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Movement, habitat selection, and survival of female wood ducks (Aix sponsa) and ducklings at Long Point, Ontario.

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by

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Abstract

Nest box programs provide additional nesting opportunities for wood ducks throughout their breeding range. The purpose of my research was to understand habitat use and survival of wood ducks produced from nest boxes during the brood-rearing period. I used radio-telemetry to monitor female wood ducks and ducklings to 30 days post-hatch. Females showed the greatest selection for swamp, scrub-shrub, and emergent marsh habitats, and used emergent marsh most. Female survival was high (0.90, 95% CI = 0.81 – 1.0). Conversely, brood survival (0.47, 95% CI = 0.33 - 0.69) and duckling survival (0.18, 95% CI = 0.14 – 0.22) were low, but similar to estimates from other studies. Brood survival decreased with hatch date, but increased with precipitation. Duckling survival was greater with younger and heavier females, and decreased with increased brood size. Management should focus on conservation and provision of swamp and scrub-shrub habitats, and increasing duckling survival to benefit recruitment.

Keywords

Co-Authorship Statement

I, Matt Dyson, was responsible for all intellectual and analytical aspects of the development and completion of my thesis under the supervison of Dr. Scott Petrie and Dr. Hugh Henry. Field methodology was developed with the assistance of Dr. Michael Schummer and Dr. Samantha Richman. I received draft edits from Dr. Scott Petrie, Dr. Hugh Henry, Dr. Michael Schummer, Dr. Tom Nudds, Dr. Shannon Badzinski, and Mr. Rod Brook. All work within this thesis has been authored by Matthew E. Dyson and will be published with co-authors including, but not limited to: Scott A. Petrie, Hugh. A.L. Henry, and Michael L. Schummer.

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1 Introduction

Where, when, and why an animal occupies various habitats are key ecological questions. Knowledge about habitat use helps develop a broader understanding of how animals survive and meet the requirements of maintenance, growth, and reproduction, ultimately influencing fitness (Aarts et al. 2008, Beyer et al. 2010). Studies that increase our understanding of habitat use enable predictions of which habitats will be occupied at various stages of the annual cycle (Manly et al. 2002, Aarts et al. 2008, Lele et al. 2013). Therefore, as a first step to a broader ecological understanding, one must first begin to explore how animals move across the landscape and use various habitats to ultimately understand how their decisions influence survival.

Complex ecological problems, such as habitat loss and climate change, can begin to be addressed by investigating animal movement and distribution (Bowler and Benton 2005, Beyer et al. 2010). Individual movements and habitat use are influenced by multiple intrinsic and extrinsic factors, therefore, quantifying basic measurements of movement and habitat use of multiple animals from a population can help to reveal temporal and spatial use patterns (Turchin 1998, Patterson et al. 2008, Schick et al. 2008). Individual movement is not an independent ecological process, it is governed by complex interactions between life-history stage, physiology, behaviour, weather, and habitat (Patterson et al. 2008, Beyer et al. 2010). Therefore, linking individual animal movement, environmental data, and landscape features can help increase our understanding of behaviours governing movement patterns (Schick et al. 2008).

Acquiring resources, mate choice, predator avoidance, and rearing offspring are activities that shape habitat use (Beyer et al. 2010). Habitats are rarely homogenously distributed, and their heterogeneous distributions, combined with an animal's behavioural traits, influence an animal's location in space (Poysa and Paasivaara 2006). Decisions related to occupancy are also likely influenced on an evolutionary scale in relation to fitness. On a shorter time scale, decisions of space use are likely based on perceived risk. For example, a trade-off likely occurs when choosing habitats related to the perceived benefit (i.e., food reward) against the perceived risk (i.e., risk of predation) (Beyer et al. 2010). Therefore, investigating spatial and temporal movements relative to habitat use,

combined with quantifying survival and reproduction, can help to make inferences about complex behavioural processes and their potential influences on fitness (Johnson 1980, Aarts et al. 2008, Beyer et al. 2010, Fieberg et al. 2010, Lele et al. 2013).

There is a general assumption that if an animal uses a specific habitat type disproportionately to its availability then that habitat must have a positive influence on fitness (Johnson 1980, Aebischer et al. 1993, Beyer et al. 2010, Kaminski and Elmberg 2014). This assumption is the basis of resource selection studies in the literature, and is generally accepted to be scientifically sound (Granfors and Flake 1999, Hartke and Hepp 2004, Beyer et al. 2010). Unfortunately, selection studies include numerous interpretations and definitions for terms such as: use, availability, selection, preference, and quality (Hall et al. 1997, Thomas and Taylor 2006). It is therefore prudent to define these terms in the context of individual studies to allow correct interpretations and comparisons among studies.

The term habitat has many definitions and interpretations in the literature (Hall et al. 1997). For this study, habitat is defined as the resources and conditions present in an area that influence occupancy, survival, and reproduction. These resources include food, cover, water, and any specific features required by a species for survival or reproductive success (Leopold 1933, Krausman 1999). Another term that shares numerous definitions in ecology is habitat quality. For consistency, Hall (1997) considered habitat quality to be the ability of the environment to provide conditions appropriate for individual and population persistence. Unfortunately, this definition fails to acknowledge the different conditions potentially required by an individual or population. For example, an individual would benefit from a habitat offering few high quality resources; however, that habitat would not sustain a population. Conversely, a population could be sustained by a habitat with an abundance of lower quality resources at a cost to an individual (Johnson 2007). Therefore, for an individual, habitat quality is the contribution to population growth expected from a given habitat (Johnson 2007).

Habitat availability is the quantity, or proportion of habitat that is accessible to an animal (Johnson 1980, Jones 2001). Habitat use is the proportion, or quantity, of time that an animal spends in that particular habitat type (Johnson 1980, Beyer et al. 2010). For

example, habitat use can be used to quantify and understand the distribution of a species on a landscape (Jones 2001). Habitat use is considered selective if a habitat is used in lesser or greater proportion to its availability (Johnson 1980, Beyer et al. 2010, Lele et al. 2013). Habitat preference is selection given equal availability, such as in laboratory studies (Johnson 1980); however, in field studies habitat availability is variable. Since habitat preference is difficult, or impossible, to measure in field studies, selection ratios are used to measure use relative to availability (Manly et al. 2002, Aarts et al. 2008, Beyer et al. 2010).

The selection ratio can be interpreted by investigating deviations from direct proportionality between use and availability, indicating selection for habitats (Aarts et al. 2008). Selection can be assessed by means of chi-squared tests, or more commonly multivariate analysis of variance (MANOVA) techniques (Aebischer et al. 1993). The interpretation of selection; however, must be preceded by an understanding of the underlying variables influencing the ratio, use and availability.

Habitat use is relatively intuitive to understand, but it is important to consider that use does not indicate selection. For example, based on sampling procedures, some measurements of use may occur incidentally during movement between selected patches of habitat, or during exploratory expeditions (Aarts et al. 2008, Beyer et al. 2010). Therefore, use is not necessarily an indication of value, or quality, of a habitat to an organism. Availability is less intuitive, and as a result it is imperiled by investigator subjectivity.

Two main factors influence the way an investigator defines availability, scale and accessibility (Arthur et al. 1996, Manly et al. 2002, Beyer et al. 2010, Fieberg et al. 2010, Lele et al. 2013). Scale is spatially and temporally distinct. It has been suggested that scale occurs at four levels: 1) geographic range, 2) individual home-range within a landscape, 3) habitat use within a home-range, and 4) selection of resources such as food in patches (Johnson 1980). Scale is relatively easy to assess in selection studies, whereas accessibility is much more difficult to quantify. As a result, an important assumption is that within a defined available space, all habitat is equally accessible (Jones 2001, Aarts et al. 2008, Beyer et al. 2010). Investigators must, therefore, limit interpretations of

selection ratios to the assumptions based on use and availability measurements to make objective inferences.

The utility of these methods is valuable in landscape-level studies, provided the user considers appropriate questions and scale of analysis. Advances in technology of transmitters have allowed for finer scale understanding of movement, while advances in remote sensing and geographic information systems (GIS) have provided a more comprehensive characterization of landscape features, allowing advanced analytical techniques (Beyer et al. 2010, Lele et al. 2013). Results of these analyses can then be used to direct habitat conservation and can advance science through a better understanding of life-history strategies.

1.1   Waterfowl Management

Few animal taxa garner as much concern for the management of populations as North American waterfowl (Baldassarre and Bolen 2006). There is a strong expectation from waterfowl enthusiasts for abundant and managed waterfowl populations now and into the future (Baldassarre and Bolen 2006, NAWMP 2012, Cooper et al. 2015). As a result, legislation and policies (e.g. Migratory Bird Treaty Act - 1917, North American Waterfowl Management Plan - 1986) have been established to sustain waterfowl populations. Although not mutually exclusive, there are two accepted forms of waterfowl management, 1) population management that involves regulation of harvest, control of disease, and other mortality, and 2) conservation and manipulation of habitat (Baldassarre and Bolen 2006). Management cannot alter the life history of waterfowl in the short-term, but it can synchronize the abundance, availability, and distribution of food, cover, and water resources to coincide with specific life events (Baldassarre and Bolen 2006).

1.1.1   Population Management

Waterfowl population management occurs across the annual cycle, which is defined temporally by individual life history events, such as breeding, rearing, moulting, and wintering, and spatially as a result of movements and migration (Batt et al. 1992, Bellrose and Holm 1994, Baldassarre and Bolen 2006). Therefore, waterfowl encounter numerous landscapes and challenges over the course of a year, and these dynamic temporal and spatial scales can have various effects on waterfowl populations over time. In harvested

populations, such as waterfowl, harvest rates influence annual mortality (Peron et al. 2012, Cooch et al. 2014, Koons et al. 2014), but the non-hunting period, especially nesting and brood-rearing, can also have substantial influence on population dynamics (Coluccy et al. 2008).

Recruitment, a population demographic, is the number of young being added to the autumn migration on an annual basis (Batt et al. 1992). Waterfowl populations are strongly influenced by recruitment, which is a function of the number of birds hatched, and their subsequent survival into the autumn migration (Dzus and Clark 1998, Davis et al. 2001). Nest success, which is the percentage of nests that hatch at least one egg, is often reported as a recruitment index (Rotella and Ratti 1992*a*, Dzus and Clark 1998). Hatch success, the proportion of eggs hatched from a clutch, is also used to estimate recruitment in waterfowl species, such as mallards (*Anas platyrhynchos*) (Simpson et al. 2005, Krapu et al. 2006, Chouinard and Arnold 2007). Mortality rates during brood-rearing can be substantial, therefore, an assessment of survival of females and ducklings during that time provides a more accurate estimate of recruitment (Simpson et al. 2005, Davis et al. 2007).

In waterfowl, females are highly philopatric to natal and breeding areas, and many species form pair bonds on the wintering grounds, with mates returning to a female's previous nesting, or natal location, to produce young (Batt et al. 1992). Therefore, recruitment in waterfowl is often studied in relation to females, assuming there is an adequate abundance of males (Hepp et al. 1989, Batt et al. 1992, Baldassarre and Bolen 2006). Female waterfowl exhibit lower rates of survival compared to males, mostly from increased costs of parental investment during reproduction (i.e., brood-rearing), that expose them to greater risks of predation or starvation (Krapu et al. 2000, Yerkes 2000, Arnold et al. 2012). Moreover, female mortality during brood-rearing may result in total loss of a brood, especially when ducklings are young and require the greatest parental care (Krapu et al. 2000, Pietz et al. 2003). Finally, decisions by females during rearing, such as selection of habitats to occupy, are often reflected by female offspring in future years, having a generational effect on choices that may influence survival (Hepp et al. 1987, Hepp and Kennamer 1993).

Duckling survival can be influenced by many factors, including female age and experience, hatch date and initial brood size, habitat quality and availability, predation, and weather (Pietz et al. 2003). Although ducklings are precocial, females provide post-hatch care (Yerkes 2000). Older females often have greater survival of offspring compared to younger females (Hepp and Kennamer 1993, Yerkes 2000). For the purpose of my thesis, I define older females as after second year (ASY), and younger females as second year (SY). Older females have successfully exploited the landscape before and may be more capable of exploiting resources and avoiding predation compared to younger females (Yerkes 2000). Older females generally nest earlier, which can increase duckling survival (see below) (Hepp and Kennamer 1993, Devries et al. 2003). Additionally, older females may be larger and able to spend more time providing parental care, compared to younger females that may have to feed more during brood-rearing (Yerkes 2000). Finally, older females often have higher annual survival rates compared to younger females (Hepp and Kennamer 1993).

A widely understood phenomenon in waterfowl, and other avian species, is that later hatch dates result in reduced survival of young (Granfors 1996, Dzus and Clark 1998, Davis 2001). Waterfowl, and many other avian species, have evolved to time their hatch dates to coincide with maximum food availability on the landscape for their offspring (Dzus and Clark 1998). Ducklings that hatch early may experience less competition for limited food resources, receive increased parental care because females have longer to restore energy used in reproduction prior to autumn migration, exploit additional habitats available as a result of increased wetland inundation, and have a longer period of growth to prepare for migration (Rotella and Ratti 1992*a*, *b*, Dzus and Clark 1997, 1998). Late-hatched ducklings likely have a lower probability of survival as a result of decreased parental care, because females may leave their brood to moult (Bellrose and Holm 1994, Krapu et al. 2000, Pietz et al. 2003). Further, as the brood-rearing period progresses less food is available, and there is potential for higher concentration of ducklings on smaller wetlands as a result of reduced habitat availability caused by habitat desiccation (Rotella and Ratti 1992*b*, Dzus and Clark 1998, Davis et al. 2007). Conversely, a study in Mississippi and Alabama found ducklings that hatch early

in the season were exposed to an environment with little cover, and therefore, were highly susceptible to predation and the weather (Davis et al. 2007).

Duckling survival is least during the first two weeks of life and is thought to be greater and relatively stable thereafter until fledging (Dzus and Clark 1998, Krapu et al. 2006, Poysa and Paasivaara 2006, Davis et al. 2007). Cold temperatures can decrease duckling survival as a result of limited thermoregulatory capabilities (Krapu et al. 2006), and cold intolerance can be intensified by precipitation (Davis et al. 2007). Additionally, habitats that have greater predator densities, and/or limited food resources, can result in decreased duckling survival (Granfors 1996, Granfors and Flake 1999, Davis 2001, Davis et al. 2007). Therefore, survival is also a function of the habitat that ducks select, making it beneficial to relate survival and habitat to inform population management and conservation efforts.

1.1.2 Habitat Management

Waterfowl are synonymous with wetlands; however, wetland habitats have been greatly decreasing in abundance since the 1800s as a result of human influences, including drainage and conversion to agricultural, industrial, or urban land uses (Mitsch and Gosselink 2007, Ducks Unlimited Canada 2010, Ma et al. 2010). It is estimated that 50% of the world's wetlands have been converted to other land uses, with what remains degraded to varying degrees (Ma et al. 2010). In some areas of Ontario, only 15% of historical wetlands remain (Petrie 1998, Ducks Unlimited Canada 2010). With prediction of further wetland loss, it is imperative to understand how waterfowl use remaining habitats, and use sound science to manage these habitats (Mitsch and Gosselink 2007, Ma et al. 2010).

Quality habitats provide food, cover, water and space (Leopold 1933, Kaminski and Elmberg 2014). The features of quality waterfowl habitat have been studied extensively and are influenced by vegetation, food type and functional availability, water depth and hydrological cycles, and wetland size and connectivity (Ma et al. 2010). Interspecific variation in habitat requirements, both spatially and temporally, make it necessary to base management decisions on region, and species, specific knowledge (Baldassarre and Bolen 2006, Mitsch and Gosselink 2007). Additionally, it is important

to acknowledge that potential management solutions to meet the life history needs of all species may not exist within single wetlands (Kaminski et al. 2006, Ma et al. 2010, Kaminski and Elmberg 2014). Therefore, it is necessary to manage and maintain wetland complexes to maximize benefits to the greatest diversity of species.

Food for growth and cover to escape predation are habitat requirements of brood-rearing waterfowl (Batt et al. 1992, Baldassarre and Bolen 2006). During early stages of growth, ducklings require protein from invertebrates and they generally increase the amount of carbohydrate-rich foods in their diets as the brood-rearing period progresses (Drobney and Fredrickson 1979, Baldassarre 2014). Therefore, wetland vegetation provides substrate for invertebrate foods, cover to facilitate escape from predators, and later, direct forage (Ma et al. 2010). As a result, habitats for waterfowl and other wetland-dependant wildlife are often classified in relation to the vegetation communities that are present (Cowardin et al. 1979). Therefore, knowledge of habitats that ducks use and how they influence survival can help managers provide additional quality habitats on the landscape to benefit populations.

1.2 The Wood Duck

The wood duck (*Aix sponsa*) is a small-bodied, cavity nesting, waterfowl species that nests in hardwood bottomland and riparian wetland habitats. They are the only member of the genus *Aix* endemic to North America, and have one of the most extensive breeding ranges of all Nearctic waterfowl species. Wood ducks are biologically intriguing because of their distribution, rebound from near extinction, and interesting behaviours, such as obligate cavity nesting, double-brooding, and conspecific brood parasitism (Bellrose and Holm 1994, Granfors 1996, Davis 2001, Baldassarre 2014).

Deforestation of eastern North America's bottomland habitats, combined with unregulated market hunting during the late 1800s and early 1900s, resulted in substantial population declines and concerns of extinction (Bellrose and Holm 1994, Baldassarre 2014). The Migratory Bird Treaty Act (1917) provided legislation that closed seasons and eliminated market hunting of wood ducks, allowing populations an opportunity to recover. Additionally, sustainable forestry initiatives helped to retain important habitats throughout the wood ducks breeding range. By 1941, conservative harvest was

reestablished for the wood duck and today it often ranks as one of the top 3 harvested waterfowl species throughout the Mississippi Flyway. Current population estimates of the wood duck are 3 million birds in North America (Baldassarre 2014).

