

Assessment of Wildlife Population Status and Trends at the St. Clair River Area of Concern



Robert Stewart Wetland, St. Clair AOC. Photo by U.S. EPA.

Produced for: Environment Canada

10 August 2011

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Summary

The St. Clair River Area of Concern (AOC) has been the focus of remediation and monitoring to address potential contamination threats to aquatic communities. The response of wildlife populations to the contaminations and subsequent remediation efforts has been listed as "requiring further assessment". This report addresses some of the information gaps regarding the status and trends of wildlife populations. I examine five wildlife datasets, including the Atlas of Breeding Birds of Ontario, furbearer harvests reported to the Ontario Ministry of Natural Resources, marsh bird and amphibian surveys through the Marsh Monitoring Program, and decadal waterfowl surveys from the Canadian Wildlife Service. The datasets differ in their scale, duration, quality and protocol, necessitating different analytical methods to assess status and trends.

I employed an indicator approach, selecting biodiversity metrics and sentinel species which reflect the composition and function of the St. Clair River aquatic ecosystems. In total, 50 metrics were analyzed, covering birds, amphibians and mammals. I suggest that a few key metrics be used to inform decisions on the status of the St. Clair River AOC, including metrics of marsh-nesting birds, waterfowl counts, amphibian indicator species richness, and the harvest of muskrats.

Lacking quantitative benchmarks for wildlife populations, this assessment used the status and trends of the broader region as a benchmark. I used statistical methods to test whether St. Clair River values were significantly better or worse than regional averages, as well as calculating the rank-percentile of St. Clair wildlife values versus regional values.

Overall, 26% of the indicators score as "good" or "excellent", 42% score as "fair", and 16% score as "poor" (16% could not be scored). In summary: there is no evidence of impairment to amphibian populations; mammal harvests are increasing; and the trends of waterfowl and marsh-associated species seem to be improving or 'declining less steeply' than compared to regional trends. Of concern are the negative trends fall diving ducks, and most upland bird species (forest, grassland, bushy-species).

Introduction

Background

The St. Clair River Area of Concern (AOC) is one of 42 Great Lakes areas listed in 1985 by the International Joint Commission (IJC) as failing to meet the environmental objectives of the Canada-United States Great Lakes Water Quality Agreement (GLWQA; amended by Protocol, 1987). A number of water-quality problems were seen to potentially impair beneficial uses and compromise the ability of the area to support aquatic life. As a response, the governments of Ontario and Michigan developed a joint Remedial Action Plan Committee in 1987, comprised of federal, state and provincial representatives, to begin a multi-stage comprehensive process to identify beneficial use impairments (BUIs), determine causality, guide remedial actions, and measure the progress of such efforts. The trajectory of remediation efforts and whether they meet the RAP objectives is important in deciding whether to "delist" the St. Clair River from the list of AOCs.

Fourteen BUIs were specified in the GLWQA, including "degradation of wildlife populations and/or loss of wildlife habitat". While monitoring and assessment of other BUIs has received much documentation, the dynamics of wildlife populations is listed as "requiring further assessment". The Stage 1 and 2 St. Clair River AOC report and updates (St. Clair River RAP Team, 1992; St. Clair River RAP Team & St. Clair River BPAC Team, 1995; Mayne, 2005) documented a number of wildlife concerns, including suspected declines in Muskrat harvests, declines in diving ducks, high contaminant concentrations in snapping turtles, colonial gulls and terns, and Mink. The reports also identify a number of potential wildlife taxa and corresponding data sources which may resolve the gap in information of wildlife populations. This report takes the lead from the Stage 1 and 2 reports to examine the utility of the identified wildlife datasets, and analyze a subset of 5 taxa/datasets to assess the status and trends of the St. Clair River AOC. This report uses the "indicator approach" to attempt to distil the immense complexity of wildlife communities into a few, meaningful indicators.

Objectives

"to assess the status and trends of wildlife populations in the St. Clair River Area of Concern by suggesting and analyzing a few key wildlife indicators."

Subject to the limitations of available data sources, these key indicators attempt to represent a wide variety of taxa (marsh birds, waterfowl, amphibians and aquatic mammals) and reflect the AOC's ability to support and provision its faunal communities. In addition, a broader suite of wildlife indicators, not necessarily pertaining to aquatic ecosystems, are presented to help contextualize changes within the St. Clair River ecosystem (e.g., indicators of upland avian species).

Indicator Framework

The particular indicator framework used in the report is motivated by both the main objective to assess wildlife populations, as well as to adequately deal with two fundamental challenges of wildlife assessments:

- *limitations in the quality and availability of long-term data sources.* E.g., most of the indicators suffer from sparse data collection, in both time and space, which reduces power to detect meaningful changes; and

- *conceptual issues with the indicator approach for wildlife populations.* E.g., even where there is sufficient data for a taxa, it is rarely clear *what* to measure and *how* to attribute biologically meaningful endpoints or thresholds.

The latter point is particularly important and drives much of the rationale for the makeup of this report.

In response to these objectives and challenges, the following concepts are fundamental to the assessment method:

I) Regional Comparisons

Where possible, the indicators are not absolute values of the St. Clair River AOC, but are comparisons to the greater region, such as the difference between the AOC value and the regional average. Wildlife populations are open systems, subject to large-scale spatial patterns, which implies that trends at the St. Clair River AOC may not be unique to the AOC itself, but instead reflect general regional trends. This regional focus distinguishes these wildlife indicators from many physical or chemical indicators, where data from a single focal site can be sampled alone and compared against an authoritative quantitative threshold. Here, adequately sampled and sound data are necessary not only for the AOC itself, but also from the surrounding region. For example, the standardized protocol of datasets such as the of the Marsh Monitoring Program and the Atlas of Breeding Birds facilitate such regional comparisons, while other datasets, such as government reports on furbearer harvests and the Canadian Wildlife Service decadal waterfowl survey, were not intended for such uses.

The physical definition of the greater "region" was particular to each dataset. The rationale for each definition is explained in the Section on Regional Comparisons and Appendix 1.

II) Species, Biodiversity Metrics, and Community Analyses

Subject to data availability, each dataset may have been analyzed at different levels or scales of biological aggregation (figure 1), including:

- **Species-scale:** abundance of an individual species, selected based on the assumption of being a "sentinel" or "indicator" of greater ecosystem changes;
- **Biodiversity metrics:** aggregations of many species, such as total species richness, total species abundance, total abundance of a foraging guild, selected for representing a key element of the ecosystem's structure, composition and/or function;
- **Community Analyses:** analyses of the entire community as a whole, without making assumptions about which species or guilds are important, such as dissimilarity-based Multivariate Analyses of Variance.

All three scales of aggregation can be assessed as a *status* indicator (e.g., abundance of Marsh Wrens in a discrete time interval), or as a *trend* (e.g., annual proportional change in the richness of marsh-nesting obligates).

Community analyses are common in academia, but are not easily understood or transformed into simple indicators to track over time. They help provide a context for more finer-detailed analyses at the species-scale or biodiversity metric-scale (hereafter referred to as "metrics"). Only the species and biodiversity metrics are summarized into indicators, and they comprise the main content of this report.

The distinction between "metric" and "indicator" is subtle: a metric is a measure of a wildlife population, while an indicator is an assessment of the performance of a metric against the

regional benchmark. Put another way, a metric is merely is a number (e.g., abundance of Marsh Wrens, or percent change in Marsh Wrens, while its equivalent Indicator has an inherent quality of “value” (e.g., “50th percentile” or “fair”). Indicators are scores and/or rankings of metrics, as described below.

III) Indicators as Rank-Percentiles

All wildlife metrics used in this report are compared to the greater regional distribution of values, i.e., the rank-percentile. This is motivated by the lack of authoritative quantitative thresholds for wildlife indicators, relying instead upon the assumption that low-ranking sites (as compared to the regional distribution) are likely suffering some impairment unique to the AOC, while sites around the median or mean are not likely impaired, or at least, have wildlife populations' which are mostly influenced by greater regional forces, and are not facing harm unique to the AOC. The reader should note that the magnitude and direction of the wildlife metric is lost in this rank-percentile, and should bear in mind that it is entirely possible to have cases where an AOC metric is large and negative (e.g., a 5% annual decrease in diving ducks) but may still have a favourable rank-percentile, if the entire region faces a similar trend.

IV) Indicators as Statistical Tests

Some of the wildlife metrics were subjected to statistical tests of significant difference from regional values. This is partially motivated by the question of whether observed differences are real or fall within the realm of acceptable conditions, and partially to satisfy many people's preoccupation with statistical “p-values”. However, one should keep in mind several caveats to such statistical tests. First, lack of evidence for differences between the AOC and the broader region is not evidence for there being no difference. Rather, p-values reflect both the magnitude of the effect, as well as the amount of sampling. With enough sampling, a statistically significant difference can be found for a very small and possibly ecologically unimportant difference. Likewise, inadequate sampling may fail to provide enough power to ascribe statistical significance to large and ecologically important effects. Most of the datasets in this study are of this second category, having low power to detect differences. Therefore, I am more likely to say there is no difference, when there really is a difference.

The various statistical methods are explained more specifically within the sections on each dataset. The following categorization scheme was used for the assessment framework: “good” was ascribed when the AOC values were significantly higher than the greater region, while “poor” was used when the AOC had significantly lower values, and non-significant results were called “fair”. This indicator assessment provides a complimentary narrative to the rank-percentile indicators, although the overall narrative remain the same.

Selection of Metrics and Indicators

The fundamental aim of the indicator approach is to distil the complexity of wildlife communities into a few simple measures which can be tracked over time. In some datasets, there is simply not enough quality data to attempt such comprehensive community descriptions (e.g., mammals are represented by just one aquatic mammal metric). Other datasets are information-rich, such as the Marsh Monitoring Program avian point counts, and allow data-driven methods to try and assess which metrics best represent the community, such as Non-metric Multidimensional Scaling (Michin, 1987).

In general, the selection of metrics was informed by: discussions with ecosystem scientists familiar with the datasets; suggestions of the St. Clair River AOC Stage 1 and 2 reports (St. Clair River RAP Team, 1992; St. Clair River RAP Team & St. Clair River BPAC Team, 1995); and metrics used previously in assessments of these datasets (Crewe et al., 2007;

Timmermans et al., 2004). The metrics are discussed in more detail in the sections devoted to each dataset (see Table 5 and Appendix 4 for the classification of Amphibian and Bird species respectively into the various metrics).

Biodiversity and ecosystem indicator studies have often employed the ecosystem "structure, composition and function" paradigm (Franklin, 1988), to comprehensively describe biodiversity constituents (Federal, Provincial and Territorial Governments of Canada. 2010). In the context of wildlife population studies, "structure" often refers to population structure, such as total richness or total abundance, "composition" refers to the relative abundance or presence/absence of species within a community, and "function" refers to a wide variety of metrics which alter and control the previous two, such as keystone species, or the provisioning of food, often referring to the abundance different foraging guilds as a proxy for ecosystem functions. This paradigm is helpful for considering which metrics to include to provide a broad context for the changes in the AOC, keeping in mind that many metrics overlap these fuzzy categories (e.g., waterfowl dabbler and divers foraging guilds may be both function and composition indicators).

Key Metrics

In general, however, the number of metrics necessary to adequately describe a regional pool of communities can become overwhelming, and methods to integrate the many measures into a single value, such as averaging or weighted averaging, are difficult to implement (Silvert, 2000), and may lose important information. Furthermore, when multiple statistical tests are employed, the chance of detecting a significant result when there is none increases with many tests. Therefore, this report attempts to balance the number of metrics used to adequately handle complexity, while not overwhelming the reader.

At the beginning of each dataset, the reader is presented with a simple summary of indicators used in this report. This is to provide a coarse overview, but the preferred reading is to explicitly make judgements on the value of different community constituents, and narrow in on a few key indicators, while retaining the larger suite of wildlife metrics and averages to serve as a broader context. For example, the reader is advised to focus on the marsh-nesting obligate species and waterfowl species metrics for the MMP Bird and Breeding Bird atlas datasets, given their correlations with dominant community dimensions, and use in previous studies. For the Waterfowl Survey data, the total use-days of divers and dabblers are likewise considered functionally important (Russell, personal communication) and have strong correlations with dominant community dimensions. There is just one key metric for the amphibian dataset (richness of indicator species), and similarly the mammalian data (Muskrat harvests).

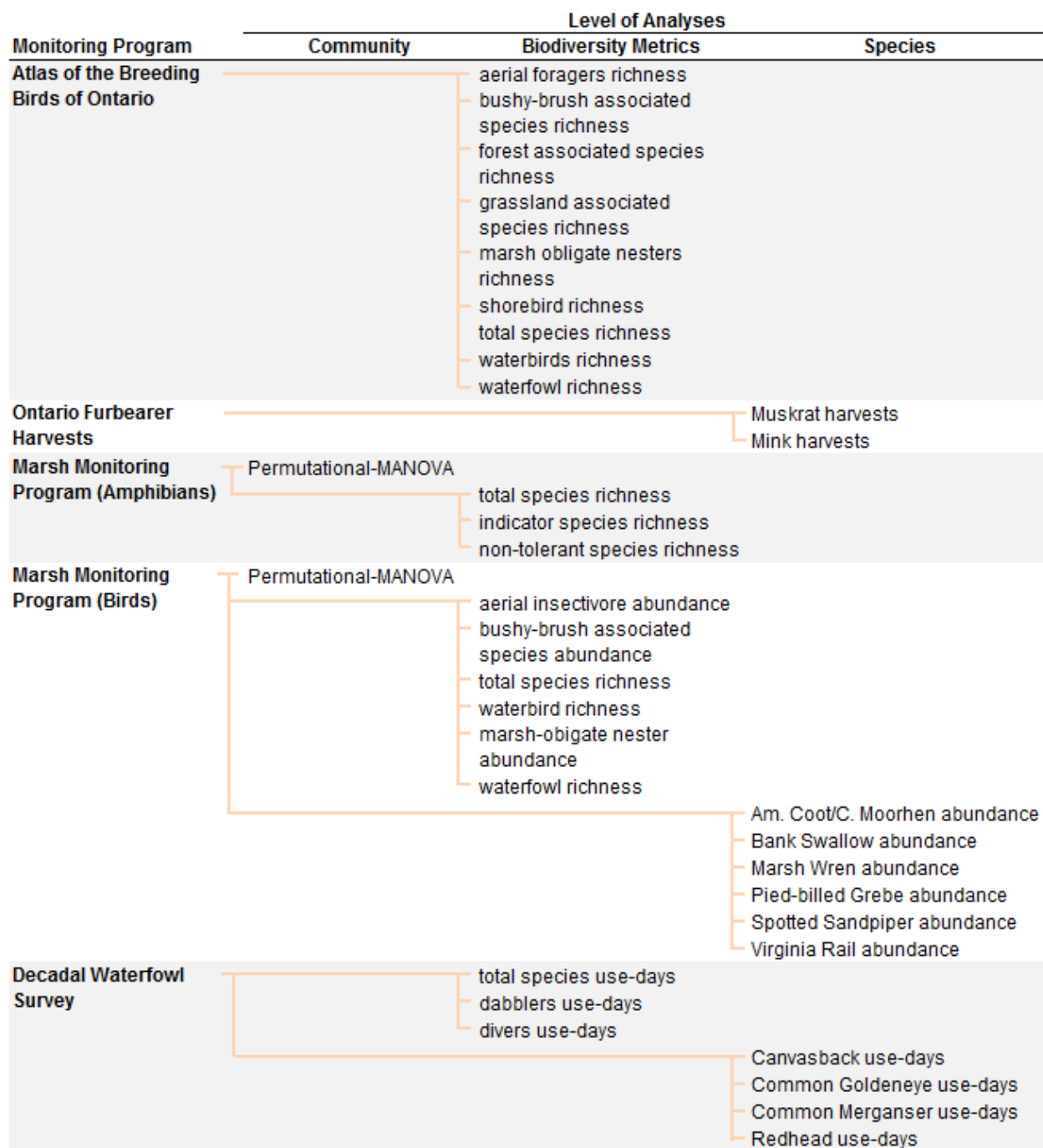


Figure 1 Monitoring Programs, their level of analysis, and metrics used for indicators.

Summary of Data Sources

This assessment includes analyses of the Atlas of Breeding Birds of Ontario, the Ontario Ministry of Natural Resources annual furbearer harvests, Bird Studies Canada's Marsh Monitoring Program (MMP) amphibian and bird surveys, and the Canadian Wildlife Service (CWS) Decadal Waterfowl Surveys. Other suitable sources of wildlife status and trend information were listed in the St. Clair AOC Stage 1 & 2 Reports (St. Clair River RAP Team, 1992; St. Clair River RAP Team & St. Clair River BPAC Team, 1995), but many of these programs had objectives and methods not suitable for status and trend assessments, such as relying on opportunistic records or non-random sampling. Even for the five data sources selected (table 1), a few were not intended for regional comparisons, and the results should be interpreted carefully, while keeping in mind the possibility of confounding influences due to non-random sampling structures. For example, the CWS Decadal Waterfowl Survey is suited to assess the distribution of waterfowl, and to monitor changes over time within one sector or similar sectors (Petrie et al., 2002), but the survey was not designed for making regional comparisons.

