Effects of Commercial Forest Harvesting on the Distribution of the American Black Duck (*Anas rubripes*) During the Breeding Period in New Brunswick, Canada

By

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ABSTRACT

American black duck populations (*Anas rubripes*) have declined range-wide since the 1990s; however, what may be driving this decline is unknown. Commercial forest harvesting may reduce the amount of breeding habitat available for black ducks. To determine if breeding black ducks are affected by commercial forestry, I analyzed how distribution and productivity differed in areas with varying amounts of commercial forestry. I found that distribution of breeding adult black ducks was influenced by wetland area, the presence of mallards (*A. platyrhynchos*), the proportion of intact forest within 1000m radius of the wetland edge, and the distance to the closest harvest. I did not find an effect of commercial forestry on predation of artificial nests, nor on the distribution of real broods. My results indicate that the commercial forestry practices I assessed may alter adult black duck distribution, but do not seem to impact nest predation or brood distribution.

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List of Terminology, Symbols, Nomenclature or Abbreviations

Δ - Delta

ABDU – American black duck

AIC – Akaike's Information Criterion

BDJV – Black Duck Joint Venture

Black duck – American black duck

Buffer – Forested riparian buffer zone

Clear cut – forest harvest that results in every merchantable stem being removed

CWS – Canadian Wildlife Service

DERD – New Brunswick Department of Energy and Resource Development

EHJV – Eastern Habitat Joint Venture

EWS –Helicopter-based waterfowl breeding pair survey in eastern Canada also referred to as the Eastern Waterfowl Survey

GLM – Generalized linear model

GLMM – Generalized linear mixed model

ha – hectares

Harvest block – A block of forest that has been harvested

Indicated breeding pair – A term used to account for incubating females that may not be observed in surveys. For black ducks this is a single duck, 2-bird groups, and flocks of 3-4 individuals and in other dabbling waterfowl species this is a pair, a lone male, and all males in in flocks of 2-5

km – kilometers

m – meters

MALL – Mallard

USFWS – United States Fish and Wildlife Service

Chapter 1. General Introduction

Large-scale anthropogenic landscape changes influence ecological processes and require a thorough understanding to properly conserve these landscapes. Human modification of landscapes has accelerated (Lindenmayer et al. 2007), and historic sources of disturbance in temperate forests, such as fire and insect outbreaks, are being replaced by human-induced ones (Wein and Moore 1976). Landscape modifications can cause habitat fragmentation which may also result in habitat loss, degradation, or isolation (Fischer and Lindenmayer 2007). In temperate forests, the dominant disturbance regime is now from forest harvesting (Higdon et al. 2006). In commercial forests this may create a loss of landscape suitable for some species, putting them at risk of extirpation (Higdon et al. 2006). In boreal forests of north-central Alberta, forest bird communities may be altered for up to 28 years following disturbance (Hobson and Schieck 1999). Waterfowl, although they are predominantly aquatic, may also experience habitat degradation from commercial forest harvesting (Lemelin et al. 2007, Börger and Nudds 2014). American Black Ducks (*Anas rubripes*; "black ducks") are a waterfowl species that inhabit forested areas, putting them at risk of extirpation from commercial forest harvesting disturbance (Higdon et al. 2006).

American Black Duck Distribution and Breeding Ecology in Forested Habitats

Over 50% of the black duck harvest in the Atlantic flyway and 44% of the continental black duck harvest occurs in Eastern Canada (based on mean 1999-2006 values for Canada and US; EHJV 2017). Of the continental population of black ducks, 95% breed in the region administered by the Eastern Habitat Joint Venture (EHJV;

~169,150 to ~348,850 breeding pairs), which encompasses the six provinces of Eastern Canada (EHJV 2017). Midwinter inventory surveys conducted in the United States indicate that the black duck population declined by >50% from the 1950's to the 1980's (BDJV Management Board 2008). The cause of this population decline remains largely unknown, but Conroy et al. (2002) suggest that changes in breeding and wintering habitat quality, liberal hunting limits, and negative interactions with Mallards (*A. platyrhynchos*) may be responsible. Following all-time population lows in the 1980's, black duck harvest was severely restricted. The hunting season was shortened, and international partnerships were formed under the North American Waterfowl Management Plan (BDJV Management Board 2008). From 1990 to 2010, black duck populations in the Maritime provinces (New Brunswick (NB), Nova Scotia (NS), and Prince Edward Island) generally increased – except for notable local declines in the extensively forested region of interior NB (Stewart et al. 2015), the cause of which is unknown.

Despite the population decline in this species, black ducks are the most abundant breeding waterfowl species in NB and make extensive use of forested habitats (Stewart et al. 2015). The black duck is an economically important game species (Devers and Collins 2011), as well as a priority species for management in eastern North America (Maisonneuve et al. 2006), but many key information gaps remain. Forestry operations can benefit breeding waterfowl by creating nesting habitat for species such as Canada Geese (*Branta canadensis*) and American Green-winged Teal (*A. carolinensis*; Lieske et al. 2012). For example, artificial ground nests with Japanese quail (*Coturnix japonica*) eggs in clearcuts have been found to have lower risk of predation than those in forest strips (Rudnicky and Hunter 1993). However, disturbance is a factor limiting black ducks

(Korschgen and Dahlgren 1992) and they are often described as “wary” and “intolerant of disturbance” (Coulter and Miller 1968; Morton 1998; Morton 2002). Commercial forestry practices may directly or indirectly disturb breeding black ducks during forest harvest, by people using infrastructure, habitat loss and degradation, or lasting effects from forest harvesting (Robert et al. 2000). Commercial forestry may also introduce pesticides to wetlands resulting in reduced aquatic invertebrate food sources, which are an important food source for black ducks, or reduce nesting vegetation through herbicide application (Rusch et al. 1989).

There has been no research on breeding populations of black ducks in commercially-harvested Acadian forest, especially in NB where commercial harvest is the most intense, despite forestry being identified as an area requiring further research since the population decline in the 1980’s (Rusch et al 1989; Conroy et al. 2002). Loss and degradation of breeding grounds from economic development such as forest harvesting remains listed as a major threat in the Conservation Action Plan for the American Black Duck (Devers and Collins 2011). In boreal forests of Ontario, forest harvesting was found to affect waterbird occupancy, which was more pronounced in the first ten years post disturbance for black ducks than after twenty years (Börger and Nudds 2014). In Quebec, cavity nesting waterfowl were more likely to be negatively influenced by forestry practices than ground nesting waterfowl such as the black duck (Lemelin et al. 2007), but this assessment was not spatially explicit about proximity of harvest to wetlands and does not address forestry practices that may directly affect black ducks.

Black ducks are thought to be attracted to areas with preferred nesting cover with good brood-rearing and feeding areas nearby (Kirby 1988). Disturbance close to wetlands caused by forest harvesting may cause black ducks to emigrate from more desired wetlands and establish in less suitable habitat, potentially exposing them to greater predation risk. Forest harvest close to wetlands decreases habitat patch size and increases edge in black duck nesting habitat because black ducks will often nest in forested areas away from wetlands, sometimes up to 1.5km from water (Stotts and Davis 1960, Ringelman et al. 1982). Forest management that retains forest strips and riparian buffers can provide nesting locations. However, depending on the patch size, forested buffer strips can sometimes act as ecological traps (Gates and Gysel 1978) due to edge-related nest predation (Vander Haegen and Degraaf 1996, Pasitschniak-Arts et al. 1998). Reported forest buffer zone sizes to reduce edge related nest predation rates for passerines range from 20m (Darveau et al. 1997) to >150m (Vander Haegen and Degraaf 1996). Most studies that provide buffer zone width requirements for birds focus on passerine nesting success, there have been no studies of waterfowl nests in riparian buffers, which differ from passerine nests in morphometry and phenology. Therefore, black duck nest predation may differ from these studies by the degree of depredation, prevalent predator species, and general food availability for predators.

Forest harvest close to wetlands may also disturb or alter the quality of brood-rearing areas, or, separate nesting and brood-rearing areas. Quality brood-rearing habitat is vital for duckling survival and recruitment into the breeding population. Two important aspects of quality brood-rearing areas are food quality and the presence and density of loafing areas that allow for predator detection (Afton and Paulus 1992). Because broods are mobile, they can selectively move to wetlands with these traits. Afton and Paulus (1992) recommend that ephemeral, semi-permanent, and permanent wetlands close to nesting areas are all important habitats for breeding waterfowl. Factors that contribute to wetland use by broods in commercial forests are unknown.

Mallards, a close relative to black ducks, were once rare in eastern North America but are becoming increasingly common because of range expansion and game farm escapees (Collins 1974, Heusmann 1974, Bordage et al. 2017). Mallards may competitively exclude black ducks from preferred habitats (Petrie et al. 2012), and introgressive hybridization may occur during pairing on the wintering grounds because of a male bias and similar courtship behaviours (Brodsky and Weatherhead 1984). In NB, black ducks and mallards have similar reproductive phenology and success (Petrie et al. 2000). Forests may somewhat insulate black ducks from the negative effects of mallards (Dwyer and Baldassare 1994). However, mallards are considered tolerant of habitats undergoing extensive alteration such as those being converted from forest to agriculture (Heusmann 1991) and may occupy habitats abandoned by black ducks because of disturbance (Maisonneuve et al. 2006).

Study Area

This study was focused in NB, where forestry is the largest industry in the province and seeks to balance a strong environmental responsibility with acceptable economic loss from forgoing harvesting in certain areas, such as vegetated riparian buffer zones (buffers). Buffers separate aquatic systems from the potential negative effects of adjacent land uses and are an important tool in maintaining ecological integrity and water quality in an industrial forest landscape (Castelle et al. 1994, Fischer and Fischenich 2000). In NB, forestry operations must maintain ≥30m buffers around wetlands ≥1ha.

(NB Clean Water Act 1989). Although this distance is adequate in achieving the primary goal of maintaining water quality (Castelle et al. 1994), this area also provides wildlife habitat and there has been little examination of the efficacy of the ≥30m buffer requirement and its role in providing waterfowl habitat in NB. If wildlife are considered in buffer zone planning, requirements are typically to meet the needs of aquatic species, while avian habitat requirements are often ignored (Fischer, 2000). Buffer zone requirements for birds have been reported to range from 40m (Hagar 1999) to >500m (Kilgo et al. 1998). Research of buffer zone size is notably lacking in avian species that require both terrestrial and aquatic habitats to complete their breeding cycle, such as waterfowl.

My study was conducted in northeastern NB. NB has few large lakes but has numerous small wetlands (Warner and Rubec 1997). These wetlands support 17 species of breeding waterfowl (Stewart et al. 2015). NB is also in the Acadian forest ecozone which is dominated by mixed forest with deciduous trees on well-drained slopes and hillsides, and conifers in moist and disturbed areas (Rowe 1972). NB is primarily forested; >80% of the province’s landcover is forest (Government of NB 2019). Most of this land is privately owned (50%) or the responsibility of the provincial government (48%), and a small portion is under federal jurisdiction (2%; Nadeau et al. 2012). This area has experienced continuous anthropogenic changes since European colonization (Loo and Ives 2003). NB experienced extensive forest harvesting during the mid-1900’s to a degree where there was a risk of timber shortages (Holloway 2008). The Crown Lands and Forests Act (1982) was put in place to improve sustainable forest harvesting. In 2016, 9,341,187m^3 of timber were harvested from 81,439 ha of forest of which 17,625 ha were replanted and the remainder left to regenerate naturally (Natural Resources Canada 2018). Pulp and paper products currently have the largest domestic impact, create the most employment opportunities, and generate the most value in trade (Natural Resources Canada 2018).

Logical Overview and Thesis design

Because Acadian forest is important for breeding black ducks (Ashley et al., 2010), I hypothesized that changes on the breeding grounds from commercial forestry affect breeding black duck distribution in New Brunswick. Data for Chapters Two and Three of this thesis are stored and accessible on the digital repository, Dryad (McLean 2020; https://doi.org/10.5061/dryad.hx3ffbg9w). Raw data for Chapter Four are provided in Table 4.2, page 88 of this thesis.

Research Objectives

To answer my research questions, I focus on three main phases of the black duck breeding cycle: breeding site selection by adults, nesting and incubation, and brood-rearing. The specific objectives of this research are to determine if commercial forest harvesting affects:

1. The distribution of breeding black ducks during the laying/incubation period and if the presence of mallards influences black duck presence in forested areas;
2. Nest predation rates of early, ground-nesting waterfowl in riparian buffer zones;
3. The distribution of black duck broods.

Thesis Structure

In Chapter Two, I conduct various analyses to achieve the first objective. Börger and Nudds (2014) found black ducks avoid recently disturbed areas. Therefore, I predict that black ducks will vacate wetlands after forest harvesting occurs nearby, and that wetlands with a higher proportion of harvested forest surrounding them will be less likely to have black ducks present. I also included the presence or absence of mallards as a predictor in models and predict that the presence of mallards will negatively influence the presence of breeding black ducks on forested wetlands. To test these predictions, I overlaid existing breeding black duck observations from the helicopter-based waterfowl breeding pair survey in eastern Canada with historical forest harvesting patterns and wetlands in New Brunswick over a 22-year period. This assessment will determine if commercial forest harvesting affects the distribution of breeding black duck pairs by altering settlement patterns.

In Chapter Three, I analyze field experiments to achieve the second objective. I predict that nests closest to harvested areas will experience reduced nest success, compared to those that are farther away, or in intact forest. To meet these objectives, I conducted field experiments with artificial nests designed to simulate the appearance and duration of early, ground-nesting waterfowl nests. This assessment will determine if commercial forest harvesting affects waterfowl productivity by reducing nest success.

In Chapter Four, I collected field observations to achieve the third objective. I predict that broods will be less likely to be present on wetlands with higher amounts of forest harvesting in proximity to them. To meet this objective, I surveyed wetlands over a range of harvest intensity to determine if they were used by duck broods. This assessment will determine if forest harvesting affects female black duck habitat selection for brood-rearing.

In Chapter Five, I synthesize overall findings by linking primary conclusions to research objectives. This Chapter interprets primary results on how commercial forest harvesting affects breeding waterfowl. This will help to develop a better understanding of large-scale anthropogenic landscape disturbances on wildlife. Suggestions and guidance for related future research are included.

