A Guild Approach to Wetland Biodiversity Monitoring in the National Capital Region of Canada

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1.0 Introduction:

Biodiversity is changing at an unprecedented rate due to the magnitude of anthropogenic impacts occurring at the global scale (Sala et al., 2000). These impacts negatively affect biodiversity, especially in sensitive habitats such as wetlands (Dirzo et al., 2014). This "anthropocene defaunation" is related to (in order of decreasing magnitude) land-use changes, climate change, nitrogen deposition, biotic exchange, and increased CO_2 atmospheric loading (Sala et al., 2000).

Global wetland degradation and wetland biodiversity changes have resulted in a net loss of over 50% of the world's wetland habitats (Millennium Ecosystem Assessment, 2005). The primary factors responsible for this loss of wetland habitat are infrastructure development, land conversion, pollution, and invasive alien species (Mitsch and Hernandez, 2013). In addition, climate change is expected to exacerbate these impacts, further reducing total wetland cover (Millennium Ecosystem Assessment, 2005). Consequently, 41% of bird species that are dependent upon wetlands are declining and 21% are globally extinct or threatened (Millennium Ecosystem Assessment, 2005).

Despite providing a multitude of recreational, cultural, and physical goods to humans and maintaining biodiversity strongholds, only 25% of wetlands in southern Ontario remain since settlement (OMNR, 1992; Findlay and Houlahan, 1996; NCC 2016). Road construction and land conversion were the primary drivers reducing wetland habitat (Findlay and Houlahan, 1996). The increasing anthropogenic pressures upon wetland habitat have led to a series of federal and provincial policies to curb wetland loss (Findlay and Houlahan, 1996).

The federal and provincial governments have indicated a commitment towards conserving biodiversity through international multi-lateral environmental agreements (i.e., the UN Convention on Biological Diversity) and national legislation (*Species-at-Risk Act*) (ECCC, 2017; Waples et al., 2013). Although there is no federal legislation protecting wetlands, there is the *Federal Policy on Wetland Conservation* which protects wetlands on federal land, such as those owned or operated by the National Capital Commission (NCC) (Government of Canada, 1991). Other protections such as the *Canadian Environmental Assessment Act* (2012) and *Fisheries Act* (1985) may also be triggered depending on the proposed activity on federal lands. Further provincial protections to conserve biodiversity within wetlands in Ontario are given by the *Conservation Authorities Act* (1990) and *Endangered Species Act*. More locally, the NCC is responsible for protecting and conserving biodiversity as well as providing public goods within the Greenbelt through their Master Plan (NCC, 2013), deriving authority from the *National Capital Act* (1985).

These series of policies have allowed biologically diverse wetlands such as Mer Bleue Bog, Stony Swamp, and Shirley's Bay to be protected amidst pressure from urban development, industrial activity, agricultural production, and invasive species (NCC, 2013). While wetland habitat removal can easily be ascertained through land-cover changes, the quality or functionality of the wetland can be diminished by surrounding land-use, introduction of invasive species, and water regime fluctuations (Brinson and Malvárez, 2012).

Within the NCC Greenbelt, those three protected wetlands host provincially and federally "*Threatened*" species-at-risk: least bittern (*Ixobrychus exilis*), western chorus frog (*Pseudacris triseriata*), and Blanding's turtle (*Emydoidea blandingii*) (COSEWIC, 2009; COSEWIC, 2008; Environment Canada, 2016). These species form the cornerstone of an "umbrella group" which indirectly protects wetlands and other wetland species from anthropogenic threats (BTRT, 2002). One of the characteristics of an umbrella species is having a large range size, allowing for greater protection of the habitat (Caro, 2010). In addition, umbrella species tend to be charismatic whereas the co-occurring wetland species do not evoke the same sympathetic response in humans (Caro, 2010). Hence, by protecting these three species, many other less enigmatic species that may even provide greater ecological functions are protected (Caro, 2010).

Changes to the quality or functionality of wetlands can be difficult to assess, however indicator species can aid monitoring efforts (Carignan and Villard, 2002). In particular, bird communities are good indicators of vegetation shifts and can predict responses of other bird species within the same guild (Caro, 2010). Furthermore, obligate wetland species such as amphibians, turtles, and some birds can be used as indicator species to assess and monitor the quality of the wetland and surrounding area (Quesnelle, Fahrig and Lindsay, 2013). Using functional groups as indicators is called the "guild approach" (Landres et al., 1988). Given the high costs of monitoring all declining wetland species, it may also be appropriate to use indicator species as proxies for other species found in the same guild.

The guild approach to managing wildlife conservation can be beneficial as it may be an adequate monitoring tool while being quantitatively accurate and cost-effective (Verner, 1984). Following Root (1967), a guild can be defined as "a group of species that exploit the same class of environmental resources in a similar way". Severinghaus (1981) defined a guild as a species assemblage that have similar responses (i.e. population and abundance impacts) to environmental changes. Furthermore, the guild approach is recommended when "attributes are too difficult, inconvenient or expensive to measure" (Landres, Verner and Thomas, 1988). Biodiversity monitoring programs are resource-intensive as it may require years of data to show distinct changes that are only measurable over 5, 10 or 25 year intervals. By focusing upon indicator or umbrella species, these changes can be seen more immediately and further action to increase monitoring efforts, conserve existing ecosystem functions or improve ecological functions can be implemented quickly (Caro, 2010).

The effectiveness of an indicator species is dependent upon the sensitivity of the species to habitat changes that also affect the species of interest (Kerr, Sugar and

Packer, 2000). In addition, an indicator species can also be used to assess population changes and the presence of co-occurring species within the same guild (Landres et al., 1988). Thus, each species should exploit similar non-limiting habitat resources, however, negative interactions (i.e. predation, resource competition) between the species of interest and the co-occurring species will likely diminish the effectiveness of this approach (Favreau et al., 2006; Verner, 1984).

Developing these techniques to reduce costs to monitor biodiversity and population impacts can improve conservation efforts by re-allocating those resources to more direct action to preserve wildlife (Favreau et al., 2006). Using the guild approach, one may be able to predict the co-occurrence of species based upon another proxy species. A guild-based monitoring technique has already been used within the Great Lakes region since 1995 and has been recognized as an appropriate methodology within wetland habitats (Crewes and Timmermans, 2005).

The least bittern, a provincially and federally listed "*Threatened*" species-at-risk, is thought to have 1500 pairs breeding in Canada with the majority occurring in southern Ontario (COSEWIC, 2009). Due to increasing pressure on wetlands, habitat fragmentation and invasive aquatic species, the population of least bittern has declined by 30% from 1999-2009 (COSEWIC, 2009). In addition, climate change is projected to reduce water quality and increase water level variability throughout its range, further reducing habitat quality (COSEWIC, 2009). Federal action plans have been launched with Parks Canada in Bruce Peninsula N. P., Point Pelee N. P., and Thousand Islands N.P. (Government of Canada, 2016). In addition to its intrinsic value, the least bittern is an iconic species (alongside other heron species) (COSEWIC, 2009). Hence, there is much interest to conserve this declining and rare species across Ontario.

The least bittern is difficult to detect due to its nocturnal habits, concealment behaviour, and propensity to nest in inaccessible areas (Poole, 2009). In contrast, the marsh wren (*Cistothorus palustris*) is easy to detect as it calls frequently, vigorously defends its territory by singing, and flies above marshland (Kroodsma and Verner, 2013). Due to its secretive behaviour, the detection rate of breeding least bittern pairs is significantly lower than that of marsh wren (Smith and Chow-Fraser, 2010a). Crewe and Timmermans (2005) considered marsh wren and least bittern both as obligate marsh nesting species and marsh indicator species.

In general, marsh wrens rely upon insects for their main sources of food, mainly insects (Kroodsma and Verner, 2013). The dietary requirements of least bittern differ as they consume higher trophic prey such as amphibians and fish (Poole, 2009). Hence, least bitterns and marsh wrens do not compete for food. Both require dense emergent cattail for their foraging techniques, similar depths of water to reduce nest depredation, and limited anthropogenic disturbances (Kroodsma and Verner, 2013, Jobin et al., 2013). The elimination of any of those characteristics have been shown to reduce the likelihood of marsh wren, as well as least bittern, being present within that marsh. Thus, these two species could be considered within the same guild, given the criterion accepted within the literature as both these species inhabit wetlands and can be found within the same wetland habitat type and area.