Nest box programs were introduced to increase nest site availability throughout the wood duck's breeding range as early as 1912, with wide scale use by 1937 (Bellrose and Holm 1994, Semel and Sherman 1995). These programs have contributed greatly to our knowledge of wood duck ecology (Bellrose et al. 1964, McGilvrey 1969, Heusmann 1975, Smith and Flake 1985, Hepp et al. 1989, Davis et al. 2007, Hepp and Kennamer 2012). An estimated 300,000 wood duck ducklings were produced from 100,000 nest boxes annually in the eastern United States as of 1990. Of those ducklings, it was estimated that 150,000 were recruited into the autumn migration (Baldassarre 2014). Boxes are still used extensively today across North America; however, some studies have suggested that sustainable forestry and better land stewardship practices has increased the availability of natural cavities in much of the wood duck's range, with predictions of increasing abundances, therefore making nest boxes redundant on those lands (Soulliere 1988, Denton et al. 2012).

The addition of nesting opportunities by installing wood duck boxes would seem to undoubtedly increase reproductive success. However, conversion of riparian habitats and wetlands for agriculture and urbanization may limit the availability of quality brood-rearing habitat and reduce any potential added value of additional nest sites. Therefore, awareness of how wood ducks and broods use habitats post-hatch from nest boxes is valuable for ensuring the strategic placement and management of nest boxes (Semel and Sherman 1995).

Wood ducks typically use habitats with a high proportion of vegetative cover, which provides substrate for invertebrate food resources, escape from predators, and facilitates thermoregulation (Drobney and Fredrickson 1979, Granfors 1996, Davis 2001). Brood-rearing females must locate habitats with adequate nutritional resources for ducklings while minimizing the threat of predation over the course of the rearing period (Granfors and Flake 1999, Davis et al. 2001). Ducklings are dependent on aquatic food resources, primarily invertebrates, during the first 30 days post-hatch. Therefore, an

explicit division of the landscape can be made into suitable habitat (aquatic), versus unsuitable habitat (terrestrial) (Poysa and Paasivaara 2006). Finally, duckling movement is considerably limited because they are flightless during the rearing period (Bellrose and Holm 1994). Overall, these limitations must be considered when interpreting habitat use and movement patterns for brood-rearing wood ducks (Poysa and Paasivaara 2006).

Wood ducks nest in cavities and, therefore, have greater rates of survival during incubation relative to other waterfowl (Bellrose and Holm 1994, Hartke et al. 2006, Roy Nielsen et al. 2006). For example, survival rates have approached 100% during the incubation and brood-rearing period from studies in the southern and central portions of the wood duck's breeding range (Granfors 1996, Davis et al. 2001, Hartke et al. 2006). Duckling survival is considerably lower (4 – 45%), although it is highly variable, and may limit recruitment in some areas (Heusmann 1972, Granfors 1996, Davis et al. 2007). Survival of female wood ducks and their ducklings at northern latitudes; however, may differ from birds breeding at southern latitudes, because of a contracted breeding season and increased costs of migration (Hepp et al. 1989). Predation has been predicted as the most important influence on female wood duck and duckling survival during brood-rearing and is most likely related to habitat use. Additionally, it may be influenced by other parameters, such as hatch date, brood size, and movement (Bellrose and Holm 1994, Davis et al. 2001, Hartke et al. 2006). Nest success alone is, therefore, not an appropriate parameter to determine the contribution of nest box programs to populations (Simpson et al. 2005, Davis et al. 2007).

Long Point, Ontario, is one of the few remaining extensive wetland complexes along the north shore of Lake Erie and one of Ontario's most important waterfowl habitats, supporting millions of birds annually, especially during migration (Petrie 1998, Ducks Unlimited Canada 2010). Two of Canada's largest National Wildlife Areas (NWA) occur here: Long Point NWA, and Big Creek NWA, with the latter comprising a considerable portion of the study area. The study area also includes the Lee Brown Marsh, managed by Long Point Region Conservation Authority (LPRCA), as well as the Crown Marsh, managed by the Ontario Ministry of Natural Resources (OMNR). The remaining portions of the study area are privately owned by hunt clubs, and conservation-minded members of the public. Long Point is also one of the best areas to hunt waterfowl

in southwestern Ontario. As a result, waterfowl are both of high social, and economic importance in the region, with wood ducks being one of the region's most sought after ducks (Petrie 1998). As a result, there is an established nest box program in Long Point on private hunt clubs dating back to before 2012 (Schummer et al. 2012). Nest box occupancy by wood ducks was low, with an estimated 37% use in 2012, and 26% use in 2013. Low occupancy may be a result of an abundance of natural cavities (i.e., alternative nesting locations), or low recruitment of ducklings produced from nest boxes (Hepp et al. 1989, Davis 2001, Mallory et al. 2002).

1.3   Research Objectives and Hypothesis

The goal of my study was to gain a better understanding of brood-rearing ecology for wood ducks produced from nest boxes at their northern breeding range. My objectives were to: 1) determine how female wood ducks and ducklings moved throughout the landscape post-hatch, 2) determine what habitats female wood ducks and ducklings use throughout the brood-rearing period, and 3) quantify survival of female wood ducks and ducklings during the brood-rearing period. I hypothesized that if females used the greatest quality habitats available, then those habitats would be used in greater proportion to their availability. I predicted that movement and habitat selection of wood ducks with broods would be different from those without broods (i.e., lost broods), as a result of specific dietary requirements of ducklings and necessity for increased predator avoidance. I also predicted that habitat selection would be affected by female age/experience (ASY vs. SY), hatch date (May vs. June), and nest site location (Big Creek vs. Other). I also hypothesized that wood ducks and ducklings at northern latitudes would have lower survival rates than wood ducks at southern latitudes as a result of increased costs of migration and a contracted breeding season. I predicted brood and duckling survival would be a function of female age, female mass, hatch date, initial brood size, and an interaction between temperature and precipitation.

In this Chapter, I provided a review of pertinent literature and presented my hypotheses. In Chapter 2, I present my findings for the first two objectives of determining movement and habitat use. In Chapter 3, I quantify and model survival to 30 days post-hatch for females, broods and duckling. In Chapter 4, I discuss the study in a broader ecological context, address some limitations of this study, and propose future research.

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2 Movement and habitat selection of female wood ducks (*Aix sponsa*) and ducklings at Long Point, Ontario.

2.1 Introduction

Draining, filling, and degradation of wetlands are the greatest threats to waterfowl populations in North America (Batt et al. 1992, Baldassarre and Bolen 2006). To facilitate the conservation, restoration, and management of wetland habitats for waterfowl, it is imperative to study habitat selection throughout the annual cycle. The brood-rearing period is when a considerable amount of annual mortality occurs, primarily of young of the year, and it is particularly important to study habitat selection at that time (McGilvrey 1969, Rotella and Ratti 1992*a*, Dzus and Clark 1998, Krapu et al. 2000). Habitat selection is commonly quantified as a proportional measure of use compared to availability, and selected habitats are assumed to provide a fitness benefit (Morris et al. 2008, Beyer et al. 2010). Therefore, knowledge of habitat selection can provide direction for future habitat conservation strategies.

Wood ducks (*Aix sponsa*) are a small-bodied, cavity nesting, waterfowl species primarily found in riparian hardwood forests of eastern North American; however, they have a broad geographic breeding range across North America (Baldassarre 2014). Wood ducks are biologically intriguing in that they nest in trees, will produce two clutches of eggs in a year near the southern portion of their range, are conspecific nest parasites, and have rebounded from near extinction (Bellrose and Holm 1994). They are intensively managed throughout their breeding range using artificial nest boxes, which provide additional nesting opportunities to compensate for reduced natural cavity availability (Semel et al. 1988, Bellrose and Holm 1994). Nest boxes have undoubtedly provided additional nesting opportunities, but the contribution of nest box programs may be compromised if the quality and quantity of brood-rearing habitat is limited (Hepp et al. 1989, Semel and Sherman 1995).

Wood duck habitat use has been investigated at various locations in the United States (McGilvrey 1969, Smith and Flake 1985, Hepp et al. 1989, Bellrose and Holm 1994, Semel and Sherman 2001, Davis et al. 2009). However, little information exists about wood duck habitat use in the Great Lakes region, which is near the northern extent

of their breeding range (Dennis 1988, Mallory et al. 2002). Great Lakes' wetlands provide internationally significant staging and breeding habitat for waterfowl, including a large population of wood ducks (Dennis 1988, Petrie 1998). Therefore, developing habitat models from information gathered from across the wood duck's breeding range could be help to sustain their population and guide conservation (Cooper et al. 2015, Crosby et al. 2015).

Wood ducks characteristically are habitat generalists and use habitats that provide vegetative cover, which provides substrate for invertebrate food resources, escape from predators, and facilitates thermoregulation (Batt et al. 1992, Krapu et al. 2006, Davis et al. 2007). Brood-rearing females must locate habitats with adequate nutritional resources for ducklings while minimizing the threat of predation over the course of the rearing period (Granfors and Flake 1999, Davis et al. 2007). Ducklings are dependent on aquatic food resources, such as invertebrates and submerged aquatic vegetation, during the first 30 days post-hatch (Drobney and Fredrickson 1979, Davis 2001). Finally, duckling movement is considerably limited because they are flightless, and these limitations must be considered when interpreting movement patterns and habitat selection data (Granfors and Flake 1999, Poysa and Paasivaara 2006).

I used radio-telemetry to track female wood ducks and their ducklings daily to 30 days post-hatch. My objectives were to determine movement and habitat use of females and ducklings post-hatch. I hypothesized that if females used the greatest quality habitats available, then those habitats would be used in greater proportion to their availability. I predicted that movement and habitat selection of wood ducks with broods would be different from those without broods (i.e., lost broods), as a result of specific dietary requirements of ducklings and necessity for increased predator avoidance. I also predicted that habitat selection would be affected by female age/experience (SY vs. ASY), hatch date (May vs. June), and nest site location (Big Creek vs. Other). Knowledge of wood duck habitat selection will identify quality habitats and inform future habitat conservation, as well as elucidate the brood-rearing ecology of wood ducks produced in the Great Lakes region.

2.2   Methods

2.2.1   *Study Area*

The study took place from April - July 2014 at Long Point, Ontario (17T 540613 4717249, Figure 2.1). Long Point is one of the few remaining extensive wetland complexes along the north shore of Lake Erie and one of Ontario's most important waterfowl habitats, supporting millions of birds annually, primarily as staging grounds for migration. This wetland complex also provides important breeding habitat for a few waterfowl species, including wood ducks. Two of Canada's largest National Wildlife Areas (NWA) occurred here, Long Point NWA, and Big Creek NWA, with the latter comprising a considerable portion of the study area. The study area also includes the Lee Brown Marsh, managed by Long Point Region Conservation Authority, as well as the Crown Marsh, managed by the Ontario Ministry of Natural Resources and Forests (OMNRF). The remaining portions of the study area were privately owned managed wetlands.
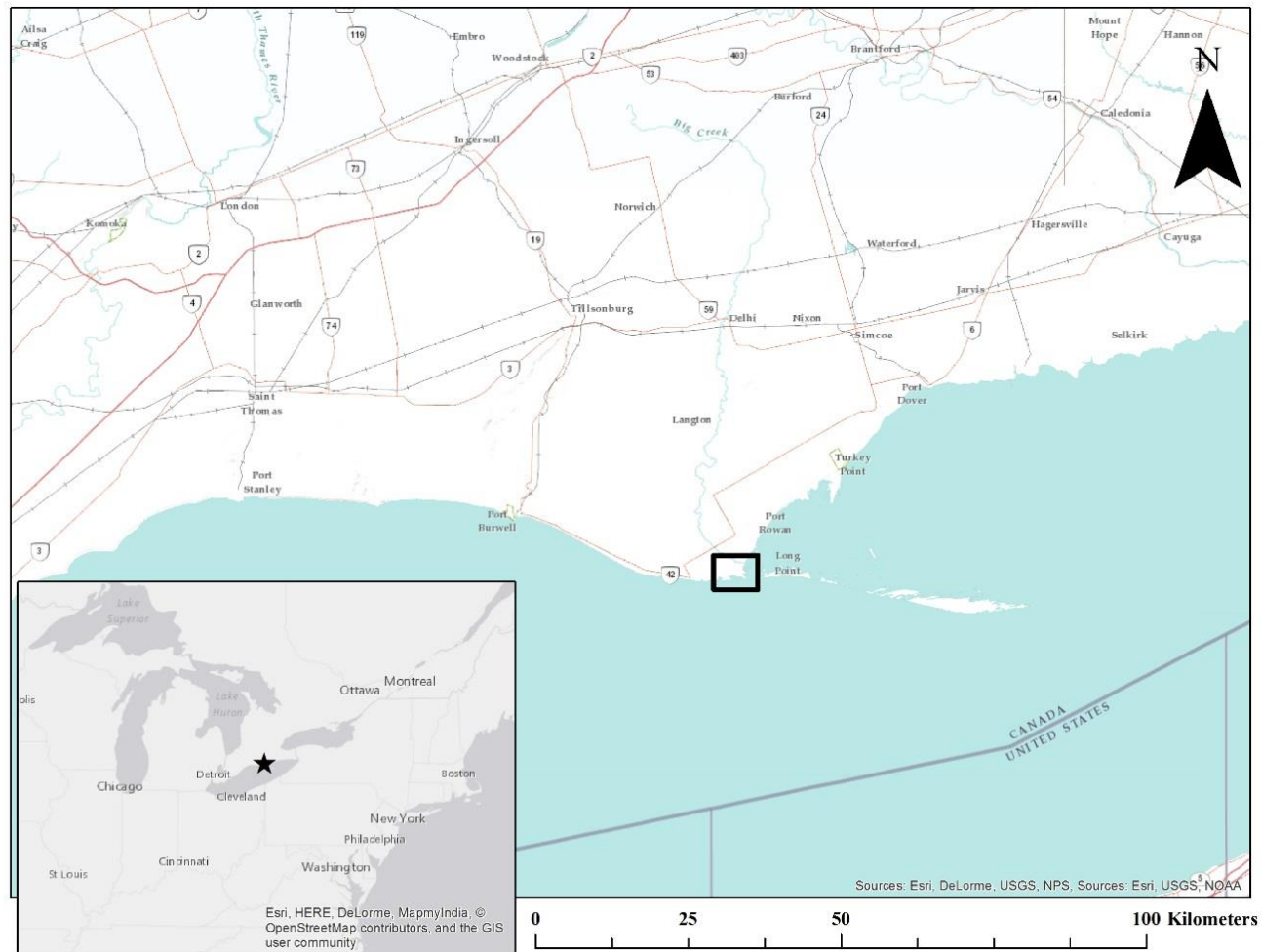
Figure 2.1. Map of the study area, Long Point, Ontario, encompassed by a black rectangle relative to southern Ontario. Inlay identifies study area with a black star relative to the Great Lakes and eastern North America.

The total study area was approximately 15000 ha, with dominant land cover types being open water (7356 ha), agriculture (3900 ha), emergent marsh (1736 ha), forest (942 ha), scrub-shrub (579 ha), urban (370 ha), and swamp (217 ha) (Figure 2.2). The primary agricultural production was corn and soy beans directly adjacent to the study area. Open water habitats included the inner bay of Long Point (Lake Erie), Big Creek, which drains into the inner bay, and open ponds throughout the marshes. The emergent marshes that occurred in the study area are subject to various management regimes, where most include some degree of hydrological management. Emergent marshes contained stands of cattail (*Typha* sp.), and European common reed (*Phragmites australis*), as well as other obligate wetland species, such as wild rice (*Zizania aquatic*), American lotus (*Nulumbo nutea*), and duck weeds (Family: Araceae). Forested wetlands (hereafter swamps) and lowland scrub-shrub habitats formed most of the transitional zones from riverine and emergent marsh to upland habitats (e.g., forests and agriculture). Scrub-shrub habitats were primarily defined by the presence of woody plants such as swamp loosestrife (*Decadon verticillatus*), and buttonbush (*Cephalanthus occidentalis*), but lacked an abundance of trees. Swamps were subject to fluctuating water levels, mostly from seasonal river flooding and commonly contained silver maple (*Acer saccharinum*), red oak (*Quercus rubra*), sycamore (*Platanus occidentalis*), and American beech (*Fagus grandifolia*).
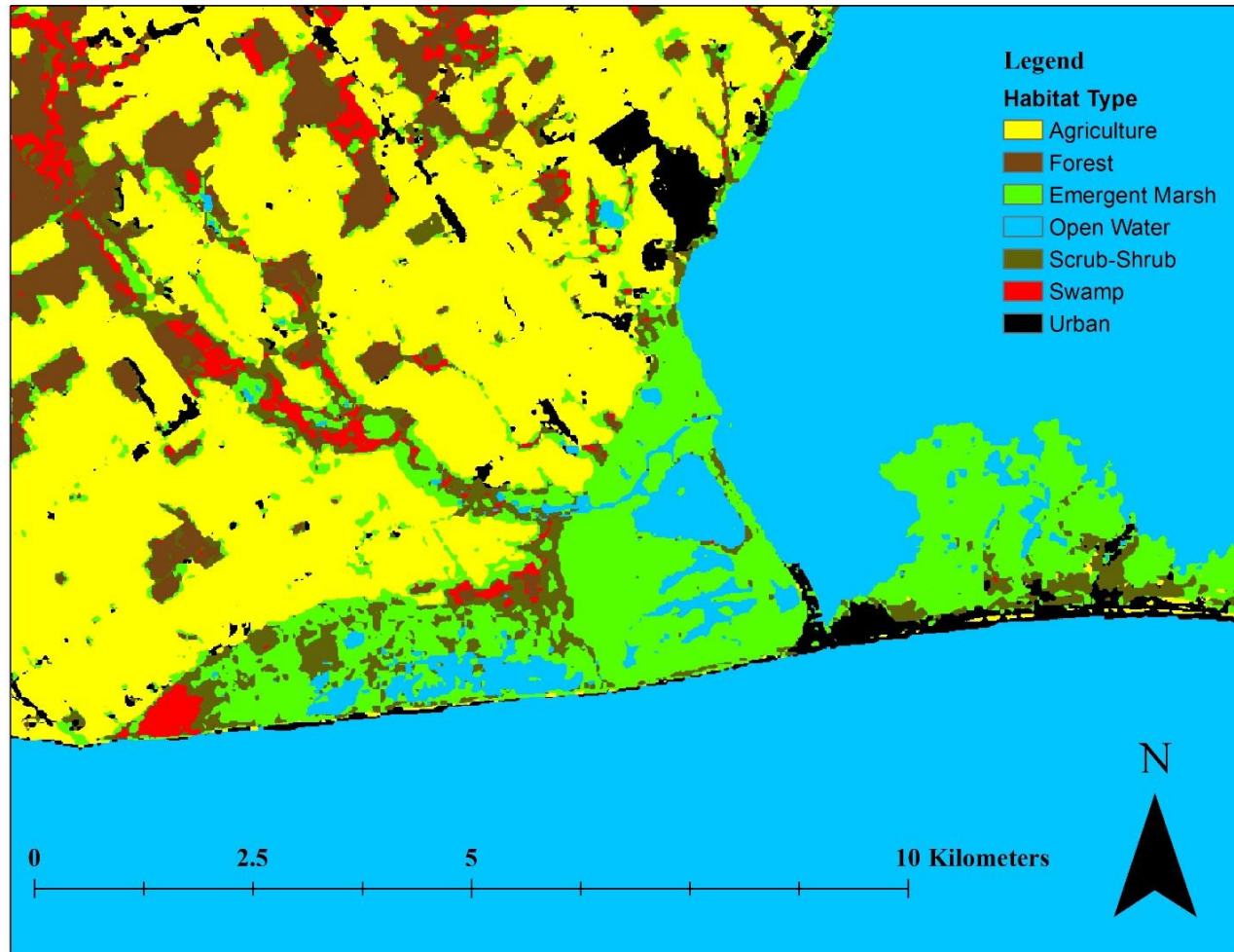
Figure 2.2. Landcover classifications for Long Point, Ontario, adapted from the Michigan Tech Research Institutes Coastal Wetland Mapping Layer.