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Chapter 2. Recency of Commercial Forest Harvesting Affects the Distribution of Breeding American Black Ducks

Abstract

Breeding American black duck ("black duck"; *Anas rubripes*) populations have declined range-wide since the institution of systematic surveys in the 1990s; however, factors that may be driving this decline are unknown. Black ducks can be intolerant to disturbance and may be subject to local threats, such as those from commercial forest harvesting. To determine if breeding black duck distribution is affected by commercial forest harvesting, I overlaid breeding black duck observations with historical forest harvesting patterns and wetland characteristics in New Brunswick, Canada. Data were obtained from an existing systematic helicopter survey conducted in eastern Canada for 785 wetlands surveyed on a rotational schedule from 1995-2017. I determined for each wetland the proportion of intact forest within 30m and 1000m, the distance to the closest forest harvest within 1000m, the year of forest harvest, and forest harvest method for the most recent ten- and twenty-year periods. For the ten-year period the distance to harvest had a negative relationship with the presence of black ducks, and the proportion of intact forest within 1000m, wetland area and presence of mallards had a positive relationship with black duck presence. In the twenty-year period wetland area and presence of mallards had a positive relationship with black ducks. For both the ten- and twenty-year periods for mallards only the predictor of black duck presence explained mallard presence. Commercial forestry may have positive effects on breeding black duck presence following harvest which decrease over time. This may be caused by increased vegetation growth in regenerating forests, creating better nesting habitat.

Keywords: American black duck, disturbance regime, landscape change, mallard, riparian zone

Introduction

Large-scale natural disturbances, such as forest fires and insect outbreaks, affect nutrient recycling and biodiversity maintenance (Wein and Moore 1976; Börger and Nudds 2014). Suppression of fires and insect outbreaks has caused forest harvesting to become the dominant disturbance regime in temperate forests (Higdon et al. 2006). These disturbances alter forest habitat composition and may extirpate some vertebrate species in industrial forests (Higdon et al. 2006). American black ducks (*Anas rubripes;* "black ducks") have been identified as a species at high risk of extirpation in commercial forests because of habitat loss or degradation (Higdon et al. 2006). Species that rely on both aquatic and terrestrial habitats to complete their lifecycle, such as waterfowl, are often difficult to manage and receive little research attention in forested habitats (Lemelin et al. 2007).

It is unknown why populations of breeding black ducks have declined range-wide since the 1990s (USFWS 2017). Black ducks can be intolerant to disturbance and may be subject to local threats (Coulter and Miller 1968; Morton 1998; Morton 2002). Loss and degradation of breeding habitat from economic development activities, such as forest harvesting, remains listed as a major threat in the *Conservation Action Plan for the*

American Black Duck (Devers and Collins 2011) and forestry has been identified as an area requiring further research since the population decline was first recognized (Rusch et al 1989; Conroy et al. 2002).

Certain forestry practices can result in decreased animal food sources in wetlands, exposure to pesticides (Rusch et al. 1989), direct nest loss, removing nest sites closest to wetlands, and disturbance after harvest by people using the roads (Robert et al. 2000). Black ducks tend to nest in upland areas within 1.5km of a wetland (Ringelman et al. 1982). Riparian buffer zones are an important part of the industrial forest landscape as they maintain the integrity of wetlands by separating aquatic systems from the potential negative effects of adjacent land uses (Castelle et al. 1994, Fischer and Fischenich 2000). For black ducks, these riparian zones provide nesting habitat, movement corridors, and maintain wetland health. Therefore, appropriate forest management is crucial for forest breeding black ducks as they need a complex of upland habitat to nest in and wetland habitat in which to forage and raise broods.

The Acadian forest provides important breeding habitat for black ducks; stable isotope feather analysis showed that >50% of juvenile black ducks harvested in the eastern sub-portion of their breeding range originated in the forested areas of New Brunswick and Nova Scotia, Canada (Ashley et al. 2010). Black ducks in the boreal forest seem to avoid recently disturbed and mature forests, but not successional forests (Börger and Nudds 2014). Research in Quebec has suggested that clear-cutting may not have a negative effect on ground-nesters like black ducks (Lemelin et al. 2007), but this assessment was not spatially explicit in terms of proximity to waterbodies. Understanding how landscape disturbances alter species distributions is important in effective forest management plans (Börger and Nudds 2014).

Interactions with mallards (*A. platyrhynchos*) may play a role in the decline of black duck populations (Ankney et al. 1987, Conroy et al. 2002, Morton 1998). Mallards are genetically similar to black ducks (Avise et al. 1990). Their populations have increased significantly in eastern North America (Ankney et al. 1987), and their range now overlaps considerably with that of the black duck (Longcore et al. 2000). It is possible that introgressive hybridization, competitive exclusion, and/or interference competition with mallards has been detrimental to black ducks (Ankney et al. 1987, D'Eon et al. 1994, Maisonneuve et al. 2006, Petrie et al. 2012). Black ducks may not recognize mallards as heterospecifics and they use similar habitats (Merendino and Ankney 1994). The two species breed at the same time and have similar incubation periods, clutch and brood sizes (Petrie et al. 2000). However, mallards reduce the amount of breeding habitat available for black ducks, possibly through interference competition (Petrie et al. 2012)

Despite the importance of healthy wetlands to waterfowl, and our reliance on forest products, it is surprising that we do not know how close forest operations can occur to these wetlands without affecting their use by black ducks. Therefore, I sought to determine if commercial forest harvesting affects the distribution of breeding black ducks. Specifically, I asked whether the amount of intact forest around a wetland, distance to nearest harvest, and harvest method affects the presence of breeding black ducks in the Acadian forest. Given the potential for negative interactions with mallards, I also sought to determine whether they exerted any influence over the distribution of breeding black ducks.

Methods

Study Area

I conducted my study in northeastern New Brunswick (NB), Canada. The area is in the Acadian forest ecozone, and most of the province has experienced intense, multigenerational forest harvesting. NB has numerous small wetlands including swamps, marshes, fens, bogs, beaver ponds, and shallow water (Warner and Rubec 1997). In NB, forestry operations must maintain ≥30m riparian buffer areas around waterbodies (NB Clean Water Act 1989). There is some variation in the distance from a wetland edge that harvest occurs because of forest value, logistical constraints, additional constraints in ecologically significant areas, and in some situations a portion of the 30-meter riparian zone can be harvested (NB Clean Water Act 1989).

The Acadian forest is mainly mixed forest and a complex of deciduous trees in well drained soils and conifers in moist and disturbed areas (Rowe 1972). Characteristic tree species include red spruce (*Picea rubens*), yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*), and balsam fir (*Abies balsamea*; Loo and Ives 2003). Eighty three percent of NB's landcover is forest, approximately half of which is crown land and half is privately owned (Government of NB 2019). Historical sources of disturbance were fire and insect outbreaks (Wein and Moore 1976). Fire rotations in red spruce- hemlock- pine forests were ~230 years, and hardwood and high elevation conifer forests had fire rotations of over 1000 years (Wein and Moore 1976). From 1920-1975 mean forest fire size was 45ha and yearly totals ranged from 400-40000ha; the mean amount of forest burned was 0.11% (Wein and Moore 1976). Approximately 1% of NBs forests are harvested annually (Holloway 2008), which means a current disturbance rotation of ≤100 years, which is more frequent and widespread than historic natural disturbance to the landscape.

The black duck breeding range extends across NB and they can be found year-round along the ocean coasts (Longcore et al. 2000). Nesting density is relatively high across NB in comparison to other areas of the black duck breeding range, and most of the province has <20 pairs/25km^2, although some key areas have >30 breeding pairs/25km^2 (Lieske et al. 2012).

Black Duck Observations

I obtained georeferenced breeding black duck observations on NB wetlands from a helicopter-based waterfowl breeding pair survey in eastern Canada, which has been conducted annually by the Canadian Wildlife Service since 1990 (Bordage et al. 2017). Methods were standardized in 1995, therefore I included observations from 1995-2017 in my analysis. The years 2005, 2006, 2014, and 2015 were excluded because observations were not georeferenced to the specific wetland in those years. Forty-one haphazardly located 5x5km plots are surveyed by helicopter for breeding waterfowl across NB in a rotational (among years) schedule (Bordage et al. 2017; Figure 2.1; Table 2.1). Observations of waterfowl species present are recorded and georeferenced to the wetland. Surveys are timed to occur when approximately half the black duck females are laying, and half are incubating (early to mid-May in NB). Because females on a nest are likely to go undetected, and there is a skewed sex ratio, organizers of the survey use Dzubin's (1969) criteria with modifications by Wishart (1983) to classify "indicated breeding pairs" of dabbling waterfowl species as a pair, a lone male, and all males in flocks of 2-5. Because black duck sex is not consistently recorded in the survey, this was further modified by the survey organizers for black ducks such that an "indicated breeding pair" of black ducks is represented by a single black duck, 2-bird groups, and flocks of 3-4 individuals (Bordage et al. 2017). Therefore, groups of >5 individuals were excluded because they are not considered breeding individuals (Petrie et al. 2012, Bordage et al. 2017). I excluded nine plots with < 10% combined non-forest and urban land use, and/or within 5km of ocean from my analyses, as these areas are under stronger influence from non-forestry factors (e.g., agricultural or coastal effects). The helicopter-based surveys included any portion of a wetland within the plot boundary. However, in my analyses, I included only wetlands completely contained within the plot. Black ducks defend territories during the breeding season so it is unlikely that more than one pair will occupy the same wetland (Longcore et al. 2000). Therefore, I determined the presence/absence of black ducks and mallards on 785 wetlands each year the wetland was surveyed. Since mallards breed at the same time as black ducks, the survey also captures peak mallard breeding numbers.

Landcover Data

I used the NB Department of Energy and Resource Development (DERD) NB Forest Inventory Database. This GIS layer contains spatially explicit standardized forest and wetland polygons for the province. Polygons were determined from air photo interpretation, with a subset ground-truthed and checked by DERD staff. Forest polygons contain attributes on the species composition, stand productivity, and stand origin. They also include harvest history (e.g., date, method, volume), stand management (e.g., pre commercial thinning), and post-harvest treatment (e.g., planting) attributes. Harvest was classified as being one of eight methods, including stand management treatments, which I condensed into one of four categories (Table 2.2). Similar to Lemelin et al. (2007) I obtained forest harvest data within a 1000m radius of the edge of each wetland surveyed because this is the approximate home range size of forest breeding waterfowl (Ringelman et al. 1982, Kirby et al. 1985). However, unlike Lemelin et al. (2007), I considered this distance around the entire wetland, not just the observation point of an indicated breeding pair because individuals may be disturbed into flight by the helicopter during the survey, and the observation point may not represent the center of the home range. Wetland attributes included type (wetland, lake, watercourse), water regime, wetland class, and vegetation type. I excluded streams because it is difficult to determine local effects of forest harvest on long, linear features (e.g., effects may only be noticeable downstream). Wetland and waterbody polygon boundaries were based on the wetland class. Waterfowl were observed in each of the classes, so these polygons were merged to have contiguous wetland boundary outlines. The wetland area was then determined to be the total size of the entire merged polygon. Black ducks were observed in each vegetation type but most observations (62%) were made in an unknown vegetation type. Therefore, I did not include vegetation type as a variable in any models. I determined for each wetland the proportion of intact forest that had not been harvested within 30m as this is the minimum riparian zone required by the province (NB Clean Water Act 1989), and the proportion of intact forest within 1000m of the entire wetland edge. I did this using the “buffer” tool in ArcGIS to create a 30 and 1000m buffer around each wetland. I then used the “erase” tool in ArcGIS to remove any harvest blocks that fell within those ranges and calculated the proportion of intact forest based on the total buffer area around the wetland (excluding the area of the wetland itself). I also determined the distance to the closest forest harvest within 1000m of the wetland edge, the year, harvest method, and size of the closest forest harvest block using the “generate find near table” tool in ArcGIS. The closest harvest block to the wetland edge was included because I expected it to have a larger effect on the wetland than blocks that were harvested more recently but farther from the wetland. Because waterfowl surveys were conducted on a rotational schedule, I did this for each year the wetland was surveyed but excluded years where harvest treatment was unknown.

Because forest harvesting in NB is both intensive and extensive, there are few/no sites near which harvesting has not occurred, therefore I chose to use sites with the least amount of harvest as controls. Black ducks have been found to avoid recently disturbed, but not successional (10-20 years) forest (Börger and Nudds 2014). Therefore, I analyzed harvest data for the ten- and twenty-year periods prior to each wetland survey year to determine if an effect was present, and if it changed over time.

Statistical Analysis

I used ArcMap 10.4.1 (ESRI 2016) to overlay wetland, waterfowl observation, and harvest layers to generate a spreadsheet that contained spatially explicit data on harvest in proximity to the wetland. I then created a set of 20 biologically appropriate candidate models (Anderson et al. 2000) and analyzed them using a generalized linear mixed-effects modelling approach (GLMM; including a null model) for both the ten- and twenty-year harvest periods. GLMMs are an appropriate method to analyze non-normal data with random effects (Anderson et al. 2000, Bolker et al. 2008). I used a binomial family to fit breeding black duck presence or absence data with a logit link function using the lme4 package (Bates et al. 2015) in the program R 3.4.3 (R Core Team 2017). I added a random effects term to account for spatial autocorrelation of wetlands within each plot and nested the unique wetland identifier within it to account for repeated surveys of wetlands among years. The variable of "year" was not included in the model because of the staggered sampling regimen used in the helicopter-based surveys. All forest harvest and wetland variables were treated as fixed effects (Table 2.3). I ran the same candidate ten- and twenty-year models with the presence/absence of mallards as the response and replaced the presence/absence of mallards predictor variable with the presence/absence of black ducks. I tested for multicollinearity between numerical predictors prior to model fitting using Pearson's correlation coefficients. No pairs were eliminated as r values were all <0.7, which is a common threshold for collinearity (Dormann et al. 2012; Table 2.4). I centered skewed numeric variables to within 2 standard deviations of the mean and took the square root of the distance to harvest because of large variance (0-1000m). Top candidate models for both the ten- and twenty-year harvest disturbance periods were selected using Akaike's Information Criterion (Akaike 1974). Models with ΔAIC< 2 were considered strongly supported and models with ΔAIC of 2-4 were considered to have little to moderate support. AIC favours larger, more complex models with more predictors over simpler, more parsimonious models with fewer predictors (Burnham and

Anderson 2002). Therefore, if two models were within 2ΔAIC of each other, the models were considered equal and the more parsimonious model was selected as the top model. Relationships between retained predictor variables were plotted against the response variable using simple linear models to determine the direction of the relationship.

