LANDSCAPE-SCALE INFLUENCES ON LEAST BITTERN (*IXOBRYCHUS EXILIS*) HABITAT USE IN SOUTHERN ONTARIO COASTAL MARSHES

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ABSTRACT.---Least Bittern (*Ixobrychus exilis*) populations have declined in Canada, and this has led to the species being listed as threatened under the Species-at-risk Act. Wetland loss and degradation has been extreme in southern Ontario (> 90% loss in some areas) and this loss has been identified as a potential contributor to population declines. The objective of this study was to determine the influence of land-use surrounding wetlands, wetland size, isolation and water quality in predicting the presence of the Least Bittern in southern Ontario coastal marshes. Between 2006 and 2008, we surveyed 20 coastal marshes for Least Bitterns in southern Ontario. The proportion of urbanized land within 4,000m of the marsh was the most important variable in predicting their presence/absence. Least Bitterns were more likely to be found in wetlands surrounded by low levels of urbanization and high levels of rural land-uses. We also found that sites with higher levels of urbanization and poorer water quality, as indicated by the Water Quality Index (WQI), were less likely to support Least Bitterns. Water quality may impact the ability of this species to forage successfully and may be one potential route through which the Least Bittern is impacted by urbanization. Based on these results, urbanization should be limited within 4,000m of the wetland edge to protect existing rural marshes from degradation. Further research is needed to identify the impact that small-scale patterns of urbanization may have on habitat of Least Bitterns in Great Lakes coastal marshes.

The Least Bittern (*Ixobrychus exilis*) is the smallest heron occurring in North America (COSEWIC 2009). It breeds in freshwater or brackish marshes dominated by cattails (*Typha* spp.) and with patches of open water (Gibbs et al. 2009). Its breeding distribution includes southeastern Canada, through the United States and into Mexico and Costa Rica (Gibbs et al. 2009) with the majority of the breeding population of Canada in southern Ontario (COSEWIC 2009). Within this Canadian population, there is estimated to be about 1,500 pairs, with 200 pairs in Manitoba, 200-300 pairs in Quebec, about 10 pairs in New Brunswick, and the rest breeding in southern Ontario (Erskine 1992, COSEWIC 2009).

There still remain uncertainties about population size and distribution although intense efforts are underway to increase search effort, detectability and track these populations in Canada mainly through the Marsh Monitoring Program and the Least Bittern Recovery Team (Crewe et al. 2006, COSEWIC 2009, Recovery Strategy for the Least Bittern (*Ixobrychus exilis*) in New Brunswick, Canada 2009). Between 1994 and 2005, there has been a decline of 11% per year in the population throughout the Great Lakes Basin (Crewe et al. 2006), and this decline, combined with the already small population size, led to this species being listed as threatened in Canada under the Species-at-Risk Act (SARA 2002). Habitat loss and degradation are the main factors limiting this species, as greater than 90% of wetlands have been lost in some areas of southern Ontario since settlement (Snell 1987).

Studies on habitat preferences have focused primarily at within-site scales examining variables such as the amount of open water, emergent vegetation, and shrubs (Weller 1961, Post 1998). In general, Least Bitterns prefer freshwater marshes with tall emergent vegetation (e.g. *Typha* spp., *Carex* spp., *Schoenoplectus* spp.) interspersed with patches of open water (Weller 1961; Gibbs et al. 2009) and stable water levels are also important for this species (Jobin et al. 2009). Studies on the influence of land-use in southern Ontario marshes are lacking; however, Hay (2006) found that within-marsh characteristics (within 50m) such as percent vegetation cover and open water were more important in predicting the presence/absence of Least Bitterns in Manitoba marshes than landscape-scale factors (within 500m and 5km) such as cultivated land, moist prairie, and wet meadow. If urbanization had been included as one of the factors in Hay's study however, different results may have been obtained since urbanization has such an over-arching impact on bird communities elsewhere (Marzluff 2001, DeLuca et al. 2004). The possible influence of urbanization on the distribution of Least Bitterns has not been addressed and further research is needed to determine if there is a relationship between site occupancy and adjacent land-use in southern Ontario coastal marshes (Valente 2009).