Nest boxes ($n = 304$) were managed throughout the study area and were primarily placed along Big Creek and adjacent riparian habitats (classified for comparison as Big Creek); however, they also were placed along a smaller drainage basin, James Berry Drain, and Dedrick Creek (classified for comparison as Other) (Figure 2.3). Nest boxes were mounted on steel poles with predator guards at a density of about 0.41/ha (Figure 2.3). A total of 109 boxes existed in 2012, and we installed 140 boxes in 2013, and 50 in 2014.
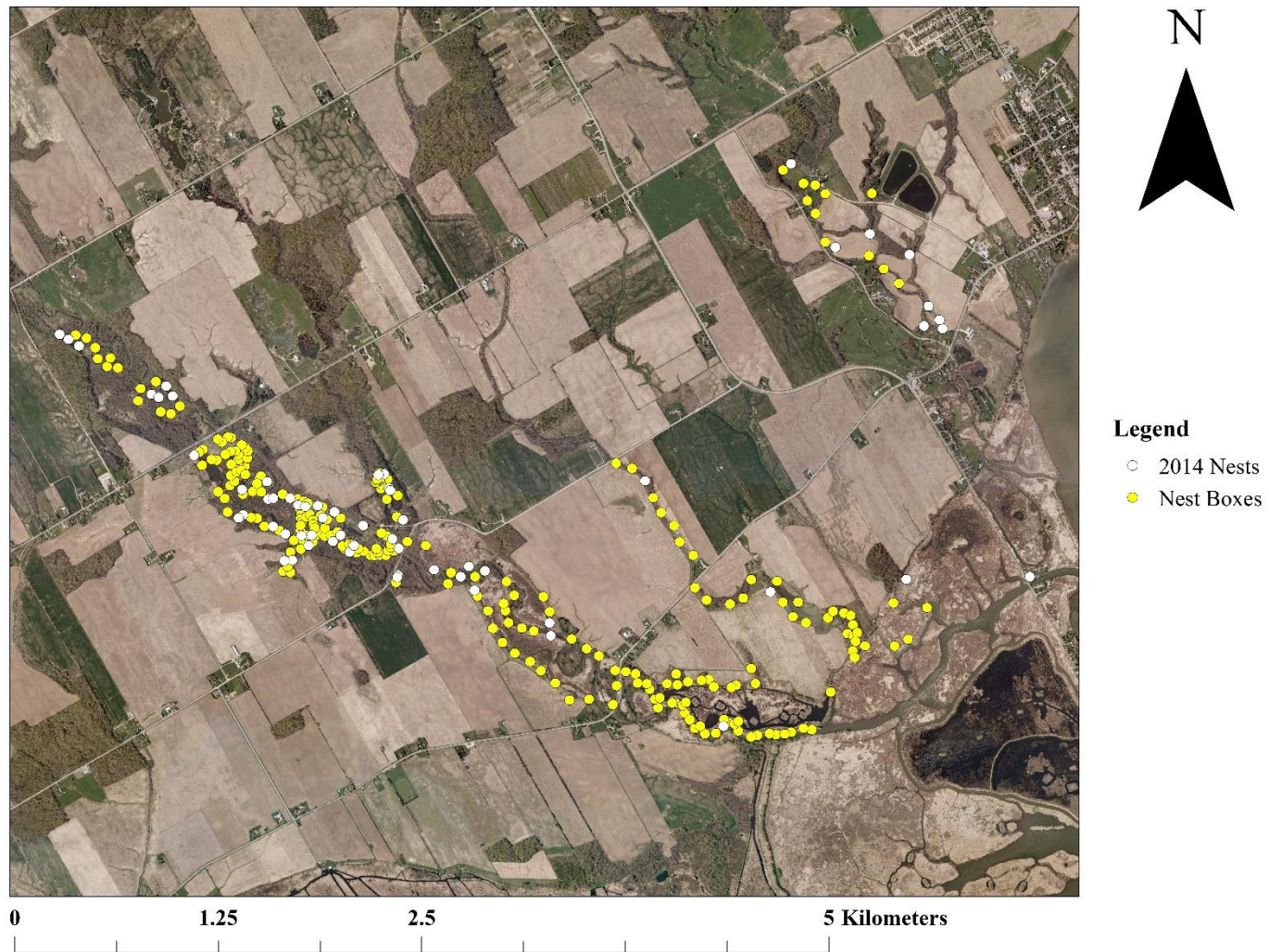
Figure 2.3. Map of nest box locations ($n = 304$) and nests ($n = 61$) in 2014 at Long Point, Ontario.

2.2.2   Study Design

Field procedures were reviewed and approved by the Western Animal Care Committee Committee (2014-007, Appendix A), and the Ontario Ministry of Natural Resources and Forestry Wildlife Animal Care Committee (13-304, Appendix B). I monitored nest boxes twice per month beginning mid-April through to the end of July. When a wood duck nest was detected, eggs were candled to determine stage of incubation (Weller 1956). Females ($n = 40$) were captured using a modified nest box trap, which was a pool noodle used to block the entrance hole of the box before dawn. Once captured, females were marked with a radio transmitter and U.S. Fish and Wildlife Service aluminum leg band at ≥ 20 days incubation across 3 different capture periods (7 May, 20 May, and 2 June). A prong and suture style transmitter was attached following a standardized procedure (Davis 2001, Hepp et al. 2002). Transmitters weighed 7.2 g, measured 26 mm × 23 mm × 8 mm (l×w×h) and had approximately 60 d of battery life (Appendix C. Technical specifications for prong and suture transmitters used for marking female wood ducks ($n = 40$, ATS Model 4410)

, model A4410, Advanced Telemetry Systems, Isanti, Minnesota, USA).

After marking, I monitored females on nests daily using a hand-held Yagi antenna to determine hatch date. I began tracking post-hatch movements the day a female exited the nest box with her brood using a truck mounted null-peak antenna system (Granfors 1996, Brinkman et al. 2002). I alternated tracking regimes daily as follows: temporally: 1) early (0600-1400), and 2) late (1400-2200) and spatially: 1) north-south, and 2) south-north, to reduce temporal and spatial autocorrelation in data collection. Females were triangulated once daily during the tracking period and I verified my measurements in the field using orthographic photos. I tracked females to 30 days post-hatch, until the female died, or the transmitter malfunctioned (Davis 2001). Female mortality was indicated by a mortality signal and visually confirmed within 2 days in all cases ($n = 4$). I determined and monitored system accuracy by relocating manually placed transmitters and comparing estimated to known locations at three intervals throughout the tracking period.

I observed females, and their broods, at 15 and 30 days post-hatch to quantify duckling survival. I used a hand-held Yagi antenna to home to a female location based on

the prior day's triangulated location. Once I determined the general location of a female, I located a spot where I could observe most of the wetland and waited for the female and brood to become visible. Once visible, I counted ducklings present, and noted completeness of the count (i.e., full count/partial count). I assumed a full count if females and ducklings were seen foraging on an open area for an extended period of time (>10 minutes), and indicated partial counts if broods were only counted through vegetation. I confirmed observations using direction of greatest signal strength on the receiver antenna and the presence of a transmitter on the female. I assumed complete brood loss upon the death of a female. A successful brood was defined as at least one duckling surviving to 30 days.

2.2.3   *Statistical Analyses – Movement Metrics*

To estimate female locations based on triangulations from the field, I used Location of A Signal software (LOAS, Ecological Software Solutions, 2013). I estimated locations based on Lenth's maximum likelihood estimator with a bearing standard deviation of 3 degrees. The LOAS output produced estimated locations along with error ellipse polygons. I plotted estimated locations in ArcGIS and verified all locations, deleting erroneous estimates with extremely large error ellipses.

I used the Animal Movement Ecology extension ArcMET in ArcGIS to calculate movement metrics (Wall 2014). I used the trajectory tools (path statistics, path metrics) to calculate total path distance, mean step length, total displacement, and length of first movement. To calculate home-ranges I used range tools to calculate minimum convex polygons (MCPs) at 50, 90, 95, and 100 percent isopleths (Hartke and Hepp 2004). I also calculated kernel density home-ranges under the UD tools set using the 'h ref' method, and created percent contours at 50, 90, and 95 percent isopleths (Granfors and Flake 1999, Wall 2014).

I compared movement for females and broods for the first 15 days and last 15 days post-hatch based on my observation intervals. I also investigated movement differences by brood survival status for the full 30 d post-hatch. I used non-parametric Mann-Whitney U tests to compare means between total path distance, mean step length, total displacement, length of first move, and home-range size. I also compared

differences in estimated home-range size between the MCP and kernel density methods using a non-parametric Mann-Whitney U test to determine which measurement best represented space use for my study. All analyses were completed in R at $\alpha = 0.10$, because this level of confidence is appropriate for wildlife studies with small sample sizes (Tacha et al. 1982, Cherry 2008, R Development Core Team 2011). I choose to set my α above the conventional 0.05, because of the relationship between type I and type II errors in observational studies. A higher alpha increases the chance of accepting a false null (type I), or, I have a 10% chance of concluding a difference when there isn't one. However, because of my smaller sample size and the lack of a controlled experiment, I was more concerned with committing a type II error, or concluding no difference when there really is one (Tacha et al. 1982).

2.2.4   *Statistical Analyses – Habitat Selection*

I measured habitat selection using compositional analysis, comparing proportional use to availability (Aebischer et al. 1993, Pendleton et al. 1998). I defined used habitat as a 100 m buffer (radius) around all locations for an individual to account for measurement error in location estimation and the fact that broods are mobile. I defined availability separately for females with broods and those that lost broods to 30 days post-hatch. I defined availability differently for the two groups, because females without broods are more mobile and moved further distances on average and, therefore, had more habitat available (Arthur et al. 1996, Schick et al. 2008, Beatty et al. 2014). I used mean max step for the two groups to define availability, because it represents the largest amount of habitat that may be available for wood duck on a daily basis.

I used the Great Lakes Coastal Wetland Mapping layer with 30 m resolution, produced by Michigan Tech Research Institute, to classify land cover types in my study area (Fig. 2.1) (Bourgeau-Chavez et al. 2015). I generated used and available buffers around each location in ArcGIS (Appendix F). I overlaid my used and available polygons with the land cover raster and extracted proportional habitats within each buffer using the Geospatial Modelling Environments intersect polygon and raster tool (Beyer 2015). I reduced the amount of land cover classifications by pooling like classifications together

(e.g., urban, suburban, urban grass), and by removing classifications that did not occur in my study area (e.g., peatland) (Fig 2.1, Appendix G).

I used R to complete my analysis of habitat selection, along with the statistical package adehabitatHS (Calenge 2015). I measured selection daily and estimated the mean selection ratio for the brood-rearing period (30 days post-hatch) for each individual. I used compositional analysis to test if selection was occurring during the brood-rearing period and also created a rank of selected habitats (Aebischer et al. 1993). Compositional analysis compares the log ratios for each habitat using a multivariate analysis of variance (MANOVA) (Aebischer et al. 1993, Pendleton et al. 1998, Granfors and Flake 1999, Hartke and Hepp 2004, Davis 2012, Varner and Hepp 2013). Log-ratio transformations are desirable for compositional data because of the unit sum constraint; the sum of proportions is one (Pendleton et al. 1998). The transformation removes the linear dependencies in the data, while conserving all the information (Aebischer et al. 1993, Pendleton et al. 1998). I substituted 0.0001 for missing habitat use data to allow for calculations of log-ratios (Aebischer et al. 1993, Pendleton et al. 1998). I examined potential interactions in selection between brood survival status, age of female (SY v. ASY), hatch date (May v. June), and nest location (Big Creek v. Other) using a factorial MANOVA.

2.3   Results

2.3.1   Marking and Tracking

I marked 40 nesting female wood ducks in 2014, of which 39 successfully hatched a nest of at least 1 duckling. I tracked and observed a total of 27 birds to 30 days post-hatch. Of the 13 birds not included in my analysis of movement and habitat selection, 4 females were predated, 8 females either left the study area, or their transmitter malfunctioned, and 1 female was censored as she abandoned her original nest and re-nested successfully, but her transmitter life expired (i.e., >60 days post-attachment). I observed 14 female wood ducks with broods at 30 days post-hatch, and 13 females without broods. I analyzed movement data based on 811 wood duck locations ($X = 30.1$, SE $= 0.2$ locations/female, $n = 27$; Appendix H). The mean error polygon for all locations was 1.34 ha (SE $= 0.08$)

and the mean maximum displacement, possible distance of actual location from estimated location, was 65.5 m (SE = 16.4).
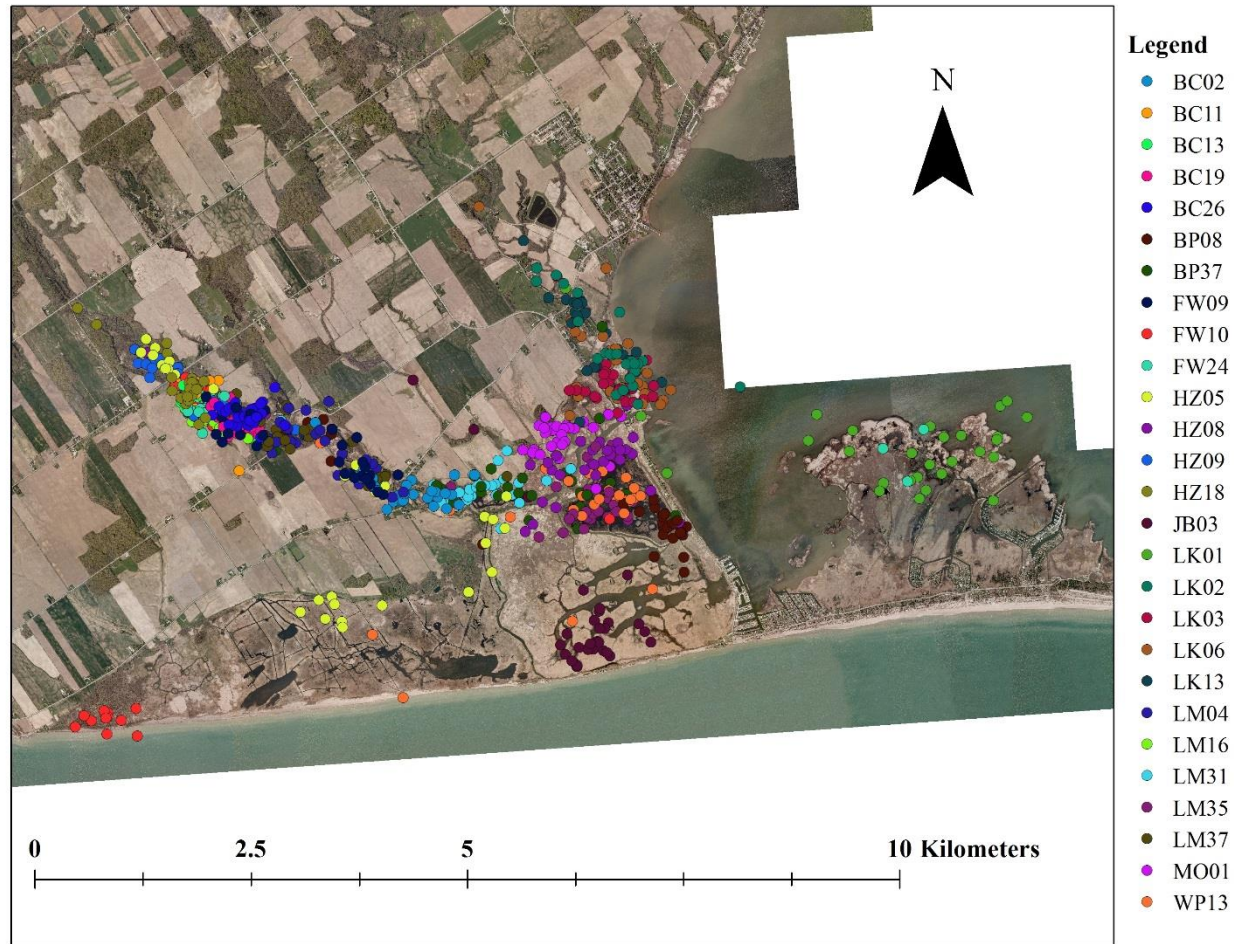
Figure 2.4. Map of all female wood duck locations to 30 days post-hatch in 2014 at Long Point, Ontario (*n* = 27). Individuals are represented by different colours and identified in the legend.

