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# Assessing terrestrial wildlife populations in the Toronto and Region Area of Concern

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ABSTRACT

Beneficial use impairments (BUIs) under the Great Lakes Water Quality Agreement identify environmental issues requiring remedial action within the Great Lakes Areas of Concern (AOCs). We conducted this study to support the assessment of the wildlife component of BUI 3: degradation of fish and wildlife populations. We compared bird and amphibian (frogs and toads) data from the Toronto and Region Conservation Authority's Terrestrial Long-term Monitoring Program in the Toronto and Region AOC to an adjacent, but otherwise similar, reference watershed, Duffins Creek. Twelve of 13 targets were met within the AOC for forest bird, wetland bird, meadow bird and amphibian populations based on averages of mean annual values at sites within the AOC that were within two standard deviations of averages at sites in the Duffins Creek reference watershed between 2008 and 2017. Even though wildlife populations within the AOC were within the normal range of variability expected from a reference watershed, they were often at lower levels than within the Duffins Creek reference watershed. In addition, forest bird and amphibian populations were negatively affected by urbanization within the AOC and meadow bird indices declined. We conclude that while wildlife populations within the AOC currently meet targets for BUI 3, they continue to be negatively impacted by numerous stressors that are primarily related to past and ongoing urbanization. Thus, continued restoration of wildlife habitat and protection of existing habitat within the AOC is highly recommended.


## Introduction

The Laurentian Great Lakes contain 21% of the world's surface freshwater (US EPA, 2017) which provides drinking water for millions of people and supports numerous species of fish, invertebrates, birds and mammals. Despite these rich assets, the region has seen ongoing and widespread environmental challenges requiring regulatory and non-regulatory intervention. The Great Lakes Water Quality Agreement was first signed by the United States and Canada in 1972 after pollution became a problem in several locations within the Great Lakes (Krantzberg, 2012). Later, the development and implementation of Remedial Action Plans (RAPs) for Areas of Concern (AOCs) were added to the agreement to provide community-based environmental protection and remediation (Krantzberg, 2012). Fourteen beneficial use impairments (BUIs) and programs were identified to help restore each AOC including BUI 3: degradation of fish and wildlife populations. In recent decades, much progress has been made in restoring and cleaning up Great Lakes AOCs, including the delisting of BUIs and entire AOCs in various locations (Hartig et al., 2018).

The Toronto Region of Ontario, Canada was listed in 1985 as 1 of 42 Great Lakes AOCs. This 2000-km$^2$ Toronto region spans 42 km of shoreline along the northwest portion of Lake Ontario, and contains 4 million people in one of the fastest-growing urban areas in North America (Kidd, 2016). The justification for listing the Toronto and Region AOC included high pollution and contaminant runoff from the City of Toronto and high rates of natural vegetation loss due to urban sprawl. In the intervening decades, much remedial work has been completed, and five of the original BUIs have now been delisted (Kidd, 2016). Remedial actions continue to improve the health of the AOC, including a focus on BUI 3.

The objective of this study was to support the assessment of the wildlife component of BUI 3 within the Toronto and Region AOC. The fish component of the BUI was not addressed within this paper, but progress on improving its status can be found in Kidd (2016). Specifically, we aimed to: 1) set targets for wildlife populations in the Toronto and Region AOC, because no targets

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were previously set (Metro Toronto and Region 1994); 2) assess wildlife populations within the Toronto and Region AOC to determine if targets have been met and 3) compare wildlife populations between the urban and rural areas within the AOC.

## Methods

### *Target selection*

We conducted a literature and internet search to obtain guidance for setting targets for the wildlife component of BUI 3. We reviewed guidance documents from the International Joint Commission (IJC) (IJC, 1991) including an IJC guidance document created by four agencies (US EPA, Environment Canada, Michigan Department of Environmental Quality, Ontario Ministry of Environment; IJC, 2013), Birds Canada (Wheeler and Archer 2008), and other AOCs including Detroit River (Detroit River Public Advisory Council, 2014), Thunder Bay (InfoSuperior, 2016), Bay of Quinte (Bay of Quinte, 2016), Lower Green Bay and Fox River (Wisconsin Department of Natural Resources, 2012), Hamilton Harbour (Hamilton Harbour Remedial Action Plan, 2012), and ones within Ohio (Ohio Environmental Protection Agency, 2017).

IJC (1991) suggests the following delisting guideline for BUI 3: "When environmental conditions support healthy, self-sustaining communities of desired fish and wildlife at predetermined levels of abundance that would be expected from the amount and quality of suitable physical, chemical and biological habitat present. An effort must be made to ensure that fish and wildlife objectives for Areas of Concern are consistent with Great Lakes ecosystem objectives and Great Lakes Fishery Commission fish community goals. Further, in the absence of community structure data, this use will be considered restored when fish and wildlife bioassays confirm no significant toxicity from water column or sediment contaminants." We followed this guidance while formulating the targets for BUI 3 used in this study.

A Four Agency Framework (US EPA, Environment and Climate Change Canada, the Michigan Department of Environmental Quality and the Ontario Ministry of the Environment; IJC, 2013) recommends that all delisting criteria for AOCs shared by Ontario and Michigan must be: 1) measurable (quantitative endpoint that determines when a beneficial use is no longer impaired); 2) achievable (reflective of local conditions and respects existing regulations and guidelines); 3) be consistent with the applicable federal and state/provincial regulations, objectives, guidelines, standards and policies, when available, and the principles and objectives embodied in Annex 2 and supporting parts of the Great Lakes Water Quality Agreement; and 4) amenable to actions that will remedy original or on-going cause of impairments. We also incorporated these guidelines while formulating the targets for BUI 3 used in this study.