Results

Each of the 785 wetlands in this study was surveyed 1-12 times (mode = 7, ten- and twenty-year models). This resulted in 6732 and 6791 observations from 1995-2017 for the ten- and twenty-year models, respectively. For the ten-year model, 544 breeding black ducks were observed on 401 occasions at 178 wetlands, and 51 breeding mallards were observed on 46 occasions at 33 wetlands. For the twenty-year model, 558 breeding black ducks were observed on 411 occasions at 175 wetlands, and 53 breeding mallards were observed on 46 occasions at 32 wetlands. Mallards and black ducks were observed on the same wetland 17 times, in the same year.

Clear-cutting was the most frequently used forest harvest method within 1000m of a wetland edge in the ten-year model, followed by stand management, none, and other harvest methods (2691, 1990, 1202, and 849 observations, respectively; see table 2.2 for method breakdowns). Clear-cutting was also the most frequently used forest harvest method within 1000m of a wetland edge in the twenty-year model, followed by stand management, other harvest methods, and none (3026, 1867, 1222, and 676 observations, respectively), although harvest blocks with a stand management treatment were generally larger. Wetland area ranged from <1 to 237 hectares (mean= 4.5 ± 3.9SE). Mean wetland area with black ducks present was 12.6ha ± 5.5 SE, and 22.1ha ± 7.0SE for mallards.

Wetland area where both mallard and black duck were observed in the same year ranged from ~2-237ha. Black ducks and mallards were both more likely to be observed on larger wetlands that had harvesting near the wetland and a large proportion of intact 1000m buffer (Figures 2.1-2.4).

Black Duck Model Selection

Twelve models explained the variation better than the null in the ten-year model (Table 2.5). The top candidate model for the ten-year time period was model 10, which retained four variables (proportion of intact forest within 1000m of wetland edge, distance to closest harvest, wetland area, and presence/absence of mallards). In this model, proportion of intact forest within 1000m of the wetland edge, wetland area and presence/absence of mallards had a positive relationship with the presence of black ducks and the distance to closest harvest had a negative relationship ($\beta_{\text{proportion intact 1000m}}=0.612$ [CI = 0.383, 0.841], $\beta_{\text{wetland area}}=2.167$ [CI = 1.9407, 2.939); $\beta_{\text{mallard presence/absence}}=2.166$ [CI = 1.7103, 2.623], $\beta_{\text{closest harvest in 1000m}}=-0.0263$ [CI = -0.0359, -0.0167; Figures 2.5-2.9). For the ten-year period, black ducks were more likely to be present on larger wetlands with a larger proportion of intact forest within 1000m, where harvest occurred closer to the wetland, and in the presence of mallards.

Eleven models explained the variation better than the null for the twenty-year model (Table 2.6). The top model, model 18, contained only the variables of wetland area and presence/absence of mallards. These variables also had positive relationships with the presence of black ducks ($\beta_{\text{wetland area}}=2.429$ [CI = 2.167, 2.690], $\beta_{\text{mallard presence/absence}}=2.259$

[CI = 1.7901, 2.728]). For the twenty-year period, black ducks were more likely to be present on larger wetlands in the presence of mallards.

Mallard Model Selection

Fourteen models explained the variation better than the null for the ten-year model (Table 2.7). Three models were well supported by being within 2ΔAIC of each other. The most parsimonious and thus, top candidate model for the ten-year time period was model 6 which retained the single variable of presence/absence of black ducks. Models 18 and 10 also received strong support and retained wetland area, and presence/absence of black ducks, and proportion of intact forest within 1000m of wetland edge, distance to closest harvest, wetland area, and presence/absence of black ducks, respectively. In the top model, the presence of mallards had a positive relationship with black ducks ($\beta_{\text{black duck presence/absence}}$=2.111 [CI = 2.108, 2.114]).

Fifteen models explained the variation better than the null for the twenty-year model (Table 2.8). The same three models as the ten-year model demonstrated support and were within 2ΔAIC of each other. The most parsimonious model was again model 6, which retained the single variable of black duck presence and had a positive relationship with the presence of mallards ($\beta_{\text{black duck presence/absence}}$ =2.170 [CI = 1.706, 2.634]). Models 18 and 10 also received strong support and retained wetland area, and presence/absence of black ducks, and proportion of intact forest within 1000m of wetland edge, distance to closest harvest, wetland area, and presence/absence of black ducks, respectively. For both the ten and the twenty-year periods, mallards were more likely to be present on wetlands in the presence of black ducks.

Discussion

I found that commercial forestry and the presence of mallards affect wetland use by black ducks in forested areas of New Brunswick. Black ducks in this area are more likely to be found in the presence of mallards, on larger wetlands, with a larger proportion of intact forest within 1000m of the wetland, and forest harvest having occurred near the wetland within ten years. Black duck distribution was influenced by forest harvesting within ten years, but not twenty years. Forest harvesting did not influence mallard distribution in either the ten- or twenty-year period.

Effects of forest harvesting

The proportion of intact forest within 30m of a wetland, the year of harvest, harvest method, and harvest block size were not retained in any models that received support. The proportion of intact forest within 1000m was supported in competitive models for the ten -year models for black ducks and ten- and twenty-year models for mallards (although only the top chosen model for black ducks within 10 years). Mallards make extensive use of habitats disturbed by other large-scale landscape modifications such as agriculture (Lieske et al. 2018), so this may be because mallards are more tolerant of landscape disturbances than black ducks and their distribution is not influenced by forest harvesting.

Forest harvesting may influence food sources in wetlands (Rusch et al. 1989), so wetlands with less intact forest nearby may experience nutrient fluxes due to increased run-off. This is unlikely to explain why black ducks seem to prefer wetlands with harvesting having happened nearby, as black ducks are often observed on nutrient poor wetlands (Merendino and Ankney 1994). A more likely explanation is that forest harvesting creates attractive nesting habitat. Ground-nesting waterfowl species typically place nests in dense, low cover (Bellrose 1976). Following disturbance from forest harvesting, the herbaceous layer regrows quickly, and grasses and shrubs contribute proportionally more to overall biomass of the stand than they do in older stands (MacLean and Wein 1977). Lemelin et al. (2007) suggested that clear cut logging created suitable nesting habitat for several species of ground-nesting waterfowl, including black ducks. Although I did not find support for any models that included the harvest treatment type, understory growth may differ between harvest treatments (Roberts and Zhu 2002). Clear cutting is the predominant harvesting method in the area, so I may not have seen an effect because of a lack of sufficient samples from other harvesting methods, or, the harvest methods I quantified may not be different enough to elicit a response in black duck presence. I also did not find support for models that included the size of the closest harvest block. Models that included the proportion of intact forest within 1000m of the wetland edge did receive support, so harvesting in single harvest blocks likely induces less effect than the overall intensity of harvest across the landscape.

For black ducks, the proportion of intact forest within 1000m of a wetland edge and distance to the closest wetland variables were only supported in the ten year model, suggesting that the effects of forest harvesting are more pronounced within ten years of harvesting than within twenty years. In Quebec, Lemelin et al. (2007) did not find any local, short term effects on ground-nesting waterfowl when harvesting occurred within 1000m of an observed pair. Börger and Nudds (2014) similarly found that black ducks were likely to avoid recently disturbed forests, but not successional forests within 10-20 years old. This may also be driven by fundamental changes in forest harvesting practices. When analyzing a wetland surveyed in 1995, I considered the harvest that occurred from 1984-1994 and 1974-1994. Forestry practices have become more ecologically conscious since the *Crown Lands and Forest Act* was put in place in 1982 (Holloway et al. 2008).

Potential for Interactions with Mallards

The positive relationship I detected between black ducks and mallards is similar to the results of Dwyer and Baldassare (1994) who found that undisturbed forest was not an isolating mechanism for black ducks from mallards. Börger and Nudds (2014) found that black ducks and mallards had similar occupancy patterns in the boreal forest, which is similar to my finding that black ducks and mallards are likely to be observed on the same wetland. It is unlikely that the presence of the other species is what drives this relationship, but rather that they are both attracted to the same habitats. It is possible that some observations included hybrids, which would be consistent with both species being present on the wetland. Because it is difficult to determine the sex of black ducks from a distance, sex is often not recorded for most black duck observations (sensu Bordage et al. 2017) and it remains unknown whether observations of potential pairs were heterospecific or included hybrids.

Black ducks and mallards have been found to compete directly in the western part of NB where agriculture is more prevalent (Petrie et al. 2012) and mallards are more likely to be observed. Although I did not directly measure competition, I found no evidence of competitive exclusion as black ducks and mallards occurred on many of the same wetlands. However, it is likely that black ducks compete with mallards for resources in these wetlands, as these species have similar diets (English et al. 2017). This was unexpected because Petrie et al. (2012) found that on small wetlands (<1ha) black ducks were more likely to be observed where mallards were removed.

Wetland Characteristics

Black ducks and mallards were more likely to be present on larger wetlands (>2ha) than on smaller wetlands. The amount of available habitat is likely not limiting to these waterfowl as there was a high proportion of large wetlands without any black ducks or mallards observed. It is possible that my sample of wetland areas is unrepresentative of the wider range of wetland areas on the landscape. I only included wetlands that were completely within the survey boundaries to ensure that the entire wetland was surveyed. This resulted in some large wetlands being excluded and may have resulted in a disproportionate representation of small wetlands. Black ducks use a variety of wetland areas including small, ephemeral pools as small as ~3m^2 (Ringelman et al. 1982) and were more likely to be found on wetlands <8ha in Quebec (Lemelin et al. 2010). It is possible that black ducks using small wetlands may be less detectable on surveys in forested environments. Black ducks and mallards defend territories intra-andinterspecifically (Anderson and Titman 1992; Seymour 1992). Because of this spacing mechanism, it is unlikely that >1 pair will be present on a wetland, unless it was suitably large enough to support multiple territories. It may be possible that habitat variables I did not measure, such as vegetation type, are more responsible for wetland selection.

Management Implications

Most wetlands had a high proportion of intact 30m buffer, which eliminated any negative effect on black duck presence. As such, a 30m buffer around wetlands (as required in NB) appears to be adequate in preserving the presence of black ducks. The 30m buffer size was not retained in any of the models, but models that included the proportion of intact forest within 1000m were, which may mean that the 1000m buffer size is more representative of the actual area that influences black duck distribution. Maintaining a mosaic of intact upland forest and harvested sites providing nesting habitat around wetlands will benefit breeding black ducks in NB. I did not include post-harvest management such as natural regeneration or plantations in analysis. These methods may differentially affect nesting habitat and wetland health. Future work would also benefit from understanding how other post-harvest management forest practices, such as the spraying of glyphosate on plantations, affect nesting habitat.

Tables and Figures

Table 2.1 Centroid locations of the helicopter-based waterfowl breeding pair survey in eastern Canada plots. Plots are 25km^2 and surveyed on a semi-regular schedule by the Canadian Wildlife Service. Plot distribution is located in Figure 2.1.

Plot ID	Latitude	Longitude
56052A	-64.96679	45.92413
56089A	-65.15434	46.10436
56055A	-65.69938	46.13688
56053A	-65.03241	46.18400
56054A	-65.44432	46.22453
56090A	-64.96678	46.27012
56066D	-65.40252	46.58737
56067A	-65.13369	46.65156
56082A	-65.43051	46.90894
56065A	-65.93561	47.04186
56086A	-65.69049	47.19368
56070A	-65.18011	47.72015
56058A	-66.60553	45.37050
56084A	-67.27911	45.51991
56085A	-67.18760	45.53822
56091A	-67.40306	45.62501
56059A	-67.20222	45.82251
56060A	-67.61337	45.93265
56056B	-66.32283	45.94569
56076A	-67.07766	46.33091
56061A	-67.17356	46.57582
56088A	-66.96594	46.59617
56064A	-66.28028	46.80871
56081A	-66.12515	46.95953
56063A	-66.85118	47.10253
56077A	-67.39327	47.28510
56078A	-67.33763	47.33740
56083A	-67.03344	47.51975
56071A	-66.23454	47.69403
56075A	-67.56629	47.73191
56074A	-67.43173	47.77154
56079A	-66.32873	47.83304
56080A	-66.18844	47.83239

Table 2.2. Breakdown of the closest harvest block harvest method categories. The thirteen harvest types were condensed into four main categories based on the degree of potential habitat disturbance for that harvest type.

Harvest Type	Count (10 Year)	Count (20 year)	Category	Description
None	1202	676	None	No harvest blocks within 1000m of wetland edge
Clear Cut	2691	3026	Clear cut	Even aged stand management, every merchantable stem removed.
Precommercial thinning	1635	1576	Stand management treatment	Maintenance to improve stand. Stems are removed but harvest is not the main priority.
Plantation cleaning	316	255		
Commercial Thinning	39	36		
Partial Cut	536	889	Other harvest treatment	Removal of merchantable stems resulting in even or uneven stand management.
Selection cut	143	134		
Shelterwood cut	77	100		
Regeneration protection clear	35	29		
Salvage cut	23	34		
Strip cut	17	16		
Softwood removal cut	8	8		
Residual removal	6	8		
Patch cut	4	4		

Table 2.3. Description of variables included in general linear mixed effects candidate models. The same models were used to determine the effects of harvest within the ten- and twenty-year periods preceding the wetland survey year.

Variable	Description
ABDU	Response variable - presence/absence of breeding black ducks (binomial family)
MALL	Presence/absence of breeding mallards
WL_ID	Random factor - individual wetland identification
Plot_ID	The individual identification of the plot that the wetland is located within
WL_ha	Wetland area in hectares. Centered within 2 standard deviations of the mean.
Prop30	Proportion of intact forest within 30m of wetland edge. Centered within 2 standard deviations of the mean.
Prop1000	Proportion of intact forest within 1000m of wetland edge. Centered within 2 standard deviations of the mean.
NEAR_DIST	Distance in m to the closest harvest block within 1000m of the wetland edge. Square root was taken to account for variation.
RecentTRT_condensed	Harvest treatment of the closest harvest block within 1000m of the wetland edge. Fifteen unique treatments were condensed into four categories (Table 2.2)
Cut_Area	Harvest block size in hectares. Centered within 2 standard deviations of the mean.

Table 2.4. Pearson correlation coefficients (*r*) between numeric predictor variables. All variables were retained as no *r*-values were >0.7. Variables names are in table 2.3.