Co-occurrence data have shown that 91% of least bittern observations also had marsh wren present (Jobin et al., 2013). However, this study did not look at the converse; whether given the presence of marsh wren, would there be significantly higher likelihood of least bittern being present. If true, since marsh wren is easier to detect with conventional survey techniques, land managers would be able to assert that the habitat would also be likely suitable for least bittern. The ideal habitat types for least bittern in Ontario and Québec are cattail (*Typha spp.*) or buttonbush (*Cephalanthus occidentalis*) dominated wetlands that have a water depth of at least one meter, with a minimum area of 0.5 ha (Jobin et al., 2013). Hence, appropriate habitat with the presence of marsh wren would indicate that least bittern might be present within that wetland.

Given that marsh wren territory size is smaller than that of least bittern, multiple territories of marsh wren can overlap one least bittern territory (Kroodsma and Verner, 2013). Therefore, the territory of one pair of breeding least bittern could vary between observational sites of marsh wren, leading to false negatives at the site level as the bittern may be occupying a different area of the marsh. Hence, the most effective analysis may occur at the scale of a least bittern territory size, which can be approximated to a 500 m radius centered from a known least bittern sighting. Corroborating this assumption, habitat analysis at the approximate scale of least bittern territory size (usually at 500 m) was found to be the most revealing spatial-scale for habitat selection (Hay, 2006).

To become a candidate indicator species, the species should co-occur with the species of interest (Caro, 2010). Assessing the relationship between the indicator species with the species of interest is necessary to establish their strength of association. From this pattern, one may be able to predict the occupancy of the species of interest based upon the presence or absence of the indicator species. As discussed within previous studies, marsh wren may be a good indicator species to determine the presence of least bittern. The habitat preferences of marsh wren are similar to those of least bittern. Consequently, the presence of marsh wren can indicate that there is available habitat for least bittern. Hence, the distribution of least bittern would favour areas where marsh wren is present. Thus, the purpose of this study is to test whether least bittern are more likely to occur in areas where marsh wren are also present and assess the strength of that relationship.

2.0 Methods:

2.1 Site Selection

There were two main considerations to gathering data, the first was site selection and the other was the survey protocol. The favoured habitat of least bittern is cattail-dominated wetlands with a water depth of approximately 100 cm (Lor and Melecki, 2005). These wetlands must have an approximate area of at least 0.5 ha to support at least one pair of least bittern, however more extensive wetlands are preferred (COSEWIC, 2009). Survey sites must be accessible either by waders or canoe and a survey route must have between five to eight point counts per day to be effective (Jobin et al., 2011). Thus, locations must be reasonably accessible by trails, road or water. Generally, this means that the first survey point must be within 500 m of the original access point.

More practically, we were also restricted by land-access within the National Capital Region. The NCC owns and operates the Greenbelt and granted permission to access and conduct surveys on their land (NCC, 2013). We were also granted access to Shirley's Bay through the Department of Defence at Connaught Range. However, we were not permitted to access private land either to survey or walk through to another survey point. Using GIS imagery and expert knowledge of Greenbelt lands, I was able to choose approximately 30 marshes that fit these criteria (ESRI, 2016). Moreover, the previous records of the field season also recommended appropriate sites to visit. The primary sites selected occurred in the Ramseyville marsh complex, the Stony Swamp marsh complex and Shirley's Bay. Smaller marshes such as Bruce Pit and the Landfill Marsh were also selected due to their proximity to these other sites. For exact site descriptions, see Appendix A.

2.2 Survey Protocol

A national survey was developed by Jobin *et al.* (2011) to standardize least bittern survey protocols. This standardization allows for researchers to compare data across temporal and spatial scales. This increases the strength of each individual study. I will give a brief overview of the protocol and how it was applied to my research project. An example of the data sheet is in Appendix B.

Surveys by the field research team took place between late May and early July in 2016 and 2017, which is the period when the detectability of least bitterns is highest. Each survey point was taken between 30 minutes before sunrise to approximately 10:00. Least bitterns are detected more often in morning than in evening surveys (Conway and Gibbs, 2005). Due to time limitations, no evening surveys took place. The field team was composed of two people who conducted each point count, reducing observer error and increasing detection of the target species. Although personnel differed in each field season, the ability to accurately identify avian species and vegetation was similar as each crew had at least one person with eight years of field experience identifying birds and vegetation.

Weather conditions for each survey day were favourable and below the recommended limits given by Jobin *et al.* (2011). No surveys took place during adverse weather events such as precipitation, wind speeds above three on the Beaufort Scale, and temperatures above 30 degrees Celsius. Due to unseasonal precipitation in May and June 2017, marshes along the Ottawa River were underwater until late June where emergent vegetation had begun to grow above the waterline. In addition, six field days were unsuitable for surveying as the weather was unfavourable, leaving only 23 days for field work. This was a significant setback as some sites could only be visited twice, instead of the recommended three visits.

Least bittern and marsh wren were detected by the observers either auditorily by their distinctive vocalizations or visually. The type of detection was noted. In addition, the behaviour of observed least bitterns such as their location, timing of call, number of calls, and breeding behaviour were also recorded. These data was useful to limiting double observations of the same least bittern individuals. Habitat indicators such as vegetation type, water depth, vegetation density and water quality indicators were also recorded.

A five-minute passive listening period was followed by a call-back period of five minutes. During the call-back period, a “coo-coo-coo” call was broadcast at 85 Hertz by two Bluetooth portable speakers for 30 seconds followed by 30 seconds of silence. This was repeated five times. The call-back period was then followed by three minutes of passive listening. All bird species identified by the observers were noted, along with number of individuals, including marsh wren. As marsh wrens are readily detected by either visual or auditory cues and are negatively affected by playback, no additional playbacks were used to increase detection of marsh wren (Conway and Gibbs, 2005).

During the 2017 field season, three sites were visited three times, 58 sites were visited twice and four sites were visited once for a total of 129 surveys. We prioritized sites with good potential habitat, as described above. Some sites were only visited once due to poor habitat conditions, generally denoted by the absence of suitable vegetation or water depth. Within the 2016 field season, the total number of sites surveyed was 57, with 131 observations as most sites were repeated three times, with some with poorer habitat quality being visited once or twice. Hence, the level of effort was similar across both field seasons.

Additional data were provided by Benoit Jobin, Environment Canada and Climate Change. The data were restricted to sites with similar habitat and characteristics to those found in the National Capital Region. The same protocol that was used within the Ottawa region was followed in his data-collection occurring within southern Québec. These data were a necessary addition as the least bittern is rare within Canada and is also difficult to detect, reducing the number of observations (COSEWIC, 2009). Therefore, the effort needed to measure potential co-occurrences is high and requires years of data-collection. Hence, data-sharing amongst researchers is necessary to evaluate co-occurrence of potential wetland species surrogates or potential habitat preferences of least bittern.

2.3 Statistical Methods

2.3.1 Assumptions:

For each site, it was assumed that all species were present if they were detected on at least one occasion. All analyses pooled point counts for a site. Each site was an observation point. To reduce potential false negatives, a second analysis assumed that least bittern was present at each site within a radius of 500 m, if detected, as their territory size could be assumed to include those sites. In addition, detectability was assumed to be similar during the survey period and time.

2.3.2 Methods:

The data was analyzed at two scales, at the observational site scale (detection radius = 150 m) and also at the least bittern territorial scale (radius = 500 m of any least bittern observations). For habitat analysis, an approximation of least bittern territory size of 500 m is considered to be appropriate (Hay, 2006). This distance was used to account for observation sites where the territory size of a least bittern could have overlapped with marsh wren territories. In some wetlands, this meant that five observational sites could have had only one least bittern pair present. As such, the second scale would allow for possible exclusion of those points for detection.

In addition to those two spatial scales, I analyzed the data in two ways. First, I pooled all sites from the National Capital Region and Québec to see if a measurable effect could be determined using the larger sample size. Then, I analyzed data in each region separately to isolate potential geographic differences because least bittern seemed to be more prevalent in the Québec region.