In addition to land-use impacts, water quality deterioration may also affect the presence of Least Bitterns, since they consume primarily small fish and aquatic invertebrates and capture prey by stalking along the reeds of the marsh near water (Gibbs et al. 1992). Wetlands with high amounts of phosphorus and nitrogen, and high turbidity levels tend to have decreased water clarity and this may impair the ability of Least Bitterns to forage effectively (Chow-Fraser et al.1998, Gibbs et al. 2009). Wetlands with poor water quality may have diminished invertebrate populations (Anderson and Vondracek 1999, Chipps et al. 2006) and may also have less fish habitat (Seilheimer and Chow-Fraser 2006).

In this study, we surveyed marshes throughout southern Ontario to determine the influence of adjacent land-use, wetland size, isolation and water quality in predicting the presence of Least Bitterns. We then used this information to derive recommendations for land-use planning and land management surrounding wetlands for maintaining habitat for Least Bittern populations.

METHODS

Study Area.---From 2006-2008, we conducted point counts at 20 wetlands along the shores of Lake Erie and Lake Ontario, Ontario, Canada (Fig. 1, Table 1). All 20 study sites were freshwater coastal marshes with the exception of one large inland marsh (Wye Marsh). This shoreline contains the remnants of a once extensive coastal wetland system and the remaining marshes are dominated by tall emergent vegetation (primarily *Typha* spp.) and interspersed with patches of open water. Water levels of Lakes Ontario and Erie are relatively stable between years for the months of May to July (range of mean water level = 174.25-174.35m above sea level between years) because they are regulated (Canadian Hydrographic Service 2010).

Avian Sampling.---All point counts were sampled from a canoe between 2 May and 16 July of each year. We conducted two point counts at each wetland, except for four of the smaller wetlands at which only one point count could be conducted (CY, BR, GC and PB). Each count was conducted twice throughout the season at least 10 days apart (Siegel et al. 2001). Point count locations within sites were selected to ensure there was approximately 50% emergent vegetation and 50% open water in the area of the count. This was to avoid the situation where a point count could be randomly selected where there was no vegetation present (only open water) or where there was only emergent vegetation present (inaccessible). All point counts were at least 250 m apart with a mean distance between points of 484 m (range 252-1,009 m; Rehm and Baldassarre 2007). All counts were conducted between sunrise and four hours after sunrise, during periods of low winds (<20 km/h) and avoiding periods of rainfall (Krzys et al. 2002, Hanowski et al. 2007).

We used unlimited radius point counts that lasted 10 min in duration. After the 10 min passive period, we broadcasted the songs of secretive marsh birds (Gibbs and Melvin 1993) in the following order including the American Coot (*Fulica americana*), American Bittern (*Botaurus lentiginosus*), Least Bittern, Pied-billed Grebe (*Podilymbus podiceps*), Sora (*Porzana carolina*), Virginia Rail (*Rallus limicola*), Common Moorhen (*Gallinula chloropus*), King Rail (*Rallus elegans*), and Yellow Rail (*Coturnicops noveboracensis*). Calls were broadcast at a sound level of 70-85 dB at a distance of 1 m from the front of the speakers that were oriented to broadcast directly into the patch of emergent vegetation. Speakers were held at a height of 0.75 m above the water surface. In the broadcast sequence, each species' call varied in length (35 to 110 sec), but each species' call was separated by a 30 sec pause. Call-broadcasts were played for a total of 14 min after the passive period and 2 min were left at the end of the call-broadcasts to listen for responses.

Land-use Classification.---Land-use analysis was performed with the Southern Ontario Land Resources Information System (SOLRIS; Ontario Ministry of Natural

Resources 2008). SOLRIS is a geographical information system platform consisting of digital polygons for 23 different land-use classes for all of southern Ontario (Table 2). For analysis, we grouped these 23 land-use classes into 5 subclasses: forest, rural, marsh, urban, and open water. It is important to note that SOLRIS was created based on aerial images from 2000-2002, whereas our study utilized information collected from 2006-2008. We identified changes in land-use since 2000-2002 using Google Earth images from 2004-2007 for five randomly selected sites. Changes were minimal, and involved the conversion of on average 0.23% of the land at varying scales from either rural or forest to impervious urban areas or roads. We also updated known land-use changes at other sites using 2005 updated Ministry of Natural Resources shapefiles and Google Earth satellite images.