The reliability and treatment of the wildlife data sources varies, as each differs in a number of important ways, including: the ability to provide either status or trend information; ability to provide occupancy or abundance information; temporal coverage (figure 2); frequency of sampling; geographic extent; spatial scale of sampling units; and degree of effort standardization. These differences necessitated different types of data manipulations and modelling, which are explained more within each dataset's *Methods* section and are summarized in Table 2. In general, most of the datasets required some method to try to standardize differing levels of sampling effort. The Atlas of Breeding Birds, for example, required an elaborate decision tree to align sampling Squares' species list to the equivalent amount of effort in the earlier Atlas. The furbearer harvest data included covariates for the price of pelts and the number of licensed trappers. Readers are therefore advised caution when interpreting comparisons which required these corrections to account for such differences.

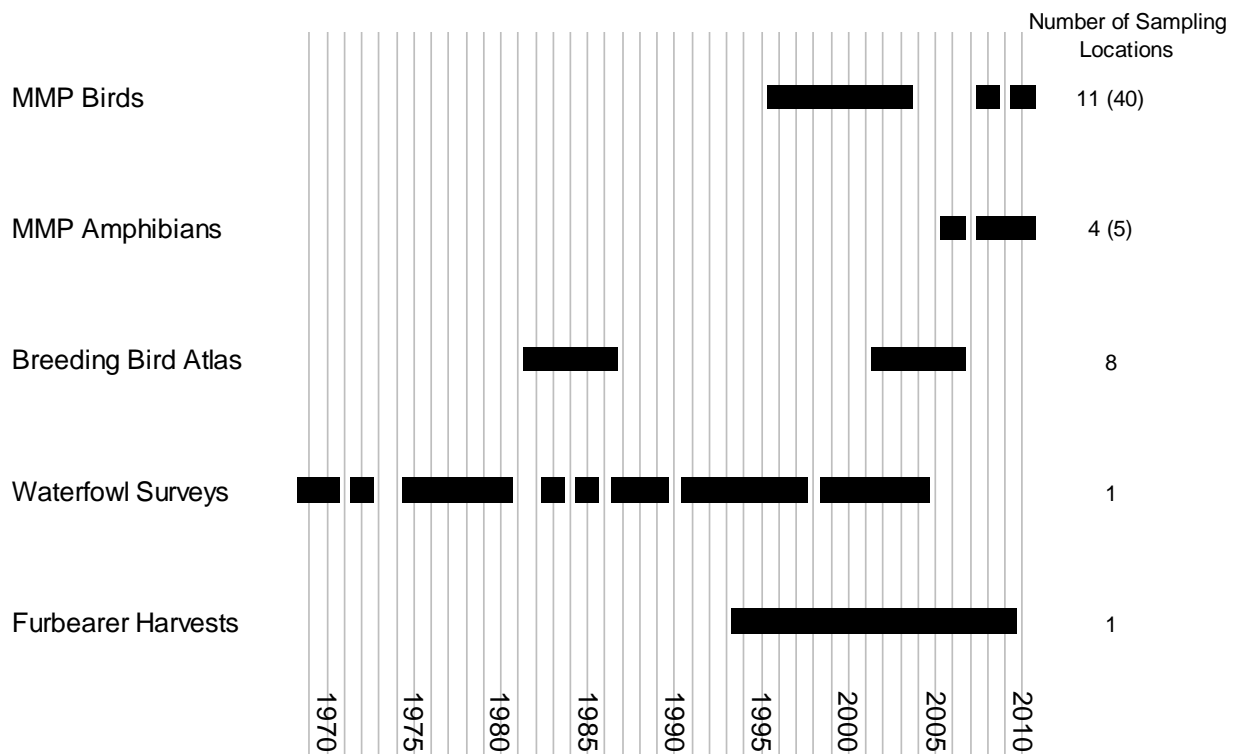


Figure 2 Temporal coverage of wildlife datasets and number of sampling locations to represent the St. Clair River AOC.

Table 1 Summary of wildlife data sources for St. Clair River AOC assessment

	Coordinators	Description	Units	Spatial Structure	Spatial Extent
Atlas of Breeding Birds Ontario	Bird Studies Canada, Environment Canada, Ontario Field Ornithologists, Ontario Nature	Atlassers attempt to find all breeding species in survey square throughout breeding season	breeding bird occupancy	10 km x 10 km grid	Ontario
Furbearer Harvests	Ontario Ministry of Natural Resources	Licensed trappers report their success harvests throughout year	number of harvests	Counties	Ontario
Marsh Monitoring Program - Amphibians	Bird Studies Canada, Environment Canada, United States Environmental Protection Agency	Surveyors conduct 2 play-back point counts during breeding season, counting all birds seen or heard	calling amphibians occupancy	point-count stations nested in wetland-level routes	Great Lakes
Marsh Monitoring Program - Birds	Bird Studies Canada	Surveyors conduct 3 counts of singing amphibians throughout early spring	marsh bird relative abundance	point-count stations nested in wetland-level routes	Great Lakes
Waterfowl Decadal Surveys	Canadian Wildlife Service	All waterfowl are counted from an airplane along shoreline transects, repeated multiple times in Autumn and Spring.	waterfowl use-days	Variable-length shoreline sectors	Shores of Canadian Great Lake

Table 2. Summary of data sets, metrics, indicators and tests for the St. Clair AOC wildlife assessment.

	Key Metrics	Number of Metrics	Status Indicators	Trend Indicators	Standardized Effort	Potential Confounding Effects	Statistical tests	Power
Atlas of Breeding Birds Ontario	waterfowl richness, marsh-obligate nesters species richness	9		X		variable effort	repeated-measures MANOVA, Rank-Sum tests	weak
Furbearer Harvests	Muskrat harvests	1		X		fur prices, number of trappers; county size	Outlier test	very weak
Marsh Monitoring Program - Amphibians	Indicator species richness	3	X	X	X	observer effects	distance-based Permutational MANOVA; Generalized Least Squares mixed models	weak
Marsh Monitoring Program - Birds	waterfowl richness, marsh-obligate species abundance	12	X	X	X	observer effects	distance-based Permutational MANOVA; Generalized Least Squares mixed models	fair
Waterfowl Decadal Surveys	diver use-days (spring & fall), dabbler use-days (spring & fall)	7		X		variable transect lengths; lake basin effects	Outlier test	very weak

Regional Comparisons

The regional context is central to the indicators in this report. Selecting suitable sites and sectors to serve as a regional benchmark is not a trivial exercise. Similar assessments in the past have used different methods to find suitable benchmarks for comparison, including pairing every focal site with a neighbouring reference site of similar biophysical constituency (Doka et al., 2006), or comparing focal sites to an entire enveloping ecoregion (Crewe et al., 2007). Such fine and large scales have their advantages and disadvantages. For example, neighbouring sites are not independent of each other, because animal communities may interact and influence one another, or sites may depend on a third, local, anomalous effect. Drawing reference sites further afield may randomize such effects, but eventually, large distances result in entirely different communities and should no longer be considered suitable reference sites.

In order to find a suitable cut-off distance with which to bound the "region", I conducted an analysis of the turnover of species composition with distance from paired sites using the MMP bird, MMP amphibians and Atlas data, where georeferenced community information was available. The analysis is described in more detail in Appendix 1, and the results are displayed in figure 3. The main fit indicates an upward trend as paired-sites become more dissimilar in species composition the further away they are in space. Each dataset showed a characteristic sharp increase in species turnover within a close proximity of sites (~40 km) suggesting strong spatial autocorrelation within small distances, followed by a decline in the rate of species turnover. The MMP bird and MMP amphibian communities show a plateau within 300km, after which species turnover seemed to steadily increase again, suggesting that reference sites beyond this distance would not be suitable for a regional comparison. In contrast, the Atlas data yielded a continuous increase in the change of species composition with distance. This difference between the MMP and Atlas is likely due to the different sampling regimes: MMP surveyors seek-out wetlands to survey, whereby wetlands and wetland communities remain more similar to each other over large distances, while the surrounding landscape and its species assemblage may gradually change. The Atlas data and its systematic grid layout is a better representation of this gradual landscape turnover. I am therefore confident to sampling within 300km for MMP data comparisons, but only under more strict criteria for the Atlas data (described more in Appendix 1).

In addition to the cut-off distance for regional comparisons, additional measures were included in a metric-by-metric manner to handle effects of spatial-autocorrelation. For the MMP bird and amphibian datasets, statistical models incorporated bivariate splines or second-order polynomial interactions for latitude and longitude variables (rescaled to the same unit distance). For Atlas data, mantel statistic tests assessed spatial autocorrelation, and mostly suggested it was not particularly strong.

Such measures and analyses were not possible for the waterfowl or furbearer data sets, which lacked sufficient community and georeferenced data. Their general sparsity of sample locations made modelling of autocorrelation unsuitable. Nonetheless, an approximate cut-off of ~300 km was used to limit reference sectors and counties.

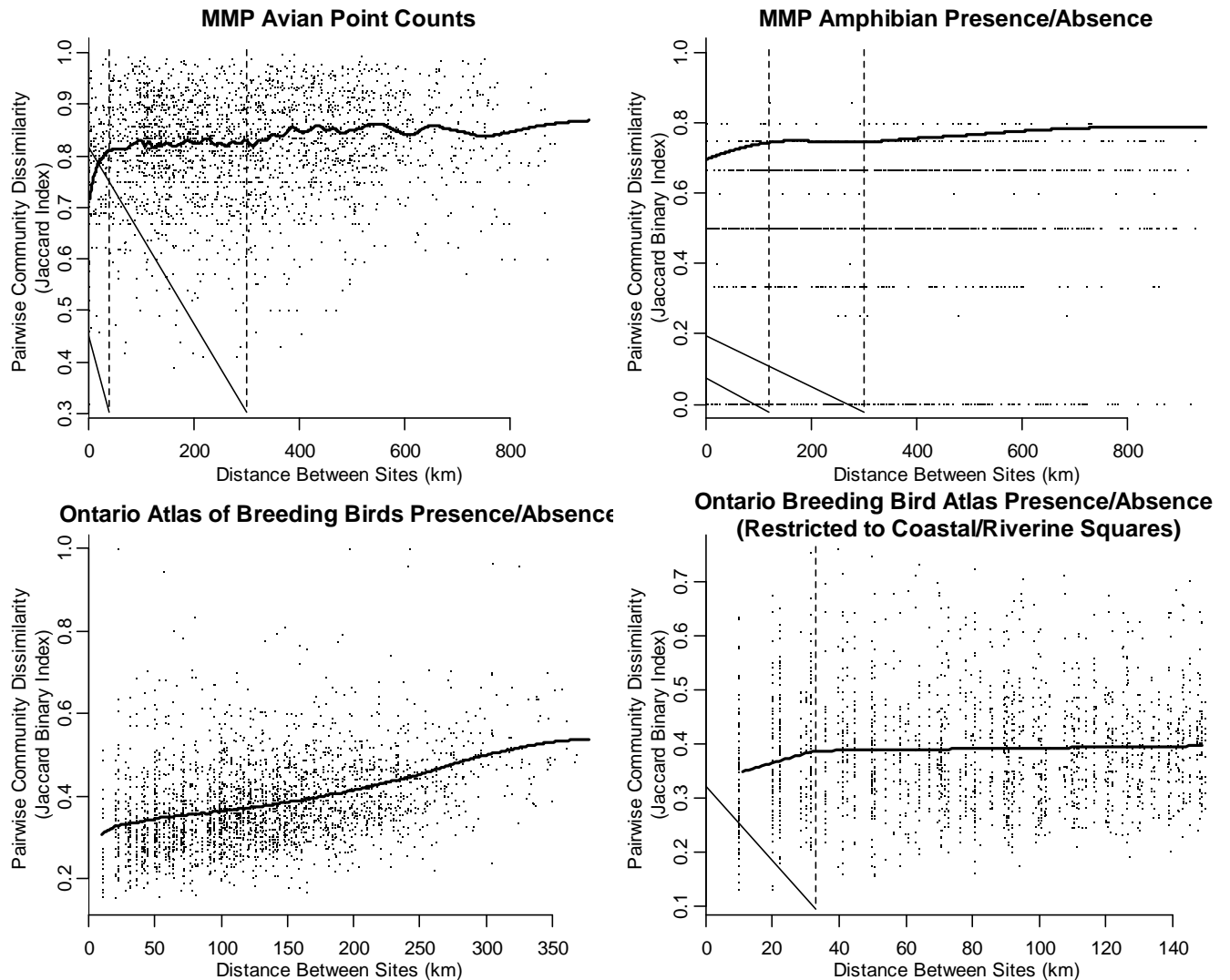


Figure 3 Analysis of species turnover with distance for three datasets used in the St. Clair River AOC assessment. Individual points represent pair-wise community dissimilarity (Jaccard index). Regions beyond the vertical dotted line do not serve as part of the regional benchmark. The Ontario Atlas of Breeding Birds (Bottom graphs) was reanalyzed under more restricted criteria (bottom right), such as only including coastal and riverine squares, and squares within 300km of St. Clair River AOC.

Atlas of Breeding Birds of Ontario

Summary

Figure 4 shows a summary of the indicator results. Most of the metrics show declines in richness over the two decades. However, most of the "poor" scores are for uplands species. For the two key metrics, focused on waterfowl and marsh-obligate nesters, the trends are better in the AOC than in the greater region, resulting in percentiles above the 50th percentile, and scores of "fair".

Description

The Breeding Bird Atlas of Ontario is a major effort including thousands of highly skilled volunteers to describe the distribution of breeding birds for all of Ontario. So far, two Ontario Atlas's have been completed, the first occurring during the mid-1980's (Cadman et al., 1987), and the second occurring in the 2000's (Cadman & Nature Ontario, 2007). The completion of the two surveys provides us with a large-scale view of changes in bird communities over two decades, and has been used previously to assess AOCs (Crewe et al., 2007).

Both Atlas's employed the same survey method, based on the British Atlas (Sharrock, 1976). According to the method, the province was divided into 10 km squares, and surveyors sought-out as many species as possible within their allotted squares. Surveyors categorized their species observations by standard criteria of breeding evidence, including "possible", "probable", and "confirmed" breeding categories. This report used the "probable" breeding category as the minimum criteria to denote species occupancy in a square. This category included observations such as: courtship behaviour; nest-building or hole-excavation behaviour; evidence of a brooding patch on females; agitated or anxious calling by adults; adult visitations to potential nest sites; territorial singing; occurrence of adults at the same location for a week or more; and pairs being observed in a suitable nesting habitat.

Each Atlas Square had a varying amount of survey time. Such effort and "sampling effects" can strongly influence the recorded number of species in a square. A framework was devised in the 2007 AOC report (Crewe et al., 2007; see Appendix 2) to assess when a square was adequately covered, how total species richness increased with effort, and how to adjust species-lists for each square to match effort between Atlases. As in the 2007 analysis, squares were apportioned to being a part of an AOC if 25% of their total area was within the AOC boundaries. 8 squares were used to represent the AOC. Such spatial queries were performed using ArcView 3.2

The Atlas data provides an important compliment to other bird datasets used in this report. Notably, it has a much larger spatial and temporal scale than the MMP point counts. Furthermore, its systematic grid ensures that the same areas are surveyed twice, unlike the MMP, where routes are re-surveyed or dropped based on the interest of local volunteers and authorities.

Metric and Indicator Selection

The selection of metrics follows the 2007 AOC report (Crewe et al., 2007) which used Atlas data to analyze wildlife trend differences between AOCs and the broader ecoregion context. In that report, a variety of metrics were selected to represent avian habitat guilds, feedings guilds, and taxonomical groups (20 metrics in total). Many of these same guilds were selected for this report, particularly those with an emphasis on aquatic ecosystems. However, the number of

metrics were reduced to a more manageable 9 metrics, to somewhat address concerns of “overdoing” statistical tests, which otherwise increases the chance of getting a significant result by random chance. The selected metrics include: total species richness; richness of forest-associated species; richness of bush/brush low-canopy species; richness of grassland species; richness of aerial insectivores; richness of shorebirds; richness of waterfowl; richness of waterbirds; richness of marsh-obligate nesters. Of this suite of indicators, most were selected to provide an overview of the changes taking place in the greater AOC environment, such as the upland species metrics. More attention should be given to those key metrics which are potentially affected by the aquatic ecosystem's ability to provision food and habitat: richness of waterfowl and marsh-obligate nesters.

Methods

A preliminary analysis tested all metrics simultaneously in a repeated-measures Multivariate Analysis of Variance (rm-MANOVA), using the statistical package "car" (Fox & Weisberg, 2010), in the R programming language (R Development Core Team, 2010). The multivariate analysis tests whether there is an effect of the St. Clair River AOC, a trend effect (Atlas 1 versus Atlas 2), and an interaction between the St. Clair effect and the trend. A significant effect in the MANOVA suggests that at least one metric is different.

Finding a significant effect in the multivariate test, I then proceeded with univariate tests of the effect of the St. Clair River AOC on the change of each metric between Atlases. Unlike the Multivariate test, which is robust to violations of normality, the few St. Clair River AOC squares (8) in the univariate tests necessitated that I use a lower-power non-parametric rank-sum test (Wilcoxon).

Furthermore, a Mantel Test of Dissimilarity Matrices was used to assess the significance of auto-correlation for each metric, using latitude and longitude values (scaled to the same unit distance) as predictor variables. This was performed in lieu of a way of addressing spatial autocorrelation in the rank-sum and MANOVA tests.

Results

The multivariate test suggested strong evidence for a significant effect of St. Clair ($p < 0.001$) and a significant effect of the St. Clair-Trend interaction ($p < 0.001$). According to the 9 metrics, the St. Clair River AOC is different in its status from the region, and it is changing in a different way.

