RESOURCE SELECTION OF MALLARDS DURING AUTUMN AND WINTER AT LAKE ST. CLAIR, ONTARIO

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Abstract:

1. Animals select resources to maximize fitness but costs to acquire resources vary because resource quality and quantity are not distributed uniformly in space or time. Differences in wetland management influence resource availability for ducks and mortality risk from duck hunting. The local distribution of the Mallard (*Anas platyrhynchos*) is affected by this resource heterogeneity and variable risk from hunting, but regional conservation strategies focus on the relationship of foraging resources and waterfowl distribution during the non-breeding season. To test if Mallard resource selection was related to the abundance of resources, risks, or a combination, we studied the diurnal and nocturnal resource selection of adult female Mallards during Autumn and Winter.
2. We developed a digital spatial layer for Lake St. Clair, Ontario, Canada, that classified habitats important to Mallards and assigned these habitats a risk level related to ownership type and presumed disturbance from hunting. We monitored 59 individuals with GPS back-pack transmitters prior to, during, and after the hunting season, and used discrete-choice modeling to generate diurnal and nocturnal resource selection estimates.
3. The model that classified habitat types based on available resources and presumed risk best explained Mallard resource selection strategies. Resource selection varied within and among seasons, but ducks selected for federal, state and privately managed wetland complexes that provided an intermediate or relatively greater amount of refuge and resources than publicly accessed habitat type. Across all diel periods and seasons there was selection for federally managed marshes and private supplemental feeding refuges that prohibited hunting.

4. Synthesis and applications. Federal, state and privately managed wetlands either limited or precluded hunting and many private wetlands provided supplemental food for staging ducks. These habitats were selected for during the hunting season and we infer that this selection was based on reduced mortality risk and increased food availability. Therefore, we conclude that Mallard resource selection is related to management of mortality risk, anthropogenic disturbances, and foraging opportunities. Understanding how waterfowl respond to heterogeneous landscapes of resources and risks can inform regional conservation strategies during a period of the annual cycle where anthropogenic mortality risk is substantial.

Key Words:

anthropogenic disturbance, discrete-choice models, GPS satellite transmitters, habitat management, hunting, Lake St. Clair, Mallard, resource selection.

1. Introduction:

Animals select resources of greatest available quality to maximize fitness through trade-offs of costs and benefits. Costs to acquire resources vary because resource quality and quantity are not distributed uniformly in space or time (Madsen 1988; Manly, McDonald, Thomas, McDonald, & Erickson, 2002). Mortality risk is a cost that varies across landscapes but can be reduced by remaining in habitats with decreased predation risks. However, basing habitat use decisions solely upon predation risk could compromise nutrient acquisition if these habitats are of relatively poor quality or if food availability or quality declines over time (Creel, Winnie, Maxwell, Hamlin, & Creel, 2005; Creel, Christianson, Liley, & Winnie, 2007). In highly modified landscapes, managers of private and public lands strive to conserve suitable wildlife habitat while also allowing wildlife-related recreational activities (North American Waterfowl

Management Plan 2012). As such, the balance between wildlife habitat quantity and quality and recreational opportunity, must coincide with life history strategies of those species managers are attempting to conserve.

In North America, regional conservation strategies for waterfowl assume that foraging resources during the Autumn and Winter limit the distribution ducks due to the energetic constraints individuals experience (Soulliere et al., 2007). The amount of energy on the landscape can be estimated to inform managers where deficits exist in local carrying capacity and management practices are implemented to adjust foraging resources to conserve local populations. Often, these management practices are aggregated into wetland complexes, that are areas of several wetlands that provide a variety of resources to meet daily and seasonal needs (Dwyer, Krapu, & Janke, 1979). Therefore, habitat types used by waterfowl (Anatidae) within wetland complexes are variable in food resources but many also provide differences in types of refugia. (Dwyer, Krapu, & Janke, 1979; Merendino & Ankney, 1994). This heterogeneity in foraging resources and refugia influences waterfowl resource selection and movements because during Autumn and Winter, waterfowl hunting can influence distribution as ducks modify movements to avoid risks while still ensuring that daily nutritional needs are met (Fox & Madsen, 1995, 1997; Madsen, 1998; Guillemain, Fritz, & Duncan, 2002; Stafford, Horath, Yetter, Hine, & Havera 2007, Cresswell, 2008). Of the different waterfowl species, Mallards (*Anas platyrhynchos*) are abundant habitat generalist and are exposed to risks and disturbances from hunting because they are the most sought after and harvested waterfowl species world-wide (Baldassarre, 2014; Weaver et al., 2015).

Within the Great Lakes, the Lake St. Clair region of southern Ontario, Canada, is one of the most important migratory stopovers for waterfowl (Fig. 1). The area sustains thousands of waterfowl during Autumn with peak dabbling duck abundance estimates of 123,000–150,000 (personal communication D. R. Luukkonen Michigan Department of Natural Resources, 9 September 2017; Dennis, North, & Ross, 1984; Weaver et al., 2015). Within the counties around Lake St. Clair (Essex, Kent, and Lambton), approximately 98% of the wetlands have been drained or filled (Ducks Unlimited Canada, 2010). Most remaining coastal wetlands are intensively managed for hunting or as inviolate waterfowl refuges. Waterfowl habitat management practices and levels of human disturbance within Lake St. Clair wetland complexes differ and thus provide variable foraging options and risks to waterfowl (Heitmeyer, 2006; Straub et al., 2011). Inviolate refuges, such as the Canadian Wildlife Service National Wildlife Area (hereafter CWS-NWA), provide roost areas of relatively low mortality risk, but food resources could potentially become limited due to greater concentrations of foraging ducks (Madsen, 1988; Guillemain et al., 2002; Stafford et al., 2007; Beatty et al., 2014*a*). In contrast to refuges, public hunting areas expose birds to greater mortality risk, but also may provide greater foraging opportunities due to decreased waterfowl densities. Hunt clubs in private ownership regulate hunting pressure, likely exposing birds to a moderate amount of mortality risks. However, they manage habitats intensively (e.g., supplemental feed and flooded agricultural crops) to offer abundant resources and attract waterfowl. Therefore, the Lake St. Clair region provides a spatially and temporally heterogeneous environment of available resources and hunting pressure and a unique opportunity to study how resource abundance and mortality risk are related to resource selection.

We hypothesized that resource selection was drive not only by resource abundance but the composition of foraging resources (i.e., area of habitat types) and mortality risks from hunting. Therefore, we predict resource selection models representing both resource quality, quantity, and mortality risk will best explain Mallard resource selection. Our objective was to estimate Mallard resource selection based on landscape composition during periods when birds were exposed to, and free from, mortality risks from hunting. Studying Mallard resource selection will inform managers about how ducks of this region select habitats and elucidate how Mallard distribution is related to resource quality, quantity and mortality risks for regional conservation planners.