We reviewed various targets used by other AOCs for delisting wildlife under BUI 3 and found that the nature of the targets and how they were measured varied based on the amount of wildlife population data available (e.g., Hamilton Harbour Remedial Action Plan, 2012 versus Bay of Quinte, 2016). One prominent theme was to compare wildlife communities at sites within AOCs to communities at sites within suitable reference areas using standard deviation of mean values of selected metrics to assess differences. If average values within the AOC are within a certain acceptable range of variation observed within the reference area, as measured by standard deviation, then wildlife within the AOC is deemed unimpaired and the BUI can be delisted. Based on the guidance in IJC (1991), we did not select reference sites that were completely unimpacted, but those outside the AOC with similar physical, chemical and biological attributes present. Selected metrics have been assessed previously in this manner for the Bay of Quinte AOC by setting a target of being within two standard deviations of the Lake Ontario average (Bay of Quinte, 2016, see also Macececk and Grabas, 2011). Credit Valley Conservation (2010) also used standard deviation to determine if their long-term monitoring data for wildlife populations were outside the range of normal variability. Credit Valley Conservation (2010) based their assessment on the literature on Statistical Process Control and Maurer et al. (1999) where upper and lower thresholds of a data series are set using standard deviation to objectively distinguish "out-of-control" conditions. Based on the guidelines found during our review, we developed the targets listed in Table 1 for supporting the assessment of the wildlife component of BUI 3 in the Toronto and Region AOC, and applied them to data collected both within the AOC and the adjacent Duffins Creek reference watershed.

### *Assessing wildlife population targets*

To determine if our targets for the assessment of the wildlife component of BUI 3 had been met, we used data from the Toronto and Region Conservation Authority's (TRCA) Terrestrial Long-term Monitoring Program (LTMP), which tracks flora and fauna across the range of vegetation types and land uses found throughout the Toronto Region (Fig. 1). The LTMP has been operating annually since 2008 and uses standardized scientific data collection protocols for valid comparisons among sites and over time.

**Table 1**
Targets for the wildlife component of beneficial use impairment 3: degradation of wildlife populations within the Toronto and Region Area of Concern. Year range was determined based on the availability of data.

| Taxa | Target |
|---|---|
| Marsh birds | The average mean annual marsh bird Index of Biotic Integrity (IBI) value within the Area of Concern (AOC) is within (or above) two standard deviations of the average mean annual IBI value in a reference watershed outside the AOC based on data from 2011 to 2016 (separate urban and rural assessments) |
| Amphibians (frogs and toads) | The average mean annual amphibian IBI value within the AOC is within (or above) two standard deviations of the average mean annual IBI value in a reference watershed outside the AOC based on data from 2011 to 2016 (separate urban and rural assessments) |
| Forest birds | The average mean annual forest-dependent bird species richness, forest-dependent bird abundance and the number of L1-L3 bird species values in the AOC are within (or above) two standard deviations of average mean annual values of these same variables in a reference watershed outside the AOC based on data from 2010 to 2017 (separate urban and rural assessments) |
| Meadow birds | The average mean annual meadow-dependent bird species richness, meadow-dependent bird abundance and the number of L1-L3 bird species values in the AOC are within (or above) two standard deviations of average mean annual values of these same variables in a reference watershed outside the AOC based on data from 2008 to 2017 (separate urban and rural assessments) |

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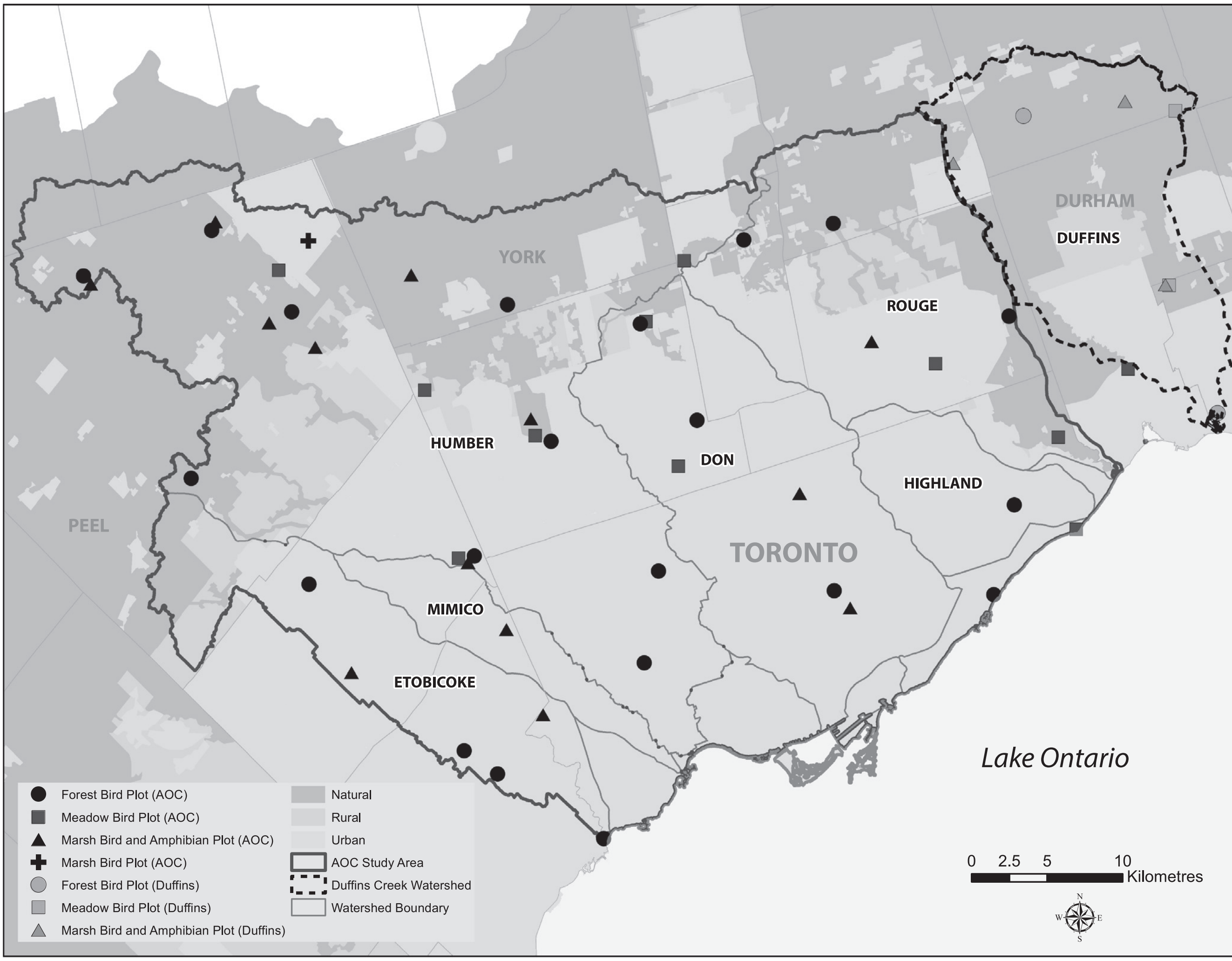