Water Quality.---Wetland water quality was sampled primarily between 2001 and 2002 at 12 sites (Table 1). We did use water quality data for one wetland that was collected in 2007. Based on water quality samples, we then calculated the Water Quality Index (WQI) which was created from 12 water quality variables (Chow-Fraser 2006). WQI scores can range from -3 to +3 with negative scores representing highly degraded wetlands (higher total phosphorus, turbidity, suspended solids, chlorophyll, and conductivity) and positive scores representing more pristine wetlands (lower total phosphorus, turbidity, suspended solids, chlorophyll, and conductivity). Detailed water quality sampling protocols and development of WQI scores are found in Chow-Fraser (2006).

Statistical Analyses.---We used ArcMap 9.2 with the Spatial Analyst extension (ESRI Inc. 2006) to determine the amount of each land-use within 500 m, 1,000 m, 2,000 m and 4,000 m of the edge of the wetland. We calculated the proportion of each land-based sub-class (including marsh) out of the total amount of land in the area. We measured the following variables: proportion urban, proportion rural, proportion forest, proportion marsh, and marsh size. To measure isolation we used the amount of marsh within 4,000 m from the edge of the focal wetland (called "proportion marsh") as birds are highly mobile and are more likely influenced by isolation at a large scale (Brown and Dinsmore 1986). Marsh size represents the size of the focal marsh. We used Pearson correlation to determine similarities in land-use/cover at multiple spatial scales, and between categories of land-use/cover.

STATISTICA^{TM} was used for all analyses (StatSoft 2001). We $\log_{10}$ transformed marsh size and ArcSin(Sqrt+0.001) transformed proportion marsh to give the data a normal distribution. We used logistic regression with proportion urban, proportion rural, proportion forest, proportion marsh, and marsh size as the independent variables and the presence/absence of the Least Bittern as the response variable.

We used the "model selection" approach to rank and weigh various models to explain the presence/absence of Least Bitterns. We used Akaike's Information Criterion (AIC) to determine the relative importance of each variable and combinations of these variables. Comparing model support allowed us to identify which model was most parsimonious and most closely reflected the actual data. We calculated Δi to examine the difference between the AIC_c (AIC corrected using a bias adjustment for small sample sizes) for each candidate model and the model with the lowest AIC_c score. Akaike weights (w_i) were calculated for each model to examine the relative likelihood of the model given the data. These resulting weights sum to one across all models and are interpreted as probabilities where a model with an Akaike weight approaching one is strongly supported by the data (Johnson and Omland 2004).

We used simple linear regression to determine if there was a relationship between water quality and urbanization, and a Mann-Whitney U-test to compare water quality (WQI) between sites where Least Bitterns were absent and sites where they were present.

RESULTS

We conducted a total of 72 point counts consisting of 36 point count locations at 20 wetlands that were each conducted twice over the season. We detected Least Bitterns at 9 of 20 wetlands and at 12 of 72 (17%) point counts that corresponded to 10 of 36 (28%) point count locations (at two point count locations we detected a Least Bittern on both of the seasonal surveys). Of the 12 Least Bitterns detected, 7 (58%) were aural detections and 5 (42%) were visual detections.

We found that each land-use type was significantly correlated at all spatial scales (Pearson Correlation r = 0.72-0.99, all $P < 0.05$) indicating that the land-use types were found in similar proportions regardless of the scale used (500m, 1,000m, 2,000m, 4,000m). Therefore, we only examined land-use at a 4,000m scale to be consistent with the analysis of isolation (proportion marsh) and to take into consideration the high mobility of birds and the potential influence of larger spatial scales. We also found that the proportion urbanization was highly negatively correlated with proportion rural (r = -0.91, $P < 0.0001$). Therefore, we decided to use proportion urbanization as our predictor for both proportion urbanization and proportion rural since urban areas are generally being created and not destroyed at a landscape-scale.