2. Methods and Materials:

2.1 Study Area:

Lake St. Clair has an average depth of 3 m and connects Lake Huron and Lake Erie within the Great Lakes System (Fig. 1). The lake is bisected by an international border between Canada and the United States. The political jurisdictions of Walpole Island First Nations, the province of Ontario, state of Michigan, and several cities towns, villages, and unincorporated areas surround the lake. Waterfowl habitats in the region include lacustrine wetlands, impounded wetlands, flooded agricultural fields, dry agricultural fields, open lake water, and supplemental feeding refuges where hunting is prohibited within 400 m from the deposit site (Weaver et al., 2015). These habitats are interspersed throughout the landscape in patches that are associated with different management or ownership groups. These groups include: Walpole Island First Nations, public property, private property (predominantly hunt clubs), Canadian Wildlife Service St. Clair National Wildlife Area (CWS-NWA), and the Michigan Department of Natural Resources St. Clair Flats Areas (MICH-DNR, Herdendorf, Raphael, & Jaworski, 1986; Bookhout, Bednarik, & Kroll,1989; Great Lakes Commission, 2006; Weaver et al., 2015).

2.2 Land Classification Data

We used land classification information from the Ducks Unlimited Canada (DUC) Hybrid Wetland Layer Version 2.1.1 as our base layer for all spatial analyses of resource selection (Ducks Unlimited Canada, 2011). This digital layer contains continuous raster land cover data across Canada at a resolution of 38.7 m. We assigned a level of hunting intensity within respective habitat types, based on ownership type because property managers regulate the frequency and duration of hunting activities (daily and seasonally). To estimate property boundaries and ownership type within Ontario, we supplemented the DUC layer with spatial information that we gathered through recording property boundaries with hand held GPS units, Teranet POLARIS Boundary Data for Chatham-Kent, the Agricultural Resource Inventory layer produced by the Ontario Ministry of Agriculture, Food, and Rural Affairs (revised 2010), spatial information from Indian Reserve layer produced by the Ontario Ministry of Natural Resources (2008) and GIS Open Data Website for the State of Michigan. We compiled all land classification data and property boundary data into a single spatial layer (here after, the Lake St. Clair spatial layer) through ArcMap (Environmental Systems Research Institute, Inc., Redlands, CA, USA 10.3

2.3 Habitat Variables

We measured landscape composition of several different land class types for used and available resource units. We grouped the original 12 modified land classes of the DUC spatial layer into three habitat types relevant to foraging and migrating waterfowl (agriculture, water, and marsh) and classified all other habitat types as other. We reclassified cells as flooded agriculture from meeting with land owners along the Canadian shore and having them identify parcels where crops were intentionally flooded for waterfowl use. We also reclassified raster cells as supplemental feeding refuges from buffering locations of supplemental feed by 400 m.

Locations of supplemental feed in Ontario were provided by the Ontario Ministry of Natural Resources and Forestry. All raster cells within 400 m of classified feeding refuges were reclassified as a supplemental feeding refuge. Therefore, after reclassification we used five habitat types to represent foraging habitat composition (agriculture, water, marsh, supplemental feeding refuge, and flooded agriculture; Supp-Table 1.).

To categorize risk associated with ownership of habitat type, we used classifications based on access to hunting. Public property was assumed to be the least restrictive towards the number of hunters allowed access, their frequency, and hours afield. The most restrictive ownership type was the CWS-NWA where hunting was prohibited. The other property types of private, Walpole Island, and MICH-DNR were assumed to be at a risk level that is intermediate of the two extremes as these properties manage the frequency and duration of daily and weekly access but allow hunting. Hunting is prohibited within the 400 m boundary of supplemental feeding refuges, but they are located within private property boundaries with the management goal of attracting waterfowl to be harvested. Therefore, we assigned the level of risk associated with using a supplemental feeding refuge as intermediate level relative to other habitat types. Therefore, our most detailed land classification represented the combination of habitat and ownership type (Table 1.). We did not have similar habitat information for MICH-DNR as we did for the DUC layer and only categorized MICH-DNR as a different ownership type. We estimated the area (ha) of each habitat and ownership type within in each resource unit using ArcMap (Environmental Systems Research Institute, Inc., Redlands, CA, USA 10.3. 1.) and Global Spatial Modeling Environment Version 07.4.0 (Beyer 2015

2.4 Capture and Transmitter Deployment

Within the Great Lakes region, non-breeding season survival of adult female Mallards has been suggested to be a particularly important determinant of population growth (Coluccy et al., 2008). Based on this, and the potential survival implications of non-breeding season resource selection, we only studied adult female Mallards (Palumbo, 2017). In late August and early September of 2014 and 2015, we captured and marked ducks (n = 59) on private property along the Canadian shore of Lake St. Clair (UTM 17 N 383701 E, 4697376 N), using a swim-in baited trap. We determined age as hatch-year (a duck that hatched that calendar year) or after-hatch year (a duck that hatched before the calendar year; hereafter adult) based on wing plumage and retrices (Carney, 1992). We determined sex based on wing coloration and cloacal examination. We inspected wing plumage to determine if ducks had finished molting for transmitter attachment. Of the 2014 cohort (n = 20 ducks), nine adult female Mallards were equipped with 22 g Platform Terminal Transmitters (PTT), NorthStar Science and Technology, LLC, King George, Virginia, USA) back-pack style solar powered Global Positioning System (GPS) transmitters (Model 22GPS). The remaining 11 were equipped with 25 g Groupe Spécial Mobile (GSM) back-pack style GPS transmitters (Model Saker-H, NorthStar Science and Technology, LLC, King George, Virginia, USA and Ecotone Telemetry, Sopot, Poland). PTTs were programed to collect six location fixes per 24 h period while the GSM transmitters were programmed to collect eight fixes per 24 h period. We used a combination of transmitters initially because we did not know how well the cellular network in the study area would enable the GSM transmitters to perform. The GSM transmitters from the 2014 cohort performed very well, therefore due to their greater fix rate and lower cost, the entire 2015 cohort (n = 39) consisted of 25 g GSM back-pack style GPS transmitters. Transmitters were equipped with a 3.5 g Very High Frequency (VHF) transmitter (Holohil Systems Ltd., Carp, ON, Canada) enabling us to determine fate and transmitter status. We trimmed and glued a 3.2 mm neoprene pad to the base of each transmitter as a protective barrier between the feathers and transmitter and attached transmitters dorsally between the wings using a harness of 0.38 cm wide Teflon ribbon (Bally Ribbon, Bally PA, USA; Petrie, Rogers, & Balyoi, 1996; Krementz, Asante, & Naylor, 2011; Krementz, Asante, & Naylor, 2012). The completed harness was one continuous strand of ribbon that included posterior and anterior body loops knotted to connect over the keel (Petrie et al, 1996; Krementz et al., 2011; Krementz et al., 2012). Total transmitter package weight was ≤ 32 g and was ≤ 5% of the body mass of marked ducks (average body mass at capture was 1072.05 ± 21.26 g) as recommended by the guidelines for transmitter mass by the American Ornithologists Union (Fair, Paul, & Jones, 2010). Ducks were released immediately after being equipped with GPS transmitters (Animal Use Protocol 2014–017).

