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## Resource Selection, Survival, and Departure of Adult Female Mallards From The Lake St. Clair Region During Autumn And Winter

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A thesis submitted in partial fulfillment of the requirements for the Doctor of Philosophy degree in Biology

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## Abstract

During autumn and winter, mallards (*Anas platyrhynchos*) maximize fitness through their spatiotemporal distribution to avoid mortality risks while balancing trade-offs to access foods to undergo migration and maintain homeostasis. Thousands of mallards use Lake St. Clair as it is an important, but threatened, migratory staging area in the Great Lakes. My goal was to understand how mallards were selecting resources in the region and potential relationships of selection strategies. My objectives were to estimate resource selection of adult female mallards, in relation to perceived risk of hunting mortality, and determine if selection strategies were related to survival and timing of departure. At Lake St. Clair, I equipped 59 adult female mallards with GPS back-pack transmitters to monitor resource selection and movements from 27 August to 31 January 2014–15 and 2015–16. I used discrete-choice modeling to determine if mallard resource selection strategies were best explained by composition of habitat type (i.e., quality) and ownership type (i.e., presumed level of mortality risk). I observed selection for habitat types managed by the Canadian Wildlife Service, private landowners, and Michigan Department of Natural Resources throughout the monitoring period. I classified these habitat types as low to moderate mortality risk. The area of public water was selected for prior to and after the hunting season and classified as high mortality risk, suggesting that disturbances and mortality risks from hunting could have influenced selection. I used time-to-event analysis to determine how diurnal selection estimates were related to mortality risk and probability of regional departure. As mallards selected public water, mortality risk decreased during the non-hunting season, but increased during the first half of the hunting season. Probability of departure decreased with selection for public water across the second half of the hunting season and post hunting season. Selection for Walpole Island water was related to an increase in mortality risk and departure probability across seasons. As mallards selected for private water, departure probability decreased during the second half of the hunting season, but increased during the post hunting season. My research describes how mallards select resources in a heterogeneous landscape of resources and risks.

## Keywords

Cox proportional hazard, discrete-choice modeling, hunting, Kaplan-Meier, Lake St. Clair, mallard, migratory departure, resource selection, survival, waterfowl.

## Co-Authorship Statement

Drs. Scott Petrie and Michael Schummer provided technical guidance throughout the duration of the study which included assisting with conceptualizing the study, facilitating funding for research, and providing editorial comments on the writing. They will be listed as second and third author on the publication of Chapters 2–4.

Dr. Ben Rubin provided technical assistance with data analysis for Chapters 2–3 and will be included as a co-author on these chapters.

Dr. Simon Bonner provided technical assistance with data analysis on Chapter 2 and will be included as a co-author on this chapter.

Dr. John Benson provided technical assistance with data analysis on Chapter 3 and will be included as a co-author on this chapter.

## Dedication

To my dad, who passed away shortly after starting this endeavor.

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## Chapter 1

# 1 AN INTRODUCTION TO RESOURCE SELECTION, THE GREAT LAKES MALLARD POPULATION, AND THE LAKE ST. CLAIR REGION

## 1.1 Resource Selection Strategies

Natural selection favours individual animals that exploit habitat resources to maximize survival and reproduction (hereafter fitness, [Fretwell and Lucas 1970, Manly et al. 2002, Johnson 2007]). Fitness benefits derived from use of resources varies based on availability, quality, strategy and experience to acquire, and associated cost (e.g., travel time, accessibility, competition, and risk of predation including harvest). Thus, habitat selection affects fitness because food, energy budgets, and survival can differ greatly among habitats and resource use strategies employed by animals (Stephens et al. 2007).

Foragers should avoid risks of predation unless risk of starvation is substantial (Lima and Dill 1990, Werner and Anholt 1993, Lima 1998, Cresswell 2008). Remaining in habitats with limited predation risks will reduce predation-related mortality, but may be deleterious (Creel et al. 2007) if food quantity or quality are limited (Creel et al. 2005). Alternatively, moving among habitats may increase predation risk by increasing exposure while traveling or being in unfamiliar surroundings. The decision to relocate between habitats can potentially provide a trade off or benefit by allowing access to more or greater quality food. Predictability of risks influence an animal's likelihood of behavioural modification to increase survival (Lima and Dill 1990). The variation in timing of predator activity can cause temporal variation in foraging risk and behaviour (Cresswell 2008, Creel and Christianson 2008). For example, birds can modify timing of movements to avoid mortality risks (e.g., human recreational hunting) and disturbances (e.g., human presence) when the timing and locations of these events are predictable (e.g., regulation of recreational hunting seasons, [Cresswell 2008]). Overall, temporal and spatial variation in resource availability and predation risk can influence space-use and movement decisions.

During autumn and winter, many waterfowl species are hunted, which can influence their distribution and abundance (Madsen and Fox 1995, Fox and Madsen 1997, Stafford et al. 2007, Lancaster 2013). Shooting and human movement among habitats can influence spatiotemporal distribution of waterfowl because birds seek spatial refugia (i.e., areas with limited human activity) and modify timing of feeding flights to avoid perceived threats (Fox and Madsen 1997, Madsen 1998, Guillemain et al. 2002, Creel et al. 2005, Lancaster 2013, St. James et al. 2013). For example, in Denmark Madsen (1988) observed waterfowl space-use during years of relatively moderate and intense shooting. Waterfowl staged in areas where shooting was prohibited and relocated to areas where shooting occurred, after daily hunting hours (i.e., at night). Also, during the year of more intense shooting disturbance, the refuge areas experienced greater rates of food depletion due to increased concentrations of waterfowl and waterfowl departed the area earlier, presumably to reduce risk and find resources elsewhere.

While disturbance-related declines in food accessibility can affect habitat use, they can also influence cues for migration departure as waterfowl are acquiring nutrients for migration. Obligate migrants are species that depart before food resources become limiting and in anticipation of deteriorating conditions. Departure is proximately caused by changing photoperiod as a surrogate indicator of declining resources and harsh weather (Gwinner 2003, Dingle and Drake 2007). Obligate migrants winter in areas of relatively stable habitats and resources leading to the adaptation of recognizing this consistent cue. In contrast, facultative migrants depart in response to increasing thermoregulatory costs (energy expenditure theory) and decreasing food abundance (energy acquisition theory, [Alerstam and Christie 1993, Newton 2010]). These cues evolved in facultative migrants that winter in areas of relatively less stable habitats and resources, and therefore variability in weather conditions and food availability influence migration chronology (Newton 2010). Dabbling duck species (genus *Anas*) have been suggested to possess a range of obligate and facultative strategies based on body size and life history traits (Schummer et al. 2010, Baldassarre 2014).

Many dabbling ducks are facultative migrants, thus abiotic factors such as weather are migration cues and influence how these birds use wetland complexes at different

latitudes. Researchers anticipate that habitats at the northern edge of the winter range, such as the Great Lakes, will become increasingly important to wintering facultative migrants due to changes in migration chronology in response to a predicted rise in air temperatures and decreased snow cover (Schummer et al. 2010, Notaro et al. 2014). This potential increase in use of northern wetland habitats occurring concomitantly with continued habitat loss and decreased habitat availability due to disturbances could affect the regional distribution and concentrations of waterfowl.

The mallard (*Anas platyrhynchos*) is a facultative migrant and is a good fit to investigate resource selection and how it is related to survival, and migratory departure from a region because these behaviours are presumed to be related but these relationships have not been commonly quantified. Also, mallards use a diversity of wetland and terrestrial habitats and exhibit flexibility among individuals in their movements between roosting and foraging areas and are subject to the disturbance of hunting as they are the most harvested duck in North America (Baldassarre 2014).

## 1.2 Resource Selection Analysis

Studies of the relationships between habitat and wildlife populations have been part of wildlife management since its foundation (Strickland and McDonald 2006). A primary driver for these studies was the need to describe resource selection strategies to inform habitat management. It is assumed that since individuals select greater quality resources over lesser quality resources and resources are not uniformly available throughout the environment, that habitat use varies and changes in response to spatiotemporal changes in availability.

Habitat selection differs from habitat use in that selection can only be inferred by comparing used resources to available or unused resources. Furthermore, use is concluded to be selective when resources are used disproportionately to their availability (Manly et al. 2002). To quantify this relationship, Manly et al. (2002) defines the amount of resources that are used by an animal in a given period of time as the usage of a resource. The availability of resources is the amount of the resource that is accessible to that animal in the same period of time.

Identifying used resources units (i.e., a quantifiable amount of use) is usually based on some observation made by the investigator from a sample of individuals; for example, the space deemed occupied by an individual using radio telemetry locations (Boyce and MacDonald 1999) or the observed presence of an individual based on signs of its previous occupancy, such as the presence of fecal pellets (Murray et al. 1994).

Identifying what the animal considers available is a difficulty inherent to most research selection studies, because researchers must try to approximate how individuals perceive the landscape (McClellan et al. 1998, Buskirk and Millspaugh 2006, Forester et al. 2009). Most definitions of availability are separated into a hierarchical spatial scale of the species geographic distribution, an individual's local distribution (i.e., home range) within the species geographic distribution, to habitat patches or resource units within the local distribution, or to selection of specific features (e.g., food items) within the habitat patches or resource units (Johnson 1980, Buskirk and Millspaugh 2006).

How researchers define resource availability for an animal is important as it can affect results and interpretation of analyses (Johnson 1980, McClellan et al. 1998, Boyce et al. 2003, Baasch et al. 2010). Resource selection studies are increasingly including knowledge of how animals move through the landscape (e.g., distance between observations) to assist in defining availability, as it is less subjective than previous methods (Arthur et al. 1996, Cooper and Millspaugh 1999, Rhodes et al. 2005, Forester et al. 2009). In addition to understanding the spatial scale of what resources are used and are available to animals, the temporal scale of when resources are used and area available is also important. For example, mallards monitored in the Mississippi Alluvial Valley during winter switched between diurnal and nocturnal habitat types at different propensities depending on what habitat type they occupied during the day (Davis and Afton 2010). Annual variation in habitat selection may also occur since environmental conditions fluctuate and influence space-use (Boyce 2006).

Technological advances of monitoring (e.g., GPS transmitters) enables researchers to compile large detailed data sets on space-use of individuals. However, for individuals, information that is gathered close together in time and space is likely to be more similar than observations that are further apart (Boyce 2006, Fieberg et al. 2010, Dale and Fortin

2014,). These observations are considered auto-correlated, which implies that they are not independent, and this lack of independence can increase the possibility of a type I error (Dale and Fortin 2014). Additionally, repeated observations on the same individual are likely to be correlated due to individual heterogeneity. Auto-correlation is central to spatial and temporal phenomena and is part of the variability in the process of how animals are making decisions that need to be understood (Olivier and Wotherspoon 2005, Boyce 2006). There are several analytical techniques to explain and incorporate auto-correlation in resource selection analyses, including autoregressive models, mixed-modeling, and creating extra covariates to account for spatial or temporal auto-correlation (Hebblewhite and Merrill 2008, Zuur et al. 2009). Furthermore, mixed modeling or using individual specific random intercepts and slopes in resource selection analyses allows for the inclusion of unbalanced designs which can result from inconsistent location fixes from telemetry data and individual heterogeneity (Gillies et al. 2006).

The statistical techniques to analyze resource selection data have a common goal of understanding how animals use resources compared to what is available to them in the environment (Johnson 1980, Dunn and Braun 1986, Aebischer et al. 1993, Cooper and Millsbaugh 1999, Manly et al. 2002, Kranstauber et al. 2012). Many of these statistical techniques are within the approach of resource selection probability functions (RSPFs) which are functions that generate probabilities of use for disparate resource units. Conceptually, this approach fits when the resource being considered is part of a finite population of  $N$ , used and unused, available units. This population of units is characterized by certain values of vector  $\mathbf{x}$  (Manly et al. 2002, Thomas and Taylor 2006). Not all study designs and statistical models allow for the estimation of a RSPF, rather some limitations allow for the generation of only a resource selection function (RSF). The limitation is to whether or not all resource units can be identified and categorized as used or unused (i.e., a census), as opposed to taking only a sample of resources units. When all available resource units can be identified and designated, used and unused, errors in estimating the RSPF only come from a stochastic process. Thus, a RSF is a model that generates values proportional to the probability of use of a resource. Further, the RSF allows resource units to be ranked relative to use, but the probability of use itself cannot be estimated (Boyce et al. 2002, Manly et al. 2002, Thomas and Taylor 2006).

Discrete-choice models are useful analytical tools that are increasingly being applied to estimate RSFs (Cooper and Millspaugh 1999, McDonald et al. 2006, Beatty et al. 2014). They are founded in economic utility theory where utility can be analogous to satisfaction. These models therefore assume that individuals are acquiring this “satisfaction” from selecting certain resources. The benefit is unknown, but fitness related, such as safety from mortality risks or increased energy intakes, and is assumed to be a function of the resources. Therefore, it is assumed that an individual will choose resources that maximize this benefit when presented with a set of resources. This assumption is the theoretical foundation for discrete-choice estimation of resource selection processes (Cooper and Millspaugh 1999).

The set of resources presented to an individual is considered a choice set and constitutes all possible resources available at a specific location and time. Thus, a benefit of a discrete-choice model is the choice sets can vary in space and time (Cooper and Millspaugh 1999). Further, discrete-choice modeling allows for inclusion of attributes of the decision maker (e.g., sex, age, or body size of the individual being monitored) in addition to the attributes of the potential choices (McCracken et al. 1998). The theoretical framework of fitness benefits derived from choices made and the flexibility of changing the choice sets makes discrete-choice models an appropriate method to investigate how mallards are selecting resources among variable habitats and variable risks of mortality from hunting.

### 1.3 Great Lakes Mallards

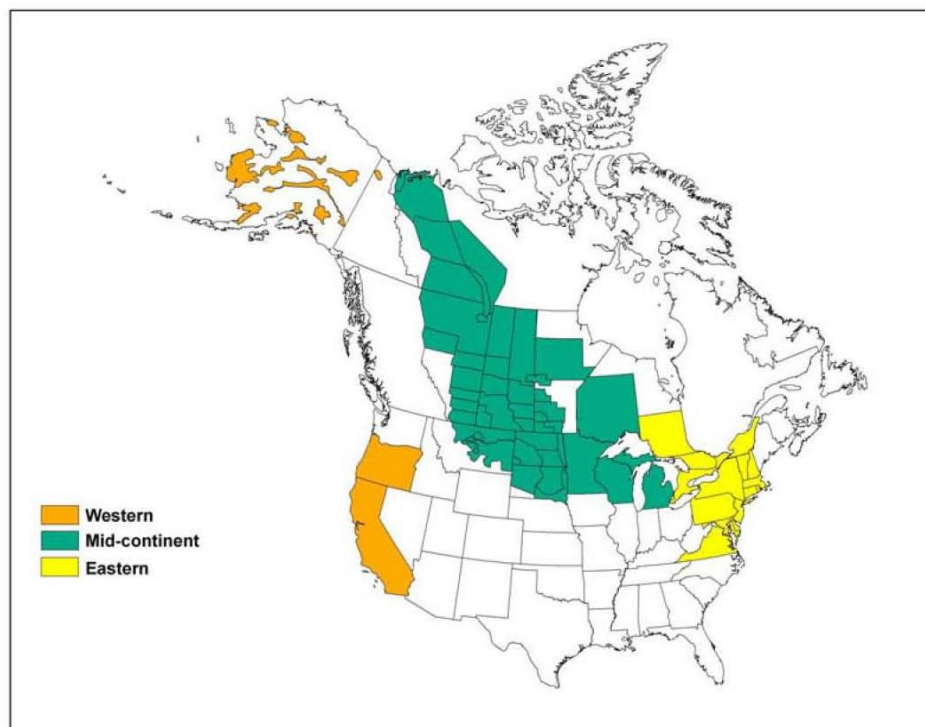
In North America mallards are the most studied waterfowl species. Each spring, since 1955, the United States and Canada undertake the Waterfowl Breeding Population and Habitat Survey which is a coordination of aerial surveys with ground observations to determine mallard and other waterfowl abundance (Zimpfer et al. 2015). Since 1960, approximately 6 million mallards have been individually marked with leg bands and >1 million recoveries reported. These data form the basis for the decision-making framework of adaptive harvest management, which determines the annual allowable take of mallards (Williams and Johnson 1995). Harvest regulations are determined each year based on



estimates of population size, reproduction, and compensation for harvest mortality (Nichols et al. 1995).

For continental management of the mallard there are three recognized breeding populations: the western, mid-continent, and eastern stocks (Figure 1–1. U.S. Fish and Wildlife Service 2016). A substantial amount of research has focused on mid-continent mallard populations and has been the basis for many waterfowl management strategies (Krapu et al. 2000, Hoekman et al. 2002, Devries et al. 2003). Despite this body of research, harvest information suggests that mallards from the Great Lakes region, which border the eastern population, could be separate from the greater mid-continent population (Figure 1–1. U.S. Fish and Wildlife Service 2016). Compared to other mid-continent mallards, the Great Lakes population experiences different environmental conditions, uses different habitats, and is influenced by different population drivers (Anderson and Henry 1972, Munro and Kimball 1982, Zuwerink 2001, Coluccy et al. 2008).

In eastern North America mallard populations have increased their range and numbers since the 1970s, and this trend is assumed to include mallards within the Great Lake states (Wisconsin, Michigan, Illinois, and Ohio) and southern Ontario (hereafter collectively referred to as the Great Lakes region, [Heusmann 1992, Sheaffer and Malecki 1996, Van Horn et al. 2016, Coluccy et al. 2008]). Mallards are important within the Great Lakes region as they are the most harvested waterfowl species and harvest derivation indicates that most of the harvested birds were hatched locally (Munro and Kimball 1982, Zuwerink 2001, U.S. Fish and Wildlife Service 2016). However, mallards staging and breeding within the Great Lakes region have received much less research attention than other mid-continental mallards.



**Figure 1–1 U.S. Fish and Wildlife Service Adaptive Harvest Management survey areas assigned to western, mid-continent and eastern stocks of mallards.**

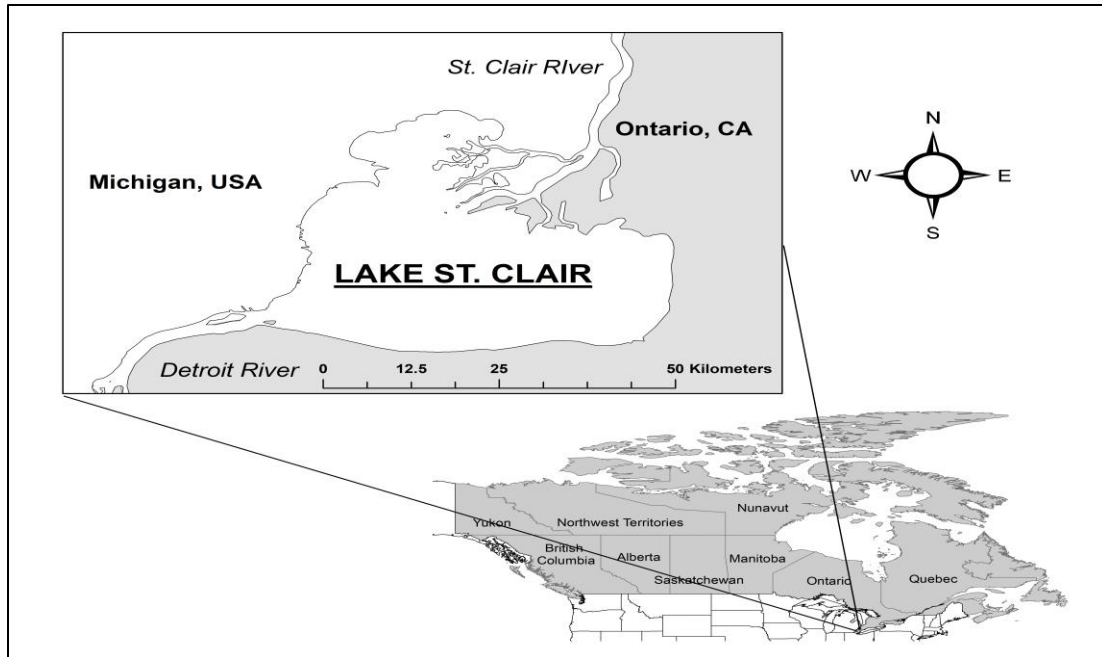
Research pertaining to other mid-continent mallards has revealed that population growth for these birds is most sensitive to changes in nest success and female survival during the breeding season. (Hoekeman et al. 2002). Complementary research has been conducted within the Great Lakes region to determine important population drivers based on the distinctions of the other mid-continent and Great Lakes mallards (Simpson et al. 2005, Coluccy et al. 2008). Coluccy et al. (2008) determined through their sensitivity analysis that non-breeding season survival of adult females, duckling survival, and nest success constitute the majority of the variation in population growth, each representing 36%, 32%, and 16%, respectively. Compared to other mid-continent mallards, the Great Lakes population was more sensitive to changes in non-breeding season survival of adult females (Hokeman et al. 2002, Coluccy et al. 2008).

Understanding how vital rates affect populations is essential for effective management. While duckling survival and nest success are important vital rates of Great Lakes mallards, non-breeding season survival of adult female mallards is the single most

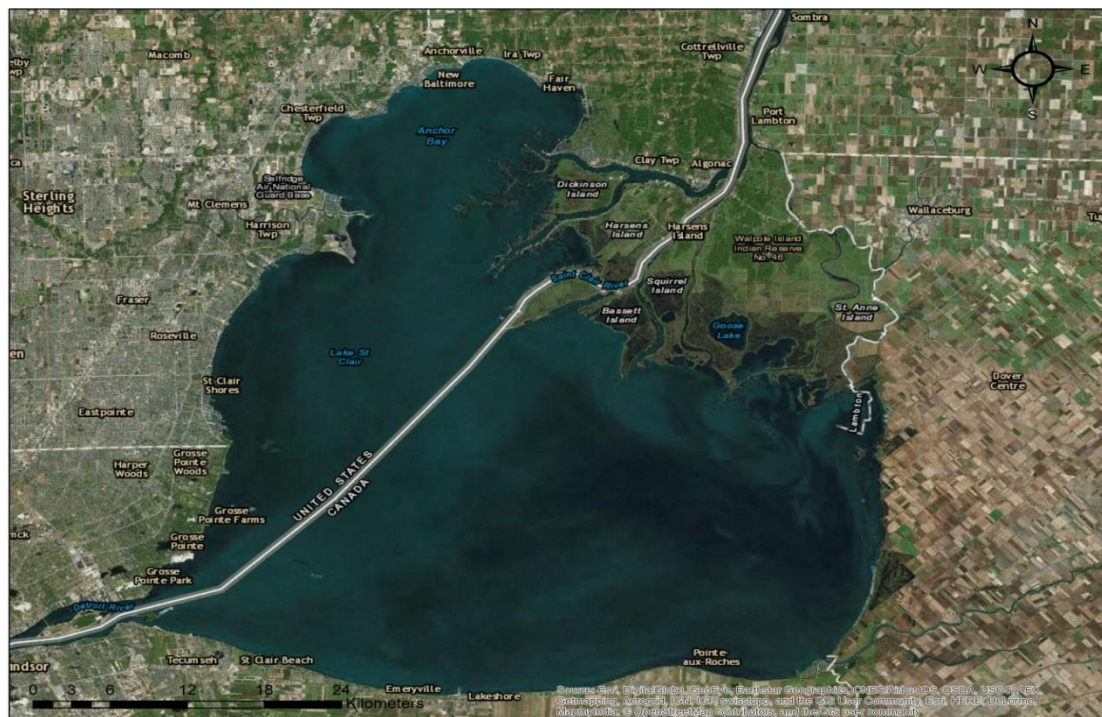
influential determinant of population growth. It has been suggested that conservation efforts to increase nest success would be challenging due to low nest densities and the difficulty of restoring and managing large blocks of grassland habitat within the fragmented landscapes of the region. In contrast, targeted conservation programs (e.g., wetland restoration and enhancement) towards increasing duckling survival have been suggested to have the potential to influence population growth based on its relative sensitivity. Population management of Great Lakes mallards through adaptive harvest management has been suggested, but there is a need to further understand the relationships between harvest and population dynamics (Coluccy et al. 2008) as well as between harvest and regional space-use (i.e., resource selection).

## 1.4 Description of the Lake St. Clair Region

The Great Lakes make up the greatest reservoir of freshwater on earth. The 5 lakes include a coast line that extends  $> 15,100$  km, cover an area of  $246,568$  km<sup>2</sup>, and contain approximately  $25,000$  km<sup>3</sup> of water. Within the Great Lakes system, Lake St. Clair is the smallest lake, and is not considered a Great Lake itself, but a connector lake between the outlet of Lake Huron via the St. Clair River and the Detroit River to Lake Erie (Figure 1–2 and 1–3, Environmental Systems Research Institute, Inc. Redlands, CA, USA). The lake is a shallow heart shaped basin with an average depth of 3 m, a maximum depth of 6.4 m (excluding the navigation channel), and a volume of  $4$  km<sup>3</sup>. A 29 km long navigation channel connects the St. Clair River to the Detroit River and is dredged to 8.2 m. The lake has a drainage basin of  $16,900$  km<sup>2</sup> and a surface area of  $1,110$  km<sup>2</sup>. The length of the shoreline is 496 km (Herdendorf et al. 1986). Within 10 km of the shoreline there are approximately 16,919 ha of marsh and 14,813 ha of forest and shrub communities (Great Lakes Commission 2006). The lake is bisected by an international border which includes the political jurisdictions of the Canadian and United States federal government, Walpole Island First Nations, the Province of Ontario, the State of Michigan and many cities, towns, villages and unincorporated areas.



**Figure 1–2 Picture of Lake St. Clair within the Great Lakes System.**



**Figure 1–3 Picture of Lake St. Clair and surrounding area in Ontario Canada, and Michigan, United States. Sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and GIS User Community.**

### 1.4.1 Historical Land Use Change

The land on the Canadian side (Essex, Chatham-Kent, and Lambton counties) of Lake St. Clair is premier farmland which generates more than half of Ontario's gross farm revenue. These agricultural lands established in the 1800's make up 75% of the region. Past and predicted land-use trends indicate that farm sizes, farming intensity and the number of non-farming residents are increasing in rural areas (Great Lakes Commission 2006). Overall, the agricultural trend is toward larger more efficient operations with integrated production and distribution which results in less agricultural waste grain available for waterfowl. Settlement of the area and agricultural production has resulted in approximately 98% wetland loss in southwestern Ontario and  $\geq 40\%$  loss of the wetlands directly associated with the lake (Great Lakes Commission 2006, Duck Unlimited Canada 2010).