We found proportion urbanization to be the most important factor in predicting the presence of Least Bitterns with the independent predictor "proportion urban" resulting in the highest Akaike weight (w_i = 0.181; Table 3). Least Bitterns were more likely to be present in marshes surrounded by lower levels of urbanization (β = -2.99; Fig. 2). The inflection point for this relationship was 0.27, indicating that Least Bitterns were more likely to be found in marshes surrounded by less than 27% urbanization within 4000m. The amount of forest within 4,000m of the marsh was another important factor in predicting the presence of Least Bitterns with the model including only forest resulting in the second highest Akaike weight (w_i = 0.115). Other parameters alone showed that Least Bitterns were more likely to be found in wetlands that are less isolated and larger but these models were not as highly supported.

We found a significant negative relationship between water quality (WQI) and the amount of urbanization within 4,000m of the wetland edge (R^2 = 0.292, P = 0.041, n = 12). In addition, we found that WQI scores were significantly higher in wetlands where we detected Least Bitterns (median: 0.276, range: -0.75 – 0.64; Z = 2.49, P = 0.013; Fig. 3) than in wetlands where we did not (median: -1.68, range: -2.3 – 0.45).

DISCUSSION

We wanted to standardize sampling effort across sites, so it is extremely likely that the larger wetlands contained many more individuals than we detected (Brown and Dinsmore 1986). As such, the total number of Least Bitterns detected in this study should not be used as any type of synoptic survey for southern Ontario. Most detections were aural (7 of 12; 58%), but visual detections were also frequent (5 of 12; 42%). In a previous study by Swift et al. (1988), they found that 55 of 73 (75%) detections were aural and 18 of 73 (25%) detections were visual. At two point count locations we detected a Least Bittern on consecutive surveys over the breeding season, suggesting that these individuals may have been holding territories.

Our land-use variables were correlated at all spatial scales. This finding should be expected because these spatial scales are not independent, with smaller scales automatically included in larger scales (Roth et al. 1996). It was also expected that urban and rural land-uses would be highly negatively correlated because rural lands are often converted to urban land-uses (McBean et al. 1996, Hofmann 2001, Watkins et al. 2003). Using urbanization as our independent variable allowed us to indirectly examine the impact of this conversion on Least Bittern habitat selection.

Least Bitterns were more likely to be found in marshes surrounded by low levels of urbanization (< 27% within 4,000m). This result is both consistent and inconsistent with other literature on wading birds and the influence of urbanization (DeLuca et al. 2004, Pearce et al. 2007). DeLuca et al. (2004) found that there was a significant reduction in the Index of Marsh Bird Community Integrity (IMBCI) when the percent urbanization within 500m reached 14%, and within 1,000m reached 25% surrounding marshes of Chesapeake Bay, USA. IMBCI scores were created for each wetland with species more reliant on wetland habitat contributing to higher IMBCI scores, and the Least Bittern was one of these “high-scoring” species.

Studies focusing specifically on urbanization are few, but other studies have found that road density (often a surrogate for urbanization; Hennings and Edge 2003) was not an important predictor of the marsh bird community (Shriver et al. 2004, Pearce et al. 2007). Shriver et al. (2004) found no influence of road density on marsh bird richness in salt marshes along the New England coast, USA, although the Least Bittern was only detected at one site in this study. Pearce et al. (2007) also found no influence of road density in predicting the presence of "waders" (included Least Bittern) in urban and near-urban marshes of London, Ontario; however, this could also be due to the lack of low road density sites (i.e. actual rural sites) in their study.

Even though Least Bitterns were more likely to be encountered in marshes with lower levels of surrounding urbanization, we still detected them in several more urbanized wetlands. Port Darlington, Westside Creek and Second Marsh all contained Least Bitterns and all had levels of urbanization of greater than 27% (37%, 38%, and 63% respectively). The presence of this species at Second Marsh could be explained by the extensive restoration program implemented in the 1990s to restore hydrological function, exclude common carp, and re-plant natural vegetation (Wilcox and Whillans 1999). Least Bitterns may also be subject to the "funnel effect" in these wetlands, where they are forced to use sub-optimal habitat because of the little habitat remaining.