Table 3 shows a simplified summary of the direction of change for each metric for the St. Clair River AOC, and the difference between the St. Clair River AOC and the greater region. An expanded table is available in the Appendix 3, and figure 5 summarizes this information, including colour-codes for statistical tests and percentiles of the St. Clair River AOC versus the regional values.

In general, there is a decline in species numbers, both regionally and within the AOC. Relative to the greater regional trend, the change in total number of species was strongly negative for the St. Clair River AOC, but this trend seems to be most heavily influenced by upland species, such as forest, bush / low-canopy, and grassland-associated species, which all have low percentiles in the 21 - 25% range. Aside from waterbirds, the shorebirds, marsh obligate nesters and waterfowl seem to be equal or slightly increasing relative to the regional average, with higher percentiles (50 - 59%). Aerial foragers have a marginally significant decline ($p < 0.1$), but the Mantel test suggested strong spatial autocorrelation for aerial foragers ($p < 0.05$), making it

difficult to ascribe causality to their decline: the effect could be unique to the AOC itself, or a purely spatial artefact.

According to the indicator framework, 5 of 9 indicators have a score of "poor", and 4 have a scoring of "fair". The overall average percentile for all indicators is 35%. However, this is largely a reflection of the decrease in upland and aerial species. Focusing on the stated key indicators for waterfowl and marsh-obligate nesters, the St. Clair River AOC fares well compared to regional trends.

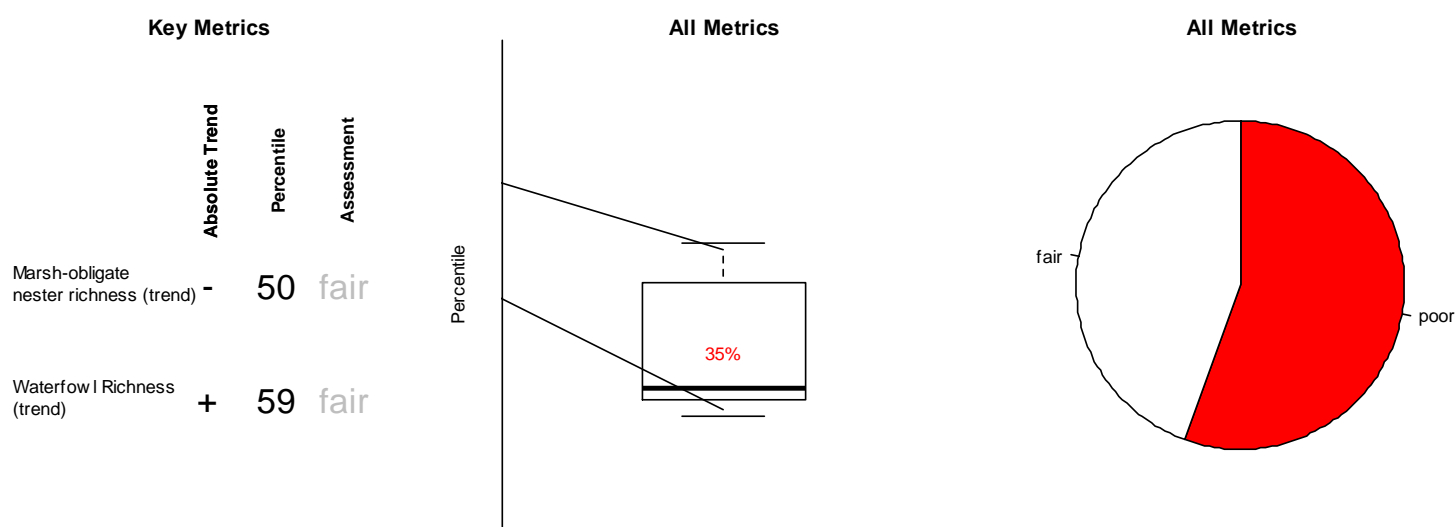


Figure 4 Overview of results for the Atlas of Breeding Birds of Ontario. From left to right, results for 1) key metrics, 2) rank-percentile for all 10 metrics, and 3) scorings from statistical tests for all 10 metrics.

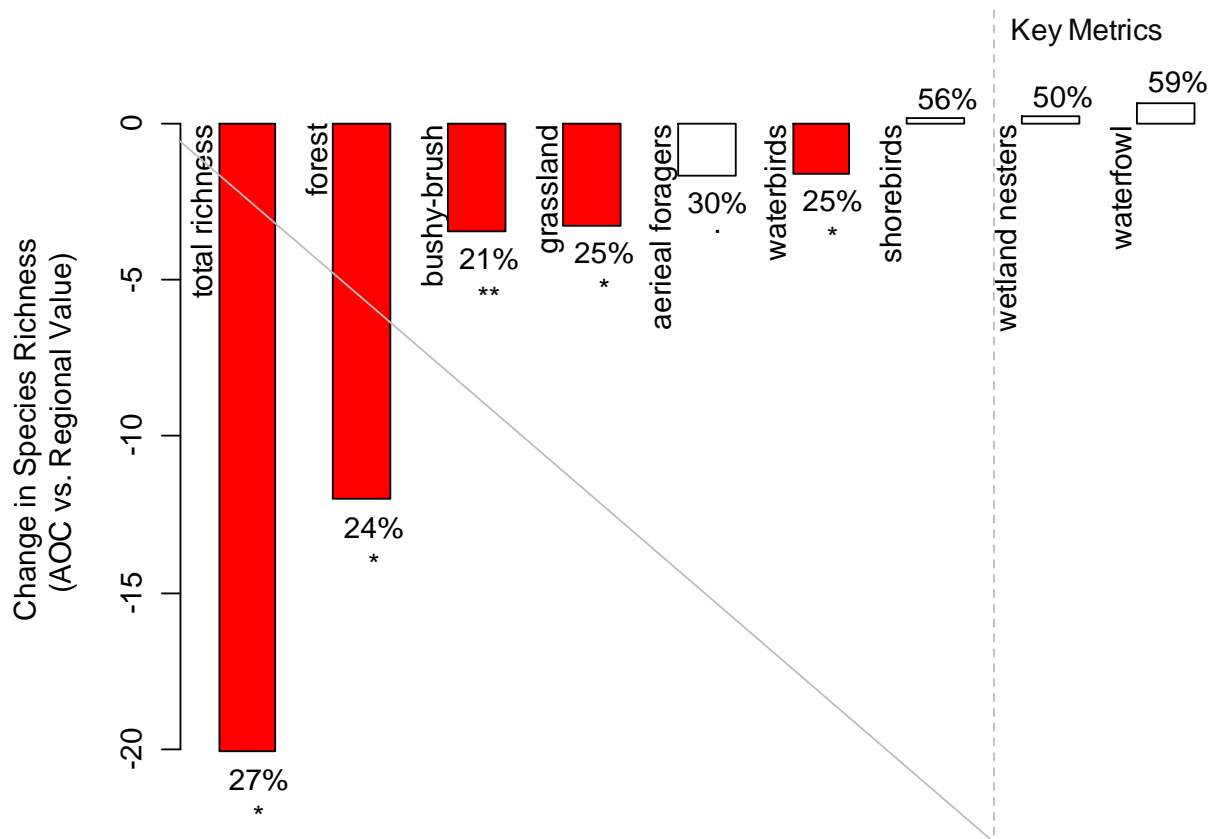


Figure 5 Summary of Atlas of Breeding Birds of Ontario: magnitude of difference between St. Clair River AOC trends and regional trends. Percentages of the rank-percentile of the St. Clair value versus regional benchmark. * = rank-sum test p-value < 0.05; ** = rank-sum test p-value < 0.01.

Table 3 Summary of results for the Atlas of Breeding Birds of Ontario: direction of trends, difference between the St. Clair River AOC trends and the regional benchmark, and indicator assessments. Key metrics to consider are highlighted in gray.

Metric	AOC Change in richness	Change in Richness (AOC vs. Region)	p-value (AOC vs. Region)	Percentile	Assessment
aerial foragers	-	-	.	29.84	fair
bushy-brush	-	-	**	21.28	poor
forest	-	-	*	24.34	poor
grassland	-	-	*	25.27	poor
marsh-obligate nesters	-	+		50.40	fair
shorebirds	-	+		56.04	fair
total richness	-	-	*	27.13	poor
waterbirds	-	-	*	24.60	poor
waterfowl	+	+		59.31	fair

Furbearer Harvests

Summary

Both Mink and Muskrat had positive trends in harvests, which were higher than the regional trends (> 88th percentile).

Description

The Ontario Ministry of Natural Resources manages wild populations of furbearers, including licensing of trappers, enforcing harvest seasons and area closures, setting quotas, and collecting harvest information from trappers. The harvest dataset provides one of the few trend datasets for mammals in Ontario (OMNR, unpublished) dating back to 1993 for some species. The data includes reported numbers of harvested pelts per species as well as the total number of licensed trappers, linked to administrative counties. I can get an approximate idea of the locations of the harvests, as trappers must declare the township within which they reside or intend to trap (although in reality they may trap anywhere within the county). As the St. Clair River AOC boundaries are not aligned with county boundaries, I assumed that the townships adjacent to the St. Clair River and the northern shore of Lake St. Clair were representative of the AOC, including the townships of Sombra, Moore, Sarnia, Chattam, and Dover. These townships were amalgamated into one unit. I assumed that the surrounding counties would serve as a representative regional benchmark, including: Elgin, Essex, Huron, Lambton-Kent (excluding St. Clair townships), Middlesex, Norfolk, Oxford, and Perth counties.

Indicator and Metric Selection

The sparsity of harvest information for most aquatic mammal species, such as Beaver and Otter, precluded their use in this analysis. Only Mink and Muskrat information was available in reasonable quantities for analysis. The Mink was of particular interest to the RAP Team, being scrutinized for contaminant body-burdens (St. Clair River RAP Team & St. Clair River BPAC Team, 1995; Mayne, 2005), and so was included in this report. However, some scientists have warned against using Mink as a sentinel species, due to the high incidents of escapees from Mink-farms in Southern Ontario (Bowman, 2009).

Status indicators were not possible for the furbearer data, as direct comparisons between counties are confounded by their different size, and different number of trappers, limiting the analysis exclusively to differences in trends (with suitable modelling).

Method

In order to focus on trend information, and not on differences in absolute numbers of harvested pelts, the furbearer harvest counts were analyzed in species-specific Poisson-family Generalized Additive Mixed Models (GAMM) using the R programming language and the "mgcv" package (Wood, 2004). This family of models, using the logarithmic link-function, allows us to look at proportional changes in harvest, rather than absolute counts. Furthermore, each county was modelled with a random-intercept and random-slope.

To attempt to account for variation in harvests explained by the differences in trapping effort, I included the number of trappers in each county and the price of pelts as model covariates. A temporal auto-correlation structure was fit to each county's residuals to account for the non-independence of such repeated-measures.

Because the St. Clair River AOC has only a single value for its furbearer trends, I could not test for the effect of St. Clair on the distribution of harvest trends. Rather, the only test available was an outlier test, which tests whether the St. Clair River trend is an extreme value compared to the rest of the region (Dixon, 1950). Such outlier tests have much lower power to detect effects than tests with distributions.

Results

Both the Muskrat and the Mink trends in the St. Clair River AOC had high percentiles compared to other counties, even after accounting for the effects of the number of trappers or the price of pelts. Muskrat ranked as the highest trend in the region, and Mink ranked at the 88th percentile. Neither showed evidence of being an outlier (p values 0.13 and 1 respectively), so I cannot claim that the trends in fall outside of the realm of regional possibilities. However, it is promising that both species had positive trends in the AOC, while the average trend for the region was negative (table 4 for a summary of results; see the expanded table of results in Appendix 3).

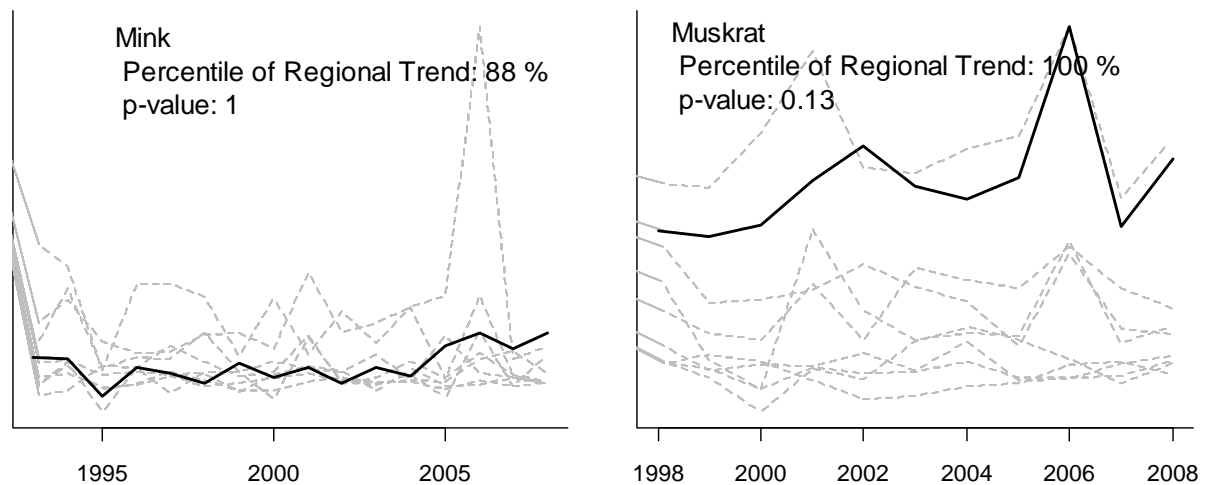


Figure 6 Trends of furbearer harvests (after accounting for influences of fur prices and number of trappers), including rank-percentile of trends versus regional trends and Dixon outlier test. Bold line is for townships adjacent to the St. Clair River AOC. Hashed lines are for surrounding counties. Note, the scale for the intercepts has been omitted.

Table 4 Summary of results for the furbearer harvests: St. Clair River AOC trend, regional trend, rank-percentile and outlier test of trend versus regional distribution of trends. The key metric to consider is highlighted in gray.

Species	AOC Trend (Proportional Annual Change)	Region Trend (Proportional Annual Change)	p-value (Regional Trend)	Percentile	p - value (Outlier test)	Covariates
Mink	0.02	-0.01	0.67	87.50	1.00	Price of Mink; Number of Trappers
Muskrat	0.00	-0.05	0.00	100.00	0.13	Price of Muskrat; Number of Trappers

Marsh Monitoring Program (Amphibians)

Summary

Figure 7 shows the summary of indicators. The key metric, richness of indicator species, scored above the 50th percentile with a "fair" assessment, as did the other 2 metrics.

Description

The Marsh Monitoring Program is a joint undertaking by Bird Studies Canada, Environment Canada, and the USA Environmental Protection Agency. The program began in 1995 to provide baseline information about the status and trends of Great Lakes marsh birds and amphibians. One of the program's goals was to facilitate the assessment of AOCs in the Great Lakes Basin. BSC and Environment Canada also use the data to estimate overall trends for species across the Great lakes. To date, there has been over 800 routes surveyed by hundreds of volunteer surveyors.

The MMP Amphibian dataset is spatially structured by routes and stations. A contiguous wetland typically has one or two routes, which themselves have a variable number of survey stations (i.e., the actual locations of point counts). Observers are responsible for visiting routes on three evenings, between early April to mid-July, with at least 15 days occurring between surveys. Surveys are scheduled to occur on evenings with a minimum night air temperatures of 5, 10 and 17 degrees Celsius respectively, owing to the strong association between calls and local weather. Surveys run from 1/2 hour before sunset to midnight, and last for a duration of three minutes. To date, only species' presence/absence data has been used in analyses at BSC.

Indicator and Metric Selection

Typical of Amphibian species, there are few routes, stations, and detections of amphibian species within the St. Clair River AOC. Early studies of the AOC had used observations from the nearby St. Clair National Wildlife Area (Chabot et al., 1998), which is now outside the AOC boundaries. This paucity of data made trends inestimable. Only status information was assessed for the selected indicators, using data since 2006.

Previous MMP analyses have used the opinions of experts and staff at BSC and Environment Canada to categorize Amphibian species into indicator classes (table 5), using attributes such as: sufficiently common to make detections likely; dependent on marshes for breeding; requiring relatively undisturbed habitat conditions; and the inclusion of both early and late-season callers. I continued with these efforts, summarizing the richness of Chorus Frog (*Pseudacris triseriata* & *Pseudacris maculata*), Mink Frog (*Rana septentrionalis*), Northern Leopard Frog (*Rana pipiens*), and the Spring Peeper (*Pseudacris crucifer*) as the metric "richness of indicator species" and the reader is encouraged to focus on this metric. To provide some greater context to interpret results, I also summarized two additional richness metrics: total species richness, and richness of non-tolerant species.

Community Analysis

Metrics and indicator species are a proxy of those aspects of the community which I am interested in, such as community structure, composition and ecosystem functions. With a fine-

resolution dataset, going back a few years, the MMP Amphibian dataset allows the assessment of the entire species assemblage community directly, without making any assumptions about what constitutes its main dimensions. Owing to this possibility, I conducted a community composition analysis, in addition to the individual-metric analyses.