2.5 Temporal Scale

After deployment, we censored the first 4 days of GPS fixes to allow individuals to recover from handling and transmitter attachment (Cox & Afton, 1998). We used legal shooting time to categorize the period of all GPS fixes as either diurnal (if it occurred from 30 min before sunrise to 30 min after sunset) or nocturnal (fixes outside of this time). We monitored ducks until 31 January, the transmitter failed to report fixes, or a duck was reported shot by a hunter (Supp 1). GPS fixes from both monitoring years were combined to increase sample size and we then divided the study data into four seasons to examine differences in resources selection over time. Seasons were based on the 106 day Ontario southern district open hunting season for ducks; PRE hunting season (27 August to 26 September 2014 and 30 August to 25 September 2015); FIRST half of the hunting season (27 September 2014 to 18 November 2014 and 26 September to 17 November 2015); SECOND half of the hunting season (19 November 2014 to 10 January 2015 and 18 November 2015 to 9 January 2016); and POST hunting season (11 January to 31 January 2015 and 10 January to 31 January 2016). We divided the hunting season into early and late periods because food availability, thermoregulatory costs, waterfowl abundance, and hunting pressure all could change substantially during the 106 day waterfowl season. There was no hunting during the PRE and POST hunting seasons.

2.6 Spatial Scale

We restricted the spatial extent of our study to southwestern Ontario and MICH-DNR. To determine the scale of resource selection within this region, and define the size of resource units, we used movement data from all marked ducks (Boyce, 2006). We examined the movement patterns of individuals by calculating the distance between GPS fixes (i.e., step lengths) using ArcMET (Movement Ecology Tools for ArcGIS, version 10.3.1 v1) through ArcMap (Environmental Systems Research Institute, Inc., Redlands, CA, USA 10.3. 1.). To decrease the influence of movements that happened when transmitter and satellite connectivity was substantially less than the programmed duty cycle, we only used intervals that were < 24 hrs apart (Beatty et al., 2014*b*). Also, to decrease the effects of GPS fixes downloaded in errant rapid succession outside of the programmed duty cycles, we only used GPS fixes that were > 2 hrs apart. We calculated the natural log transformation of all step lengths > 0 km to plot the observed distribution of movement distances. We fitted a Gaussian kernel density estimator to the natural log transformed observed distribution using the geom_density function in the ggplot2 package (Wickham & Winston, 2016) of R version 3.3.2 (Beatty et al., 2014*b*; R Development Core Team, 2016).

We classified each GPS fix into one of three spatial groupings based on the straight-line distance from the preceding fix. We partitioned spatial scale categories based on visually identifying breaks in the distribution of the smoothed data (Beatty et al., 2014*b*). We categorized step lengths that were > 0.33 km but < 25 km as local movements. We considered any step length < 0.33 km as a fine scale movement and anything > 25 km as a relocation movement. Our categorized range of local movements was similar to recently published movements for dabbling ducks (0.25–30.0 km; Jorde, Krapu, & Crawford, 1983; Davis & Afton, 2010; Link, Afton, Cox & Davis, 2011; Beatty et al., 2014*b*; Fig. 2). We used only local scale fixes for statistical analysis because movements within this range could be influenced by habitat components similar to 3rd order selection (Johnson, 1980) and our land classification data represented these components.

2.7 Statistical Analysis

2.7.1 *Identifying Choice Sets:* We used discrete-choice models to investigate resource selection at the local scale (movements 0.33–25.0 km) in the Lake St. Clair region (Cooper & Millspaugh, 1999; Thomas, Johnson, & Griffith, 2006; Beatty et al., 2014*b*). Our total sample size was the number of choice sets, where in each choice set, one used resource unit was selected from a group of available resource units (McCracken, Manly, & Heyden, 1998; Cooper & Millspaugh, 1999). To discretely categorize resource units, we plotted all GPS fixes that were at the local scale and within the boundaries of the Lake St. Clair spatial layer. We then over laid a grid system of 2.12 km^2 cells across the Lake St. Clair spatial layer using Global Spatial Modeling Environment Version 07.4.0 (Beyer, 2015) and ArcMap (Environmental Systems Research Institute, Inc., Redlands, CA, USA 10.3. 1.; Thomas et al., 2006; Carter, Brown, Etter, & Visser, 2010) as this was the average step length for all local scale movements (Beatty et al., 2014*b*). We then intersected all local scale GPS fixes with the grid system of 2.12 km^2 cells and grid cells that contained a GPS fix were categorized as a used resource unit. Choice sets included available resource units that were grid cells whose center was within 9.6 km from the center of the used resource unit (Fig. 3). The radius of 9.6 km represented the 97.5^{th} quantile of all step lengths within the local scale movements (Güthlin et al., 2011). We measured the area of landscape composition variables within used and available resource units for each choice set.

2.7.2. _Discrete-Choice Models:_ We used a Bayesian random-effects multinomial logit model, (i.e., mixed logit discrete-choice model), that incorporates each individual as a random effect to account for correlation from repeated observations (Thomas et al., 2006; Beatty et al., 2014*b*). Bayesian random effects models allow for estimating individual and population-level selection coefficients given the observed data (i.e., GPS fixes). We used the modeling approach and discrete choice equation developed by Beatty et al. (2014*b*). We used all possible alternatives in a choice set but the number of alternatives within a choice set varied depending on the location of the used resource unit and the edge of the Lake St. Clair spatial layer. The maximum size of choice set consisted of 69 resource units.

