding in the mid-1990’s resulted in a decrease in willow cover.

From 1993 – 2014, researchers and staff intermittently surveyed 36 vegetation transects within the Peace-Athabasca Delta. Two types of surveys were completed. One was line-intercept transects where surveyors recorded distance intervals along the transect that were covered by individual shrubs and trees. The second type of data collected was percent cover for each species at permanent vegetation plots. Previous summaries of these data sets referred to changes in percent cover by “willow”, but it was unclear what species were included in these summaries. Therefore, for this analysis I assessed factors affecting cover of Tall Shrub species that might be strongly influenced by flooding events and that might have cascading effects on other species (Table 31). I also assessed factors affecting changes in the distribution of invasive species, namely non-native thistle.

Depth to Water was recorded at each plot with negative values indicating depth of standing water and positive values indicating depth to water table. When depth to water was missing, I used the median depth from all plots on a transect as recommended in the metadata. One challenge with water depth is that willow cover measured in one year may depend on water depth through previous years. Each plot was also assigned a soil drainage class with 0 being dry and 7 being wet. Values within the study area ranged between 4 and 7. Similar to water depth, I used the median value of the transect for missing values. I assessed this covariate as both a categorical variable and a continuous variable. For the transect level, line intercept analysis I used the mean value of depth to water and drainage measured across all plots within a year.
Table 31. Species classified as *Tall Shrub* and *Invasive*. Dandelions were removed from the invasive species analysis because effort to estimate cover for dandelions may have varied over time and they may be less of a management issue compared to thistles.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Code</th>
<th>Latin Name</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tall Shrub</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey (Hoary) Alder</td>
<td>alnuinc</td>
<td><em>Alnus incana</em></td>
</tr>
<tr>
<td>Saskatoon Berry</td>
<td>amelaln</td>
<td><em>Amelanchier alnifolia</em></td>
</tr>
<tr>
<td>Red Osier Dogwood (Red Willow)</td>
<td>cornsto</td>
<td><em>Cornus stolonifera</em></td>
</tr>
<tr>
<td>Little Tree Willow</td>
<td>saliarb</td>
<td><em>Salix arbusculoides</em></td>
</tr>
<tr>
<td>Beaked (Bebb's) Willow</td>
<td>salibeb</td>
<td><em>Salix bebbiana</em></td>
</tr>
<tr>
<td>Pussy Willow</td>
<td>salidis</td>
<td><em>Salix discolor</em></td>
</tr>
<tr>
<td>Sandbar (Narrow Leaved) Willow</td>
<td>saliexi</td>
<td><em>Salix exigua</em></td>
</tr>
<tr>
<td>Sandbar (Narrow Leaved) Willow</td>
<td>saliexi</td>
<td><em>Salix interior</em></td>
</tr>
<tr>
<td>Shining Willow</td>
<td>saliluc</td>
<td><em>Salix lucida</em></td>
</tr>
<tr>
<td>Yellow Willow</td>
<td>salilut</td>
<td><em>Salix lutea</em></td>
</tr>
<tr>
<td>Basket Willow</td>
<td>salipet</td>
<td><em>Salix petiolaris</em></td>
</tr>
<tr>
<td>Flat(plane) Leaved Willow</td>
<td>salipla</td>
<td><em>Salix planifolia</em></td>
</tr>
<tr>
<td>Mackenzie's Willow</td>
<td>salipro</td>
<td><em>Salix prolixa (mackenziana)</em></td>
</tr>
<tr>
<td>Autumn Willow</td>
<td>saliser</td>
<td><em>Salix serissima</em></td>
</tr>
<tr>
<td>Willow</td>
<td>salisp</td>
<td><em>Salix species</em></td>
</tr>
<tr>
<td><strong>Invasive</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada Thistle</td>
<td>cirsarv</td>
<td><em>Cirsium arvense</em></td>
</tr>
<tr>
<td>Perennial Sow Thistle</td>
<td>soncarv</td>
<td><em>Sonchus arvensis</em></td>
</tr>
<tr>
<td>Sow Thistle</td>
<td>soncsp</td>
<td><em>Sonchus species</em></td>
</tr>
<tr>
<td>Smooth Perennial Sow Thistle</td>
<td>sonculi</td>
<td><em>Sonchus uliginosus</em></td>
</tr>
<tr>
<td>Common Dandelion</td>
<td>taraoff</td>
<td><em>Taraxacum officinale</em></td>
</tr>
</tbody>
</table>
The data set consists of 36 permanent linear transects varying in length between 98 and 918 metres (median = 525 m). On each transect surveyors laid out a measuring tape and recorded the start and end distance of each shrub and tree. In some years surveyors grouped clumps of shrubs and therefore estimates of shrub size may not be comparable among years. However, percent of the transect covered by willows is comparable.