Logistic regression was used to determine whether marsh wren presence could be a reliable indicator of least bittern presence, given the data obtained by conducting point counts. I used marsh wren (presence or absence at a site) as the independent variable and least bittern (presence or absence at a site) as the dependent variable. As there is no variance in values and only variable between the co-occurrence of least bittern and marsh wren, the y-intercepts of the regression were used to determine the probability likelihood. Hence, only two values would be obtained, one for the likelihood of least bittern presence when marsh wren was absent and the other where both species co-occur. These results were converted to probability using the "logit" method. A goodness-of-fit test was conducted to see whether the results of the linear regression would be significant compared to chance.

The linear regression analysis was done in R (R Core Team, 2017), primarily using the "glm" function. In order to manipulate the data within other software programs, the "strgr" package was used (Wickham, 2017). Another function, "ggplot2" was used for the graphs (Wickham, 2009). Another software program, ESRI ArcMap (ESRI, 2016) was used to determine the 500 m buffer and develop the maps in Appendix A. Additionally, the imagery layers used for those maps are courtesy of the National Capital Commission.

3.0 Results:

3.1 Field Results

3.1.1 Least Bittern and Marsh Wren Presence Results:

In 2017, we detected 12 least bittern territories following the Least Bittern Protocol (Jobin et al., 2011). These territories were found by either auditory detections (either male or female) or by visual detections. There were 22 sites where marsh wrens were present. A total of 65 sites were surveyed during this field season. Hence, the abundance proportion of least bittern was approximately 18.5%. The abundance proportion of marsh wren was 33.8%. In 2016, a total of 11 least bittern territories were located out of 57 survey locations. Hence, the proportion of sites occupied by least bittern was 19.3%. Marsh wren was present at 27 sites of those sites , giving an abundance proportion of 47.4%. These data are summarized in Table 1.

3.1.2 Least Bittern and Marsh Wren Detections:

A re-finding (detection) proportion for both least bittern and marsh wren was calculated for both 2016 and 2017. Of those 12 least bittern territories, only three were re-found at a different date. As each site was visited twice, the number of potential observations at these known sites containing least bittern was 12. Hence, we were only able to re-locate least bittern 25% of the time, as the other nine least bittern were only detected once despite subsequent or previous site visits. In 2016, only two of the 13 least bittern territories were subsequently re-found, giving a re-detection proportion of 15.3%. These proportions assume that the least bittern is present within the wetland complex throughout the breeding season.

There were 22 sites with marsh wren present out of 65 total sites (33.8%) for the 2017 field season. Out of those 22 sites, marsh wren could have been observed during 46 surveys. Marsh wrens were observed 39 times out of a possible 46 surveys, giving a detection proportion of 84.8%. Of the potential 39 marsh wren observations, marsh wren was re-detected 23 times (59.0%). These data are summarized in Table 1.

Table 1: Observations of least bittern and marsh wren used within the preliminary analysis of the field results. Detectability and percent of occupied territories between field seasons are represented.

Summary Table of Observations			
	NCR 2016	NCR 2017	Québec (2004 - 2016)
Number of Sites	57	65	75
Number of Surveys	131*	129	128
Number of Least Bittern Territories	11	12	N/A
Repeat Least Bittern Observations	2	3	N/A
Number of Marsh Wren Observations	27	22	N/A
Repeat of Marsh Wren Observations	23	39	N/A
Percent of Sites Occupied by Least Bittern	19.3%	18.0%	N/A
Percent of Sites Occupied by Marsh Wren	47.4%	33.0%	N/A
Detection Rate - Least Bittern	15.3%	25.0%	N/A
Detection Rate - Marsh Wren	59.0%	84.8%	N/A

3.1.3 Marsh Wren and Least Bittern Co-occurrence:

There were a total of 158 surveys without marsh wren or least bittern in the National Capital Region in 2016 and 2017. Marsh wren was solely observed in a combined 73 surveys. Least bittern was encountered without marsh wren at 12 sites (2016 and 2017). A total of 17 sites had least bittern and marsh wren co-occurring within the NCR. These data are summarized in Table 2.

Within Québec, only 12 sites did not have either least bittern nor marsh wren. There were 14 sites with only marsh wren observations. Furthermore, 7 sites had only detected least bittern, whereas 42 sites had marsh wren and least bittern co-occurring.

Table 2: A summary of the number of observations, sites, and count of least bittern and marsh wren used within the linear model, separated by geographic area and date.

Summary of Data Used in Analysis							
Date	Region	Number of Surveys	Number of Sites	Point Counts Without Marsh Wren or Least Bittern	Surveys With Marsh Wren Presence but not Least Bittern	Surveys with Least Bittern but not Marsh Wren	Surveys with both Marsh Wren and Least Bittern
Spring/Summer 2017	National Capital Region	129	65	84	30	7	9
Spring/Summer 2016	National Capital Region	131	57	74	43	5	8
Data 2004-2015	Québec	128	75	12	14	7	42

3.2 Statistical Results

The observations made from each survey were aggregated into sites where a total of four possible results could be found. These four possibilities were whether marsh wren was either absent or present, shown in Figures 1-4 as (0, 1) respectively and whether least bittern was absent or present at that same location, represented in the Figures 1-4 as (0,1) respectively. This matrix allowed for a logistic regression analysis.

The logistic regression showed that there was a higher likelihood of least bittern being present when marsh wren was observed (39.5% +/- SE 4.10%) than when marsh wren was absent (10.1% +/- SE 2.00%) when all data, including data from Québec, was pooled (Figure 1). The goodness-of-fit test showed that results from the logistic regression were significant ($X^2 = 40.9$, $df = 1$, $p < 0.0001$). Table 3 shows a summary of all statistical results.

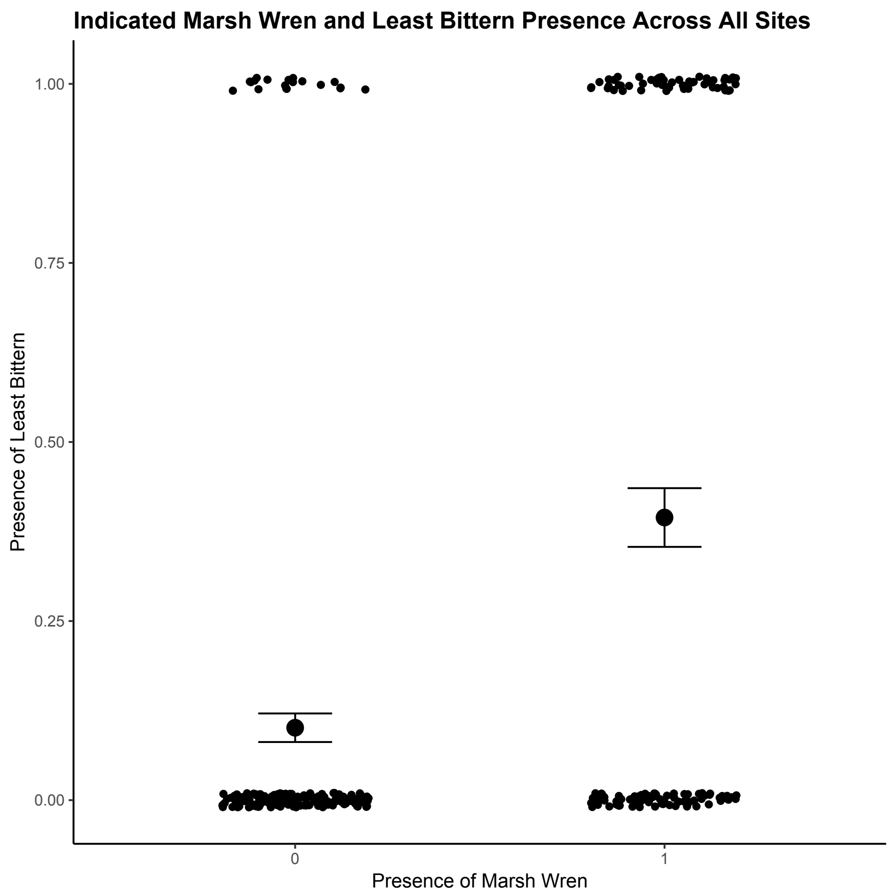

Figure 1: The relationship between marsh wren presence and the probability of least bittern presence (n = 334 sites) in wetlands surveyed in Québec and the National Capital Region represented by site. The larger circles are the predicted probabilities (10.1% and 39.5%, respectively) with standard error of 2.00% and 4.10% respectively from the logistic regression model.