We assumed that all individual level coefficients of all independent variables were normally distributed with population mean centered at zero and standard deviation σ_k to generate population level coefficients. For all hyper-parameters, we assumed prior distributions with $\mu_k \sim Normal(0, 2.786)$ and $\sigma_k \sim t(0, 2, 3)$ truncated to remain positive. These priors assisted with achieving model convergence (Sauer, Link, & Royle, 2005; Gelman, 2006; Thomas et al., 2006). To construct discrete-choice models we identified the independent variables whose area estimates within choice sets were not highly correlated (pair-wise $|r| < 0.8$) using the Pearson correlation matrix for each season and each diel period (Staub, Binford, & Stevens, 2013). This process reduced convergence issues with multi-collinearity but retained variables of biological interest. We fitted 4 separate models per diel period (day, night) for each season (PRE, FIRST, SECOND, POST) for a total of 32 models (four seasons × two diel periods × four candidate models; Supp-Table 2). Each model represented a biological hypothesis that Mallard resource selection was related to either resource abundance, mortality risk, a combination of resource abundance and mortality risk, or was random (Supp-Table 2). We ranked the four candidate models by their deviance information criterion (DIC), the Bayesian analog to Akaike's information criterion (Burnham & Anderson 2002; Spiegelhalter, Best, Carlin, & van der Linde, 2002; Beatty et al., 2014*b*). We calculated ΔDIC values from the top most parsimonious model and used >5 ΔDIC units to determine which model ranked best for each diel period and season (Thomas et al., 2006; Beatty et al., 2014*b*). We were specifically interested in population level resource selection strategies thus we based inferences on the posterior distribution of the population level mean μ_k and its 95% credible intervals for each top-ranking model (Beatty et al., 2014*b*). We further inferred that variables whose 95% credible intervals that did not include zero as being important in the resource selection models (Beatty et al., 2014*b*). We fitted candidate discrete-choice models in JAGS v 4.2.0 using the package R2jags (Su & Masanao, 2015) in R version 3.3.2 (R Development Core Team 2016). We used the function jags.parallel within this package to run three separate chains for all candidate models. The number of iterations, thinning, and burn-in varied per season and candidate model (Supp-Table 3.). We used Brooks-Gelman-Rubin statistic as an assessment of convergence where values <1.1 indicate convergence to the posterior distribution (Brooks & Gelman, 1998; Gelman & Hill, 2007). We standardized all independent variables using two standard deviations ($\frac{x-\bar{x}}{2s}$) to interpret coefficients on a common scale (Gelman & Hill, 2007; Beatty et al., 2014*b*).

3. Results:

We censored two ducks during the first 4 days of monitoring leaving 57 to study Mallard resource selection. We used 42,273 GPS fixes to calculate movement distances. To isolate the local scale movements to be used in the resource selection analysis, we removed 30,571 fine scale movements and 100 relocation scale movements, resulting in 11,602 local scale movements. Of the local scale movements, we removed 1,447 fixes that were beyond the extent of geospatial data. Therefore, our final sample included 10,155 GPS fixes. The number of individuals per season and diel period ranged from 19 to 57 and the total number of fixes per season and diel period varied from 199 to 2,191 (Table. 2). We did not track individual ducks for more than one year.

Based on the Pearson correlation matrix, we removed the CWS-WATER variable as its occurrence in choice sets was highly correlated (r > 0.8) with CWS-MARSH. The top model for every season and diel period was the full model that categorized resource units by area of habitat type and ownership type thus representing a combination of resource abundance and mortality risk. Influential resource selection parameters were variable per season and diel period. During the PRE season, adult female Mallards selection was positively influenced by the landscape composition variables of federally managed marsh (0.91, 95% CI 0.73 – 1.07) and private agriculture (1.87, 95% CI 0.87 – 2.86) during the daytime only. Ducks selected for MICH-DNR (diurnal 0.74, 95 % CI 0.07–1.29; nocturnal 0.66, 95% CI 0.05 – 1.24) , private flooded agriculture (diurnal 0.66, 95% CI 0.52 – 0.8; nocturnal 0.62, 95% CI 0.43 –0.8) , private marsh (diurnal 0.79, 95% CI 0.54–1.04; nocturnal 0.95, 95% CI 0.66–1.24) , private supplemental feeding (diurnal 1.3, 95% CI 1.06–1.53; nocturnal 0.58, 95 % CI 0.28–0.86), private water (diurnal 1.57, 95% CI 1.3 –1.84; nocturnal 1.82, 95% CI 1.54 – 2.11), and public water (diurnal 2.76, 95% CI 1.84–3.77; nocturnal 2.6 95% CI 1.24 – 4.03) during both diel periods. Public marsh was avoided during the day (-1.24, 95% CI -2.1 –-0.53) and selected for at night (0.54, 95% CI 0.08 – 0.95). The posterior distribution for all other variables overlapped zero (Fig. 4).

During the FIRST season ducks began to select federally managed marsh at night (0.7, 95% CI 0.38 – 1), avoiding public marsh during day (-3.12, 95 % CI -4.64 – -1.76) and night (-1.65, 95% CI -2.6 – -0.83), and the shift in the posterior distribution of public water to include zero suggesting that the influence of this variable was not substantial. Ducks also began to select for Walpole Island marsh during the day (1.3, 95% CI 0.31 – 2.17) while avoiding Walpole Island water (-1.34, 95% CI -2.26 – 0.54) and agriculture (-1.27, 95% CI -2.42 – -0.32) at night (Fig. 4). During the SECOND half of the hunting season, ducks selected public water (1.25, 95% CI 0.32 – 2.23) and Michigan water (1.26, 95% CI 0.56 – 1.95) at night. Many of the other landscape composition variables continued to be selected by ducks but the posterior distributions of private agriculture and private marsh, and Walpole Island marsh overlapped zero (Fig. 5). During the POST season adult female Mallards selected federally managed marsh (diurnal 0.92, 95% CI 0.56 –1.28; nocturnal 0.84, 95% CI 0.36 – 1.27), Michigan water (diurnal 1.6, 95% CI 0.13 – 3.13; nocturnal 1.99, 95% CI 0.35 – 3.81) , private flooded agriculture (diurnal 0.36, 95% CI 0.05 – 0.62; nocturnal 0.62, 95% CI 0.23 – 1.06)), supplemental feeding refuges (diurnal 1.58 95% CI 1.23 – 1.93; nocturnal 1.56, 95% CI 0.78 – 2.32), private water (diurnal 1.11, 95% CI 0.64 – 1.57; nocturnal 0.85, 95% 0.28 – 1.366), and public water (diurnal 2.2, 95% CI 0.7 – 3.77; nocturnal 3.29 95% CI 1.46 – 5.24). During the day ducks also selected for MICH-DNR (1.35, 95% CI 0.56 – 1.28) and Walpole Island agriculture (1.1, 95% CI 0.23 – 1.88) while avoiding private agriculture (-3.53, 95% CI -5.76 – -1.39) at night. The posterior distribution of all other landscape composition variables included zero (Fig. 5).