	WL_ha	Prop30	Prop1000	NEAR_DIST	Cut_Area
WL_ha	-	0.0276	-0.0229	-0.0931	0.00558
Prop30	0.0276	-	0.440	0.369	-0.0122
Prop1000	-0.0229	0.4400	-	0.695	-0.232
NEAR_DIST	-0.0931	0.369	0.695	-	-0.219
Cut_Area	0.00558	-0.0122	-0.232	-0.219	-

Table 2.5 AIC selection of models describing the effects of forest harvesting and presence of mallards on the presence of black ducks within 10 years of a wetland being surveyed. If competing models were <2 ∆AIC apart, the most parsimonious model was selected. Models are displayed in order of increasing AIC value. Models within 2∆AIC were considered to receive strong support, models within 2-4∆AIC were considered to receive moderate support. The top model that described the presence/absence of black ducks within ten years of harvesting retained the variables wetland area (WL_ha), Proportion of intact forest within 1000m of the wetland edge (Prop1000), distance to the closest harvest within 1000m of the wetland edge (NEAR_DIST), and the presence/absence of mallards (MALL). Variable abbreviations are shown in Table 2.3.

Model number	Model	AIC	∆AIC
10	ABDU ~ WL_ha + Prop1000 + NEAR_DIST + MALL + (1|Plot_ID/WL_ID)	2253.4	0
18	ABDU~ WL_ha+ MALL + (1|Plot_ID/WL_ID)	2258.4	5
20	ABDU~ Prop1000+NEAR_DIST +WL_ha + (1|Plot_ID/WL_ID)	2273.5	20.1
19	ABDU~ Prop30+NEAR_DIST + WL_ha + (1|Plot_ID/WL_ID)	2279.2	25.8
4	ABDU ~ WL_ha + (1|Plot_ID/WL_ID)	2279.3	25.9
9	ABDU ~ WL_ha + Prop1000 +(1|Plot_ID/WL_ID)	2279.7	26.3
8	ABDU ~ WL_ha + Prop30 +(1|Plot_ID/WL_ID)	2280.8	27.4
12	ABDU~ RecentTRT_condensed + RecentTRT_YR + WL_ha + (1|Plot_ID/WL_ID)	2283.1	29.7
13	ABDU~ RecentTRT_condensed + RecentTRT_YR + WL_ha + NEAR_DIST +(1|Plot_ID/WL_ID)	2283.6	30.2
17	ABDU~ RecentTRT_condensed + WL_ha+ Cut_Area + (1|Plot_ID/WL_ID)	2283.6	30.2
6	ABDU ~ MALL + (1|Plot_ID/WL_ID)	2355.6	102.2
16	ABDU~ Prop1000 + NEAR_DIST+ (1|Plot_ID/WL_ID)	2369.7	116.3
null	ABDU~ 1 + (1|Plot_ID/WL_ID)	2373.6	120.2
3	ABDU ~ Prop1000 + (1|Plot_ID/WL_ID)	2374.3	120.9
5	ABDU ~NEAR_DIST + (1|Plot_ID/WL_ID)	2374.3	120.9
15	ABDU~ Prop30 + NEAR_DIST +(1|Plot_ID/WL_ID)	2375.2	121.8
2	ABDU ~ Prop30 + (1|Plot_ID/WL_ID)	2375.5	122.1
11	ABDU~ RecentTRT_condensed + RecentTRT_YR +(1|Plot_ID/WL_ID)	2378.2	124.8
7	ABDU ~ RecentTRT_condensed + (1|Plot_ID/WL_ID)	2378.5	125.1
14	ABDU~ RecentTRT_condensed + NEAR_DIST+ RecentTRT_YR + (1|Plot_ID/WL_ID)	2379.5	126.1

Table 2.6 AIC selection of models describing the effects of forest harvesting and presence of mallards on the presence of black ducks within 20 years of a wetland being surveyed. If competing models were <2 ΔAIC apart, the most parsimonious model was selected. Models are displayed in order of increasing AIC value. Models within 2ΔAIC were considered to receive strong support, models within 2-4ΔAIC were considered to receive moderate support. The top model that described the presence/absence of black ducks within twenty years of harvesting retained the variables wetland area (WL_ha) and presence/absence of mallards (MALL). Variable abbreviations are shown in Table 2.3.

Model number	Model	AIC	ΔAIC
18	ABDU~ WL_ha+ MALL + (1|Plot_ID/WL_ID)	2284.9	0
10	ABDU ~ WL_ha + Prop1000 + NEAR_DIST + MALL + (1|Plot_ID/WL_ID)	2287.4	2.5
4	ABDU ~ WL_ha + (1|Plot_ID/WL_ID)	2306.0	21.1
19	ABDU~ Prop30+NEAR_DIST + WL_ha + (1|Plot_ID/WL_ID)	2306.6	21.7
8	ABDU ~ WL_ha + Prop30 +(1|Plot_ID/WL_ID)	2307.3	22.4
9	ABDU ~ WL_ha + Prop1000 +(1|Plot_ID/WL_ID)	2308.0	23.1
20	ABDU~ Prop1000+NEAR_DIST +WL_ha + (1|Plot_ID/WL_ID)	2308.4	23.5
13	ABDU~ RecentTRT_condensed + RecentTRT_YR + WL_ha + NEAR_DIST +(1|Plot_ID/WL_ID)	2309.1	24.2
12	ABDU~ RecentTRT_condensed + RecentTRT_YR + WL_ha + (1|Plot_ID/WL_ID)	2309.8	24.9
17	ABDU~ RecentTRT_condensed + WL_ha+ Cut_Area + (1|Plot_ID/WL_ID)	2309.8	24.9
6	ABDU ~ MALL + (1|Plot_ID/WL_ID)	2376.4	91.5
null	ABDU~ 1 + (1|Plot_ID/WL_ID)	2395.2	110.3
5	ABDU ~NEAR_DIST + (1|Plot_ID/WL_ID)	2396.0	111.1
3	ABDU ~ Prop1000 + (1|Plot_ID/WL_ID)	2397.0	112.1
15	ABDU~ Prop30 + NEAR_DIST +(1|Plot_ID/WL_ID)	2397.0	112.1
2	ABDU ~ Prop30 + (1|Plot_ID/WL_ID)	2397.1	112.2
16	ABDU~ Prop1000 + NEAR_DIST+ (1|Plot_ID/WL_ID)	2397.9	113
7	ABDU ~ RecentTRT_condensed + (1|Plot_ID/WL_ID)	2399.8	114.9
11	ABDU~ RecentTRT_condensed + RecentTRT_YR +(1|Plot_ID/WL_ID)	2400.4	115.5
14	ABDU~ RecentTRT_condensed + NEAR_DIST+ RecentTRT_YR + (1|Plot_ID/WL_ID)	2401.7	116.8

Table 2.7 AIC selection of models describing the effects of forest harvesting and presence of black ducks on the presence of mallards within 10 years of a wetland being surveyed. If competing models were <2 ∆AIC apart, the most parsimonious model was selected. Models are displayed in order of increasing AIC value. Models within 2∆AIC were considered to receive strong support, models within 2-4∆AIC were considered to receive moderate support. The top model explaining the presence/absence of mallards within ten years of harvesting retained the variables presence/absence of black ducks (ABDU). Models also containing the variables wetland area (WL_ha), proportion of intact forest within 1000m of a wetland edge (Prop1000), and distance to the closest harvest within 1000m of the wetland edge (NEAR_DIST) also received strong support. Variable abbreviations are shown in Table 2.3.

Model number	Model	AIC	∆AIC
6	MALL ~ ABDU + (1|Plot_ID/WL_ID)	423.8	0
18	MALL~ WL_ha+ ABDU + (1|Plot_ID/WL_ID)	423.9	0.1
10	MALL ~ WL_ha + Prop1000 + NEAR_DIST + ABDU + (1|Plot_ID/WL_ID)	425.7	1.9
12	MALL~ RecentTRT_condensed + RecentTRT_YR + WL_ha + (1|Plot_ID/WL_ID)	436.5	12.7
11	MALL~ RecentTRT_condensed + RecentTRT_YR +(1|Plot_ID/WL_ID)	438.5	14.7
13	MALL~ RecentTRT_condensed + RecentTRT_YR + WL_ha + NEAR_DIST +(1|Plot_ID/WL_ID)	439.0	15.2
4	MALL ~ WL_ha + (1|Plot_ID/WL_ID)	440.2	16.4
14	MALL~ RecentTRT_condensed + NEAR_DIST+ RecentTRT_YR + (1|Plot_ID/WL_ID)	440.3	16.5
20	MALL~ Prop1000+NEAR_DIST +WL_ha + (1|Plot_ID/WL_ID)	440.4	16.6
19	MALL~ Prop30+NEAR_DIST + WL_ha + (1|Plot_ID/WL_ID)	441.1	17.3
5	MALL ~NEAR_DIST + (1|Plot_ID/WL_ID)	441.4	17.6
16	MALL~ Prop1000 + NEAR_DIST+ (1|Plot_ID/WL_ID)	441.8	18
8	MALL ~ WL_ha + Prop30 +(1|Plot_ID/WL_ID)	442.2	18.4
9	MALL ~ WL_ha + Prop1000 +(1|Plot_ID/WL_ID)	442.2	18.4
null	MALL~ 1 + (1|Plot_ID/WL_ID)	442.3	18.5
15	MALL~ Prop30 + NEAR_DIST +(1|Plot_ID/WL_ID)	442.4	18.6
2	MALL ~ Prop30 + (1|Plot_ID/WL_ID)	444.2	20.4
3	MALL ~ Prop1000 + (1|Plot_ID/WL_ID)	444.3	20.5
7	MALL ~ RecentTRT_condensed + (1|Plot_ID/WL_ID)	444.5	20.7
17	MALL~ RecentTRT_condensed + WL_ha+ Cut_Area + (1|Plot_ID/WL_ID)	445.3	21.5

Table 2.8 AIC selection of models describing the effects of forest harvesting and presence of black ducks on the presence of mallards within 20 years of a wetland being surveyed. If competing models were <2 ∆AIC apart, the most parsimonious model was selected. Models are displayed in order of increasing AIC value. Models within 2∆AIC were considered to receive strong support, models within 2-4∆AIC were considered to receive moderate support. The top model explaining the presence/absence of mallards within twenty years of harvesting retained one variable; presence/absence of black ducks (ABDU). Models also containing the variables wetland area (WL_ha), proportion of intact forest within 1000m of a wetland edge (Prop1000), and distance to the closest harvest within 1000m of the wetland edge (NEAR_DIST) also received strong support. Variable abbreviations are shown in Table 2.3.

Model ID	Model	AIC	∆AIC
6	MALL ~ ABDU + (1|Plot_ID/WL_ID)	421.4	0
18	MALL~ WL_ha+ ABDU + (1|Plot_ID/WL_ID)	421.7	0.3
10	MALL ~ WL_ha + Prop1000 + NEAR_DIST + ABDU + (1|Plot_ID/WL_ID)	422.3	0.9
12	MALL~ RecentTRT_condensed + RecentTRT_YR + WL_ha + (1|Plot_ID/WL_ID)	429.8	8.4
11	MALL~ RecentTRT_condensed + RecentTRT_YR +(1|Plot_ID/WL_ID)	431.7	10.3
5	MALL ~NEAR_DIST + (1|Plot_ID/WL_ID)	437.4	16
17	MALL~ RecentTRT_condensed + WL_ha+ Cut_Area + (1|Plot_ID/WL_ID)	437.8	16.4
19	MALL~ Prop30+NEAR_DIST + WL_ha + (1|Plot_ID/WL_ID)	438.2	16.8
20	MALL~ Prop1000+NEAR_DIST +WL_ha + (1|Plot_ID/WL_ID)	438.2	16.8
7	MALL ~ RecentTRT_condensed + (1|Plot_ID/WL_ID)	438.8	17.4
4	MALL ~ WL_ha + (1|Plot_ID/WL_ID)	438.9	17.5
9	MALL ~ WL_ha + Prop1000 +(1|Plot_ID/WL_ID)	439.4	18
15	MALL~ Prop30 + NEAR_DIST +(1|Plot_ID/WL_ID)	439.4	18
16	MALL~ Prop1000 + NEAR_DIST+ (1|Plot_ID/WL_ID)	439.4	18
8	MALL ~ WL_ha + Prop30 +(1|Plot_ID/WL_ID)	440.0	18.6
null	MALL~ 1 + (1|Plot_ID/WL_ID)	440.7	19.3
3	MALL ~ Prop1000 + (1|Plot_ID/WL_ID)	441.1	19.7
2	MALL ~ Prop30 + (1|Plot_ID/WL_ID)	441.9	20.5
2	MALL ~ Prop30 + (1 |WL_ID)	440.0	20.5
17	MALL~ RecentTRT + Cut_Area_cat + WL_ha+ (1|WL_ID)	457.4	37.9

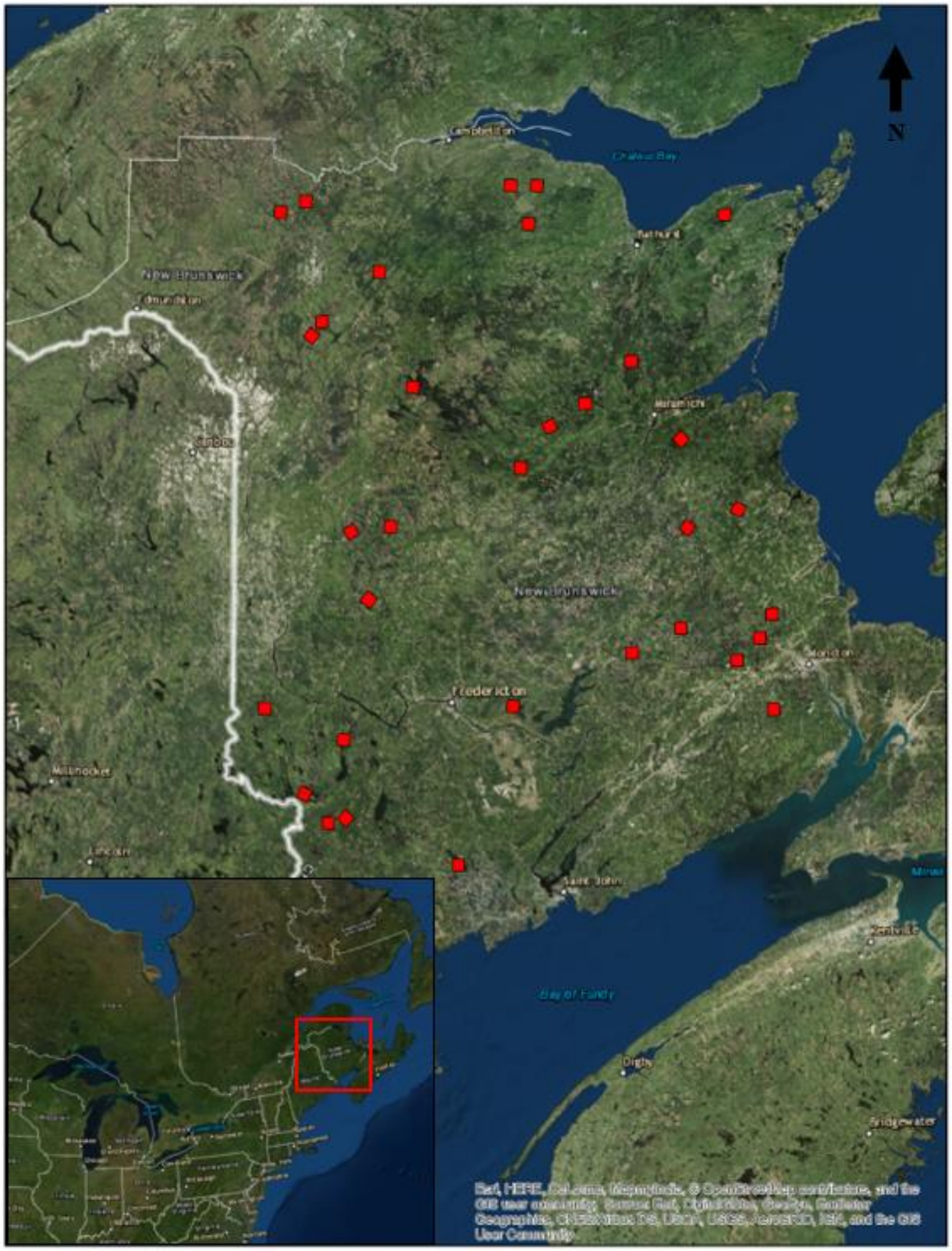

Figure 2.1. Distribution of Helicopter-based waterfowl breeding pair survey in eastern Canada plots across the province of New Brunswick, Canada. Plots are 25km^2 and surveyed on a rotational schedule (among years) by the Canadian Wildlife Service since 1995. Coordinates of plot centroids are located in Table 2.1.