Methods

Community assessment

As in the Atlas of Breeding Bird analysis, I started with a repeated-measures Multivariate Analysis of Variance (rm-MANOVA). MANOVA tests for a significant effect, in general, for the entire community of species. I tested the effect of St. Clair River AOC. Unlike the Atlas dataset, I employed Permutational MANOVA on Dissimilarity Matrices, using the R package "vegan": the method is more robust to varying time intervals and makes less assumptions. In particular, the analysis allows direct tests on the community composition, rather than selecting arbitrary biodiversity metrics of the community (as was necessary in the Atlas dataset), by using ecologically-meaningful dissimilarity matrices (Hellinger distance). To account for the repeated-measures and station-route structure of the dataset, permutation tests were performed by stratifying permutations of stations within the same years. I partitioned out the variation explained by large-scale spatial trends such as latitude and longitude (rescaled to the same unit length, and entering as a 2nd-order polynomial interaction), and whether a site was located inland or on the Great Lakes coastline.

Metric analysis

The St. Clair River AOC includes only 5 amphibian survey stations, and mostly since 2006. I used all of this data since 2006 to assess the status of the above metrics. However, stations measured repeatedly are not independent: to avoid this "pseudo-replication", I used a mixed-model framework, inducing a correlation structure among stations in the same routes, as well as testing the use of an autoregressive residual correlation structure for stations measured repeatedly over many years. The analysis was conducted using the "mgcv" and "nlme" (Pinheiro et al., 2010) packages in R.

The difference in metric values between the AOC and the greater region were tested using a Generalized Additive Mixed Model (GAMM). In order to account for community differences due to large spatial trends, I included model covariates for latitude and longitude (rescale to the same unit distance), as well as a categorical variable for whether wetland stations were located inland or on the Great Lakes coast. The rescaled-latitude and longitude variables entered as a bivariate smooth spline term with approximately 5 degrees-of-freedom. These spatially-detrended St. Clair metric values were then used to calculate the St. Clair River AOC percentile indicators (figure 8). The estimated differences between the AOC values and the regional values, and the tests' p-values, were used to make assessment indicators as described in the Indicator Framework section.

Results

The permutational MANOVA showed no evidence of there being a significant difference between the community composition of the St. Clair AOC versus the other regional sites. This is perhaps a more sensitive test than the GAMM modelling on the metrics, which also showed no significant difference.

There was no evidence in support of a difference between the St. Clair River AOC amphibian metrics and the greater regional context. In this manner, the assessment indicators were all classed as being "fair". The percentiles values for the St. Clair River AOC amphibian metrics

were all above the 50th percentile, suggesting a fair performance of the AOC (Table 6; see Appendix 3 for an expanded table of results). In a predictable pattern, the total species richness ranked the highest, at the 72nd percentile on average; the non-tolerant species were somewhat lower, at the 60th percentile; and the indicator species richness metric was the lowest at the 56th percentile. This apparent pattern of decreasing percentiles for all species, less-tolerant species, to indicator species, may seem intuitive (more sensitive species should probably be less common), but percentiles do not imply that the absolute amount of indicators species are lower than other species. Rather, the comparison is only sensical relative to the regional context, i.e., the St. Clair River has much higher than average total species richness than the regional average, but it is less-high regarding its indicator species. It could be that remediation efforts are promoting non-indicator and tolerant species more than indicators species, or perhaps the pattern is a residual effect of previous impairments to amphibian species. Nonetheless, the percentiles are all higher than the regional average, and the effect is not statistically significant.

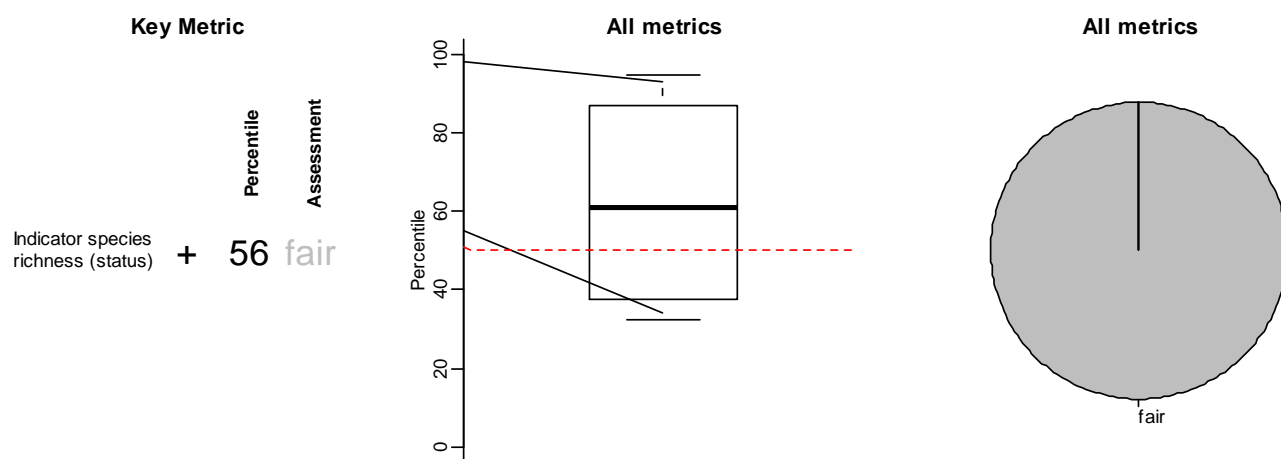


Figure 7 Summary of results for the Marsh Monitoring Program Amphibian dataset. From left to right, 1) key metrics, 2) rank-percentile for all 3 metrics, and 3) scores for all 3 metrics

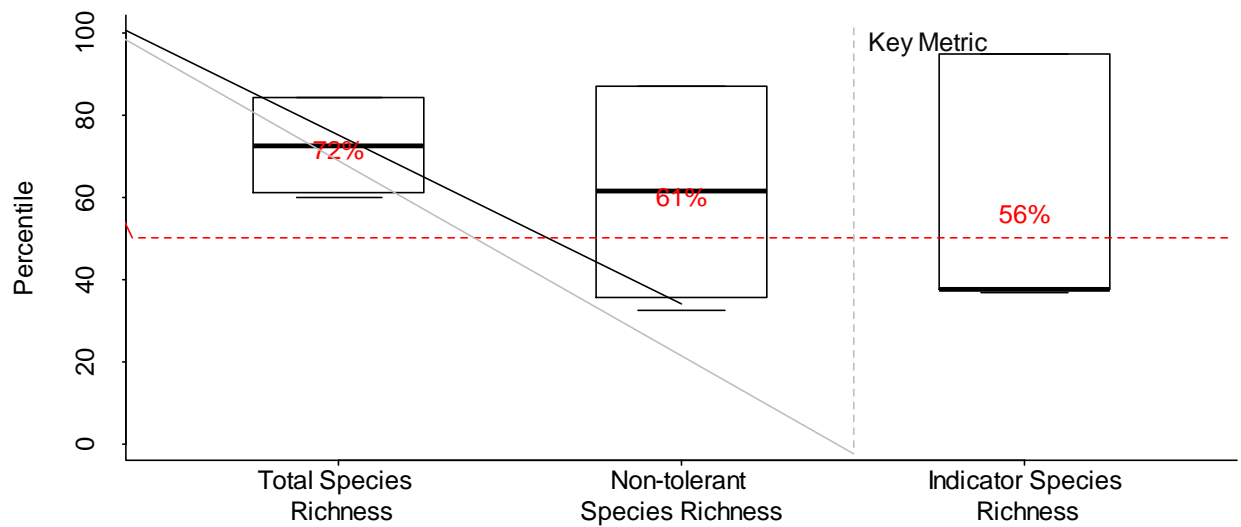


Figure 8 Results for the Marsh Monitoring Program Amphibians dataset, rank-percentiles for St. Clair River AOC value versus regional values.

Table 5 Summary of species classification for the Marsh Monitoring Program Amphibians

Common Name	Latin Name	Woodland Associated	Disturbance Tolerant	Not disturbance tolerant	Basin-wide distribution	Declining MMP trend	Indicator Species
American Toad	Bufo americanus		X		X	X	
Blanchard's Cricket Frog	Acris crepitans blanchardi			X			
Bullfrog	Rana catesbeiana			X			
Cope's (Diploid) Gray Treefrog	Hyla chrysoselis			X			
Chorus Frog	Pseudacris triseriata & Psudacris maculata		X			X	X
Fowler's Toad	Bufo woohhousei fowleri			X			
Green Frog	Rana clamitans melanota		X		X	X	
Gray (Tetraploid) Treefrog	Hyla versicolor	X	X				
Mink Frog	Rana septentrionalis			X			X
Northern Leopard Frog	Rana pipiens			X	X	X	X
Pickerel Frog	Rana palustris			X	X		
Spring Peeper	Pseudacris crucifer	X	X				X
Wood Frog	Rana sylvatica	X		X	X		

Table 6 Summary of results for the Marsh Monitoring Program Amphibians dataset: direction of difference in values between the St. Clair AOC and regional benchmark, rank-percentiles, and scores. The key metrics to consider is highlighted in gray.

Metric	Richness (AOC vs. Region)	p-value (AOC vs. Region)	Percentile	Assessment
Total species richness	+	N.S.	72.35	fair
Indicator species richness	+	N.S.	56.46	fair
Non-tolerant species richness	+	N.S.	60.79	fair

Marsh Monitoring Program (Birds)

Summary

There was a high spread of scores and percentiles for the MMP bird dataset (figure 9). Most of the status (discrete time) indicators, including the key metrics, had high percentiles and scored "good". It was among the trend indicators that some indicator species and key metrics, such as the abundance of marsh-nesting obligates, was lower.

Description

The avian point counts of the Marsh Monitoring Program typically occur in the same routes as in the amphibian dataset, albeit with more routes and stations, providing a much larger dataset. The spatial structure is identical to the MMP amphibian surveys, with each wetland typically having one route, enveloping a number of survey stations (point count locations), whereupon all stations in a route are surveyed on the same day by the same observer. Bird surveys occur later in the year than amphibian surveys, between mid-May to early July, with at least 10 days between visits. Surveys begin after 18:00, and last for 15 minutes: 5 minutes of silent listening, 5 minutes of playback (broadcasting audio recordings of focal marshbird species), followed by 5 minutes of more silent listening. The playback focuses on secretive species who are difficult to see, but may call in response to the recordings, including the Virginia Rail, Sora, Least Bittern, Common Moorhen, American Coot, and the Pied-Billed Grebe. All species heard or seen within 100m are recorded, and fly-through observations are discarded (except for aerial foragers).

The MMP's standardized protocol and the quantity of MMP avian routes allows for a variety of assessments, on both status and trends, as well as at various levels of aggregation, including analyses on individual species, biodiversity metrics, and the community composition.

Indicator and Metric Selection

From the outset of the MMP, experts from Bird Studies Canada and Environment Canada defined certain indicator species to assist with AOC assessments, using criteria such as: sufficiently common to make detections likely; dependent on marshes for breeding; and requiring relatively undisturbed habitat conditions. In addition, BSC has tested and used a variety of richness and abundance metrics to serve as constituents within an overall "Index of Biological Integrity" (Crewe & Timmermans, 2005), including such metrics as: marsh-obligate nesters; area-sensitive marsh-obligate nesters; marsh-nesting generalists; water foragers; aerial foragers; and generalists. To analyze all these indicator species, and richness and abundance metrics, for both status and trends, as well as to provide more contextual indicators, such as total species richness, would quickly become overwhelming. Furthermore, many of these metrics are redundant, with overlapping species-lists, thereby potentially biasing the reader's overall impression of the AOC, if essentially the same effect is repeated many times in the guise of different metrics.

Instead, I devised a method to explore which species and metrics constituted the major ecological dimensions of the wetland communities surrounding the St. Clair River AOC. To do this, I used Non-metric Multidimensional Scaling (NMDS) to find the major latent dimensions of the MMP bird data set, and selected metrics and species which were strongly correlated with the yielded dimensions, and not highly correlated with each other. The motive behind this method is the recognition that although a wetland's species composition may vary in as many ways as there are species, in reality, some species co-occur together predictably, allowing the

application of variation-reduction techniques, such as the popular Principal Component Analysis, to reveal the main community dimensions. NMDS is generally regarded as the most robust variation-reduction technique for ecological data (Michin, 1987) and is analogous in its outcomes to a PCA, but uses species' rank-orders, rather than absolute values. I used the R package "vegan" (Oksanen et al., 2010) for NMDS, using the Hellinger distance metric (Legendre & Gallagher, 2001). I first removed variation explained by large-scale spatial trends, by partialling out 2nd-order polynomial interactions with latitude and longitude (rescaled to the same unit distance). I applied randomized-permutation tests to assess how many significant dimensions there were, ranging from 3 to 10. While all 10 dimensions tested as significant, I selected 6 dimensions, as the algorithm had trouble converging beyond 6 dimensions, and the marginal increase in the fit was minimal (i.e., the "stress" values plateaued around 5 - 6 dimensions)

Indicator species

Figure 10 shows the first three dimensions of the NMDS ordination. The results show that the MMP indicator species (in bold) occupy similar space along the 2nd dimension but otherwise differ in their responses on other dimensions. Limited by species' occurrences at the St. Clair River AOC, I selected the Virginia Rail (VIRA), Marsh Wren (MAWR), Pied-billed Grebe (PBGR) and American Coot/Moorhen complex (MOOT) from the indicator species for further analysis, as they had different extremes and niche spaces along the various dimensions. I also included the Banks Swallow (BANS) and Spotted Sandpiper (SPSA), which have not been considered indicator species in previous analyses, but are implicated in this analysis as having strong associations with these major NMDS dimensions, as well as for representing other important guilds which are not themselves the focal species of the MMP (aerial insectivores and shorebirds).

Biodiversity Metrics

The following biodiversity metrics had highly positive or negative correlations ($r > 0.4$) with at least one of the 6 NMDS dimensions: abundance of marsh-nesting obligates, richness of waterfowl (these two represented the first 2 dimensions), richness of waterbirds, abundance of aerial insectivores, and abundance of bush-brush/low-canopy associated species. I also included total species richness as an overall structural metric. Of the above indicators, I suggest the reader focus on the abundance of marsh-nesting obligate species and the richness of waterfowl, not only as they describe the two first dimensions of the NMDS analysis, but also, as described before in the section on the Atlas of Breeding Birds, they occupy important functional aspects of wetland communities.

Community Analysis

Metrics and indicator species are intended to represent different aspects of the structure, composition and function of ecosystems. But with a fine-resolution dataset which goes back many years, the MMP dataset allows for an analysis on the community directly, without making any assumptions about what constitutes its main dimensions. As done previously with the MMP Amphibian dataset, I conducted a community composition analysis using the MMP bird dataset.

Methods

Community assessment

As in the Atlas of Breeding Bird and MMP Amphibian dataset, I started with a repeated-measures Multivariate Analysis of Variance (rm-MANOVA). MANOVA tests for a significant effect among the entire assemblage of species, as a prelude to more specific tests of individual biodiversity metrics or species. I tested the effect of St. Clair River AOC, the effect of time (trend) and their interaction (the latter addresses the question: *is the St. Clair River AOC*

changing differently than the region as a whole?). Unlike the Atlas dataset, I employed Permutational MANOVA on Dissimilarity Matrices, using the R package "vegan". The analysis allows direct tests on the community composition, rather than selecting arbitrary indicator metrics of the community (as was necessary in the Atlas dataset), by using ecologically-meaningful dissimilarity matrices (Hellinger distance). To account for the repeated-measures and station-route structure of the dataset, permutation tests were performed stratifying permutations of stations within routes across years (by customizing the "vegan" code with the function "permute.index2", as recommended by the software's authors). I partitioned out variation explained by large-scale spatial trends, by partialling covariates for latitude and longitude (rescaled to the same unit length, and entering as a 2nd-order polynomial interaction), whether a site was coastal or not, and a factor variable for the wetland size (small/medium or large)

Finding significant differences in the community composition at the St. Clair River AOC, I then proceeded with analyses of individual metrics and indicator species, for both status and trends.

Status assessment

The analysis of the status of metrics and indicator species was similar to that of the MMP amphibians, using St. Clair River routes surveyed in the past 4 years. The effect of St. Clair was tested in a Poisson Generalized Additive Mixed Model, where each route had a random intercept, and there was an auto-correlation structure of residuals within a route. To account for possible variation explained by large-spatial trends and wetland size, I added covariates for latitude and longitude (rescaled to the same unit length, and entering the model as a bivariate smooth spline), whether a site was coastal or not, and a factor variable for the wetland size (small/medium or large). Some species had too few observations to account for so many explanatory variables, and variables were selected based on AIC. The statistical tests of the effect of St. Clair as a variable were used to make assessment indicators, using the direction of the difference and the p-value's to assess the effects as "poor", "fair", or "good", as described in the Indicator Framework section. Importantly, standard error estimates were inflated if there was evidence of overdispersion. Percentiles were generated by first removing variation accounted for by other covariates, and then comparing the residuals to the regional values.

Trend analysis

The analysis of the MMP bird trends was similar to the above analysis, using a Poisson Generalized Additive Mixed Model, but also included "year" as a linear variable, and tested whether the interaction of the trend (year) and St. Clair River AOC was significant (i.e., *is St. Clair River AOC changing differently than the region as a whole?*). The direction of the year-St. Clair interaction, and its p-value, were used to ascribe assessment categories, as described in the Indicator Framework. For the calculation of percentiles, a slight modification of the mixed-model included a random year-effect (random slope) for each route. This distribution of year-effects served as the "regional distribution" with which to rank the St. Clair River AOC trend estimate.