The data from two field seasons from the National Capital Region were separated from the results of the Québec region to determine regional differences (Figure 2). Within the NCR, the results were inconclusive as the probability of detecting least bittern was 21.8% (+/- SE 4.90%) without marsh wren being present whereas the probability of detecting least bittern with marsh wren being present was lower (16.9% +/- SE 10.9%) (Table 3). The overlapping error bars also indicate that the results would be inconclusive. The goodness-of-fit showed that these results were not significant (X^2 = 0.34, df = 1, p = 0.56).

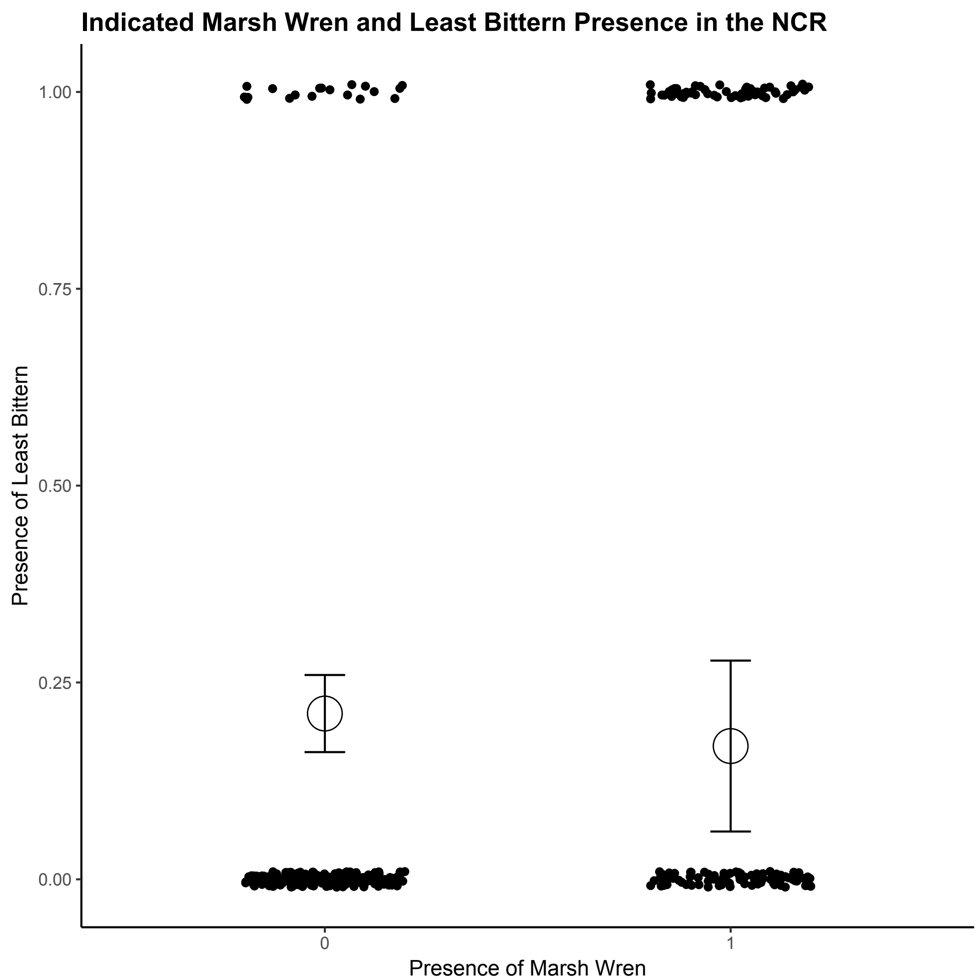

Figure 2: The relationship between marsh wren presence and the probability of least bittern presence (n = 121 sites) in wetlands surveyed in National Capital Region represented by site. The larger circles are the predicted probabilities (21.8% and 16.9%, respectively) with standard error (+/- standard error of 4.90% and 10.9% respectively) from the logistic regression model. There is significant overlap in error bars and the predicted probabilities.

The third analysis, which incorporated the 500 m buffer, did not significantly change the respective results obtained by the previous pooled analysis (Figure 1). When all sites were pooled together for the logistic regression analysis (Figure 3), the likelihood of least bittern presence significantly differed when marsh wren was present (55.5% +/- 4.10%) compared to marsh wren absence (2.00%). The goodness-of-fit analysis showed that these results were also significant ($X^2 = 25.5$, $df = 1$, $p < 0.0001$).

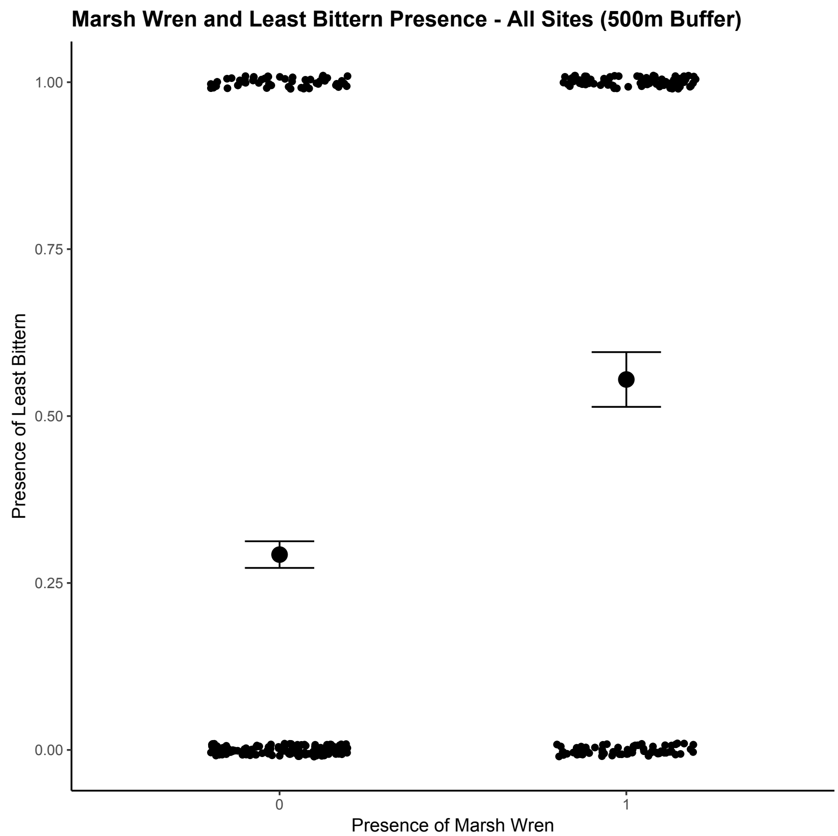

Figure 3: The relationship between marsh wren presence and the probability of least bittern presence (n = 334 sites) in wetlands surveyed across all areas represented by site buffered by 500m. The larger circles are the predicted probabilities (29.3% and 55.5%, respectively) with standard error (+/- standard error of 2.00% and 4.10% respectively) from the logistic regression model.

The fourth analysis incorporated the 500 m buffer at sites within the NCR (Figure 4). Despite this difference, the logistic regression results were similar to those obtained from the previous analysis, which excluded the data from Québec (Figure 2). The results were inconclusive as the probability of least bittern being present given the presence of marsh wren (32.4% +/- 10.9%) was comparable to that of the absence of marsh wren (38.6% +/- SE 4.90%). This can also be seen as the error bars overlap significantly within Figure 4. Testing the results with a goodness-of-fit analysis showed that the logistic regression did not yield a significant result ($X^2 = 0.53$, $df = 1$, $p = 0.47$).