Land use on the U.S. side of Lake St. Clair is driven by the growth in population, households, employment, income and their relationships with government policies. St. Clair, Macomb, and Wayne counties border the western shores of Lake St. Clair in Michigan. St. Clair County is 40% farm land divided between crops and livestock. Within Michigan, Macomb County ranks third in population size while being the ninth smallest county. Wayne County is the nation's eighth most populous county with 2 million residents primarily in the metropolitan Detroit region. The predominant land use in southeast Michigan is manufacturing with developed areas increasing 17% from 1990 – 2000. Of the newly developed land, 88% has been converted from agriculture and contributed to a 13% loss in the regions agricultural land, indicating that new development primarily occurs in agricultural areas (Great Lakes Commission 2006). Over 5,000 ha of wetlands on the Michigan side of Lake St. Clair have been lost since the late 1800's (Herdendorf et al. 1986).

Walpole Island is part of the homeland of the Potawatomi, Ottawa, and Ojibwa people who collectively are the Three Fires Confederacy. Most households on Walpole Island are indirectly or directly involved with hunting, fishing, and trapping activities. The foremost industry is recreational tourism and the second largest is agriculture. The Walpole Island First Nation largely consists of six islands in the St. Clair delta along the

international border of the St. Clair River. These islands are Walpole, Bassett, St. Anne, Squirrel, Seaway, and Potawatomi which collectively consist of 140 km of shoreline. Walpole Island First Nations is approximately 23,472 hectares with 43% classified as agriculture and 30% as wetland (Great Lakes Commission 2006). Of the upland communities, tallgrass prairies have been reduced from 730 ha to 470 ha primarily due to the absence of fires, conversion to agriculture, and expanding forest communities. Oak savannas have been reduced from 570 ha to approximately 360 ha while deciduous forests have increased by nearly 400 ha. The 12,000 ha of wetlands on Walpole Island represent one of the largest wetland complexes in region. Since 1910 approximately 6,240 ha of marsh has been drained and converted to agriculture (Great Lake Commission 2006).

#### 1.4.2 Upland and Wetland Communities

The St. Clair Delta (hereafter Delta) is the largest delta within the Great Lakes system. The combination of sediments discharged from the St. Clair River and a shallow receiving basin has formed the Delta. Outside of the Delta, most Lake St. Clair coastal marshes occur along the eastern shore of the lake from Mitchell's Bay to the Thames River in Ontario. There are also coastal marshes in Anchor Bay between the Delta and the Clinton River, in Michigan (Herdendorf et al. 1986, Bookhout et al. 1989, Weaver et al. 2015). The eastern and southern shore is largely cultivated leaving sparse native communities and primarily impounded wetlands composed of open water and submergent and emergent vegetation (Weaver et al. 2015).

Along the Canadian shoreline and extending inland 10 km between Mitchell's Bay and the Thames Rivers there are approximately 2,305 ha of wetlands. These wetlands are predominately submerged aquatic beds (19%), cattail (*Typha* spp., 38%) and *Phragmites* spp. (33%), but also contain some shrub wetland (9%), and forested wetland (1%) (Weaver et al. 2015). Coastal wetland plant communities include wild celery (*Vallisneria americana*), pickerel weed (*Pontederia cordata*), Eurasian water-milfoil (*Myriophyllum spicatum*), water smartweed, (*Polygonum amphibium*), muskgrass (*Chara asp*), cattails (*Typha* spp.), *Phragmites* (*Phragmites australis*), bulrushes (*Schoenoplectus* spp.), sago pondweed (*Potamogeton pectinatus*), and yellow water lily (*Nuphar advena*) [Herdendorf

et al. 1986]). Approximately 39% of the privately-owned marshes along the Canadian shore are impounded, have water control structures, and are maintained for waterfowl hunting (Bookhout et al. 1989). The remaining marshes are either federally managed as refuges, extend into the lake or are on private property not maintained for waterfowl hunting. Dominant plants within impounded marshes are cattail (*Typha* spp.), *Phragmites* (*Phragmites australis*), duckweed (*Lemna minor* and *Spirodela polyrhiza*), water-milfoil (*Myriophyllum* spp.), and bladderwort (*Utricularia vulgaris*). Along the Canadian side of the lake there are 2,432 ha of agriculture land within 10 km of the shore (Herdendorf et al. 1986, Weaver et al. 2015). The primary crops are corn, wheat, and vegetables including peas, beans, celery, beets, onions, peppers, carrots, and tomatoes (Weaver et al. 2015).

Walpole Island's upland communities of tallgrass prairie and oak savanna consist of many plant and animal species which are rare in Canada due to being at the northern extent of their range. The wetland communities on the island are primarily cattail and sedges. The south channel of Chenail Ecarte (i.e., the Snye), Johnston Channel, Bassett Channel, and St. Clair River represent the open water and lacustrine communities of the Island in addition to Goose Lake (Great Lakes Commission 2006).

Along the western and United States shore of the Delta the largest parcels of undeveloped land are owned and managed by the Michigan Department of Natural Resources (MDNR). This area includes St. John's Marsh (931 ha), a large portion of Harsen's Island (3,226 ha) which is Michigan's largest portion of the Delta, and most of Dickinson Island (1,214 ha). Twelve percent of St. John's Marsh is impounded, and a similar amount of area is managed as a green tree reservoir for forested wetlands to provide waterfowl habitat (Baldassarre and Bolen 2006, Great Lake Commission 2006). Dickinson and Harsen's Island traditionally consisted of open coastal marsh. Approximately 15% of the marsh on Dickinson Island has been impounded and Harsen's Island has extensive marshes of which approximately 22.5% have been impounded (Great Lakes Commission 2006).

### 1.4.3 Management of Waterfowl Habitat and Hunting at Lake St. Clair

South of Walpole Island, along the Canadian side of the lake, privately owned wetland complexes are primarily hunt clubs ( $n \sim 11$ ) that are intensively managed to attract waterfowl during autumn and early winter. Portions of these properties are impounded and have water control structures that are used to maintain hemi-marsh conditions of 50% emergent vegetation (e.g., cattail and bulrush) and 50% open water with submergent vegetation (e.g., sago pondweed, watermilfoil, coontail, and bladderwort) that are foods for waterfowl and provide habitat for a variety of invertebrates (Kaminski and Prince 1981, Bookhout et al. 1989, Callicutt et al. 2011). Several properties have boundaries that extend into the lake encapsulating lacustrine marshes where submergent and emergent aquatic vegetation is influenced by the naturally fluctuating water levels of the lake (Bookhout et al. 1989).

Management techniques used to attract foraging waterfowl include flooding standing and harvested agricultural crops during September to December, and legally providing supplemental feed for waterfowl. Corn fields are commonly flooded to attract waterfowl, but there are some small parcels of barley, buckwheat, and soy beans that are also flooded. Supplemental feeding is allowed in accordance with permits issued by the Canadian Wildlife Service (CWS) that are valid from 1 August to 31 December and stipulate the size of the deposit pile, signage, and that hunting of waterfowl is prohibited within 400 m of the deposit site (Bookhout et al. 1989, Migratory Bird Regulations C.R.C., C. 1035). Feed at deposit sites typically consists of shelled or cob corn. Since hunting is prohibited within 400 m of feed, each of these foraging areas represents a sanctuary that is at least 50.3 ha in size. There is variation within and among how hunt clubs regulate mortality risks and disturbances from hunting; management tactics include restricting shotgun shell size, number of shells, and shotgun caliber; regulating the size of hunting parties; regulating the frequency and duration of when certain areas are hunted; delaying the start of the hunting season on their property; ending the hunting season early based on weather conditions.



The Canadian Wildlife Service manages The St. Clair National Wildlife Area (355 ha, SCNWA) which is comprised of two units: St. Clair (244 ha) and Bear Creek (111 ha) (Weaver et al. 2015). Hunting is prohibited within the SCNWA and public access is restricted to a walking path to a viewing tower at the St. Clair unit. The typical vegetation communities of the SCNWA are emergent marsh areas among dune ridges and scrub-shrub islands (Dennis et al. 1984, Weaver et al. 2015). The St. Clair Unit was originally established in 1978 and is one of the most important habitats for migratory waterfowl and other wetland bird species in the region (Weaver et al. 2015).

Agricultural fields adjacent to the private, public, and federal wetlands that border the shore of Lake St. Clair provide additional food resources to waterfowl and have variable hunting intensity. Availability and suitability of grains left following harvest (i.e., waste grain) is influenced by crop type, timing of harvest and post-harvest treatments (e.g., disking stubble, rolling, mowing, burning) implemented by the landowner (Baldassarre and Bolen 1984, Barney 2008, Foster et al. 2010).

In Ontario, waterfowl hunting is open for 107 days which includes one waterfowl heritage day (3<sup>rd</sup> Saturday of September) for youth hunters a week prior to the 106 day open season for ducks (4<sup>th</sup> Saturday in September) in the southern district of Ontario. Public hunting is restricted to less than 300 m in open water from the lake shore, from emergent vegetation, or a waterline that forms a boundary of private property (Migratory Bird Regulations C.R.C., C. 1035).

Along the US shore of Lake St. Clair in Michigan is the St. Clair Flats State Game Area (hereafter St. Clair Flats) which is an area of substantial use by waterfowl. Within the marshes MDNR control water levels to promote submergent and emergent aquatic vegetation in addition to planting and flooding crops for waterfowl. The MDNR regulates hunting activity on the St. Clair Flats by managing the types of decoys allowed, number and size of shotgun shells, size of hunting parties, the number of hunting parties, and areas designated open to hunting or restricted as waterfowl sanctuaries (John Darling, Michigan Department of Natural Resources, personal communications). The St. Clair Flats occurs in Michigan's South waterfowl zone where the hunting season occurred for

60 days from 11 October to 7 December and 27 December to 28 December for both the 2014–15 and 2015–16 waterfowl seasons. Hunting access in the Michigan public water is not restricted to any distance from lake shore, emergent vegetation, or a waterline that forms a boundary of private property as it is on the Canadian side of the lake.

Waterfowl and habitat management on Walpole Island are similar to those of the public and private areas along the Canadian shore of Lake St. Clair. The island consists of private hunt clubs, wetland complexes accessible to members of the first nations and extensive agricultural fields of similar crops in Ontario. The waterfowl hunting regulations for southern Ontario are the same regulations mandated by the Walpole Island First Nations Department of Resource Protection for non-residents of the Walpole Island First Nations (personal communication, Carl Smith, Resource Protection Officer). Residents can subsistence hunt throughout the year.

## 1.5 Objectives

Heterogeneous landscapes that vary in quality and quantity of resources, and mortality risk influence how animals select resources needed to survive. Understanding the spatiotemporal variation in resource selection among mallards in the Lake St. Clair region and how it relates to their survival and departure is the ultimate goal of my research. This research will advance our understanding of waterfowl resource selection, survival, and migration ecology and will help to guide management of the waterfowl and wetland resources within the region. The objectives of this thesis are to: 1) describe resource selection of mallards in relation to perceived risk of mortality from hunting, (2) determine how resource selection relates to survival, and (3) determine if resource selection relates to the probability and timing of departure from Lake St. Clair

## 1.6 Thesis Structure

The thesis is divided into 3 data chapters, each intended for separate publication, but all bound by the common theme of resource selection of adult female mallards in the Lake St. Clair region during autumn and winter. To better understand how adult female mallards are navigating a threatened and variable landscape of resources and risks, in

Chapter 2, I investigated resource selection of adult female mallards using spatiotemporal data collected from GPS transmitters and digital habitat classification layers I compiled through a Geographic Information System. In Chapter 3, I determined survival from tracking adult female mallards equipped with GPS and radio transmitters and reports by hunters who harvested individuals. This chapter provides insight into how individuals are selecting resources and how their selection strategies relate to their survival at a critical portion of the annual cycle. In Chapter 4, I studied the relationship of resource selection and the probability and timing of ducks departing south from the region. Information from this chapter is an initial estimate of how resources within the region relates to migratory departure which has both local and flyway-wide conservation implications. In Chapter 5, I discuss the 3 data chapters in a broader ecological context and provide the overall conclusions, areas for future research, and scientific implications of this research.

## 1.7 Significance of Research

Optimality theory suggests that selection favors animals that choose habitats to maximize fitness. Linking direct fitness effects with a multivariate process such as resource selection can be difficult and is rare. My research represents an original approach to understand how adult female mallards navigate a dynamic landscape of variable resource benefits and mortality risks. Quantifiable estimates of resource selection and the relationships with fitness effects (i.e., survival) and behaviors (i.e., migratory departure) are unknown for this region, which is a vital staging for waterfowl in the lower Great Lakes. My results contribute to the science of resource selection and waterfowl staging ecology and will provide relevant and new information to conservation planners for understanding the implications of current and future management practices.

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## Chapter 2

# 2 RESOURCE SELECTION OF ADULT FEMALE MALLARDS IN THE LAKE ST. CLAIR REGION DURING AUTUMN AND WINTER

## 2.1 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 across landscapes (Manly et al. 2002, Stephens et al. 2007). Search, handling and travel time, accessibility, competition, and predation risk further modify costs of acquiring resources and influence selection of these resources by animals (Manly et al. 2002). Animals should avoid risks of predation while foraging unless risk of starvation is relatively greater (Lima and Dill 1990, Werner and Anholt 1993, Lima 1998, Cresswell 2008). Remaining in habitats with decreased predation risks will reduce predation-related mortality, but risk could compromise nutritional and other life-history needs if these habitats are of relatively lesser quality (Creel et al. 2005, Creel et al. 2007). Alternatively, moving among habitats may increase predation risk by increasing exposure while traveling or by moving into unfamiliar areas, but these movements may provide access to better nutrition. Further, there is an unknown risk associated with traveling to locations where predation risk and resource availability is unidentified. Predictability of risks influence the likelihood an animal will modify behavior to increase survival (Lima and Dill 1990), but variation in timing of predator activity can cause temporal variation in foraging risk and behavior (Cresswell 2008, Creel and Christianson 2008). For instance, if predation risks are greater during the day than at night, at locations with preferred resources, then animals could choose to relocate to these areas with quality resources at night, if the predation risk is reduced.

Habitat types within wetland complexes differ in the amount and quality of resources due to anthropogenic and natural causes (Dwyer et al. 1979, Merendino and Ankney 1994). As a result of resource heterogeneity, and variable risk, wetland landscape composition influences habitat selection and movements of wetland dependent birds.

During autumn and winter, many waterfowl species are hunted, which can influence their distribution and abundance (Madsen and Fox 1995, Fox and Madsen 1997, Stafford et al. 2007). Shooting and human movement among habitats can influence spatiotemporal distribution of waterfowl because birds seek spatial refugia (i.e., areas with reduced human activity) and modify timing and possibly periodicity of feeding flights to avoid these mortality risks and disturbances (Fox and Madsen 1997, Madsen 1998, Guillemain et al. 2002, Cresswell 2008, Lancaster 2013, St. James et al. 2013).

Within the Great Lakes, the Lake St. Clair region is one of the most important migratory stopovers (hereafter staging areas) for waterfowl. The area sustains thousands of waterfowl during autumn, providing nearly 4-7 million duck-use days (i.e., the number of ducks counted per day in the area, summed over the number of days they were there) and peak abundances have been observed to be approximately 123,000–150,000 dabbling ducks (personal communication David R. Luukkonen Michigan Department of Natural Resources, Dennis et al. 1984, Weaver et al. 2015). These lacustrine and palustrine wetlands and terrestrial agricultural habitats vary in available resources (e.g., food and refugia) for waterfowl and waterfowl are increasing their length of stay in the region during the non-breeding period (Weaver et al. 2015).

A diversity of management practices and levels of disturbance from human activity within wetland complexes around Lake St. Clair provide a variety of foraging options and risks to waterfowl (Heitmeyer 2006, Straub et al. 2011). Sites of limited human disturbance, such as waterfowl sanctuaries, provide roost and rest areas of relatively lower risk of mortality but food resources can become limited due to greater concentrations of birds (Guillemain et al. 2002, Stafford et al. 2007, Beatty et al. 2014a). In contrast, heavily (public hunting areas) and moderately (hunt clubs) hunted areas expose birds to greater mortality risk but possibly provide better foraging opportunities due to decreased waterfowl densities and the supplemental provision of food. Therefore, the Lake St. Clair region provides a spatially and temporally dynamic environment of available resources with variable human disturbance and a unique opportunity to understand the relationship between resources and risk of mortality in these habitat types.

The Mallard (*Anas platyrhynchos*) is an abundant habitat generalist that uses many wetland habitat types within the St. Clair region and thus is a good fit to investigate spatiotemporal movements and resource selection. Harvest information suggests that the Great Lakes population of mallards could be managed separately from other mid-continent mallards due to differences in environmental conditions, habitats, and population vital rates but have been relatively less studied (Anderson and Henry 1972, Munro and Kimball 1982, Zuwerink 2001). Of these vital rates, limited evidence suggests that the population of Great Lakes' mallards may be particularly sensitive to variation in non-breeding season survival of adult females (Coluccy et al. 2008). Non-breeding season survival is predominately influenced by hunter harvest (Blohm et al. 1987, Reinecke et al. 1987, Fleskes 2007), and harvest management strategies have been proposed for the Great Lakes' mallard population (Coluccy et al. 2008). In addition to being a potentially important mortality factor, hunting has been documented to influence local abundance and distribution of waterfowl (Madsen 1998). Thus, disturbance and mortality risk associated with hunting could affect habitat selection of waterfowl and have regional influences on their population dynamics. Waterfowl hunting in the Lake St. Clair region is common and the region includes private hunt clubs, areas open to public hunting, commercial hunting guides, and waterfowl sanctuaries (Weaver et al. 2015). The spatial distribution and intensity of disturbance and mortality risk to waterfowl from hunting are variable and are presumed to be related to management and regulation of hunter access to properties used by waterfowl. Therefore, a better understanding of resource selection and movements of mallards within this region could influence local management practices and regional conservation of the population.

Previous research has used discrete-choice modeling to investigate how mallard habitat selection was influenced by landscape composition throughout multiple periods of the annual cycle and at different spatial scales (Beatty et al. 2014b). Landscape composition is the percentage or area of different resources within a given boundary and is a commonly used to estimate the spatial heterogeneity of the landscape (Abiescher et al. 1993, Beatty et al. 2014b). This boundary is related to the spatial scale at which resources are considered available and estimated by the researcher. The hierarchy of spatial scales includes the geographic distribution of the species, individual home ranges, patches

within the home range, and items within the habitat patches (Johnson et al. 1980). My objective was to use discrete-choice modeling to estimate the relationship of landscape composition (presumed level of disturbance and habitat type) within the Lake St. Clair region with resource selection of adult female mallards during a portion of the non-breeding season when waterfowl are subject to the disturbance of hunting.

## 2.2 Study Area

In Chapter 1, I described the habitats of the Lake St. Clair region of southwestern Ontario and Michigan. I also detailed how waterfowl management can influence available resources and mortality risks from hunting. The region consists of a heterogeneous mix of lacustrine marshes, impounded wetlands, flooded agricultural fields, dry agricultural fields, and supplemental feeding areas. These habitats provide a variable amount of resources for mallards to access during autumn and winter. The habitats are interspersed throughout the landscape in patches that can be associated with the different management or ownership groups of Walpole Island First Nations, publicly accessible property, private accessible property (predominantly hunt clubs), Canadian Wildlife Service St. Clair National Wildlife Area (SCNWA), and the Michigan Department of Natural Resources St. Clair Flats Areas (Herdendorf et al. 1986, Bookhout et al. 1989, Great Lakes Commission 2006, Weaver et al. 2015).

## 2.3 Methods

### 2.3.1 Land Classification Data

As the base layer for all spatial analyses of resource selection, I used land classification information from the Ducks Unlimited Canada (DUC) Hybrid Wetland Layer Version 2.1.1 which was prepared in October 2010 and modified in May 2011 (Ducks Unlimited Canada 2011). This digital layer contains continuous raster land cover data across Canada at a resolution of 38.7 m. The DUC layer was intended for estimating open water, wetland, and upland habitats at a regional or national scale which made it ideal for estimating habitat types within southwestern Ontario.



I also classified areas by level of mortality risk waterfowl may experience from hunting. I used ownership type to categorize what level of hunting intensity that presumably occurred within respective habitat types as property managers regulate hunting practices via various self-imposed hunting restrictions. To estimate property boundaries and ownership type within Ontario, I supplemented the DUC layer with spatial information that I gathered through recording property boundaries with hand held GPS units (e.g., property boundaries extending in Lake St. Clair) and from the Teranet POLARIS Boundary Data for Chatham-Kent. For Walpole Island, I gathered the property boundary information from the Agricultural Resource Inventory layer produced by the Ontario Ministry of Agriculture, Food, and Rural Affairs (revised 2010) and spatial information from Indian Reserve layer produced by the Ontario Ministry of Natural Resources (2008). I outlined the boundary of St. Clair Flats from the State Forest, Wildlife, and Game Areas Open to Hunting feature layer (2015) accessed from the GIS Open Data Website for the State of Michigan ([http://gis.michigan.opendata.arcgis.com/datasets/403b88ca6cc443a59e54eb28e4f4de98\\_5](http://gis.michigan.opendata.arcgis.com/datasets/403b88ca6cc443a59e54eb28e4f4de98_5)). I 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. 1.).

### 2.3.2 Capture and Transmitter Deployment

Within the Great Lakes, non-breeding season survival of adult female mallards has been suggested to be important to population growth (Coluccy et al. 2008). Therefore, I only monitored adult female mallards due to the potential importance of non-breeding season activities that could be related to survival at Lake St. Clair. Additionally, tracking this demographic assisted in overcoming logistical constraints of trapping and transmitter deployment. In 2014 and 2015, I captured adult female mallards on private property along the Canadian shore of Lake St. Clair (UTM 17 N 383701 E, 4697376 N). I trapped waterfowl using a swim-in trap baited with whole kernel corn, in late August to early September. The 2014 trapping season consisted of 5 trapping events ranging from 21 August to 12 September while the 2015 trapping season consisted of 14 events ranging from 25 August to 10 September. Overall, I captured 1579 mallards and all captured

waterfowl were banded with federal aluminum leg bands. I 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, retrices (Carney 1992), and I determined sex based on wing coloration and cloacal examination. I recorded body mass ( $\pm 10$  g) by placing birds in a nylon mesh bag, weighing the bag with a hand-held scale (Berkley BTDFS50-1 digital fish scale) and subtracting the weight of the bag. The 2014 cohort consisted of 20 adult female mallards and the 2015 cohort consisted of 39 adult female mallards that were equipped with a Global Positioning System (GPS) transmitters. I inspected the wing plumage to determine the status of molt for each bird as I wanted to only track adult female mallards that had finished the wing molt. I also marked birds that weighed enough to meet the required transmitter to body weight proportion (transmitter being  $\leq 5\%$  of the bird's body weight) as recommended by the American Ornithologists Union (Fair et al. 2010).

Of the 2014 cohort, 9 adult female mallards were equipped with 22-gram Platform Terminal Transmitter (PTT) back-pack style solar powered GPS transmitters (Model 22GPS). The remaining 11 adult female mallards were equipped with 25-gram Groupe Spécial Mobile (GSM) back-pack style GPS transmitters (Model Saker-H). The PTT transmitters collected six fixes per 24 h period while the GSM transmitters collected eight fixes per 24 h period. I used a combination of transmitters as I did not initially know how well the GSM back-pack style GPS would perform due to the cellular network in the study area. The GSM transmitters from the 2014 cohort performed successfully, therefore due to their greater fix rate and a lower financial cost per unit, the entire 2015 cohort consisted of 25-gram GSM back-pack style GPS transmitters (NorthStar Science and Technology, LLC, King George, Virginia, USA and Ecotone Telemetry, Sopot, Poland). Transmitters were equipped with a 3.5-gram Very High Frequency (VHF) transmitter (Holohil Systems Ltd., Carp, ON, Canada) which allowed me to determine fate and transmitter status. I trimmed and glued a 3.2 mm neoprene pad to the base of each transmitter as a protective barrier between the feathers of the bird and the transmitter. I attached transmitters dorsally between the wings using a harness of 0.38 cm wide Teflon ribbon (Bally Ribbon, Bally PA, [Petrie et al. 1996, Krementz et al. 2011, Krementz et al. 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  $\leq 32$  g and was  $\leq 5\%$  of the body weight of ducks (average body mass at a capture  $1072.05 \pm [21.26]$  g) used in the sample as recommended by the guidelines for transmitter mass by the American Ornithologists Union (Fair et al. 2010). Ducks were released immediately after being equipped with GPS transmitters (Animal Use Protocol 2014–017).

### 2.3.3 Temporal Scale for GPS Fixes

After deployment, I censored the first 4 days of GPS fixes to allow individuals to recover from handling and transmitter attachment (Cox and Afton 1998). All GPS fixes were periodically uploaded through either the Argos satellite system (PTTs, CLS America Inc., Lanham, MD, USA) or local cellular towers (GSM). I assumed that the periodicity of GPS fixes represented a range of diurnal and nocturnal locations of mallard space use (Beatty et al. 2014b, Bengtsson et al. 2014). I converted all the time information associated with each GPS fix to Eastern Standard Time and Eastern Daylight Savings Time as they were originally recorded in Coordinated Universal Time for the Greenwich Mean Time zone.

The 106 day open season for ducks in the southern Ontario district, which Lake St. Clair is part of, during my study was 27 September 2014 to 10 January 2015 and 26 September 2015 to 9 January 2016. Legal shooting time during the hunting season is 30 min before sunrise to 30 min after sunset. Therefore, I categorized the period of all GPS fixes as either a diurnal location if it occurred from 30 min before sunrise to 30 min after sunset, fixes outside of this time were considered nocturnal locations. I determined the time of sunset and sunrise for each fix from National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) Global Monitoring Division daily solar calculation spread sheet using the approximate center of St. Clair National Wildlife Area St. Clair Unit as the reference location (<http://www.esrl.noaa.gov/gmd/grad/solcalc/calcdetails.html>).

I monitored birds until 31 January, the transmitter failed to report fixes, or a bird was reported shot by a hunter. When transmitters failed to report fixes for multiple duty

cycles, I attempted to recover carcasses and transmitters by searching at the last known GPS location through homing to the VHF signal via a VHF receiver and a hand-held Yagi antenna. I monitored individual's locations by downloading GPS fixes from manufacturer provided software and internet access portals. If birds did not move approximately >150 m between GPS fixes I waited until GPS fixes were no longer being transmitted for multiple duty cycles before attempting to determine the fate of the individual. I implemented this strategy because the unsuccessful transmission of GPS fixes could have been a result of poor reception between the transmitter and the Argos satellites or GSM network and not an indication of a mortality event. Also, since access to many of the locations the ducks used was limited, and a goal was to not introduce extra disturbance (i.e., human presence) in areas of waterfowl use, waiting until multiple duty cycles lapsed before transmission of GPS fixes, increased the likelihood that a mortality event truly occurred and not a data transmission error.