Water quality, as indicated by the WQI, was significantly higher in wetlands with lower levels of urbanization and in wetlands where we detected Least Bitterns. The negative relationship between urbanization and water quality is well demonstrated in the literature (Ehrenfeld and Schneider 1991, Houlahan and Findlay 2004, Chow-Fraser 2006), and is a result of the increased run-off related to impervious surfaces and densely populated areas (McBean et al. 1996). Water quality may directly affect Least Bitterns by limiting their ability to forage effectively. Obtaining sufficient food is essential for adult survival as well as the growth and survival of offspring for some bird species (Cox et al. 1998, Sparling et al. 2007). Increased nutrients and turbidity cloud the water column and could make foraging difficult, or even limit prey availability since many fish species and invertebrates are sensitive to changes in water quality (Anderson and Vondracek 1999, Gage et al. 2004, Chipps et al. 2006, Seilheimer and Chow-Fraser 2006).

Conclusions and Management Implications.---The results of this study first and foremost stress the need for more studies examining the impacts of urbanization on Least Bittern populations in southern Ontario. Federal-level recovery strategies integrate the need to eliminate wetland loss as an important requirement for the persistence of the species and its critical habitat in southern Ontario, but requirements for land surrounding marshes has received less attention. Water quality may be one potential route by which urbanization influences habitat selection for the Least Bittern, but future research is needed to examine other impacts of urbanization on marsh-nesting birds such as nest predation pressures, direct human disturbance and the influence of urban noise. Understanding the relationship between urbanization and wildlife communities in wetlands of southern Ontario is a first step towards incorporating natural areas into future development plans and management strategies.

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TABLE 1. Wetland study sites in southern Ontario showing corresponding site codes, year sampled for Least Bitterns, the Water Quality Index (WQI) at each wetland, and the year of water quality sampling.

Site	Site code	Year sampled for Least Bittern	Water quality index (WQI) score	Year sampled for water quality
Westside Creek	WC	2007	-	-
Crysler Point	CY	2007	-	-
Port Darlington	PD	2007	-	-
Second Marsh	SM	2007	-	-
Turkey Point	TP	2007	0.638	2002
Long Point	LP	2007	0.613	2001
Rondeau	RN	2008	0.410	2001
Wye Marsh	WY	2008	-	-
Presqu'ile	PQ	2007	0.470	2002
Bronte Creek	BR	2006	-0.983	2002
Credit River	CR	2006	-1.476	2002
Fifteen Mile	FI	2007	-1.987	2002
Grand River	GR	2006	-1.876	2001
Grindstone Creek	GC	2007	-2.308	2002
Oakville Marsh	OK	2007	-	-
Port Britain	PB	2007	-	-
Rattray Marsh	RT	2007	-	-
Van Wagners	VW	2007	-2.030	2007
Blessington Bay	BB	2007	0.142	2002
Hay Bay	HB	2007	0.451	2002

TABLE 2. SOLRIS designation of 23 land-use classes and descriptions, grouped into sub-classes for analysis.

Land-use class	Sub-class	Description
Open cliff and talus	Rural	Vertical or near-vertical exposed bedrock > 3 m in height / slopes of rock rubble at the base of cliffs. Subject to active processes / < 25% vegetative cover
Open shoreline	Rural	Substrate consists of unconsolidated parent or mineral material. Subject to active processes / < 25% vegetative cover
Open bluff	Rural	Steep to near-vertical exposure of unconsolidated material > 2 m in height. Subject to active processes / < 25% vegetative cover
Open sand barren and dune	Rural	Exposed sands formed by extant or historical shoreline or Aeolian processes. Subject to active processes / < 25% vegetative cover
Open tallgrass prairie	Rural	Ground layer dominated by prairie gramminoids; variable cover of open-grown trees. Tree cover < 25%; shrub cover
Tallgrass savannah	Rural	Ground layer dominated by prairie gramminoids; variable cover of open-grown trees, 25% < tree cover < 35%
Tallgrass woodland	Forest	Ground layer dominated by prairie gramminoids; variable cover of open-grown trees, 35% < tree cover < 60%
Forest	Forest	Tree cover > 60%. Upland tree species > 75% canopy cover > 2 m in height
Coniferous forest	Forest	Tree cover > 60%. Upland conifer tree species > 75% canopy cover > 2 m in height
Mixed forest	Forest	Tree cover > 60%. Upland conifer tree species > 25% and deciduous tree species > 25% of canopy cover > 2m in height
Deciduous forest	Forest	Tree cover > 60%. Upland deciduous tree species > 75% of canopy cover > 2 m in height
Plantations – tree cultivated	Forest	Tree cover > 60%, minimum 2 m in height, linear organization, uniform tree type
Hedge rows	Forest	Tree cover > 60%, minimum 2 m in height, linear arrangement, minimum 10 m width, maximum 30m width
Transportation	Urban	Highways, roads
Extraction	Urban	Pits, quarries
Built-up area	Urban	Urban recreation areas, e.g. golf courses, playing