**Fig. 1.** Toronto and Region Conservation Authority Terrestrial Long-term Monitoring Program plot locations within the Toronto and Region Area of Concern and the Duffins Creek reference watershed.

The TRCA's Terrestrial LTMP was created to monitor and measure long-term changes in the terrestrial ecosystem in the TRCA jurisdiction and to report and share standardized data to identified partners. Permanent plots were established across all watersheds and were distributed south to north to represent the existing urban to rural land use gradient. Plots were established in areas representing the various physiographic regions and vegetation communities (e.g. sugar maple-beech upland forest versus white cedar coniferous forest) and were primarily established on public lands to maintain long-term data collection. Long-term monitoring plots were established across the jurisdiction in three habitat types: forest, wetland and meadow and focussed on various taxa including vegetation, birds and amphibians. The number of plots established was determined based on an a priori power analysis in order to achieve sufficient power to detect temporal declines in bird and amphibian populations that may indicate an emerging threat or issue. The LTMP was not developed specifically for the assessment of this BUI; but it is a large, long-term dataset, and as such, there are both limitations and benefits of its use here. The primary limitation is the low sample size in the Duffins Creek reference watershed to develop standard deviation values. The benefit of using these data include valid comparisons of species communities both spatially and temporally due to standardized methodologies between the AOC and reference watershed and between the urban and rural zones within the AOC.

Marsh birds and amphibians were surveyed annually within 100-m radius semicircular plots (sites) following Birds Canada's Great Lakes Marsh Monitoring Program (GLMMP) (Bird Studies Canada, 2009a,b). Each marsh bird site was surveyed for 15 min on two different occasions, during which observers recorded the number of individuals of each species seen or heard. Each amphibian site was surveyed for 3 min on three different occasions, during which observers recorded the occurrence of each frog species heard. Forest and meadow birds were surveyed annually within 100-m radius circular plots (sites) following the Ontario Forest Bird Monitoring Program (FBMP) (Cadman et al., 1998). Each forest or meadow bird site was surveyed for 10 min on two different occasions, during which observers recorded the number of individuals of each species seen or heard. Bird surveys were completed throughout the breeding season during late-May to late-June between sunrise and 1000 and frog surveys were completed after sunset and before midnight in April, May, and June to capture variation among species in calling phenology.

Several variables were selected for comparison between sites within the AOC and sites within the Duffins Creek reference watershed (Table 2). Crewe and Timmermans (2005) developed a marsh bird and an amphibian index of biotic integrity (IBI) to assess wetland health using data collected through the GLMMP. These IBIs provide a single value (0–100) for each site that represents a combination of several taxa-specific metrics that are sensitive to

**Table 2**
Variables selected to indicate forest, wetland and meadow health.

| Variable | Description |
|---|---|
| Marsh bird IBI | Calculates an Index of Biotic Integrity (IBI) score per wetland ranging from 0 (poor quality) to 100 (high quality) using the following avian metrics from Crewe and Timmermans (2005): Water forager abundance, Water forager richness, Area-sensitive marsh-nesting obligate richness, Area-sensitive marsh-nesting obligate abundance, Indicator species abundance |
| Amphibian IBI | Calculates an IBI score per wetland ranging from 0 (poor quality) to 100 (high quality) using the following amphibian metrics from Crewe and Timmermans (2005): Total richness, Woodland species richness, Woodland species occupancy |
| # L1-L3 species | The number of bird species with L-ranks of L1, L2 or L3. Species ranked L1-L3 are considered species of concern within the jurisdiction due to their apparent intolerance to urbanization |
| Forest-dependent bird species richness | The number of bird species (species richness) dependent on forest habitats for nesting. This includes both forest edge and interior species nesting at various heights (low, mid, and upper) |
| Forest-dependent bird abundance | The number of individual birds (abundance) dependent on forest habitats for nesting. This includes both forest edge and interior species nesting at various heights (low, mid, and upper) |
| Meadow-dependent bird species richness | The number of bird species dependent on meadow habitats for nesting. This includes species nesting at various heights within meadows (low, mid, and upper) |
| Meadow-dependent bird abundance | The number of individual birds (abundance) dependent on meadow habitats for nesting. This includes species nesting at various heights within meadows (low, mid, and upper) |

human disturbance in the landscape, such as species richness of area-sensitive marsh-nesting obligate birds and species richness of woodland-associated amphibians (Crewe and Timmermans, 2005). Wetlands with higher IBI scores are considered to be in better biological condition than those with lower IBI scores. These IBIs were developed using data from across the Great Lakes and are suitable for use throughout Lake Ontario. Other IBIs and indices of ecological condition exist for these types of data (e.g., Howe et al., 2007; Smith-Cartwright and Chow-Fraser 2011), and perform differently depending on various factors (Chin et al., 2015). Here we chose to use the approach developed by Crewe and Timmermans (2005) due to its simplicity and ease of interpretation by managers and its history of use for similar assessments in the region (e.g., Macececk and Grabas, 2011).