The GPS transmitters were programmed to store thousands of GPS points until a suitable connection to off-load fixes was established. When I could recover the GPS unit and recharge the solar battery there was the possibility of downloading more GPS fixes prior to what was known at the time of recovery. Thus, criteria for determining when GPS fixes stopped being representative of a live duck were based on a set of scenarios: (1) if I recovered the carcass with an attached transmitter at a location that was  $\leq 150$  m from the location of the last reported GPS fix, then the date the bird arrived at that location and GPS fixes moved <150 m was the date of death and the last location used; (2) if I recovered the carcass with an attached transmitter >150 m from the last reported location, I used all of recorded GPS fixes and randomly picked a day from the last day a fix was transmitted to the day before I found the transmitter as the date of death (Frair et al. 2007); (3) if GPS fixes stopped being transmitted and I could not recover the transmitter the last downloaded fix was used as the last location for that bird. For harvest mortalities, I considered the duck to have been alive and provided accurate location information prior to the day and time when the hunter reported harvesting the bird. I categorized an adult female mallard as dead if there was evidence (e.g., feathers, bones, or a carcass) obtained at the site or if a hunter reported harvesting a bird with a transmitter.

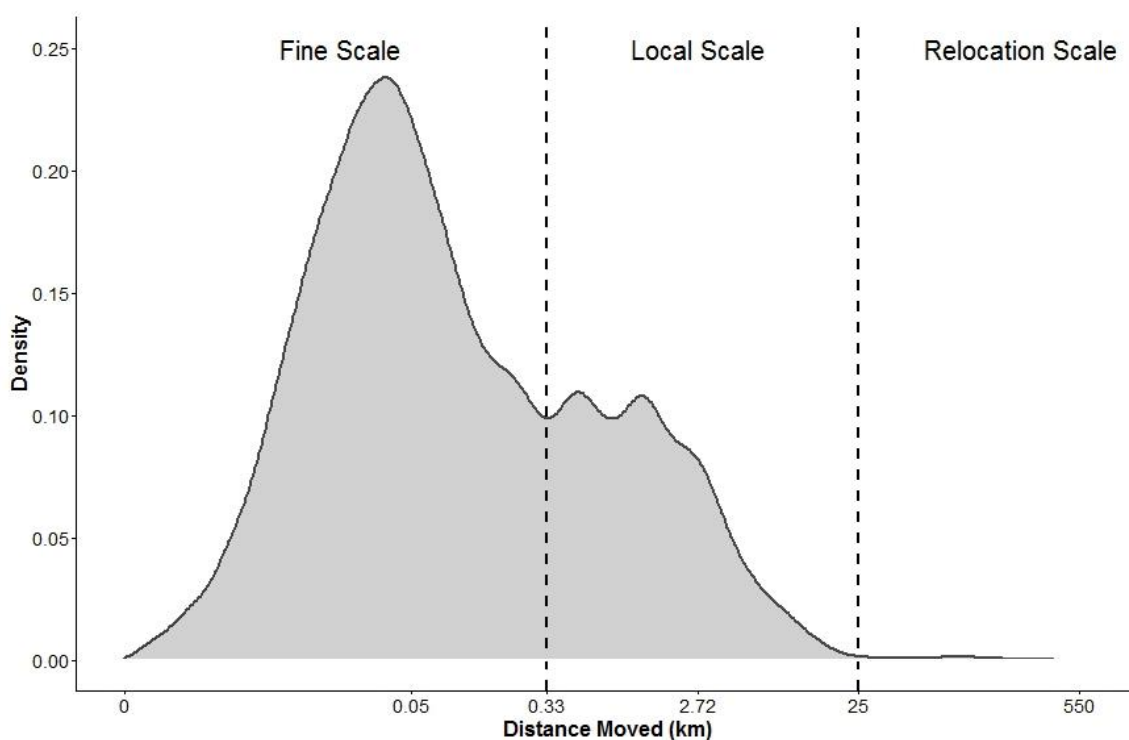
I divided each 2014–15 and 2015–16 monitoring years into 4 seasons to examine differences in resources selection over time. GPS fixes from both monitoring years were combined to increase sample size. Seasons were based on the Ontario southern district open season for ducks. A PRE hunting season was from 27 August to 26 September 2014 and 30 August to 25 September 2015. A FIRST half of the hunting season was from 27 September 2014 to 18 November 2014 and 26 September to 17 November 2015. A SECOND half of the hunting season was from 19 November 2014 to 10 January 2015 and 18 November 2015 to 9 January 2016. I created two hunting seasons to investigate potential changes in resource selection when mortality risk from hunting was present, since environmental conditions (e.g., food availability and thermoregulatory costs), waterfowl abundance, and disturbances could be variable between the two seasons. I designated a POST hunting season from 11 January to 31 January 2015 and 10 January to 31 January 2016. There was no hunting during the POST hunting season.

### 2.3.4 Spatial Scale

Animals select resources at several spatial scales on potentially different criteria (Johnson 1980). The extent of the spatial scale in this study was limited by consistent digital spatial data and was therefore restricted to southwestern Ontario and the St. Clair Flats of Michigan. To determine the scale of resource selection within this region, and define the size of resources units, I used movement information gathered from all the monitored mallards (Boyce 2006). I 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 signal was insufficient, I only used intervals that were < 24 hrs apart (Beatty et al. 2014b). Also, to decrease the effects of GPS fixes downloaded in errant rapid succession outside of the programmed duty cycles, I only used GPS fixes that were > 2 hrs apart. I calculated the natural log transformation of all step lengths > 0 km to plot the observed distribution of movement distances. I fitted a Gaussian kernel density estimator to the natural log transformed observed distribution using the `geom_densisty`

function in the ggplot2 package (R Core Team 2016, H. Wickham ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2009, [Beatty et al. 2014b]).

I classified each GPS fix  $a$ , into one of three spatial groupings based on the straight-line distance from the preceding fix,  $a - 1$ . I partitioned spatial scale categories based on visually identifying breaks in the distribution of the smoothed data (Beatty et al. 2014b). I categorized step lengths that were  $> 0.33$  km but  $< 25$  km as local movements. I considered any step length  $< 0.33$  km as a fine scale movement and anything  $> 25$  km as a relocation movement. I used only local scale movements based on the spatial information available to investigate resource selection with the Lake St. Clair region. My categorized range of local movements was similar to recently published movements for dabbling ducks (0.25–30.0 km; Jorde et al. 1983, Davis and Afton 2010, Link et al. 2011, Beatty et al. 2014b; Figure 2-1.)

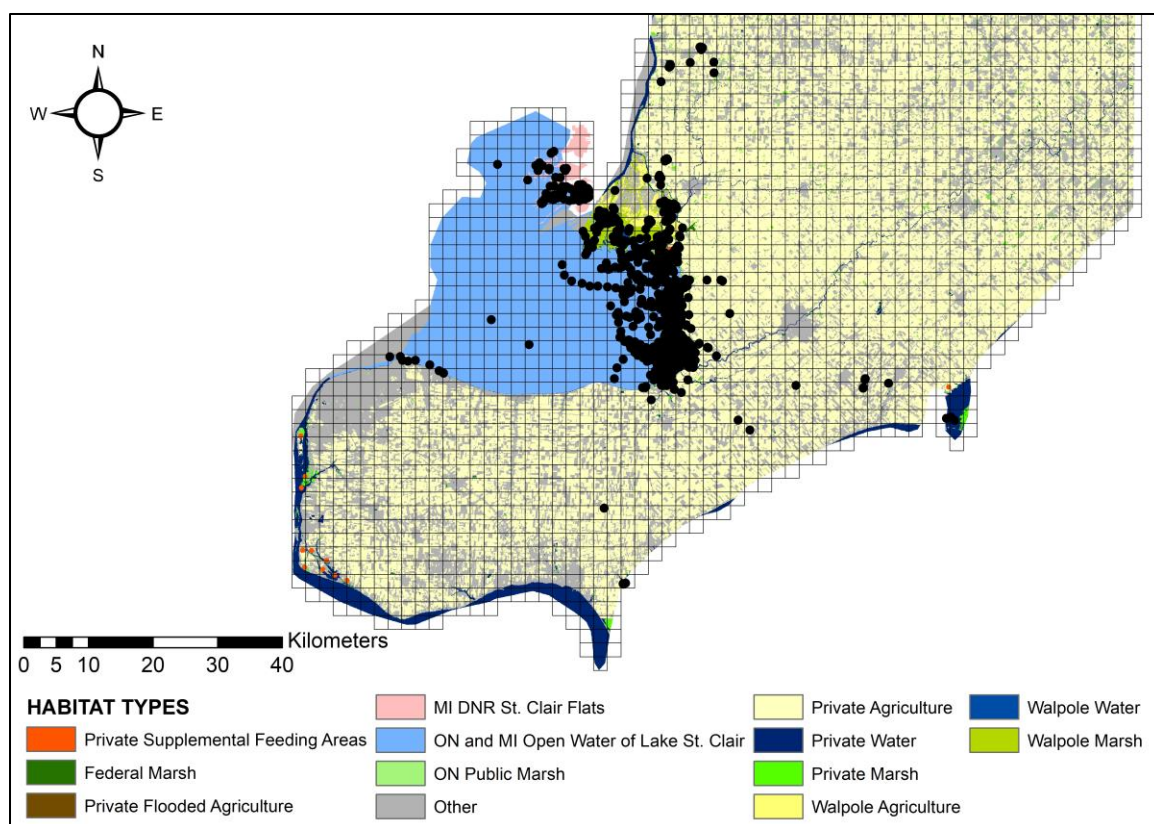


**Figure 2–1 Spatial scales based on the probability density of natural log transformed step lengths for adult female mallards during the 2014–15 and 2015–16 monitoring periods. Distance moved corresponds to the natural log of the distance between GPS focal fix  $a$  and the previous fix  $a - 1$ , for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

### 2.3.5 Identifying Choice Sets

I 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 and Millspaugh 1999, Thomas et al. 2006, Beatty et al. 2014*b*). Using local scale movements decreased bias associated with fixes in close spatial proximity associated with dead birds that were not recovered and potential influences of different resource selection strategies associated with migratory movements at the relocation scale (Beatty et al. 2014*b*). Discrete-choice models treat resource selection as a set of trials where animals make choices from a group of options within a choice set. Thus, my 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 et al. 1998, Cooper and Millspaugh 1999).

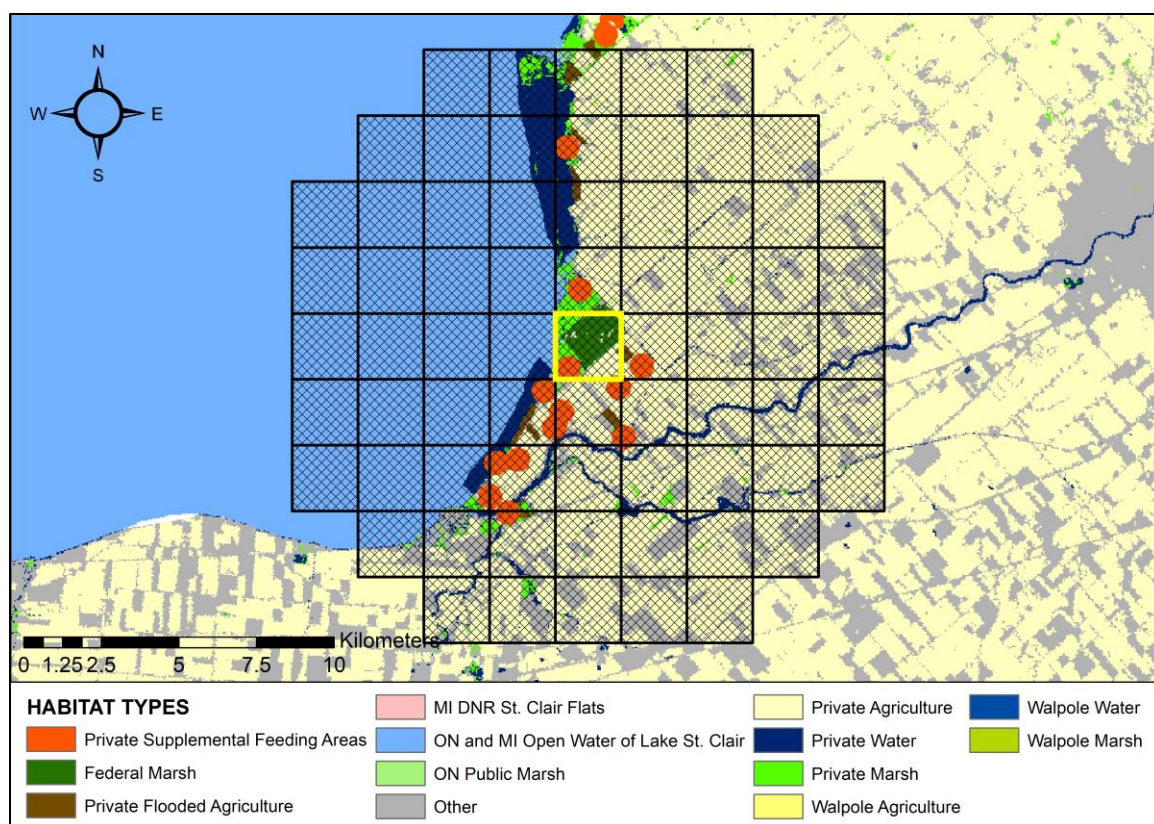
To discretely categorize resource units, I plotted all GPS fixes that were at the local scale and within the boundaries of the Lake St. Clair spatial layer. I then overlaid a grid system of 2.12 km<sup>2</sup> cells across the Lake St. Clair spatial layer using Global Spatial Modeling Environment Version 07.4.0 (Beyer 2015) and ArcMap (Environmental Systems Research Institute, Inc., Redlands, CA, USA 10.3. 1. [Thomas 2006 et al. 2006, Carter et al. 2010]) as this was the average step length for all local scale movements (Beatty et al. 2014*b*, Figure 2–2).



**Figure 2–2 The distribution of GPS fixes of adult female mallards within the extent of the Lake St. Clair spatial layer during the 2014–15 and 2015–16 monitoring periods. Grid size is 2.12 km<sup>2</sup>**

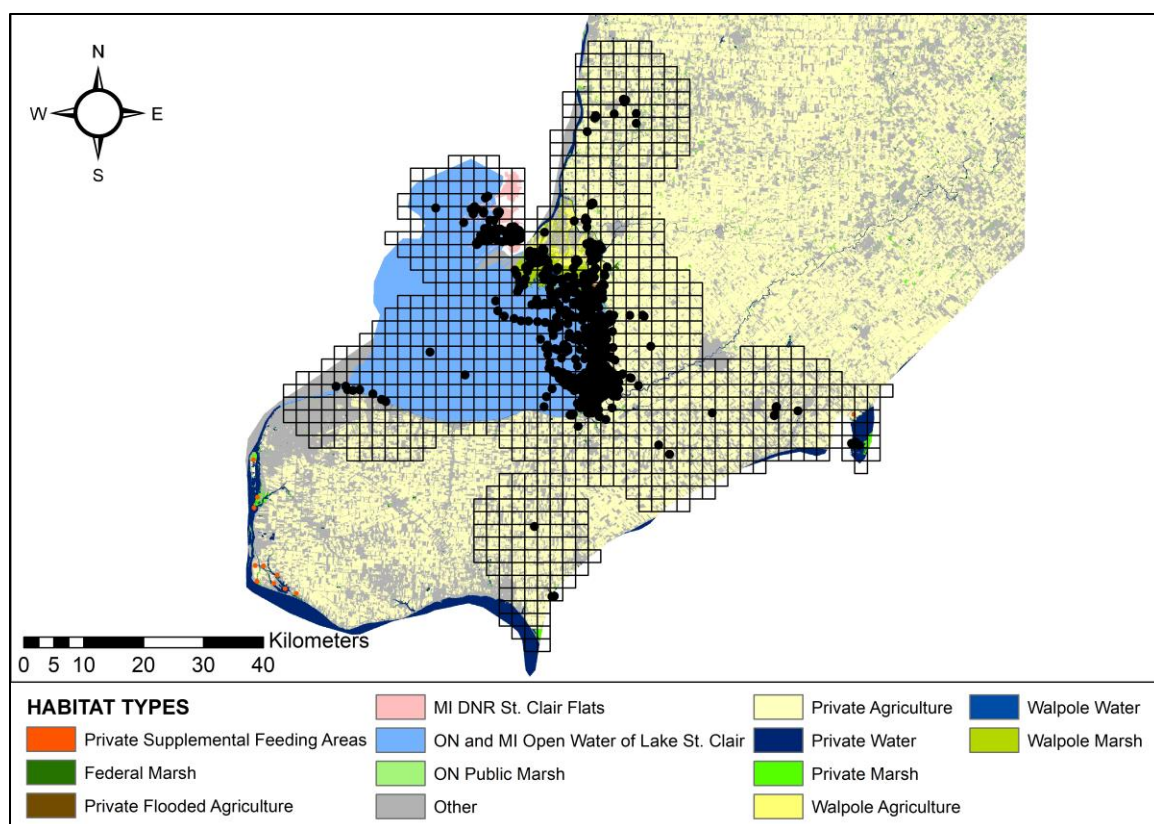
I then intersected all local scale GPS fixes with the grid system of 2.12 km<sup>2</sup> cells and grid cells that contained a GPS fix were categorized as a used resource unit. Choice sets included available resource units that were grid cells whose center was within 9.6 km from the center of the used resource unit (Figure 2–3).





**Figure 2–3 An example of a choice set for the discrete-choice model of adult female mallard resource selection within the Lake St. Clair region. The cross hatched cell with a yellow outline is the used resource unit and the hatched black outlined cells are the available resource units.**

The radius of 9.60 km represented the 97.5<sup>th</sup> quantile of all step lengths within the local scale movements (Güthlin et al. 2011). This approach approximates that 97.5% of the time a local movement is within this radius of 9.6 km (Arthur et al. 1996). I used this threshold in attempt to minimize bias and maximize precision through approximating the available area to be relative to the area of use, but also limiting the amount of contamination among choice sets (Johnson et al. 2006, Baasch et al. 2010; Figure 2–4). I then measured habitat variables for each used and available resource unit for each choice set.



**Figure 2–4 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.**

### 2.3.6 Habitat Variables

Landscape composition influences resource use of dabbling ducks during migration and winter (Webb et al. 2010, Pearse et al. 2012, Beatty et al. 2014b). I measured landscape composition of several different land class types for used and available resource units. I reclassified the original 12 modified land classes of the DUC spatial layer into 4 habitat types relevant to foraging and migrating waterfowl (Agriculture, Water, Wetland, and Other). I reclassified cells as flooded agriculture from meeting with land owners along the Canadian shore and having them identify parcels where crops were flooded for waterfowl use. I also reclassified raster cells as supplemental feeding areas (also referred to as Baiting Areas) 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 areas were

reclassified as a supplemental feeding area. Therefore, after reclassification I used 5 habitat types to represent landscape composition (Table 2–1). To calculate landscape composition for each 2.12 km<sup>2</sup> resource unit I estimated the area (ha) of each habitat type using ArcMap (Environmental Systems Research Institute, Inc., Redlands, CA, USA 10.3. 1.) and Global Spatial Modeling Environment Version 07.4.0 (Beyer 2015).

**Table 2–1 The categorized habitat types from the DUC 2011 Hybrid Wetland Layer Version 2.1.1 and their associated variable names.**

<sup>a</sup>Habitat types classified as other were not used in the resource selection analysis.

Data Source	Habitat Type	Categorized Habitat type	Habitat Variable Name
Ducks Unlimited Hybrid Wetland Layer 2.1.1	Cropland	Agriculture	AGRI
	Agriculture		
	Water	Water	WATER
	Wetland	Wetland	MARSH
	Upland	Other	NA <sup>a</sup>
	Non-vegetated		
	Developed		
	Shrubland		
	Native Grassland		
	Forage/Pasture/Perennial Crops		
	Coniferous		
	Broadleaf		
	Mixedwood		
Landowners	Flooded Agriculture	Flooded Agriculture	FLAG

Ontario Ministry of Natural Resources and Forestry	Supplemental Feeding Areas	Supplemental Feeding Areas	SUPP
--	----------------------------	----------------------------	------

The amount and intensity of human disturbance and mortality risk from hunting can influence dabbling duck habitat use (Madsen 1998, Guillemain et al. 2002, Stafford, et al. 2007, Beatty et al. 2014a). Within the region this is an observation anecdotally supported by landowners and wetland managers. To categorize risk associated with ownership of habitat type, I used classifications based on access to hunting (Table 2–2). 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 St. Clair National Wildlife area where hunting was prohibited. The other property types of Private, Walpole, and Michigan were assumed to be at a risk level that is intermediate of the two extremes as these properties manage access but can allow hunting. Hunting is prohibited within the 400 m boundary of supplemental feeding areas but they are located within private property boundaries with the management goal of attracting waterfowl to be harvested. Therefore, I assumed that the level of risk associated with using a supplemental feeding area was at an intermediate level relative to other habitat types.

**Table 2–2 The ownership of habitat types with the Lake St. Clair region, their categorized level of hunting access and associated assumed risk from hunting, and variable prefix.**

Ownership Type	Access to Hunting	Assumed Risk	Variable – Prefix
Federal	Prohibited	Low	CWS
Private	Managed	Intermediate	PRI
St. Clair Flats	Managed	Intermediate	MICH
Walpole	Managed	Intermediate	WAL
Public	Liberal	High	PUB

### 2.3.7 Statistical Analysis

I 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. 2014b).

Bayesian random effects models allow for estimating individual and population-level selection coefficients given the observed data (i.e., GPS fixes). For statistical analyses in

a Bayesian framework all individual duck and population-level parameters must be defined by ‘prior’ distributions that represent the potential likely values of selection parameters (Sauer et al. 2005, Carter et al. 2010). The estimated mean and variance of the selection parameter are described by the ‘posterior’ probability distributions. Thus, for the Bayesian random-effects multinomial logit models, individual duck selection parameters were sampled from prior distributions that were then used in the discrete-choice equation (Equation 1) to adjust individual duck posterior distributions for each iteration of the model through an internal algorithm (Carter et al. 2010).

The remainder of this section describes the discrete-choice equation and modeling approach that was used by Beatty et al. 2014b. I applied this framework to the local scale GPS fixes from the Lake St. Clair spatial layer, where I modeled the probability of choosing alternative  $j$  in choice set  $i$  by animal  $a$  based on  $k$  independent variables:

$$P_{aij} = \frac{\exp(\beta_{1a}x_{1ij} + \beta_{2a}x_{2ij} + \dots + \beta_{ka}x_{kij})}{\sum_{j=1}^J \exp(\beta_{1a}x_{1ij} + \beta_{2a}x_{2ij} + \dots + \beta_{ka}x_{kij})} \quad (1)$$

$j$  indexes resource units (i.e., alternatives) within a choice set (e.g. ranged from 1 to 69),  $J$  is the total number of resource units with in a choice set,  $i$  indexes each choice set and is the sample size ( $i = 1 \dots N$ ),  $a$  indexes individual level coefficients to account for individual heterogeneity in selection strategies among ducks, and  $\sum_{j=1}^J P_{aij} = 1$  (Beatty et al. 2014b). 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. Because the Lake St. Clair spatial layer only covered southwestern Ontario and the St. Clair Flats, my inferential space was limited to the available resources within this area and, thus resource selection was based on what was estimated to be available in this spatial extent.

I assumed that all individual level coefficients of all independent variables were normally distributed with population mean centered at zero and standard deviation  $\sigma_k$  to generate population level coefficients. For all hyper-parameters I 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 et al. 2005, Gelman 2006, Thomas et

al. 2006). To control for variability in selection strategies among individuals all models included random coefficients. I did not include an intercept term as part of the parameter vectors as it would have canceled with the same term in the denominator and could have been problematic for convergence in Bayesian estimation (Thomas et al. 2006). To construct discrete-choice models of useful variables I identified sets that were not highly correlated (pair-wise  $|r| < 0.8$ ) using the Pearson correlation matrix for each season and each diel period. This process assisted to reduce convergence issues with multicollinearity but retained variables of biological interest (Table 2–3, Staub et al. 2013). I fitted 4 separate models per diel period (day, night) for each season (PRE, FIRST, SECOND, POST) for a total of 32 models ( $4 \text{ seasons} \times 2 \text{ diel periods} \times 4 \text{ candidate models}$ ).

**Table 2–3 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	2,448.56
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	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 Supplemental Feed	PRI-SUPP	Area of supplemental feed under private management in southwestern Ontario	926.54
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

In an informational theoretic approach, each model represented a biological hypothesis of resource selection (Burnham and Anderson 2002). Model (1) was a null model that assumed the probability of use for all alternatives within a choice set was equal to random chance. Model (2) was an ‘ownership model’ that included habitat types grouped by ownership as the dependent variables. This model would be appropriate if waterfowl habitat selection was influenced by the management practices of the property owner (i.e., amount of disturbance and mortality risk from hunting) but not the composition of the habitat. Model (3) was a landscape composition model that includes the area of different habitat types within each resource unit. I included the St. Clair Flats as a single habitat type as I did not have access to similar spatial data that were available for southwestern Ontario. This model would be appropriate if waterfowl habitat selection was influenced by the amount of these habitat types within the Lake St. Clair region regardless of who was the managing entity. Model (4) was the full model of landscape composition by ownership that included the area of different habitat types categorized by ownership. This model would be appropriate if waterfowl habitat selection was influenced by the amount of these habitats with the Lake St. Clair region and the ownership of these habitat types (Table 2-4).



**Table 2–4 List of Candidate models and variables representing adult female mallard resource selection in the Lake St. Clair regions during the 2014–15 and 2015–16 monitoring periods.**

<b>Model Number</b>	<b>Model</b>
<b>1</b>	(NULL)
<b>2</b>	(PUB)+(PRI)+(WAL)+(CWS)+(MICH-DNR)
<b>3</b>	(WATER)+(MARSH)+(FLAG)+(SUPP)+(AGRI)+(MICH-DNR)
<b>4</b>	(PUB-WATER)+(PRI-WATER)+(WAL-WATER)+ (CWS-WATER)+(MICH-WATER)+(PUB-MARSH)+(PRI-MARSH)+(CWS-MARSH)+(WAL-MARSH)+(PRI-FLAG)+(PRI-SUPP)+ (PRI-AGRI)+(WAL-AGRI)+(MICH-DNR)

I ranked the 4 candidate models by their deviance information criterion (DIC), the Bayesian analog to Akaike's information criterion (Burnham and Anderson 2002, Spiegelhalter et al. 2002, Beatty et al. 2014*b*). I calculated  $\Delta$ DIC values from the top most parsimonious model and used  $>5$   $\Delta$ DIC units to assess fit to the data (Thomas et al. 2006 Beatty et al. 2014*b*). I was specifically interested in population level resource selection strategies thus I based inferences on the posterior distribution of the population level mean  $\mu_k$  and its 95% credible intervals for each top ranking model (Beatty et al. 2014*b*). I further inferred that variables whose 95% credible intervals did not include zero as being important in the resource selection models (Beatty et al. 2014*b*).