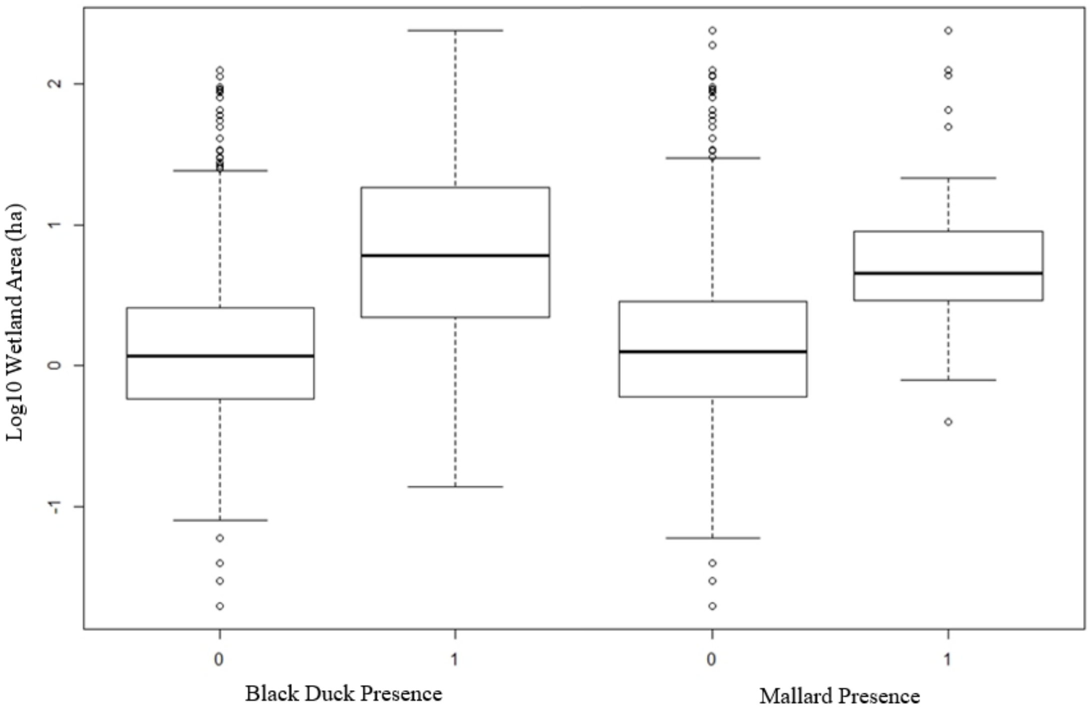

Figure 2.1. Wetland area with black ducks and mallards present (1) or absent (0) in New Brunswick, Canada. Both black ducks and mallards were more likely to be present on larger wetlands.

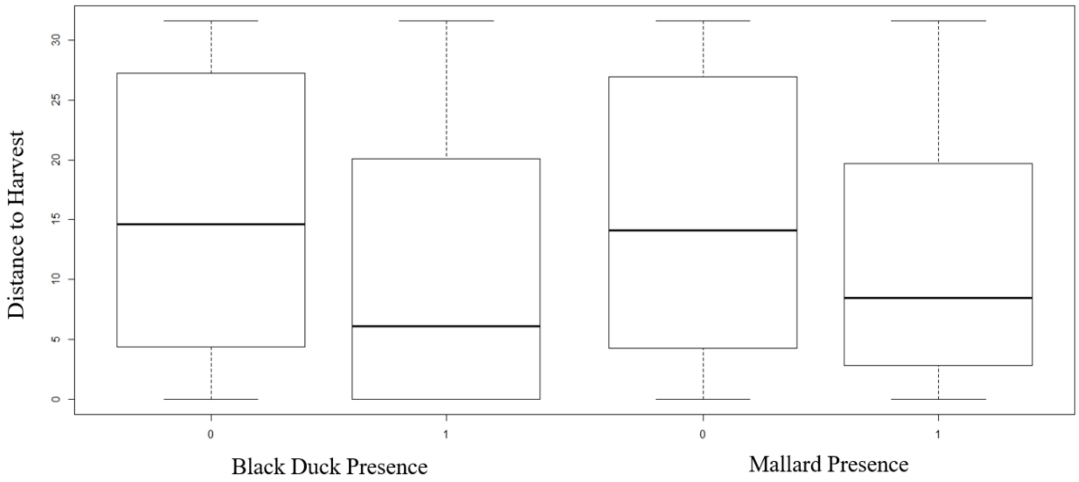

Figure 2.3. Distance to forest harvest from a wetland edge (square root) with black ducks and mallards present (1) or absent (0) in New Brunswick, Canada. Both black ducks and mallards were more likely to be present on wetlands where harvest occurred near the wetland.

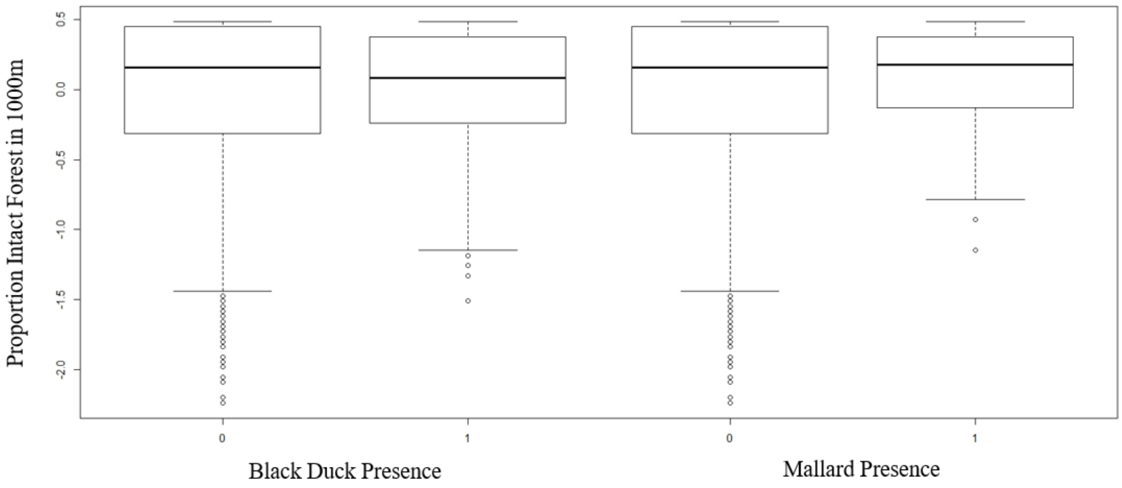

Figure 2.4. Proportion of intact forest within 1000m of the wetland edge (centered within 2 standard deviations of the mean) with black ducks and mallards present (1) or absent (0) in New Brunswick, Canada. Both black ducks and mallards were more likely to be present on wetlands where most of the buffer zone was intact.

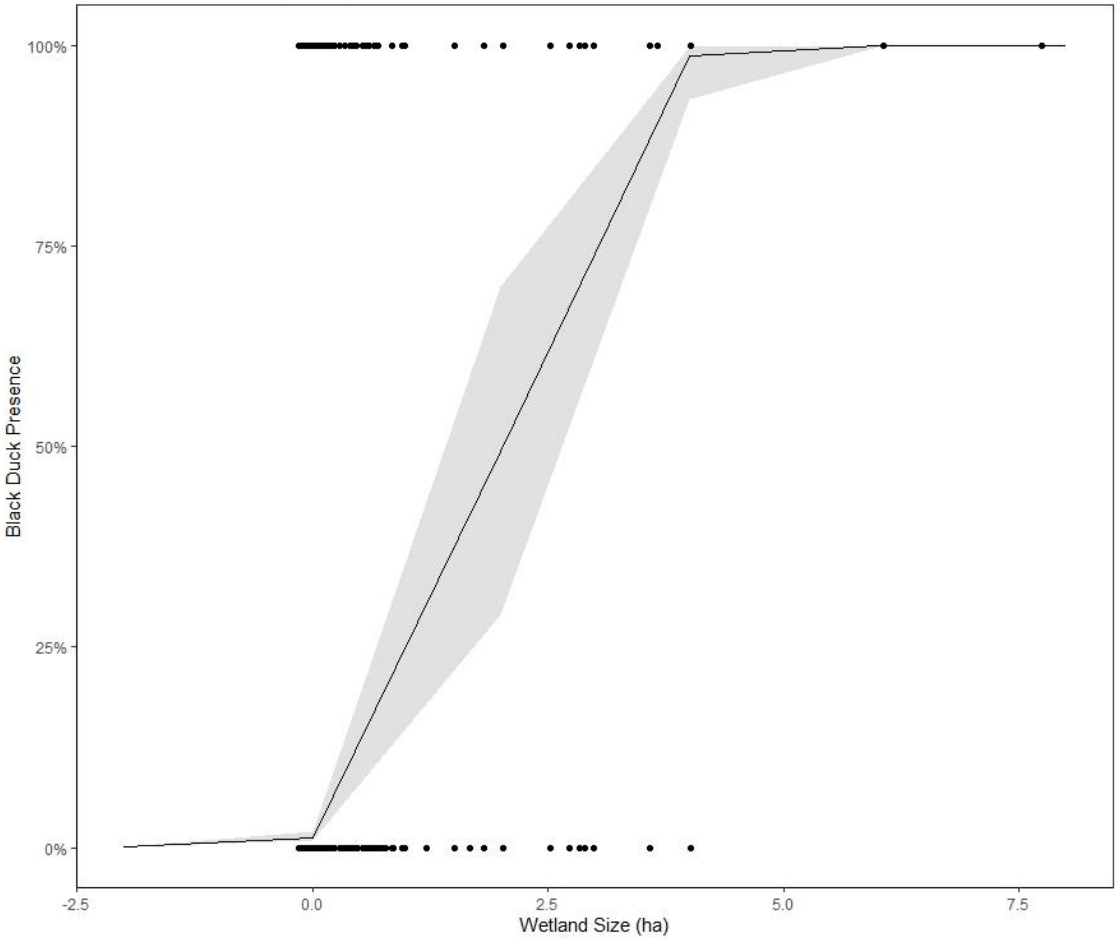

Figure 2.5. Predicted probabilities with 95% confidence intervals (gray shading) and data points (black points) of black duck presence/absence. Wetland area (centered within two standard deviations of the mean) had a positive predicted relationship with the presence of black ducks in commercial forests of New Brunswick, Canada.

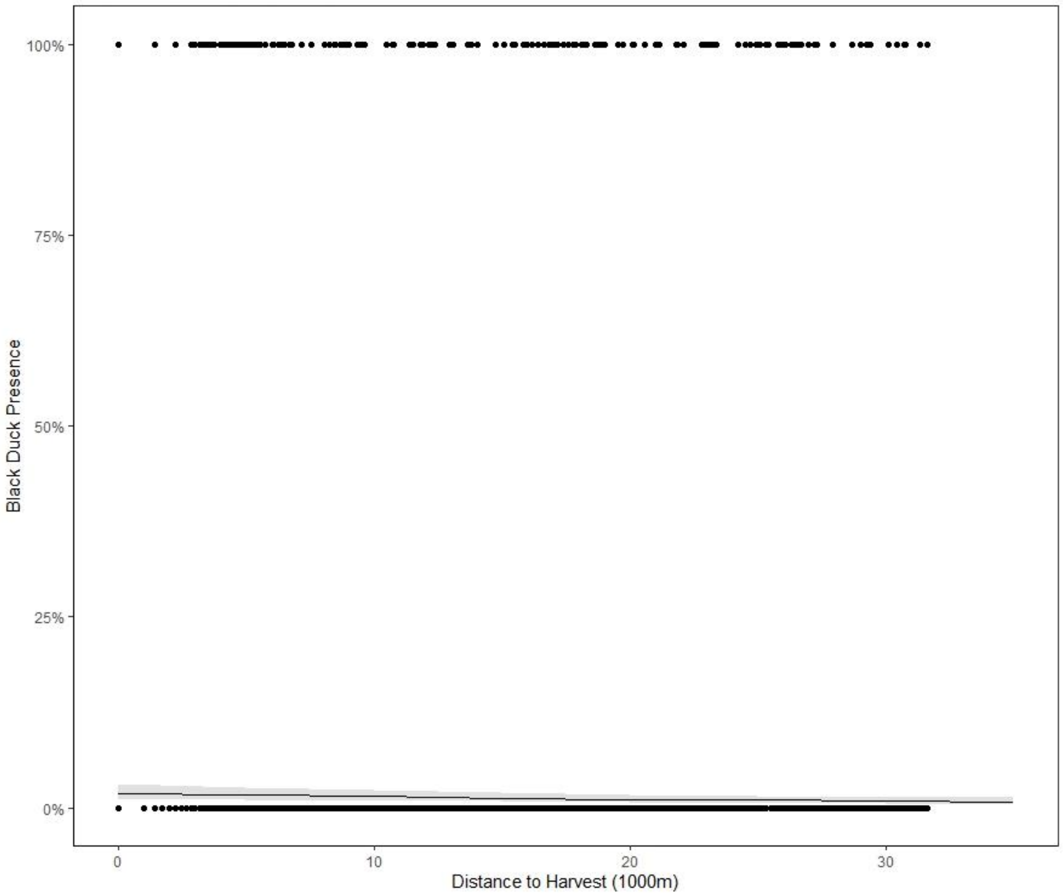

Figure 2.6. Predicted probabilities with 95% confidence intervals (gray shading) and data points (black points) of black duck presence/absence. Distance to harvest (square root) had a negative predicted relationship with the presence of black ducks in commercial forests of New Brunswick, Canada.