IBIs were not available for forest or meadow birds within the region so we used the local-rank (L-rank) system, which is a species scoring and ranking system (similar to an IBI or provincial/national/global ranking systems) developed by TRCA to provide guidance for natural heritage protection and management within the Toronto region. The L-rank system uses simple ranks to convey individual species' ecological needs and sensitivities rather than just "rarity" in order to portray such complexities on a simple ordinal scale (TRCA, 2017a). Fauna L-ranks are based on scores for seven criteria including local occurrence, population trends, habitat dependence, area sensitivity, mobility restriction and sensitivity to development. Local occurrence is based on species occurrence/distribution across the jurisdiction. Population trends are from the North American Breeding Bird Survey and local population trends within the jurisdiction. Habitat dependence considers the degree to which a species can be classified as a specialist in its ecological requirements. Area-sensitivity reflects the degree to which the species is area-sensitive (requiring large areas of habitat). Mobility restriction represents the species response to habitat isolation and fragmentation. Sensitivity to development represents species responses to both the negative and positive effects of urbanization. For example, species ranked L1 would have: 1) limited local occurrence, 2) declining population trends, 3) special habitat and area sensitivity requirements, 4) restricted mobility and 5) sensitivity to development. Species ranked L5 would have characteristics opposite to those for L1. These are extreme examples and species can be ranked L1 through to L5 based on the scores associated with this combination of ecological needs and population status assessments. Thus, for forest and meadow birds we chose to use the number of L1-L3 ranked species as a measure of the number of species of regional conservation concern. Higher numbers of L1-L3 ranked species indicates a healthier system and lower numbers or an absence of L1-L3 species indicates a more impaired system. For a full description of methodology used to develop L-ranks, please see TRCA (2017a). In addition to L-ranks, we measured richness and total abundance of forest-dependent and meadow-dependent bird species as further indicators of the status of these species groups, with higher numbers indicating healthier systems.

Reference sites were selected within the Duffins Creek watershed because it was outside the Toronto and Region AOC and immediately to the east of the AOC having similar physical, chemical, and biological attributes due to its geographic location. Although the Duffins Creek watershed is affected by several factors similar to the AOC such as urbanization in the lower reaches, it is generally regarded to be in better condition than other watersheds in the region because of higher amounts of natural cover (Shrestha et al., 2020 this issue) and better water quality (TRCA, 2017b). The AOC area also contains several watersheds, or portions of watersheds, that are considered to be in good condition such as the Upper Humber River watershed and the Lower Rouge River watershed. Sites within the urban and rural land use zones of the AOC were compared to sites within the urban and rural land use zones of Duffins Creek, respectively. The number of AOC and reference sites available for comparison and the years they were surveyed varied among wetland, forest and meadow LTMP plots (Table 3), so comparisons between reference sites and AOC sites may use different year ranges based on habitat type.

We compared patch size and Ecological Land Classification (ELC) vegetation community types in forest, meadow and wetland LTMP plots between sites in the Duffins Creek reference watershed and sites in the AOC. We compared patch size and ELC vegetation community types at urban reference sites to five randomly selected urban AOC sites and rural reference sites to five randomly selected rural AOC sites. This was to ensure there were no differences in habitat/landscape attributes that might contribute to differences in bird or amphibian communities. Patch size was determined in ArcGIS (ESRI Inc., 2015), and patch boundaries were defined by any break in the primary habitat type (wetland, forest, meadow) by roads, railway tracks and rivers. Vegetation community types at sites were visually examined in ArcGIS, and the dominant vegetation type in forests and meadows was determined along with percent open water and percent habitat cover (by ELC vegetation community type) for wetlands.

**Table 3**
Long-term Monitoring Program (LTMP) plot type, land use zone, number of Area of Concern (AOC) and Duffins Creek (reference) sites and year range used for analysis.

| LTMP plot type | Land use zone | Number of AOC sites | Number of reference sites | Year range used for analysis |
|---|---|---|---|---|
| Marsh birds | Rural | 6 | 2 | 2011–2016 |
| | Urban | 8 | 1 | |
| Amphibians | Rural | 6 | 2 | 2011–2016 |
| | Urban | 7 | 1 | |
| Forest birds | Rural | 9 | 2 | 2010–2017 |
| | Urban | 12 | 1 | |
| Meadow birds | Rural | 4 | 2 | 2008–2017 |
| | Urban | 6 | No sites available | |

To assess wildlife targets, we first calculated mean IBIs (marsh birds and amphibians) or metrics (forest and meadow birds) for each year of the study (i.e., mean annual values for each year between 2008 and 2017) for urban and rural AOC sites and urban and rural reference sites. We concluded that targets had been met if the average of the mean annual IBIs or metrics for AOC sites was within (or above) two standard deviations of the average of the mean annual IBIs or metrics for reference sites. In total, we attempted to assess 16 targets within the AOC compared to the Duffins Creek reference watershed: 8 IBIs or metrics (marsh bird IBI, amphibian IBI, L1-L3 birds in forests, species richness forest-dependent birds, total abundance forest-dependent birds, L1-L3 birds in meadows, species richness meadow-dependent birds, total abundance meadow-dependent birds) across two land use zones (rural, urban) (see Table 1 for more details). We only had data to assess 13 targets because there were no meadow bird sites in the urban land use zone in the Duffins Creek reference watershed. In addition, we tested for differences in IBIs or metrics in urban compared to rural AOC sites. An average of the annual values from the year range available was calculated for each site and was used to determine differences between urban and rural AOC sites. Standard t-tests were used to compare the urban and rural AOC sites if data met normality assumptions, while Wilcoxon tests were used if data could not be successfully transformed and did not meet normality assumptions (SAS JMP, 2018). Results are averages unless otherwise indicated. We used the non-parametric Mann-Kendall test to determine if there were changes in meadow bird community metrics over time (R Core Team, 2018).