I fit candidate discrete-choice models in JAGS v 4.2.0 using the R package R2jags (Su and Yajima 2015, R version 3.2.3 2015). I 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 (Table 2–5).

**Table 2–5 Reference number for candidate models associated with Markov Chain Monte Carlo (MCMC) settings to investigate adult female mallard habitat selection (A) prior to the hunting season, (B) the first and (C) second halves of the hunting season and (D) post hunting season during the 2014–15 and 2015–16 monitoring periods of adult female mallards in Lake St. Clair region.**

**A. Preseason**

Diel Period	Model	Iterations	Burn-in	Thinning
Diurnal	1	NA	NA	NA
	2	125,000	25,000	1
	3	100,000	5,000	1
	4	100,000	5,000	1
Nocturnal	1	NA	NA	NA
	2	100,000	5,000	1
	3	100,000	5,000	1
	4	100,000	5,000	1

**C. Second Half**

Diel Period	Model	Iterations	Burn-in	Thinning
Diurnal	1	NA	NA	NA
	2	100,000	5,000	1
	3	100,000	5,000	1
	4	100,000	5,000	1
Nocturnal	1	NA	NA	NA
	2	100,000	5,000	1
	3	100,000	5,000	1
	4	100,000	5,000	1

**B. First Half**

Diel Period	Model	Iterations	Burn-in	Thinning
Diurnal	1	NA	NA	NA
	2	100,000	5,000	1
	3	100,000	5,000	1
	4	125,000	25,000	1
Nocturnal	1	NA	NA	NA
	2	100,000	5,000	1
	3	100,000	5,000	1
	4	100,000	5,000	1

**D. Post Season**

Diel Period	Model	Iterations	Burn-in	Thinning
Diurnal	1	NA	NA	NA
	2	100,000	5,000	1
	3	100,000	5,000	1
	4	100,000	5,000	1
Nocturnal	1	NA	NA	NA
	2	100,000	5,000	1
	3	100,000	5,000	1
	4	100,000	5,000	1

I used Brooks-Gelman-Rubin statistic as an assessment of convergence where values  $<1.1$  indicate convergence to the posterior distribution (Brooks and Gelman 1998, Gelman and Hill 2007). I centered and standardized all independent variables using two standard deviations ( $\frac{x-\bar{x}}{2s}$ ) to interpret coefficients on a common scale (Gelman and Hill 2007, Beatty et al. 2014b).

## 2.4 Results

### 2.4.1 Capture and GPS Telemetry

One duck from the 2014–15 cohort moved outside the Lake St. Clair spatial layer during the first 4 d of monitoring and did not return therefore it was censored, and one duck died during the same censoring period in 2015–16. My sample was reduced to 57 individuals at the beginning of the PRE season. A total of 43,466 GPS fixes were generated over the duration of the study. After the initial filtering of movement steps, I used 42,273 GPS fixes to calculate movement distances. To isolate the local scale movements, I removed 30,571 fine scale observations and 100 observations at the relocation scale resulting in 11,602 local scale movements. Of the local scale movements, I removed 1,447 fixes that were beyond the extent of geospatial data. Therefore, my final sample was 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 2–6.). I did not track birds for more than one year since the 2014–15 cohort of GPS equipped ducks were not providing sufficient GPS fixes during the 2015–16 monitoring year.

**Table 2–6 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 Period	Diel Period	<i>IDs</i>	<i>N</i>	$\bar{x}$	<i>SD</i>	Range
Pre	Diurnal	57	1724	30.25	13.86	2–59
	Nocturnal	56	771	13.77	7.97	1–35
First Half	Diurnal	51	2191	42.96	24.76	1–99
	Nocturnal	50	1895	37.9	21.03	1–76
Second Half	Diurnal	42	1550	36.9	18.19	1–73

Post	Nocturnal	41	1583	38.61	18.22	1–81
	Diurnal	19	242	12.74	7.86	1–26
	Nocturnal	19	199	10.47	7.09	2–27

### 2.4.2 Habitat Selection

Based on the Pearson correlation matrix, I removed the variable of CWS WATER as it 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 composition and ownership type (Table 2–7). Influential resource selection parameters were variable per season and diel period.

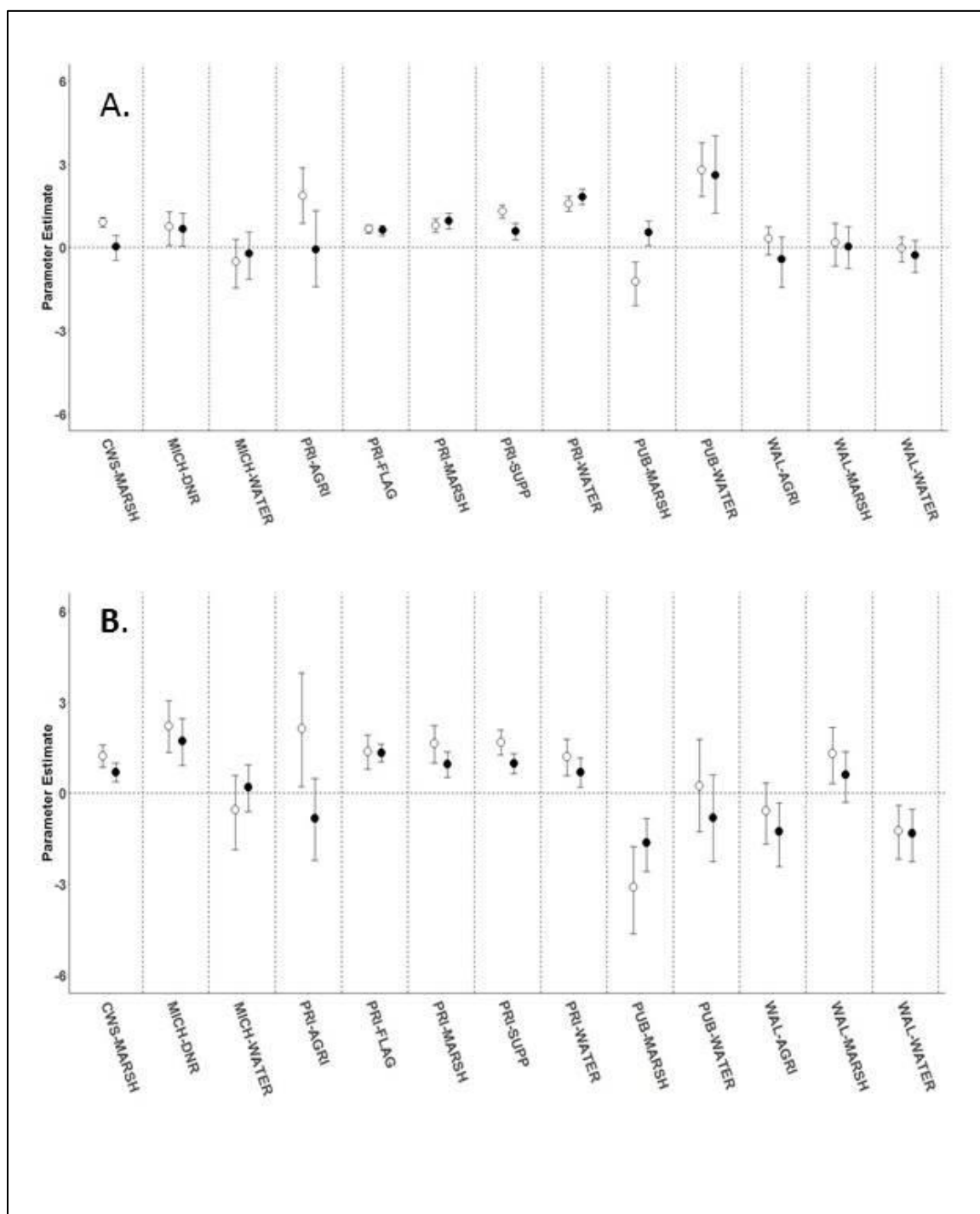
**Table 2–7 A. Deviance information criterion values for all resource selection models during the PRE hunting season, FIRST half of the hunting season, SECOND half of the hunting season, and POST hunting season seasons and for both diurnal and nocturnal diel periods. B. Delta DIC values ranking each resource selection model.**

A.									
Deviance Information Criterion Values									
	Pre		First		Second		Post		
Model	Diurnal	Nocturnal	Diurnal	Nocturnal	Diurnal	Nocturnal	Diurnal	Nocturnal	
4	7659.5	3666.5	4832.3	5539.6	5281.2	6621.5	1276.3	988.4	
3	9297.8	5324.5	6363.2	6807.2	6027.2	7135.5	1338.4	1098.3	
2	11739.0	5837.5	9519.8	9928.7	8158.8	10254.4	1621.1	1381.1	
1	14581.7	6519.4	18512.9	15996.1	13100.8	13372.7	2047.0	1684.2	

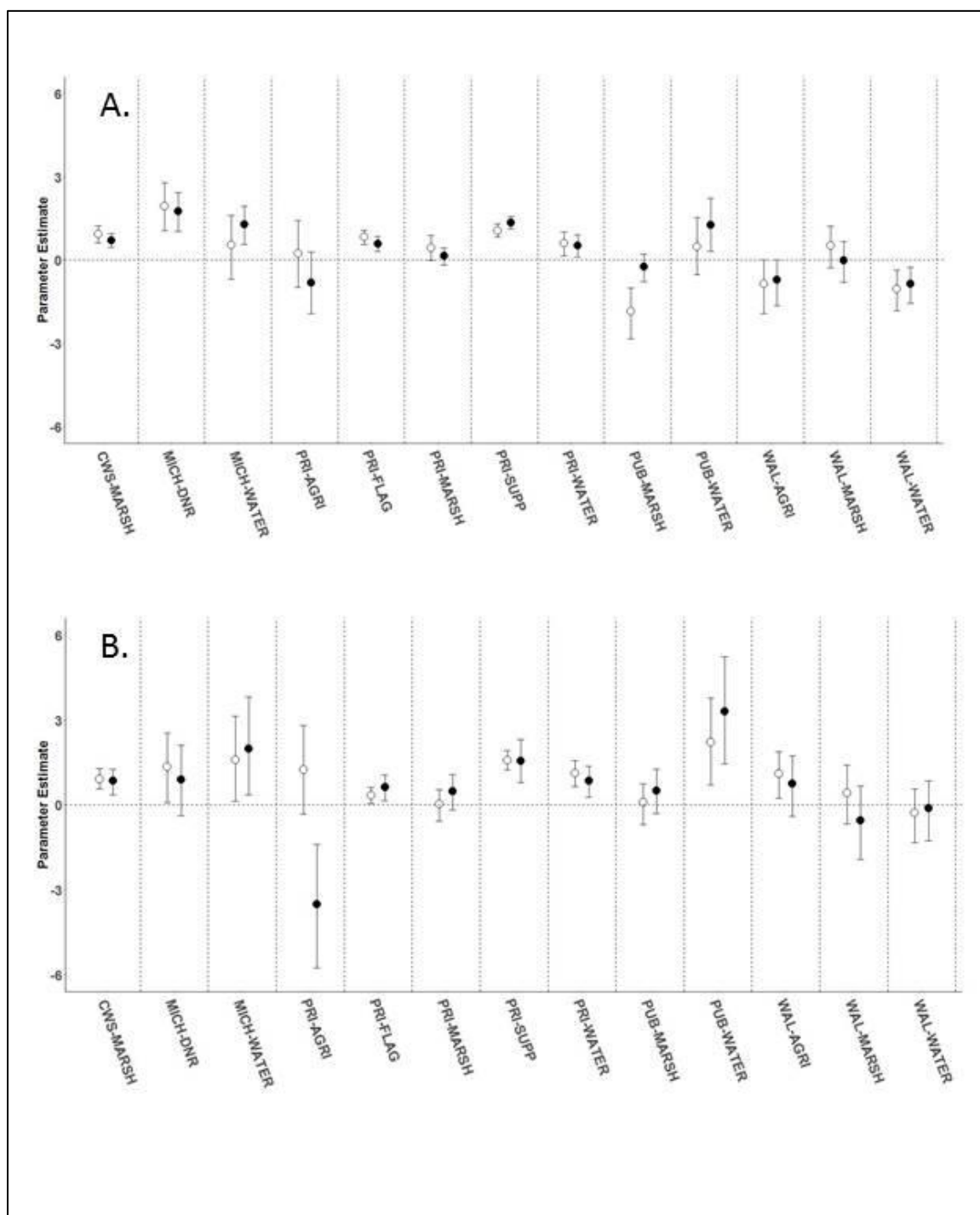
B.									
DELTA Deviance Information Criterion values									
	Pre		First		Second		Post		
Model	Diurnal	Nocturnal	Diurnal	Nocturnal	Diurnal	Nocturnal	Diurnal	Nocturnal	
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
3	1638.3	1658.0	1530.9	1267.6	746.0	514.0	62.1	109.9	
2	4079.5	2171.0	4687.5	4389.1	2877.6	3632.9	344.8	392.7	
1	6922.2	2852.9	13680.6	10456.5	7819.6	6751.2	770.7	695.8	

During the PRE season, adult female mallards selection was positively influenced by the landscape composition variables of federally managed marsh and private agriculture during the daytime only, while selecting for Michigan St. Clair Flats, private flooded agriculture, private marsh, private supplemental feeding, private water, and public water had a positive influence during day and night. Public marsh was avoided during the day and selected for at night. The posterior distribution for all other variables overlapped zero (Figure 2–5.A, Appendix A). During the FIRST half of the hunting season, the influence of several landscape composition features on adult female mallard selection remained positive. The most substantial changes from the PRE to the FIRST season were that ducks began to positively select for federally managed marsh at night, avoiding public marsh for both periods, and the shift in the posterior distribution of public water also included zero. Ducks also began to select for Walpole Island marsh while avoiding Walpole Island water and agriculture at night (Figure 2–5.B, Appendix A). During the SECOND half of the hunting season, the landscape composition of public water and Michigan water both positively influenced resource selection of ducks during the night. Many of the other landscape composition variables continued to positively influence resource selection of ducks but the posterior distributions of private agriculture and private marsh, and Walpole Island marsh overlapped zero (Figure 2–6.A, Appendix A). During the POST season adult female mallards selected the landscape composition variables of federally managed marsh, Michigan water, private flooded agriculture, private supplemental feeding areas, private water, and public water. During the day ducks also selected for Michigan St. Clair Flats and Walpole Island agriculture while avoiding private agriculture at night. The posterior distribution of all other landscape composition variables included zero (Figure 2–6.B, Appendix A.)



**Figure 2–5** Parameter coefficients and 95% credible intervals for the top ranking discrete-choice models that investigated habitat selection strategies for adult female mallards PRIOR to the 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 2–6** Parameter coefficients and 95% credible intervals for the top ranking discrete-choice models that investigated habitat selection strategies for adult female mallards **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.

## 2.5 Discussion

A key component to conservation strategies is the consideration of how animal movements and habitat selection are affected by resource heterogeneity and anthropogenic disturbances (Davis et al. 2010, Beatty et al. 2014a). I examined adult female mallard resource selection during a portion of the non-breeding season in the Lake St. Clair region, an area which has experienced substantial habitat loss and alteration with regionally and temporally variable levels of anthropogenic disturbance. Despite these threats, the region remains a critical staging area for waterfowl in the lower Great Lakes (Weaver et al. 2015). Conservation and management of wetland complexes is conducted by many stakeholders using various strategies to maximize productivity, conserve biodiversity, and sustain ecological services (Euliss et al. 2008). Therefore, it is valuable for natural resource managers to understand how animals select resources given the diversity of management practices employed and varying levels of disturbances and mortality risk from hunting.

I documented substantial selection by mallards for wetland complexes managed by private landowners and government agencies (e.g., Canadian Wildlife Service and Michigan DNR) throughout the monitoring period suggesting wetland complexes under these management types provided resources for a generalist waterfowl species (Baldassarre 2014). Of the habitat types in these wetland complexes, the greatest change in effect size was a 28-fold increase of CWS marsh during the nocturnal period from the PRE to FIRST season. Mallards decreased selection for public water from the PRE to FIRST season as increased disturbance levels and mortality risk from hunting also increased (Dooley et al. 2010a, Dooley et al. 2010b). Mallards exhibited some ability to navigate the risk during the hunting season as there was an increase in selection for public water from the FIRST to SECOND season (O’Neal et al. 2012). Public water had the greatest positive influence on resource selection only before and after the hunting season suggesting that hunting pressure influenced birds to avoid these areas during the hunting season.

Historically, conservation strategies focused on public land management for many species including waterfowl (Meretsky et al. 2006). A large portion of North America’s

wetlands have been drained while most remaining wetlands are now located on privately owned property (e.g., 82% in contiguous USA, [Heimlich et al. 1998]). Private wetland management has become an important component in landscape-level conservation strategies (Beatty et al. 2014a). The Lake St. Clair region is representative of many areas within the Great Lakes that have intensively managed private wetland complexes closely associated with lacustrine habitats that are open to public hunting but are not actively managed by a government agency (Weaver et al. 2015). I have demonstrated that mallards in southwestern Ontario selected habitats that experienced lower hunting intensity founded on the premise that hunting intensity is greatest on public areas of this region. This is supported by the substantial decline in selection for public hunting areas early in the hunting season (e.g., public water). Comparatively, the 95% credible intervals that represent the influence of private water (i.e., a similar habitat type), demonstrate a continued positive influence of resource selection during the same time period. Diurnal parameter estimates for public water decreased 68% more than those for private water with the onset of the hunting season (PRE to FIRST season, [Davis et al. 2011]), I hypothesize that differences in posterior distributions between private and public water is related to less disturbance and mortality risk on private than public water as private clubs limit hunting days and hunter numbers, relative to public areas (Dooley et al. 2010a, Dooley et al. 2010b). Vegetative composition was categorized as relatively similar for both variables as they were both derived from the DUC hybrid layer. Also, despite that the substantial amount of private water was in the lake nearshore and prone to freeze earlier than public open water, private water continued to be selected for through time. Regardless if ice formation happened, mallards continued to select private water presumably to avoid disturbance in the public portions of the lake.

Field-feeding waterfowl generally increase the amount of time spent foraging in agricultural fields as weather conditions deteriorate. This behavior can be attributed to increased nutritional needs for thermoregulation and pending migration (Jorde et al. 1983. Schummer et al. 2010). Interestingly, birds in this study decreased selection for agricultural fields as the season progressed. Typically, waterfowl abandon field feeding locations when waste grain biomass decreases below 50 kg/ha (Reinecke et al 1989, Foster et al 2010). Therefore, decreased field use as the season progressed may have been

related to the depletion of waste grain availability due to foraging and decreased accessibility due to post harvest treatments such as plowing. Further, the provision of multiple supplemental feeding areas possibly enables mallards to satisfy their nutritional requirements without having to incur the risks associated with relocating to agricultural fields where hunting pressure can be substantial.

Mallards selected flooded unharvested agricultural fields diurnally and nocturnally throughout the monitoring period. This habitat type not only provided similar grains as unflooded fields but in greater densities and with easier accessibility. Flooded unharvested agricultural fields are also selected for nocturnal loafing and roosting locations due to the presence of water (Pearse et al. 2012). Flooded unharvested agricultural fields and dry harvested agricultural fields provide a highly nutritional and readily available food source for several species of granivorous waterfowl (Stafford et al. 2010, Pearse et al. 2012). Corn provides approximately 32.7% more metabolizable energy (kcal/g dry mass) than moist-soil plant parts (Kaminski et al. 2004) which allows ducks to access energy dense foods and meet daily energetic needs in less time. Despite that mallards are exposed to an intermediate level of risk at these hunted areas in the Lake St. Clair region, flooded agricultural fields had a positive influence on resource selection with minimal variability between diurnal and nocturnal periods per season (Figure 2–5, 2–6).

The influence of private marshes on resource selection changed to not being substantially influential after the FIRST season, whereas mallards continued to select for federally managed (CWS) marshes. These differences suggest that the intermediate level of disturbance assumed to occur on private marshes may have had a continual gradual effect on waterfowl distribution if resources were similar among marshes (Hagy and Kaminski 2015). Federally managed marsh and supplemental feeding areas were relatively free of disturbance and ducks selected these areas throughout the entire monitoring period. Refuge areas or sanctuaries are prioritized as critical to waterfowl conservation (Madsen 1998, Stafford et al. 2007, Beatty et al. 2014a). The sanctuaries of the Lake St. Clair regions vary greatly in habitat quality but consistent positive selection by mallards for these areas suggest benefits derived from this management practice can be important to

waterfowl in the region. The federally managed areas are hemi-marsh environments of open water, submergent and emergent vegetation. The supplemental feeding areas of dense resources (i.e., a deposit site of cob corn feed) are continually replenished prior to and throughout the majority of the hunting season, but also contained variable amounts of marsh, open water, dry agriculture, and flooded agriculture within the 400 m boundary that prohibits hunting. Not all supplemental feeding areas were used equally, possibly suggesting that the composition of the supplemental feeding area (e.g., amount of food or amount of other habitat types) and juxtaposition to other resources and disturbance influences their use.

The two parcels of the St. Clair National Wildlife Area, the St. Clair and Bear Creek units, were used differently by mallards during the monitoring period. GPS fixes that occurred on National Wildlife Area property only occurred on the St. Clair unit, which is located directly adjacent to the shore of Lake St. Clair, private hunt clubs, and agricultural fields. Throughout the monitoring period, it was unclear if food availability in National Wildlife Area marshes was depleted thereby forcing birds to forage in other habitats (i.e., reaching giving-up density; Brown 1988, Hagy and Kaminski 2015). Even if giving-up density was met within the St. Clair Unit, it likely had negligible effect on waterfowl use because ducks could offset energetic constraints by relocating daily to nearby supplemental feeding areas. This relationship has been supported by observations of waterfowl density being influenced by variables outside of those present at the specific site of observation (Hagy and Kaminski 2015). Thus, the benefits of selecting the St. Clair Unit are difficult to uncouple between ducks meeting foraging needs and using it as refugia. Monitoring food abundance and waterfowl use among these habitat types throughout the hunting period would provide further insight into the selection coefficients detected in my study.

The Michigan St. Clair Flats area contained flooded agriculture fields (e.g., standing corn) that were managed as sanctuaries adjacent to hunted marshes, which could have influenced the positive selection of mallards for this habitat type. I did not have specific habitat composition data, similar to the DUC layer, and therefore categorized the St. Clair Flats as one habitat type. The influence of sanctuaries (i.e., non-hunted wetland habitats)

is most likely conservative as the geospatial data only represents sanctuaries as supplemental feeding areas and federally managed properties. The duck hunting season in Michigan is approximately half the duration of the season in the southern district of Ontario. The hunting season in Michigan began approximately 2 weeks after the FIRST season in Ontario and ended nearly a month prior to the end of SECOND season (except for the 27–28 December hunting days). Differential season dates resulted in the St. Clair Flats being a spatial refuge for ducks that were experiencing hunting disturbance in Ontario. Also, many privately managed areas intensively manage waterfowl hunting disturbance. Despite the conservative representation of refugia, resource selection strategies suggest that the permanent sanctuaries within southwestern Ontario are important for autumn staging waterfowl.

Within Walpole Island there are multiple hunt clubs, private properties, and public properties accessible to resident hunters. The coarse categorization of Walpole Island as a single ownership type may have reduced my ability to detect differences in resource selection of various habitats or there were other confounding factors that I could not measure that caused the influence of area of habitat types on Walpole Island to not be estimated as influential (e.g., disturbance, habitat quality). More detailed delineation of habitat types could result in a further understanding of resource selection strategies on the island compared to adjacent habitat types.

Wetland conservation in North America is shared among many stakeholders with adjacent geopolitical boundaries. Understanding animal movement and resource selection within and across these borders is critical for regional conservation (Fahrig 2007). I demonstrated that mallards, which are a generalist species, shift patterns of resource selection throughout a period of the non-breeding season as they navigated a landscape of variable resources and anthropogenic disturbance. The Lake St. Clair region contains some unique habitat types, but is characteristic of areas that waterfowl use throughout North America, as the majority of wetland management occurs on private lands adjacent to government managed complexes and it experiences common threats to wetland loss.

These estimates of resource selection strategies are a novel contribution to the science of waterfowl ecology supporting the importance of protected areas within managed wetland complexes (Beatty et al 2014a). This importance is evident in the increased selection for federally managed marsh during the FIRST half of the hunting season and fluctuation in selection estimates for public water where disturbance was assumed to be greatest. My results suggest that consideration of anthropogenic disturbance is important for waterfowl management, similar to research elsewhere (Beatty et al. 2014a). I recommend further investigations of how sanctuary juxtaposition and composition influence resource selection to inform management of waterfowl and wetland complexes of the region (Nichols et al. 1995, Williams 1997). My estimates of resource selection strategies in the Lake St. Clair region can provide local area managers with insight into how ducks are using their properties in addition to allowing regional conservation planners to make informed and prioritized future management decisions.

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## Chapter 3

### 3 INFLUENCE OF RESOURCE SELECTION ON MORTALITY RISK FOR ADULT FEMALE MALLARDS IN THE LAKE ST. CLAIR REGION DURING AUTUMN AND WINTER

#### 3.1 Introduction

Animals are assumed to maximize fitness (survival and reproduction) when they use resources in a greater proportion than their availability (Manly et al. 2002). The decision-making processes of resource selection that have fitness ramifications depend on the scale at which choices are considered (Johnson 1980, Boyce 2006). At increasingly greater spatial and temporal scales, complexity between the relationships of resource selection and fitness also increases because of accumulating factors influencing decision-making (Johnson 1980). Understanding the details of the multifaceted relationships between resource selection and fitness has been a challenge in ecology because experimental manipulation is difficult at landscape and local scales (McLoughlin et al. 2005). For instance, the scale of local resource selection for dabbling ducks (genus *Anas*) can be relatively large (e.g., 30 km radius) and include many resources (Jorde et al. 1983, Davis and Afton 2010, Link et al. 2011, Beatty et al. 2014a, Chapter 2). Understanding how ducks use resources relative to availability (i.e., resource selection) within their home range is important for understanding how ducks respond to management practices. More important, but rarely investigated, is the relationship of how resource selection strategies by animals influences seasonal survival.