For each transect-year, I divided each transect into 10 cm increments and determined whether or not each segment was occupied by a live Tall Shrub (see Table 31 for species list). I then calculated the percentage of each transect occupied by live tall shrubs. For the analysis, I used generalized linear mixed effects models with \textit{Transect} as a random effect. The random effects terms were added because the data comprised repeated measurements at the same transects over time. I used a binomial link with the proportions included as a combination of \textit{LengthWithWillow} and \textit{LengthOther}. Proportion data are difficult to analyse because the response variable is always bounded between 0 and 1. Thus, predictions and residuals should also be bounded between 0 and 1. Other options for analysis would be to use beta regression or Gaussian models with a logit link. I compared models using AIC with the following explanatory variables: quadratic for depth to water (depth in cm was divided by 10), drainage type (range 4 to 7, centred on 5), drainage type as a categorical variable, flood year, years since flood, years since flood with a maximum value of 10 (\textit{flood.10}), and interactions between drainage and years since flood. After adding ecologically based covariates, I compared models with and without the addition of year as a linear variable (centred on 2000) and as a categorical covariate. The top model was:

\begin{verbatim}
glmer(cbind(perc.shrub, perc.other) ~ flood.10 + year.c + (1 | transect.number), family = binomial)
\end{verbatim}
Percent of the transect covered by tall shrubs increased with time since floods and generally over time from 1993 to 2014.

Table 32. Fixed effects parameter estimates from the top model predicting the percent of linear transects covered by tall shrubs.

| Estimate | Std. Error | z value | Pr(> |z|) |
|----------|------------|---------|-------|
| (Intercept) | -1.914 | 0.229 | -8.34 | < 0.001 |
| flood.10 | 0.076 | 0.005 | 14.49 | < 0.001 |
| year.c | 0.038 | 0.003 | 12.07 | < 0.001 |

Figure 34. Percent of 36 linear transects with tall shrubs in the Peace-Athabasca Delta. Blue triangles indicate flood years.

Figure 35. Plot for the effects of years since last flood and mean depth to water on percent of transects covered by tall shrubs.
Figure 36. Predictive plots showing the effects of years since last flood and year on percent tall shrub cover on line intercept transects.

1b. Vegetation Plots: Tall Shrubs

This data set consists of vegetation data collected within a 10 m² plot for shrubs and within 25 cm² quadrats for herbaceous plants. Plot locations were marked and thus returned to during repeat surveys. Surveyors estimated the percent of the plot covered by each species. Between 8 and 29 plots were located along 36 permanent transects totaling 670 plots. For each plot I tallied the percent cover of tall shrub species and the presence-absence of non-invasive thistles.

Figure 37. Number of vegetation and transects and plots surveyed in the Peace-Athabasca Delta.
The discrepancy in percent shrub cover from 1993 to 1996 is surprising because 1996 was a flood year and flooding was thought to cause a decrease in willow cover (Figure 39). Even if there was a lag effect such that willow did not die back until the year following floods, 1996 values should be more similar to 1993 to 1995 values. Timoney and Argus (2006) noted that willow cover peaked in 1993 and then declined through 2001 which does not match observed data. Finally, plots of percent willow cover vs depth to water have a very different distribution compared to previously published data (Figure 40) even though water depths
recorded for each year and transect look reasonable (Figure 41). There’s a chance I made a mistake, but I triple checked that I included all tall shrubs in the analysis and cross referenced my data with raw data provided. Without being familiar with the data collection and ecosystem, I am interpreting the vegetation plot data with caution.