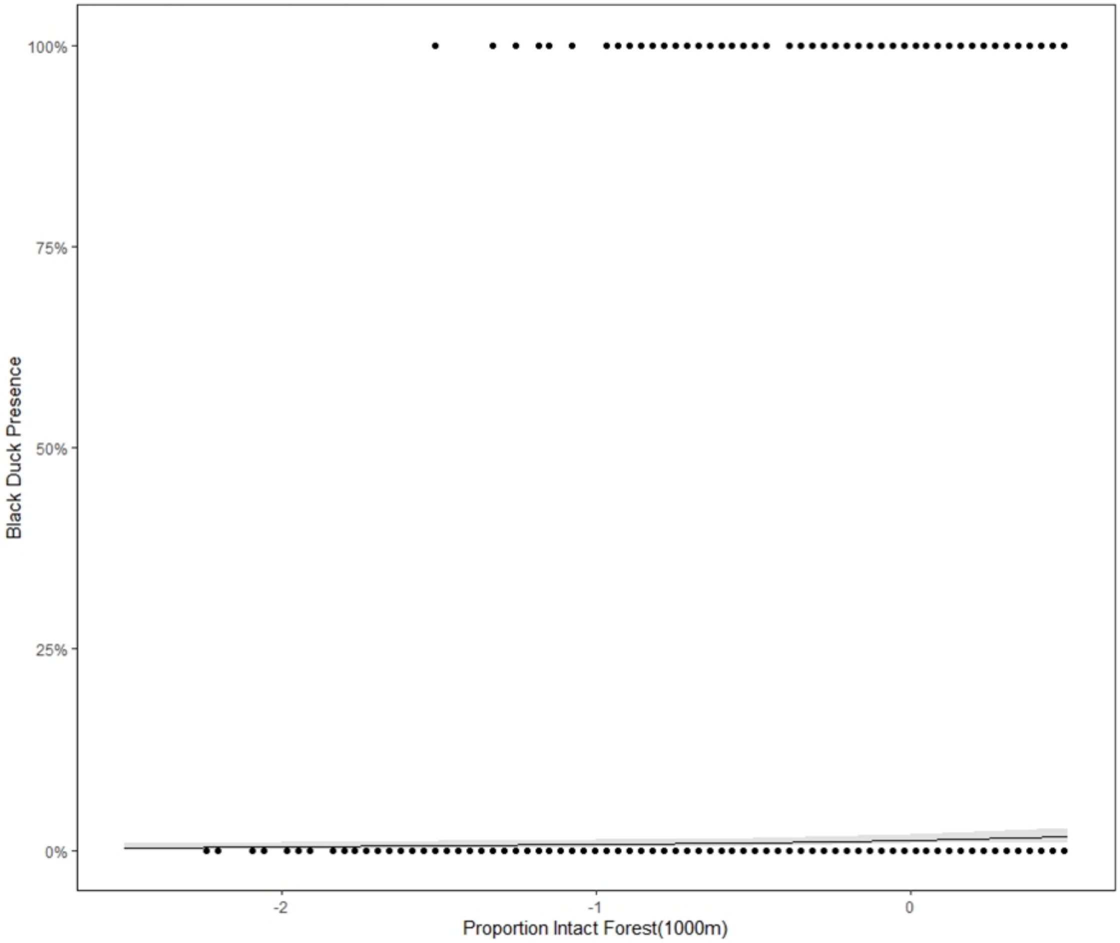

Figure 2.7. Predicted probabilities with 95% confidence intervals (gray shading) and data points (black points) of black duck presence/absence. The proportion of intact 1000m buffer (centered within 2 standard deviations of the mean) had a small, positive predicted relationship with the presence of black ducks in commercial forests of New Brunswick, Canada.

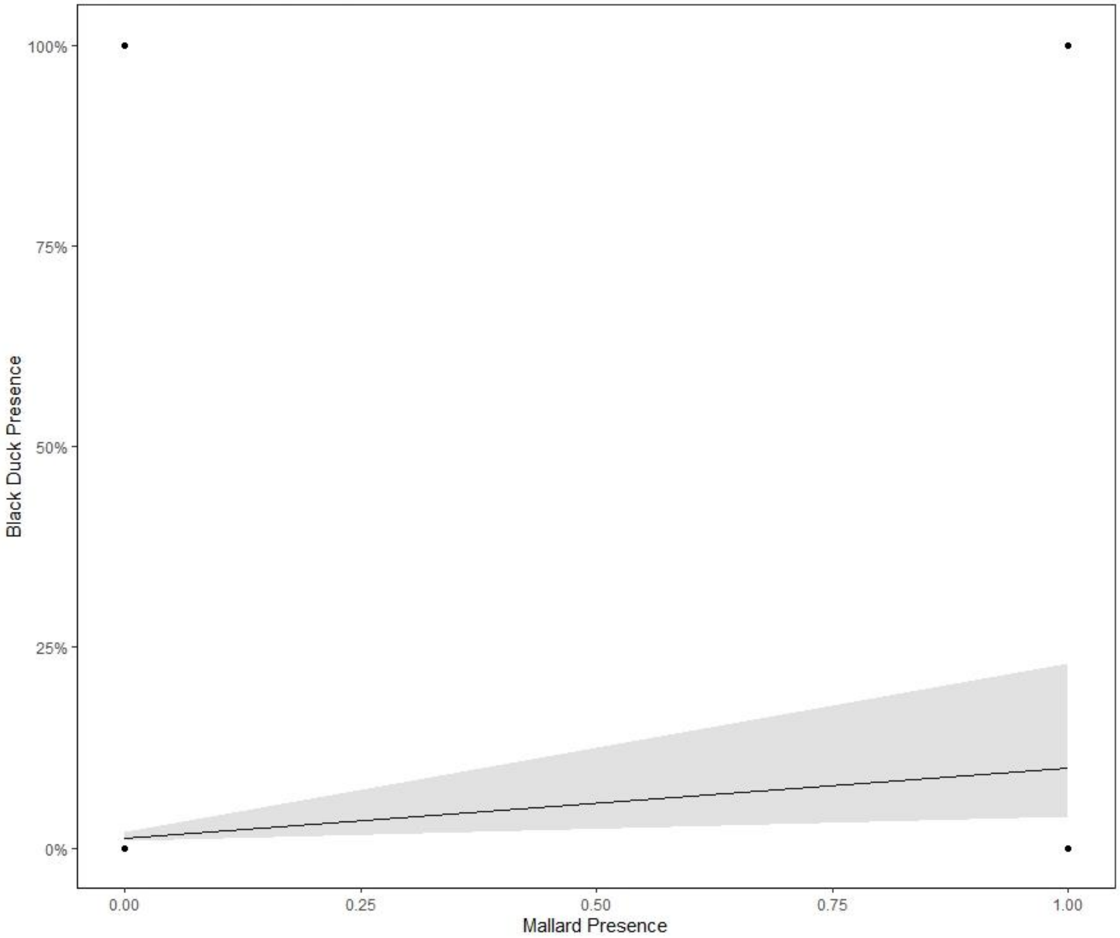

Figure 2.8. Predicted probabilities with 95% confidence intervals (gray shading) and data points (black points) of black duck presence/absence. The presence of mallards had a positive predicted relationship with the presence of black ducks in commercial forests of New Brunswick, Canada.

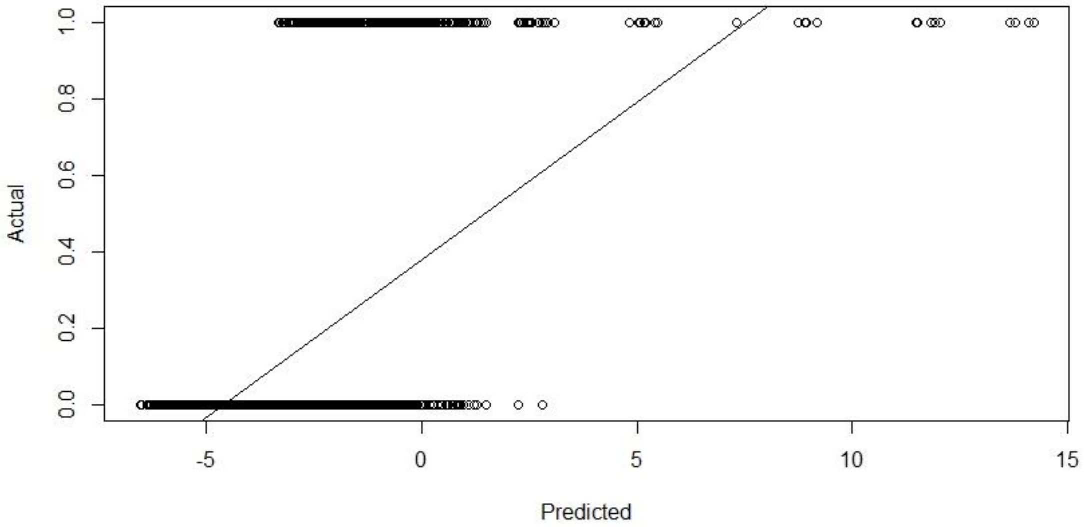

Figure 2.9. Actual vs. predicted values for the top model selected to describe the presence (1) or absence (0) of black ducks on wetlands in commercial forests of New Brunswick, Canada.

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Chapter 3. Predation Rates on Artificial Waterfowl Nests in Forest Habitat

Abstract

American black duck (*Anas rubripes)* populations steeply declined from 1950-1980 and have not returned to historic abundance levels. This decline has correlated with changes in breeding habitat, although it is unknown how anthropogenic disturbance on the breeding grounds (such as those from commercial forestry) affects nest success. I used artificial duck nests designed to mimic black duck nests to determine if commercial forestry affects nest predation rates of ground-nesting waterfowl. I deployed 100 artificial nests for a 26-day period near wetlands in an industrial forest area of New Brunswick, Canada. Nest success was high (77%), and the daily nest survival rate was 0.972. I used a generalized linear mixed effects model approach to model habitat variables with nest success or failure. None of the predictors (total buffer size, distance to the wetland edge, distance from the nest to the closest harvest block, the year the harvest block was harvested or the harvest method, distance to a road, cardinal direction from the wetland, and deployment date) influenced nest success. Predators included black bear (*Ursus americanus*), common raven (*Corvus corax*), and eastern red squirrel (*Tamiasciurus hudsonicus)*. My results indicate that ground-nesting waterfowl in the study area experience low rates of nest predation and that forestry operations at their current extent do not appear to be affecting predation rates. Future forestry operations should ensure that harvest intensity does not reach a level where ground-nesting waterfowl nest success is compromised.

Keywords Acadian forest, American black duck, *Anas rubripes*, commercial forestry, New Brunswick, forested wetlands

Introduction

American black duck (*Anas rubripes*) populations experienced steep declines of >50% during the mid-1900's and although populations have since generally stabilized, they remain below historical levels (Devers and Collins 2011). The cause of this decline remains unknown, but loss and degradation of breeding and wintering habitats, overharvesting, and interactions with mallards (*A. platyrhynchos*) have been implicated (Conroy et al. 2002). There is correlative evidence that the population decline is related to reduced habitat availability on the breeding grounds, but this has never been experimentally tested in areas facing habitat degradation (Conroy et al. 2002). Breeding black ducks make extensive use of forested habitats (Stotts and Davis 1960, Longcore et al. 2000) and commercial forest harvesting has been listed as a potential cause of black duck habitat loss and degradation (Devers and Collins 2011). Commercial forestry operations remove available forest nesting habitat, fragment remaining forest habitat, create road infrastructure, and cause disturbance both during operations and by people accessing previously remote habitat using remaining infrastructure post-harvest.

The province of New Brunswick (NB), Canada, is situated within the black duck breeding range and has experienced intensive, multigenerational commercial forest harvesting. Vegetated riparian buffer zones (“buffers”) have been identified as important areas that should receive protection because they are important habitat for numerous wildlife species, including nesting black ducks (Belanger et al. 1998). In NB, 30m buffers must be left along any wetland ≥1ha, and any natural watercourse with a discernible channel ≥0.5m (NB Clean Water Act 1989). This buffer distance is reduced to 7m for wetlands <1ha and natural watercourses <0.5m and without continuous flow, and all merchantable trees within this zone can be harvested (NB Clean Water Act 1989). This protects a portion of forested habitat for wildlife like breeding black ducks because they provide upland areas to nest and travel between water sources if they are not connected by a stream system. However, buffers can sometimes act as ecological traps (Gates and Gysel 1978) and nesting success may be compromised due to edge-related nest predation (Vander Haegen and Degraaf 1996). Quality habitat for breeding waterfowl often encompasses open water, wetland, and upland areas because this complex provides nesting sites, food sources, cover, and meets behavioural requirements such as predator avoidance (Kadlec and Smith 1992). Predation may be higher in buffers because they provide predators with opportunistic foraging opportunities while using buffers as travel lines, they may forage more in buffers because prey are present in higher densities, or they may provide foraging opportunities when located adjacent to a more preferred habitat (Andrén 1995). Optimal buffer widths to minimize edge-related nest predation vary. Artificial nests designed to mimic passerine nests have been reported to experience lower predation rates in 20m wide strips than 40-60m wide strips (Darveau et al. 1997). However, Vander Haegen and Degraaf (1996) who also used artificial nests designed to mimic passerine nests, recommended buffers be >150m to reduce edge-related predation.