The Lake St. Clair region includes a diversity of resources for waterfowl including lacustrine and palustrine marshes, managed impounded wetlands, and terrestrial agricultural habitats that are variable in the quality, quantity, and timing of available resources (Bookhout et al. 1989). These habitats also experience variable amounts of disturbances and mortality risk from hunting during autumn and winter. Indeed, the St. Clair region is a heterogeneous landscape, whereby differences in resources selection may influence waterfowl survival. Mallards (*Anas platyrhynchos*) are habitat generalist that

are abundant and the most harvested waterfowl species in the Lake St. Clair region. Mallards in this region are part of the Great Lakes population, which have been suggested to be separate from more abundant and extensively studied mid-continent population (Anderson and Henry 1972, Munro and Kimball 1982, Zuwerink 2001).

Previous research suggests that the Great Lakes' mallard population dynamics are influenced by non-breeding season survival of adult females (Coluccy et al. 2008). Non-breeding season survival of mallards has also been suggested to be related to hunter harvest (Blohm et al. 1987, Reinecke et al. 1987, Fleskes et al. 2007). Harvest management strategies have been proposed to ensure sufficient mallard survival and conservation of the population in the Great Lakes region (Coluccy et al. 2008). The dynamics between hunter harvest and regional mallard population growth is of particular importance because most mallards harvested within the Great Lakes region are presumed to be hatched in that region (Munro and Kimball 1982, Zuwerink 2001). Therefore, understanding the relationship between habitat management practices, harvest management, and survival can help direct management of the Great Lakes mallard population and is currently limited.

The wetland complexes within the Lake St. Clair region provide a diversity of resources that are selected by waterfowl to meet their energetic needs and provide refuge from anthropogenic disturbance or risk of mortality (Weaver et al. 2015). Since anthropogenic disturbance and mortality risk from hunting can influence local waterfowl distribution and movement (Madsen 1998, Brochet et al. 2009, Dooley et al. 2010a, Chapter 2), protected areas (i.e., sanctuaries) provide important refuges when these factors are substantial (Webb et al. 2010, Beatty et al. 2014b, Chapter 2). I previously described the variable management practices that influence available resources and the assumed mortality risks that mallards experience during a portion of the non-breeding season in the St. Clair region (Chapter 2). I categorized the level of mortality risk per habitat type as a function of how much access hunters could have during the hunting season and this access was regulated by ownership type. By tracking the diurnal and nocturnal space-use of adult female mallards from the end of August to the end of January for two field seasons I documented that mallard resource selection was influenced by the composition

of habitat types and ownership types. I inferred that resource selection by mallards was influenced by forage quality and levels of anthropogenic disturbance and mortality risk from hunting because mallards disproportionately selected for managed habitats and those that prohibit or manage these risks (e.g., Canadian Wildlife Service, Michigan DNR, or on private hunt clubs; Chapter 2). The areas that were assumed to experience the most risk of mortality from hunting were the public accessed areas, specifically publicly accessed water. This habitat type was selected by mallards only before and after the hunting season, demonstrating a shift in selection strategies, which I inferred was in response to hunting season disturbances and mortality risks.

My goal for this chapter was to assess how female mallard resource selection related to mortality risk while they were in the Lake St. Clair region. I hypothesized mallards select habitats in relation to anthropogenic mortality risk and attributed this to trade-offs between the benefits of accessing available resources and the risk of exposure to mortality. I predict a positive relationship between survival and selection for habitat types presumed to be associated with the least amount of risk and a negative relationship with selection for habitat types of presumed greatest risk. My objectives are to determine if individual resource selection parameters relate to the probability of survival during a portion of the non-breeding season and to estimate the probability of survival for adult female mallards while in the Lake St. Clair region.

## 3.2 Study Area

As all birds were marked in Canada, the study area was primarily on the Canadian side of Lake St. Clair and included Essex, Chatham-Kent, and Lambton counties as well as Walpole Island First Nation. The study area also included the Michigan, USA portion of the lake and Michigan St. Clair Flats. The region has experienced substantial wetland loss and habitat alteration since European settlement (Weaver et al. 2015). Remaining wetlands are conserved through a combination of private property owners, the Canadian Federal Government, Walpole Island First Nations, the Michigan Department of Natural Resources, or are the wetlands that are influenced by the fluctuating water levels of the lake. Ownership type and management strategies influence both the resources that are available and mortality risk associated with harvest during autumn and winter. I

previously provided a detailed description of the landscape of the study area (Chapter 1 and 2). I used the Lake St. Clair spatial layer that I created in Chapter 2 as the extent for investigating mallard survival (Chapter 2).

### 3.3 Methods

#### 3.3.1 Capture and Transmitter Deployment

Mallard capture and transmitter deployment were described in detail in Chapter 2. I only tracked adult female mallards to understand survival of this demographic at Lake St. Clair as it has been suggested to be important to population growth of mallards within the Great Lakes (Coluccy et al. 2008). I captured adult female mallards at a private property along the Canadian shore of Lake St. Clair in late-August to early-September 2014 and 2015 (UTM 17 N 383701 E, 4697376 N). I recorded body mass ( $\pm 10$  g) by placing birds in a nylon mesh bag, weighing the bag and bird with a hand-held scale (Berkley BTDFS50-1 digital fish scale) and subtracting the weight of the bag. I measured the length of culmen, tarsus, and head of each bird with calipers and wing chord was measured using a flat-edged ruler. All morphometric measurements were used to index body size and condition. Due to logistical constraints, I could not keep birds for extended periods of time (e.g. 3–8 hrs) to allow for digestion of ingesta that was consumed while in the traps (Dufour et al. 1993).

The 2014 and 2015 cohorts consisted of 20 and 39 adult female mallards, each of which were equipped with Global Positioning System (GPS) transmitters. Of the 2014 cohort, 9 adult female mallards were equipped with 22-gram Platform Terminal Transmitter (PTT) back-pack style solar powered GPS transmitters (Model 22GPS) and 11 adult female mallards were equipped with 25-gram Groupe Spécial Mobile (GSM) back-pack style GPS transmitters (Model Saker-H). The PTT transmitters collected six fixes per 24 h period while the GSM transmitters collected eight fixes per 24 h period. The 2015 cohort consisted of 25-gram GSM back-pack style GPS transmitters (NorthStar Science and Technology, LLC, King George, Virginia, USA and Ecotone Telemetry, Sopot, Poland). All transmitters were equipped with a 3.5-gram Very High Frequency (VHF) transmitter (Holohil Systems Ltd., Carp, ON, Canada) which I used to assist with determining fate of

individuals. I trimmed and glued a 3.2 mm neoprene pad to the base of each transmitter as a protective barrier between the feathers of the bird and the transmitter. I attached transmitters dorsally between the wings using a harness of 0.38cm wide Teflon ribbon (Bally Ribbon, Bally PA). 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  $\leq 32$  g and was  $\leq 5\%$  of the body weight of ducks (average body mass at capture  $1072.05 \pm [21.26]$  g) used in the sample as recommended by the guidelines for transmitter mass by the American Ornithologists Union (Fair et al. 2010). Ducks were released immediately after being equipped with GPS transmitters (Animal Use Protocol 2014–017).

### 3.3.2 Determining Fate and Categorizing Mortality Events

I determined the fate of individuals that remained within the Lake St. Clair spatial layer to assure that I had accurate resource selection estimates for each individual. If an individual left the Lake St. Clair spatial layer it was censored from the survival analysis on the last day a location was recorded in the spatial layer. I monitored birds until 31 January, the transmitter failed to report fixes, a bird was reported shot by a hunter, or I recovered evidence of a mortality event. When transmitters failed to report fixes for multiple duty cycles, I attempted to recover carcasses and transmitters by searching at the last known GPS location through homing to the VHF signal via a VHF receiver and a hand-held Yagi antenna. I monitored individual's locations by downloading GPS fixes from manufacturer provided software and internet access portals. If birds did not move approximately  $>150$  m between GPS fixes I waited until GPS fixes were no longer being transmitted for multiple duty cycles to attempt to determine the fate of the individual. I implemented this strategy because the unsuccessful transmission of GPS fixes could have been a result of poor reception between the transmitter and the Argos satellites or GSM network and not an indication of a mortality event. Also, waiting until multiple duty cycles lapsed before transmission of GPS fixes increased the likelihood that a mortality event truly occurred and not a data transmission error. Access to many of the locations

the ducks used was limited, and a goal was to not to introduce extra disturbance in areas of waterfowl use.

The GPS transmitters were programmed to store thousands of GPS points until a suitable connection was established to the Argos system or GSM network to off-load fixes. When I could recover an intact GPS unit and recharge the solar battery there was the possibility of downloading more GPS fixes prior to what was known at the time of recovery from tracking the duck from online information. Thus, my criteria for determining the date of a mortality event was based on evidence provided by all GPS fixes and the remains found at the location of discovery. If I recovered the carcass with an attached transmitter at a location that was  $\leq 150$  m from the location of the last downloaded GPS fix, then I used the date the bird arrived at that location and never moved  $>150$  m as the date of the mortality event and the last location used. If I recovered the carcass with an attached transmitter  $>150$  m from the last downloaded location, I used all recorded GPS fixes and randomly picked a day from the last day a fix was transmitted to the day before I found the transmitter as the date of the mortality event (Frair et al. 2007). If GPS fixes stopped being transmitted and I could not recover the transmitter, the last downloaded fix was used as the last location for that bird's resources selection information, but the bird was censored from the survival analysis on the date of the last GPS fix. For harvest mortalities, I considered the duck to have been alive and provided accurate location information prior to when the hunter reported harvesting the bird. I categorized the date a bird was harvested as the date of the mortality event. I categorized an adult female mallard as dead if there was evidence (e.g., feathers, bones, or a carcass) obtained at the site or if a hunter reported harvesting a bird with a transmitter.

### 3.3.3 Temporal Scale for GPS fixes for Resource Selection Analysis

In Chapter 2, I described how I categorized all GPS fixes that occurred 30 min before sunrise to 30 min after sunset as diurnal locations and all other fixes outside of this time frame were considered nocturnal locations. I also described how I categorized GPS fixes based on 4 seasons of a PRE hunting season, FIRST half of the hunting season, a SECOND half of the hunting season, and POST hunting season to estimate changes in

resource selection over time. The 106 day 2014–15 open hunting season for ducks in the southern Ontario district was 27 September to 10 January and the 2015–16 open hunting season was 26 September to 9 January.

### 3.3.4 Survival Analysis Variables

In chapter 2, I categorized the movement of ducks equipped with GPS transmitters at three spatial scales: fine, local, and relocation scale movements. I used the local scale movements to calculate resource selection estimates based on the area (ha) of different habitat variables through a Bayesian random effects discrete-choice model, producing an estimate of how each variable influenced the probability of each duck selecting a resource unit during a specific diel period and season. Of the candidate set of models I analyzed, the top model ( $> 5 \Delta\text{DIC}$  units) that consisted of variables categorizing resource units based on the composition of habitat type and ownership type for each diel period and each of the 4 seasons (Table 3–1).

**Table 3–1 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	2,448.56
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	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 Supplemental Feed	PRI-SUPP	Area of supplemental feed under private management in southwestern Ontario	926.54
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



From these models, I used each duck's individual diurnal parameter coefficient as an estimate how each duck was selecting resources (i.e., resource selection strategy) during the 4 pre-defined seasons. This approach resulted in 13 resource selection variables. Mortality risks can differ from year to year. I also included a “year” covariate, to account for variation in risk of mortality among study years.

Lipid reserves are an important source of energy for mallards that can influence their survival during autumn and winter. These reserves can be related to the individual variation in body mass which can be influenced by the structural size of the bird (Whyte and Bolen 1984). To account for this variation, I calculated a body condition index based on body mass corrected for structural size (Dufour et al. 1993). I conducted a principal component analysis on the correlation matrix of the four morphometric measurements of head, culmen, tarsus and wing chord length. I interpreted the scores along the first (PC1) and second (PC2) principal axis as estimates of body size. Both principal components had eigenvalues  $> 1$  and cumulatively represented 0.67 of the variation in the morphometric measurements. I removed body mass variation based on the residuals from a linear regression that modeled the dependence of body mass on PC1 and PC2. From this regression, I calculated expected values of body mass which were used in the following equation:

$$m_{adj} = (m_{obs} - m_{pred}) + \bar{m}_{obs} \quad (1)$$

where  $m_{obs}$  is the observed body mass,  $m_{pred}$  is the predicted value calculated from the regression equation and  $\bar{m}_{obs}$  is the average body mass of all individuals included in the model (Dufour et al. 1993). Therefore, I generated 13 variables and 2 covariates (13 diurnal resource selection coefficients + 1 year covariate + 1 body condition covariate) to be included in survival analyses (Table 3–2). The resource selection coefficients varied per season while the year and body condition covariates were fixed.

### 3.3.5 Statistical Analysis

I analyzed adult female mallard survival and investigated how the 13 variables and 2 covariates were related to mortality risk using the Anderson-Gill extension of the Cox

proportional hazard (Cox PH) regression model using the function “coxph” in package “survival” in R version 3.3.2 (R Core Team 2016, [Dinkins et al. 2014]). Time-to-event data, e.g., survival data from telemetry tracking, are commonly analyzed with Cox PH models as the models are semiparametric, such that they do not require specifying a probability distribution for the baseline hazard, they can easily incorporate time-varying variables, and they include both survival times and censoring information (Cox 1972). There are two components to a Cox PH model: the non-parametric baseline hazard  $h_0(t)$  representing the hazard when all independent variables are zero and parametric variables ( $x$  values) that affect survival. These components provide the semiparametric framework to estimate the expected hazard at time  $t$  which is  $h(t|x_t)$ . The exponential regression survival model assumes that the baseline hazard is constant.

$$h(t|x_t) = h_0(t) \times \exp(\beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_x x_{ik}) \quad (2)$$

Positive coefficients correspond to a greater risk of death and lower survival as these coefficients represent the hazard of risk. The antilog of an estimated regression coefficient is interpreted as the hazard ratio (Hosmer et al. 2008). If the hazard ratio  $< 1$  then the predictor is related to an improvement in survival and if the hazard ratio is  $> 1$  then the predictor is related to an increased risk or decreased survival. I further extended the Cox PH model to include multiple strata. A stratified Cox PH model contains stratum-specific baseline hazard functions,  $h_{s0}(t)$ , incorporating the effect of all variables with constant values in each stratum. The proportional hazard function for stratum  $s$  is

$$h_s(t|x_t) = h_{s0}(t) \times \exp(\beta_1 x_{i1} + \beta_2 x_{i2} + \beta_x x_{ik}) \quad (3)$$

where  $s$  represents strata 1, 2, ...,  $S$ . The effect of variables can be modeled with a constant slope across strata or with different slopes. The reasoning behind using strata instead of treating the strata factor as a variable itself, is that the effect of the strata is assumed to be related to survival but is of secondary importance relative to the other variables. Additionally, this extension allows for stratum-specific baseline hazard functions for all variables that are constant within a stratum. (Hosmer et al. 2008).

I combined the PRE and POST hunting season (see Chapter 2) into one NON-HUNTING season factor due to the small number of events that occurred in both seasons which otherwise would result in lack of model convergence. Additionally, I assumed that these two seasons experienced a similar level of disturbance. I used the 3 factors of: NON-HUNTING season, FIRST half of the hunting season, and SECOND half of the hunting season as the strata for my Cox PH models. Through stratifying by season, I allowed mortality risk to differ between each half of the hunting season and non-hunting season. With this approach, my primary interest was not the effect of the season itself but understanding the effect of the variables during that season, which aligns with my objective to estimate how resource selection is related to mortality. I developed models with 0-3 variables to reduce over-fitting (Table 3–2 [Benson et al. 2014]). I developed 15 stratified Cox PH models with a constant slope, 15 Cox PH models with different slopes across strata and a null Cox PH model. The Cox PH models with different slopes involve interaction terms that determine the change in the relationship of the variable and mortality risk over seasons (Hosmer et al. 2008).

**Table 3–2 Candidate models of mortality risk of GPS equipped adult female mallards in the Lake St. Clair region during the autumn and winter, 2014–15 and 2015–16.**

Constant Slope Models			Interaction Models		
Strata	Slope	Variable	Strata	Slope	Variable
SEASON	+	YEAR	SEASON	x	YEAR
SEASON	+	BODY CONDITION	SEASON	x	BODY CONDITION
SEASON	+	MICH-DNR	SEASON	x	MICH-DNR
SEASON	+	PUB-WATER	SEASON	x	PUB-WATER
SEASON	+	PRI-WATER	SEASON	x	PRI-WATER
SEASON	+	WAL-WATER	SEASON	x	WAL-WATER
SEASON	+	MICH-WATER	SEASON	x	MICH-WATER
SEASON	+	PUB-MARSH	SEASON	x	PUB-MARSH
SEASON	+	PRI-MARSH	SEASON	x	PRI-MARSH
SEASON	+	WAL-MARSH	SEASON	x	WAL-MARSH
SEASON	+	CWS-MARSH	SEASON	x	CWS-MARSH
SEASON	+	PRI-FLAG	SEASON	x	PRI-FLAG
SEASON	+	PRI-SUPP	SEASON	x	PRI-SUPP

SEASON	+	PRI-AGRI	SEASON	x	PRI-AGRI
SEASON	+	WAL-AGRI	SEASON	x	WAL-AGRI

If an individual was alive and within the Lake St. Clair spatial layer it was censored on the last day of the season and entered the next season on the next day. I standardized the origin for the 2014 cohort on 27 August and the 2015 cohort on 26 August and both ending on 31 January. The difference in one calendar day between years for the origin allowed for the day at which individuals left one season and entered the next season to sum to the same total. These data were left-censored (i.e., staggered entry) for individuals entering the study 4 days after being equipped with a GPS transmitter and right-censored for individuals that did not die, moved outside of the Lake St. Clair Spatial layer, or stopped providing local movement data (Dinkins et al. 2014). I assumed that censoring was unrelated to fate (Benson et al. 2014).

I used the test suggested by Therneau and Grambsch (2000) to assess violations of the proportional hazards assumption of Cox PH models using the “cox.zph” function in package “survival” in R (Benson et al. 2014, Dinkins et al. 2014). I did not detect significant violations in the proportionality in the variables used in the survival models (all  $P > 0.05$ ). I evaluated models of mortality risk of adult female mallards through an information-theoretic approach (Burnhman and Anderson 2002), where my sample size was the number of events (i.e., mortalities) I used to calculate Akaike’s Information Criteria corrected for small sample size ( $AIC_c$ : Therneau and Grambsch 2000, Burnhman and Anderson 2002, Benson et al. 2014). I did not use the number of individuals or records for my sample size as the number of mortalities was more conservative and favored the simplest model with least number of variables and assumptions (i.e., parsimony) in my model selection process (Benson et al. 2014). I reported models with  $< 2 \Delta AIC_c$  units of the top model (i.e., model with 0  $\Delta AIC_c$ ) as these models have substantial empirical support and I also report the null and year model for reference. I used hazard ratios and 95% confidence intervals of hazard ratios to assess the contribution of each variable of the supported models (Thernau and Grambsch 2000). For continuous variables, I report the hazard ratio equivalent to a 0.1-unit change in the variable and confidence interval. I used this scaling to allow for more biologically

interpretable differences in the effect size of variables of coefficients of resource selection (Hosmer et al. 2008, Benson et al. 2014). I also estimated robust “sandwich” standard errors for parameter estimates as data were not independent per individual thus I modeled them as clustered (Benson et al. 2014).

I calculated survival rates from the beginning of the monitoring period to the end of each of the 4 seasons (PRE, FIRST, SECOND, and POST) through a Kaplan-Meier product limit estimator which allows for left and right censoring. The survival rate to the end of the post season is analogous to the null Cox PH model (Therneau and Gramsch 2000, Benson et al. 2014). I also converted the 158 d (27 August – 31 January) survival estimate to a 30 d survival estimate using the formula:

$$30\text{ d survival estimate} = \sqrt[158/30]{\text{Kaplan} - \text{Meier survival estimate}} \quad (4)$$

Coluccy et al. (2008) provided non-breeding season survival estimates for adult female mallards with the Great Lakes and suggested that this parameter explains the most variation in population growth for the Great Lakes mallard populations. To compare my non-breeding season survival estimates to Coluccy et. al (2008) on a uniform scale, I converted the average non-breeding season (16 Aug – 31 March) survival estimate to a 30 d survival estimate (Davis et al. 2015) using the formula:

$$30\text{ d survival estimate} = \sqrt[228/30]{\text{adult female non} - \text{breeding season survival estimate}} \quad (5)$$

Coluccy et al. (2008) did not report confidence intervals for their adult female non-breeding survival estimates.

### 3.4 Results

Of the 59 GPS equipped mallards, 56 were included in the survival analyses. One duck from the 2014–15 cohort moved outside of the Lake St. Clair spatial layer during the first 4 d of monitoring and did not return. During the 2015–16 monitoring period, I excluded one duck that died during the first 4 d of monitoring and one duck because of extended periods without local resource selection data. I did not detect support for yearly

differences in mortality risk and combined both years of data (Table 3–3). I recorded 17 mortality events that occurred within the Lake St Clair spatial layer during the 2014–15 and 2015–16 monitoring periods. The top model predicting adult female mallard mortality risk had the interaction of the season strata and resource selection coefficients for public water (Table 3–3).

**Table 3–3 Top candidate model configuration (Model), the number of variables ( $k$ ), AIC for small sample size ( $AIC_c$ ), and  $AIC_c$  differences ( $\Delta AIC_c$ ) for all candidate models of mortality risk of GPS equipped adult female mallards with  $AIC_c$  less than the null model in the Lake St. Clair region during the 2014–15 and 2015–16 monitoring periods.**

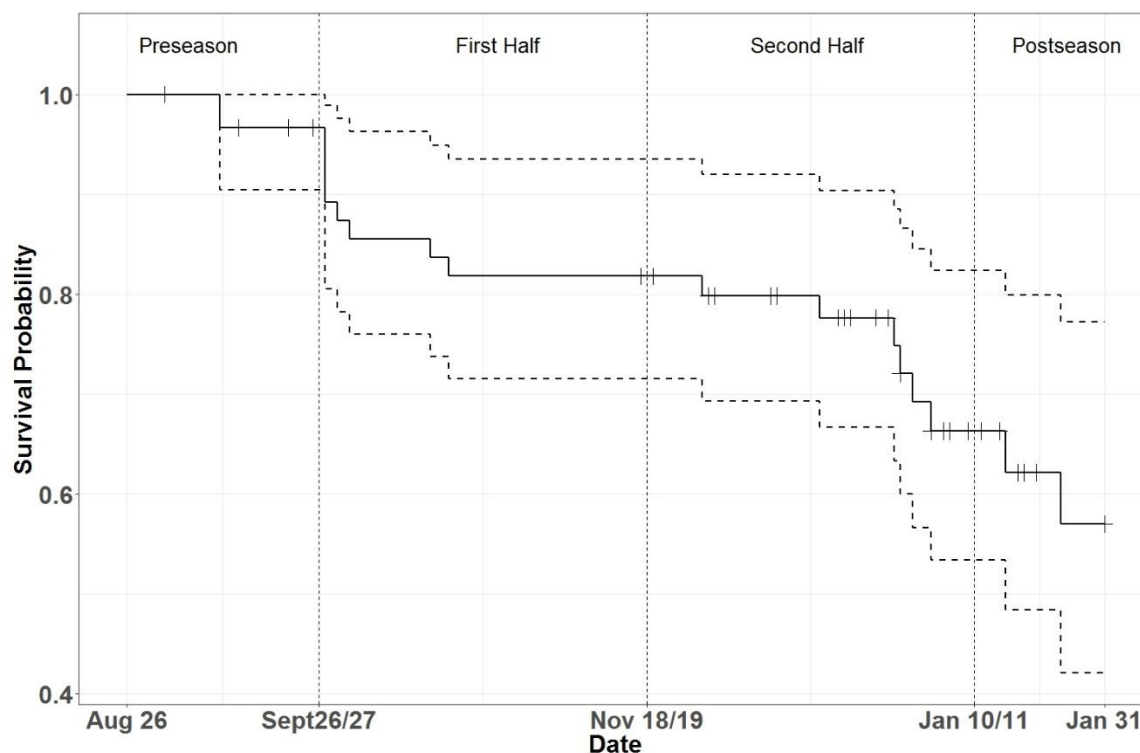
Model	$k$	$AIC_c$	$\Delta AIC_c$
strata(Season) * PUB-WATER	3	117.85	0
strata(Season) + WAL-WATER	1	119.05	1.2
strata(Season) + PRI-WATER	1	119.07	1.22
strata(Season) * PRI-WATER	3	119.75	1.9
strata(Season) + PRI-SUPP	1	119.82	1.97
Null	0	120.1	2.25
strata(Season) + YEAR	1	120.17	2.32

Four models were ranked within  $< 2 \Delta AIC_c$  of the top ranked model suggesting there are 5 models with competing levels of support for describing the relationships of variables and mortality risks during the monitoring period.

The top model suggests that adult female mallards increased survival by selecting for public water during the non-hunting season (robust standard error = 1.78, hazard ratio = 0.676, 95% CI 0.477–0.958). During the first half of the hunting season, the top model indicates that selecting for public water increased mortality risk (robust standard error = 1.80, hazard ratio = 1.545, 95% CI 1.084–2.2) and a similar effect of increased mortality risk was observed during the second half of the hunting season, but with a smaller effect size and was not substantially influential as the confidence interval included one (robust standard error = 1.82, hazard ratio 1.344, 95% CI 0.941–1.919). The second ranked model contained the main effect of selecting for the area of water classified on Walpole Island. This model describes mortality risk of adult female mallards increased with selecting for this variable throughout the entire monitoring period (robust standard error = 0.307, hazard ratio = 1.11, 95% CI 1.045–1.179). The third, fourth, and fifth models all

contain variables that do not substantially contribute to explaining mortality risk as their confidence intervals overlap one, but based on AIC<sub>c</sub> values these models are competitive with the top model. The third and fourth ranked model include the main effect of selecting for private water throughout the monitoring period and the interaction of season strata and coefficients of selecting for private water, respectively. The main effect model describes mortality risk as decreasing throughout the monitoring period as selection for private water increases (robust standard error = 0.309, hazard ratio = 0.946, 95% CI 0.891–1.005). The fourth model including the interaction of season strata and private water provides additional information about these relationships. This model describes mortality risk decreasing during the non-hunting season (robust standard error = 2.237, hazard ratio = 0.752, 95% CI 0.485–1.165), the mortality risk increased with increasing selection for private water during the first half of the hunting season (robust standard error = 2.214, hazard ratio = 1.307, 95% CI 0.847–2.016), and during the second half of the hunting season mortality risk also was increased with increasing selection for private water (robust standard error = 2.319, hazard ratio = 1.097, 95% CI 0.696–1.728). The fifth model contained the relationship of mortality risk and coefficients of selection for private supplemental feeding areas, suggesting that mortality risk increased as selection for private supplemental feeding areas increased throughout the monitoring period (robust standard error = 2.38, hazard ratio 1.091, 95% CI 0.993–1.198).