2.3.2 Movement

I detected no difference in movement for female wood ducks and broods between the first 15 days post-hatch and final 15 days for all defined measures of movement; therefore, I pooled the movement data over the full brood-rearing period (see Appendix F, Appendix G). Females that lost broods (X = 16.64 m, SE = 1.72), on average, moved 5.77 km further than females with broods (X = 10.87 km, SE = 1.0 km) over the rearing period, moved 200 m further daily (X = 573 m, SE = 60 m) compared to females with broods (X = 373 m, SE = 33 m), displaced themselves 2 km further from their nests (X = 3.38 km, SE = 0.51 km) compared to brood-rearing females (X = 1.29 m, SE = 0.27 m), and had home-ranges 3.5 km^2 larger (X = 4.6 km^2, SE = 1.0 km^2) than females with broods (X = 1.08 km^2, SE = 0.22 km^2). However, females that lost broods at 30 days post-hatch had no detectable difference in primary movement (X = 792 m, SE = 205 m) compared to females with broods at 30 days post-hatch (X = 781 m, SE = 156 m).

2.3.3 Habitat Selection

I detected that habitat selection was occurring for wood ducks during brood-rearing (l_{Wilks} = 0.068, $P < 0.01$, Figure 2.1). Female wood ducks showed the strongest selection for swamps (4.51, 90% CI = 2.86 – 6.17), followed by scrub-shrub (2.44, 90% CI = 1.95 – 2.93) and emergent marsh (2.05, 90% CI = 1.52 – 2.57) habitat types (Figure 2.5, Table 2.1, Table 2.2). Females used agricultural (0.18, 90% CI = 0.13 – 0.24) and urban (0.13, 90% CI = 0.01 – 0.26) habitat types proportionally less than available (Figure 2.5, Table 2.1, Table 2.2). Females showed no selection for forest (0.87, 90% CI = 0.58 – 1.17) or open water (0.81, 90% CI = 0.47 – 1.15) habitats, indicating that they are used in proportion to availability (Figure 2.5, Table 2.1, Table 2.2).
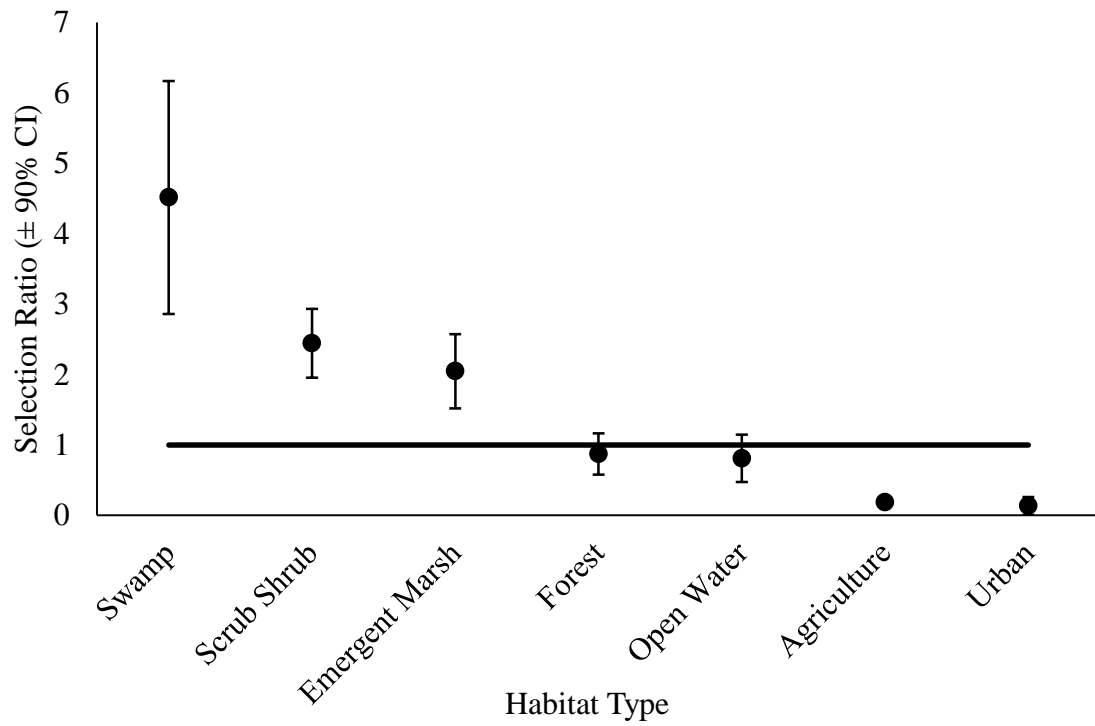
Figure 2.5. Selection ratios of brood-rearing female wood ducks to 30 days post-hatch in 2014 at Long Point, Ontario (*n* = 27). Bars represent 90% confidence intervals. The solid horizontal line indicates habitats used in equal proportion to availability, or no selection occurring.

Table 2.1. Mean percentages of used and available habitats for female wood ducks and ducklings to 30 days post-hatch in 2014 at Long Point, Ontario (X (SE), $n = 27$).

Habitat	Urban		Agriculture		Forest		Open Water		Emergent Marsh		Scrub-Shrub		Swamp	
Used	0.31	(0.13)	7.82	(1.08)	3.82	(0.71)	17.10	(3.64)	40.29	(3.63)	17.52	(2.08)	13.13	(2.62)
Available	2.32	(0.23)	42.46	(3.89)	4.38	(0.71)	21.10	(4.09)	19.68	(1.88)	7.17	(0.50)	2.91	(0.52)

Table 2.2. Log-ratio differences between used and available habitats for female wood ducks and ducklings to 30 days post-hatch at Long Point, Ontario ($n = 27$).[a]

Habitat Type	Urban	Agriculture	Forest	Open Water	Emergent Marsh	Scrub-Shrub	Swamp
Urban	0	-3.67*	-4.98*	-5.52*	-6.27*	-6.17*	-6.30*
Agriculture	3.67*	0	-1.30*	-1.84*	-2.60*	-2.50*	-2.62*
Forest	4.98*	1.30*	0	-0.54	-1.29*	-1.19*	-1.32*
Open Water	5.52*	1.84*	0.54	0	-0.75*	-0.65	-0.78
Emergent Marsh	6.27*	2.60*	1.29*	0.75*	0	0.10	-0.03
Scrub-Shrub	6.17*	2.50*	1.19*	0.65	-0.10	0	-0.13
Swamp	6.30*	2.62*	1.32*	0.78	0.03	0.13	0
Rank[b]	7	6	5	4	2	3	1

[a] Habitats in rows are to be compared to habitats in columns, positive values indicate greater selection for a habitat relative to another and * indicates significance from t-tests of log-ratios ($\alpha = 0.1$).

[b] Rank is based on the sum of the positives in each row. Lesser values indicate increased selection for a habitat.

Habitat selection did not differ by female age ($\lambda_{Wilks} = 0.726$, $F_{6,20} = 1.26$, $P = 0.320$), brood survival status ($\lambda_{Wilks} = 0.750$, $F_{6,20} = 1.11$, $P = 0.389$), or hatch date ($\lambda_{Wilks} = 0.670$, $F_{6,20} = 1.64$, $P = 0.188$) (Table 2.3). Females at Big Creek showed lesser selection for swamp habitat than females that nested at Other ($\lambda_{Wilks} = 0.533$, $F_{6,20} = 2.92$, $P = 0.033$) (Table 2.3). All other selection ratios for habitat types did not differ between nest locations ($P > 0.10$; Table 2.3).

Table 2.3. Selection ratios for habitat types by nest location with MANOVA results (X (SE), $\lambda_{Wilks} = 0.533$, $F_{6,20}=2.92$, $P = 0.03$).

Habitat Type Nest Location	Urban		Agriculture		Forest		Water		Marsh		Scrub-Shrub		Swamp	
Big Creek ($n = 20$)	0.12	(0.05)	0.20	(0.03)	1.23	(0.33)	5.04	(2.03)	2.48	(0.23)	1.95	(0.25)	2.59	(0.35)
Other ($n = 7$)	0.05	(0.04)	0.18	(0.05)	0.78	(0.25)	0.74	(0.13)	1.59	(0.15)	3.28	(0.44)	9.06	(2.02)
F - statistic	-		1.06		0.93		0.31		0.66		1.85		3.05	
*P – value**	-		0.31		0.34		0.58		0.43		0.19		0.09	

*$\alpha = 0.1$

2.4   Discussion

Habitat use by females at Long Point, Ontario was not random and indicated they were selecting swamp, scrub-shrub, and emergent marsh. I determined that female wood ducks that lost broods moved, on average, 200 m further daily than females with broods, but I did not detect that these differences in movement distance influenced habitat selection. Similarities in habitat selection may indicate similarity in resources required by female wood ducks and ducklings during brood-rearing to replenish nutrients needed for reproduction. Additionally, similar habitats may be used for moulting and brood-rearing to facilitate predator avoidance. At the scale of my study, my results support that wood ducks are wetland habitat generalists, because selection did not differ among the selected wetland habitats I designated at Long Point.

2.4.1   Movement and Home-Range Sizes

It has been proposed that female ducks move to 1) obtain better resources in habitats disjunct from nesting locations, and 2) avoid predation (Davis et al. 2007). Therefore, interpretation of movement patterns is useful in the assessment of habitat selection. Additionally, an understanding of movements can help to discern cues used by females to select habitat that increase fitness. Increased movement distances may imply that cues used by females to select habitats, such as food availability, are not being met. For example, extensive movements away from nesting locations could be indicative of resource limitation and/or high predation pressures (Granfors 1996, Davis 2001).

Females with broods travelled less than females without broods, and this was likely a result of the limited mobility of ducklings. Females without broods are not constrained by parental care and are capable of flying between habitats prior to moult. In contrast, brood-rearing females must travel throughout waterways or terrestrial routes, because ducklings do not have the ability to fly during the brood-rearing period (Poysa and Paasivaara 2006). Therefore, adequate corridors, such as creeks, streams, or channels, that facilitate movement between brood-rearing habitats are required (Granfors and Flake 1999, Davis et al. 2007). A lack of corridors may isolate broods to discrete wetland units or force them to make terrestrial movements, which increases predation pressures (Granfors and Flake 1999). Connectivity is likely not an issue at Long Point because it is a diverse wetland complex with riparian wetlands being connected by Big

Creek and other drainages; however, future habitat conservation should consider the influence of connectivity as an important objective.

Females that lost broods generally moved further away from nest site locations than birds with broods. Further displacement could be a result of a female's ability to fly to alternative habitats, which may occur prior to moult, because of different resource requirements for females during that time (Thompson and Baldassarre 1988). For example, wood ducks show increasing preference for wooded wetlands as the post-breeding period progresses, likely as a function of increasing availability of food (e.g. acorns) (Thompson and Baldassarre 1988). Alternatively, further displacement could result from females leaving habitats occupied by broods, close to nesting locations, to reduce the perceived risk of predation (Davis et al. 2007). Home-range size for brood-rearing females ($X = 1.08$ km^2, SE $= 0.22$ km^2) was 3.5 km^2 smaller than females that lost broods. Relatively small home-ranges for brood-rearing females may be a result of decreased mobility (Granfors and Flake 1999), but also may be indicative of quality habitats making it unnecessary to make more extensive movements.

Limited research has been conducted on the movement patterns of pre-fledging wood ducks. A study conducted on prairie-nesting wood ducks showed that birds moved greater preliminary distances (1.5-3.5 km; Granfors and Flake 1999) than broods in my study. However, wood ducks in my study moved on average at least 4 km further in total distance than prairie wood ducks, but it is not clear what the number of days used to determine total distance moved was in the prairie study, so it is difficult to directly compare the two (i.e., total distance moved increases daily). As indicated by Granfors and Flake (1999), prairie wetlands tend to be discrete wetland units separated by agricultural fields, whereas Long Point consists of an extensive wetland complex, which likely explains differences in movement patterns. In Mississippi and Alabama, greater intra-day brood movement was positively correlated with survival; however, mean movement distances were not reported (Davis et al. 2007). This positive relationship between movement and survival may be associated with predator avoidance techniques, or the pioneering of new habitats to exploit better resources (Davis et al. 2007, 2009). Alternatively, habitats that provide adequate resources may reduce the need to move, and result in lower movement distances (Bellrose and Holm 1994, Granfors 1996).

Other factors that likely influence movement of females include brood density, and variation in water conditions. Competition for resources, increased by greater brood densities of wood ducks, or other waterfowl species, may result in females moving to exploit alternative habitats (Davis et al. 2007). Additionally, changes in water levels as a result of desiccation, flooding, or precipitation, influence the availability of habitats and presence of food (Drobney and Fredrickson 1979, Granfors and Flake 1999). It is difficult to infer a direct mechanism motivating behavioural choices for a female to move, but it seems most likely that it is strongly influenced by habitat availability.

2.4.2   *Habitat Use and Selection*

The study area included 217 ha of swamp, 579 ha of scrub-shrub, and 1736 ha of emergent marsh habitat. Swamp and scrub-shrub were the most strongly selected habitats, while emergent marsh was used most predominantly (Table 2.1, 2.2). Extensive use of emergent marsh habitat indicates its importance to wood duck broods, but is also a function of its greater availability on the landscape (see section 2.2.1, Fig 2.1, Table 2.1). Based on vegetative characteristics, my results indicate that habitat selection may be related to vertical structure present in each habitat type (Appendix G). For example, swamp habitats contain the most vertical structure, because they are characterized by woody vegetation greater than 6 m in height with crown closure greater than 50%, whereas scrub-shrub is defined similarly, with the exception of vegetation less than 6 m in height. However, I did not detect a difference between selection ratios for swamp, scrub-shrub, or emergent marsh habitats, which may indicate selection ratios were most influenced by availability, and not vertical stratification (Table 2.4).

Females showed the highest selection ratio for swamp, but it is the least available habitat on the landscape (Figure 2.2, Figure 2.5). The majority of swamp habitats within the study area are adjacent to corridors, such as Big Creek, and influenced by varying water levels, potentially further influencing availability. As a result, my estimated selection ratio for swamp may actually be biased based on varying water levels, where low levels would result in desiccation creating an overestimate of availability. Swamps provide necessary food and cover as a result of complex habitat structure (Fredrickson and Reid 1986). Conversely, swamps also may improve predator efficiency as a result of increased perch availability, and varying water levels concentrating ducklings (Davis et

al. 2009). I speculate that if predation risks are in fact higher in swamp habitats that wood ducks must perceive a benefit from swamp, perhaps of food availability.

Scrub-shrub had the second greatest selection ratio, but ranked third based on compositional analysis. Scrub-shrub often occurred adjacent to swamp habitats because of successional characteristics common to riparian wetlands (Fredrickson and Reid 1986). Mature shrubs that rise approximately 0.5-1 m above the water with spreading branches are thought to be ideal for concealment and loafing structures for wood duck broods (Bellrose and Holm 1994). Scrub-shrub habitats may also offer dense thickets of shrubby vegetation, such as buttonbush (*Cephalanthus occidentalis*), which may decrease predation risk as a result of increased escape cover (Davis et al. 2009). Wood ducks are also known to forage on swamp loosestrife (*Decadon verticillatus*), a plant common to Long Point's scrub-shrub wetlands later in the brooding period (Drobney and Fredrickson 1979).

Emergent marsh ranked second, but had the third greatest selection ratio. Emergent marsh contains vertical structure that provides protective and thermal cover, but also substrate for valuable food resources (Kaminski et al. 2006). One advantage of emergent marsh habitats may be the lack of vertical perches for avian predators (Davis et al. 2009). Most of the emergent marsh habitat at Long Point covers an expansive area (Figure 2.2, Table 2.1), which may deter some avian predators from long periods of prey searching through cattail mosaics and channels. Conversely, detectability of ducklings may be increased in marsh habitats as a result of less dense woody cover.

Forest and open water were used in proportion to their availability and this is likely a result of proximity to other selected habitats. For example, forest habitats were associated with swamp and scrub-shrub habitats as an adjacent upland component and open water often abutted emergent marsh locations used by wood ducks. Wood duck ducklings are obligate aquatic foragers and tend to avoid terrestrial habitats, with the exception of when travelling between adjacent aquatic habitats (Drobney and Fredrickson 1979, Bellrose and Holm 1994, Davis et al. 2007). Overall, there was very little use of either urban or agricultural habitats indicating little value of these habitat types to brood-rearing wood ducks. As a result, conversion of riparian habitats to agriculture or urbanization should be avoided to conserve habitats for wood duck broods

Nest site location had an influence on habitat selection ratios, indicating that nest box placement is an important consideration. Wood ducks that did not nest on Big Creek showed stronger selection for swamp habitats (Table 2.3). This phenomenon likely occurred because nest boxes associated with more agricultural and urban habitat had less access to swamp habitats within a reasonable distance that broods were found to travel. These results further support the perceived value of swamp habitats, and woody vegetation, to brood-rearing wood ducks (Bellrose and Holm 1994, Baldassarre 2014).

Habitat selection studies are intrinsically linked to the scale at which they are conducted and interpreted. While it is likely true that wood ducks are wetland generalists, I suggest that a finer scale analysis in relation to food availability may elucidate further mechanisms of habitat selection that could better indicate habitat quality. In addition to food availability, risk of predation also influences habitat selection (Matassa and Trussell 2011). Indeed, identifying what habitats wood ducks select is beneficial to management but revealing the mechanisms of habitat selection is required in future research.