pervious		fields
Built-up area impervious	Urban	Residential, industrial, commercial and civic areas
Swamp	Forest	Open, shrub and treed communities - water table seasonally or permanently at, near, or above substrate surface - tree or shrub cover > 25% - dominated by hydrophytic shrub and tree species
Fen	Marsh	Open, shrub and treed communities - water table seasonally or permanently at, near, or above substrate surface. - tree cover (trees > 2m high) ≤ 25% - sedges, grasses and low (< 2 m) shrubs dominate, sedge and brown moss peat substrate
Bog	Marsh	Open, shrub and treed communities - water table seasonally or permanently at, near, or above substrate surface - tree cover (trees > 2m high) ≤ 25% sphagnum peat substrate
Marsh	Marsh	Open, shrub and treed communities - water table seasonally or permanently at, near, or above substrate surface - tree and shrub cover ≤ 25% - dominated by emergent hydrophytic macrophytes
Open water	Open water	No macrophyte vegetation, trees or shrub cover
Undifferentiated	Rural	Includes all agricultural features (e.g. field and forage crops and rural properties) as well as urban brown fields, and openings within forests

TABLE 3. Urbanization was the most important factor in predicting the presence or absence of Least Bitterns in southern Ontario coastal marshes. Logistic regression models ranked using AIC to determine the influence of each landscape-scale factor in predicting the presence of the Least Bittern. Urban = proportion of urbanization within 4,000m of the marsh edge, Forest = proportion of forested land within 4,000m of the marsh edge, Isolation = proportion of marsh within 4,000m of the marsh edge (not including the focal marsh), Area = the size of the focal marsh. Where *k* is the number of parameters in the model and β is the parameter estimate.

Model	*k*	AIC_c	Δi	w_i	β
Urban	2	28.645	0	0.181	-2.989
Forest	2	29.543	0.898	0.115	6.036
Isolation	2	29.928	1.283	0.095	4.402
Urban + Forest + Isolation	4	30.065	1.421	0.089	-
Urban + Area	3	30.381	1.737	0.076	-
Area	2	30.618	1.973	0.067	1.048
Forest + Isolation	3	30.746	2.102	0.063	-
Area + Forest	3	30.752	2.107	0.063	-
Area + Isolation	3	30.926	2.281	0.058	-
Urban + Forest	3	31.007	2.363	0.056	-
Urban + Isolation	3	31.290	2.646	0.048	-
Forest + Isolation + Area	4	31.965	3.320	0.034	-
Urban + Forest + Isolation + Area	5	33.180	4.536	0.019	-
Urban + Isolation + Area	4	33.251	4.607	0.018	-
Urban + Forest + Area	4	33.328	4.683	0.017	-

Note: The corrected values of Akaike's information criterion (AIC_c), Δi (AIC_c model i – AIC_c minimum), and Akaike weights (w_i) are shown for 15 logistic regression models.

FIG. 1. Coastal wetland study sites in southern Ontario surveyed for Least Bitterns between 2006 and 2008.

FIG. 2. Least Bitterns were more likely to be present (1) than absent (0) in southern Ontario coastal marshes surrounded by a lower proportion of urbanized land within 4,000m of the wetland edge. These data are based on the highest-ranking logistic regression model from Table 3. Site names matching site codes shown here can be found in Table 1.