Figure 40. Plots of percent tall shrub cover vs depth to water from data used for this analysis and the relationship between percent cover and mean water from (Timoney and Argus 2006).
I analysed the data using generalized linear mixed effects models with a binomial link and random effects terms for Transect and Plot within Transect. The random effects terms were added because the data comprised repeated measurements at permanent plots and plots within transects were likely spatially correlated. For the response variable I used the combination of $\text{PercentTallShrub}$ and $100 - \text{PercentTallShrub}$, which the model assesses essentially as proportional data. I compared models with the following explanatory variables: depth to water (depth in cm was divided by 10), drainage type (range 4 to 7, centred on 5), drainage type as a categorical variable, flood year, years since last flood, and years since last flood to a maximum of 10 years (flood.10), and interactions between drainage and flood year. After adding environmental explanatory variables, I tried adding Year as both a continuous and categorical variable to assess trends over time. The percentage of tall shrubs on plots increased over time and increased with time since last flood (Table 3333). Drier soils had much higher tall shrub cover than wet soils (Figure 4242). There was an interaction where shrubs increased with time since flood more on wet sites than dry sites, but the interaction was not readily visible because of the strong effects of soil drainage.
Table 33. Fixed effects parameter estimates from the top model predicting percent cover of tall shrubs.

|                      | Estimate | Std. Error | z value | Pr(>|z|) |
|----------------------|----------|------------|---------|----------|
| (Intercept)          | -9.996   | 0.611      | -16.35  | < 0.001  |
| flood.10             | 0.647    | 0.010      | 65.82   | < 0.001  |
| drain.c              | -4.276   | 0.293      | -14.58  | < 0.001  |
| year.c               | 0.151    | 0.001      | 101.21  | < 0.001  |
| flood.10:drain.c     | 0.108    | 0.013      | 8.39    | < 0.001  |

Figure 42. Predictive graphs showing the effects of drainage class and time since last flood on percent tall shrub cover.

1c. Vegetation Plots: Invasive Species (Thistle)

Similar to the Tall Shrub analysis above, I analysed the data using generalized linear mixed effects models with random intercepts for Transect and Plot within Transect. Again, I have questions about data quality, so the results should be interpreted with caution. For this analysis I used a binomial link such that the response variable was whether or not invasive species were detected (yes = 1, no = 0). The top model was:

\[
glmer(\text{invasive.01} \sim \text{flood.10} + \text{drain.c} + \text{depth} + \text{year.c} + (1 \mid \text{transect.number}) + (1 \mid \text{transect.number:plot}), \text{family} = \text{binomial})
\]

Invasive thistle was more likely to occur with increasing time since floods, on well drained soils, and at plots with a large depth to water. The distribution of thistles increased over time.
Table 34. Fixed effects parameter estimates from the top model predicting the occurrence of invasive thistle.

|          | Estimate | Std. Error | z value | Pr(>|z|) |
|----------|----------|------------|---------|----------|
| (Intercept) | -6.002   | 0.478      | -12.6   | < 0.001  |
| flood.10   | 0.285    | 0.029      | 9.8     | < 0.001  |
| drain.c    | -0.967   | 0.177      | -5.5    | < 0.001  |
| depth      | 0.097    | 0.014      | 6.9     | < 0.001  |
| year.c     | 0.033    | 0.014      | 2.4     | 0.017    |

Figure 43. Percent of vegetation plots with non-native thistle in the Peace-Athabasca Delta. Note all plots were not sampled each year and thus the sample of plots could influence proportions.
Figure 44. Predictive graphs showing the influence of depth to water, drainage class, years since flood, and time on the probability of Invasive Thistle occurrence.

2. Vegetation Measure for Ecological Integrity

The monitoring question and interim thresholds posted in ICE were:
What is the relative abundance of non-native species in delta meadows, and how is it changing through time?
   Good: <5% of plots have invasive species (1988 levels)
   Fair: 5-25% of plots have invasive species.
   Poor: >25% of plots have invasive species.

Questions tabled in the 2014 PAD Vegetation Monitoring Protocols were:

1. What are the trends in relative abundances of plant community types in the PAD over 20 years?
2. Has the extent and severity of invasive non-native plants changed in extent over 20 years?
3. Are willows encroaching on the PAD?

Based on the ICE Thresholds, the state of vegetation in Wood Buffalo National Park is currently in *Fair* and *decreasing* condition.

![Figure 45. Percent of plots vegetation plots in the Peace-Athabasca Delta with non-native species of thistle.](image)

**Summary**

Time since flooding, soil drainage, and depth to water were strong predictors of percent tall shrub cover (linear transect and plot) and invasive thistle occurrence. I capped time since flood at 10 years (i.e. set all years ≥ 10 years to equal 10) because I predicted that the effects of increasing time since flood should decay with time. In addition to the effect of time since last flood, tall shrub cover and invasive species all increased over time.