4. Discussion:

A key component to conservation is the consideration of how resource selection is influenced by habitat heterogeneity and anthropogenic disturbances (Beatty et al., 2014*a,* Beatty et al., 2014*b*). Conservation and management of wetland complexes is conducted by a diversity of stakeholders that use various strategies to maximize use, productivity, biodiversity, and to sustain ecological services (Euliss, Smith, Wilcox, & Browne, 2008). Therefore, it is valuable for natural resource managers to understand how animals select resources given the diversity of available habitats, disturbances, and mortality risks. The results of our modeling process support our hypothesis and predication that Mallard resource selection was related to a combination of resource quality, quantity and mortality risks from hunting within the region. Furthermore, the parameter estimates of different variables in our top-ranked models describe how ducks were balancing daily and seasonal trade-offs between habitat resources and mortality risk.

During the hunting season mallards decreased selection for public water which we presumed experienced the greatest use by hunters. In contrast, waterfowl continued to select private water throughout the hunting season. Based on the digital classification of habitat types, private and public water had similar foraging resources but different mortality risks from hunting (Palumbo 2017). Therefore, we suggest that ducks were selecting private water, during the hunting season to benefit from reduced hunting pressure relative to public water (Dooley, Sanders, & Doherty, 2010*a*; Dooley, Sanders, & Doherty, 2010*b*). Also, private marsh and CWS-NWA (i.e., federally managed marsh) provided similar foraging benefits with different amounts of perceived mortality risk. We observed that the area of private marsh became not substantially influential after the FIRST season. We suggest that this response was related to a shift in the balance of trade-offs. This shift is supported with how ducks continued to select for, CWS-NWA, a similar habitat type but with no mortality risk from hunting (Madsen 1988, Dooley et al., 2010a, Doooley et al., 2010b). Disturbances and risks at private marshes may have had a chronic effect on Mallard distribution, making the cost associated with using this habitat type outweigh the benefit over time.

Dry harvested and intentionally flooded agricultural fields provide food that is high in carbohydrates, and readily available for several species of granivorous waterfowl, thus representing a foraging benefit (Stafford, Kaminski, Reinecke, 2010; Pearse, Kaminski, Reinecke, & Dinsmore, 2012). Field-feeding waterfowl generally increase time spent foraging in agricultural fields as weather conditions deteriorate to balance thermoregulatory costs and prepare for migration (Jorde et al., 1983). However, field-feeding waterfowl can quickly deplete food availability in fields, (Foster, Gray, & Kaminski, 2010; .Hagy & Kaminski, 2015) post-harvest treatments (plowing and cultivating) can substantially reduce accessibility of waste grains during that time (Baldassarre and Bolen, 1984; Stafford et al., 2010), and availability may change due to increased snow cover (Schummer, Kaminski, Raedeke, & Graber, 2010), increasing the energetic costs to access this resource. Ducks in our study reduced field use as the season progressed suggesting the benefit of selecting for agricultural fields decreased over time or the cost increased to levels that were not sustainable. Wetland managers on private lands flood unharvested agricultural fields to provide waterfowl foraging opportunities and roosting sites. Despite being hunted and therefore representing a substantial mortality cost, flooded agricultural fields were selected by Mallards both diurnally and nocturnally and throughout the monitoring period (Figs 4–5.) suggesting that ducks were able to navigate the perceived hunting-related mortality risks to access benefits derived from the resource. Flooded agricultural fields provide readily available, accessible and carbohydrate rich foods and afford quality roosting habitat (Pearse et al., 2012).

Wetland managers provide supplemental feeding refuges to attract and hold ducks within their wetland complexes but are prohibited from hunting from within 400 m of the deposit site. To access this habitat individuals are exposed to a relatively moderate energetic and mortality cost of traveling over habitats that are hunted during the day, but these refuges contain a substantial foraging and safety benefit. The dense abundance of corn at the deposit site and variable amounts of other habitat types, allow ducks to satisfy their daily activities (i.e., foraging, thermoregulation, courtship) without needing to relocate to other habitat types where hunting pressure can be substantial. Areas that prohibit hunting are prioritized as critical to waterfowl conservation (Madsen, 1998; Stafford et al., 2007; Beatty et al., 2014*a*), but can be difficult to incorporate in regional conservation strategies due the variability in implementation. These types of habitats in the Lake St. Clair region vary greatly in relative energy density but consistent positive selection by Mallards for these areas suggest benefits derived from these different management practices were important to waterfowl in the region. However, the benefits of selecting these types of habitats are difficult to uncouple between ducks meeting foraging needs, refugia requirements, or both. Our observed influence of non-hunted waterfowl habitats is also most likely conservative. We could only consider supplemental feeding refuges and federally managed properties as inviolate refuges but due to variability in hunting management strategies there most likely were areas free from hunting within other habitat types at various times. For example, the different hunting season duration in Michigan and variable hunting strategies on Walpole Island.

The Lake St. Clair region is characteristic of many areas that have experienced habitat loss and the majority of wetland management occurs on private lands adjacent to government managed complexes. Our resource selection analysis supports the importance of areas protected from anthropogenic disturbance within wetland complexes (Beatty et al., 2014*a*) in addition to providing foraging resources, during Autumn and winter, to conserve local waterfowl population. Regional conservation strategies could benefit from incorporating how waterfowl distribution responds to variables risks in addition to foraging resources, such as those in our study, during the non-breeding season. Furthermore, understanding how these management practices explicitly relate to survival would provide further insight into how management practices are linked to the fitness trade-offs we describe.

5. References:

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6. AUTHOR CONTRIBUTIONS

MP, SP, and MS conceived the study, designed methodology, and acquired funds. MP collected the data. MP, SB, and BR analysed the data. MP led the writing with substantial editorial guidance from SP and MS. All authors made substantial contributions to previous drafts and have approved the final version.

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Figures

Figure 1. Picture of Lake St. Clair within the Great Lakes System.