Results

Community assessment

The Permutational MANOVA using Dissimilarity Matrices analysis suggested strong evidence of there being a difference in the overall composition of St. Clair River AOC vs. the greater region, and that the composition of St. Clair is changing over time (p-values < 0.001). The MANOVA analysis does not test which species are changing, but it is useful as a justification for probing further, and indicates that the St. Clair River AOC is changing in its own way. I can get a sense

of which species seem to be driving the significant results, by taking species' weighted scores of the eigenvectors associated with both the St. Clair River AOC variable (figure 11, top), and the year-St. Clair interaction variable (figure 11, bottom). The top graph can be interpreted as the "status" of St. Clair River AOC, how its species' abundances compare to the greater region. I see there is an even distribution of indicator species, some being on the right-side of the graph and having high associations with the AOC (e.g., Marsh Wren, Coot/Moorhen), and others being on the left-side and having lower associations with the AOC. On the bottom graph, the right-side contains species which are increasing in the AOC more than the regional average, and species on the left are decreasing more than the regional average. Most of the indicator species have negative trends (figure 11, bottom), even those with high abundance in St. Clair River AOC.

Status assessment

Figure 12 and Table 7 show the rank-percentiles of status indicators. Overall, total species richness, marsh birds and water birds, and waterfowl, have higher percentiles, including some indicator species such as (e.g., Marsh Wren, Coot/Moorhen, Spotted Sandpiper). Aside from total species richness, these were statistically significant. Lower percentiles held for other species' assemblages, such as aerial insectivores and bush-brush associated species, but were not significantly different. The status of indicator species was highly variable, ranging from the 28.1st percentile for the Pied-billed Grebe, to the 66.9th percentile for the Marsh Wren, as may be expected, as these indicator species are not a monolithic group, but occupy various positions along the latent ecological dimensions (figure 10). Only the Virginia Rail had significantly different negative results.

Focusing on the key metrics of marsh-nesting obligate species and waterfowl metrics, the status assessment for St. Clair status is good.

Trend assessment

Figure 14 and Table 8 show the magnitude of the difference between the St. Clair River AOC trend and the regional trend, as well as the percentiles. Some of the species showed opposing status and trend results, such as the Marsh Wren and the Pied-Billed Grebe, which may represent species on the extremes in terms of abundance, who are adjusting to more normal values. Focusing on the key metrics of marsh-nesting obligate species and waterfowl, once again I see that the St. Clair River AOC fares well. Waterfowl richness has shown a significant increase versus the regional trend, and the trend in the abundance of marsh-nesting obligates is not significantly different. Both of these metrics show absolute declines in both the St. Clair River AOC and the greater region, but these declines seem to be shallower in the St. Clair River AOC.

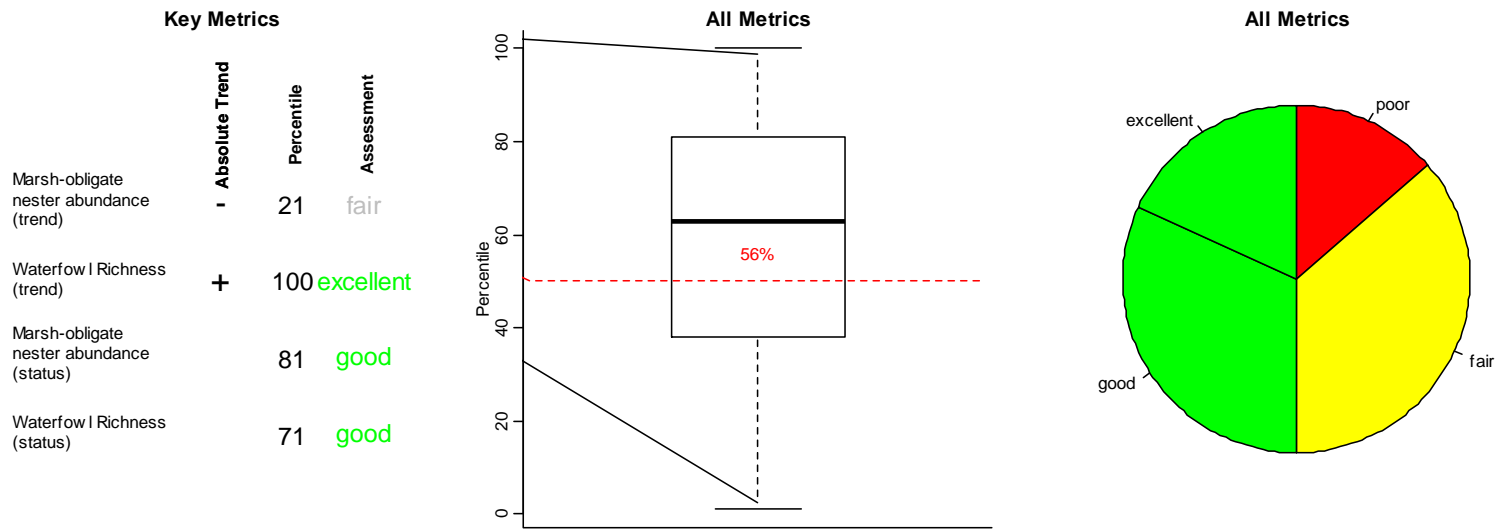


Figure 9 Summary of results for the Marsh Monitoring Program Bird dataset. From left to right, 1) key metrics, 2) rank-percentile for all 22 status and trend metrics, and 3) scores for all 22 (status and trend) metrics.

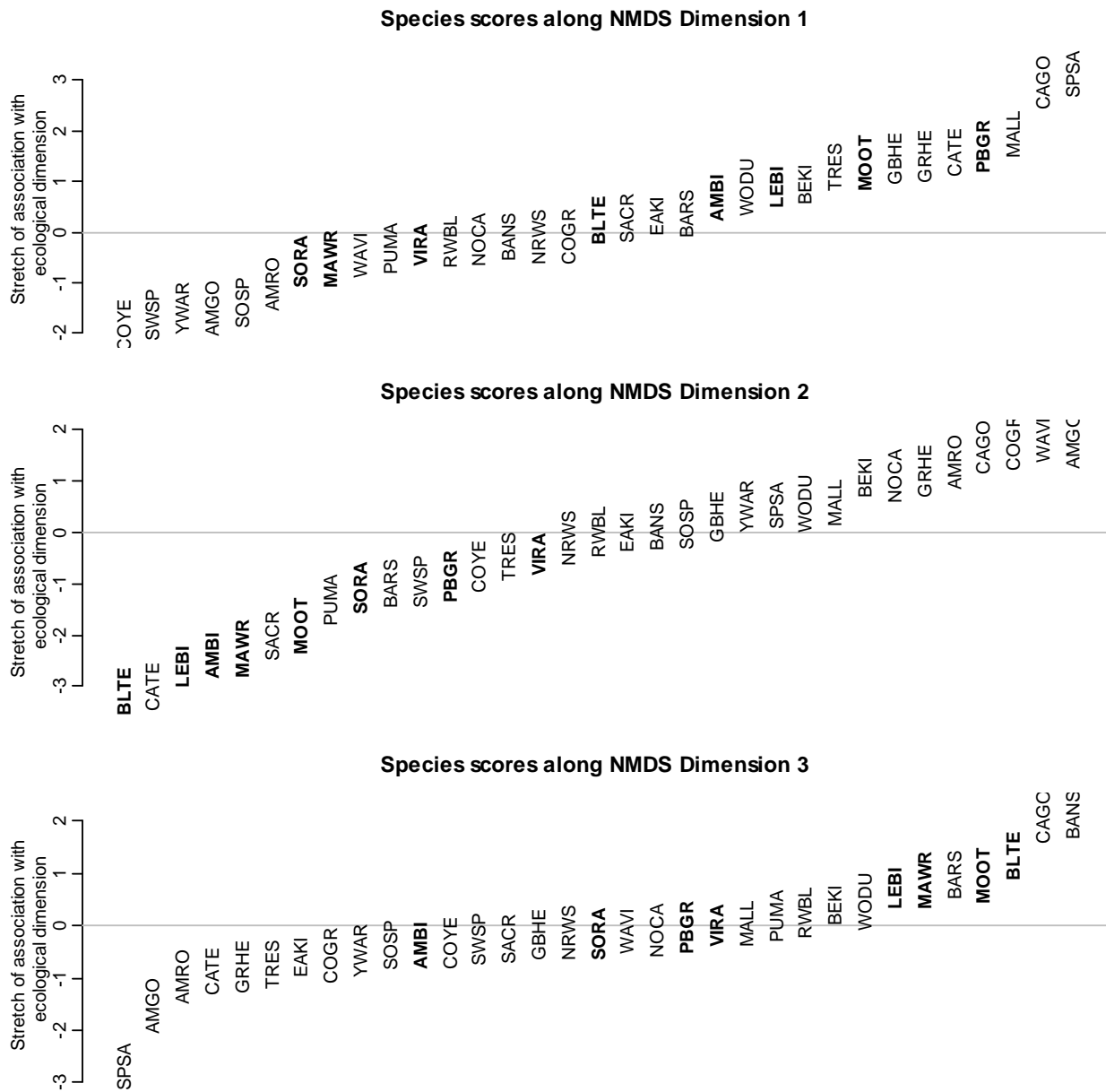


Figure 10 MMP Bird species scores along the first three dimensions of a Non-metric Multidimensional Scaling ordination. Species in bold are considered indicator species in previous MMP reports.

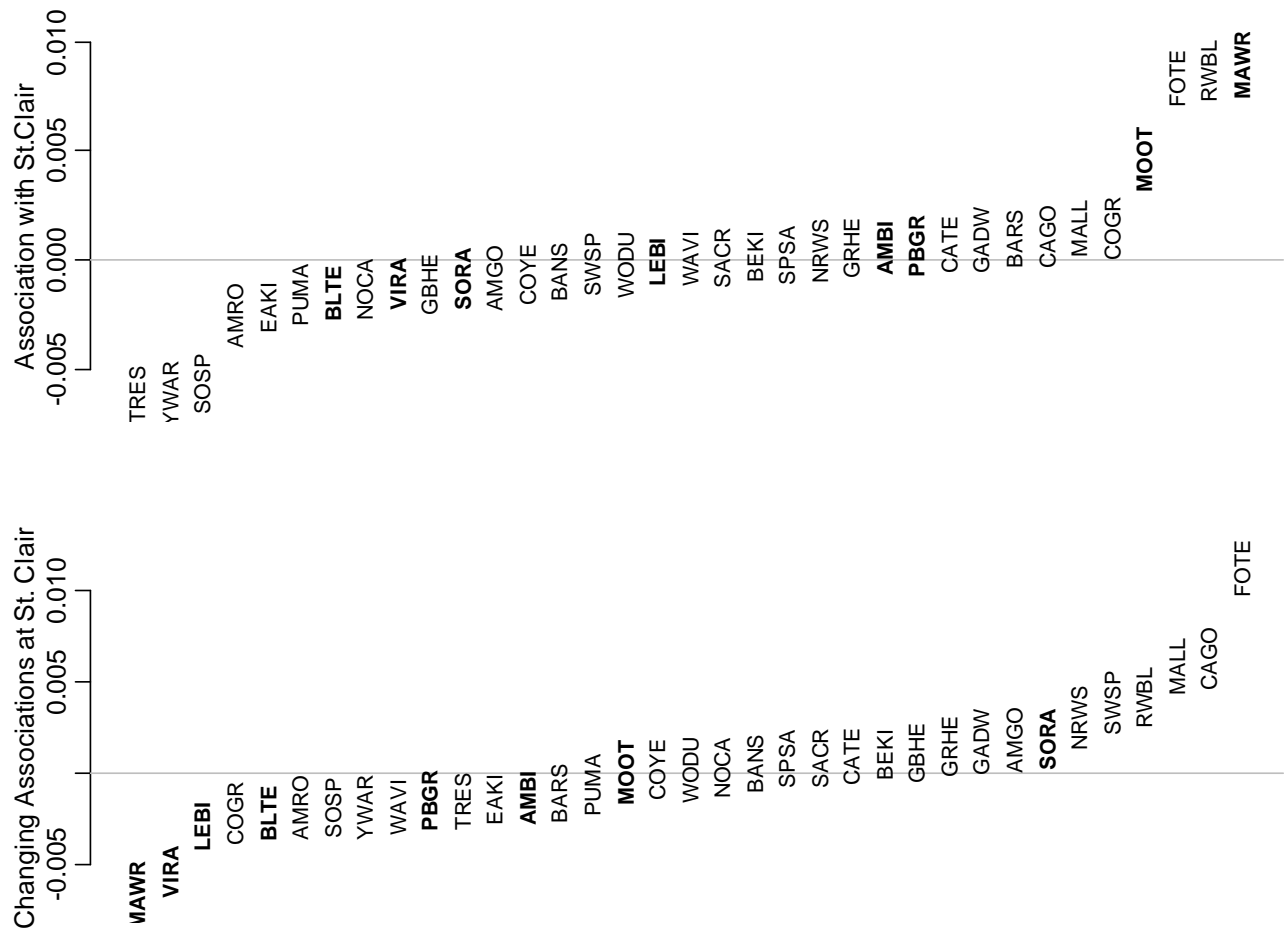


Figure 11 MMP species scores along eigenvectors for permutational-MANOVA. From left to right show increasing association with (top) high abundance at St. Clair River AOC, and (bottom) positive trends at the St. Clair River AOC.

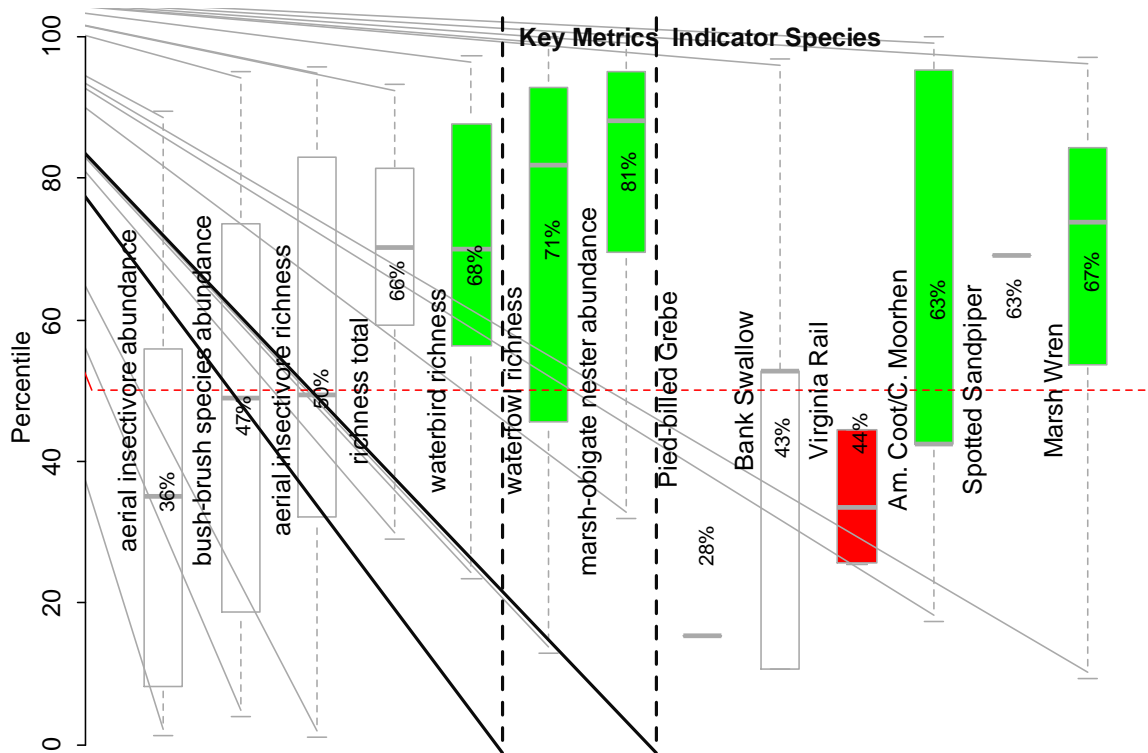


Figure 12 MMP bird abundance rank-percentiles versus regional benchmark. Green boxes are significantly higher than regional benchmark; red boxes are significantly lower.