Vegetation plots take a lot of resources and time to do properly. If the main data to be used from the plots is percent tall shrub cover and invasive species, then Wood Buffalo National Park might consider limiting the data collection to line-intercept transects. Similarly, if the park is more concerned with change in cover rather than individual plant size, then cover might be more efficiently estimated by entering data for clusters of shrubs rather than each individual shrub. That said, for continuity, invasive species data could still be collected at the plot level as present-absent.

**Literature cited**

Appendices

Appendix I: Time series plots of potential water quality parameters

![Time series plots of potential water quality parameters](image-url)

- Zinc Total
- Sulphate Dissolved
- Total Dissolved Solids, Calculated
- Phosphorous Total
- PH
- Nickel Total
- Nitrogen Total, Calculated
- Oxygen Dissolved
Appendix II: List of Waterbird families found in Canada.

The list was based on definition of “waterbirds” by Wetlands International 2010, and the list established by Bird Studies of Canada on http://avibase.bsc-eoc.org/avibase.jsp#

Anatidae (Ducks, Geese and Swans)  Phalacrocoracidae (Cormorants)
Ardeidae (Heron)  Podicipedidae (Grebes)
Charadriidae (Plovers)  Rallidae (Rails, Gallinules and Coots)
Gaviidae (Divers/Loons)  Recurvirostridae (Stilts and Avocets)
Gruidae (Cranes)  Scolopacidae (Sandpipers, Snipes and Phalaropes)
Haematopodidae (Oystercatchers)  Sternidae (Terns)
Laridae (Gulls)  Threskiornithidae (Ibises and Spoonbills)
Pelecanidae (Pelicans)

Species from other families are also known to be associated with wetlands, and have been detected in WBNP, i.e. Blackbirds (Icteridae) and Marsh sparrow (Emberizidae)
Appendix III: Comparison of trends in waterfowl abundance between the Peace-Athabaska Delta area and the Central Migratory Flyway

Data were transformed to a value relative to the maximum abundance observed to simplify the comparison.

Model: \( \text{glm}(\text{Relative.pop} \sim \text{Year} \times \text{Area}, \text{data}=\text{dataset}) \)

Source of data: [https://migbirdapps.fws.gov/mbdc/databases/mas/maydb.asp](https://migbirdapps.fws.gov/mbdc/databases/mas/maydb.asp)

Strata defining the Central Flyway for this analysis: 12-18, 20-23, 25-49, 75-77

1) Species showing similar trends:

Increase of population in both areas.
Decrease of population in both areas
2) Species showing different trends

Increase in Central Flyway, stable in PAD area
Stable in Central Flyway, and decline in PAD area

Increase in Central Flyway, and decline in PAD area
Appendix IV: Effects of the Bennett Dam completion in 1968 on waterfowl trends in Peace-Athabaska Delta

1) Statistical approach

- Piecewise regression to compare slope in abundance of waterfowl before vs after the building completion of the Bennett Dam in 1968.
- Negative binomial modelling to account for count data nature
- Model structure:  glm.nb(Abundance ~ Year + I((Year-13)*bin.Period), data=dataset)
  - Abundance = Number of individual birds
  - Year = number of years since the beginning of monitoring in 1956
  - Bin.Period = binary variable describing the status of data before vs after the dam completion in 1968

2) Comparison of slopes

<table>
<thead>
<tr>
<th>Species</th>
<th>1956-1968</th>
<th>1969-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year effects</td>
<td>Std.err</td>
</tr>
<tr>
<td>American coot</td>
<td>0.079</td>
<td>0.062</td>
</tr>
<tr>
<td>Green-winged teal</td>
<td>-0.074</td>
<td>0.027</td>
</tr>
<tr>
<td>American wigeon</td>
<td>-0.065</td>
<td>0.024</td>
</tr>
<tr>
<td>Blue-winged teal</td>
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<td>0.034</td>
</tr>
<tr>
<td>Bufflehead</td>
<td>-0.008</td>
<td>0.024</td>
</tr>
<tr>
<td>Canada goose</td>
<td>0.151</td>
<td>0.058</td>
</tr>
<tr>
<td>Canvasback</td>
<td>-0.085</td>
<td>0.027</td>
</tr>
<tr>
<td>Gadwall</td>
<td>0.116</td>
<td>0.038</td>
</tr>
<tr>
<td>Generic goldeneye</td>
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<td>0.038</td>
</tr>
<tr>
<td>Generic scaup</td>
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<td>0.028</td>
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<tr>
<td>Mallard</td>
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</tr>
<tr>
<td>Mergansers</td>
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<td>0.044</td>
</tr>
<tr>
<td>Northern pintail</td>
<td>-0.155</td>
<td>0.039</td>
</tr>
<tr>
<td>Northern shoveler</td>
<td>-0.058</td>
<td>0.025</td>
</tr>
<tr>
<td>Redhead</td>
<td>-0.124</td>
<td>0.023</td>
</tr>
<tr>
<td>Ring-necked duck</td>
<td>-0.104</td>
<td>0.032</td>
</tr>
<tr>
<td>Ruddy duck</td>
<td>-0.009</td>
<td>0.036</td>
</tr>
</tbody>
</table>