2.5   Research and Management Implications

My results support past wood duck research regarding habitat use, including the importance of, and need for, swamp habitat conservation. One management objective for brood-rearing wood ducks should be maintaining aquatic movement corridors between nest locations and brood-rearing habitats. Overland movements generally cause increased predation in waterfowl so aquatic corridors should reduce overland mortality (Granfors 1996, Krapu et al. 2000, Davis et al. 2007).

Management for vertical stratification of woody vegetation in swamp and scrub-shrub wetland habitats would be beneficial. These habitats provide wood ducks with a mix of optimal food, cover, and protection from aerial predators. Unfortunately, these habitats are often ephemeral resulting in a decline in availability as the brood-rearing period progresses (Fredrickson and Reid 1986, Granfors 1996). Water control structures (e.g., berms, weirs, etc.) could be installed in swamp and scrub-shrub habitats to increase the duration of inundation, thereby increasing the availability of these selected habitats during brood-rearing. Drainage prevention and the conservation of existing swamp and scrub-shrub habitats should also be a conservation priority.

My results also indicate that future nest box placement should consider the proximity of selected habitats on the landscape. Locations where rearing habitats are distant from nesting areas, or isolated, should be avoided for nest box placement (Semel and Sherman 1995). Wood ducks do have the ability to move considerable distances to find adequate brood-rearing habitats; however, extensive movements likely increase exposure to adverse weather and predation (Granfors and Flake 1999).

Overall, brood-rearing wood ducks will most likely benefit from maintenance of a heterogeneous mixture of habitat types. Various habitats allow females to make choices based on brood requirements and environmental factors. For example, emergent marshes often have more stable water levels, mitigating the negative effects of drought. However, in wet years, flooded swamps or scrub-shrub may be preferred because of increased food availability and additional provision of escape cover. Future research should include increased periodicity of brood observations to establish better daily and habitat specific survival estimates, identify and quantify predation, and estimate food availability to better assess habitat quality.

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3 Post-hatch survival of female wood ducks (*Aix sponsa*) and ducklings at Long Point, Ontario.

3.1 Introduction

Quantifying survival is an important component in the management of any species (Leopold 1933, Silvy 2012). Waterfowl management is geared towards maintaining populations that sustain harvest, and this requires accurate estimates of vital rates (Batt et al. 1992). The breeding period is when all additions to a population occur, but also when a majority of mortality occurs, primarily to young of the year (Baldassarre and Bolen 2006). Most juvenile mortality occurs during the brood-rearing period, and particularly during the first two weeks (Krapu et al. 2000, Pietz et al. 2003). Brood-rearing females also experience increased mortality because of costs and risks associated with parental care (Dzus and Clark 1998, Krapu et al. 2000). Consequently, it is valuable to quantify female and duckling survival throughout the rearing period (Rotella and Ratti 1992*a*, Devries et al. 2003, Krapu et al. 2006, Chouinard and Arnold 2007, Davis et al. 2007).

Recruitment is the number of young being added to the autumn migration on an annual basis (Batt et al. 1992). Waterfowl populations are strongly influenced by recruitment, which is a function of the number of birds hatched, and their subsequent survival into the autumn migration (Dzus and Clark 1998, Davis et al. 2001). Traditionally, nest success has been used as an estimate of waterfowl recruitment (Simpson et al. 2005). However, nest success estimates overestimate recruitment, because brood-rearing mortality is disregarded. Consequently, duckling survival estimates provide more accurate estimates of annual recruitment.

Wood ducks (*Aix sponsa*) are obligate cavity nesters that readily nest in artificial nest boxes, making them convenient study organisms (McGilvrey 1969, Smith and Flake 1985, Hepp et al. 1989, Bellrose and Holm 1994, Davis 2001). Consequently, wood duck nesting ecology has been studied extensively (Semel et al. 1988, Hepp et al. 1989, Davis et al. 2007, Hepp and Kennamer 2012). However, the contribution of these programs to overall wood duck recruitment is inconclusive (Semel and Sherman 1995, Heusmann 2000, Davis 2001, Baldassarre and Bolen 2006). Brood-rearing ecology and survival are difficult to quantify in comparison to other waterfowl species (e.g. mallard, *Anas*

platyrhynchos; northern pintail, *Anas acuta*), because wood ducks primarily breed and nest in swamp and scrub-shrub habitats with dense vegetative cover (Ball et al. 1975). Therefore, increased knowledge of post-hatch survival helps to improve nest box and habitat conservation strategies.

Wood ducks survival has been studied previously in the southern and central United States (McGilvrey 1969, Heusmann 1972, Smith and Flake 1985, Bellrose and Holm 1994, Hartke and Hepp 2004, Davis et al. 2007), but little is known about the ecology of birds from the Great Lakes region (Dennis 1988, Mallory et al. 2002). The Great Lakes' provide substantial nesting habitat, which is close to the northern latitude of the wood duck's breeding range. Nest success and recruitment are known to vary geographically in mallards (*Anas platyrhynchos*) (Coluccy et al. 2008), but it is unknown if latitudinal differences occur for wood ducks. Consequently, knowledge of wood duck survival in the Great Lakes region could identify differences from southern populations and contribute to knowledge of North American wood duck populations.

Female wood ducks experience greater survival during incubation relative to other waterfowl, primarily because they nest in cavities (Hepp et al. 1987). In the southern portion of their breeding range, predation accounts for the majority of female mortality; however, it is negligible (Davis et al. 2001, Hartke et al. 2006). Unfortunately, little is known about female survival at northern latitudes, despite the fact that it might differ from southern latitudes. The primary reasons that it might differ are contracted breeding seasons, greater costs of migration, and differing environmental influences at northern latitudes (Hepp et al. 1989).

Waterfowl time their breeding to coincide with optimal food availability and to minimize competition (Batt et al. 1992, Baldassarre and Bolen 2006). Almost universally for waterfowl and other avian species, young that hatch earlier in the breeding season have higher survival rates (Dzus and Clark 1998, Baldassarre and Bolen 2006). Conversely, wood ducks in Mississippi and Alabama that hatched early in the season were exposed to reduced cover making them more susceptible to predation and adverse weather, resulting in lower survival rates (Davis et al. 2007). After second year females (ASY) may be better at providing parental care than second year (SY) females because

they have more experience (Hepp and Kennamer 1993, Davis et al. 2007). Waterfowl ducklings are precocial, but females provide a certain level of parental care, including predator defence (Yerkes 2000). Therefore, predation of a brood-rearing female often results in complete brood loss (Pietz et al. 2003). Brood size might also influence survival rates if larger broods are more easily detected by predators (Krapu et al. 2000, 2006). Cold temperatures and precipitation can decrease survival, because ducklings have a limited ability to thermoregulate (Krapu et al. 2000, 2006, Pietz et al. 2003, Davis et al. 2007). Additionally, habitats that have high predator densities, or limited food resources, can result in increased duckling mortality (Bellrose and Holm 1994, Granfors and Flake 1999, Hartke et al. 2006).

Investigating female and duckling survival will increase our understanding of wood duck brood-rearing ecology and management. I quantified female, brood (>1 duckling), and individual duckling survival at Long Point, ON during 2014 using Kaplan – Meier product-limit estimates. To compliment my estimates, I also modeled brood and duckling survival to 30 days post-hatch as a function of female, brood, and weather variables using an extension of Cox's proportional hazards regression. I hypothesized that wood ducks and ducklings at northern latitudes would have lower survival rates than wood ducks at southern latitudes as a result of increased costs of migration and a contracted breeding season. I predicted brood and duckling survival would be a function of female age, female mass, hatch date, initial brood size, temperature, and precipitation.

3.2 Methods

3.2.1 *Study Area*

Please see section 2.2.1. for the description of the study area.

3.2.2 *Study Design*

Please see section 2.2.2. for the description of the study design.

3.2.3 *Statistical Analyses*

Brood survival is the survival of at least 1 duckling to 30 days post-hatch, whereas duckling survival is the survival of individuals within a brood. To quantify female, brood, and duckling survival I calculated Kaplan-Meier product-limit estimates of the probability of survival to 30 days post-hatch (Kaplan and Meier 1958). I assumed that

right censoring (unknown fates) of females, broods, and ducklings following loss of their transmitter signal was independent of their fate. I also assumed that survival was not influenced by capture, handling, or radio-marking (Mauser et al. 1994, Davis et al. 1999). Finally, I assumed that females marked by staggered entry (i.e., different marking dates) had similar survival probabilities. For ducklings, I accounted for intra-brood dependence by performing 1000 bootstrap iterations (Davis et al. 2007).

　　　To model survival, I developed a set of biologically relevant covariates (Table 3.1). These variables were related to the 1) female, (i.e., age and mass), 2) the brood (i.e., hatch date and initial brood size), and 3) the environment (i.e., precipitation and temperature). Definitions of these variables, along with biological relevance, can be found in Table 3.1. I used the same suite of variables for both broods and ducklings, because the two are not independent of each other. I developed a set of biologically plausible candidate models based on the selected covariates. I developed a total of 21 candidate models for both brood and duckling survival (Appendix N, O). I used Cox's proportional hazards regression (COXPH, Package: Survival; R Development Core Team 2011) to model survival with respect to the covariates to 30 days post-hatch. For ducklings, I used an extension of the model to account for intrabrood dependence, which considers each brood as a cluster and inflates standard errors of the estimated coefficients in relation to intrabrood correlation (Johnson et al. 2004, Davis et al. 2007).

　　　To select the top model(s), I calculated Akaike's Information Criterion adjusted for small sample sizes and compared models (Burnham and Anderson 1998). I present the best models for brood and duckling survival, and made inferences from the top models, presenting coefficients, standard errors, and confidence intervals (Arnold 2010). I assessed model assumptions by looking at the Schoenfeld residuals, ensuring they were nonsignificant, indicating that hazards are proportional over time (Johnson et al. 2004).

Table 3.1. Description of variables used in candidate models to explain survival of wood duck broods and ducklings.

Variable	Variable Type	Description	Biological Relevance
Age	Nominal	Female age (SY or ASY)	Female age has been hypothesized to be important in rearing success, where older females (ASY) are better at rearing young compared to younger females (SY) (Hepp and Kennamer 1993, Yerkes 2000, Davis et al. 2001, Hartke et al. 2006).
Mass	Continuous	Mass of the female at date of marking (g)	Larger females may be better at acquiring resources, or in better condition to provide parental care post-hatch (Harvey et al. 1989, Yerkes 2000, Simpson et al. 2005).
Hatch	Ordinal	Date of hatch	Asynchronous hatch dates are known to be important evolutionary strategies. Different hatch dates may expose ducklings to different environmental conditions (Hepp et al. 1989, Dzus and Clark 1998).
BC0	Ordinal	Initial brood size, or number of ducklings hatched.	Larger brood sizes may be more detectable by predators reducing survival, or conversely result in more ducklings surviving (Davis et al. 2007).
Temp	Continuous	Mean daily low over the 30 day brood-rearing period (°C)	Ducklings are not able to thermoregulate, so cold temperatures result in increased costs of brood-rearing, potentially resulting in poor survival (Krapu et al. 2000, 2006).
Precip	Continuous	Sum of precipitation over the 30 day brood-rearing period (mm)	Precipitation may increase habitat availability, but can also increase the costs of thermoregulation (Simpson et al. 2005).

3.3   Results

3.3.1   Marking and Tracking

I marked 40 nesting female wood ducks in 2014, of which 39 successfully hatched a nest of at least 1 duckling. A total of 8 females either left the study area, or their transmitter malfunctioned before 30 days post-hatch. I observed 23 female wood ducks with broods at 15 days post-hatch, and 14 with broods at 30 days post-hatch.

3.3.2   Female Survival

I estimated female survival to be 0.897 (95% CI = 0.807 – 0.998) to 30 days post-hatch (Figure 3.1). The first female died 14 days after marking, so I assumed that transmitter attachment did not influence survival. A total of 3 females were determined to be predated through recovery of the transmitter at a kill site; however, a fourth suspected predation could not be confirmed because the transmitter was not recovered.
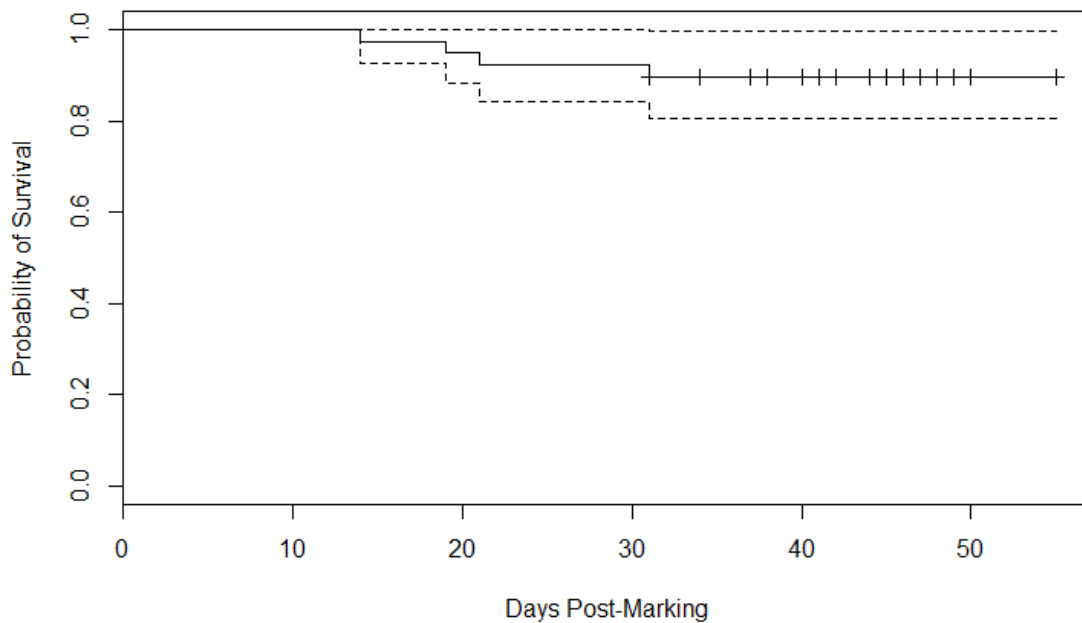
Figure 3.1. Kaplan-Meier survival estimate for female wood ducks from the marking day to the end of the 2014 study period at Long Point, Ontario. Changes in slope indicate mortality events, error bars are 95% confidence intervals, and vertical dashes are censoring events ($n = 39$).

3.3.3   *Brood and Duckling Survival*

I estimated brood survival to be 0.676 (95% CI = 0.536 − 0.853) to 15 days post-hatch, and 0.474 (95% CI = 0.327 − 0.685) to 30 days post-hatch (Figure 3.2). I estimated duckling survival to be 0.387 (95% CI =0.341 − 0.439) to 15 days post-hatch, and 0.178 (95% CI = 0.142 − 0.224) to 30 days post-hatch (Figure 3.3).
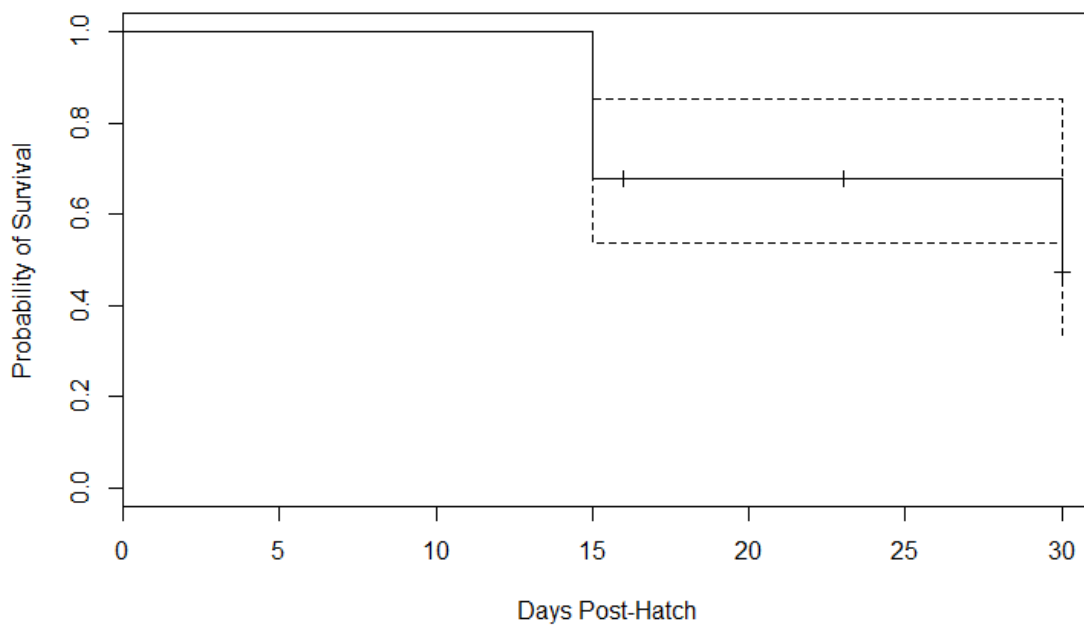
Figure 3.2. Kaplan-Meier survival estimate for broods to 30 days post-hatch in 2014 at Long Point, Ontario. Hashed lines represent 95% confidence intervals, and vertical dashes are censoring events ($n = 34$).
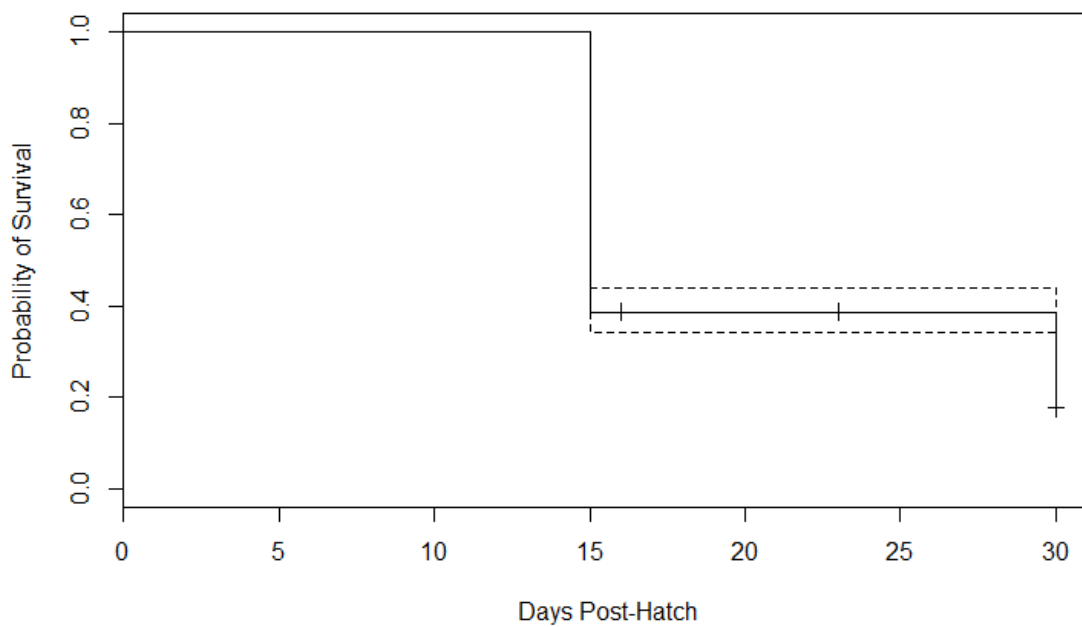
Figure 3.3. Kaplan-Meier survival estimate for ducklings to 30 days post-hatch in 2014 at Long Point, Ontario. Hashed lines represent 95% confidence intervals, and vertical dashes are censoring events (*n* = 380).