Passerines may experience different predation pressures than black ducks because their nests are smaller and contain fewer, smaller eggs. Peak passerine nesting occurs in early to mid-June, but black duck nesting activity in NB begins in late April/early May. Black duck nest predation may also differ from these studies by the degree of depredation and prevalent predator species. Predation on breeding waterfowl in the prairies has been studied extensively (e.g., Sargeant and Arnold 1984, Cowardin et al. 1985, Greenwood et al. 1995, Emery et al. 2005) but has received little attention in forested habitats.

Abundant waterfowl populations are driven by high productivity during the breeding season. One way to increase local breeding populations is to undertake management actions that increase breeding success (Anderson et al. 1997). Nest success is one of the most influential factors in waterfowl population maintenance (Borgo and Conover 2015). Nest predation can alter short term population trends and long-term population trajectories (Elmberg and Gunnarsson 2007) and may help explain changes in black duck populations. The impacts of anthropogenic activities on breeding waterfowl at a forest patch scale are unknown, and Holpainen et al. (2015) state that there is an “urgent need” for studies addressing this. Forestry may influence waterfowl nest locations and predator behaviour (Slattery et al. 2011). Understanding the effects of forest harvesting on waterfowl breeding habitat and nest success is crucial considering the long-lasting effects of forestry and time required for habitat to return to pre-disturbance quality (Lemelin et al. 2007). Nest success rates to maintain population stability for dabbling ducks ranges between 15-20% in the prairie pothole region (Sovada et al., 1995), but nest success rates in forest habitats are largely unknown, as is black duck susceptibility to nest predation. Given the importance of nest success to population levels, and the desire to increase breeding black duck numbers to reach population targets, it is important to understand factors influencing nest success in a key area of the black duck breeding range. Therefore, to evaluate predation pressure on black duck nests in a forested habitat undergoing habitat degradation, I conducted artificial nest experiments to quantify predation rates and identify important predators of forest-nesting black ducks.

Methods

Study Area

In 2018, I conducted experiments in central NB, north of Doaktown (46.620N, -66.124W; figure 1). The area is in the Acadian forest ecozone, and has experienced intense, multi-generational forest harvesting. This area has small oligotrophic lakes and numerous smaller wetlands including swamps, marshes, bogs, and beaver ponds. The Dungarvon and Bartholomew rivers run north through the survey area, as well as numerous permanent and semi-permanent streams. The Acadian forest is characterized by the predominance of red spruce (*Picea rubens*), black spruce (*P. mariana*), yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*), and balsam fir (*Abies balsamea*; Loo and Ives 2003). Approximately 1% of NBs forests are harvested annually (Forests NB 2019). In NB, forestry operations must maintain a minimum ≥30m riparian buffer around wetland ≥1ha (NB Clean Water Act 1989). There is some variation in this as in some situations a portion of the merchantable stems in the buffer can be harvested as long as a 7m “no track” zone is maintained from the wetland edge, and these buffers can also be larger because harvest near the wetland is unfeasible due to forest value and logistical constraints (NB Clean Water Act 1989). Potential nest predators in the area include common raven (*Corvus corax*), American crow (*C. brachyrhynchos*), black bear (*Ursus americanus*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), and red squirrel (*Tamiasciurus hudsonicus*).

Field Experiments

Breeding waterfowl surveys flown annually by the Canadian Wildlife Service have found that breeding black duck density for most of the forested area of NB, although high for the black duck breeding range, is lower than those observed in other studies of waterfowl nests, such as those in the prairies. This survey is conducted when a portion of black duck females are incubating and thus, unlikely to be observed, so a pair, a lone male, and all males in in flocks of 2-5 are considered to represent breeding pairs ("indicated breeding pair"; Bordage et al. 2017). Indicated breeding pair density for the study area is <20 indicated breeding pairs /25km² (Lieske et al. 2012). Therefore, the likelihood of finding an adequate sample size of real black duck nests is unlikely in a study such as this. I instead deployed artificial nests to determine an index of predation pressure on ground nests of forest-breeding waterfowl. Artificial nests are generally less conspicuous than natural nests because they lack parental visits and scent, there is no nest defense, they may be placed in unrealistic locations, and may retain human scent (Rudnicky and Hunter 1993, Guyn and Clark 1997). However, data from artificial nests can provide a relative index of predation pressure and spatial and temporal trends in predation risk (Gunnarsson and Elmberg 2008, Elmberg et al. 2009, Bentzen et al. 2017).

I designed artificial nests designed to mimic black duck nests. Natural black duck nests begin as a scrape on the ground, then the hen adds material such as grass, twigs, leaves, stems, or conifer needles to create a nest bowl after egg laying begins, and down is added by the fourth or fifth egg (Longcore et al. 2000). Black ducks lay an average of nine eggs, approximately one every day (Longcore et al. 2000), and incubation onset is gradual, so nests with fewer eggs are common (Elmberg and Gunnarsson 2007). To replicate these natural nests, I created a nest bowl by creating a slight depression in the ground in which I placed six large white chicken eggs dyed light tan using black tea. I used vegetation from nearby, but not immediately adjacent to, the nest to form a nest bowl around the depression and I placed a handful of vegetation from immediately adjacent to the nest over the nest to simulate cover from a hen (Reardon 1951). To aid in nest relocation, I placed a small piece of flagging tape (<15cm) 10m west of the nest and inserted a tongue depressor below the nest with 1cm remaining above ground to aid in relocating the nest in the event of total egg loss. To reduce the amount of human scent at the nest site, I washed eggs in wetland water and wore latex gloves when creating nests and handling eggs. Using aerial images, I measured the linear distance from the edge of the wetland to the closest source of anthropogenic disturbance (harvest block or road) at each cardinal direction (N, S, E, W) because they formed the edge of the buffer patch. I deployed one nest at each cardinal direction of 25 wetlands in the study area (Figure 3.1). I used a random number generator to pre-determine the distance (0-300m or the edge of the buffer) from the water’s edge at which the nest would be placed. Nests were deployed when I observed a 1:1 ratio of lone to paired drake black ducks, as this indicates half of the black duck females are laying and half are incubating (Bordage et al. 2017). I constructed artificial nests at the pre-determined point which I located using a Garmin handheld GPS that had an accuracy ± 10m. If possible, I placed nests at the base of a tree, fallen log, or other structure to aid in relocating nests and better replicate natural nesting areas (Longcore et al 2000). I placed one trail camera ~5m from one randomly chosen (using a random number generator) nest per wetland. Cameras were programmed to take 3 burst shots at 15s intervals when triggered. Nests were deployed for 26 days, the mean incubation time for black ducks (Longcore et al. 2000), and I checked them on days 2, 5, 11, 18, and 26. On day 26, I removed intact nests along with the flagging tape and tongue depressors. If ≥1 egg remained at the end of the 26-day exposure period, I considered the nest successful.

The number of nests that I deployed is higher than the estimated black duck indicated breeding pair density and therefore nest density of the area (Lieske et al. 2012). However, this estimate does not include other ground-nesting waterfowl species in the area (Mallard and Green-winged Teal [*A. carolinensis*]), so overall, natural ground-nesting waterfowl nest density of the area is higher than black duck nesting density alone.

Landcover Data

I plotted artificial nest locations in ArcMap10.4.1 (ESRI 2016) and overlaid them with wetland and forest landcover data from the NB Department of Energy and Resource Development ("DERD") NB Forest Inventory Database. Wetland and forest harvest polygons in this layer were determined from air photo interpretation, with a subset ground-truthed and checked by DERD staff. A buffer was considered a contiguous forest patch that extended from the edge of the wetland. Therefore, a road, harvest block, or other anthropogenic activity determined the furthest buffer boundary. I used the "find near" tool in ArcGIS to extract data on the harvest date, method, and area for harvest blocks closest to artificial nests. I also used the "find near" tool to determine the distance from each nest to the closest road and determine what type of road it was (main road, logging road, dirt track, or atv trail).

Statistical Analysis

I used a logistic exposure method (Shaffer 2004) to determine daily nest survival. This method does not assume homogeneity of nest success over the exposure period. To do this, I used a generalized linear mixed effects (GLMM) approach with a modified logit link function. I used a binomial family to fit nest success or failure using the “glmer” function of the lme4 package (Bates et al. 2015) in the program R 3.4.3 (R Core Team 2019). I added a random effects term of “wetland” to account for each wetland having four artificial nests. To determine the effects of forest harvesting on nest success, I again used GLMMs as they are an appropriate method to analyze non-normal data with random effects (Anderson et al. 2000, Bolker et al. 2008). I used a binomial family to fit nest success or failure and again included a random effect term of “wetland” to account for multiple nests at a wetland. I created a set of 20 biologically appropriate candidate models (Anderson et al. 2000) and ranked them using Akaike’s Information Criterion (Akaike 1974). Models with ΔAIC< 2 were considered strongly supported and models with ΔAIC of 2-4 were considered to have little to moderate support. AIC favours more complex models with more predictors over simpler models with fewer predictors (Burnham and Anderson 2002). Therefore, if two models were within 2ΔAIC of each other, the models were considered equal and the more parsimonious model was selected as the top model. Fixed effect predictors included wetland area, distance from the nest to water, total buffer width, distance to harvest, year of harvest, size of the closest harvest block, Ordinal date of nest deployment, cardinal nest direction, distance to the closest road, road type, and wetland area. I tested for multicollinearity between numerical predictors prior to model fitting using Pearson's correlation coefficients. If *r* values were >0.7 (a common threshold for collinearity; Dormann et al. 2012) then pairs were considered colinear and not included in the same models. No *r* values were >0.7, so no pairs were eliminated (Table 3.1)

Results

Nests were deployed 19-29 May 2018. Depredations occurred throughout the trial period, with an increasing number of depredations as exposure time increased (Figure 3.2.). One nest was accidentally destroyed by personnel and excluded from analysis. In total, 23 nests were depredated. Trail camera analysis identified black bear (one nest) and common raven (one nest) depredation events. The black bear destroyed the nest bowl and consumed all eggs, leaving small eggshells in the nest bowl. The common raven removed all eggs from the nest bowl and left the nest bowl intact. Eastern red squirrels were seen on trail cameras at three nests. They cached or scattered eggs near the nest site but did not completely remove the eggs from the area. This pattern of disturbance occurred at an additional five nests and these depredations were attributed to red squirrels. Predator species could not be determined for the remaining 13 depredated nests. Fourteen of 23 depredated nests were found during the last nest check and had occurred between day 18 and 26.

Overall, nest success was high (77%). The daily nest survival rate was 0.972. Three models were well supported and were within 2ΔAIC of each other; the null model,

model three, and model four (Table 3.2). Model four corresponded to the numerically lowest AIC value and only retained the variable of distance to road. However, because it was within 2ΔAIC of the null, none of the models are considered to explain the variation in nest success better than the null. Only on one occasion was >1 nest per wetland depredated in the same check period, indicating that I did not induce density-dependent nest predation.

Mean buffer width at a nest location was 181±102 meters and nests were placed 1-230 meters from the wetland edge. Mean distance to a harvest block was 101±121 meters; these values varied between wetlands and between cardinal directions (Table 3.3).

Discussion

I found that artificial nests designed to mimic black duck nests had a low probability of predation in forest habitat of NB, and that predation was more common as exposure time increased. None of the habitat variables that I measured influenced nest predation rates, indicating that predation rates are driven by other factors than I addressed here.

The purpose of this study was to determine the difference between predation rates of waterfowl nests in riparian buffer zones of differing widths. Similar to a study on predation of passerine nests by Darveau et al. (1997), I cannot conclude that forestry practices, and specifically riparian buffer width, alter predation rates. I also did not find an effect from roads on nest success. This is similar to a study of artificial waterfowl and shorebird nests in Alaska (Bentzen et al. 2017). The lack of an effect may be because of the low predation rates I found in my study. Some of the most common waterfowl nest predators such as raccoon and skunks are present in much lower densities in forest habitats, likely due to minimal human occupation (Darveau et al. 1997). In New Brunswick, the density of raccoons in forest habitat is approximately 9 per km^2, which is doubled in agricultural areas at 18 per km^{2}and over 200 per km^2 in urban parks (Belyea et al. 2018). Forest fragmentation in NB is widespread, so the effect of smaller scale fragmentation may be masked; harvest occurring in less fragmented forest may have a more apparent effect.

I found an increasing number of nest depredations later in the exposure period, and most predation events occurred during the last 8 days of the trial. This may indicate that late nesting or renesting individuals experience decreased nest success. Black duck nests initiated earlier are typically more successful. This has been reported for black ducks nesting along the St. Lawrence estuary in Quebec (Belanger et al. 1998) and in the Chesapeake Bay (Stotts and Davis 1960).

Black duck nest success in an agricultural area of NB has been reported to be 35% (n= 17; Petrie et al. 2000). However, black ducks nesting in woodlots, peatbogs, and shrublands have higher nest success than those in other habitats (Belanger et al. 1998). Black duck nest success at undisturbed, isolated, and dispersed wetlands in NS also had very high nest success (86%, n=22) and all failures were attributed to predation (Seymour and Jackson 1996). Daily survival rates of black ducks in the Chesapeake Bay range from 0.949-0.988 (Krementz et al. 1992) and 0.945-0.968 in the St. Lawrence Estuary in Quebec (Laperle 1974). My daily survival rate of 0.972 is within the range found in the Chesapeake Bay, but above those found in Quebec. This may be because the St.

Lawrence Estuary study site was closer to an urban center and has a higher density of predators. A study by Belanger et al. (1998) reported that 12.1% black duck nest failures were caused by female abandonment. Because artificial nests do not measure non-predation nest failures, or failures related to female predation, natural black nest success in the area is likely lower than the estimates provided in my study. One major limitation to my study is that I was unable to find real nests to which I could compare the results of artificial nests. Predation is the leading cause of waterfowl nest failure in the boreal forest of Alaska, but variation in nest survival differs between regions and may additionally include female mortality, nest abandonment, weather, and flooding (Walker et al. 2005). It is possible that predators avoided visiting the artificial nests, despite my attempts to minimize human scent and trails to the nest. Alternatively, although females on a nest give off very little scent, the artificial nests may have been too inconspicuous since there is some movement at a nest when females leave and return from incubation breaks.