## Results

Meadow and wetland patch size was similar at urban and rural AOC sites compared to urban and rural reference sites, respectively (all $p > 0.05$; Electronic Supplementary Material (ESM) Tables S1, S2 and S3). Forest patch size was also similar at urban AOC sites compared to urban reference sites ($t_4 = 1.76$, $p = 0.154$). By contrast, forest patch size was significantly larger at rural reference sites (724 ha) compared to rural AOC sites (121 ha; $t_5 = 2.76$, $p = 0.04$). This difference remained even after the largest forest patch in the Duffins Creek reference watershed, East Duffins Headwaters (Glen Major; 1125 ha), was removed from the analysis (Duffins Creek: 324 ha; AOC: 121 ha; $t_4 = 6.19$, $p = 0.004$). We continued with the analysis of forest birds in the rural land use zone with East Duffins Headwaters removed, but it is important to note that the larger patch size in the Duffins Creek reference watershed may contribute to any differences we detected in forest bird communities. Vegetation communities in wetlands, forests and meadows did not show any strong differences in primary vegetation community type between reference sites and AOC sites.

## Assessing targets (AOC versus reference)

Average marsh bird and amphibian IBIs at urban and rural AOC sites were within two standard deviations of the average at urban and rural reference sites, respectively (Figs. 2 and 3). Average forest-dependent species richness and forest-dependent total abundance at urban and rural AOC sites was within two standard deviations of the average at urban and rural reference sites, respectively (Fig. 4). The number of L1-L3 ranked species at urban AOC

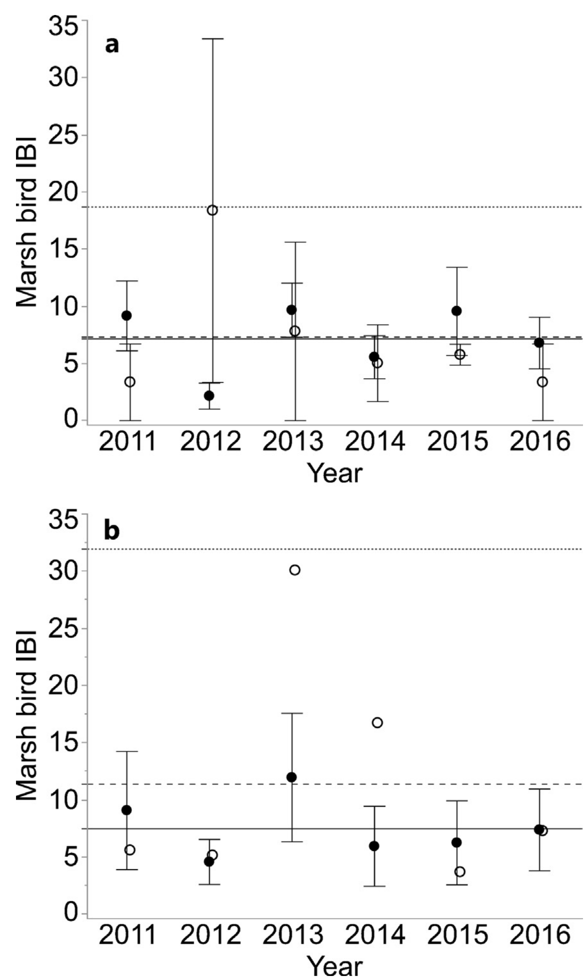


**Fig. 2.** Marsh bird index of biotic integrity (IBI) within the Toronto and Region Area of Concern (AOC) and a reference watershed (Duffins Creek) as a function of sites in: a) rural and b) urban land use zones between 2011 and 2016. Duffins Creek (○) average ± 1 standard error, AOC (●) average ± 1 standard error, Duffins Creek 2011–2016 average (_ _), AOC 2011–2016 average (__), Duffins Creek ± two standard deviations (……).

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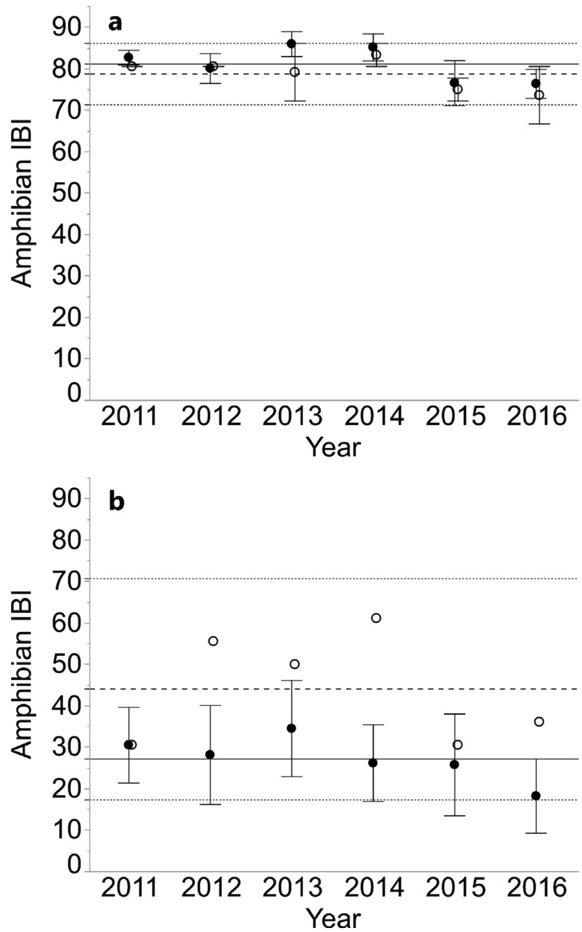


**Fig. 3.** Amphibian (frog and toad) index of biotic integrity (IBI) within the Toronto and Region Area of Concern (AOC) and a reference watershed (Duffins Creek) as a function of sites in: a) rural and b) urban land use zones between 2011 and 2016. Duffins Creek (○) average ± 1 standard error, AOC (●) average ± 1 standard error, Duffins Creek 2011–2016 average (_ _), AOC 2011–2016 average (__), Duffins Creek ± two standard deviations (……).

sites was within two standard deviations of the Duffins Creek although the number of L1-L3 ranked species at rural AOC sites was outside of (and below) two standard deviations of rural sites within the Duffins Creek reference watershed (Fig. 4). Average metrics for all meadow bird targets at rural AOC sites were within two standard deviations of the average at rural reference sites, respectively (Fig. 5). The status of meadow bird targets at urban AOC sites is unknown because there were no meadow LTMP sites in the urban land use zone in the Duffins Creek reference watershed.