3.3.4   Survival Models

Confidence intervals for female survival were close to 1 (Upper 95% CI = 0.998) during the brood-rearing period. Therefore, I did not model female survival as a function of the covariates, because there were too few mortality events to model. Prior to running the candidate models, I investigated possible correlations between the covariates. I identified a strong correlation between hatch date and mean daily low temperature. I performed linear regression on these two variables and found a positive relationship with hatch date accounting for 78% of the variation in temperature (Appendix I). As a result, I removed the temperature variable from all candidate model sets because of its relationship with hatch date (Burnham and Anderson 1998, Zuru et al. 2007).

I selected one top model that best predicted brood survival to 30 days post-hatch. Brood survival was best explained by the model containing hatch date and precipitation (Table 3.2). There were 2 alternative competing models (i.e., within 2 ΔAIC_c); however, I chose the Hatch + Precip model based on the principle of parsimony, because it explained the most variation with the least number of terms (Pietz et al. 2003, Arnold 2010). Duckling survival was also best explained by one model containing female age, female mass, and initial brood size (Table 3.3). Competing models are also presented in the table and I selected the top model based on the principal of parsimony. To note, a fully parameterized model (including all covariates) was included among the top models for both brood and duckling survival.

Table 3.2. Competing models for brood survival to 30 days post-hatch in 2014 at Long Point, ON. Models are from the candidate model set selected using AIC_c[a].Table includes model description, number of parameters (K), Log-likelihood (LL), Akaike's Information Criterion adjusted for small sample sizes (AIC_c), the change in AIC_c compared to the best model (ΔAIC_c), and Akaike weights (w_i).

Model[b]	K	LL	AIC_c	ΔAIC_c	w_i
Hatch + BC0 + Precip	5	-48.47	103.75	0.00	0.23
Hatch + Precip	**3**	**-49.93**	**104.25**	**0.50**	**0.18**
Age + Mass + Hatch + BC0+ Precip	5	-46.38	104.91	1.16	0.13
Mass + Precip	2	-51.08	106.55	2.80	0.06

[a]See appendix N for full candidate model set

[b]Model in bold was selected as the top model

Table 3.3. Competing models for duckling survival to 30 days post-hatch in 2014 at Long Point, ON. Models are from the candidate model set selected using AIC_c[a]. Table includes model description, number of parameters (K), Log-likelihood (LL), Akaike's Information Criterion adjusted for small sample sizes (AIC_c), the change in AIC_c compared to the best model (ΔAIC_c), and Akaike weights (w).

Model[b]	K	LL	AIC_c	ΔAIC_c	w_i
Age + Mass + Hatch + BC0+ Precip	5	-1571.32	3152.80	0.00	0.43
Age + Mass + BC0	**3**	**-1572.39**	**3152.83**	**0.04**	**0.42**
Age + Mass + Hatch + BC0	4	-1573.36	3154.82	2.02	0.16

[a]See appendix O for full candidate model set

[b]Model in bold was selected as the top model

I present coefficients, along with standard errors, 95% confidence intervals, and hazard ratios for the best models explaining brood and duckling survival (Table 3.4 and Table 3.5). For covariates, a positive coefficient indicates an increased risk of mortality with a unit increase in the predictor, whereas a negative coefficient indicates an increased risk of mortality with a decrease in the predictor. Hazard ratios are an exponent of the coefficient; for example, a one unit (day) increase in hatch date results in a 1.08 (95% CI $= 1.00 - 1.17$) times greater risk of mortality for a wood duck brood (Table 3.4).

Table 3.4. Beta coefficient (β), standard error (SE), 95% confidence intervals (LCI, UCI), and hazard ratio for the brood survival model.

Variable	β	SE	Hazard	LCI	UCI
Hatch	0.08	0.04	1.08	1.00	1.17
Precip	-0.05	0.02	0.95	0.91	0.99

Table 3.5. Beta coefficients (β), standard errors (SE), hazard ratios, and 95% confidence intervals (LCI, UCI) for the duckling survival model.

Variable	β	SE	Hazard	LCI	UCI
Age (SY)	-0.76	0.34	0.47	0.24	0.92
BC0	0.15	0.04	1.17	1.07	1.27
Mass	-0.009	0.002	0.991	0.985	0.996

For brood survival, I estimated that later hatch dates were associated with a greater risk of mortality (Table 3.4). I also estimated that greater amounts of precipitation during the 30 day brood-rearing period resulted in a decreased risk of mortality (Table 3.4). For duckling survival, I estimated that increasing brood size resulted in a greater risk of mortality, while an increase in female mass resulted in a decreased risk of mortality (Table 3.5). Additionally, ducklings of SY females had a decreased risk of mortality relative to ducklings reared by ASY females (Table 3.5).

3.4   Discussion

3.4.1   Female Survival

High female survival during the brood-rearing period has been observed at numerous locations throughout the wood duck's breeding range (0.90, 95% CI = 0.78-1.0 – Davis 2001 (30 days post-hatch), 0.99, 95% CI = 0.98-1.0 – Hartke and Hepp 2004 (daily), 0.85 ± 0.04 ($X \pm SE$) – LeMaster and Trost 1994). My study confirms that survival is similar at northern breeding latitudes and provides credence to assuming a high rate of female survival during the brood-rearing period across breeding latitudes for future wood duck survival models. It is estimated that annual survival of wood duck females is 50%, therefore, most annual mortality occurs outside of the brood-rearing period and warrants future investigation (Bellrose and Holm 1994, LeMaster and Trost 1994). Mortality occurring within the rearing period has been attributed to predation in other studies (Davis et al. 2001, Hartke et al. 2006). Predators likely responsible for female wood duck mortality were northern raccoons (*Procyon lotor*), great horned owls (*Bubo virginianus*), or red-tailed hawks (*Buteo jamaicenis*), based on field observations of these species in the study area and from past research (Davis et al. 2001, 2009).

3.4.2   Brood and Duckling Survival

Brood survival in my study (0.47, 95% CI = 0.33-0.69) was similar to other studies considering confidence intervals (0.64, 95% CI = 0.54-0.73 – Davis 2001; 0.82, 95% CI = 0.43-1.0 – Granfors 1996). Duckling survival estimates (0.18. 95% CI = 0.14-0.22) were also similar to other studies (0.21, 95% CI = 0.15-0.28 – Davis 2001; 0.35 (no CI reported) – Granfors 1996). Mallard (*Anas platyrhynchos*) brood and duckling survival on the prairies were observed to be 0.49 (range = 0.34 – 0.70) and 0.22 (range = 0.16 –

0.26), respectively (Rotella and Ratti 1992*a*). Additionally, mallard duckling survival at the Great Lakes was reported to be 0.47 (SE = 0.03) (Simpson et al. 2005). Survival of northern pintail (*Anas acuta*) broods and ducklings ranged from 0.72-0.88 and 0.42-0.65 across years, respectively (Guyn and Clark 1999). Gadwall (*Anas strepera*) brood survival was estimated at 0.84 (SE = 0.05), while duckling survival was 0.44 (SE = 0.04) (Pietz et al. 2003). Overall, survival estimates for my study appear relatively consistent with survival estimates of other species to 30 days post-hatch. My estimates of duckling survival, although more consistent with mallards, do appear lower than in pintails, or gadwall, and therefore could be influencing recruitment.

3.4.2.1 *Brood Survival*

Risk of brood mortality increased with hatch date and this is consistent with many previous studies (Dzus and Clark 1998, Guyn and Clark 1999, Krapu et al. 2006). Conversely, in Mississippi, wood duck duckling mortality was found to decrease with hatch date (Davis et al. 2007). Behavioural differences of southern wood ducks, such as double brooding and extended breeding periods, are likely responsible for this relationship (Hepp et al. 1989). For example, if a female double broods it may reduce the parental investment in the first (early) brood to begin incubating the second clutch, therefore, reducing the probability of early brood survival. Reduced parental investment for early broods could expose ducklings to harsh weather during cold periods and increase the probability of predation, because ducklings likely have a reduced ability to perceive risk (Stafford et al. 2002, Krapu et al. 2006).

Brood survival also increased with increasing precipitation. I suspect the positive relationship between precipitation and brood survival is related to increased habitat availability. Many habitats within the study area are in floodplains, and increased precipitation often results in overflow of the creek, creating more riparian wetland habitats for wood ducks. Additionally, higher early season survival may be related to increased wetland availability and less competition from conspecifics (Granfors 1996, Krapu et al. 2000). In spring, seasonally inundated wetlands are often full of water from spring melt, creating more habitat to exploit, effectively reducing competition and the concentration of ducklings (Krapu et al. 2000). Increased habitat availability results in an increased abundance of prey, such as invertebrates, which is known to increase survival

(Drobney and Fredrickson 1979). As the rearing period progresses, these wetlands dry up, creating a concentration effect whereby ducklings are forced to congregate on remaining wetlands. Alternatively, selected habitats (e.g., swamp and scrub-shrub) often dry out, forcing females to revert to emergent marsh and open water habitats with less escape cover. As a result, predators are likely better at detecting ducklings, and successfully capturing them (Davis et al. 2009).

Competition for resources also increases as the rearing period progresses, because the number of conspecific ducklings and those from other species increases (Granfors 1996, Davis 2001). Higher brood densities also increase, intraspecific and interspecific, duckling interactions resulting in brood mixing and straying, as well as adult combat, which all result in lower duckling survival (Batt et al. 1992). Finally, the number of predators on the landscape and demand for prey increases as the season progresses, resulting in an increased risk of mortality (Amundsdon and Arnold 2011).

3.4.2.2   Duckling Survival

The risk of duckling mortality was greater for ASY females relative to SY females, increased with brood size, and decreased for females with greater mass. Increased mortality for ducklings of ASY females relative to SY females is contrary to past wood duck research, and waterfowl research in general (Davis et al. 2007); however, some studies have found no effect of female age on duckling survival (Guyn and Clark 1999, Krapu et al. 2000). Wood ducks nesting for the first time (SY) have been shown to nest later than ASY females potentially resulting in reduced duckling survival (Hepp and Kennamer 1993), but there was no difference in hatch dates between SY and ASY females for my study. I speculate that my results may be explained by increased reproductive efforts by ASY females during nesting, resulting in reduced parental investment during brood-rearing (Yerkes 2000). Alternatively, investment of SY females may have been greater during brood-rearing, because of more energy available post-hatch (i.e., females in better condition at the end of incubation invest more energy in brood care resulting in greater offspring survival) (Afton 1984, Hepp et al. 1987, Batt et al. 1992, Hepp and Kennamer 1993). Additionally, wood duck ducklings are known to be more independent at an early age, therefore, the potential of observing lost ducklings, or brood loss, at 30 days may not have been a result of mortality (Bellrose and Holm 1994).

Finally, I only collected duckling survival data for one year, therefore, this relationship could be a result of a year effect.

I suggest that increasing duckling survival for SY females is related to initial brood size. Second year females had smaller brood sizes compared to ASY females in my study and larger broods had a greater risk of mortality. Larger broods may be more detectable and vulnerable to predators (Dzus and Clark 1997). Initial brood size is inherently correlated with clutch size, because larger clutch sizes generally hatch more ducklings. Clutch size decreases across the breeding period and may be an adaptive trait to lower duckling survival later in the period (Pietz et al. 2003, Davis et al. 2007). For example, a female may lower her reproductive output in relation to a perceived risk of greater mortality in larger broods later in the season. I suggest the relationship between female age, clutch size, and duckling survival warrants further investigation.

Heavier females also experienced the greatest duckling survival, which could be a result of their increased capacity to acquire resources (Yerkes 2000). In contrast, light females had high duckling survival in Mississippi and Alabama, which was attributed to easier movement throughout habitats (Davis et al. 2007). The relationship to female mass may be concealed by high food availability (i.e., high quality habitat) post-hatch, because the advantages of a greater lipid reserve would not be realized if resource acquisition was easy. Wood ducks breeding at their northern range complete a long migration prior to breeding, and gain all the energy required for egg production on the breeding grounds (Hartke et al. 2006, Hepp and Kennamer 2011). Moreover, females need to regain energy stores post-hatch in preparation for the fall migration. Therefore, I suggest that females at southern latitudes may not need to gain as much mass as a result of differing migration strategies, resulting in different relationships between mass and offspring survival.

I excluded temperature from my models because it was highly correlated with hatch date (Appendix M.). Temperature increased with hatch date; therefore, ducklings that hatched later were exposed to warmer temperatures relative to ducklings hatched earlier. Past research has indicated that ducklings exposed to colder temperatures have a higher risk of mortality (Krapu et al. 2000, 2006, Davis et al. 2007). I found the opposite relationship, where ducklings in warmer temperatures had a higher risk of mortality. I believe that this relationship was spurious, in that survival was more associated with

hatch date than temperature. Alternatively, increasing temperatures have been associated with reduced habitat quality promoting algal blooms and increasing the abundance of parasites in small wetlands potentially influencing duckling survival (Ma et al. 2010). Temperature extremes could have some influence on survival; however, it seems that its effect is minimal in this system (Krapu et al. 2006, Howerter et al. 2014).

Predation is possibly the strongest driver of brood and duckling survival but I was unable to quantify it. For example, predators are a major direct mortality factor, but predator avoidance also results in reduced feeding opportunities, as well as water-soaking of feathers from diving, which could be linked to the negative effects of cold temperatures (Bellrose and Holm 1994). However, quantifying predation is a difficult task, particularly when multiple predators exist on the landscape (e.g., northern raccoon (*Procyon lotor*), great-horned owl (*Bubo virginianus*), red-tailed hawk (*Buteo jamaicensus*), great blue heron (*Ardea herodias*), common snapping turtle (*Chelydra serpentine*), and pike (*Esox* sp.)) (Davis et al. 2009). Knowledge of the influence of predators on movement, habitat selection, and duckling survival is necessary to provide a better understanding of wood duck breeding ecology. Future research should seek to understand predation rates, and types, across various habitats.

Other possible covariates I could have included were movement and habitat use in relation to survival; however, because of my observation intervals I was not able to associate mortality events with specific movement metrics or habitat types. Annual variation in reproductive success relative to predators, wetland conditions, and food abundance is one of the most important research needs for understanding wood duck recruitment, but remains elusive due to the logistical constraints and scope of data collection required for these studies (Dzus and Clark 1998, Davis 2001).

3.5   Research and Management Implications

Female survival was determined to be high, but brood and duckling survival were low. Wood ducks are philopatric and female ducklings often return to within 1.5 km of their natal site (Hepp et al. 1989). Therefore, low duckling survival may result in low nest box occupancy at Long Point in subsequent years limiting the efficiency of nest box programs, but this requires further study.

Future nest box management should seek to erect boxes in densities and locations that deter large clutch sizes because of increased risk of mortality in large broods (Granfors 1996, Davis et al. 2007). Fewer, strategically and inconspicuously, placed boxes may result in reduced levels of conspecific brood parasitism (CBP), and the CBP has the potential of inflating clutch sizes in wood ducks (Semel et al. 1988, Semel and Sherman 1995).

Habitat management may also be used to increase brood and duckling survival and potentially enhance recruitment. Increased water levels have been shown to increase habitat availability and accessibility of selected habitats for wood ducks, which may also provide additional cover to escape predators. The installation of water level control structures to increase the availability of scrub-shrub and swamp habitats, may increase survival because these habitats often desiccate prior to the completion of the brood-rearing period. For example, many waterfowl species experience lower survival in drought years as a result of reduced habitat availability, which increases competition and concentrates ducklings (Krapu et al. 2000). Therefore, water level management in seasonally inundated riparian wetlands may buffer this effect for wood duck ducklings.

3.6   References

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4   General Discussion

My study revealed patterns of movement and habitat selection of female wood ducks during the brood-rearing period, as well as quantified survival of females, broods, and ducklings at Long Point, ON. Female wood ducks are able to use a variety of wetland habitats to satisfy their requirements during brood-rearing (Bellrose and Holm 1994, Baldassarre 2014). My results confirm that some drivers of survival are different between southern and northern populations of wood ducks (e.g. hatch date, female age). My results also support other studies of waterfowl species that investigated factors related to survival (e.g., brood size) (McGilvrey 1969, Rotella and Ratti 1992*b*, Dzus and Clark 1998, Granfors and Flake 1999, Davis et al. 2001, 2007). Finally, my results indicated that there may be a causal link between survival and selected habitat at Long Point; however, it is difficult to make direct inference here because of my method of data collection.