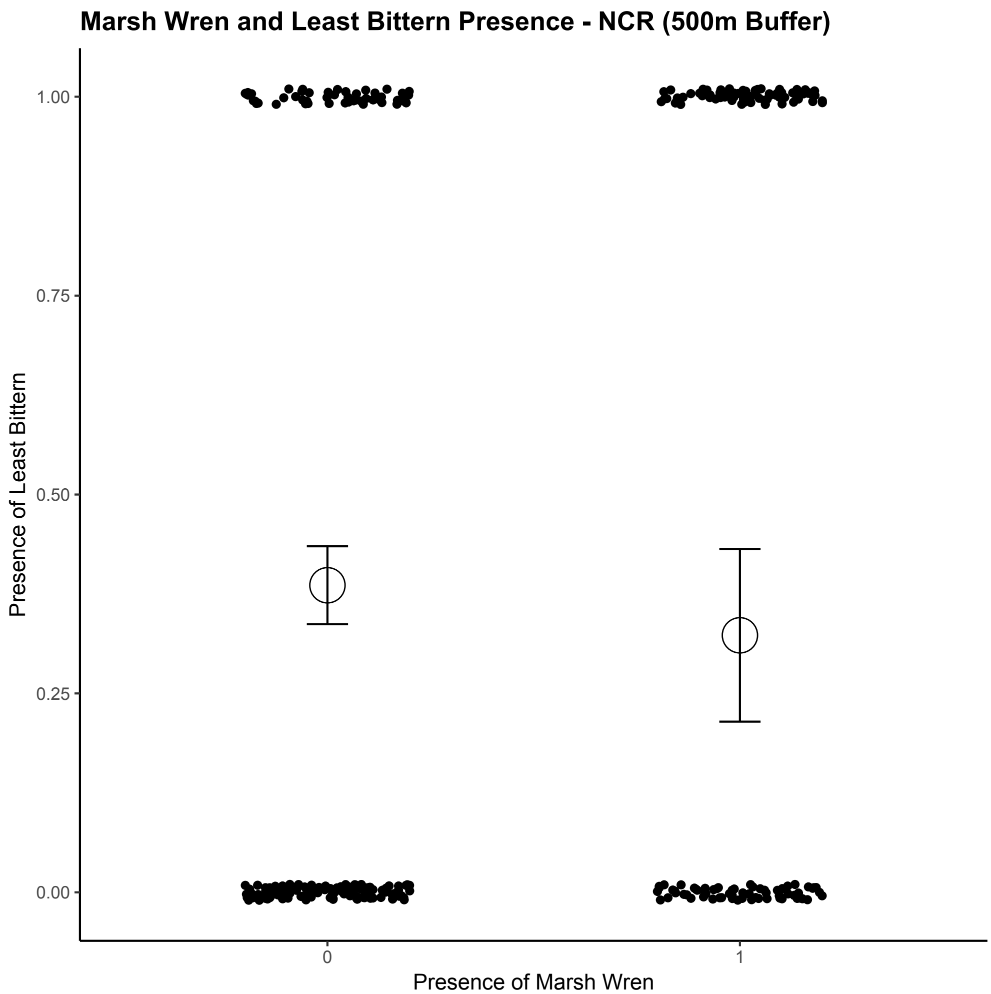

Figure 4: The relationship between marsh wren presence and the probability of least bittern presence (n = 121 sites) in wetlands surveyed across all areas represented in the NCR buffered by 500m. The larger circles are the predicted probabilities (38.6% and 32.3%, respectively) with standard error (+/- 4.90% and 10.9% respectively) from the logistic regression model.

Table 3: The results of the goodness-of-fit tests for the four logistic regression analysis.

Logistic Regression Results			
Test Data	*Chi Square Value*	*Degrees of Freedom*	*P-value*
LEBI Presence at All Sites	40.9	1	$p < 0.0001$
LEBI Presence in the NCR	0.34	1	$p = 0.56$
LEBI Presence at All Sites (buffered by 500m)	25.5	1	$p < 0.0001$

Logistic Regression Results			
Test Data	*Chi Square Value*	*Degrees of Freedom*	*P-value*
LEBI Presence in the NCR (buffered by 500m)	0.53	1	$p = 0.47$

4.0 Discussion:

4.1 Occupancy of Marsh Wren and Least Bittern

There was a significant relationship between the co-occurrence of marsh wren and least bittern once all sites were pooled together (Figure 1). Least bittern was approximately 29% more likely to be present when marsh wren was detected. However, when restricted to the NCR, there was no detectable difference in least bittern distribution based upon marsh wren occurrence (Figure 2). To account for possible false negatives, a buffer of 500 m was placed around least bittern occurrences to approximate territory size. Hence, marsh wren and least bittern occupancy increased slightly but this did not produce a notable change in the results (Figures 3-4). Other explanatory factors such as habitat quality may be better indicators of least bittern occupancy. The wetlands selected for this study were suitable for this study as other studies found similar occupancy proportions.

Both least bittern and marsh wren select wetland habitats which are cattail-dominated, water depth of >30 cm, and have limited anthropogenic disturbance (Hay, 2002; Leonard and Picman, 1987). The marsh wren requires dense emergent vegetation for their nests, foraging behaviours and a water depth greater than one meter to avoid nest depredation (Panci et al., 2017). Least bitterns also require this habitat type for foraging, nesting and avoiding predation (Poole, 2009). All 65 survey sites from this year that were visited twice had these habitat characteristics.

In addition, least bittern require larger territory sizes than marsh wren (Poole, 2009; Kroodsma and Verner, 2013). Least bittern also forage more often at the edge of open water and cattail (Poole, 2009). A positive correlation of the length of this edge habitat and least bittern abundance has been recorded (Timmermans et al., 2008). Hence, least bittern abundance may be dependent upon this variable. However, measuring the length of marsh edges may be difficult as water depth fluctuations could increase or decrease significantly each year and vegetation type could change (i.e. from cattail to shrub). Recent technology such as drones could be used to calculate the edge habitat, which may provide a better indicator of least bittern habitat selection.

Within the NCR, the number of observation sites occupied by least bittern was approximately 19.3% to 18.5% (2016, 2017 respectively) of the surveyed wetlands. This result is similar to Jobin *et al.* (2013) 26% and also Hay (2002) 10.6%. Although marsh wren occupancy is less studied, Conway and Gibbs (2005) found that approximately 30% of survey points had marsh wren. Similarly, this study showed that occupancy of marsh wren was approximately 47.4% and 33.8% in 2016 and 2017 respectively. The large difference in number of sites with marsh wren can be explained by the high water levels in 2017, which greatly reduced available habitat as the cattail was submerged for most of the season in the Shirley's Bay sector. However, across many parts of the Greenbelt there were many areas of unoccupied appropriate wetland habitat for both species

The survey effort in Québec has been sustained between 2004 and 2015, resulting in more robust dataset, although the number of observations is less than the surveys in the NCR. However, the number of least bittern observations in Québec was much greater than the observations within the NCR. Hence, more observations within the Greenbelt may have resulted in more positive results. Compared to the Québec survey, this study was geographically-limited to within the NCR, as such, more productive marshes could not be surveyed. Hence, the Québec survey had more available wetlands to survey and may have chosen sites known for least bittern, skewing these results. However, this study was the first to comprehensively survey least bittern within the NCR.

One of the main differences between the Québec results and the NCR results was the number of least bitterns at each site. If food and habitat is available, least bittern can nest semi-colonially. In Québec, there are some marshes where density of least bittern can be up to 35 breeding pairs (Jobin et al., 2008). However, within the NCR, a maximum of two territories within the same wetland was observed. This may be due to the abundance of food, available nesting sites, amount of emergent vegetation or length of edge habitat (Poole, 2009). In addition, many wetlands deemed suitable for both marsh wren and least bittern within the Greenbelt were not occupied by either species. This may be due to unknown biological limiting factors such as prey abundance, extinction/colonization rates, or predator abundance (Poole, 2009). Other factors such as water quality and anthropogenic disturbance (road noise, disturbance) may also have a role in determining least bittern abundance (Poole, 2009).

Thus, marsh wren should not be used an indicator species for least bittern as least bittern was not more likely to occur in areas where marsh wren was present. Marsh wren may indicate that habitat features suitable for least bittern would be present, but the likelihood of least bittern occurring or being detected in that wetland would not be greater.

4.2 Comparisons between Least Bittern and Marsh Wren Detectability

The detection proportion of re-located marsh wrens was greater than that of least bittern (Table 1). This can be explained either by the higher abundance of marsh wren or by their higher detectability, due to their behavioural characteristics. Marsh wrens are a very vocal species, which is reflected in their increased detectability score (Conway and Gibbs, 2005). Kroodsma and Verner (2013) found that marsh wrens call continuously during the day.

From our observations, marsh wren was detected on multiple occasions at the same site with an estimated detection proportion of 59.0-84.8%. This is higher than our estimated detection proportion of least bittern (between 15.3-25.0%). Conway and Gibbs (2005) found that the probability of detection of marsh wren was approximately 58%, which is similar to the result in Table 1. Another study found that to detect marsh wren within 80% accuracy, only two surveys are necessary whereas to achieve the same percentage of accuracy, six surveys for least bittern would be necessary (Tozer, Abraham and Nol, 2006).