*p value to determine if slope is different from zero
**p value to determine if slope in 1956-1968 differed from slope in 1969-2014
Note: value of p<0.1 is indicated in **bold*** and ***italic***
Species for which the trends in 1956-1968 is significantly different from trends in 1969-2014

DECLINE IN 1956-1968 AND INCREASE IN 1969-2014
DECLINE IN 1956-1968 AND STABLE IN 1969-2014
INCREASE IN 1956-1968 AND INCREASE, STABLE OR DECLINE IN 1969-2014

Gadwall

Canada goose

Generic scaup
Species for which the trends in 1956-1968 is not significantly different from trends in 1969-2014
Appendix V: Analysis of muskrat data sources

Objectives:
2. Operational Review of the Muskrat Measure for Ecological Integrity.

Below I outline analytical methods, summarise results, discuss strengths and weaknesses of the measure, and make recommendations for improvement.


The data set is Muskrat house count data 1973-2015.xlsx. Data was collected on snowmobile-based ground surveys from November through March. Year represents the fall preceding the survey. The data was always positive with a right skewed distribution, which is typical of count data. Therefore, I analysed the data using a Negative Binomial link which assumes all data are positive and the variance around predicted values is greater than or larger than the predicted value. The link between covariates and predicted values is \( n.houses = \exp(\text{Intercept} + B_1X_1 + \ldots + B_JX_J) \) for a data set with \( J \) covariates. I centred year so that the intercept represented values at 1980 \( (\text{year.c} = \text{year} – 1980) \) and to improve model convergence.

The data set contained 80 unique basins (figure 46) which were monitored between 1 and 11 times (median = 3 times). To track within basin changes over time (repeated measures at a site), I included \( \text{Basin} \) as a random effect. One challenge with using basin as a random effect was that basins (or basin names) surveyed in the 1970’s were not the same as basins surveyed since 1999. Consequently, many models failed to converge. I considered omitting the random effects but decided not to because it would inflate Type I error (confidence intervals would be too narrow). Another option would be to use zero-inflated models that account for excessive zero’s for basins that lacked muskrat. I decided to use negative binomial rather than zero-inflated poisson or zero-inflated negative binomial because some research suggests it performs equally well and it is much simpler to interpret. I used AIC to compare 11 models with combinations of the following covariates: \( \text{year.c}, \text{years.flood}, \log(1 + \text{years.flood}), \text{year.2} \) (within 2 years of a flood), \( \text{year.012} \) (years since flood up to a maximum value of 2), \( \text{period} \) (1973 – 1978 vs 1999 – 2015). The Time since Flood covariates were initially identified by J. Straka and Q. Gray as strong predictors of muskrat abundance. Data was analysed using the \( \text{glmer.nb} \) function in the R \( \text{lme4} \) package.

The top model was: \( \text{glmer.nb}((\text{houses } \sim \text{flood.012} + (1 \mid \text{basin})) \) (Table 35). The average number of houses per basin increased after flooding and stay relatively high during the two years before decreasing and stay low until the next flooding event. Similarly, the number of muskrat houses was substantially higher during flood years and the two subsequent years. The negative binomial dispersion parameter was 0.410, which suggests high levels of overdispersion and supports my decision to use negative binomial models. Small values indicate high dispersion.
Figure 46. Plot showing number of muskrat houses observed in each basin in each year. Blue triangles and points indicate flood years. Monitoring was conducted mainly after major flooding events. Note the three counts greater than 500 that likely had large influence on model results, but have been error checked are part of the muskrat response to flooding (J. Straka pers. Comm).