Past research on wood duck brood movement has associated longer movements with increased survival of ducklings (Granfors and Flake 1999, Davis et al. 2007). The mechanisms for this pattern have not been determined; however, it has been speculated to be related to predator avoidance, and resource exploitation (Granfors and Flake 1999, Davis et al. 2007). Wood ducks appear to leave their nesting areas to relocate to brood-rearing areas, and are often observed to pass other seemingly appropriate rearing areas (Smith and Flake 1985, Bellrose and Holm 1994). Wood ducks may leave nesting areas in response to a perceived threat of predation because nesting areas are often dense aggregations of boxes where predators may be able to key on increased prey densities (Davis 2001). Additionally, brood-rearing areas may be predetermined by females through sampling during incubation, or as areas where they were previously reared (Hartke and Hepp 2004).

I conclude that low duckling survival during the brood-rearing period may be resulting in low recruitment at Long Point. I could not establish a link between survival and habitat use, but it seems likely that selected habitats do provide some fitness benefit. The breeding ecology of wood ducks seems to play a significant role in post-hatch survival. Date of hatch and initial brood size were predictors of survival and merit further

investigation of cost/benefits of each to the ecology and evolution of the wood duck. I also speculate that predation accounts for the majority of duckling mortality, and should be further investigated to inform management. Low recruitment may result in low box occupancy, which may be a function of low duckling survival; however, this relationship must be further investigated.

4.1 Study Limitations

Here I would like to acknowledge some of the limitations to my study design and identify some possible improvements. These limitations are related to my marking techniques, tracking, data collection, and data analysis.

Numerous research efforts have documented the effects of marking waterfowl, and my method, in congruence with recommendations from the American Ornithologists Union (AOU), exceeded animal care standards (Mauser and Jarvis 1991, Davis et al. 1999, Brook et al. 2002, Hepp et al. 2002). It would be naïve to assume that marking an individual had no effect on its behaviour, and ultimately survival. However, for my study, I am confident that my marking technique had no substantial effect on behaviour, or survival, for a few reasons. First, the first female mortality during the rearing period occurred 14 days after marking, which is a considerable amount of time for healing and adjustment for the bird to life with the transmitter. Second, only two nests of the birds marked were determined to not successfully hatch, and one of those females successfully nested and hatched a nest (personal observation). Last, I have evidence of returning females nesting that were marked in previous years, including some retaining their transmitter (personal observation).

A marking technique that would have improved this study is individually marking a subsample of ducklings from selected broods. Marking individuals allows for a more accurate assessment of individual survival, as well as determination of cause-specific mortality in relation to transmitter recoveries. Furthermore, wood duck ducklings have been known to exhibit brood amalgamations as well as independence at an early age (i.e., before 30 days) (McGilvrey 1969, Davis et al. 2007). Individually marking ducklings would allow researchers to assess the degree of amalgamation, as well as survival of

ducklings that leave their mother before 30 days post-hatch. For my study, I therefore stress that my estimation of duckling survival is likely conservative.

Radio-telemetry has greatly improved our ability to understand animal movement and ecology; however, the limitations to each study are unique in relation to the research question and level of equipment sophistication (White and Garrot 1990). The truck-mounted null peak antenna system used in my study allowed for accurate triangulations and location estimations on a daily basis. However, I do conclude that more accurate location can be taken with multiple vehicles estimating simultaneous bearings to reduce the influence on movement between concurrent estimations (Murray 2006). For example, in my study, all bearings were taken less than 15 minutes apart, allowing for some movement to occur and increasing error ellipses.

Additionally, increased observations of ducklings during the rearing period would allow for a better understanding of critical survival intervals, as well as covariates that may influence survival. For example, because I observed broods at 15 and 30 days post-hatch, and derived survival estimates from those observations, it is difficult to assign cause-specific mortalities related to some variables (e.g. habitat use). Increasing the observation intervals would allow better inferences of duckling survival; however, it may also increase disturbance, so caution should be taken when designing future studies.

My study was also limited to one year of data collection as a result of a failed pilot season; however, my sample size appears to be sufficient to satisfy my research objectives. Previous studies have identified annual differences in habitat use and selection, often as a result of changing habitat availability in relation to climatic factors (Krapu et al. 2006, Chouinard and Arnold 2007). Therefore, researchers seeking to understand how habitat selection may change over time should conduct studies over multiple years to account for yearly variability.

4.2 Future Research

Future research that would enhance the outcomes of studies similar to mine would include measuring vegetation characteristics, such as species composition and percent cover, as well as quantifying water level fluctuations that influence habitat availability temporally. It would also prove beneficial to management to determine if differences

exist in habitat use and survival of wood ducks that use nest boxes versus those that nest in natural cavities. I recommend that the development of a resource selection function based on data from multiple wood ducks across time and at different locations would benefit wood duck management greatly. Additionally, web-tagging ducklings, or using genetics, may assist in better understanding duckling recruitment from the box nesting population at Long Point.

Further avenues of research related to the management of wood duck nest box programs are investigating conspecific brood parasitism (CBP), experimental nest box manipulations to enhance placement strategies, and quantifying predator-prey dynamics. Past research has concluded that CBP is a natural behaviour in wood ducks, and often observed at relatively high levels; however, with increased risk of mortality to large broods, it is important to understand how management might be influencing this phenomenon (Semel et al. 1988, Semel and Sherman 2001, Roy Nielsen et al. 2006).

Nest box placement strategies should also be considered in relation to wood duck production, but also in terms of cost to management (Semel and Sherman 1995, Davis 2001). Thresholds of nest box densities that prove to be beneficial to wood duck production should be established across the breeding range. Furthermore, cost-benefit analysis of duckling production can put an economic value on production, which would assist managers in making decisions about management intensities (Davis 2001, Davis et al. 2015). Additionally, understanding the influence of nest box competition, particularly of species such as the European starling (*Sturnus vulgaris*), may benefit future nest box placement strategies.

It has been indicated in the literature that quantifying trends in predation and determining predators that might be detrimental to wood ducks are crucial to management (Davis 2001). It is also widely known that predator-prey interactions have an influence on the movement and distribution of individuals on the landscape, and more recently, it is understood that the threat of predation may influence the behaviour and reproduction of organisms (Matassa and Trussell 2011). It therefore seems appropriate that future research include a measure of predation in relationship to habitat selection and survival.

4.3   References

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Appendices

Appendix A. Western Animal Care Protocol

AUP Number: 2014-007
PI Name: Petrie, Scott
AUP Title: Survival, Habitat Use, And Movement Patterns Of Female Wood Ducks (*Aix sponsa*) And Broods At Long Point, On.
Approval Date: 06/06/2014

Official Notice of Animal Use Subcommittee (AUS) Approval: Your new Animal Use Protocol (AUP) entitled "Survival, Habitat Use, And Movement Patterns Of Female Wood Ducks (*Aix sponsa*) And Broods At Long Point, On." 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.2014-007::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

Appendix B. OMNRF Animal Care Protocol

ONTARIO MINISTRY OF NATURAL RESOURCES

WILDLIFE ANIMAL CARE COMMITTEE
RESEARCH PROTOCOL APPLICATION

START DATE 1 March, 2013 COMPLETION DATE 31 Dec., 2015s
Submit TWO MONTHS before start date

Protocol Number 13-304 ☐ New ☐ Amendment

This project has been submitted to: ☑ MNR District Office
☐ Ontario Parks
☐ Species at Risk

Category **C**

A:	Experiments on most invertebrates or on live isolates (ie Observational Studies)
B:	Experiments which cause little or no discomfort (ie No Capture or Handling)
C:	Experiments which cause minor stress or pain levels (ie Capture/ PIT tagging/Notching/Tissue Samples)
D:	Experiments which cause moderate to severe distress or discomfort (ie Surgery/Pursuit)
E:	Procedures which cause severe pain, at, or above pain threshold of unanesthetized conscious animals (ie Toxicity Studies)

Project Title: Habitat selection and survival of Wood Duck hens and broods during spring and summer in the Big Creek watershed, Long Point, Ontario

Objective: To develop best management practices for sustaining the carrying capacity of wetland habitats in southern Ontario for breeding wood ducks we will determine; 1) use of wood duck nest boxes, 2) availability and use of natural cavities, and 3) habitat dependent survival of wood duck hens and broods in the Big Creek watershed in the Long Point region.

Max Char 420
Count 350

Principal Investigator: Dr. Scott Petrie
Company Affiliation: Long Point Waterfowl
Branch:
Address:

Secondary Investigator(s): Dr. Michael Schummer and Ted Barney
Company Affiliation: Long Point Waterfowl
Branch:
Address:

Target Species

Wood Duck	Number(s) to be handled	100 (50)
	Number(s) to be handled	
	Number(s) to be handled	

Location(s) of Projects (Municipality/MNR District)
Big Creek Watershed - Aylmer District

☑ Research ☐ Management ☐ Teaching

Type of Research:	☐ Non-Invasive	☐ Invasive	☑ Surgery	
Stress Level:	☐ Nil	☐ Low	☑ Moderate	☐ High
Pain Level:	☐ Nil	☐ Low	☑ Moderate	☐ High
Drugs:	☑ Anaesthetic	☐ Analgesic	☐ Other	
Samples:	☐ Blood	☐ Tooth	☐ Hair / Feather ☐ Tissue	☐ Other

Capture and Handling

Chase Method: ☐ Aircraft/Helicopter ☐ Snowmobile ☐ Powerboat ☑ Other

Animals to Be: ☑ Released at capture site ☐ Transported & Released ☐ Long Term Captive ☐ Terminated

Traps: ☐ Lethal ☐ Leg Snare ☐ Mist Net ☑ Live Trap [nest box captu] ☐ Net Gun ☐ Other

Marking Method ☐ PIT Tag ☐ Fur/Feather Clip ☐ Dye ☐ Tattoo ☑ Other [radio transmitter]

Device fixed to Animal: ☐ Radio Collar ☑ Leg Band ☑ Implanted Tag ☐ Other [~6g subcutanous impla]

Lay Summary:

Max Char 840

Count 833

JUSTIFICATION: In the late 19th century the number of wood ducks decreased across North America largely due to excessive logging that reduced tree cavities for nesting and artificial nest boxes have been used to provide adequate breeding habitat . Conservation programs aimed at increasing habitat also have increased availability of tree cavities in many areas to a density that artificial nest boxes are no longer needed to sustain populations OBJECTIVES: Determining use of nest boxes, availability and use of natural tree cavities, and habitat dependent survival of wood duck hens and broods. PROCEDURES: We intend to use nesting assessments (natural and nest boxes) and radio-transmitter marking and tracking of wood duck hens to develop information on best management practices for breeding wood ducks in southern Ontario.

Declaration:

All animals used in this research will be cared for in accordance with the recommendations of the Canadian Council on Animal Care and the requirements under the Animals for Research Act, (Ont. 1980).

By submitting this form I hereby indicate my agreement not to make major changes to the research procedures without obtaining approval of a new Animal Use Protocol from the MNR WACC. I also affirm that I understand that no work may be performed prior to approval of this protocol by the MNR WACC.

NOTE: I understand that portions of this protocol may be used to develop a **"Standard Species Protocol"** to be used by other researchers.

For electronic submissions please sign below and scan, or check box:

☑ I, as principal investigator, am responsible for the information submitted.

|	30 January, 2013
or)	Date Submitted

The project described in this protocol is approved under the terms of the Animals for Research Act, (Ont. 1980)

Sarah Crosgrey	March 12, 2013
Approved by	Date Approved

Appendix C. Technical specifications for prong and suture transmitters used for marking female wood ducks ($n = 40$, ATS Model 4410)

AVIAN PRONG & SUTURE
Series A4400

ATS
ADVANCED TELEMETRY SYSTEMS
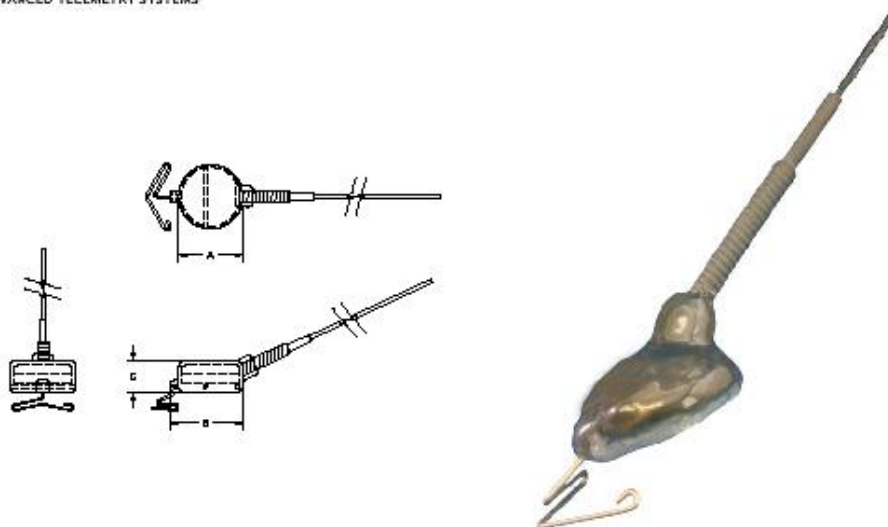
Technical Specifications

Transmitter type:	Crystal controlled 2-stage
Calibration tolerance:	± 2.5kHz
Frequency stability:	± 2.5kHz, -20°C to 40°C
Pulse rate and width:	Typical on time 20ms, off time 1100ms (controlled by uC)
Pulse rate variation:	0.01%/volt, ± 0.01% for temperatures −20°C to +40°C
Battery:	Lithium
Activation:	By removing magnet
Encapsulation:	Electrical resin, water-proof, specific gravity: 1.12

MODEL	BATTERY	BATTERY CAPACITY (days)			DIMENSIONS (mm)			WEIGHT (grams)	PRICE GROUP
	3.0V	35 ppm*	40 ppm	55 ppm	A	B	C		
A4410	2016	90	62	46	23	26	8	7.5	D
A4420	2025	166	114	84	23	26	9	8.4	D
A4430	2032	221	152	113	23	26	10	9.0	D
A4440	2430	229	169	130	27	30	12	11	D
A4450	2354	445	328	253	26	29	14	13	D
A4460	2477	796	586	452	27	30	17	19	D

*15 ms pulse width
Factors other than battery capacity may reduce life.

Warranty life is 50% of battery capacity, maximum of one year.

470 First Ave. N., Box 398 • Isanti, MN 55040
763.444.9267 • fax:763.444.9384 • sales@atstrack.com • www.atstrack.com

Appendix D. Example of daily use and availability buffers for habitat selection analysis. Used buffer was a constant 100 m around the estimated location of a female. For females that successfully reared broods, the availability buffer was 1, 414 m, and for females that lost broods, the availability buffer was 3, 074 m.
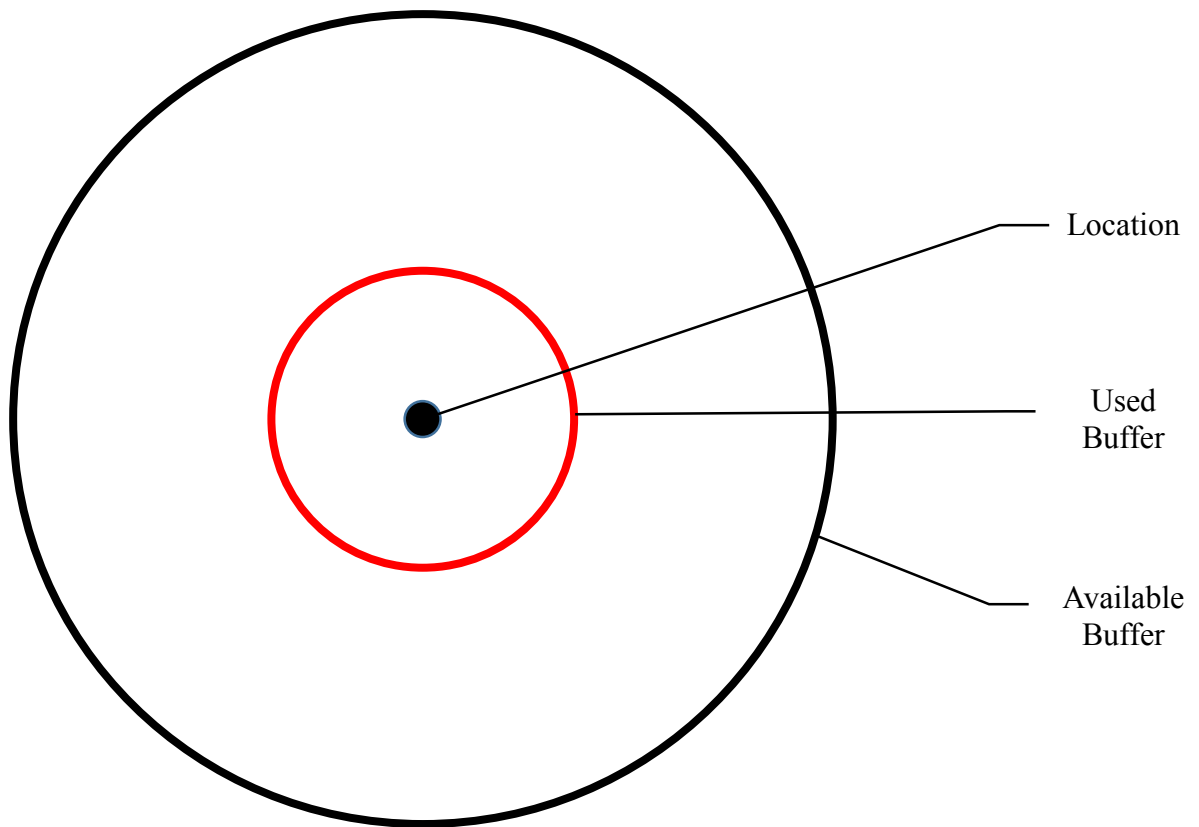
Appendix E. Definitions of land cover classes in the study area adapted from the
Michigan Tech Research Institute (Bourgeau-Chavez et al. 2015).