FIG. 3. Water quality values in marshes where Least Bitterns were detected were significantly higher than in marshes where they were not detected. Higher water quality values represent marshes with better water quality (e.g. lower amounts of nitrogen and phosphorus, lower water turbidity). Medians and lower and upper quartiles are shown. Present n = 4 wetlands, absent n = 8 wetlands.

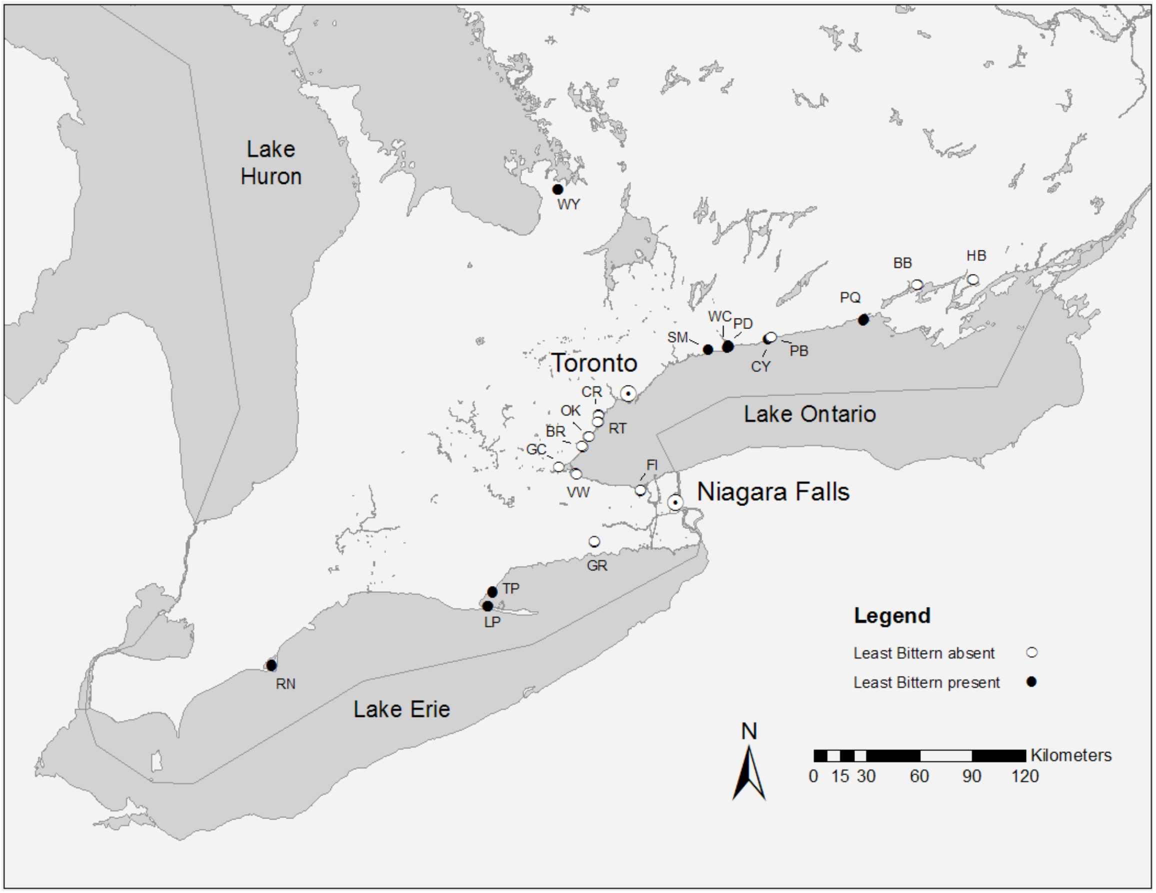
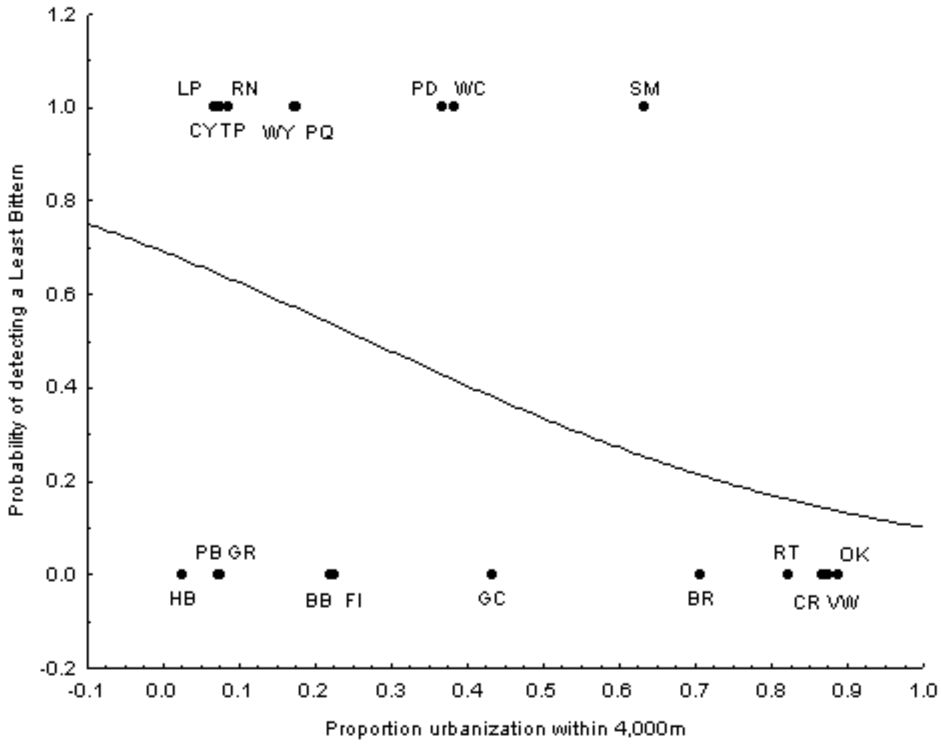