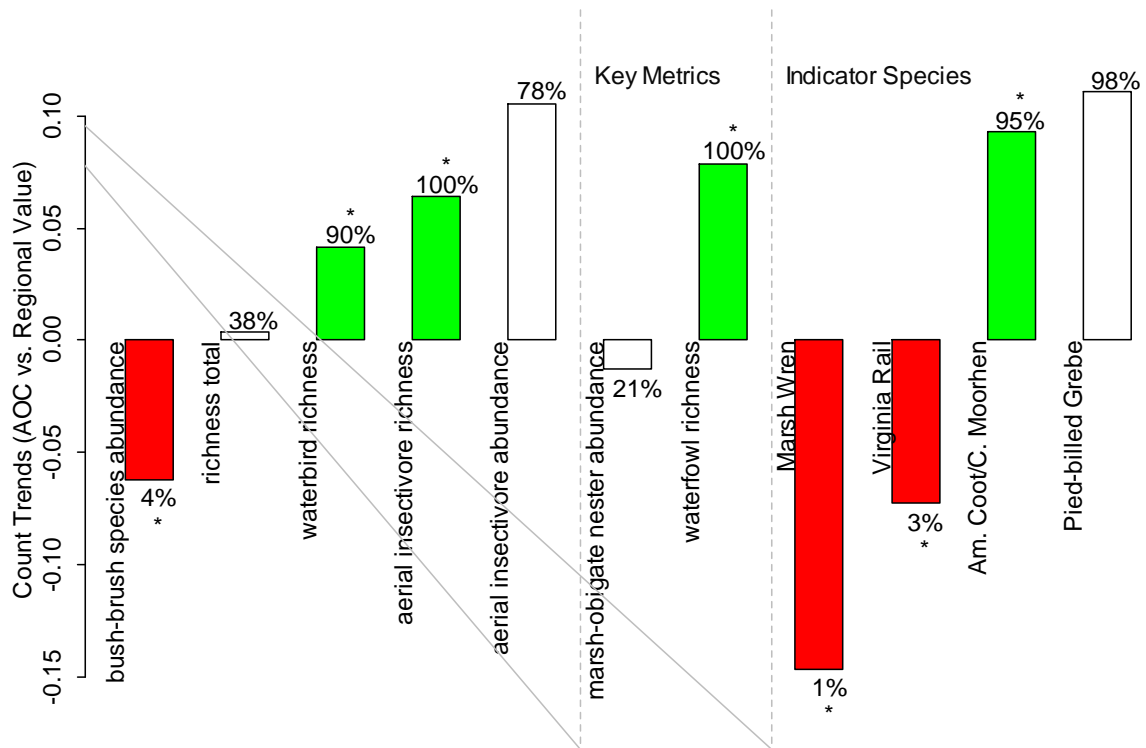


Figure 13 Summary of MMP bird trends: magnitude of difference between St. Clair River AOC trends and regional trends. Percentages of the rank-percentile of the St. Clair value versus regional benchmark. * = p-value < 0.05 for significance of difference between AOC trend and regional trend.

Table 7 MMP bird status assessment, showing greater (+) or lesser (-) abundance at St. Clair River AOC versus regional benchmark, percentiles, statistic tests, and assessment. * = p-value < 0.05. Key metrics to consider are highlighted in gray.

Metric	Species Code	Abundance (AOC vs. Region)	Percentile	p-value (AOC vs. Region)	Assessment
aerial insectivore abundance		-	36		fair
bush-brush species abundance		+	47		Fair
richness total		+	66		fair
waterbird richness		+	68	*	good
marsh-obligate nester abundance		+	81	*	good
waterfowl richness		+	71	*	good
Am. Coot/C. Moorhen	MOOT	+	63	*	good
Bank Swallow	BANS	+	43		fair
Marsh Wren	MAWR	+	67	*	good
Pied-billed Grebe	PBGR	+	28	*	good
Spotted Sandpiper	SPSA	+	63	*	fair
Virginia Rail	VIRA	+	44	*	good

Table 8 MMP bird trend assessment, showing greater (+) or lesser (-) trends at St. Clair River AOC versus regional benchmark, percentiles, statistic tests, and assessment. * = p-value < 0.05. Key metrics to consider are highlighted in gray.

Metric	Species Code	Annual Proportional Change (AOC)	Annual Proportional Change (AOC vs. Region)	Percentile	p-value (AOC vs. Region)	Assessment
aerial insectivore abundance		+	+	77.78		fair
bush-brush species abundance		-	-	3.70	*	poor
richness total				38.02		fair
waterbird richness		+	+	90.12	*	excellent
marsh-obligate nester abundance		-	-	20.99		fair
waterfowl richness		+	+	100.00	*	excellent
Am. Coot/C. Moorhen	MOOT	-	+	94.57	*	excellent
Marsh Wren	MAWR	-	-	0.99	*	poor
Pied-billed Grebe	PBGR	+	+	97.53		fair
Virginia Rail	VIRA	-	-	3.21	*	poor

Decadal Waterfowl Surveys

Summary

Figure 14 shows the summary of metrics, overall percentiles and scores. There were regional increases for most metrics in the Spring, and regional declines for most metrics in the Fall. The St. Clair River AOC had less-negative and positive trends, and thereby showed high percentiles for most metrics, including in 3 of the 4 key metrics. Fall diving ducks seem to be declining more in the AOC than compared to the greater region. Most of the low-ranking metrics occurred in the Fall.

Description

The Canadian Wildlife Service has conducted Spring and Fall Great Lakes waterfowl surveys since 1968. The surveys are repeated every decade, with the most recent round of surveys still in operation, making analysis only possible up until 2003. The survey is separated into a number of variable length shoreline transects, called sectors, the majority of which are on the Canadian shore of Lake Erie. The surveys are conducted by two observers in a fixed-wing aircraft, at an altitude of 100 m, whereby all counts of all waterfowl species are estimated. Survey flights are repeated 4-6 times during Spring (1 March-15 May) and Autumn (1 September-15 December) of each year. For monitoring species populations and distributions over time, the CWS calculates waterfowl use-days as an overall seasonal index of the quantity of waterfowl (Dennis et al. 1984). Use-days are calculated by averaging the number of waterfowl counted during two consecutive flights then multiplied by the mean by the number of days between the two surveys.

The intention of the waterfowl survey is to understand the distribution of waterfowl across the Great Lakes and to monitor trends in the use of major marsh complexes (Petrie et al., 2003). The survey design used to meet such goals is not well suited for comparing trends across sectors, and the CWS has not performed such comparisons. A major difficulty for comparing trends is the difference in sector shoreline-lengths, and non-standard survey effort. Furthermore, there are only a few sectors with data going back to the late 1960's and early 1970's as is the case for Lake St. Clair. Seven other sectors on the North Erie shore and Lake Saint Clair were used here for comparisons. Given the above stated challenges, readers are warned that the following summaries and tests represent a large extension from the original intent of the data, and are likely confounded with some uncontrolled factors. Nonetheless, I proceeded with data summaries, and weak statistic tests, given the importance of waterfowl to the St. Clair AOC wildlife assessment, and the data's long-term coverage.

Metric and Indicator Selection

Previously, the CWS has summarized waterfowl use-days in a variety of taxa and foraging guilds, perhaps the most important being dabblers and divers (Russell, personal communications). Furthermore, the St. Clair River AOC Stage 1 report (St. Clair River RAP Team, 1992 citing Dennis et al., 1984) showed diverging trends for dabblers and divers between 1968-1982. The functional importance of divers and dabblers was reaffirmed by an exploratory analysis of the major ecological dimensions of the waterfowl communities. To do this, I employed Non-metric Multidimensional Scaling (NMDS), as in the MMP bird analysis, to find the major latent dimensions of the waterfowl dataset, and selected metrics and species which were strongly correlated with the yielded dimensions, and not highly correlated among themselves.

The motive behind this method is the recognition that although waterfowl species composition may vary in as many ways as there are species, in reality, some species co-occur together predictably, allowing the application of variation-reduction techniques, such as the popular Principal Component Analysis, to unearth the main community dimensions. NMDS is generally regarded as the most robust variation-reduction technique for ecological data and is analogous in its outcomes to a PCA, but uses species' rank-orders, rather than absolute values. Again, I employed the R package "vegan" for NMDS and the Hellinger distance metric, which calculates values based on the proportional abundance of species, thereby circumventing issues with variable transect lengths. I assumed three latent dimensions, as further dimensions showed only marginal gains in improving the ordination's fit. The analysis was performed on all sectors from the 1990's and early 2000's, as this time-period included a much larger sample of sectors, opposed to the 8 sectors (below) used in the multi-decade data trend analysis. The analysis was performed for Spring and Fall datasets separately, as their combined analysis proved unsolvable.

Figure 15 shows the species-scores for the first two latent dimensions, for Fall and Spring separately. Greater Scaup, Blue-winged Teal, Common Goldeneye, Common Merganser, Canvasback, and the Redhead were (near-shore) species which seemed to consistently occupy high associations with the dimensions in both Spring and Fall. Four of these species were selected as indicator species for further analysis (Common Goldeneye, Common Merganser, Canvasback, and Redhead), perhaps representing different guilds of invertivore divers, piscivores, and herbivorous divers. Teals and Greater Scaups were not considered further, as the former are relatively late migrants and may not be present for large periods of the surveys, while the latter are difficult to distinguish with other Scaup species (Badzinski, personal communication). More offshore seaduck species (such as the Long-tailed Duck and Eiders) were also ignored. Dabblers, divers, and seaducks guilds proved highly positively and negatively correlated with the latent dimensions, and the first two were included as metrics in the trend analysis. Furthermore, total-waterfowl use-days was included as a metric, to provide an indication of the overall structure of the waterfowl community.

Methods

Given the general results of the spatial autocorrelation studies (Appendix 1), I selected sectors within approximately 300km from the St. Clair River AOC to serve as a regional comparison, resulting in 7 comparative sectors, two for the southern portion of Lake St. Clair, and 5 for the North shore of Lake Erie (sectors "WLO-LEB" 1 to 4, and "WLO-LEB" 14 and 15). Only one sector corresponded to the AOC, covering the shoreline of Walpole Island. Another transect included the St. Clair River, but it had only one Spring and Fall sampling, and was not recommended for use by the CWS.

Having a single data "point" for the St. Clair River AOC precluded the use of status, trends and community-based analyses used earlier for the Atlas and MMP data: such statistical tests compare distributions, not a single point to a regional distribution. As in the case of the furbearer dataset, I could only calculate percentiles and perform weak outlier tests. Furthermore, as in the case of the furbearer analysis, I cannot assess the status (non-trend) use-days of waterfowl, as there is non-standardized effort between sectors.

To restrict the analysis to the relative change in use-days of the various metrics, I employed a mixed-model framework, allowing random intercepts for each sector and inducing a correlations structure among observations in the same sector. No environmental covariates were included in the analysis, given the paucity of data. Total use-days were divided by each sector's shoreline length, as an attempt to somewhat standardize effort, and were analyzed according to a

Gaussian error structure (the counts were sufficient large enough to justify the normal approximation of count data). The effect of year (trend) was tested for the St. Clair River AOC in its own model, and again for all other sectors in their own model: this tests for evidence of trends in the respective regions, but does not test for a difference between the AOC trend and the regional trend (unlike MMP and Atlas analyses).

To rank the St. Clair River AOC trend versus the regional values, I fit another mixed-model which included random-effects for the year variable (trend) for each sector, and calculated the AOC's trend value versus these random-effect slopes. To derive a statistical assessment of the AOC trend, I performed Dixon Outlier's tests (Dixon, 1950) on the AOC Trend versus the random-effect slopes, judging a significantly high trend to be "good", and a significantly low trend to be "poor". Non-significant trends could not be judged as "fair", because of the weak power of this outlier test. Due to the weakness of this test, I included further decision-rules to assign "good", "fair" and "poor" categories: if the AOC trend was significantly greater than the regional trend, while the regional trend showed no evidence of a trend, I assigned the AOC a category of "good"; if the AOC trend was significantly lower than the regional trend, while the regional trend showed no evidence of trend, I assigned a category of "poor"; if the AOC trend was greater in than the regional trend (but not significant), while the regional trend was significantly declining, I assessed the AOC as being "fair"; otherwise, no category was assigned.

Results

The results for the waterfowl metrics (Figure 16, Table 9) are, unfortunately, not strong enough to draw definitive conclusions: they give us an impression that is somewhat positive for the Spring, and slightly negative and uncertain for the Fall. Most of the trends at the AOC were in the same direction as the regional trends, whereby Spring use-days were increasing, while Fall numbers were declining. The only significant difference between an AOC and regional trend was for the Common Merganser (in both Spring and Fall). This species was previously uncommon in Lake St. Clair, and so any increase can be expected to be significant, even against a general decline in Mergansers (-14% to long-term averages) for the Eastern North American Continent (U.S. Fish and Wildlife Service, 2010).

Given the weak power of these statistical tests, it is more important to consider the St. Clair River AOC percentiles. Here, I see that all of the Spring metrics rank above the 50th percentile. The reader is recommended to focus more attention on the dabblers and divers use-day metrics, which had Spring percentiles of 83 and 67 respectively (both marginally significant), the former perhaps heading in an altogether different direction than the regional trend. However, for the Fall metrics, 4 of the 7 metrics had percentiles below 50%, including the diver total use-days, suggesting that Fall species numbers are declining somewhat steeper than the regional average.

The marked difference between Spring and Fall, whereby both AOC and the regional trends are mostly positive in the Spring, and mostly negative in the Fall, may suggest that other confounding effects are at play, such as ice-freeze / thaw timing. The appearance of more positive trends in the AOC, although not significant, may be due to the St. Clair AOC having a lower baseline from historical impairments, and has since been rebounding to a more regional norm. Overall, most of the metrics suggest a fair to good assessment for the St. Clair River AOC, with more concern for Fall species.

There are several caveats to this analysis. In particular, due to the paucity of the data, I cannot test or accommodate other confounding influences on community dynamics, such as large spatial-trends or differences in lake size and depth. Furthermore, Waterfowl use-days are likely

strongly associated with ice-phenology. Lake St. Clair has shown later ice freeze-up trends (although not significant; Environment Canada, 2008), whereas Lake Erie does not typically freeze entirely. Differences in the advancement and retreat of ice, perhaps due to climate change, may change the detections of late-arriving waterfowl species, as surveys typically do not occur beyond mid-December.

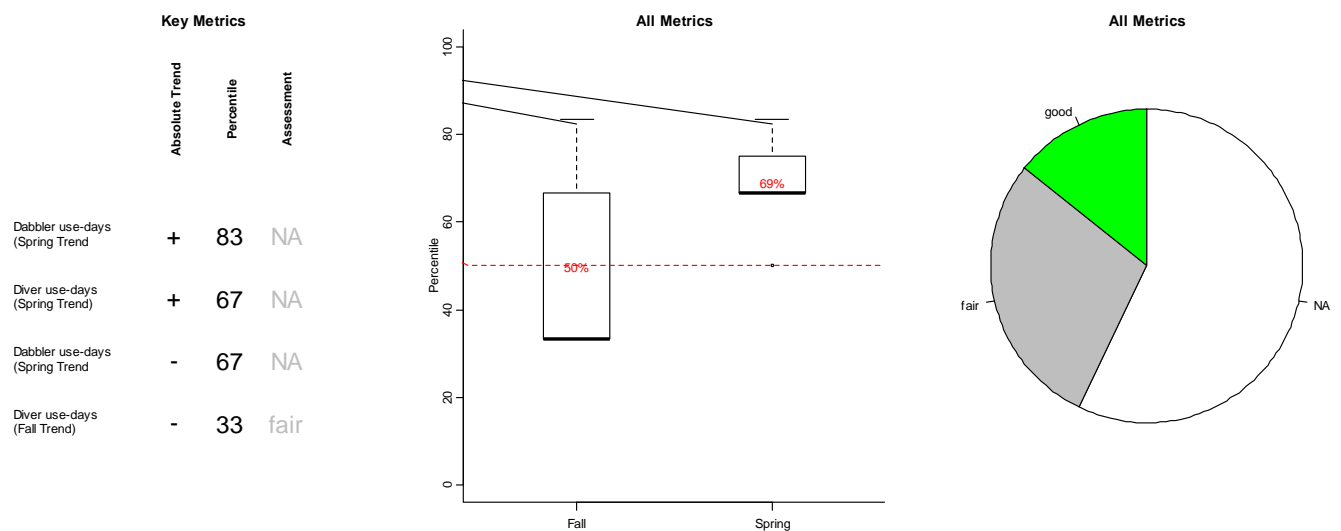


Figure 14 Overview of results for the CWS decadal waterfowl survey. From left to right, results for 1) key metrics, 2) rank-percentile for all 7 metrics (spring and fall), and 3) scorings from statistical tests for all metrics. Weak outlier tests implied that evidence for non-significant results could not be used as evidence for no difference between AOC and the regional trends, and were scored as NA).

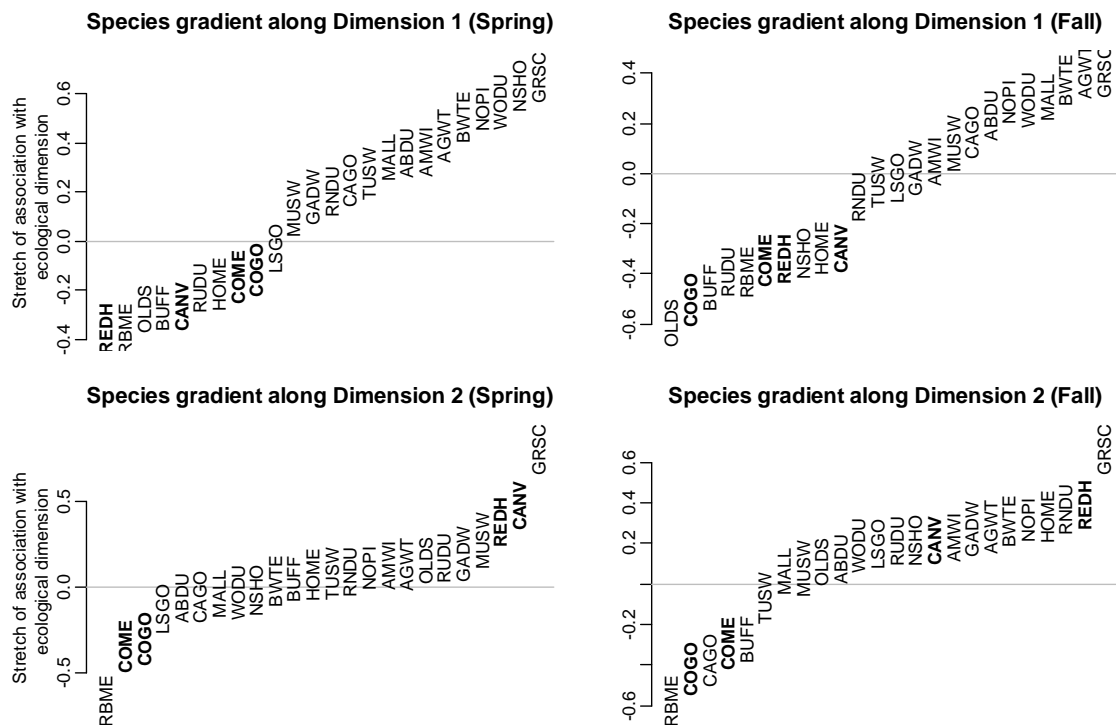


Figure 15 Decadal waterfowl survey species scores along the first two dimensions of a Non-metric Multidimensional Scaling, for Spring (left) and Fall (Right). Species in bold show are considered indicator species, consistently showing high associations with the dimensions across seasons, and are frequently detected at the St. Clair AOC.