The 158 d survival rate for all adult female mallards (2014 and 2015 cohorts) that were recovered in the Lake St. Clair spatial layer was 0.57 (95% CI 0.42–0.77). During the monitoring period 1 mortality event occurred during the PRE hunting season, 8 mortality events occurred during the FIRST half of the hunting season, 6 mortality events occurred during the SECOND half of the season, and 2 mortality events occurred during the POST season (Figure 3–2). The probability of survival through the PRE season was 0.97 (95% CI 0.91–1.00), through FIRST half of the hunting season it was 0.82 (95% CI 0.72–0.94), and through SECOND half of the hunting season it was 0.66 (95% CI 0.48–0.8, Figure 3–1). Of the 14 mortality events that occurred during the hunting season 9 were confirmed to be from hunter harvest. For all other mortality events, I could not determine the cause of death.



**Figure 3–1 Kaplan-Meier survival curve for the combined time-to-event data of the 2014 and 2015 cohort of GPS equipped adult female mallards within the Lake St. Clair region. Solid line is the estimate of survival probability as it changes over time and the dashed lines are the associated upper and lower 95% confidence intervals.**

The 30 d survival rate of adult female mallards from the 2014–15 and 2015–16 monitoring periods was 0.90. The 30 d survival rate from Coluccy et al. (2008) was 0.955.

### 3.5 Discussion

Non-breeding season survival of adult females has been suggested to influence mallard population growth within the Great Lakes (Coluccy et al. 2008). My results demonstrate that non-breeding season survival, at Lake St. Clair, was related to resource selection. However, my conclusion is based on several models that were competing for the most empirical support. There is uncertainty about how mortality risk was related to individual resource selection strategies because several models were within  $2 \Delta AIC_c$  of the top model and the confidence intervals of the parameter estimates were generally large. Small sample size of events precluded me from developing multivariate models and could have contributed to having multiple competing models. Despite these analytical



limitations, I developed conservative inferences to illustrate the potential fitness effects of habitat selection by ducks as they navigate a heterogeneous landscape of risks and resources. I highlight these potential effects to further stimulate research into how habitat availability and management may influence survival by migrating ducks. Linkages, such as these, are important to guide conservation but can be rare due to the complexities of behaviors and observational studies at large spatial scales.

Choices involved in resource selection behaviors are assumed to provide some fitness benefit. In discrete-choice modeling of resource selection, this fitness benefit is undefined but characterized by attributes of the chosen resource units (Cooper and Millsphaugh 1999). Through using the individual resource selection coefficients generated from a Bayesian random effects discrete-choice model (Chapter 2), I have begun to describe the fitness relationship of survival and resource selection in the Lake St. Clair region. Of the various habitat and property ownership types available to mallards, survival increased when mallards selected for public water outside of the hunting season and survival decreased when ducks select for public water during the hunting season. The seasonal differences in mortality risk were expected, and thus treated as strata, but the influential differences of selecting for a publicly accessed water is valuable information for conservation managers. The population level parameter estimates for selecting public water were relatively larger, outside of the hunting season, than the other landscape composition variables (Chapter 2) suggesting a greater benefit for using this habitat type, which is supported by the survival model. The decrease in survival, with the onset of the hunting season, may be the result of birds being exposed to the abrupt change in mortality risk (Dooley et al. 2010*b*). This is supported by a temporal cluster of mortality events at the beginning of the FIRST half of the hunting season (Figure 3–1.) The Lake St. Clair region has a strong tradition of waterfowl hunting and provides an abundance of opportunities for waterfowl hunters on public water (Weaver et al. 2015). Relatively greater mortality rates on public water during the hunting season supports the assumption that this habitat and ownership type incurs substantial disturbance from human presence and mortality risk from hunting.

The influence of selecting for Walpole Island water did not vary across each of the 3 seasons in the cox PH models. Historically, many of these wetlands have been used for subsistence purposes by residents and have experienced extended durations of disturbance from anthropogenic presence and mortality risk from hunting. While there has been more commercial hunting (i.e., within the waterfowl season), fishing, and trapping that has resulted in increased use of remaining wetlands (Elliot and Mulamootii 1991) there may have been mortality risks outside of the hunting season by residents of the island that I could not measure.

I assumed that federally managed marshes provided the least amount of mortality risk, but the models did not find support that these habitats were related to survival. The third, fourth, and fifth ranked models included the influence of landscape composition variables of private water and private supplemental feeding areas on mortality risk. These two habitat types were assumed to experience a moderate level of risk because private water was managed to limit disturbance and mortality risk from hunting but were also hunted, and supplemental feeding areas provide a foraging refuge on hunt clubs. It is also thought that waterfowl are attracted to supplemental feeding areas due to food availability and lack of human presence but that these birds are vulnerable to harvest when they move between habitat types. The effect of the relationship of variables with confidence intervals that overlapped one is unclear. An increase in samples size should be a goal of future research to attempt to provide a clearer understanding of the influences of these resource selection strategies.

The large survival estimate confidence interval from monitoring GPS birds for 158 days suggests that there was a substantial amount of variability in my final survival estimate by the end of the monitoring period. Birds migrating out of the Lake St. Clair region from the onset of the SECOND half of the hunting season, in addition to mortality events, and other unknown censoring events, decreased the number of individuals remaining in the sample by the end of the monitoring period contributing to this variability. There were 19 individuals entering the post season, 2 of which died and 7 were censored.

The 30 d survival rate from the GPS monitored adult females during the combined 2014–15 and 2015–16 monitoring periods (90%) was relatively similar to that estimated by Coluccy et al. (2008, 95.5%). I could not calculate measurements of error to compare estimates of precision, but this relatively small difference allows for some insight into how survival during a portion of the non-breeding season at Lake St. Clair compares to estimates in neighboring states. Coluccy et al. (2008) estimates were derived from band recovery data from ducks banded within the U. S. Great Lake states (Wisconsin, Illinois, Michigan, Indiana, and Ohio). Harvest regulations are more liberal in Ontario, where up to 6 female mallards can be harvested per day. In the Great Lake states only 1–2 female mallards may be harvested, depending on state. Additionally, season lengths differ as these states have a 60 d season while southern Ontario has a 107 d season. Hunter density may also be variable between these states, Lake St. Clair, and all of Ontario. Previous research suggested that mallard abundance in the U.S. Great Lake states was not related to excessive harvest, but incorporating parameters relating to Ontario waterfowl harvest have yet to occur (Singer 2014) and could provide for more robust survival estimates.

The Lake St. Clair region has experienced significant wetland loss and alteration since European settlement. Wetland loss has continued but many remaining wetlands have been conserved by those interested in hunting waterfowl and by government conservation agencies. Varied ownership has resulted in diverse management strategies and a variable landscape of resources and risks for ducks to navigate. Understanding the relationship of a multivariate process, such as resource selection, and the fitness results, such as survival, is challenging on a large spatial scale. My research begins to demonstrate how individual selection for landscape variables incorporating conservation management practices can influence mortality risk. This information provides the basis for understanding the effects of local management practices, but to provide more precise estimates of survival I suggest further research with larger samples sizes. Future regional research combining Great Lake states data and data from southwestern Ontario could also be more informative, as many ducks move across the international border (Singer 2014) and the ducks of Lake St. Clair are on the border of mid-continent and eastern populations (U.S. Fish and Wildlife Service 2016).

### 3.6 Literature Cited

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## Chapter 4

# 4 INFLUENCE OF RESOURCE SELECTION ON TIMING OF AUTUMN MIGRATION BY ADULT FEMALE MALLARDS IN THE LAKE ST. CLAIR REGION

## 4.1 Introduction

Seasonal migration among geographic regions occurs in many different taxa, often in response to changing environmental conditions at their current location (Dingle and Drake 2007, Dingle 2014). For birds, migration is typically seasonally coordinated between breeding and wintering locations (Dingle and Drake 2007, Dingle 2014), and is studied at two levels: the behavioral, involving individuals, and the ecological, applying to populations (Dingle and Drake 2007). The study of waterfowl migration at the individual level has substantially increased over the past 20 years due to technological advancements in monitoring movements (Krementz et al. 2011, Krementz et al. 2012, Beatty et al. 2013), allowing for a better understanding of the many extrinsic factors that influence migration strategies.

Dabbling ducks (genus *Anas*) have been hypothesized to have a range of obligate and facultative migration strategies based on body size and life history traits. Obligate migration strategies are under internal genetic control, regulated by day length, thus synchronizing timing of departure with predictable declines in resources among years. Obligate migration typically occurs in animals with breeding grounds that occur in locales where it is predictable that resources will not be available throughout winter, as well as relatively stable wintering ground resource availability (Newton 2008). On the opposite end of the continuum of migration strategies are completely facultative migrants that depart in direct response to immediate local conditions (e.g., food supplies and colder temperatures), which can result in yearly variability in departure date, short-stopping, and possibly even remaining near breeding grounds throughout the winter (Newton 2008). Autumn migration in the mallard (*Anas platyrhynchos*) is thought to be predominately influenced by facultative cues of declining food availability and increasing weather

severity (Schummer et al. 2010, Baldassarre 2014, Van Den Elsen 2016). The theory is that as temperature and food declines at northern latitudes, the energetic costs of remaining at these latitudes are too great to sustain adequate lipid levels (Alerstam 1993, Newton 2007). This energetic deficit can be offset in larger species due to a higher surface area to volume ratio (thermal tolerance hypothesis, Ketterson and Nolan 1976). However, if snow and ice cover reduce food availability and quality, or thermal tolerance thresholds are surpassed, then energy budgets may remain in a negative balance, prompting migration (Schummer et al. 2010, Van Den Elsen 2016). Populations can experience similar weather conditions, but individuals within a population can have independent resource selection strategies to cope with local conditions, and this variability could influence decisions of migratory departure. There is substantial variation in timing of migration among mallards, making them an applicable species to investigate how timing of departure is influenced by extrinsic factors.

Understanding exogenous factors that influence migratory decisions of mallards is important for habitat and harvest management of the species. Mallards are the focus of a multitude of habitat management practices that are founded in estimating total carrying capacity based on a combination of abundance estimates and duration of habitat use at specific locales (i.e., Duck-use-days, Soulliere et al. 2007, Hagy et al. 2016). Further, the distribution of this abundant duck during autumn may influence resource availability during spring migration because they are a relatively large bird with substantial energy needs (Stafford et al. 2005, Brasher et al. 2007). Mallards are also one of most harvested ducks in North America (Raftovich et al. 2016) and hunting can influence departure from a region (Legagneux et al. 2008) and non-breeding season survival (Blohm et al. 1987, Reinecke et al. 1987, Fleskes et al. 2007). Therefore, understanding the link between local management practices and probability of departure is of value to both local managers trying to attract waterfowl and regional population managers trying to ensure suitable habitats are available at the appropriate latitudes and time of year. Previous research has focused on migratory stopover ecology of mallards, such as factors influencing length of stay (Hagy et al. 2014), while others have estimated when mallards initiate migration and migration trajectory statistics (Krementz et al. 2011, Krementz et al. 2012, Beatty et al. 2013), and weather events associated with changes in local

abundance (Schummer et al. 2010). My aim was to investigate the relationships of mallard resource selection prior to the first migratory movement of the season, from one of the most important staging areas within the Great Lakes region (Bookhout et al. 1989, Weaver et al. 2015).

Lake St. Clair and its catchment consist of a heterogeneous landscape of aquatic and terrestrial resources available to mallards during autumn and winter (Bookhout et al. 1989, Weaver et al. 2015). To access these resources, mallards must navigate a landscape of variable risks of mortality from hunting, as habitats range in their amount of hunting disturbance allowed, from prohibited (i.e., no hunting) to liberal (i.e., 107 days) access (Chapter 2). During autumn and winter, hunting disturbance and mortality risk can influence local spatiotemporal distribution and abundance of waterfowl (Madsen and Fox 1995, Fox and Madsen 1997, Stafford et al. 2007), as it causes them to seek spatial refugia and modify the timing of feeding flights to avoid these risks (Fox and Madsen 1997, Madsen 1998, Guillemain et al. 2002, Lancaster 2013, St. James et al. 2013). If ducks are concentrated in refuges due to local disturbances and mortality risk from hunting, resources can become depleted in these refuge areas, decreasing local carrying capacity and possibly prompting ducks to leave the region (Madsen 1988).

Within the Lake St. Clair region, many wetland complex managers try to mitigate the likelihood of ducks leaving the area by providing substantial amounts of resources for ducks to access (e.g., aquatic vegetation, flooded agricultural grains, and supplemental feed) and minimize disturbances by managing the intensity and frequency of hunting activities. Additionally, managers provide inviolate refuges for ducks to loaf, roost, and feed. The largest refuge in the region is the St. Clair National Wildlife Area (355 ha) which is managed as a hemi-marsh environment for waterbirds (Kaminski and Prince 1981). Many private property managers also provide supplemental feed (shelled or cobb corn) for attracting waterfowl in accordance with federal permits. Supplemental feeding areas (50.3 ha per site) are also refuges, as hunting is prohibited within 400 m of the feeding site. Understanding how these available resources and nearby risks influences when ducks depart the region for southern latitudes during the hunting season has not been quantified.

I previously described diurnal and nocturnal resource selection strategies of adult female mallards in the Lake St. Clair region, August–January (Chapter 2). To investigate resource selection, I assumed that the level of disturbance and mortality risk from hunting was influenced by how much access hunters were allowed in each habitat and ownership type, during the hunting season, ranging from high (public), to moderate (private, Walpole Island and Michigan Department of Natural Resources), and to low (Canadian Wildlife Service). Mallard resource selection strategies were strongly influenced by habitat composition and ownership suggesting that selection was related to resource availability and risk of hunting mortality. For example, all habitat types managed by the Canadian Wildlife Service, Michigan Department of Natural Resources, or private hunt clubs either prohibited hunting or were considered to have moderate disturbance and mortality risk from hunting, and mallards selected these resources during the hunting season. Publicly accessible water was presumed to have the greatest amount of disturbance and mortality risk from hunting due to having the least restrictions on access. This habitat type was selected by mallards prior to and after the hunting season. I inferred that the lack of selection during the hunting season was related to hunting related disturbance and mortality risk (Chapter 2). This regional variation of resources and risks could potentially influence when mallards initiate departure due to disturbance and mortality risk from hunting among ownership types, thus concentrating birds in refuge areas, accelerating resource depletion in these refuges. Therefore, the goal of this chapter is to explore factors related to migratory departure dates among individually marked mallards using my estimates of their resource selection of habitat and ownership type (Chapter 2). My objectives were to estimate the probability of adult female mallards remaining in the Lake St. Clair region during autumn and determine whether individual diurnal resource selection parameters were related to date of departure.

## 4.2 Study Area

I described the Lake St. Clair study area in detail in Chapters 1–3. Lake St. Clair and the surrounding wetland complexes are one of the most important staging areas on the Great Lakes for waterfowl providing approximately 4–7 million duck use days (i.e., the number of ducks counted per day in the area, summed over the number of days they were there)

and peak abundances of approximately 123,000–150,000 dabbling ducks (Dennis et al. 1984, personal communication David R. Luukkonen Michigan Department of Natural Resources, Weaver et al. 2015). The region has experienced substantial wetland loss (approximately 98% [Ducks Unlimited Canada 2010]). Many of the remaining wetlands are intensively managed to attract waterfowl during autumn and winter. Management practices include altering water levels to promote submergent and emergent vegetation, flooding agricultural crops, and supplemental feeding. The uplands are dominated by agricultural fields which provide variable amounts of waste grain (i.e., corn and wheat, [Weaver et al. 2015]). For this chapter, I used the Lake St. Clair spatial layer that was created in chapter 2 to investigate how resource selection influences mallard departure from the region.

## 4.3 Methods

### 4.3.1 Capture and Transmitter Deployment

Mallard capture and transmitter deployment were described in detail in Chapter 2 and 3. I only tracked adult female mallards to address logistical constraints of trapping and transmitter deployment and to address other research objectives of understanding relationships with survival during the non-breeding season (Chapter 3). As monitoring occurred when mallards were departing the region for autumn and winter migration, I extended my investigation of this demographic to understand relationships of resource selection and departure. I captured adult female mallards at a private property along the Canadian shore of Lake St. Clair (UTM 17 N 383701 E, 4697376 N), 21 August – 12 September 2014 and 2015. I recorded body mass, tarsus length, head length, culmen length, and wing chord to index body size and condition (Dufour et al. 1993). In 2014 and 2015, 20 and 39 adult female mallards were equipped with Global Positioning System (GPS) transmitters, respectively. Transmitter type, attachment, and duty cycles were described in Chapter 2 and 3. Ducks were released immediately after being equipped with GPS transmitters (Animal Use Protocol 2014–017).

### 4.3.2 Determining Fate and Categorizing Departure Events

I determined fate of individuals that remained within the Lake St. Clair spatial layer as explained in Chapter 2 and 3. I monitored ducks until 31 January, the transmitter failed to report their location (hereafter fixes), a duck was reported shot by a hunter, or I recovered evidence of a mortality event. I categorized departure events based on movement trajectories across geopolitical boundaries. This approach has been applied to mid-continent mallards equipped with GPS transmitters where departure for autumn migration was the date a bird was last located in Saskatchewan and the next fix was recorded south of Saskatchewan. This method provided similar estimates of initiation of autumn migration compared to examining movement data (i.e., net displacement which is changes in distance between initial location and each sequential fix per individual [Beatty et al. 2013]). Therefore, the date of a departure event was the date a bird was last recorded in the Lake St. Clair spatial layer and the following location was south of the Lake St. Clair spatial layer (either in Lake Erie or the USA).

### 4.3.3 Time-to-event Analysis Variables

In Chapter 3 I described the temporal scale of categorizing diurnal and nocturnal period based GPS fixes, in addition to categorizing 4 seasons (PRE, FIRST, SECOND, POST) throughout the monitoring period to investigate changes in resource selection through time. For this time-to-event analysis, I used the same variables of diurnal resource selection coefficients (Table 4–1) to investigate their relationship with departure events, while also controlling for variation attributable to year and body condition as covariates.

**Table 4–1 List of variables and their description that were included in the top-ranking Bayesian random-effects discrete choice models that estimated resource selection for adult female mallards in the Lake St. Clair region during 2014–15 and 2015–16 monitoring periods.**

Variable	Variable Abbreviation	Variable Description	Area (ha)
Michigan St. Clair Flats	MICH-DNR	Area of property managed by the Michigan Department of Natural Resources with 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	2,448.56
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	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
Private Flooded Agriculture	PRI-FLAG	Area of flooded agriculture under private management in Southwestern Ontario	167.93
Private Supplemental Feed	PRI-SUPP	Area of supplemental feed under private management in Southwestern Ontario	926.54
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

#### 4.3.4 Statistical Analysis

I used a Kaplan-Meier product limit estimator, which allows for left and right-censoring to calculate the probability of remaining within the Lake St. Clair spatial layer from the beginning of the monitoring period to the end of each of the 4 seasons (PRE, FIRST, SECOND, and POST [Hosmer et al. 2008]). If an individual remained within the Lake St. Clair spatial layer and was alive, it was censored on the last day of the season and entered the next season on the following day. I set the origin of the 2014 cohort on 27 August and the 2015 cohort on 26 August and both ending on 31 January. This difference of one day between origins allowed for the day at which individuals left one season and enter the next to sum to the same total based on how the hunting season was structured each year.

This probability of remaining at the end of the POST season is analogous to the null Cox PH model (Therneau and Gramsch 2000). I estimated how the 13 variables influenced the probability of departure from the region using the Anderson-Gill extension of the Cox proportional hazard (Cox PH) regression model with the function “coxph” in package “survival” in R version 3.3.2 (R Core Team 2016, [Dinkins et al. 2014]). Cox PH models are useful to analyze time-to-event data as they are semiparametric, can easily incorporate time-varying covariates, and can include time and censoring information (Cox 1972). I described the components of Cox PH models and how to interpret hazard ratios previously in Chapter 3. Similar to my analysis in Chapter 3, I extended the Cox PH model to include multiple strata to estimate the effect of variables with a constant slope across strata and with interactions per strata.

Departure events only occurred during the SECOND half of the hunting season and POST season, which limited the number of events across all seasons. Therefore, I only used monitoring data from the SECOND half of the hunting season and POST season for the Cox PH models and used these two seasons as strata. I considered models with 0–2 variables to reduce model complexity (i.e., non-convergence of these models) when using all strata and to reduce over-fitting with additional variables (Table 4–2 [Benson et al 2014]). I constructed 15 stratified Cox PH models with a constant slope, 15 Cox PH models with different slopes across strata, and a null Cox PH model. The models with



different slopes include interaction terms that estimate the change in the effect of the variable and probability of departure over seasons (Hosmer et al. 2008).

**Table 4–2. Candidate models of departure probability of GPS equipped adult female mallards in the Lake St. Clair region during the 2014–15 and 2015–16 monitoring periods.**

Constant Slope Models			Interaction Models		
Strata	Slope	Covariate	Strata	Slope	Covariate
SEASON	+	YEAR	SEASON	x	YEAR
SEASON	+	BODY CONDITION	SEASON	x	BODY CONDITION
SEASON	+	MICH-DNR	SEASON	x	MICH-DNR
SEASON	+	PUB-WATER	SEASON	x	PUB-WATER
SEASON	+	PRI-WATER	SEASON	x	PRI-WATER
SEASON	+	WAL-WATER	SEASON	x	WAL-WATER
SEASON	+	MICH-WATER	SEASON	x	MICH-WATER
SEASON	+	PUB-MARSH	SEASON	x	PUB-MARSH
SEASON	+	PRI-MARSH	SEASON	x	PRI-MARSH
SEASON	+	WAL-MARSH	SEASON	x	WAL-MARSH
SEASON	+	CWS-MARSH	SEASON	x	CWS-MARSH
SEASON	+	PRI-FLAG	SEASON	x	PRI-FLAG
SEASON	+	PRI-SUPP	SEASON	x	PRI-SUPP
SEASON	+	PRI-AGRI	SEASON	x	PRI-AGRI
SEASON	+	WAL-AGRI	SEASON	x	WAL-AGRI

Individuals entered the SECOND half of the hunting season on day 84. All resource selection variables varied across the two seasons while my year and body condition covariates were constant. These data were left-censored for individuals entering the study 4 days after being equipped with a GPS transmitter and right-censored for individuals that died, moved outside of the Lake St. Clair Spatial layer but were not a departure event, or stopped providing local movement data.

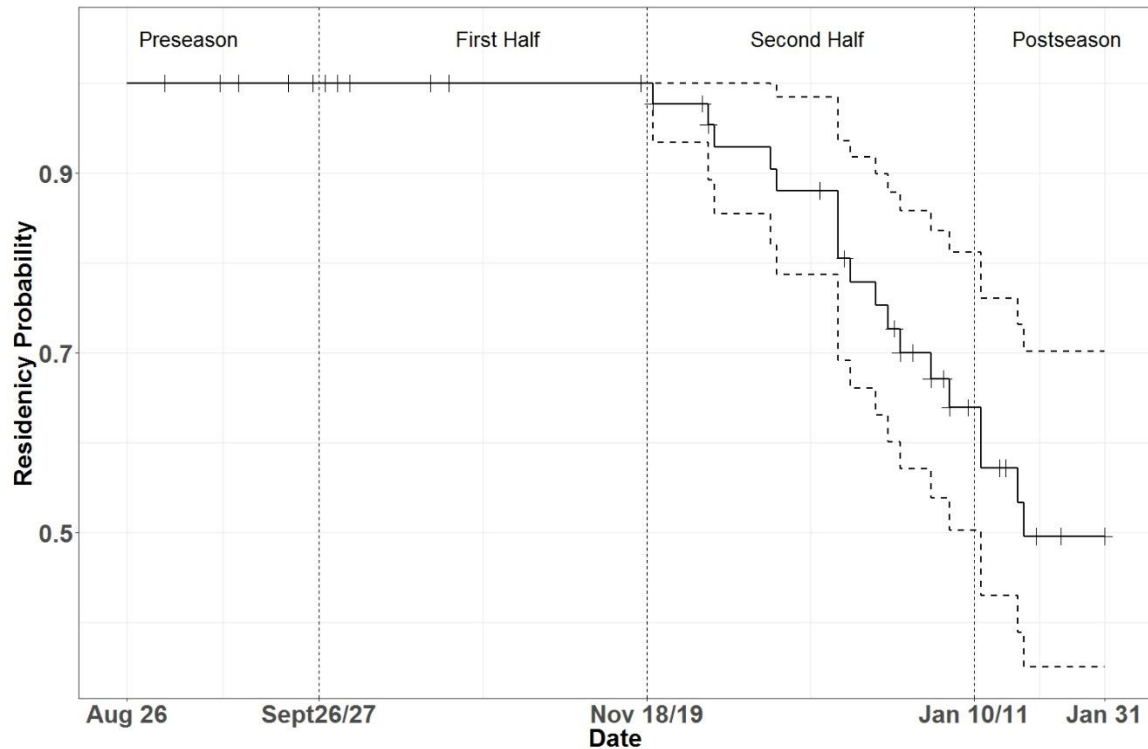
I used the test proposed by Therneau and Grambsch (2000) to test for the proportional hazards assumptions of the Cox PH models using the “cox.zph” function in package “survival” in R. and did not detect violations in the proportionality in the independent variables used in the models (all  $P > 0.05$ ; [Benson et al. 2014, Dinkins et al. 2014]). I modeled the probability of adult female mallards departing the region using an

information-theoretic approach (Burnham and Anderson 2002), where the number of departure events was the sample size I used to calculate Akaike's information criteria corrected for small sample size ( $AIC_c$ , [Therneau and Grambsch 2000, Burnham and Anderson 2002, Benson et al. 2014]). I did not use the number of records or individuals as my sample size because the number of departure events was more conservative and required parsimony for model selection (Benson et al. 2014). I reported models with  $< 2 \Delta AIC_c$  units of the top model (i.e, model with 0  $\Delta AIC_c$ ) to have substantial empirical support and I also report the null and year model for reference. To assess the contribution of each variable in a supported model, I report the hazard ratio and 95% confidence interval (Therneau and Grambsch 2000). I scaled the hazard ratio to correspond to a 0.1-unit change in the variable and confidence interval to allow for a more biologically interpretable difference in the effect size of variables and coefficients of resource selection (Hosmer et al. 2008, Benson et al. 2014). I used the robust "sandwich" standard error of parameter estimates and modeled individuals as clustered because data were not independent per individual (Benson et al. 2014).