During the surveys in the NCR, the estimated detection proportion of least bittern was between 15.8 and 25%. This was calculated by assuming that least bittern would be present within the same territory over the summer. Despite not knowing the true abundance of least bittern, a maximum of two least bittern territories were observed during the survey period in 2017 within the same wetland complex. Hence, the assumption is that, once detected, there would only one breeding pair within that territory for the summer. This proportion is similar to the detectability results obtained by other studies, which vary between 13% (Jobin et al., 2013), 14% (Conway, 2002), and 25.4% (Bogner and Baldassarre, 2002).

Playback for most wetland species significantly increases their detectability, except for marsh wren (Conway and Gibbs, 2005). Hence, no playback was used during the surveys to determine the presence of marsh wren. The detectability of least bittern has been studied extensively (Bogner and Baldassarre, 2002). There has been much debate whether playback increases the likelihood of least bittern detection (Bogner and Baldassarre, 2002). In particular, this research was used to develop the least bittern survey protocols, which would maximize observer efficiency by determining whether playback of least bittern calls would increase their detection (Conway 2009, Jobin et al., 2011). Although some studies found a decrease or no significant change to least bittern responses, more recent research has shown that playback does increase least bittern detectability (Bogner and Baldassarre, 2002; Conway, 2005; Jobin et al., 2014; Hay, 2006).

4.3 Abiotic and Biological Factors Affecting Least Bittern Populations within the NCR

There are no estimates for the regional population within the NCR, however the total Canadian least bittern population is estimated at 1500 breeding pairs, mostly located within the Great Lakes region, but spread from New Brunswick to Manitoba (Jobin et al., 2013; COSEWIC 2009). There were 23 least bittern territories found within the NCC Greenbelt between 2016 and 2017, an average of 11-12 least bittern territories per year (Table 1). Over those two years, four distinct wetland complexes had multiple least bittern sightings, suggesting that least bitterns returned to the same marsh each year, shown visually in Appendix A. However, observations at sites within the wetland complex showed that previously occupied territories in 2016 did not have any observed presence in 2017 and vice-versa. The population of least bittern may not be sufficient to occupy all suitable wetlands within the NCR. Friis and Meyer (2008) suggested that least bittern may exhibit site fidelity, however given fluctuating water levels, the habitat may not suitable for least bittern each year.

Water levels can fluctuate significantly over each year due to environmental or anthropogenic effects. The St. Lawrence and Ottawa River have been dammed, reducing the water level maxima and increasing water level minima (ORRPB, 2011). Interactions between water levels and available emergent herbaceous vegetation are complex and have not been monitored within the Ottawa region. However, the amount of precipitation in 2017 was much greater than the previous field season. In particular, the Ottawa River flooded areas of available least bittern habitat within the Shirley's Bay sector. Habitat became more available once the Ottawa River water level diminished in mid-June, however territory selection was likely finished by that date. Hence, only four least bittern territories were found compared to six in the previous year.

Conversely, habitats that were deemed suitable for least bittern from aerial imagery did not have sufficient water to support least bittern. Since water depth varies annually, estimating the amount of potential habitat available without verification should be approached cautiously. Out of an estimated 30 wetland complexes, only about 50% had the required depth of water (>30 cm) for least bittern. A berm breach at an impoundment in Québec reduced the number of nesting least bittern pairs from 37 to 15, as the water level dropped significantly (Jobin et al., 2008). Hence, water depth is one of the main habitat requirements for least bittern and can dramatically reduce or increase their breeding success.

4.4. Significance Towards Wetland Management

The similar habitat characteristics for both marsh wren and least bittern are water depth, dense emergent vegetation, and water quality (Jobin et al., 2013). However, differences in territory size, foraging behaviour, and population growth rates between the two species may explain why marsh wren can be present in wetlands where least bittern are absent. These differences could explain the inconclusive result within the NCR. Despite the inconclusive result, marsh wren presence would indicate that the wetland would have an appropriate water depth, dense emergent vegetation, and good water quality for least bittern. These are the strongest factors that indicate the presence of least bittern. Therefore, for species-at-risk surveys and biodiversity monitoring, if marsh wren is present, observers should be aware that the habitat may be suitable for least bittern, even if there are no observations of least bittern. Given the assumptions detailed above, detection rates of least bittern in the NCR were approximately 25%, similar to other studies. Hence, even if the least bittern protocol was followed, there is a high chance of least bittern remaining undetected (Jobin et al., 2011).

Anthropogenic pressures on wetlands such as roads, urban development and agricultural activities negatively affect least bittern by increasing mortality, diminishing habitat and induce changes least bittern behaviour (Hay, 2006). Collisions between least bittern, vehicles and anthropogenic structures like transmission lines and buildings are likely to increase with development (Hay, 2006). Urban expansion can also fragment wetlands by constructing roads, change wetland water regimes by reducing or increasing storm-water run-off from housing developments (Smith and Chow-Fraser 2010a). Furthermore, agricultural activities can lead to increase nutrient-loading in nearby wetlands, promoting the growth of invasive species (Smith and Chow-Fraser 2010a). Road noise may also affect least bittern vocalizations. Noise pollution from vehicles has changed the timing and frequency of bird calls in Europe (Ortega, 2012). In particular, low frequency calls like least bittern are significantly reduced by road noise (Ortega, 2012). Hence, there are many anthropogenic impacts that can affect least bittern within the NCR.

To reduce the pressure of those negative anthropogenic effects, biodiversity monitoring should be continued as species-at-risk form the cornerstone of protecting these wetlands. Biodiversity monitoring of wetland species-at-risk are necessary to determine species-at-risk populations and their critical habitat, which affects anthropogenic land-use and planning. Suitable wetland habitat for least bittern should be recognized, even if they are absent as the population of least bitterns in the NCR may not be enough to saturate wetlands. Marsh wren presence from citizen science (i.e. E-bird.org), breeding bird atlases or other databases could be an indicator that there is potential habitat for least bittern within a wetland. Hence, marsh wren presence could be used to establish priority wetlands to be surveyed since the main attributes of habitat indicators for least bittern would be present, however surveys following the least bittern protocol must be used to determine least bittern presence or absence (Jobin et al., 2011).

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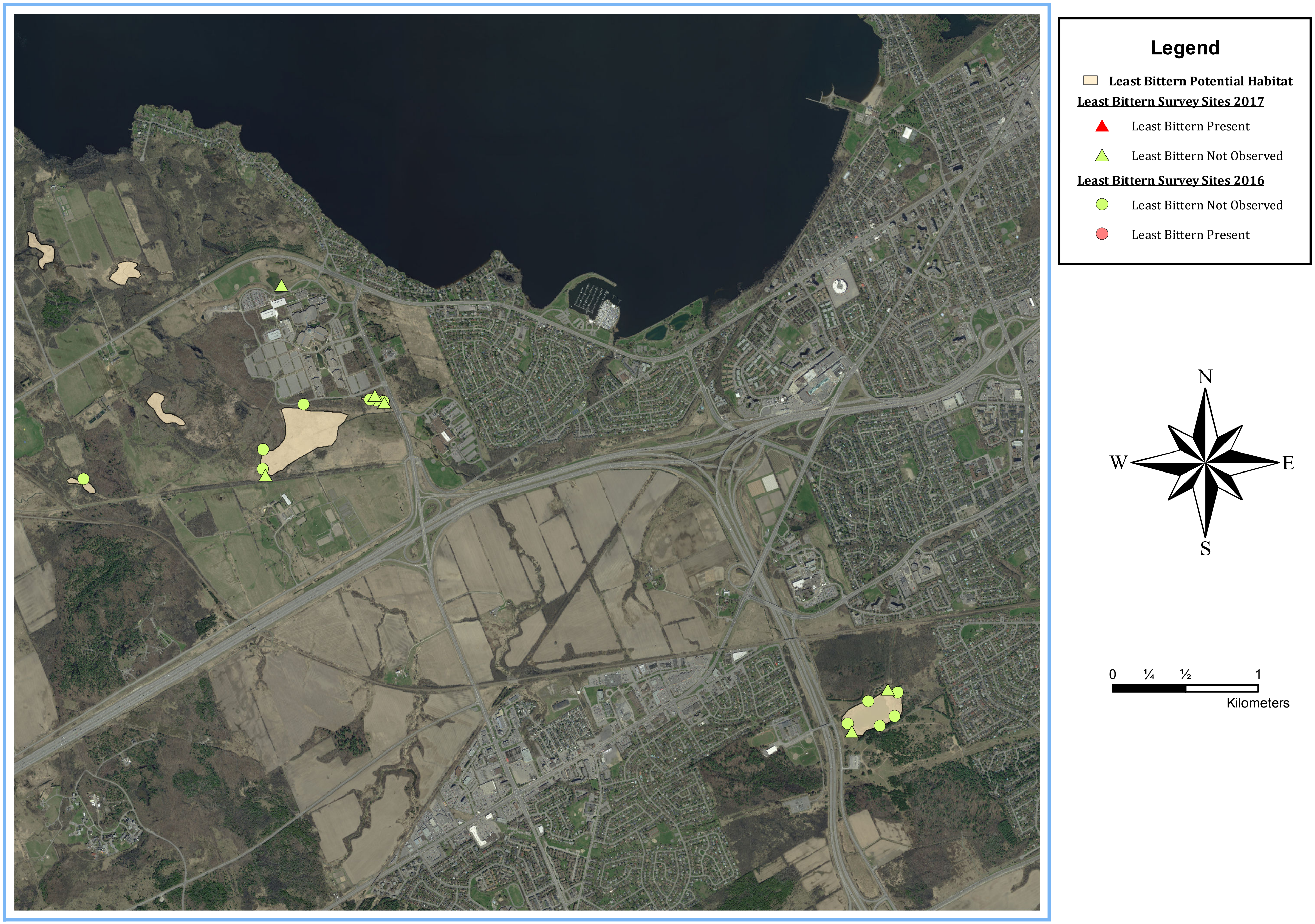
APPENDIX A: SURVEY LOCATION MAPS