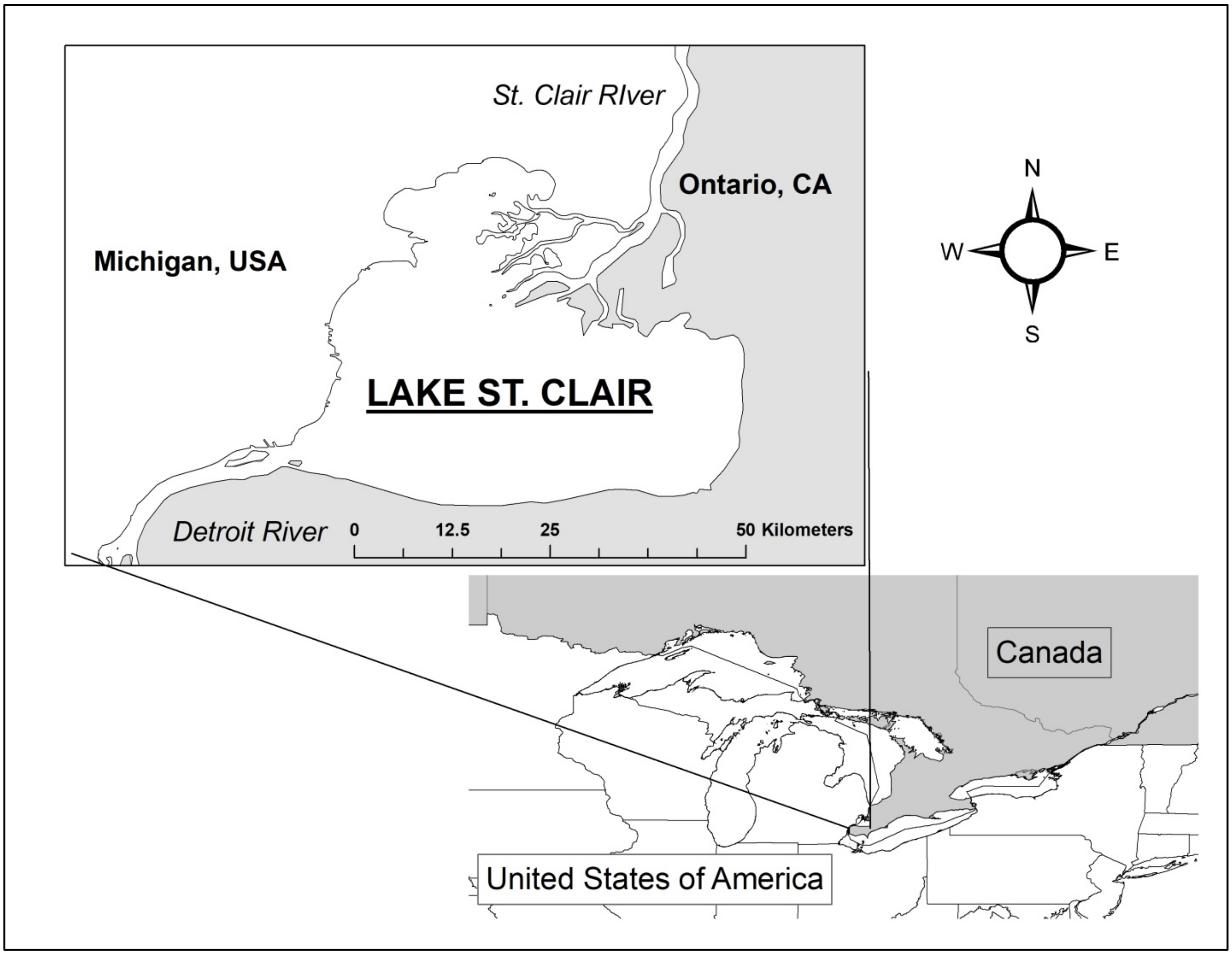


Figure. 2. Spatial scales based on the probability density of natural log transformed step lengths for adult female Mallards during the 2014–15 and 2015–16 monitoring periods. Distance moved corresponds to the natural log of the distance between GPS focal fix *a* and the previous fix *a* – 1, for focal fix *a*. Transformed distances in kilometers are on the x axis.

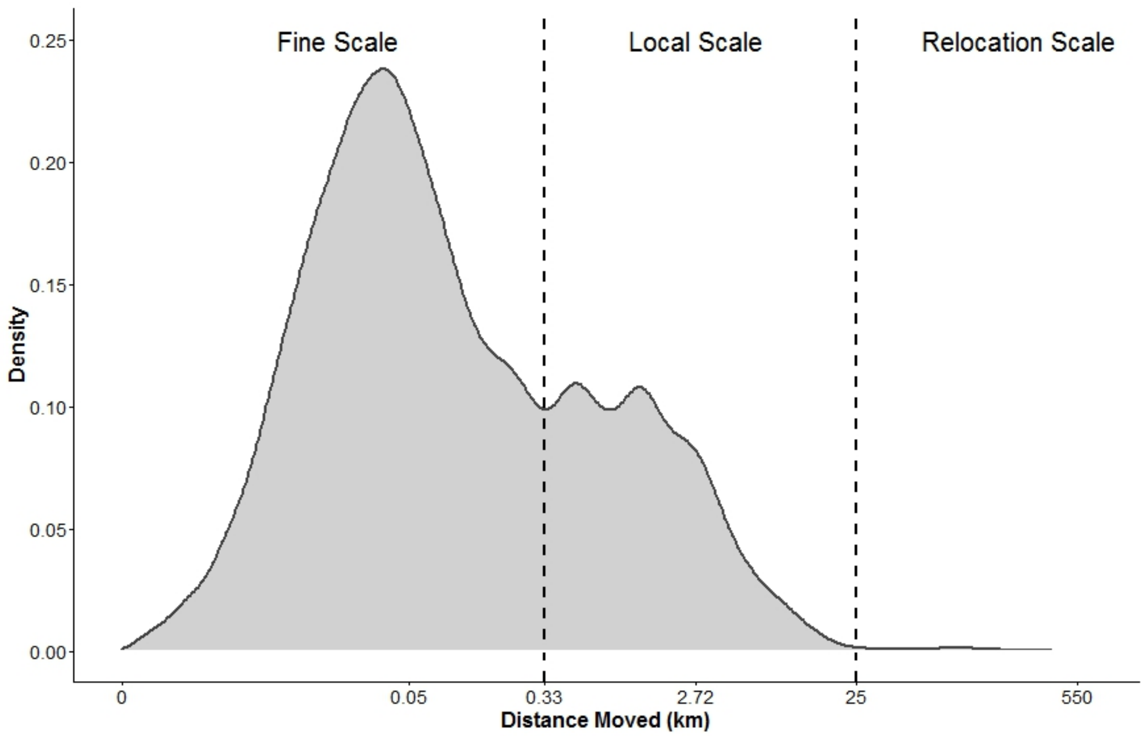


Figure 3. The GPS fixes of the local movements and the grid cells of all resources units used to determine adult female Mallard resource selection within the Lake St. Clair region.