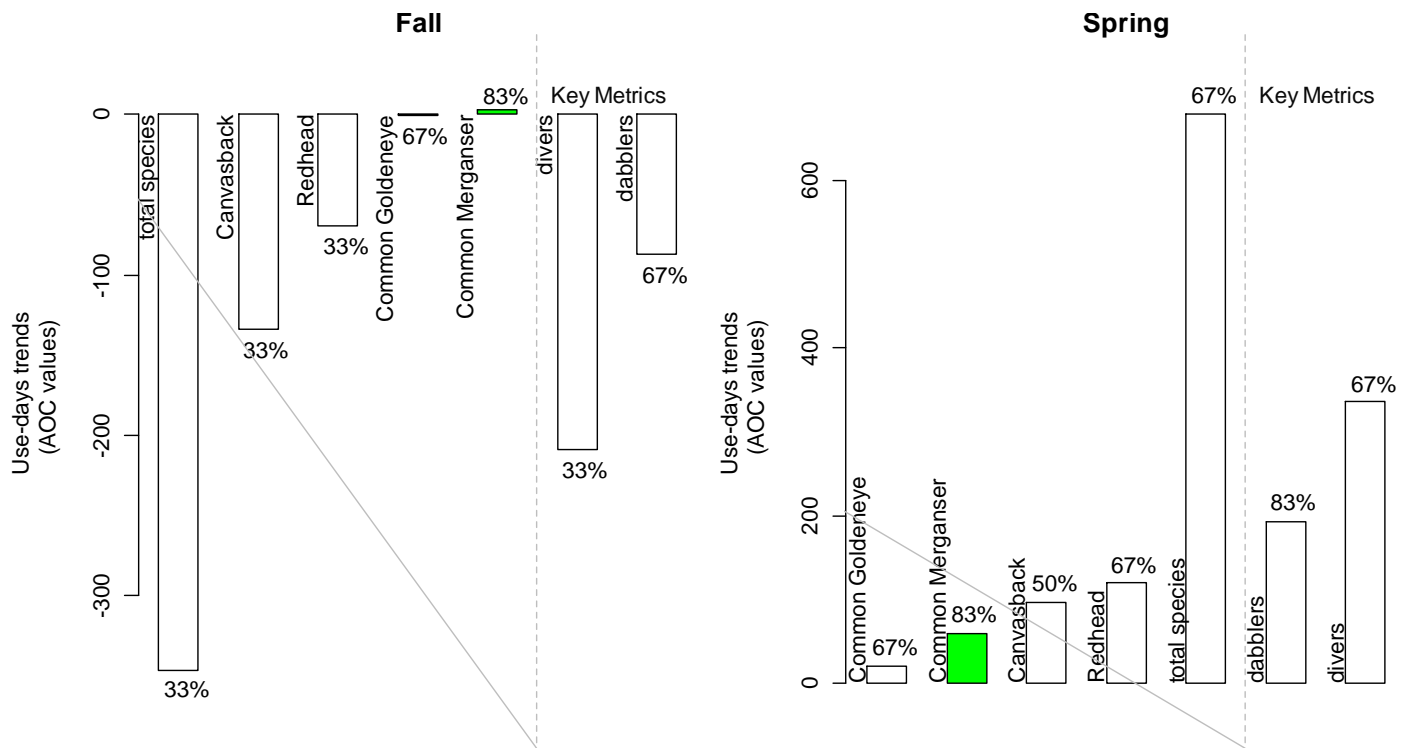


Figure 16 Summary of CWS decadal waterfowl survey (Fall and Spring): magnitude of trend (use-days / year / km of shoreline for St. Clair River AOC. Percentages of the rank-percentile of the St. Clair value versus regional benchmark. * = outlier test p-value < 0.05.

Table 9 Summary of results for the CWS decadal waterfowl survey: direction of trends at the St. Clair River AOC, direction of trends regionally, percentiles of the AOC trends versus regional trends, and indicator assessments. * = p-value < 0.05. Key metrics to consider are highlighted in gray.

Metric	Species Code	Season	AOC Trend	p-value (AOC)	Regional Trend	p-value (AOC vs Region)	Percentile	Assessment
Canvasback use-days	CANV	Spring	+	.	+		50.00	NA
Common Goldeneye use-days	COGO	Spring	+	.	+		66.67	NA
Common Merganser use-days	COME	Spring	+	*	+		83.33	good
Redhead use-days	REDH	Spring	+		+		66.67	fair
total species use-days		Spring	+	.	+		66.67	NA
dabblers use-days		Spring	+	.	-		83.33	NA
divers use-days		Spring	+	.	+		66.67	NA
Canvasback use-days	CANV	Fall	-		-		33.33	Fair
Common Goldeneye use-days	COGO	Fall	-		-		67.67	NA
Common Merganser use-days	COME	Fall	+		-		83.33	good
Redhead use-days	REDH	Fall	-		-		33.33	fair
total species use-days		Fall	-		-		33.33	fair
dabblers use-days		Fall	-		-		66.67	NA
divers use-days		Fall	-		-		33.33	fair

Overall Assessment

A coarse summary of the St. Clair River AOC indicators is as follows: 24% of the indicators score as "good" or "excellent", 40% score as "fair", and 16% score as "poor" (20% cannot be scored). If I focus on key metrics, including marsh-obligate avian nesters, all waterfowl, divers, dabblers, amphibian indicator species, and Muskrat harvests, then the proportion of scores are better, with 25% scoring as "good" or "excellent", 50% as "fair", and none as "poor" (25% cannot be scored). Overall rank-percentiles follow a similar story, with birds ranking on average at the 52th percentile, amphibians at the 63rd percentile, and furbearers at the 94th percentile.

The calculation of an overall final number or score for the entire St. Clair River AOC wildlife assemblage is a bit misleading, as the indicators are not equivalent in their scope, quality or reliability, and are biased to a particular taxa (the majority of indicators are for birds). Some researchers advocate the use of weighted-averages for multi-objective indicators based on their degree of importance, reliability and quality (Silver, 2000), but calculating such weights is often arbitrary and gives the illusion of a precision which these datasets do not possess.

Instead of relying on an overall score, the reader is recommended to consider overall patterns among the indicators, especially patterns among guilds and taxa, differences among status and trend results, and the role of confounding effects.

Of all the indicators, the "poor" scores and low ranks are found among the bird datasets. More sensitive taxa, such as the Amphibians (van der Schalie, 1999), do not show evidence of impairment. This result is repeated in two types of analytical methods: one based on biodiversity metrics, and the other based on community composition. The latter makes less assumptions and merely looks for *any* evidence of a difference. That I do not find strong evidence for a difference between the greater region and the AOC is heartening, albeit based on only a few sample sites at the St. Clair River AOC.

Among the various guilds of bird, an obvious pattern is the poorer scores and ranks for non-wetland-associated species, as seen in the Atlas dataset for forest, grassland, and bush-associated species. Marsh nesters and waterfowl, seem to fair well compared to regional results. While the declines in upland species is a serious issue, the fair status of wetland species' populations lends one line of evidence (among multiple lines of biophysical evidence being examined by the RAP) towards the assertion that the AOC the wetlands themselves may not be seriously impaired, which is the focus of the AOC designation.

Avian communities are changing, both in the region as a whole, and at the St. Clair River AOC. The three avian datasets all show evidence of change in the abundance and composition of species and guilds, most of which is positive only in comparison to the more general regional declines, as demonstrated in the Atlas and Waterfowl surveys.

Interpreting trends is difficult, especially for datasets for which I lack the context of existing population status. I have naively interpreted positive trends, or trends which are 'less worse than the regional average' (e.g., Fall dabbling ducks) as being "good", but this does not necessary imply that wildlife populations have attained levels equivalent to pre-impairment periods, or will ever be on par with the region. Furthermore, for those datasets where I have the luxury of both status and trend information, as in the MMP bird dataset, I see instances where the trends and status seem to yield opposing indicators: I have instances of negative trends but high population abundance (e.g., Marsh Wrens), as well as positive trends with a low abundance (e.g., Spotted Sandpiper). These may be examples of population extremes undergoing "corrections" or

uncommon species making slight inroads, which are not necessarily "good" or "poor" in the long-term. It is a deeper philosophical matter whether or not one should focus more on trends, or on the status of the present moment.

I have tried to use statistical models which account for likely confounding influences, such as wetland size, spatial autocorrelation, coastal versus inland locations, number of trappers, etc. In some cases, as in the decadal waterfowl data, there was not enough data to adequately estimate and accommodate obvious confounding effects, such as lake-size or ice-phenology, and these trends should be view more sceptically.

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APPENDIX 1: Species turnover with distance

Species' dynamics are likely to show spatial patterns due to a variety of influences which can or cannot be measured, such as environmental covariates, intraspecific interactions over short distances, and changing interspecific interactions as the species composition changes over distance. This is the motivation for considering distances between the St. Clair AOC and potential reference sites. How these species dynamics change with distance will be somewhat species specific, but an approximate way to consider all species at once is to look how the entire species assemblage changes with distance.

Method

The analysis compares each site within a dataset to every other site in the same year, and calculates their community dissimilarity. There are a variety of community dissimilarity metrics for ecological studies, the most popular being the Bray-Curtis (Bray & Curtis, 1957), or its metric form, the Jaccard Index (Legendre & Legendre, 1998), which is calculated as $2B/(1+B)$, where $B = (A+B-2*J)/(A+B)$, and A and B are the numbers of species at the compared sites, and J is the number of species which occur at both sites. Generally, a lower dissimilarity metric is obtained when two sites share more species, while a higher dissimilarity metric is attained the more species that are unique to either site. Such pairwise dissimilarities were calculated for the MMP bird, MMP amphibian, and the Atlas of Breeding Birds of Ontario datasets, restricting candidate pairs to being within 500 km of the St. Clair River AOC. The pairwise community dissimilarities constitute the "dependent" or "response" variable of interest, while the "predictor" or "independent" variable is the complimentary geographic distances between site-pairs. All calculations were performed in the R statistical program using the "vegan" package.

To assess each dataset's overall trend of species turnover with distance, I performed Local Polynomial Regression Fitting (with a neighbourhood span of 0.07) to produce a smooth trend between the pairwise community dissimilarity and geographic distances. The fits were then inspected visually.

The Atlas dataset required second, refined analysis, as the first analysis revealed a gradual upward trend in pairwise community dissimilarity with increasing geographic distance. Instead of selecting all squares within 500 km of the St. Clair River AOC, I restricted the analysis to squares within 300 km of the St. Clair River AOC, as well as to coastal and riparian squares, i.e., squares which intersected a large river system or were within one square-width (10km) from the Great Lakes' coastline. The spatial query was performed in ArcView 3.2. For this Atlas-specific analysis, another smooth-fitting procedure was developed to test the effect of different cut-off distances for pairwise comparisons. This modified smoothing procedure iterated through cut-off distances ranging from 100km to 300km, and fit a two-segment regression spline with one hinge-point (like an upside-down hockey stick). Each iteration's hinge-point was estimated based on the Nelder and Mead (1965) optimization algorithm to reduce the fit's sums-of-square residuals. The motivation for a two-segment regression spline was that the first segment would fit values of the dissimilarity-distance relationship from 0 km to the optimized hinge-point (consistently ~ 30 - 40 km), where the relationship is influenced by strong spatial autocorrelation close to a site, leaving the second segment to fit the more regional trend in species turnover, starting from the hinge-point distance to the iterative cut-off distance. The final cut-off distance for the Atlas dataset was select as the largest cut-off distance which lacked strong evidence for a trend (p values > 0.05).

Results

All three datasets showed the characteristic semi-variogram shape, with a rapid increase in pairwise community dissimilarity within the first ~40km, followed by a sharp reduction in the rate of change, reflecting a more regional, background turnover of species. The MMP bird and MMP amphibian datasets showed a plateau from ~40km up until around 300 km, after which dissimilarities increased again, suggesting 300km as a cut-off distance.

For the modified Atlas fitting procedure, the optimized hinge-point for each iteration was consistently in the 30km - 40km. Cut-off distances below 150km all showed no evidence of a regional trend beyond the hinge-point, suggesting 150km as a suitable final cut-off distance for the Atlas data.

APPENDIX 2: Atlas of Breeding Birds of Ontario Effort Correction

(Reproduced from Crewe et al., 2007)

Differences in hours of effort between the two Atlases were matched using the following steps:

- 1) All visits within squares were ordered and interleaved according to date and time (end time of visit). Effort without a date was assigned as the last visit of the year, and species recorded casually without visit information were also assigned to the end of the year in question.
- 2) An accumulated effort field was produced for each atlas by summing effort in the square up to that visit. Each species was assigned a first detected time based on the accumulated effort when it was first detected as Breeding (Possible, Probable, or Confirmed Breeding) and when it was first confirmed breeding in the square.
- 3) Minimum matched effort was calculated by taking the minimum of a) total hours of effort in the first atlas and b) total hours of effort in the second atlas.
- 4) Effort in the atlas with more than the minimum matched effort was pared back to the closest amount of effort that was equal to or greater than the minimum matched effort. A "match" was considered "OK" for analysis if:
 - a) Minimum matched effort was ≥ 10 hours and < 50 hours and the ratio of effort in the other atlas to minimum matched effort was less than 1.5;
 - b) Minimum matched effort was ≥ 50 hours and < 100 hours and the ratio of effort in the other atlas to minimum matched effort was less than 2.0;
 - c) Minimum matched effort was ≥ 100 hours, regardless of ratio of effort after paring back effort as above.
- 5) If squares had at least 10 hours of effort in both atlases but were not "OK" in the matching process above, effort in the atlas with greater total hours of effort was pared back to be as close to, but less than, the minimum matched effort. Possible matches were considered again according to steps a), b) and c) in step 4. If this resulted in less than 10 hours of matched effort, the square was excluded from analysis.
- 6) Breeding evidence and confirmed breeding evidence for each species in each square was used only if its first detected time was within the pared back effort that resulted in a match in step 4 or 5.

APPENDIX 3: Indicator and Test Results – Expanded Tables

Metric	AOC Change in richness	Change Standard Deviation	Change in Richness (AOC vs. Region)	p-value (AOC vs. Regional Trend)	Percentile	Percentile Standard Deviation	Assessment	comments
aerial foragers	-1.88	3.48	-1.65	0.06	29.84	37.27	fair	Mantel tests suggest some spatial autocorrelation. P value is 0.011
bushy-brush	-1.50	2.62	-3.46	0.01	21.28	24.50	poor	
forest	-7.88	12.73	-12.02	0.02	24.34	24.24	poor	
grassland	-3.63	4.44	-3.27	0.02	25.27	29.22	poor	
marsh-obligate nesters	-0.38	2.56	0.21	0.95	50.40	28.19	fair	
shorebirds	-0.13	2.23	0.15	0.72	56.04	38.51	fair	
total richness	-15.38	23.75	-20.08	0.03	27.13	17.32	poor	
waterbirds	-2.25	3.58	-1.58	0.02	24.60	31.72	poor	
waterfowl	0.38	1.85	0.67	0.46	59.31	29.79	fair	

Metric	Richness (AOC vs. Region)	Confidence Interval (up)	Confidence Interval (Down)	p-value	Percentile	Percentile Standard Deviation	Assessment	Covariates
Total species richness	1.50	2.65	0.85	0.16	72.35	12.95	fair	Coastal vs. Island, latitude x longitude (rescaled)
Indicator species richness	2.08	24.51	0.18	0.56	56.46	29.66	fair	Coastal vs. Island, latitude x longitude (rescaled)
Non-tolerant species richness	1.74	6.40	0.47	0.40	60.79	28.74	fair	Coastal vs. Island, latitude x longitude (rescaled)

APPENDIX 3

Metric	Species Code	Abundance (AOC vs. Region)	Confidence Interval (Down)	Confidence Interval (Up)	p-value (AOC vs. Region)	Percentile	Percentile Standard Deviation	Assessment	Covariates
aerial insectivore abundance		0.63	0.33	1.22	NS	35.71	26.38	fair	coastal vs. inland; latitude & longitude (rescaled);
bush-brush species abundance		1.01	0.80	1.28	NS	46.59	30.88	fair	coastal vs. inland; latitude & longitude (rescaled); wetland size
waterbird richness		1.88	1.53	2.32	*	67.64	25.93	good	coastal vs. inland; latitude & longitude (rescaled); wetland size
richness total		1.30	0.68	2.48	NS	65.58	19.28	fair	coastal vs. inland;
marsh-obigate nester abundance		3.07	2.77	3.40	*	80.95	18.76	good	coastal vs. inland; latitude & longitude (rescaled); wetland size
waterfowl richness		2.07	1.05	4.09	*	71.25	25.98	good	wetland size
Bank Swallow	MOOT	1.19	0.47	3.04	NS	43.34	25.35	fair	coastal vs. inland; wetland size
Marsh Wren	BANS	6.21	5.21	7.39	*	66.92	26.43	good	coastal vs. inland; wetland size
Am. Coot/C. Moorhen	MAWR	6.30	4.87	8.16	*	62.73	29.74	good	coastal vs. inland; wetland size
Pied-billed Grebe	PBGR	2.15	1.23	3.75	*	28.07	28.22	good	latitude & longitude (rescaled); wetland size
Spotted Sandpiper	SPSA	1.49	0.32	6.98	*	63.08	20.41	fair	wetland size
Virginia Rail	VIRA	1.59	1.07	2.35	*	44.00	25.54	good	coastal vs. inland; latitude & longitude (rescaled); wetland size