## 4.4 Results

Of the 59 GPS equipped mallards, I included 44 individuals in the Cox PH models. During the first 4 d of the monitoring period one duck from the 2014–15 cohort moved outside of the Lake St. Clair spatial layer and did not return. During the same adjustment period in 2015–16 one duck died. I excluded one duck from the sample because of lack of temporally consistent local resource selection data. Of the remaining 56 individuals, 12 individuals were censored from sample during the PRE and FIRST half seasons. Of these 12 birds: 9 died, 1 individual stopped providing fixes, and 2 individuals emigrated outside of the spatial layer but did not meet criteria of departing south across Lake Erie to be a departure event. I recorded 18 departure events from the Lake St. Clair spatial layer during the 2014–15 and 2015–16 monitoring periods which represents 40% of individuals present in the Lake St. Clair region during the SECOND half of the hunting season and POST season.

Departure dates ranged from 20 November–7 January ( $\bar{x}$  = 18 December,  $\pm$  SE 6d) for the 2014 cohort and 28 November–18 January ( $\bar{x}$  = 27 December,  $\pm$  SE 5d) for the 2015 cohort. The average date of departure for both years combined was 23 December ( $\pm$  SE 4d). I did not detect support for yearly differences in departure probability from the Lake St. Clair spatial layer and combined both years of data (Table 4–3). During the monitoring period, 14 departure events occurred during the SECOND half of the hunting season with 11 individuals being censored. Of these 11 individuals: 6 were harvested, 1 individual stopped transmitting fixes on day 84 which precluded it from being part of the sample, while 3 others were censored for the same reason later in the season. I also recovered the transmitter of one individual but could not determine its fate as a mortality event. During the POST season there were 4 departure events and 4 individuals that were censored. Of these 4 individuals: 2 were mortality events and 2 emigrated outside of the Lake St. Clair spatial layer but were not categorized as departure events. Thus, 11 individuals remained in the region at the end of the monitoring period and all were from the 2015 cohort. Based on the Kaplan-Meier analysis, the probability of remaining in the Lake St. Clair region through the PRE season and FIRST half of the hunting season was 1.00. Of the 44 individuals that entered the SECOND half of the hunting season the probability of remaining in the region through the end of that season was 0.64 (95% CI 0.54–0.81) and the probability of remaining in the Lake St. Clair spatial layer to the end of the monitoring period was 0.50 (95% CI 0.35–0.70, Figure 4–1.).



**Figure 4–1 Kaplan-Meier residency curve for the combined time-to-event data of the 2014 and 2015 cohort of GPS equipped adult female mallards within the Lake St. Clair region. Solid line is the estimate of residency probability as it changes over time and the dashed lines are the associated upper and lower 95% confidence intervals.**

The top model predicting the probability of departure of adult female mallards included the variable of PUB-WATER without an interaction with season strata. Five models were ranked within  $< 2 \Delta AIC_c$  of the top model suggesting that there are 6 models with competing levels of support for explaining the relationship of variables and probability of departing the region during the monitoring period (Table 4–3).

**Table 4–3 Top candidate model configuration and null (Model), the number of variables ( $k$ ), AIC for small sample size ( $AIC_c$ ), and  $AIC_c$  differences ( $\Delta AIC_c$ ) for all candidate models of departure risk of GPS equipped adult female mallards with  $AIC_c$  in the Lake St. Clair region during the 2014–15 and 2015–16 monitoring periods.**

Model	$k$	$AIC_c$	$\Delta AIC_c$
strata(Season) + PUB-WATER	1	103.56	0
strata(Season) + WAL-MARSH	1	103.88	0.32
strata(Season) * PRI-WATER	2	104.02	0.46

strata(Season) + MICH-WATER	1	104.88	1.32
strata(Season) + WAL-WATER	1	104.97	1.41
strata(Season) + PRI-AG	1	105.14	1.58
strata(Season) + YEAR	1	118.43	14.87
Null	0	119.78	16.22

Based on the top model, the probability of departing the Lake St. Clair spatial layer decreased by selecting PUB-WATER across both the SECOND and POST season strata (robust standard error = 0.32, hazard ratio = 0.93, 95% CI 0.877–0.993). The second ranked model contained the main effect for selecting for WAL-MARSH. This model describes the probability of departing the Lake St. Clair spatial layer increased with selecting WAL-MARSH across both season strata (robust standard error = 0.28, hazard ratio = 1.08, 95% CI 1.019–1.139). The third ranked model included how ducks were selecting for PRI-WATER and differed across the two season strata. During the SECOND half of the hunting season the probability of departing from the region decreased with selecting PRI-WATER (robust standard error = 2.438, hazard ratio = 0.573, 95% CI 0.355–0.924) while during the POST season the probability of departing the region increased as individuals selected for PRI-WATER (robust standard error = 2.36, hazard ratio = 1.786, 95% CI 1.125–2.835). The fourth, fifth, and sixth models all contain only main effects and all variables did not substantially contribute to explaining departure probability as their confidence intervals include one, but based on AIC<sub>c</sub> values these models are competitive with the top model. The fourth ranked model included the main effect of selecting for MICH-WATER suggesting that the probability of departing decreased with selecting for this habitat and ownership type (robust standard error = 0.60, hazard ratio = 0.888, 95% CI 0.789–1.000). The fifth ranked model included the main effect of WAL-WATER, suggesting that the probability of departing the Lake St. Clair region decreased with selecting WAL-WATER across both seasons (robust standard error = 0.17, hazard ratio = 0.84, 95% CI 0.67–1.053). The sixth ranked model included the main effect of selecting for PRI-AG, suggesting that the probability of departure increased as individuals selected for PRI-AG during both the SECOND and POST season strata (robust standard error = 0.101, hazard ratio = 1.016, 95% CI 0.996–1.036).

## 4.5 Discussion

The probability of departure from the Lake St. Clair region of female mallards appears to be influenced by resource selection prior to departure. However, the relationship of resource selection and departure is not explicit to one resource type, which is demonstrated by several top competing models. Multiple competing models describing the influence of resource selection are expected due to the plasticity in migration strategies exhibited by mallards and the multiple intrinsic and extrinsic factors that can influence the onset of a departure event (Baldassarre 2014). Low sample size precluded me from including more season strata and developing multivariate models that may have been more informative, thus implications from these models are conservative but a useful start to understand mallard departure from the region.

Notaro et al. (2016) estimated the average date of migration out of the Great Lakes region by mallards (data from 1979–2012) as 9 December. The range of dates for birds I monitored (20 November to 18 January) encompasses this average found by Notaro et al. (2016) and occurred at an expected later date than individuals monitored at more northern latitudes (Krementz et al 2012, Beatty et al. 2013). Through monitoring the migration trajectories of my GPS equipped mallards, I also observed that migratory distances, locations, and latitudes were similar to individuals banded at Lake St. Clair. Additionally, my estimates of survival for GPS equipped mallards were relatively similar to other estimates of banded Great Lakes mallards (Coluccy et al. 2008, Chapter 3). Based on migration initiation dates, migration trajectories, and survival estimates, I do not think that birds were affected by transmitters as reported in other studies (Kessler et al. 2014, Hupp et al. 2015).

An individual's condition can influence migration departure decisions. For example, previous research has reported that dispersal rates can increase (van der Jeugd 2001), decline (Ekman et al. 2002, Legagneux et al. 2008) or potentially have a quadratic relationship with an individual's condition and quality (Barbraud et al. 2003, Blums et al. 2003). My estimates of body condition had relatively low variability (condition index  $\bar{X}$  = 1091.55,  $\pm$  SE 12.18) due to the sex and age demographic I choose to focus on and the

mass constraints of being large enough to be fitted with a GPS transmitter. My body condition estimates were at the time of capture and I could not account for variability in body condition at the time of departure. Additionally, I could not account for corn ingested by each individual at the time of capture. An individual's condition relates to the thermoregulatory cost of coping with changing weather severity and can influence the facultative cues to depart the region (Schummer et al. 2010). I did not include estimates of weather severity or temperature due the temporal scale of resource selection estimates which included multiple weeks of data. I assumed that seasonal (PRE, FIRST, SECOND, and POST) estimates of weather severity or temperature would be too broad to include, as the signal of influential weather events could be dampened over these temporal scales.

My investigation of departure from the region focused on mortality risk and habitat characteristics. Not capturing more of the variability between individuals and how they react to independent variables of weather severity or body condition related to migratory behavior could have contributed to the lack of stronger relationships of variables and departure probability (Schummer et al. 2010). Other research that has attempted to elucidate these relationships at the individual level also concluded that the phenotypic variation among individuals makes understanding the mechanistic linkages difficult (Legagneux et al. 2008). My models provide an initial step to understand the relationship of resource selection and a flexible behavior such as migratory departure. The top model suggests that as birds increase their selection for public water during the SECOND half of the hunting season and POST season, the probability of remaining within the region will increase. I observed that selecting for public water during the first half of the hunting season positively influenced mortality risk while during the second half of the hunting season selection for public water did not substantially influence mortality risk (Dooley et al. 2010, Davis et al 2011, Chapter 2) Furthermore, selection for public water outside of the hunting season negatively influenced mortality risk (i.e., increased survival, Chapter 2). With the decreased mortality risk of selecting for public water during the SECOND and POST season, ducks that were still in the region could have gained the experience to navigate the remaining spatial risk that was present and select for the most abundant (i.e., largest area) aquatic resource (Table 4–1) in the region (O'Neal et al. 2012).

The second ranked model contained the main effects for selecting for Walpole Island marsh, indicating that the probability of departure increases with selection for this variable. Walpole Island marshes are hunted for longer periods and more frequently relative to other marshes in the region, including the ones in this study. While I could not specifically quantify these differences, I speculate that the disparity in disturbance and mortality risk from hunting could be great enough to cause ducks selecting Walpole Island marshes to depart from the region earlier.

The last model that had substantially influential covariates was the third model including the interaction of private water and season strata. This model suggests that as birds select for private water during the SECOND half of the hunting season they have a greater probability of remaining in the region, but as they select for private water during the POST season they have a greater probability of departing the region. Mortality risk associated with selecting for private water was not substantial suggesting that mortality risk associated with private water is relatively less than other habitat types and also may not be related to departure (Legagneux et al. 2008).

Private water is adjacent to other private habitat types such as marshes, flooded agricultural fields, and supplemental feeding areas. Area managers could have provided supplemental feed until 31 December and some area managers keep marshes available for waterfowl (with bubblers), but only until the end of the hunting season. Birds could have potentially been spending more time loafing in close proximity (i.e., in private water) to private land resources while resources are available during the SECOND half of the hunting season, influencing them to remain in the region. Soon after area managers ceased to provide these resources, or their availability changed (i.e., POST season), this strategy stopped providing the same benefits, thus potentially influencing departure. Increases in duration of stay for mallards has been suggested to be related to increases in available resources (Yetter et al. 2011:20, O'Neal et al. 2012, Hagy et al. 2014) on private lands. The differences in the relationship of probability of departure from the region and selecting for private water could be related to changes in available resources on private properties. Larger sample sizes would allow for multivariate models that could potentially describe these relationships



In the presence of heightened mortality risks, ducks make decisions to balance the concomitant trade-offs of remaining within the region and migratory departure. North American waterfowl conservation is conducted at the continental scale linking many ecological processes across the annual cycle. Understanding the extrinsic factors that influence migration behaviors that connect phases of the annual cycle can allow conservation planners to make more informed management decisions. The cues and extrinsic factors of mallard migration is a multivariate process that can be different between individuals within a population of partial facultative migrants. Individual resource selection appears to influence the probability of departing the Lake St. Clair region based on several different available resources and potentially how they are managed for disturbance. This relationship of influential habitat and ownership types is not explicit but does provide novel preliminary insight into how ducks are selecting resources in a threatened landscape of heterogeneous benefits and risks.

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## Chapter 5

### 5 CONCLUSION

#### 5.1 Ecological Context of the Study

I studied resource selection, survival, and migration theory in adult female mallards during a portion of the non-breeding season in the Lake St. Clair region. Optimal foraging theory assumes that individuals choose resources based on tradeoffs related to the associated costs and benefits with each habitat patch (Cayford 1993). Therefore, my objectives were to determine how adult female mallards differentially selected resources of variable quality and quantity during a time of mortality risks from hunting and how these selection strategies related to survival and initiation of migration. I developed these objectives in the context of optimal foraging theory, where I presumed predation risk was associated with different hunting management strategies (Madsen 1995).

The Lake St. Clair region is one of the most important staging areas for waterfowl in the lower Great Lakes (Weaver et al. 2015). The composition of habitats in the region is a heterogeneous mix of available foraging resources and refugia that sustain thousands of waterfowl during migration (e.g., 4–7 million duck-use-days, [personal communication David R. Luukkonen Michigan Department of Natural Resources, Weaver et al. 2015]). However, the regional wetland complexes face substantial stresses, and threats of loss and alteration (Weaver et al. 2015). Despite the loss of habitat, the mallard is one of the most abundant and harvested species in the region and a species that many wetland managers purposefully manage to attract.

Recent findings suggest that the Great Lakes population of mallard should be managed separately from the mid-continent population (Coluccy et al. 2008), but links and differences between habitat selection and survival of these birds during the non-breeding season were unknown, preventing well-informed habitat management decisions. This information gap is highlighted by previous research that suggests there are differences in population drivers between the two populations. For example, non-breeding season survival of adult females explains the most variation in growth for the Great Lakes



population, whereas nest success and female survival during the breeding season are most influential for other mid-continent mallards (Hoekeman et al. 2002, Coluccy et al. 2008). Therefore, advancing understanding of mallard habitat selection in the Great Lakes, as well as in regions that have undergone habitat loss and alteration is important for conservation of the regional population.

Not only was using mallards as a study species important from a management perspective, but also due to the life history of the species. Namely, mallards are a habitat generalist that use most habitat types present within the Lake St. Clair region (Baldassarre 2014). The variability in their habitat use allows for potential inferences of resource selection to be applied to other dabbling duck species (genus *Anas*). Moreover, as the mallard is the most harvested species of waterfowl, they are often exposed to more risks of hunting mortality (Raftovich et al. 2016), and have been observed to adjust behaviors in response to anthropogenic disturbances (Evans and Day 2002, Bregnballe et al. 2004, Dooley et al. 2010a). Also, as a facultative migrant, there is variability in migration departure strategies that are likely to be related to disturbance and mortality risks from hunting (Legagneux et al. 2008).

## 5.2 Key Findings

I investigated if spatiotemporal variation of resources and risks was related to survival and initiation of departure from the region. I estimated population-level resource selection related to habitat composition and risk at the local spatial scale for 2 years and across 4 seasons and 2 diel periods (Chapter 2). The modeling process of estimating population-level resource parameters also produced individual estimates that I used as measures of influence for each variable. I investigated the relationship of individual diurnal resource selection estimates on mortality risk (Chapter 3) and the probability and timing of departure from the region for southern locales (i.e., migration; Chapter 4).

At the population level, there was consistent positive selection for variables linked to management from the Canadian Wildlife Service St. Clair National Wildlife Area, private wetland complexes, and the Michigan St. Clair Flats, suggesting that these habitats and management strategies provide benefits for ducks in the region. During the hunting

season, ducks decreased selection for publicly accessible habitats where mortality risk was presumed greatest and selected for areas of less risk including spatial and temporal refugia (Chapter 2). Individual selection estimates for publicly accessible water also was related to mortality risk and the probability of departure. I could not determine what the benefits were for selecting publicly accessible water (or any variable), but the lack of selection for this habitat type specifically during the hunting season suggests that hunting disturbance and mortality risk are related to this behavior. The top-ranking models explaining mortality risk included habitat types that I presume would have relatively low forage quality (public water and Walpole Island water) compared to supplemental feeding areas, flooded agricultural fields, or managed marshes (CWS, private, MDNR) in the region (Chapter 3). Selection for publicly accessible water, Walpole Island marsh, and private water also were related to the probability of departure from the region (Chapter 4).

Availability of naturally occurring foods has declined substantially since European settlement due to wetland drainage, introduction of invasive species and other stressors. However, with the amount of food available in the supplemental feeding areas, flooded agricultural fields, and managed marshes (CWS, private, MDNR) in the region still provide energy for a large abundance of staging waterfowl, in relatively small localized patches (Weaver et al. 2015). The area of supplemental feeding sites, flooded agricultural fields, and managed (i.e., impounded) marshes represents only 3% of the waterfowl habitat available locally. The area of public water, private water, Walpole Island water and marsh is 10 times greater in area than these supplemental feeding sites, flooded agricultural fields and managed marshes. Therefore, relatively small patches of augmented forage quality and quantity could result in increased density within these patches. As densities increase, ducks may still be using these high-quality patches while frequenting habitats of lower forage quality and lower density resulting in the observed influence of these variables (Goss-Custard 1980). Selection for certain habitat types can be influenced by the abundance of conspecifics within these patches (i.e., attracting more ducks) but may not reflect food availability (Gurd 2006, Hagy and Kaminski 2012, Hagy and Kaminski 2015). In environments with highly clumped resources, dominant individuals may exclude subordinates making them visit more locations and having

shorter feeding times (i.e., ideal despotic distribution, [Fretwell and Lucas 1970]). In contrast, where food distributions are less aggregated, subordinates and dominants occupy quality patches equally (Gyimesi et al. 2010). The resource selection estimates that I observed as being influential could potentially be related to resource abundance and distribution on the landscape, and how ducks are influenced by the presence of conspecifics.

### 5.3 Landscape Change and Mallard Ecology

Since European settlement the landscape throughout southwestern Ontario (Lambton, Kent, Essex counties) has been converted from deciduous forests, flooded forests, tall grass prairies, wet meadows, and extensive wetlands to primarily agricultural fields and sparse remnant wetland complexes (Weaver et al. 2015). The pre-settlement coverage of wetlands in southwestern Ontario ranged in 50–83% while recent estimates of 0.8–1.6% coverage convey the magnitude of habitat loss (Ducks Unlimited Canada 2010). This conversion, along with human settlement, occurred in a relatively brief period of time, changing both the resources available to the waterfowl and risks associated with them.

Prior to European settlement the resources available to waterfowl would have been influenced primarily by fluctuating water levels of the lake and how precipitation interacted with the natural topography of the region. Interspersed wetlands would have provided habitat where ducks could access invertebrates, moist soil plants and seeds, breeding sites, and find refuge for resting and non-foraging activities (i.e., loafing and courtship). Today, the resources available to waterfowl are influenced substantially by anthropogenic sources (e.g., manipulation of water levels in impoundments, supplemental feeding, flooding agricultural fields, and waste grain), all occurring in distinct habitat patches. These landscape changes occurred concomitantly with changes in mortality risk as hunting intensity increased with a greater anthropogenic presence in the region (Weaver et al. 2015).

The results I have presented in Chapters 2–4 are observations of how mallards have evolved a generalist life history to adapt to these changes in distribution and quality of resources while facing variable risks of mortality on the landscape. The American black

duck (*Anas rubripes*), a closely related species, was historically more abundant in the Lake St. Clair region but has experienced decreases in abundances, while mallard distribution continues to grow eastward (Dennis et al. 1984, Heusmann 1991, Conroy et al. 2002). There are multiple hypotheses for these population changes, but the more competitive and adaptive life history of the mallard has been suggested to be contributing to the decline of American black ducks and the expansion of the mallard (Ankney et al. 1987, Conroy et al. 2002). Additionally, the versatility within the generalist strategy of the mallard has allowed it to be the most widely distributed duck in the northern hemisphere (Baldassarre 2014).

The future status of wetland resources throughout region are unknown, but continued wetland loss suggests the potential for conditions to deteriorate. Recent agricultural land sales in the region were approximately \$15,000–\$20,000 per acre, indicating the still present pressure of agricultural expansion (personal communication, Owen Steele, Ducks Unlimited Canada). Increases in wetland loss and degradation can influence the rate and retention of storm water runoff as pollutants such as fertilizers, pesticides, oil, and animal waste are directed into the lake and effect water quality (Great Lake Commission 2006). Increases in alternative energy development adjacent to the lake (e.g., industrial wind turbines) can influence waterfowl movements and habitat use (Larsen and Guillemette 2007, Fijn et al. 2012, Weaver et al. 2015). Increases in populations of both invasive flora (e.g., *Phragmites*) and fauna (e.g., mute swan [*Cygnus olor*]) have the potential to decrease resources for native waterfowl or exclude them from accessing resources (Wilcox et al. 2003, Meyer et al. 2012). Abiotic factors such as climate change are also anticipated to affect how waterfowl use the Lake St. Clair region. The region has become increasingly important to wintering waterfowl, likely, due to changes in migration chronology in response to changes in food availability, and these abundances are expected to increase if rises in air temperatures and decreases in snow cover occur (Schummer et al. 2010, Notaro et al. 2014, Notaro et al. 2016). If these increases in overwintering populations continue and resources are depleted at relatively greater rates, there is the potential that spring carrying capacity could also be affected.

My observations of resource selection, survival, and initiation of migration describes how the mallard has adapted to landscape changes of the region since European settlement. With projected future lands use changes, resource managers have the ability to increase or maintain current energetic carrying capacity levels and regional abundances through intense management practices, such as supplemental feeding, flooding agricultural fields, and controlling water levels to promote invertebrate populations, and submergent and emergent wetland plants. Managers also have the option to further regulate the amount of mortality risks and disturbances from hunting activities within the remnant habitat to partially mitigate regional wetland loss and degradation. Conservation managers and planners can also increase wetland and refuge area as it has been shown to be associated with increased mallard use (Stafford et al. 2010, Beatty et al. 2014a, Chapter 2). Through the latter, a diversity of plants and animal communities can benefit, in addition to restoring ecosystems services that will allow the region to be more resilient to abiotic and biotic changes (Bengtsson et al. 2003, Hansson et al. 2005, Nelson et al. 2009).

## 5.4 Recommendations for Future Research

Waterfowl populations in the Lake St. Clair region have the potential to continue to be stressed by further wetland loss and degradation (Duck Unlimited Canada 2010, Weaver et al. 2015) and therefore it is important to understand the ecological factors related to waterfowl abundance and distribution. The remaining wetlands of the region are primarily conserved for either waterfowl harvest, waterbird resting areas, or are part of Walpole Island First Nations. The amount of energy within these wetlands and how these resources change through time has not been the focus of previous research. Additionally, despite foods being available in habitats, the functional availability of these foods when hunting is and is not occurring is unknown. Density-dependent depletion of food resources in areas of spatial and temporal refugia are also unknown and may greatly influence the utility of the Lake St. Clair region for foraging waterfowl throughout the non-breeding period.

My research has begun to assess how adult female mallards select resources based on assumptions of forage quality and levels of disturbance. Through this research, I highlighted the importance of managed wetland complexes that are sparse within this

region of highly fragmented habitat. To determine if these assumptions and inferences are accurate, quantifying the energetic carrying capacity to include impounded wetlands, density of waterfowl, habitat quality, disturbance levels (i.e., frequency and intensity of hunting activities), and competitive interactions of conspecifics is warranted. Such information would assist conservation planners to better understand how changes in habitat quality, management, and juxtaposition could influence waterfowl populations, in addition to providing specific habitat management prescriptions such as size and distribution of refugia and marshes in relation to disturbance levels and mortality risks from hunting.

Furthermore, as harvest restrictions have been recommended for the Great Lakes population of mallards (Coluccy et al. 2008), the derivation of harvest pertaining specifically to Lake St. Clair would be valuable information to resource managers. The preponderance of harvest derivation information for the region is based on banding data (Arnold and de Sobrino 2012), which can be limited by the number and spatial distribution of banding sites and recoveries. Stable isotope data have proven to be an effective tool to monitor both natal and molt origins of waterfowl harvested during the autumn migration at major staging areas (Asante et al. 2017). Sampling of harvested mallards at Lake St. Clair would provide an estimate as to whether harvest of local individuals (i.e., Great Lakes mallards) transitions to migrants of more northern populations outside of the Great Lakes, and, if so, the timing of such a change. This information would be beneficial to regional conservation planners if harvest management strategies similar to those from adjacent states are to be adopted.

## 5.5 Scientific Contributions

Mallards are the most abundant and studied duck species in the world (Baldassarre 2014). Several aspects of their ecology, some of which I investigated through this research, have been previously studied using different approaches, including varying spatial and temporal scales and locations. For example, resource selection has been investigated locally and across flyways (Stafford et al. 2007, Davis et al. 2009, Davis et al. 2010, Beatty et al. 2014*b*); the effects of various disturbances have been estimated under different management practices (Dooley et al. 2010*a*, Dooley et al. 2010*b*, St. James et al.

2013); survival estimates have been produced at regional (Coluccy et al. 2008) and local levels (Fleskes et al. 2007, Davis et al. 2011); and migration statistics (Krementz et al. 2011, Krementz et al. 2012, and Beatty et al. 2013) and influences of weather on migration (Schummer et al. 2010, Notaro et al. 2016) have been studied.

The research presented in this thesis is a novel approach to investigating the multivariate process that is resource selection, ultimately using it as a foundation for investigating questions of fitness and behavior. Interpreting these relationships via analysis of observations of wild animals is often difficult due to large spatial scales, lack of experimental control, and logistical constraints making the research I have conducted valuable to the scientific community. The support I provided for multiple competing models explaining how resource selection is related to mortality risk and probability of departure is evidence of this complexity. Nonetheless, this research provides a foundation for understanding how mallards select resources in a heterogeneous environment, including how these strategies are related to fitness and behavior which previously had not been quantified.

## 5.6 Implications for Future Waterfowl Biology Studies

The results of this research emphasize the importance of investigating the relationship of current habitat management practices and the implications of waterfowl decision-making in such environments. Researchers typically study probability of survival or migration with more discrete predictors (e.g., habitat use, movements, and weather conditions) than resource selection. Estimates of resource selection provide a more robust assessment of waterfowl decision-making in response to a dynamic environment (i.e., variable mortality risks and available resources). I realize that addressing questions that bridge multivariate behaviors is logistically difficult. However, based on my research, I provide suggestions to advance the science of waterfowl biology:

1. Quantifying disturbance and mortality risk levels from hunting will provide a more accurate assessment of the stimuli and functional availability of habitats that influence waterfowl space-use compared to models that focus only on forage quality.

2. Addressing questions that span phases of the annual cycle will allow conservation planners to better connect carry-over effects that are influenced by current management practices.
3. As waterfowl are managed through a hierarchy of spatial scales (e.g., flyway, joint venture, state/provincial), an increased integration and consistent update of digital spatial information across these levels will assist researchers to more accurately address regional questions of waterfowl ecology that occurs across political borders.