Lake
Huron
WY
BB
HB
PQ
WC
PD
SM
PB
CY
Toronto
CR
OK
RT
BR
GC
VW
FI
Lake Ontario
Niagara Falls
GR
TP
LP
RN
Lake Erie
Legend
Least Bittern absent
Least Bittern present
N
Kilometers
0 15 30 60 90 120

FIG. 1.



1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
Probability of detecting a Least Bittern
LP
RN
CYTP
WY PQ
PD
WC
SM
PB GR
HB
BB
FI
GC
BR
RT
OK
CR VW
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Proportion urbanization within 4,000m

FIG. 2.

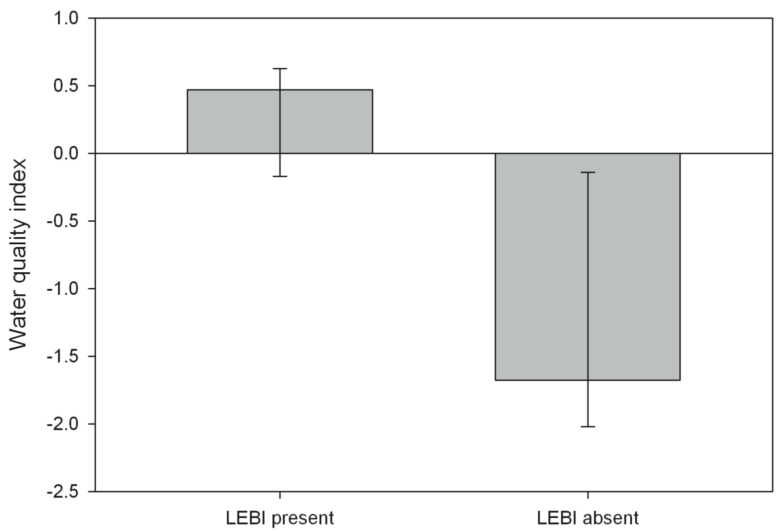

1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
Water quality index
LEBI present
LEBI absent

FIG. 3.