Table 35. Parameter estimates for factors affecting the number of muskrat houses per basin from ground counts in Wood Buffalo National Park, 1973 to 2015.

|          | Estimate | Std. Error | z value | Pr(>|z|) |
|----------|----------|------------|---------|----------|
| (Intercept) | 4.447    | 0.402      | 11.07   | < 0.001  |
| flood.012 | -0.683   | 0.224      | -3.05   | < 0.001  |

**Aerial Surveys for Muskrat Houses and Push Ups**

Wood Buffalo National Park conducted aerial surveys for muskrat houses, pushups, and beaver lodges during 2013, 2014, and 2015 (figures 47 and 48). They conducted surveys in four regions of the park and flew 21 transects per block (84 transects total) most of which were 20 km long. I used the combined number of houses and pushups observed on each transect as the response variable. Given that each transect was flown each year (i.e. a repeated measure), I included Transect as a random effect. The count data was highly right-skewed, so I used a glmm with a Negative Binomial Link. I compared 5 models with year, block, and an interaction between year and block as explanatory variables. I tried models using an offset to account for varying search distances among transects, however most models failed to converge because search area per transect did not vary among years and the model already fit a separate intercept (average) for each transect. Surveys occurred in late winter (April) and thus counts reflected muskrat activity from the previous fall and there for I used biological year as year – 1 in the analysis. The top model included a linear annual increase in muskrat house and pushup counts
The dispersion coefficient was 0.688, which suggested that the data was over dispersed and confirmed my decision to use a Negative Binomial link.

Figure 47. Number of muskrat houses and pushups observed per aerial transect in Wood Buffalo National Park, Alberta. The blue triangle indicates flood year.

Table 36. Model for aerial muskrat house and pushup counts collected in late winter 2013 – 2015.

| Parameter                  | Estimate | Std.Error | z-value | Pr(>|z|) |
|----------------------------|----------|-----------|---------|----------|
| (Intercept)                | 0.969    | 0.183     | 5.3     | <0.001   |
| bioyear (centred on 2013)  | 0.734    | 0.109     | 6.7     | <0.001   |

Figure 48. Predicted number of muskrat houses and pushups detected per transect and 95% CI’s.
Trapping Records

Trapping records have been used as indicators of relative abundance for many species including predator-prey interactions between muskrat and mink (Erb et al. 2001, Viljugrein et al. 2001, Shier and Boyce 2009). However, trapping indices depend on many other factors such as the number of trappers, trapper effort, pelt prices, reporting, and societal interest. While these factors can be addressed in large scale analyses, the results can be contentious. For example, one study found that changes in snow pack distribution affect wolverine abundance across North America (Brodie and Post 2010). However, the results of that study were strongly questioned by leading wolverine specialists because the study used trapping data as indices for abundance (Brodie and Post 2010, Brodie and Post 2011, DeVink et al. 2011, McKelvey et al. 2011). Thus, trapping data shown below should viewed in that context.

I extracted trapping data from (Milne 1989), which is also shown in (Hood et al. 2009; figures 49 and 50). Dam construction occurred from 1961 through 1967 and the dam officially opened in 1968. Construction and filling of the dam likely affected water flows of the Peace River. I compared the number of muskrat harvested from 1960 to 1975. I restricted the data to this relatively narrow time window minimize changes in harvesting effort and price on trapping records. I ran linear regression models with harvest price and pre-post dam construction as explanatory variables. The top model selected by AIC showed that harvest decreased following dam construction (Table 37). I have low confidence in this analysis given the numerous confounding factors that could have affected harvest records including natural muskrat population cycles, dam construction, pelt price, and trapping effort.

Figure 49. Number of muskrats harvested in Wood Buffalo National Park from 1950 to 1988 (Milne 1989, Hood et al. 2009).

Note: The red triangle indicates the year the Bennett Dam opened.
Figure 50. Muskrat pelt price from 1950 – 1988 (Milne 1989).

Table 37. Linear model for trends in muskrat harvest from 1960 through 1975. Fewer muskrat were harvested post-dam construction.

| Estimate  | Std. Error | z value | Pr(>|z|) |
|-----------|------------|---------|----------|
| (Intercept) | 58540.000  | 11986.000 | 4.9      | 0.000   |
| After.Dam  | -35921.000 | 17546.000 | -2.0     | 0.061   |