Class	Description
Open Water	Streams, canals, rivers, lakes, estuaries, reservoirs, impoundments, and bays. Areas persistently inundated in water that do not typically show annual drying out or vegetation growth at or above the water's surface. Where depth of water column is > 2m, such that light attenuation increases significantly and surface and subsurface aquatic vegetation persistence declines or is less detectable.
Agriculture	Hay fields and croplands where row crops such as corn, beans, and grains are in production. Land used for production of food or fiber; land use distinguishes agriculture land from similar natural ecosystem types (i.e. wetlands and rice patties). Includes agriculture fields not in row crop production, such as areas of native grasses or meadows, pastures, orchards, vineyards, and ornamental plants/trees.
Marsh	Emergent wetland and wet meadow vegetation. These are areas where the water table is at or near the earth's surface. Seasonal inundation and or drying are common phenomenon. Vegetative species distributions are strong indicators of wetland condition. Includes algal beds, aquatic mosses, rooted vascular plants (e.g. eel grasses and sea grasses, pond weeds, lily pads, milfoil) and floating vascular plants (e.g. lemna, water hyacinth, coontails, and bladderwarts). Inundated wetlands or water < 2m (excluding deep water zones) habitats dominated by plants that grow principally on or just below the water's surface.
Forest	Broad leaf and needle leaf deciduous and evergreen trees and dead forests. Characterized by woody vegetation with a height > 6m. Crown closure percentage (i.e. aerial view) > 75%.
Scrub-Shrub	Wetlands dominated by shrubs < 6m in height. Crown closure percentage (i.e. aerial view) > 50%.
Urban	Residential areas, cites, towns, industrial areas, utilities, commercial services where the man-made structures have > 75% coverage. Primarily residential areas where man-made structure (i.e. buildings, farm equipment) are present; with more than or equal 25% vegetation (trees, shrubs, grass) are interspersed. Lawns, golf courses, athletic fields, urban parks and mowed transitional zones such as medians or airfields. Linear transportation routes, large driveways, and parking areas. Transportation routes can include highways, small two lane roads, rail road beds, airfield landing areas, round-a-bouts, parking lots, and off and on ramps.
Swamp	Wetlands dominated by woody vegetation (dead or alive) > 6m in height. Includes seasonally flooded forests. Crown closure percentage (i.e. aerial view) > 50%.

Appendix F. Mann-Whitney U comparisons of movement metrics for female wood ducks over the first 15 and last 15 days post-hatch at Long Point, Ontario.

Movement Metric	First 15	Last 15	Significance[a]
Total Distance Moved (m)	7,445	7,001	-
Daily Movement (m)	523.3	474.6	-
Max Step (m)	1,837	1,713	-
Total Displacement (m)	2,235	1,017	***
Home-Range[b] (m^2)	2,130,000	1,268,000	-

[a] ->0.05, *0.05, **0.01, ***<0.01
[b]100% MCP

Appendix G. Mann-Whitney U comparisons of movement metrics for female wood ducks with and without broods to 30 days post-hatch at Long Point, Ontario.

Movement Metric	Brood ($n = 14$)	No Brood ($n = 13$)	Significance[a]
Total Distance Moved (m)	10,870	16,640	**
Daily Movement (m)	373	573	*
Total Displacement (m)	1,288	3,380	***
Max Step (m)	1,414	3,075	***
First Movement (m)	781	792	-
Home-Range[b] (m^2)	1,079,000	4,600,000	***

[a] ->0.05, *0.05, **0.01, ***<0.01
[b]100% MCP

Appendix H. Individual selection ratios for female wood ducks to 30 days post-hatch at Long Point, Ontario (n = 27).

Appendix I. Scatter plot of candidate variables hatch date (days since April 1) and mean daily low temperature (°C) for survival analysis with regression line ($R^2 = 0.78$).
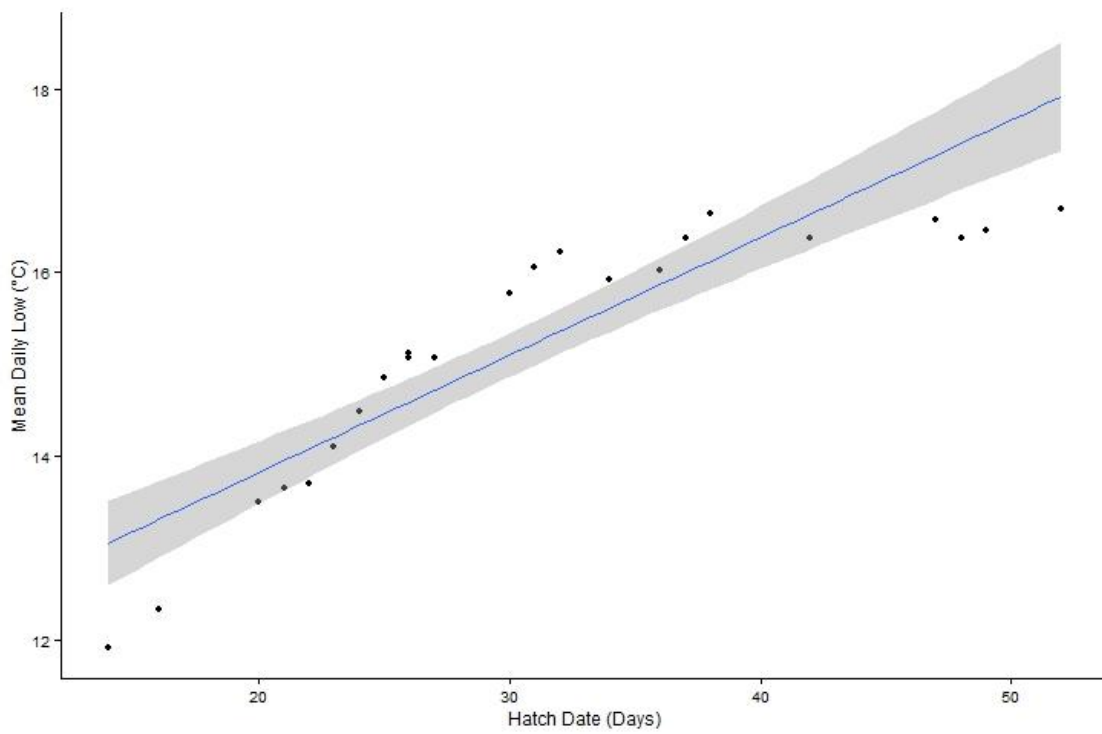
Appendix J. Candidate models ($n = 21$) used to predict brood survival to 30 days post-hatch at Long Point, ON. Table includes model description, number of parameters (K), Log-likelihood, Akaike's Information Criterion adjusted for small sample sizes (AIC_c), the change in AIC_c compared to the best model (ΔAIC_c), and Akaike weights (w_i). Models in bold were considered to be competing.

Model[a]	K	LL	AIC_c	ΔAIC_c	w_i
Female Related					
Age	1	-53.50	109.13	5.38	0.02
Mass	1	-53.54	109.21	5.46	0.01
Age + Mass	2	-52.14	108.68	4.93	0.02
Nest Related					
Hatch	1	-53.57	109.27	5.52	0.01
BC0	1	-52.98	108.09	4.34	0.03
Hatch + BC0	2	-51.79	107.97	4.22	0.03
Weather Related					
Precip	1	-52.40	106.93	3.18	0.05
Female and Nest Related					
Age + Mass + BC0 + Hatch	4	-49.91	109.20	5.45	0.01
Age + Hatch + BC0	3	-51.34	109.48	5.73	0.01
Age + Mass + BC0	3	-50.41	107.62	3.87	0.03
Hatch + Mass + BC0	3	-50.90	108.60	4.85	0.02
Age + Hatch	2	-52.52	109.44	5.69	0.01
Age + BC0	2	-52.66	109.70	5.95	0.01
Mass + Hatch	2	-53.34	111.07	7.32	0.01
Mass + BC0	2	-51.35	107.09	3.34	0.04
Female and Weather					
Age + Mass + Precip	3	-50.03	106.85	3.10	0.05
Age + Precip	2	-52.21	108.81	5.06	0.02
Mass + Precip	**2**	**-51.08**	**106.55**	**2.80**	**0.06**
Nest and Weather					
Hatch + BC0 + Precip	**5**	**-48.47**	**103.75**	**0.00**	**0.23**
Hatch + Precip	**3**	**-49.93**	**104.25**	**0.50**	**0.18**
BC0 + Precip	4	-50.36	107.85	4.10	0.03
All Variables					
Age + Mass + Hatch + BC0+ Precip	**5**	**-46.38**	**104.91**	**1.16**	**0.13**

[a]Variable definitions are available in text in Table 3.1

Appendix K. Candidate models ($n = 21$) used to predict duckling survival to 30 days post-hatch at Long Point, ON. Table includes model description, number of parameters (K), Log-likelihood, Akaike's Information Criterion adjusted for small sample sizes (AIC$_c$), the change in AIC$_c$ compared to the best model (ΔAIC$_c$), and Akaike weights (w_i). Models in bold were considered to be competing.

Model[a]	K	LL	AIC$_c$	ΔAIC$_c$	w_i
Female Related					
Age	1	-1592.67	3187.35	34.55	0.00
Mass	1	-1601.42	3204.86	52.06	0.00
Age + Mass	2	-1585.40	3174.83	22.03	0.00
Nest Related					
Hatch	1	-1602.98	3207.97	55.17	0.00
BC0	1	-1593.24	3188.49	35.70	0.00
Hatch + BC0	2	-1591.72	3187.46	34.67	0.00
Weather Related					
Precip	1	-1599.14	3200.30	47.50	0.00
Female and Nest Related					
Age + Mass + Hatch + BC0	**4**	**-1573.36**	**3154.82**	**2.02**	**0.16**
Age + Hatch + BC0	3	-1584.19	3174.45	21.65	0.00
Age + Mass + BC0	**3**	**-1572.39**	**3152.83**	**0.04**	**0.42**
Age + Hatch	2	-1591.92	3187.87	35.07	0.00
Age + BC0	2	-1586.18	3176.40	23.60	0.00
Mass + Hatch	2	-1601.24	3206.51	53.71	0.00
Mass + BC0	2	-1586.44	3176.90	24.10	0.00
Female and Weather					
Age + Mass + Precip	3	-1582.61	3171.29	18.50	0.00
Age + Precip	2	-1591.87	3187.78	34.98	0.00
Mass + Precip	2	-1595.10	3194.23	41.43	0.00
Nest and Weather					
Hatch + BC0 + Precip	3	-1588.27	3182.59	29.80	0.00
Hatch + Precip	2	-1597.71	3199.45	46.65	0.00
BC0 + Precip	2	-1591.67	3187.38	34.58	0.00
All Variables					
Age + Mass + Hatch + BC0+ Precip	**5**	**-1571.32**	**3152.80**	**0.00**	**0.43**

[a]Variable definitions are available in text in Table 3.1

Curriculum Vitae

Matthew Edward Dyson

EDUCATION

MSc Biology   **January 2014-Present**
Western University, London, ON

Honours BSc Natural Resource Management   **May 2013**
University of Northern British Columbia, Prince George, BC

PROFESSIONAL AND WORK EXPERIENCE

Graduate Research Assistant   **January 2014 – Present**
Western University, London, ON, Canada
Long Point Waterfowl, Long Point, ON

Field and Research Technician   **April 2013 – December 2013**
Long Point Waterfowl, Port Rowan and Chatham, ON
Supervisors: Drs. Scott Petrie and Samantha Richman

Undergraduate Research Assistant   **September 2012 – April 2013**
University of Northern British Columbia, Prince George, BC
Supervisor: Dr. Jane Young

National Wildlife Area Field Technician   **May – Sept 2010, 2011, 2012**
Environment Canada-Canadian Wildlife Service
Big Creek and Long Point National Wildlife Areas, Port Rowan, ON

VOLUNTEER EXPERIENCE

Waterfowl Nesting Ecology Research Technician   **May – June 2015**
Ontario Ministry of Natural Resources and Forests, Akimiski Island, NU
Supervisors: Rod Brook and Sarah Hagey

Secretary-Treasurer   **February 2014 – Present**
Canadian Section of The Wildlife Society

Committee Member   **August 2014-October 2014**
Western Biology Graduate Research Forum

Student Representative   **May 2013 – October 2014**
Canadian Section of The Wildlife Society

TEACHING EXPERIENCE

Unofficial Co-Supervisor   **April 2014-April 2015**
Western University, London, ON, Canada

Teaching Assistant   **January 2014 – Present**
Western University, London, ON, Canada

ORAL PRESENTATIONS

Dyson, M., Michael L. Schummer, Hugh A.L Henry, and Scott A. Petrie. 2015. Movement, habitat selection, and survival of female wood ducks (*Aix sponsa*) and ducklings at Long Point, ON. Inaugural Meeting of the New York Waterfowl and Wetland Collaborative Network, Oswego, NY, USA, July 2015.

Dyson, M., Hugh A.L Henry, and Scott A. Petrie. 2015. Movement, habitat selection, and survival of female wood ducks (*Aix sponsa*) and broods at Long Point, ON. Friday Philosophicals, Department of Biology, Western University, London, ON.

Dyson, M., Michael L. Schummer, Hugh A.L Henry, and Scott A. Petrie. 2015. Movement, habitat selection, and survival of female wood ducks (*Aix sponsa*) and broods at Long Point, ON. Canadian Section of The Wildlife Society Annual General Meeting, Saskatoon, SK, March 2015.

Dyson, M., Hugh A.L Henry, and Scott A. Petrie. 2014. Survival and habitat selection of female wood ducks (*Aix sponsa*) and broods at Long Point, ON. Friday Philosophicals, Department of Biology, Western University, London, ON.

Dyson, M., Samantha Richman, Michael A. Schummer, Hugh A.L. Henry and Scott A. Petrie. 2014. Survival, habitat use, and movement patterns of female wood ducks (*Aix sponsa*) and broods at Long Point, ON. 2014 Great Lakes Partners Forum. Winous Point, OH.

Dyson, M. 2014. Long Point Waterfowl Wood Duck Project. Norfolk Woodlot Owners Association Annual General Meeting. Delhi, ON.

POSTER PRESENTATIONS

Dyson, M., Hugh A.L. Henry, Michael A. Schummer, and Scott A. Petrie. 2015. Survival and habitat selection of female wood ducks (*Aix sponsa*) and their broods at Long Point, ON. Inaugural Meeting of the New York Waterfowl and Wetland Collaborative Network, Oswego, NY, USA, July 2015.

Dyson, M., Hugh A.L. Henry, Michael A. Schummer, and Scott A. Petrie. 2015. Survival and habitat selection of female wood ducks (*Aix sponsa*) and their broods at Long Point, ON. Birds by the Bay. Port Rowan, ON.

Dyson, M., Hugh A.L. Henry, Michael A. Schummer, and Scott A. Petrie. 2015. Survival and habitat selection of female wood ducks (*Aix sponsa*) and their broods at Long Point, ON. Carolinian Carnival. Aylmer, ON.

Dyson, M., Hugh A.L. Henry, Michael A. Schummer, and Scott A. Petrie. 2014. Survival and habitat selection of female wood ducks (*Aix sponsa*) and their broods at Long Point, ON. Western Interdisciplinary Research Showcase. London, ON.

Dyson, M., Hugh A.L. Henry, Michael A. Schummer, and Scott A. Petrie. 2014. Survival and habitat selection of female wood ducks (*Aix sponsa*) and their broods at Long Point, ON. The Wildlife Society Annual General Meeting – Student Research in Progress Session, Pittsburgh, Pennsylvania.

POPULAR ARTICLES

Dyson, M. 2014. Matt Dyson follows wood ducks in his 'duck truck'. Port Rowan Good News. September Edition.

Dyson, M. 2014. LPW Wood Duck Research Project. Nestbox News Research Highlight. California Waterfowl Association

Delta Waterfowl. 2014. Research – Wood duck breeding ecology in southern Ontario. Ducks today, ducks tomorrow. Delta Waterfowl.

Pierce, Daniel R. 2014. Duck tracker gets odd looks. Simcoe Reformer. July 28th. http://www.simcoereformer.ca/2014/07/28/duck-tracker-gets-odd-looks

Helsdon, Jeff. 2014. Just Ducky. Ontario Out of Doors Hunting Annual 2014-2015. Ontario Federation of Anglers and Hunters.

Digweed, Carly**.** 2013. Working for the wood duck. Stories From the Field. Nature Conservancy of Canada

WORKSHOPS ATTENDED

Boyce, M. 2015. RSFs in R. Canadian Section of The Wildlife Society Annual General Meeting. Saskatoon, SK.

Lyons, AW. 2014. Analysis of wildlife spatial behaviours with T-LoCoH. The Wildlife Society Annual General Meeting. Pittsburgh, Pennsylvania.

ACADEMIC HONOURS, AWARDS, AND GRANTS

NSERC CGSM (Declined)	April 2015
SOGS Travel Subsidy ($500)	April 2015
Best Student Poster – MSc, TWS AGM, Pittsburgh, PA.	October 2014
CSTWS Student Travel Award, TWS AGM, Pittsburgh, PA. ($500)	October 2014
OFAH/Oakville and District Rod & Gun Club Conservation Grant ($2000)	February 2014
Wildlife Habitat Canada Research Grant ($34000)	January 2014
Western Graduate Research Scholarship ($4536)	January 2014
Canadian Institute of Forestry Bursary ($750)	September 2011
Dwight Gregory Hickey Memorial Bursary ($1000)	September 2011