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## Appendices

### Appendix I Population selection parameter estimates and standard errors for the top discrete-choice models that investigated habitat selection strategies for adult female mallards PRIOR to the hunting season in the Lake St. Clair region during the 2014–15 and 2015–16 monitoring years. A. Diurnal B. Nocturnal

#### A.

Variable	Diel Period	Population selection parameter estimate	Standard deviation	95% Credible interval lower bound	95% Credible Interval upper bound
CWS-MARSH	DAY	0.905	0.086	0.734	1.074
MICH-DNR		0.743	0.307	0.068	1.289
MICH-WATER		-0.499	0.448	-1.465	0.296
PRI-AGRI		1.87	0.507	0.867	2.86
PRI-FLAG		0.662	0.073	0.516	0.803
PRI-MARSH		0.79	0.128	0.537	1.041
PRI-SUPP		1.298	0.121	1.056	1.533
PRI-WATER		1.574	0.137	1.302	1.837
PUB-MARSH		-1.237	0.400	-2.103	-0.531
PUB-WATER		2.785	0.487	1.844	3.77
WAL-AGRI		0.313	0.262	-0.264	0.758
WAL-MARSH		0.162	0.396	-0.675	0.881
WAL-WATER		-0.036	0.229	-0.529	0.377

#### B.

Variable	Diel Period	Population selection parameter estimate	Standard deviation	95% Credible interval lower bound	95% Credible Interval Upper bound
CWS-MARSH	NIGHT	0.024	0.232	-0.468	0.442
MICH-DNR		0.661	0.298	0.046	1.235
MICH-WATER		-0.213	0.433	-1.15	0.557
PRI-AGRI		-0.066	0.701	-1.423	1.328
PRI-FLAG		0.618	0.093	0.426	0.795
PRI-MARSH		0.948	0.147	0.66	1.236
PRI-SUPP		0.578	0.148	0.283	0.864
PRI-WATER		1.823	0.145	1.542	2.113
PUB-MARSH		0.535	0.225	0.075	0.954
PUB-WATER		2.595	0.714	1.236	4.031

WAL-AGRI	-0.427	0.463	-1.431	0.375
WAL-MARSH	0.031	0.381	-0.756	0.743
WAL-WATER	-0.278	0.299	-0.903	0.261

**Appendix II Population selection parameter estimates and standard errors for the top discrete-choice models that investigated habitat selection strategies for adult female mallards FIRST half to the hunting season in the Lake St. Clair region during the 2014–15 and 2015–16 monitoring years. A. Diurnal B. Nocturnal**

**A.**

Variable	Diel Period	Population selection parameter estimate	Standard deviation	95% Credible interval lower bound	95% Credible interval upper bound
CWS-MARSH	DAY	1.215	0.190	0.842	1.593
MICH-DNR		2.202	0.436	1.346	3.058
MICH-WATER		-0.558	0.620	-1.860	0.576
PRI-AGRI		2.126	0.951	0.215	3.967
PRI-FLAG		1.367	0.290	0.790	1.923
PRI-MARSH		1.627	0.317	1.000	2.240
PRI-SUPP		1.668	0.206	1.269	2.079
PRI-WATER		1.193	0.304	0.582	1.783
PUB-MARSH		-3.109	0.728	-4.643	-1.763
PUB-WATER		0.223	0.777	-1.268	1.769
WAL-AGRI		-0.594	0.512	-1.680	0.328
WAL-MARSH		1.304	0.469	0.309	2.165
WAL-WATER		-1.248	0.450	-2.176	-0.410

**B.**

Variable	Diel Period	Population selection parameter estimate	Standard deviation	95% Credible interval lower bound	95% Credible Interval Upper bound
CWS-MARSH	NIGHT	0.696	0.158	0.381	0.998
MICH-DNR		1.714	0.395	0.904	2.468
MICH-WATER		0.184	0.393	-0.610	0.939
PRI-AGRI		-0.835	0.688	-2.218	0.486
PRI-FLAG		1.317	0.145	1.034	1.606
PRI-MARSH		0.960	0.215	0.524	1.375
PRI-SUPP		0.984	0.167	0.650	1.309
PRI-WATER		0.683	0.244	0.197	1.156

PUB-MARSH	-1.646	0.452	-2.600	-0.829
PUB-WATER	-0.822	0.729	-2.266	0.604
WAL-AGRI	-1.272	0.536	-2.422	-0.323
WAL-MARSH	0.595	0.426	-0.311	1.371
WAL-WATER	-1.340	0.442	-2.261	-0.537

**Appendix III Population selection parameter estimates and standard errors for the top discrete-choice models that investigated habitat selection strategies for adult female mallards SECOND half the hunting season in the Lake St. Clair region during the 2014–15 and 2015–16 monitoring years. A. Diurnal B. Nocturnal**

A.

Variable	Diel Period	Population selection parameter estimate	Standard deviation	95% Credible interval lower bound	95% Credible Interval Upper bound
CWS-MARSH	DAY	0.935	0.153	0.629	1.239
MICH-DNR		1.943	0.439	1.053	2.789
MICH-WATER		0.535	0.581	-0.686	1.606
PRI-AGRI		0.235	0.615	-0.983	1.433
PRI-FLAG		0.821	0.129	0.562	1.071
PRI-MARSH		0.449	0.230	-0.018	0.892
PRI-SUPP		1.066	0.123	0.83	1.313
PRI-WATER		0.602	0.221	0.155	1.022
PUB-MARSH		-1.844	0.464	-2.846	-1.012
PUB-WATER		0.483	0.524	-0.539	1.522
WAL-AGRI		-0.854	0.494	-1.931	-0.003
WAL-MARSH		0.515	0.385	-0.281	1.231
WAL-WATER		-1.035	0.371	-1.823	-0.362

B.

Variable	Diel Period	Population selection parameter estimate	Standard deviation	95% Credible interval lower bound	95% Credible Interval Upper bound
CWS-MARSH	NIGHT	0.704	0.124	0.458	0.949
MICH-DNR		1.765	0.351	1.043	2.43
MICH-WATER		1.275	0.352	0.557	1.952
PRI-AGRI		-0.817	0.568	-1.934	0.299
PRI-FLAG		0.591	0.132	0.322	0.845



PRI-MARSH	0.142	0.158	-0.188	0.435
PRI-SUPP	1.351	0.114	1.121	1.572
PRI-WATER	0.518	0.201	0.118	0.905
PUB-MARSH	-0.241	0.253	-0.771	0.222
PUB-WATER	1.253	0.486	0.322	2.227
WAL-AGRI	-0.719	0.421	-1.638	0.001
WAL-MARSH	-0.011	0.373	-0.79	0.674
WAL-WATER	-0.86	0.330	-1.55	-0.256

**Appendix IV Population selection parameter estimates and standard errors for the top discrete-choice models that investigated habitat selection strategies for adult female mallards POST hunting season in the Lake St. Clair region during the 2014–15 and 2015–16 monitoring years. A. Diurnal B. Nocturnal**

A.

Variable	Diel Period	Population selection parameter estimate	Standard deviation	95% Credible interval lower bound	95% Credible Interval Upper bound
CWS-MARSH	DAY	0.92	0.181	0.558	1.275
MICH-DNR		1.35	0.618	0.086	2.543
MICH-WATER		1.597	0.768	0.127	3.133
PRI-AGRI		1.234	0.798	-0.314	2.818
PRI-FLAG		0.335	0.144	0.048	0.621
PRI-MARSH		0.026	0.281	-0.563	0.54
PRI-SUPP		1.582	0.177	1.233	1.929
PRI-WATER		1.11	0.236	0.635	1.566
PUB-MARSH		0.089	0.360	-0.684	0.742
PUB-WATER		2.203	0.782	0.699	3.768
WAL-AGRI		1.103	0.413	0.227	1.876
WAL-MARSH		0.427	0.531	-0.679	1.415
WAL-WATER		-0.289	0.486	-1.333	0.57

B.

Variable	Diel Period	Population selection parameter estimate	Standard deviation	95% Credible interval lower bound	95% Credible Interval Upper bound
CWS-MARSH	NIGHT	0.841	0.232	0.357	1.27

MICH-DNR	0.899	0.630	-0.388	2.099
MICH-WATER	1.994	0.880	0.349	3.813
PRI-AGRI	-3.526	1.115	-5.76	-1.388
PRI-FLAG	0.626	0.228	0.153	1.057
PRI-MARSH	0.475	0.320	-0.183	1.078
PRI-SUPP	1.56	0.391	0.779	2.322
PRI-WATER	0.854	0.276	0.282	1.366
PUB-MARSH	0.498	0.392	-0.296	1.263
PUB-WATER	3.295	0.969	1.455	5.239
WAL-AGRI	0.75	0.542	-0.412	1.728
WAL-MARSH	-0.56	0.667	-1.939	0.672
WAL-WATER	-0.116	0.541	-1.267	0.858

## Appendix V Multinomial logit hierarchical model variables and JAGS model

Multinomial logit hierarchical model in JAGS to examine habitat selection of adult female mallards in the Lake St. Clair region, models were run using R2jags. Modeling procedure was adjusted based on modeling procedure from Beatty et al. 2014b. Data were initially in long format where one row represents one alternative within a choice set. Each choice set contains as many rows as there are alternatives.

### Variables:

T = the total number of rows in the data sheet.

chsets = indexes choice sets in long format, ranges from 1 to the total sample size.

alts = indexes alternatives in long format within a choice set, maximum range is 1 69.

df.3 = orders the number of alternatives in each choice set.

nalts = the number of alternatives within a choice set with a maximum of 69.

use = use in long format, 0 for available resource units, 1 for used resource units.

nchsets = the number of choice sets, equal to the total sample size.

DuckID = indexes individual ducks in long format, ranges from 1 to ninds.ID

ninds = the number of unique individuals.

cws\_marsh\_stand = An example of one variable used in the model. cws\_marsh\_stand is area (hectares) of federal marsh with 2.12 km<sup>2</sup> resource unit, centered and standardized.

pri\_agri\_stand = An example of one variable used in the model. pri\_agri\_stand is area (hectares) of private agriculture within 2.12. km<sup>2</sup> resource unit, centered and standardized.

X = a matrix of habitat variables in long format.

npred = the number of predictors, equal to the number of columns for matrix X.

```

duckid2 = indexes individual ducks in wide format, ranges from 1 to ninds.
y = matrix of used and maximum available resource units

first.day.1 <- read.csv("first.day.1.csv")
T <- nrow(first.day.1)
chsets <- first.day.1$chsets
alts<- first.day.1$index
df.3 <- summarize(group_by(first.day.1, chsets), n.alt3 = max(index))
nalts<-df.3$n.alt3
use <- first.day.1$choice.x
nchsets <- max(first.day.1$chsets)
ninds <-max(first.day.1$DuckID)
cws_marsh_stand <- first.day.1$cws_marsh_stand
pri_agri_stand <- second.night.1$pri_agri_stand
X = cbind(cws_marsh_stand, pri_agri_stand)
npred <- ncol(X)
duckid2 <- subset(first.day.1, choice.x==1)$DuckID
y=cbind(1,matrix(0,nrow=nchsets,ncol=nalts-1))

jags.data <- list(npred=as.integer(npred),
                 duckid2=as.integer(duckid2),
                 ninds=as.integer(ninds),
                 nchsets=as.integer(nchsets),
                 nalts=as.integer(nalts),
                 y=cbind(1,matrix(0,nrow=nchsets,ncol=nalts-1)))

#Transcribe X matrix into wide format per number of alternatives
jags.data$Z <- array(NA,dim=c(npred,nchsets,max(nalts)))
for (i in 1:T) {
  for (j in 1:npred) {
    jags.data$Z[j,chsets[i],alts[i]] <- X[i,j]}
}

```

### **JAGS Model:**

```

model {
  ## Priors
  for (a in 1:ninds){
    for (j in 1:npred) {
      beta[a,j] ~ dnorm(0, tau[j])
    }
  }
}

```

```

## Hyperparameters
for (j in 1:npred){
  mu[j] ~ dnorm (0,.359)
  sig[j] ~ dt(0,2,3)T(0,)
  tau[j] <- 1/sqrt(sig[j])
}
## Likelihood
for (i in 1:nchsets) {
  y[i,1:nalts[i]] ~ dmulti(p[i,1:nalts[i]], 1)
  for (k in 1:nalts[i]) {
    log(phi[i,k]) <- inprod(mu[] + beta[duckid2[i],],Z[,i,k])
    p[i,k] <- phi[i,k] / sum(phi[i,1:nalts[i]])
  }
}
", fill = TRUE)

```

## Appendix VI Western University Animal Use Protocol 2014–017



**AUP Number:** 2014-017

**PI Name:** Petrie, Scott

**AUP Title:** Habitat Selection And Survival Of Female Mallards

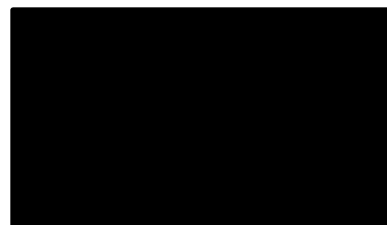
**Approval Date:** 09/05/2014

**Official Notice of Animal Use Subcommittee (AUS) Approval:** Your new Animal Use Protocol (AUP) entitled "Habitat Selection And Survival Of Female Mallards" has been APPROVED by the Animal Use Subcommittee of the University Council on Animal Care. This approval, although valid for four years, and is subject to annual Protocol Renewal. 2014-017::1

1. This AUP number must be indicated when ordering animals for this project.
2. Animals for other projects may not be ordered under this AUP number.
3. Purchases of animals other than through this system must be cleared through the ACVS office. Health certificates will be required.

The holder of this Animal Use Protocol is responsible to ensure that all associated safety components (biosafety, radiation safety, general laboratory safety) comply with institutional safety standards and have received all necessary approvals. Please consult directly with your institutional safety officers.

Submitted by: Copeman, Laura  
on behalf of the Animal Use Subcommittee  
University Council on Animal Care



*The University of Western Ontario*  
Animal Use Subcommittee / University Council on Animal Care  
Health Sciences Centre, • London, Ontario • CANADA • N6A 5C1  
PH: 519-661-2111 ext. 86768 • FT. 519-661-2028  
Email: [auspc@uwo.ca](mailto:auspc@uwo.ca) • <http://www.uwo.ca/animal/website/>

# Appendix VII Canadian Wildlife Service National Wildlife Area Permit



Environnement  
Canada

Canadian Wildlife  
Service

Environnement  
Canada

Service canadien  
de la faune



## Conduct banding and tracking of American Black Ducks & Mallards at St. Clair NWA

Permit for:

Ontario

in the province of:

4

issued under section

Name and address

Ted Barney  
Long Point Waterfowl

Wildlife Area Regulations

of

August 15, 2013

valid from

January 31, 2018

date of expiry

08/15/13

date

August 2, 2013

date

for Minister

### Special conditions

Location of any baited traps must be approved by John Haggeman and conform to hunting permit restrictions during the hunting season. Baiting will not be conducted throughout the study period and will only occur when traps are needed for implementation of translocations.

Monitoring or capture activity along common dikes with neighbouring landowners must be reviewed by John Haggeman prior to the day of the proposed activity. The review will ensure that monitoring or capturing activity does not interfere with adjacent land owners.

Capture of study birds in the NWA will not be visible to visiting public and, other than baited traps, may occur within the entire NWA. Capturing activity via means other than baited traps must be reviewed by John Haggeman to be aware of any restrictions and working within the NWA.

All structures (traps, platforms or antennae arrays) must be temporary in nature and removed within 30 days of the end of the project. All structures will not interfere with operations or access by staff performing their regular duties at the publicly accessible areas of the NWA. Temporary structures may be decommissioned subject to operational requirements and must be approved by John Haggeman.

Permittee responsible for obtaining all other permits and authorizations related to this activity and will provide copies to Bill Robinson and John Haggeman prior to commencement of the project. This permit must be signed and carried by researchers while working on the NWA.

Annual summary reports and an electronic copy of the final report/thesis will be provided to:

Andrea Gellie, Canadian Wildlife Service, Ontario AND John Haggeman, Canadian Wildlife Service, Ontario

### Attachments

no ☒ yes ☐

All attachments constitute part of this permit.

No. SCNWA-2013-05

Canada

## Appendix VIII Environment Canada Migratory Bird Banding Permit

 Environment Canada Environnement Canada		SCIENTIFIC PERMIT TO CAPTURE AND BAND MIGRATORY BIRDS PERMIS DE CAPTURE ET DE BAGUAGE D'OISEAUX MIGRATEURS	
In the Province(s) / Territoires - Dans la (les) provinces(s) / territoires Ontario		Permit No. N° de permis <b>10787 G</b>	
Issued under the Migratory Birds Regulations Sections 4 and 19. If the authorization includes any species that are not protected under the Migratory Bird Convention Act, 1994, this document represents an agreement between Environment Canada and the holder for the use of federal aid funds on those species. All conditions listed on the back of this document apply. Émis en vertu des articles 4 et 19 des règlements concernant les oiseaux migrateurs. Si les autorisations incluent des espèces qui ne sont pas protégées en vertu de la Loi de 1994 sur la convention concernant les oiseaux migrateurs, le présent document représente un accord entre Environnement Canada et le titulaire aux fins de l'utilisation de bagues fédérales sur ces espèces d'oiseaux. Toutes les conditions figurant au verso du présent document s'appliquent.			
Name and Address - Nom et adresse <b>MATTHEW PALUMBO</b> 		Issue Date Date d'émission <b>2015/05/29</b>	
		Expiration Date Date d'expiration <b>2015/12/31</b>	
		For the Minister - Pour le Ministre Name (Print) - Nom (Lettres moulées) <b>L. LAURIN</b>	
		Signature 	

### AUTHORIZATIONS – AUTORISATIONS

#### Authorized to:

- Band waterfowl
- Take oral & cloacal swabs for AI testing
- Use traps

- Use Satellite Transmitter on Mallard (MALL) (1320)

GPS with a VHF on top of it, attached with nylon backpack & harness (up to 30 females) (SATELLITE TRANSMITTER USE MAY REQUIRE CERTIFICATION OF THE DEVICE BY INDUSTRY CANADA) (IF IN POSSESSION OF A CURRENT ANIMAL CARE COMMITTEE APPROVAL) in Ontario

See Permit Conditions on the following page – Voir les conditions du permis sur la page suivante

## Curriculum Vitae

<b>Name:</b>	Matthew D. Palumbo, AWB®
<b>Post-secondary Education and Degrees:</b>	<p>Western University London, Ontario, Canada 2013 – 2017, Ph.D, Biology</p> <p>Mississippi State University Mississippi State, Mississippi, USA 2007 – 2010, M.S., Wildlife and Fisheries Science.</p> <p>State University of New York College of Environmental Science and Forestry. Syracuse, New York, USA. 2003 – 2005, B.S. Wildlife Science</p> <p>Syracuse University Syracuse, New York, USA. 2001 – 2003</p>
<b>Honours and Awards:</b>	<p>Ontario Federation of Anglers and Hunters (OFAH) Dave Ankney and Sandi Johnson Award for Avian Ecology 2014, 2015, &amp; 2017</p> <p>Duck Unlimited Canada Institute for Wetland and Waterfowl Research Award 2016</p> <p>California Waterfowl Association The Dennis Raveling Scholarship (2<sup>nd</sup> Place) 2015</p> <p>Western University Department of Biology Teaching Assistant Award 2015</p>
<b>Professional Experience</b>	<p>Doctoral Research Student Western University London, ON, Canada 2013 – 2017</p> <p>Associate Scientist Birds Studies Canada/Long Point Waterfowl London, ON, Canada 2016</p>



Wildlife Biologist  
 United States Department of Agriculture  
 Animal and Plant Health Inspection Service  
 Wildlife Services  
 White Plains, NY, USA.  
 2011 – 2013

Cooperative Wildlife Biologist  
 National Wild Turkey Federation  
 Tallahassee, Florida, USA.  
 2010 – 2011

Research Assistant  
 Mississippi State University  
 Mississippi State, Mississippi, USA.  
 2010

Wildlife Research Technician  
 Mississippi State University  
 Mississippi State, Mississippi, USA.  
 2010

Graduate Research Assistant  
 Mississippi State University  
 Mississippi State, Mississippi, USA.  
 2007 – 2010

Forestry – Wildlife Technician  
 Hoopa Tribal Forestry, Wildlife Department.  
 Hoopa, CA, USA.  
 2006

Wildlife Research Technician  
 Cornell University  
 Fort Drum, NY, USA  
 2005

Wildlife Research Technician  
 Adirondack Ecological Center  
 Newcomb, NY, USA.  
 2004

## **Teaching Experience**

Guest Lecture – Wildlife Management Techniques  
 University of Wisconsin-Stevens Point  
 Wildlife 350/550 Wildlife Capture and Marking

Spring 2017

Teaching Assistant  
Western University  
BIO 2482 Environmental Biology  
Winter 2017

Teaching Assistant – Field Course  
Western University  
Adirondack Forest Ecology  
Summer 2014, 16, & 17

Course Instructor  
Western University  
BIO 3446B Wildlife Ecology and Management  
Winter 2016

Lead Teaching Assistant  
Western University  
BIO 3446B Wildlife Ecology and Management  
Winter 2015

Co-Supervisor  
Undergraduate Honours Thesis  
Western University  
Winter 2015

Co-Supervisor  
Undergraduate Honours Thesis  
Western University  
Winter 2015

Teaching Assistant  
Western University  
Scientific Methods in Biology  
Summer 2014

Guest Lecture – Wildlife Hazard Management at Airports  
Western University  
BIO 3446B Wildlife Ecology and Management  
Winter 2014

Teaching Assistant  
Western University  
BIO 3446B Wildlife Ecology and Management  
Winter 2014

Teaching Assistant  
Western University  
BIO 1001A/1201A Biology for Science/General Biology I  
Fall 2013

Teaching Assistant  
Mississippi State University  
Wildlife and Fisheries 3133 Applied Aquatic & Terrestrial  
Ecology  
Fall 2009

### **Publications:**

#### Peer Reviewed:

**Palumbo, M. D.**, J.P. Fleming, O.A. Monsegur, and F.J. Vilella. 2016. A GIS Model of Habitat Suitability for *Solanum conocarpum* (Solanaceae) in St. John, US Virgin Islands. *Caribbean Naturalist* 36:1-10.

**Palumbo, M.D.**, F.J. Vilella, B.K. Strickland, G. Wang, and D. Godwin. 2014. Brood Surveys and Hunter Observations Used to Predict Gobbling Activity of Wild Turkeys in Mississippi. *Journal of Fish and Wildlife Management* 5:151-156.

#### Technical Reports:

Weaver, K. H. A., S. A. Petrie, S. E. Richman, **M. D. Palumbo**, M. E. Dyson, P. Brisco, and T. S. Barney. 2015 Waterfowl and Wetlands of the Lake St. Clair Region: Present Conditions and Future Options for Research and Conservation. Long Point Waterfowl, unpublished report. 134 pp.

#### Conference Proceedings:

**Palumbo, M. D.**, S. E. Richman, and S. A. Petrie. 2014. Long Point Waterfowl's Lake St. Clair Initiative: Habitat Selection and Survival of Waterfowl during Migration. Proceedings of the Great Lakes Wetlands Conservation Action Plan 2014 Great Lakes Wetlands Day.

#### Federal Reports:

**Palumbo, M.D.** 2012. Wildlife Hazard Assessment for Westchester County Airport, White Plains, NY.

Vilella, F.J. and **M.D. Palumbo**. 2010. Rapid Assessment and Habitat Suitability Model of *Solanum conocarpum* in St. John, U.S. Virgin Islands. Final Report for the United States Fish and Wildlife Service.

#### State Reports:

Vilella, F.J. and **M.D. Palumbo**. 2009. Variability of Gobbling Activity Across The State of Mississippi. Spittin' & Drummin'. 2009 Mississippi Wild Turkey Report 55.

### **Presentations:**

**Palumbo, M.D.**, S. A. Petrie, M. L. Schummer. 2017. Habitat selection adult female mallards in the Lake St. Clair Region during Autumn and winter. The Wildlife Society Annual Conference. 26 September, Albuquerque NM, USA.

**Palumbo, M.D.**, S. A. Petrie, M. L. Schummer. 2017. Habitat selection adult female mallards in the Lake St. Clair Region during Autumn and winter. American Ornithological Society and Society of Canadian Ornithologists Joint Meeting. 4 August East Lansing, MI USA.

**Palumbo, M.D.**, S. A. Petrie, M. L. Schummer. 2017. Habitat selection and survival of female mallards in the Lake St. Clair Region during Autumn and winter. University of Wisconsin-Stevens Point Duck Unlimited Chapter. April 12 Stevens Point, WI, USA.

**Palumbo, M.D.**, S. A. Petrie, M. L. Schummer. 2015. Habitat selection and survival of female mallards in the Lake St. Clair Region during Autumn and winter. North American Duck Symposium. February 1 – 5, Annapolis, MD. USA.

**Palumbo, M.D.**, S. A. Petrie, M. L. Schummer. 2015. Habitat selection and survival of female mallards in the Lake St. Clair Region during Autumn and winter. The Wildlife Society 22<sup>nd</sup> Annual Conference. October 17-21. Winnipeg, Manitoba, CAN.

**Palumbo, M.D.**, S. A. Petrie, M. L. Schummer. 2015. Habitat selection and survival of female mallards in the Lake St. Clair Region during Autumn and winter. Waterfowl and Wetlands Research, Management, and Conservation in the Lower Great Lakes: Partner's Forum. Winous Point Marsh Conservancy May 2015, Port Clinton, OH. USA.

**Palumbo, M.D.**, S. A. Petrie, M. L. Schummer. 2014. Habitat selection and survival of female mallards in the Lake St. Clair region during Autumn and winter. University of Western Ontario Biology Graduate Research Forum. October 2014, London, ON. CAN.

**Palumbo, M.D.**, S. A. Petrie, M. L. Schummer. 2014. Habitat selection and survival of female mallards in the Lake St. Clair Region during Autumn and winter. Waterfowl and Wetlands Research, Management, and Conservation in the Lower Great Lakes: Partner's Forum. Winous Point Marsh Conservancy May 2014, Port Clinton, OH. USA.

**Palumbo, M.D.**, F.J. Vilella, B.K. Strickland, G. Wang, and D. Godwin. 2009. The application of hunter observations and brood survey estimates to determine gobbling activity of the Wild Turkey throughout Mississippi. Poster presented at the Southeastern Association of Fish and Wildlife Agencies. November 1-5. Atlanta, GA. USA.

**Palumbo, M.D.**, F.J. Vilella, B.K. Strickland, G. Wang and D. Godwin. 2008. Spatio-Temporal Variation in Gobbling Activity of the Wild Turkey in Mississippi. Poster presented at The Wildlife Society Annual National Conference, Student Research in Progress Session. November 8 – 12. Miami, Fl. USA.

**Palumbo, M.D.**, F.J. Vilella, B.K. Strickland, G. Wang and D. Godwin. 2008. Spatio-Temporal Variation in Gobbling Activity of the Wild Turkey in Mississippi. Oral presentation at The Wildlife Society Mississippi State Chapter Annual Meeting. October 2. Jackson, MS. USA.