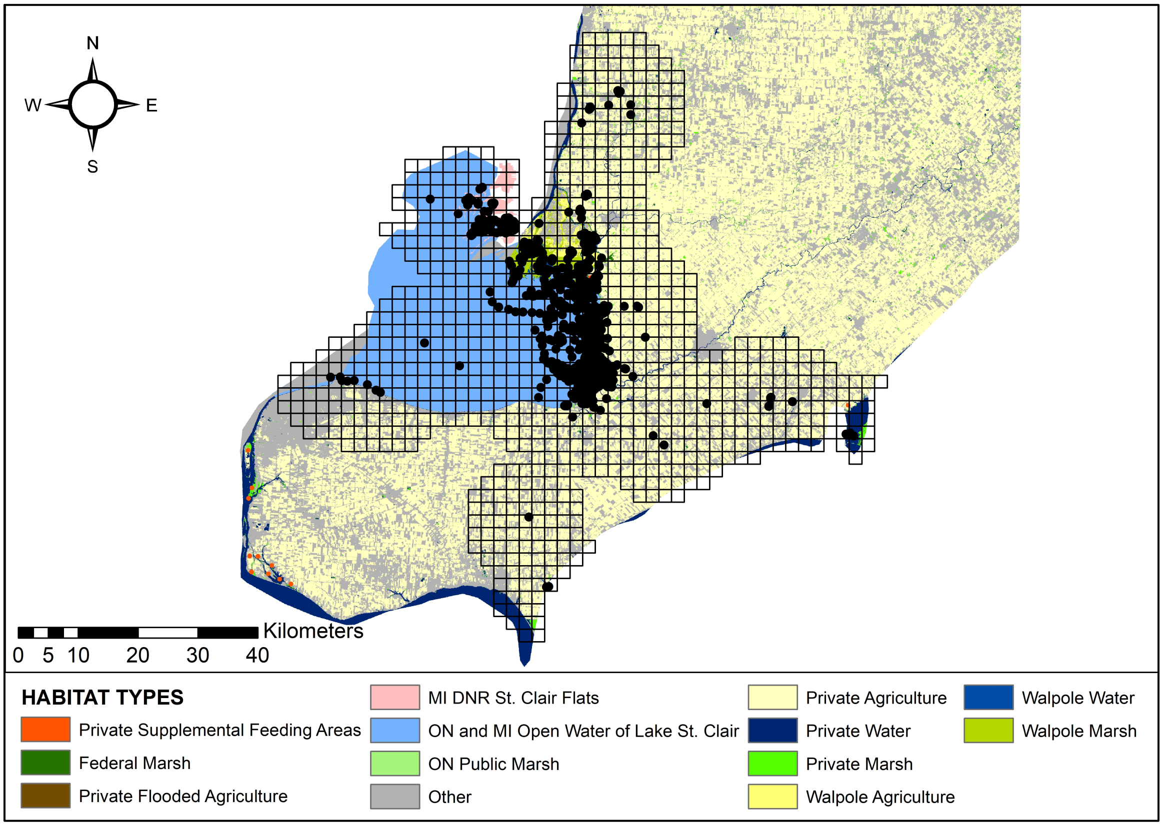


Figure 4. Parameter coefficients and 95% credible intervals for the top ranking discrete-choice models that investigated habitat selection strategies for adult female Mallards during the PRE hunting season (A) and during the FIRST half of the hunting season (B), in the Lake St. Clair region during the 2014–15 and 2015–16 monitoring periods. White circles represent parameter estimates of diurnal models and black circles represent parameter estimates of nocturnal models.

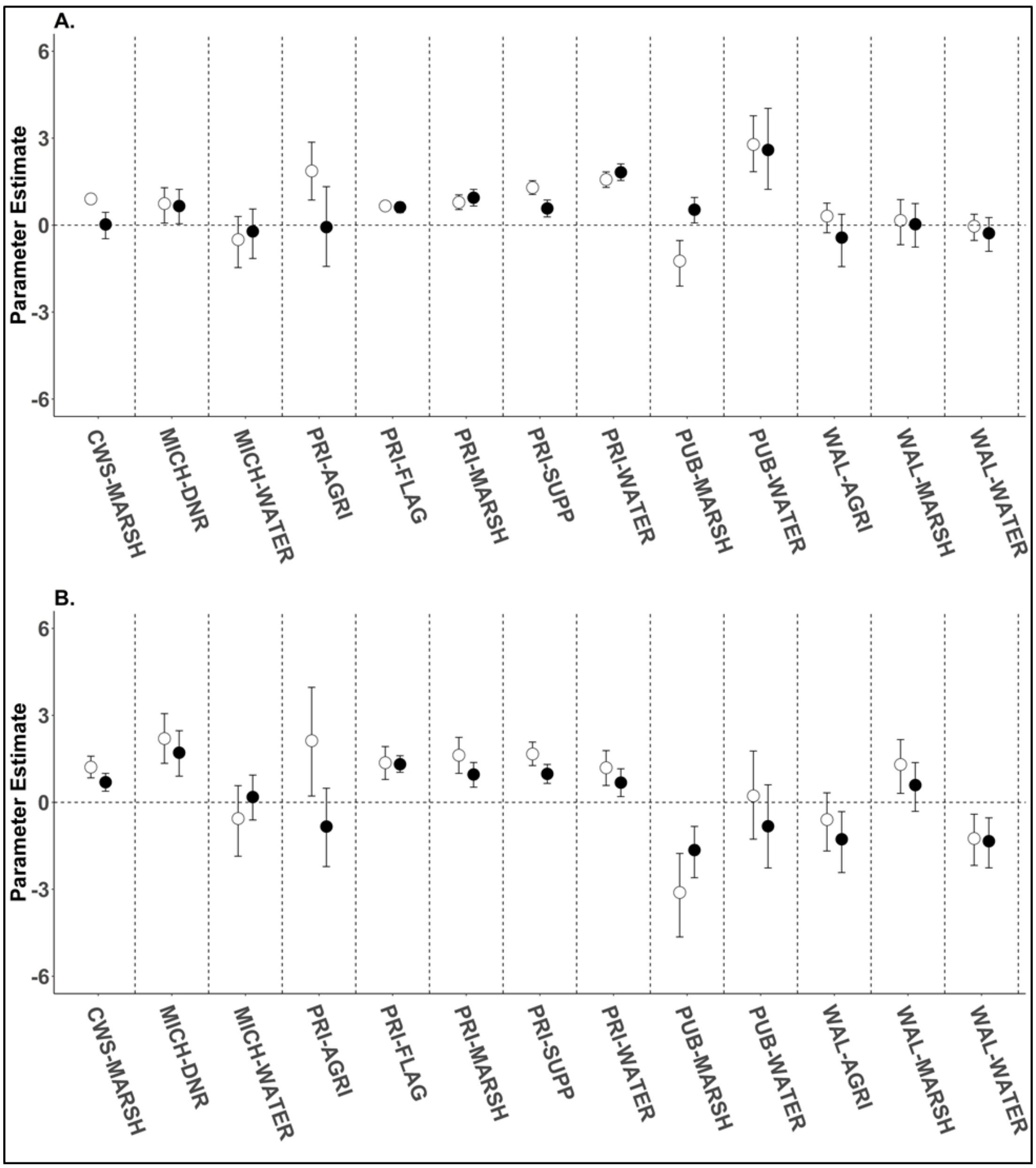
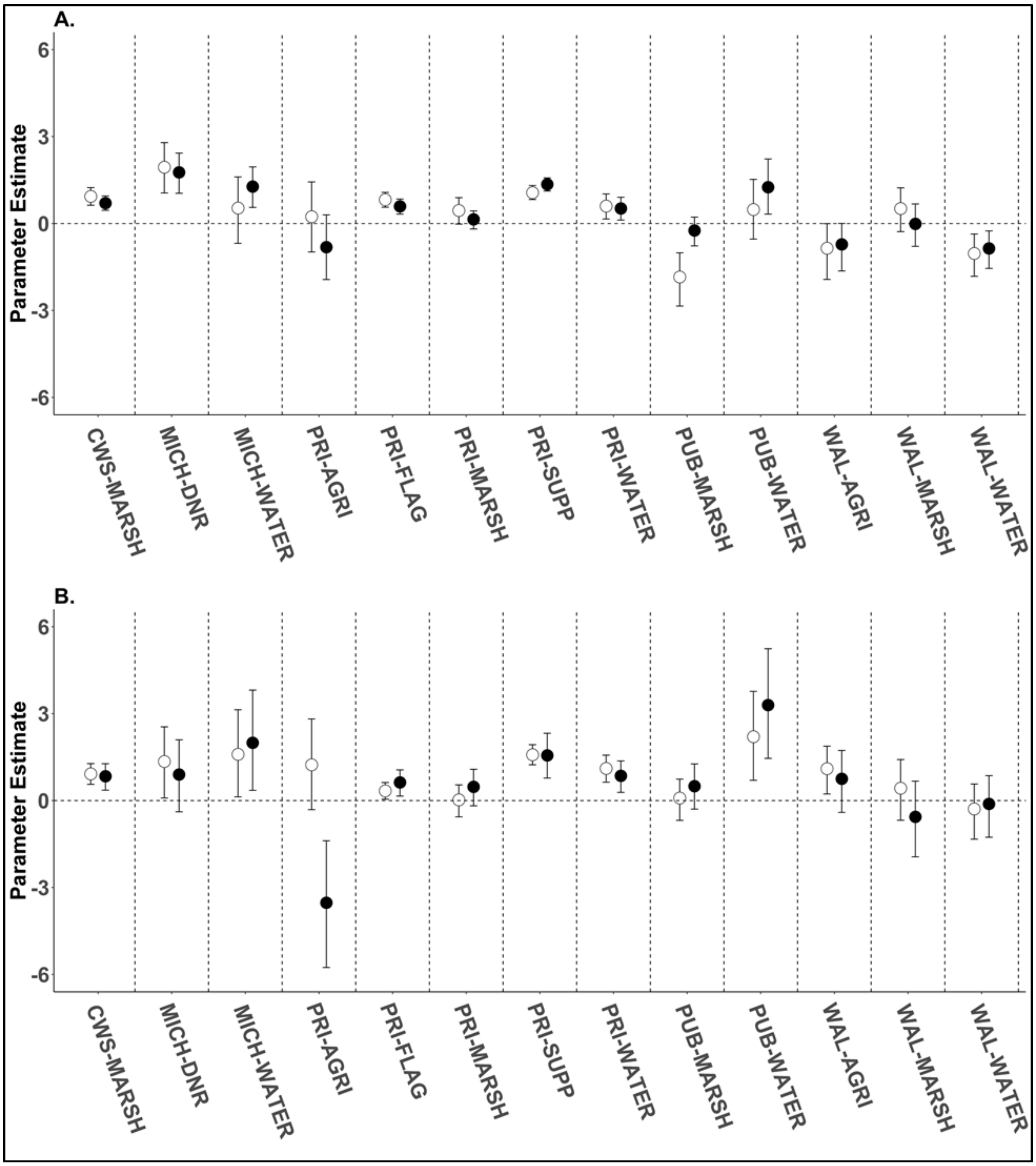