*Urban-rural comparisons with the AOC*

Marsh bird IBIs were similar for rural (7.1) and urban (7.5) AOC sites ($t_{12}$ = 0.093, p = 0.927; Fig. 2). By contrast, amphibian IBIs were significantly higher at rural AOC sites (81) compared to urban AOC sites (27) ($t_{12}$ = 4.82, p < 0.001; Fig. 3). All forest bird metrics were significantly higher at rural AOC sites compared to urban AOC sites (all p < 0.01). All meadow bird metrics were similar between the rural AOC sites and urban AOC sites (all p > 0.598).

## Discussion

We assessed wildlife populations to support the assessment BUI 3 in the Toronto and Region AOC and found that 12 of 13 targets have been met for forest, wetland and meadow bird populations and amphibian populations. We concluded that targets had been met when averages of mean annual IBIs or metrics at sites within the AOC were within two standard deviations of averages at sites in the Duffins Creek reference watershed based on the application of Statistical Process Control as used by other conservation authorities and RAP teams. Thus, meeting the targets suggests that bird and amphibian populations within the AOC are within the normal range of variability expected within a reference watershed.

Marsh bird IBIs within the Toronto and Region AOC (rural = 7, urban = 10) were similar to those found across the southern portion of the Great Lakes basin (8.7, range 0-62, n = 452 routes), including marshes within other AOCs. Marshes throughout the Great Lakes basin are subject to numerous stressors similar to those in the Toronto and Region AOC such as infilling, point source and nonpoint source pollution, water level regulation and invasive species all of which have direct and indirect impacts on wetland bird communities (Lougheed et al., 2001). Therefore, the state of marsh bird populations within the Toronto and Region AOC appears to be approximately as good as marsh bird populations found throughout the rest of the southern portion of the Great Lakes region, where human population density and associated human-induced negative impacts on marshes are generally high.

Similarly, amphibian IBIs within the Toronto and Region AOC (54) were similar to those found across the southern portion of the Great Lakes basin (52, range 0-100, n = 517 routes); however, amphibian IBIs were much lower at urban AOC sites (27) compared to rural AOC sites (81). Frog populations are known to be negatively impacted by urbanization (Knutson et al., 1999). Urban environments are generally less favourable for frogs because of increased road density and associated mortality caused by vehicular traffic, lack of adjacent terrestrial habitat required by some species for overwintering and communication interference by anthropogenic noise (Knutson et al., 1999; Lengagne, 2008; Bouchard et al., 2009). Therefore, amphibian populations at urban AOC sites need further restoration efforts (e.g., increasing habitat connectivity where possible or mitigating road mortality) and those in rural areas need protection in order to prevent declines.

Average numbers of L1-L3 ranked bird species in forests at rural AOC sites was below two standard deviations of the average at rural reference sites. This could be at least partly due to variation in forest patch sizes between rural AOC sites and rural reference sites. Larger patches generally contain more species based on the species-area relationship originally proposed by Arrhenius (1921), and the significantly larger forest patch size that we found at rural reference sites compared to rural AOC sites likely contributed to the higher number of L1-L3 ranked species observed at rural reference sites (Blake and Karr, 1987; Lin et al., 2019). We also found that all forest bird variables were higher at rural AOC sites compared to urban AOC sites. Urbanization negatively impacts forest bird communities in many ways, including direct loss of habitat and fragmentation, altered predator communities and urban noise (Reijnen et al., 1995; Haskell et al., 2001). Therefore, forests within the urban portion of the AOC need further restoration and maintenance to ensure the persistence or improvement of habitat, while those in the rural areas need protection. Restoration practices in urban forest fragments that support bird communities include increasing structural heterogeneity, increasing the amount of standing and downed wood, ensuring a high diversity of berry-producing shrubs, controlling invasive plant species and mammals such as house pets and creating buffers and corridors (Marzluff and Ewing, 2001)

Meadow bird communities within the Toronto and Region AOC appear to be dynamic. While not a specific goal of this project, we noticed decreases in meadow bird abundance across the region (rural AOC τ = -0.511, p = 0.049; urban AOC τ = -0.556,