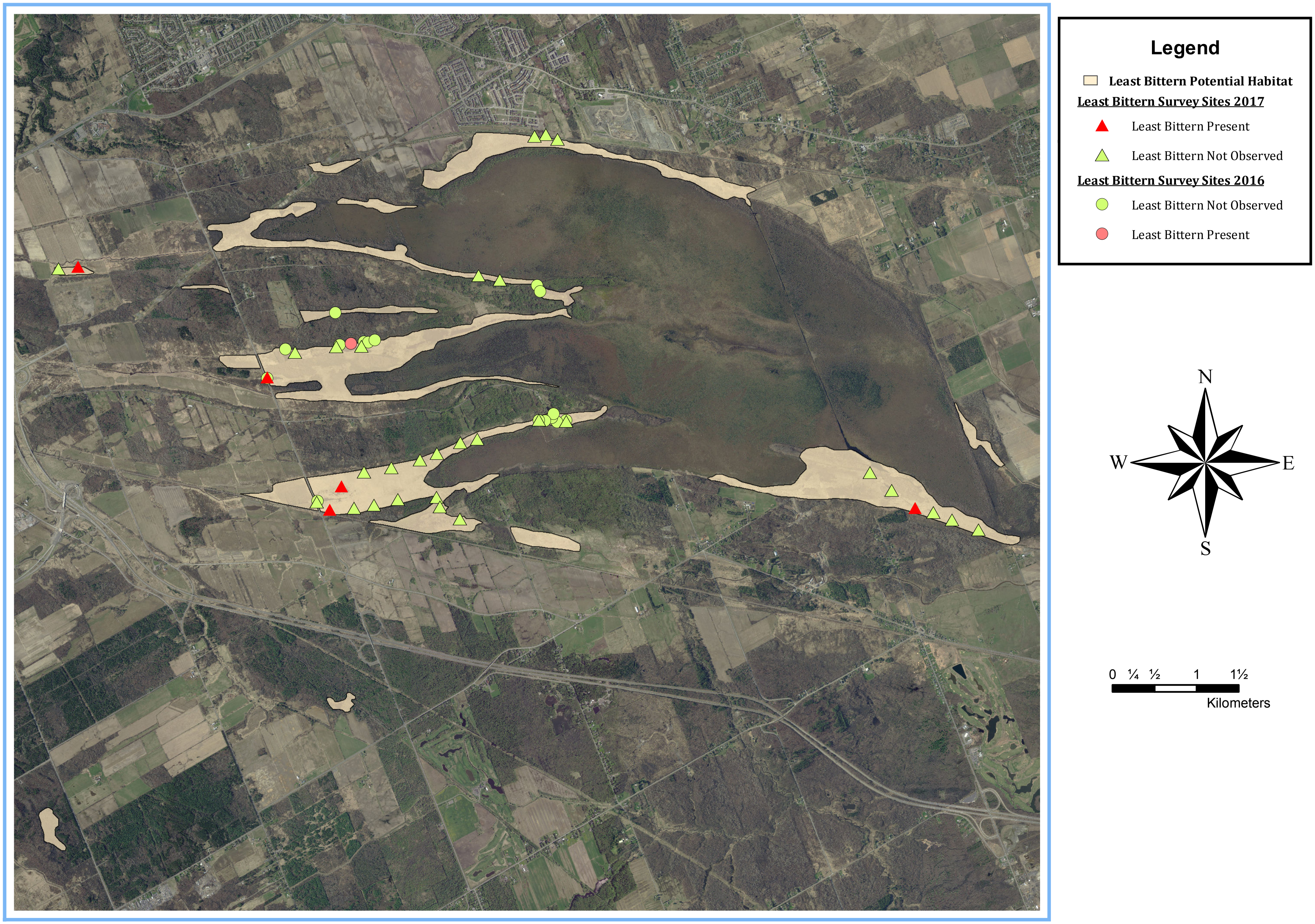
Least Bittern Survey Sites (Shirley's Bay Sector)

Least Bittern Survey Sites (Kanata Sector)



Least Bittern Survey Sites (Stony Swamp Sector)

Least Bittern Survey Sites (Mer Bleu Sector)



APPENDIX B: DATASHEET EXAMPLE

Appendix F: Least Bittern Survey Data Sheet

Canadian Wildlife Service ~ Least Bittern Call Response Survey Field Data Sheet

Site ____________ Station # ____________ Site visit # ____________
Date ____________ Start time ____________ End time ____________
Wind - Beaufort ________ Cloud cover (%) ____________ Temperature ____________
Wind - Direction ________ Precipitation ___ Speaker direction ____________
Observer (see bottom r.h. corner) 1) ______________________ Lat. ____________
2) ______________________ Long. ____________
Ambient noise level (see back of sheet for codes) ____________

Water depth (cm) ____________ Length of stake above water (cm) ____________
Live veg. ht. (cm) (2 m radius) spp1 ____________ spp2 ____________ spp3 ____________
Dead veg. ht. (cm) (2 m radius) spp1 ____________ spp2 ____________ spp3 ____________
Dom. vegetation (5m radius)
Float. vegetation (5m radius) present ☐ spp. and %
Sub. vegetation (5m radius) present ☐ spp.

NOTE: record AMBI, KIRA, LEBI, PBGR, SORA, VIRA and YERA in table

Direction of bird[1]	Species	Sex	Det. before 1st min[2]	Passive[2]					Call[2]					Passive[2]			Det. after 13 min[2]	Call Type(s) (see back)	Distance (m) (0-10, 10-25, 25-50, 50-100, >100)	Detected at a previous station	Comments
				1 min 1 min	2 min 2 min	3 min 3 min	4 min 4 min	5 min 5 min	1 min 6 min	2 min 7 min	3 min 8 min	4 min 9 min	5 min 10 min	1 min 11 min	2 min 12 min	3 min 13 min					

[1] Use arrow to mark direction of bird
[2] Mark 1 for heard, s for seen and 1s for heard/seen

* Record number of LEBI detected outside of survey period between previous, current or next station

(NOTE: count only new birds not recorded during station surveys)

☐ **Other species not recorded**

Other sp. within 100 m

☐ ABDU ________ ☐ BLTE ________ ☐ COYE ________ ☐ NSHO ________ ☐ WISN ________
☐ AMCO ________ ☐ BWTE ________ ☐ EAKI ________ ☐ RWBL ________ ☐ YHBL ________
☐ AMCR ________ ☐ CAGO ________ ☐ GADW ________ ☐ SACR ________ ☐ Other ________
☐ AMGO ☐ COGR ☐ GTBH ☐ SEWR
☐ BBCU ☐ COMO ☐ MALL ☐ SWSP
☐ BCNH ☐ CORA ☐ MAWR ☐ TRES