Figure 5. Parameter coefficients and 95% credible intervals for the top ranking discrete-choice models that investigated habitat selection strategies for adult female Mallards during the SECOND half of the hunting season (A) and during the POST hunting season (B), in the Lake St. Clair region during the 2014–15 and 2015–16 monitoring periods. White circles represent parameter estimates of diurnal models and black circles represent parameter estimates of nocturnal models.



Tables

Table 1. List of variables, variable abbreviations for model specification, variable description, and available area used for all resource selection models of Mallards in the Lake St. Clair region during autumn and winter of 2014–15 and 2015–16.

Variable	Variable Abbreviation	Variable Description	Area (ha)
Michigan St. Clair Flats	MICH-DNR	Area of property managed by the Michigan Department of Natural Resources within the St. Clair Flats	4,548.95
Public Water	PUB-WATER	Area of water in Lake St. Clair that is accessible to the public.	77,796.36
Private Water	PRI-WATER	Area of water under private management in southwestern Ontario	9,904.84
Walpole Island Water	WAL-WATER	Area of water under Walpole Island management	1,325.88
Michigan Water	MICH-WATER	Area of Lake St. Clair that is on Michigan side of the lake	27,759.99
Public Marsh	PUB-MARSH	Area of marsh in Lake St. Clair that is accessible to the public in Ontario	201.55
Private Marsh	PRI-MARSH	Area of marsh under private management in southwestern Ontario	2,448.56
Walpole Island Marsh	WAL-MARSH	Area of marsh under Walpole Island management	6,307.78
Federal Marsh	CWS-MARSH	Area of marsh under management of the Canadian Wildlife Service	308.40
Federal Water	CWS-WATER	Area of water under management of the Canadian Wildlife Service	20.26
Private Flooded Agriculture	PRI-FLAG	Area of flooded agriculture under private management in southwestern Ontario	167.93
Private	PRI-SUPP	Area of supplemental feed under private	926.54

Supplemental Feed		management in southwestern Ontario	
Private Agriculture	PRI-AGRI	Area of dry agriculture under private management in southwest Ontario	161,110.09
Walpole Island Agriculture	WAL-AGRI	Area of dry agriculture under Walpole Island management	3,899.30

Table 2. Descriptive statistics of adult female Mallard GPS transmitter data during 2014–15, and 2015–16 monitoring years, including season period, diel period, number of individuals (*IDs*), sum of fixes (*N*), mean fixes per individual ($\bar{x}$), standard deviation (SD), and range of fixes per individual, that were used for resource selection analyses.

Season	Diel Period	*IDs*	*N*	$\bar{x}$	SD	Range
PRE	Diurnal	57	1724	30.25	13.86	2–59
	Nocturnal	56	771	13.77	7.97	1–35
FIRST	Diurnal	51	2191	42.96	24.76	1–99
	Nocturnal	50	1895	37.9	21.03	1–76
SECOND	Diurnal	42	1550	36.9	18.19	1–73
	Nocturnal	41	1583	38.61	18.22	1–81
POST	Diurnal	19	242	12.74	7.86	1–26
	Nocturnal	19	199	10.47	7.09	2–27