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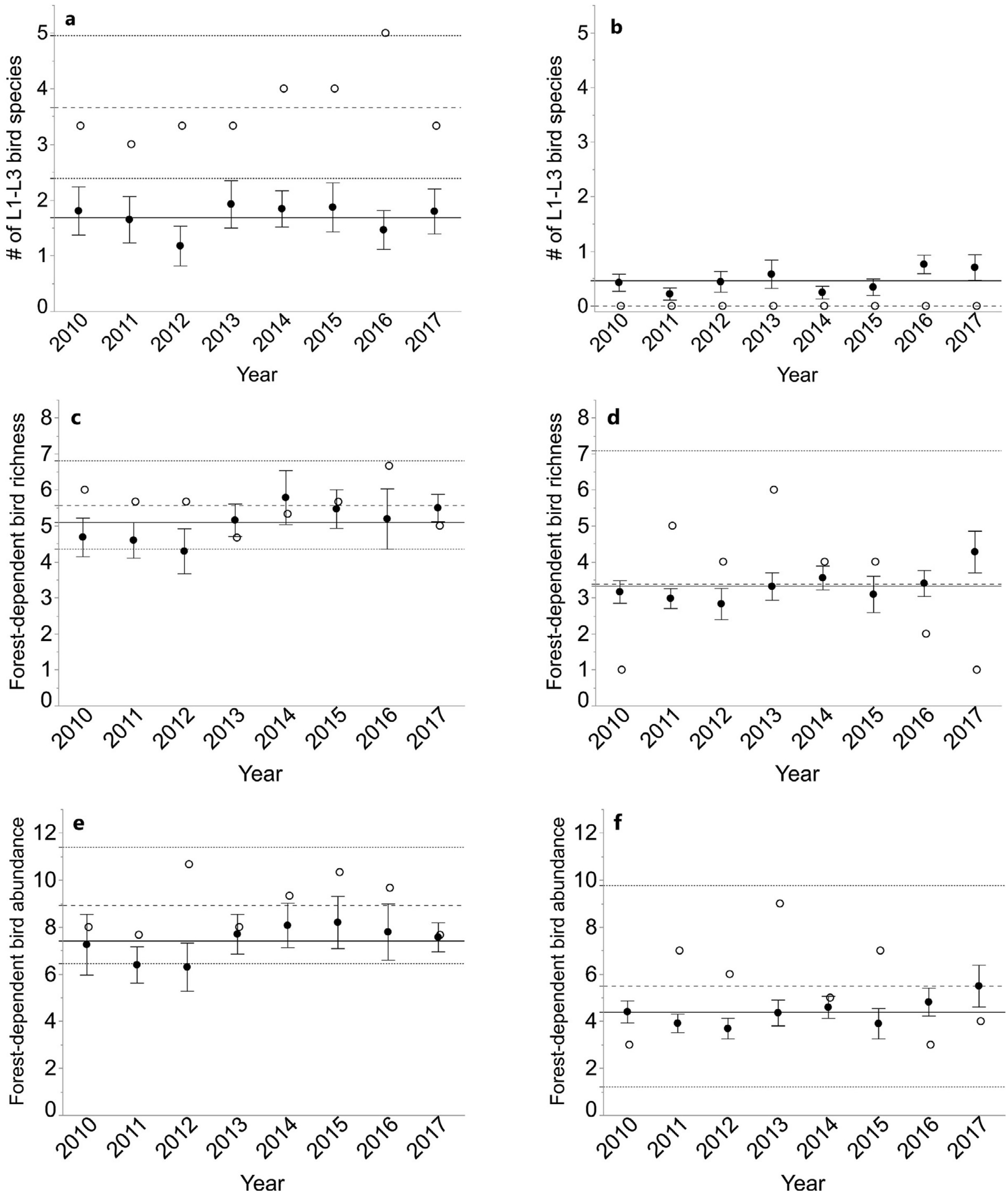


**Fig. 4.** Forest bird metrics within the Toronto and Region Area of Concern (AOC) and a reference watershed (Duffins Creek) as a function of sites in rural and urban land use zones between 2010 and 2017. Shown are number of L1-L3 ranked bird species in a) rural and b) urban; forest-dependent bird richness in c) rural and d) urban; and forest-dependent bird abundance in e) rural and f) urban. Duffins Creek (○) average, AOC (●) average ± 1 standard error, Duffins Creek 2010–2017 average (_ _), AOC 2010–2017 average (__), Duffins Creek ± two standard deviations (……).

$p = 0.032$; rural Duffins $\tau = -0.629$, $p = 0.015$) and decreases in richness in the rural zone (rural AOC $\tau = -0.659$, $p = 0.012$; rural Duffins $\tau = -0.629$, $p = 0.018$). These changes could be due to both the dynamic nature of meadow habitat and the loss of meadow habitat to urban development. Some of the meadows monitored (along with others throughout the AOC) appear to be undergoing succession either naturally or through restoration plantings to later successional community types (e.g., sparse-shrub habitats) which support a different avian community, and this could be causing declines in meadow-dependent birds. The decline in meadow birds could also be related to the decrease in meadow habitat found throughout the AOC between 2002 and 2013 (Shrestha et al., 2020 this issue). This highlights the need to develop and implement stronger policies to protect and restore meadow habitat for meadow bird species into the future.

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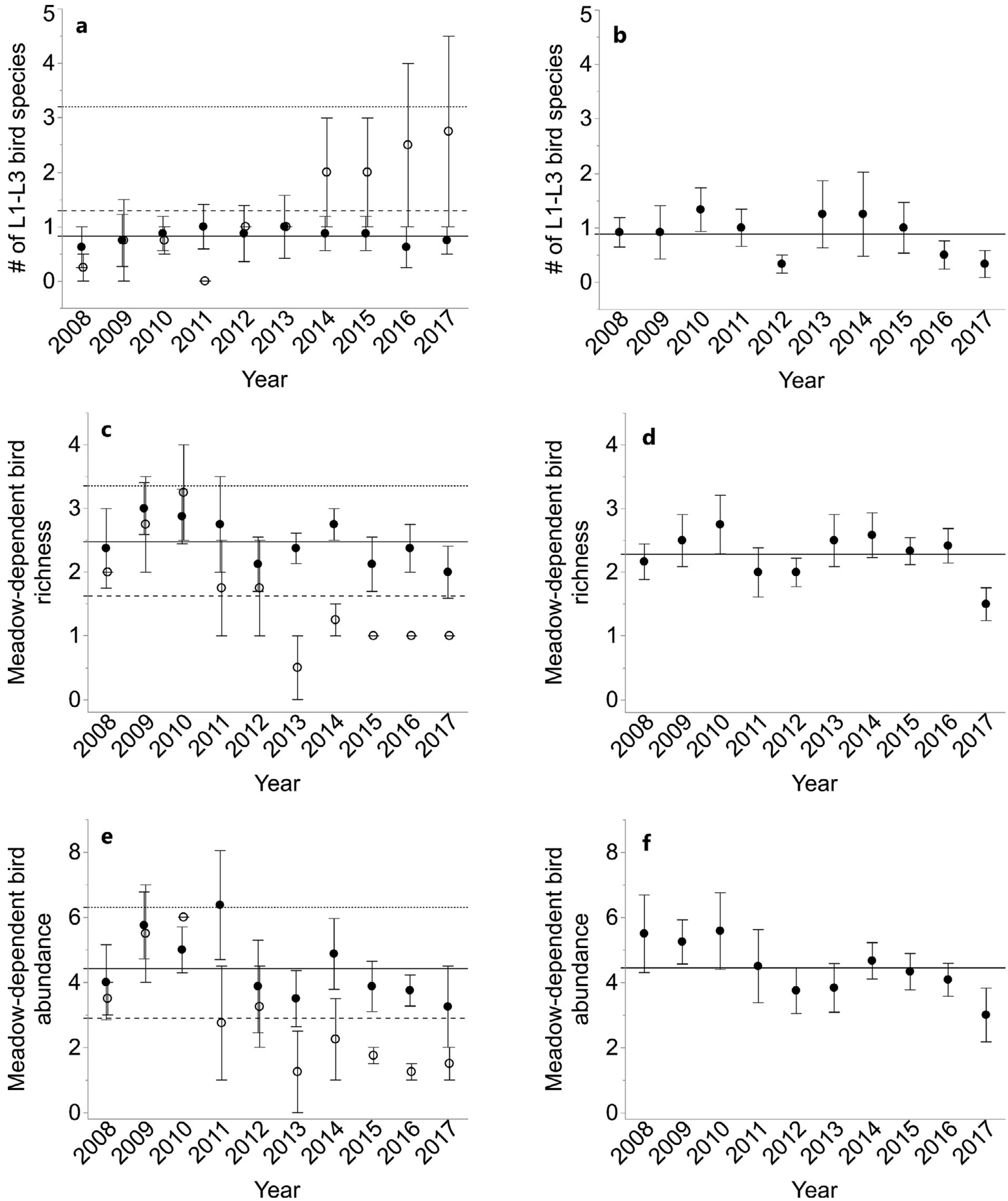