APPENDIX 3

Metric	Annual Proportional Change (AOC)	Confidence Interval (Down)	Confidence Interval (Up)	p-value (AOC)	Annual Proportional Change (AOC vs. Region)	Confidence Interval (Down)	Confidence Interval (Up)	p-value (AOC vs. Region)	Percentile	Percentile (S.E. down)	Percentile (S.E. up)	Indicator	Covariates
Am. Coot/C. Moorhen	-0.02	-0.07	0.03	NS	0.09	0.04	0.15	*	95	92	96	excellent	coastal vs. inland; wetland size
Marsh Wren	-0.14	-0.17	-0.12	*	-0.15	-0.17	-0.12	*	1	1	1	poor	coastal vs. inland; wetland size
Pied-billed Grebe	0.03	-0.08	0.15	NS	0.11	0.00	0.24	NS	98	93	99	fair	latitude & longitude (rescaled); wetland size
Virginia Rail	-0.10	-0.16	-0.03	*	-0.07	-0.14	0.00	*	3	1	8	poor	coastal vs. inland; latitude & longitude (rescaled); wetland size
marsh-obligate nester abundance	-0.04	-0.06	-0.02	*	-0.01	-0.03	0.00	NS	21	17	27	fair	coastal vs. inland; latitude & longitude (rescaled);
waterfowl richness	0.06	-0.02	0.14	NS	0.08	0.00	0.16	*	100	93	100	excellent	latitude & longitude (rescaled); wetland size
aerial insectivore abundance	0.08	-0.05	0.23	NS	0.11	-0.03	0.26	NS	78	74	82	fair	coastal vs. inland; latitude & longitude (rescaled); wetland size
bush-brush species abundance	-0.06	-0.10	-0.01	*	-0.06	-0.10	-0.02	*	4	1	6	poor	coastal vs. inland; latitude & longitude (rescaled); wetland size
richness total	0.00	-0.04	0.04	NS	0.00	-0.04	0.05	NS	38	23	62	fair	coastal vs. inland;
waterbird richness	0.02	-0.02	0.06	NS	0.04	0.00	0.08	*	90	70	97	excellent	coastal vs. inland; latitude & longitude (rescaled); wetland size

APPENDIX 3

Metric	Species Code	Season	AOC Trend (use-days/km/year)	AOC Trend S.E.	p-value (AOC)	Regional Trend (use-days/km/year)	Regional Trend S.E.	p-value (Region)	Assessment	Percentile	p-value (Outlier test)
dabblers use-days		Spring	193.164	79.850	0.094	-32.361	81.499	0.692	NA	0.833	N.S
divers use-days		Spring	335.435	117.182	0.064	527.345	302.887	0.086	NA	0.667	N.S
Canvasback use-days	CANV	Spring	96.823	32.369	0.058	377.443	158.296	0.020	NA	0.500	N.S
Common Goldeneye use-days	COGO	Spring	20.728	6.846	0.056	7.781	11.376	0.496	NA	0.667	N.S
Common Merganser use-days	COME	Spring	59.605	12.958	0.019	11.953	21.321	0.577	good	0.833	N.S
Redhead use-days	REDH	Spring	119.325	63.014	0.155	229.711	136.614	0.097	NA	0.667	N.S
total species use-days		Spring	678.531	266.473	0.084	1640.088	724.658	0.027	NA	0.667	N.S
dabblers use-days		Fall	-87.369	166.108	0.635	-91.630	214.443	0.670	NA	0.667	N.S
divers use-days		Fall	-208.990	92.943	0.110	-1574.168	476.990	0.001	fair	0.333	N.S
Canvasback use-days	CANV	Fall	-134.357	54.672	0.091	-684.993	219.911	0.002	fair	0.333	N.S
Common Goldeneye use-days	COGO	Fall	-0.406	1.219	0.761	-0.114	2.807	0.968	NA	0.667	N.S
Common Merganser use-days	COME	Fall	2.752	2.085	0.279	-22.986	9.599	0.019	good	0.833	N.S
Redhead use-days	REDH	Fall	-69.520	50.021	0.259	-865.551	260.622	0.001	fair	0.333	N.S
total species use-days		Fall	-346.670	161.448	0.121	-1234.883	611.699	0.047	fair	0.333	N.S

APPENDIX 4: Species Codes

Bird Code	Common Name	Latin Name	Atlas of Breeding Birds of Ontario	Program	Survey	MMP indicator species	seaduck	dabbler	diver	wetland associated	marsh-obligate nester	waterfowl	waterbird	shorebird	forest associated	grassland associated	aerial forager	bush-brush associated
ACFL	Acadian Flycatcher	Empidonax virens	X												X			
ALFL	Alder Flycatcher	Empidonax alnorum	X															
AMBI	American Bittern	Botaurus lentiginosus	X	X		X				X	X		X					
ABDU	American Black Duck	Anas rubripes	X		X			X		X		X						
AMCO	American Coot	Fulica americana	X			X				X	X		X					
AMCR	American Crow	Corvus brachyrhynchos	X												X			
AMGO	American Goldfinch	Carduelis tristis	X	X														
AMKE	American Kestrel	Falco sparverius	X													X		
AMRE	American Redstart	Setophaga ruticilla	X												X			X
AMRO	American Robin	Turdus migratorius	X	X											X			
TTWO	American Three-toed Woodpecker	Picoides tridactylus	X												X			
AMWI	American Wigeon	Anas americana	X		X			X		X		X						
AMWO	American Woodcock	Scolopax minor	X											X	X			
BAEA	Bald Eagle	Haliaeetus leucocephalus	X							X					X			
BAOR	Baltimore Oriole	Icterus galbula	X												X			
BANS	Bank Swallow	Riparia riparia	X	X													X	
BARS	Barn Swallow	Hirundo rustica	X	X													X	
BDOW	Barred Owl	Strix varia	X												X			
BBWA	Bay-breasted Warbler	Dendroica castanea	X												X			
BEKI	Belted Kingfisher	Ceryle alcyon	X	X						X								
BAWW	Black-and-white Warbler	Mniotilta varia	X												X			
BBWO	Black-backed Woodpecker	Picoides arcticus	X												X			

APPENDIX 4: Species Codes

BBCU	Black-billed Cuckoo	Coccyzus erythrophthalmus	X												X			X
BCCH	Black-capped Chickadee	Poecile atricapillus	X												X			X
BCNH	Black-crowned Night-Heron	Nycticorax nycticorax	X	X					X				X					
BTBW	Black-throated Blue Warbler	Dendroica caerulescens	X												X			X
BTNW	Black-throated Green Warbler	Dendroica virens	X												X			
BLTE	Black Tern	Chlidonias niger	X	X		X			X	X		X						
BLBW	Blackburnian Warbler	Dendroica fusca	X												X			
BLPW	Blackpoll Warbler	Dendroica striata	X												X			
BGGN	Blue-gray Gnatcatcher	Poliophtila caerulea	X												X			X
BHVI	Blue-headed Vireo	Vireo solitarius	X												X			X
BWTE	Blue-winged Teal	Anas discors	X		X	X		X		X		X						
BWWA	Blue-winged Warbler	Vermivora pinus	X												X			X
BLJA	Blue Jay	Cyanocitta cristata	X												X			
BOBO	Bobolink	Dolichonyx oryzivorus	X													X		
BOGU	Bonaparte's Gull	Larus philadelphia	X										X		X			
BOCH	Boreal Chickadee	Poecile hudsonica	X												X			X
BRBL	Brewer's Blackbird	Euphagus cyanocephalus	X												X			
BWHA	Broad-winged Hawk	Buteo platypterus	X												X			
BHCO	Brown-headed Cowbird	Molothrus ater	X															
BRCR	Brown Creeper	Certhia americana	X												X			
BRTH	Brown Thrasher	Toxostoma rufum	X															
BUFF	Bufflehead	Bucephala albeola	X		X			X	X		X				X			
CAGO	Canada Goose	Branta canadensis	X	X	X				X		X							
CAWA	Canada Warbler	Wilsonia canadensis	X															X
CANV	Canvasback	Aythya valisineria	X		X				X	X		X						

APPENDIX 4: Species Codes

CMWA	Cape May Warbler	Dendroica tigrina	X															X			
CARW	Carolina Wren	Thryothorus ludovicianus	X															X			X
CATE	Caspian Tern	Sterna caspia	X	X						X				X							
CEDW	Cedar Waxwing	Bombycilla cedrorum	X															X			
CERW	Cerulean Warbler	Dendroica cerulea	X															X			
CSWA	Chestnut-sided Warbler	Dendroica pensylvanica	X																		X
CHSW	Chimney Swift	Chaetura pelagica	X																	X	
CHSP	Chipping Sparrow	Spizella passerina	X																		
CCSP	Clay-colored Sparrow	Spizella pallida	X																		
CLSW	Cliff Swallow	Petrochelidon pyrrhonota	X																		X
COGO	Common Goldeneye	Bucephala clangula	X		X				X	X			X					X			
COGR	Common Grackle	Quiscalus quiscula	X	X														X			
COLO	Common Loon	Gavia immer	X							X				X							
COME	Common Merganser	Mergus merganser	X		X				X	X			X					X			
COMO	Common Moorhen	Gallinula chloropus	X			X				X	X			X							
CONI	Common Nighthawk	Chordeiles minor	X															X		X	
CORA	Common Raven	Corvus corax	X															X			
COTE	Common Tern	Sterna hirundo	X							X				X							
COYE	Common Yellowthroat	Geothlypis trichas	X	X																	X
CONW	Connecticut Warbler	Oporornis agilis	X															X			
COHA	Cooper's Hawk	Accipiter cooperii	X															X			
DEJU	Dark-eyed Junco	Junco hyemalis	X															X			
DICK	Dickcissel	Spiza americana	X																X		
DCCO	Double-crested Cormorant	Phalacrocorax auritus	X	X						X				X							
DOWO	Downy Woodpecker	Picoides pubescens	X															X			
EABL	Eastern Bluebird	Sialia sialis	X																		
EAKI	Eastern Kingbird	Tyrannus tyrannus	X	X																	
EAME	Eastern Meadowlark	Sturnella magna	X																X		

APPENDIX 4: Species Codes

[illegible]

APPENDIX 4: Species Codes

HOWR	House Wren	Troglodytes aedon	X													X			X
INBU	Indigo Bunting	Passerina cyanea	X													X			
KILL	Killdeer	Charadrius vociferus	X	X												X		X	
KIRA	King Rail	Rallus elegans	X						X	X			X						
KIWA	Kirtland's Warbler	Dendroica kirtlandii	X													X			X
LCSP	Le Conte's Sparrow	Ammodramus leconteii	X													X			
LEBI	Least Bittern	Ixobrychus exilis	X	X		X				X	X			X					
LEFL	Least Flycatcher	Empidonax minimus	X													X			
LESC	Lesser Scaup	Aythya affinis	X			X				X	X			X					
LISP	Lincoln's Sparrow	Melospiza lincolnii	X													X			
LIGU	Little Gull	Larus minutus	X							X	X			X					
LOSH	Loggerhead Shrike	Lanius ludovicianus	X															X	
LEOW	Long-eared Owl	Asio otus	X													X			
LOWA	Louisiana Waterthrush	Seiurus motacilla	X							X						X			
MAWA	Magnolia Warbler	Dendroica magnolia	X													X			X
MALL	Mallard	Anas platyrhynchos	X	X	X			X			X			X					
MAWR	Marsh Wren	Cistothorus palustris	X	X		X				X	X								
MERL	Merlin	Falco columbarius	X													X			
MODO	Mourning Dove	Zenaidura macroura	X	X												X			
MOWA	Mourning Warbler	Oporornis philadelphia	X													X			
NAWA	Nashville Warbler	Vermivora ruficapilla	X													X			X
NOBO	Northern Bobwhite	Colinus virginianus	X															X	
NOCA	Northern Cardinal	Cardinalis cardinalis	X	X															
NOFL	Northern Flicker	Colaptes auratus	X	X												X			
NOGO	Northern Goshawk	Accipiter gentilis	X													X			
NOHA	Northern Harrier	Circus cyaneus	X															X	
NOMO	Northern Mockingbird	Mimus polyglottos	X																
NOPA	Northern Parula	Parula americana	X													X			
NOPI	Northern Pintail	Anas acuta	X			X			X				X						
NRWS	Northern Rough-	Stelgidopteryx serripennis	X	X															X

APPENDIX 4: Species Codes

	winged Swallow																		
NSWO	Northern Saw-whet Owl	Aegolius acadicus	X															X	
NSHO	Northern Shoveler	Anas clypeata	X		X			X		X		X							
NOWA	Northern Waterthrush	Seiurus noveboracensis	X							X								X	
OSFL	Olive-sided Flycatcher	Contopus cooperi	X															X	
OROR	Orchard Oriole	Icterus spurius	X																
OSPR	Osprey	Pandion haliaetus	X							X								X	
OVEN	Ovenbird	Seiurus aurocapilla	X															X	
PAWA	Palm Warbler	Dendroica palmarum	X																
PEFA	Peregrine Falcon	Falco peregrinus	X																
PHVI	Philadelphia Vireo	Vireo philadelphicus	X															X	
PBGR	Pied-billed Grebe	Podilymbus podiceps	X	X		X				X	X		X						
PIWO	Pileated Woodpecker	Dryocopus pileatus	X															X	
PIGR	Pine Grosbeak	Pinicola enucleator	X															X	
PISI	Pine Siskin	Carduelis pinus	X															X	
PIWA	Pine Warbler	Dendroica pinus	X															X	
PIPL	Piping Plover	Charadrius melodus	X							X							X		
PRAW	Prairie Warbler	Dendroica discolor	X																X
PROW	Prothonotary Warbler	Protonotaria citrea	X															X	X
PUFI	Purple Finch	Carpodacus purpureus	X															X	
PUMA	Purple Martin	Progne subis	X	X															X
RBWO	Red-bellied Woodpecker	Melanerpes carolinus	X															X	
RBME	Red-breasted Merganser	Mergus serrator	X		X				X	X		X						X	
RBNU	Red-breasted Nuthatch	Sitta canadensis	X															X	
REVI	Red-eyed Vireo	Vireo olivaceus	X															X	
RHOW	Red-headed Woodpecker	Melanerpes erythrocephalus	X															X	
RNGR	Red-necked Grebe	Podiceps grisegena	X							X	X		X						

APPENDIX 4: Species Codes

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APPENDIX 4: Species Codes

TRES	Tree Swallow	Tachycineta bicolor	X	X													X
TRUS	Trumpeter Swan	Cygnus buccinator	X		X				X	X	X						
TUTI	Tufted Titmouse	Baeolophus bicolor	X											X			X
TUVU	Turkey Vulture	Cathartes aura	X											X			
UPSA	Upland Sandpiper	Bartramia longicauda	X										X		X		
VEER	Veery	Catharus fuscescens	X											X			
VESP	Vesper Sparrow	Pooecetes gramineus	X												X		
VIRA	Virginia Rail	Rallus limicola	X	X		X			X	X		X					
WAVI	Warbling Vireo	Vireo gilvus	X	X										X			
WPWI	Whip-poor-will	Caprimulgus vociferus	X											X			
WBNU	White-breasted Nuthatch	Sitta carolinensis	X											X			
WEVI	White-eyed Vireo	Vireo griseus	X											X			X
WTSP	White-throated Sparrow	Zonotrichia albicollis	X											X			
WWC R	White-winged Crossbill	Loxia leucoptera	X											X			
WIFL	Willow Flycatcher	Empidonax traillii	X	X													
WIPH	Wilson's Phalarope	Phalaropus tricolor	X						X					X			
COSN	Wilson's Snipe	Gallinago delicata	X						X	X				X			
WIWA	Wilson's Warbler	Wilsonia pusilla	X														X
WIWR	Winter Wren	Troglodytes troglodytes	X											X			
WODU	Wood Duck	Aix sponsa	X	X	X		X		X		X			X			
WOTH	Wood Thrush	Hylocichla mustelina	X											X			
YBFL	Yellow-bellied Flycatcher	Empidonax flaviventris	X											X			
YBSA	Yellow-bellied Sapsucker	Sphyrapicus varius	X											X			
YBCU	Yellow-billed Cuckoo	Coccyzus americanus	X											X			X
YBCH	Yellow-breasted Chat	Icteria virens	X														
YHBL	Yellow-headed Blackbird	Xanthocephalus xanthocephalus	X	X					X								
YRWA	Yellow-rumped	Dendroica coronata	X											X			X

APPENDIX 4: Species Codes

Warbler

YTVI	Yellow-throated Vireo	Vireo flavifrons	X													X			
YERA	Yellow Rail	Coturnicops noveboracensis	X							X	X		X						
YWAR	Yellow Warbler	Dendroica petechia	X	X															X