Miscellaneous notes:

____

____

____

Contact info of primary observer:

List species detected beyond 100 m ______________________

____

____

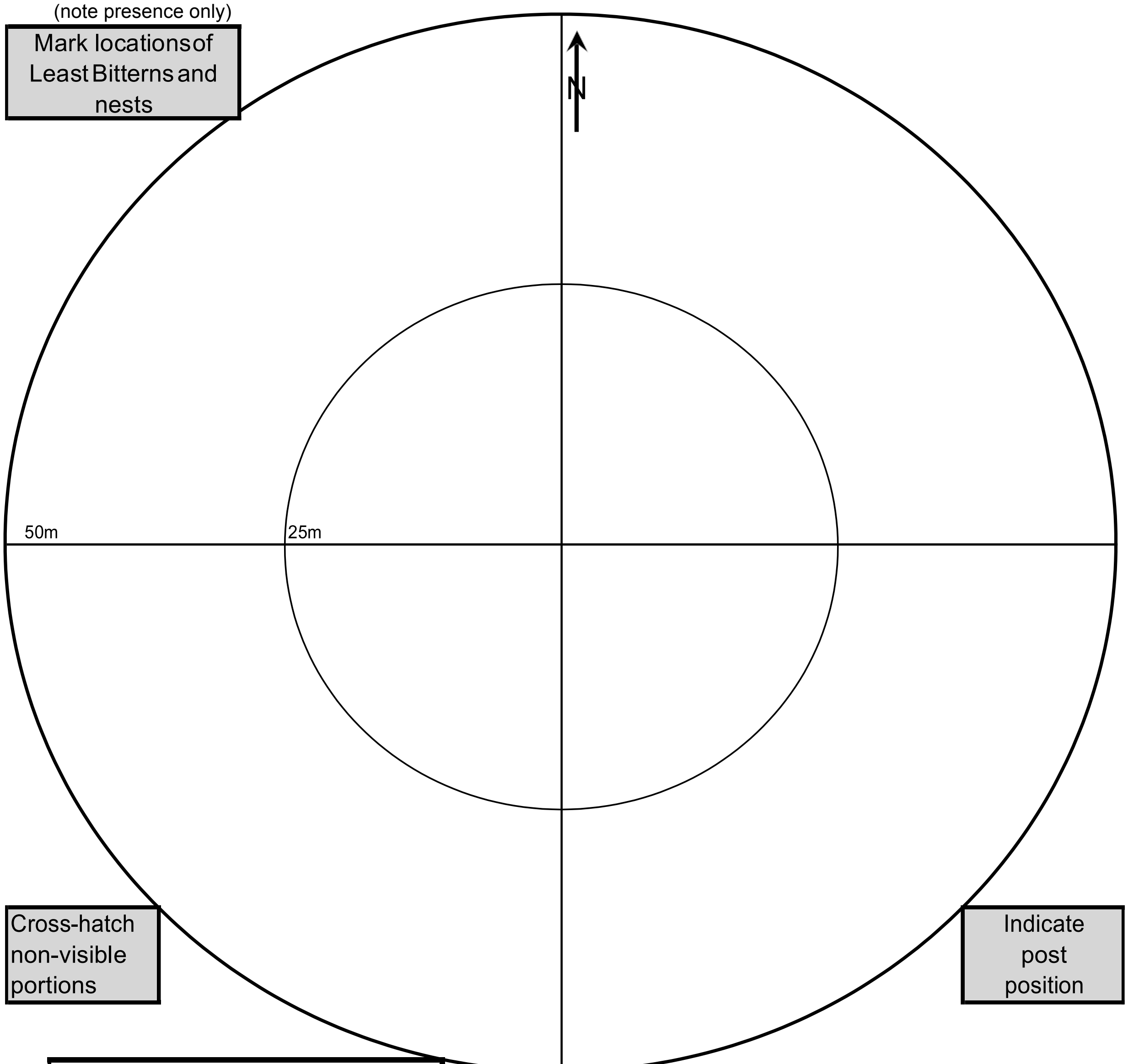
Appendix H: Least Bittern Habitat Assessment Data Sheet

Canadian Wildlife Service ~ Least Bittern Survey Station Habitat Assessment

Percent station cover (50m radius) Site ____________ Station # ____________ Date

Typha	_______	Scirpus	_______	Shrubs	_______	Visit #	__________
Carex	_______	Grasses	_______	Trees	_______		
Sparganium	_______	Phragmites	_______	Bare soil/mud	_______	Observer 1)	__________
% not visible	_______	Others	_______	Open water	_______	name 2)	__________

Invasive species (note presence only) Phragmites _______ P. loosestrife _______ Others __________



Average ht. (50 m radius)												
Species or group	Visit 1 date:			Visit 2 date:			Visit 3 date:			Visit 4 date:		
	Live	Dead	Dens.[1]	Live	Dead	Dens.[1]	Live	Dead	Dens.[1]	Live	Dead	Dens.[1]

% floating veg (relative to open water)												

[1]**High**: Difficult to walk through the vegetation; dabbling waterbirds may be detected but not seen; **Medium**: Walking through the vegetation is possible but damage to standing vegetation occurs; dabbling waterbirds can be seen but not identified to species; **Low**: Easy to walk through the vegetation with reduced or no damage; dabbling waterbirds can be identified

APPENDIX C: STATISTICAL SCRIPT

```
rm = ls()

library(car)
library("stringr")
library("ggplot2")


mydata = read.csv("/Users/alexstone/working_data_lebi.csv")

birdlist = apply(mydata[,33:56], 1, paste, collapse = ",")

mawr = data.frame(t(data.frame((str_split(birdlist, "MAWR")))))

mydata$wren = grepl("MAWR", birdlist)

mydata$wren[mydata$wren == "TRUE"] = 1

mydata$LEBI_2[mydata$LEBI_Presence_1 == "Yes"] = 1

mydata$LEBI_2[mydata$LEBI_Presence_1 == "No"] = 0

myglm = glm(LEBI_2~wren, data = mydata, family = "binomial")

summary (myglm)

summary(myglm)$coefficients[, 2]

logit2prob <- function(logit){
  odds <- exp(logit)
  prob <- odds / (1 + odds)
  return(prob)
}

logit2prob(coef(myglm))

aggregate(test.predict~wren, data = mydata, mean)

intercept <- coef(myglm)[1]
intercept
b_presence <- coef(myglm)[2]
b_presence

logits_survival <- intercept + 1* b_presence
logit2prob(logits_survival)

confint (myglm)
confint.default(myglm)
exp(cbind(OR = coef(myglm), confint(myglm)))

par(mfrow = c(2,2))
plot (myglm)
```

```
mydata.summary <- aggregate(LEBI_2~wren, data = mydata, mean)
mydata.summary$se <- (aggregate(LEBI_2~wren, data = mydata, sd)$LEBI_2)/sqrt(3)

mydata.summary$se <- c(logit2prob(-2.186) - logit2prob(-2.186-0.242),logit2prob(1.757) -
logit2prob(1.757-0.295))
z = logit2prob(1.757) - logit2prob(1.757-0.295)
z
m = logit2prob(-2.186) - logit2prob(-2.186-0.242)
m
mylimits <-aes(ymax = mydata.summary$LEBI_2+mydata.summary$se, ymin =
mydata.summary$LEBI_2-mydata.summary$se)

myplot = ggplot (data = mydata.summary, aes(x = as.factor(wren), y = LEBI_2)) +
  geom_point(size = 4) +
  geom_jitter(data = mydata, aes(x = as.factor(wren), y = LEBI_2), position = position_jitter(width =
0.2, height = 0.01)) +
  geom_errorbar(mylimits, width = 0.2) +
  theme_classic() + xlab("Presence of Marsh Wren") + ylab("Presence of Least Bittern") +
ggtitle("Indicated Marsh Wren and Least Bittern Presence Across All Sites") +
  theme(plot.title = element_text(lineheight=.8, face="bold"))

myplot
anova(myglm, test = "Chisq") # This is a likliehood ratio-test
```