**Fig. 5.** Meadow bird metrics within the Toronto and Region Area of Concern (AOC) and a reference watershed (Duffins Creek) as a function of sites in rural and urban land use zones between 2008 and 2017. Shown are number of L1-L3 meadow bird species in a) rural and b) urban; meadow-dependent bird richness in c) rural and d) urban; and meadow-dependent bird abundance in e) rural and f) urban. Duffins Creek (○) average ± 1 standard error, AOC (●) average ± 1 standard error, Duffins Creek 2008–2017 average (_ _), AOC 2008–2017 average (__), Duffins Creek ± two standard deviations (……). No data were available for meadow birds in urban areas of Duffins Creek.

While this study focussed on wildlife populations in the watersheds, data do exist for Tommy Thompson Park on the Toronto waterfront. Tommy Thompson Park is located on the western side of the Leslie Street Spit, a created landform extending 5 km into Lake Ontario and covering approximately 500 ha. The Spit is structurally composed of millions of cubic metres of concrete, earth fill and dredged sand deposited at the site throughout the twentieth century. Tommy Thompson Park provides both early- and mid-successional terrestrial and aquatic habitats for numerous species. Since the Tommy Thompson Park Master Plan and Environmental Assessment was approved in 1993, 60 ha of terrestrial and aquatic habitat restoration work has been completed. Aquatic habitat restoration projects have resulted in the creation and enhancement of 30 ha of coastal wetlands and sheltered embayments including the decommissioning and conversion of two confined disposal facilities to wetland habitat. Terrestrial habitat restoration across

30 ha has focussed on topographical grading and soil enhancements to create hydrological and microclimatic conditions suitable for shrubland and meadow ecosystems. These areas have been planted with native trees, shrubs, grasses and wildflowers. Other terrestrial habitat enhancements include the creation of hibernacula, habitat piles and songbird boxes along with continued management of invasive flora species including purple loosestrife (*Lythrum salicaria*), dog-strangling vine (*Vincetoxicum rossicum*) and common reed (*Phragmites australis*). Because the data at Tommy Thompson Park were collected using different methodologies, they were not used for this assessment although a separate, future assessment could assess wildlife data on amphibians, breeding birds, migrating birds (bird banding) and mammalian movements (radio-tracking). Data related to turtle populations and colonial waterbirds have already been assessed through turtle population studies (Dupuis-Desormeaux et al., 2020 this issue) and in the Bird and Animal Deformities or Reproductive Problems BUI document (TRCA, 2011).

## Conclusion

We found that 12 of 13 wildlife targets have been met within the Toronto and Region AOC based on averages of mean annual values at AOC sites that were within two standard deviations of averages at reference sites. Even though wildlife populations at AOC sites were generally within the normal range of variability expected from a reference watershed, they were often at lower levels than at reference sites. In addition, forest bird and amphibian populations were negatively affected by urbanization within the AOC and meadow bird populations declined. We conclude that wildlife populations within the AOC meet targets as set in this study to support the assessment of BUI 3; however, wildlife populations within the AOC continue to be negatively impacted by numerous stressors primarily related to urbanization.

The dichotomy presented here, meeting a majority of targets but the recognition that there are still concerns particularly in urban areas and meadow habitats within the AOC, needs further discussion. Urbanization, which contributed to designating the Toronto and Region as an AOC, continues within the region. Even though the assessment conducted at this point in time has considered terrestrial wildlife populations to have met targets as set in this document and as recommended by the IJC, further intensification in both existing urban areas and in more rural, northern areas of the region, will lead to degradation of the existing "good" conditions in the rural areas and further degradation of the remnant urban habitat within the AOC. Once a BUI is removed or re-designated, it can be difficult for local communities to find funding to continue to mitigate or manage the source of the problem and prevent regression or back-sliding of current conditions (Mandelia, 2016) and as such, continued protection, maintenance, enhancement and restoration of wildlife habitat across the urban to rural gradient of the AOC is necessary. Such work should include, but not be limited to: 1) protecting and maintaining all remaining natural areas, 2) restoring and maintaining degraded natural areas, 3) strengthening policies for natural heritage protection in the face of ongoing urban development and climate change, and 4) managing the built portions of the urban landscape to minimize direct and indirect effects on adjacent habitat patches. Several ongoing projects support these recommendations including the Don River Mouth Naturalization project, further habitat enhancements at Tommy Thompson Park and the Ashbridge's Bay Landform. Continued investment in the Toronto and Region will be essential to ensure that the natural heritage gains achieved so far are maintained over the long-term, especially given ongoing urbanization and climate change pressures.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jglr.2020.07.019.

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