Corvids and black bears have been reported to depredate artificial waterfowl nests in previous studies (Esler and Grand 1993) and are a common predator in forest habitats (Yahner 1996). The most common predator species I detected was eastern red squirrels, which are a frequent predator in nest studies of passerines in forest habitat (Bayne and Hobson 2002, Hagan et al. 1996, Darveau et al. 1997, Vander Haegen and Degraaf 1996). However, to my knowledge, eastern red squirrels have not been reported in the scientific literature to depredate waterfowl nests. Franklin's ground squirrel (*Spermophilus frankliii*) are a common waterfowl nest predator in the prairies and have similar predation patterns to those I observed in the eastern red squirrel, although Franklin’s ground squirrels are larger than eastern red squirrels (Sowls 1948). It is unlikely that squirrels would depredate nests while the female is incubating, but possible that predation would occur while a female takes incubation breaks. If we exclude nests depredated by squirrels, the apparent nest success increases to 85% and a daily survival rate of 0.991. This is higher than reported daily survival rates for black duck nests. Eastern red squirrels may be able to readily detect and respond to nests available for predation and, as such, predation events are likely not incidental (Pelech et al. 2010). It is possible that artificial nests were unwittingly placed in non-natural nest locations, so were more evident to predators. It is also likely that red squirrel depredations were over-represented in my study because artificial nests lacked parental defence and camouflage from an incubating hen. I did not observe some of the most commonly reported waterfowl nest predators; raccoons, striped skunks, and coyote. I captured images of a *Lynx spp.* travelling past a nest, but it did not appear to be interested in the nest, and the nest was not depredated.

Although I did not find an effect of forest harvesting on the success of artificial waterfowl nests, I recommend maintaining the current buffer width size to maintain low predation rates. Given the importance of waterfowl nest success to population recruitment, future research should focus on monitoring real black duck nests with the use of satellite transmitters to determine where black ducks are nesting and how that habitat can better be protected.

Tables and Figures

Table 3.1. Correlation matrix for numerical predictors. No pairwise *r* values were >0.7 so all pairs were considered in models.

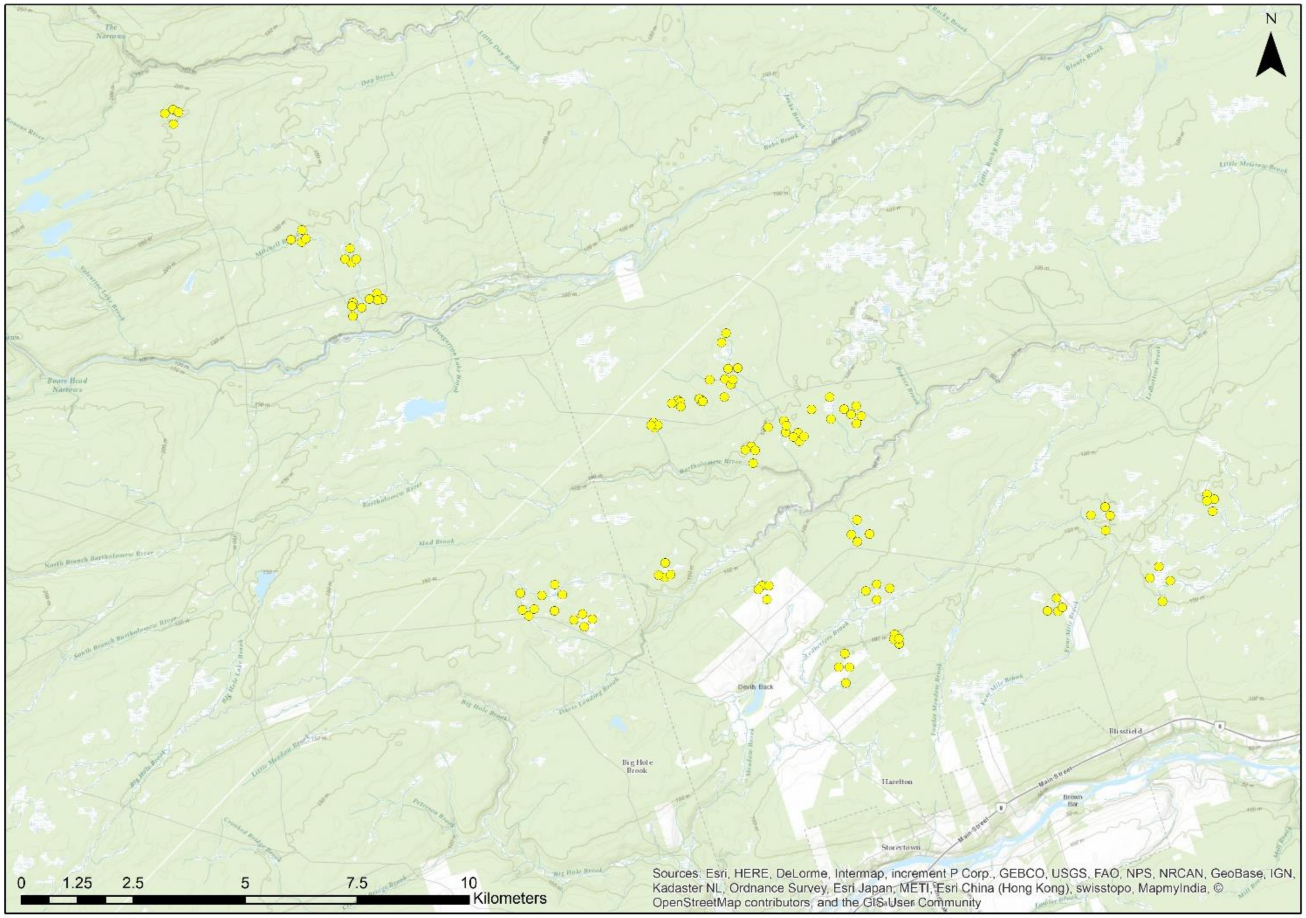
	Ordinal Deployment Date	Distance to Harvest	Harvest Area	Harvest Year	Distance to Road	Wetland area	Distance to Wetland Edge	Total Buffer Width
Ordinal Deployment Date	-	-0.056	0.308	-0.079	-0.208	-0.197	-0.138	0.024
Distance to Harvest	-0.056	-	-0.005	0.132	0.300	0.135	0.121	0.250
Harvest Area	0.308	-0.005	-	-0.166	-0.079	-0.106	-0.112	0.252
Harvest Year	-0.079	0.132	-0.166	-	-0.107	-0.045	-0.124	-0.136
Distance to Road	-0.208	0.300	-0.079	-0.107	-	0.355	0.400	0.061
Wetland area	-0.197	0.135	-0.106	-0.045	0.355	-	0.300	0.206
Distance to Wetland Edge	-0.138	0.121	-0.112	-0.124	0.400	0.300	-	0.122
Total Buffer Width	0.024	0.250	0.252	-0.136	0.061	0.206	0.122	-

Table 3.2. AIC model selection to determine the effects of predictors on the response of artificial nest success or failure. Models are displayed in order of increasing AIC value. Models with ∆AIC< 2 were considered strongly supported and models with ∆AIC of 2-4 were considered to have little to moderate support.

Model	Parameters	AIC	∆AIC
4	survive~ distance to road +(1|wetland ID)	109.6	0
null	survive~ 1 +(1|wetland ID)	110.8	1.2
3	survive~ distance to harvest block +(1|wetland ID)	111.2	1.6
2	survive~ distance to wetland edge +(1|wetland ID)	111.7	2.1
1	survive~ total buffer width +(1|wetland ID)	112.2	2.6
6	survive~ distance to wetland edge + direction + (1|wetland ID)	112.3	2.7
17	survive~ harvest year of closest harvest block + (1|wetland ID)	112.7	3.1
18	survive~ ordinal deploy date + (1|wetland ID)	112.7	3.1
13	survive~ distance to harvest + harvest area of closest harvest block + (1|wetland ID)	113.0	3.4
9	survive~ total buffer width + distance to wetland edge + (1|wetland ID)	113.7	4.1
5	survive~ distance to road + road type + (1|wetland ID)	114.0	4.4
7	survive~ total buffer width + ordinal deploy date + (1|wetland ID)	114.1	4.5
10	survive~ total buffer width + distance to wetland edge + distance to harvest + (1|wetland ID)	114.7	5.1
11	survive~ total buffer width + distance to wetland edge + distance to harvest + distance to road + (1|wetland ID)	114.9	5.3
12	survive~ total buffer width + distance to harvest + harvest area of closest harvest block + (1|wetland ID)	114.9	5.3
8	survive~ total buffer width + ordinal deploy date + direction + (1|wetland ID)	115.0	5.4
16	survive~ harvest treatment of closest harvest block + harvest year of closest harvest block + (1|wetland ID)	118.5	8.9
14	survive~ distance to harvest + harvest area of closest harvest block + harvest treatment of closest harvest block + (1|wetland ID)	119.5	9.9
15	Survive~ distance to harvest + harvest area of closest harvest block + harvest treatment of closest harvest block + harvest year of closest harvest block + (1|wetland ID)	120.6	11.0

Table 3.3. Metrics for wetlands where artificial nests were deployed. One artificial nest designed to mimic an American black duck (*Anas rubripes*) nest was deployed at each cardinal (north, south, east, west) of these 25 wetlands in a commercially forested area of New Brunswick, Canada. Means are displayed ± standard deviation.

Wetland	Wetland area (ha)	Number of nests	Ordinal nest deploy date	Number of failed nests	Mean distance to harvest (m)	Mean harvest area (ha)	Mean distance to road (m)	Mean distance to wetland edge (m)	Mean total buffer width (m)
BHB11	2.4	4	147	1	0±0	7.2±6.1	185±135	69±55	222±80
BHB14	1.2	4	140	1	16±31	6±1.5	137±88	52±34	203±103
BHB15	2.2	4	142	0	173±48	2.3±1.6	267±42	96±92	254±80
BHB19	5.0	4	140	0	56±54	3±0.7	217±101	72±47	182±137
BHB2	0.3	4	142	0	109±106	6.3±2.8	198±53	64±43	116±80
BHB21	1.1	4	140	0	53±42	9.9±10.4	249±98	105±52	156±55
BHB27	0.2	4	140	1	71±55	7.8±11.4	308±134	112±93	168±124
BHB6	5.6	4	142	0	274±202	4.5±2.5	325±164	143±57	248±58
BHB8	2.6	4	145	2	103±91	8.5±6.9	250±223	57±52	195±124
Bliss1	3.4	4	141	1	247±125	7.8±0	245±153	91±97	232±131
Bliss10	3.0	4	143	3	204±95	6±9.2	439±134	95±100	215±100
Bliss11B	0.9	4	143	0	19±18	1.3±1.1	153±38	22±18	48±24
Bliss14	8.5	4	148	1	65±91	13.1±7	361±169	138±118	250±101
Bliss16	0.8	4	148	0	23±46	6.1±7.1	168±90	119±48	258±84
Bliss19	2.0	4	148	1	93±61	8.5±6.5	164±39	22±36	120±63
Bliss2	3.7	4	141	2	124±130	1.6±0.2	250±89	124±87	186±132
Bliss20	0.7	4	149	1	290±37	18.2±7	133±48	24±10	253±94
Bliss21	0.8	4	149	2	194±67	12±0	209±61	11±22	216±58
Bliss24	2.5	3	149	2	98±48	7.9±6.1	274±149	107±140	233±115
Bliss25	1.2	3	149	2	7±11	36.4±43.3	148±55	122±67	231±120
Bliss5	5.5	4	143	1	93±130	1.6±0.7	343±154	148±44	198±24
Bliss6	0.8	4	150	0	23±31	10.2±11.9	115±141	48±92	89±143
Bliss8	11.0	4	141	2	234±276	5.5±0	258±140	88±68	195±128
Haz13	1.6	4	147	0	51±28	6.6±3	159±96	56±55	99±57
Haz8	1.6	4	147	2	102±55	3.8±2.4	280±137	177±95	166±105



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 3.1. Artificial waterfowl nest locations in a commercially forested area of New Brunswick, Canada. Nests were deployed in central New Brunswick between 19-29 May 2018. Nest fate was checked on days 2, 5, 11, 18, and 26. Intact nests on day 26 were considered successful.

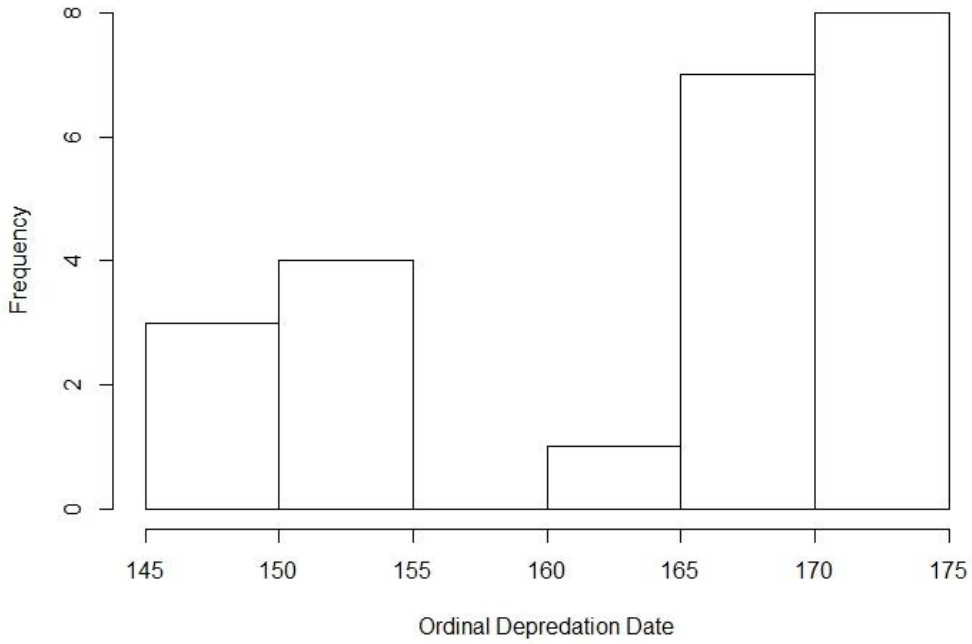


Figure 3.2. Frequency of artificial waterfowl nest depredation events in a commercially forested area of New Brunswick, Canada. The number of nests depredated increased throughout the exposure period. Nests were deployed 19-29 May 2018. Ordinal date of 145 = 25 May, the first date nests were checked.

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Chapter 4. Distribution of American black duck (*Anas rubripes*) broods in a commercially forested habitat

Abstract

The Acadian forest has experienced extensive commercial forest harvesting which is projected to increase and may influence the breeding habitat of American black ducks (*Anas rubripes*). Brood survival and appropriate habitat use are vital for population recruitment, but the impacts of forest harvesting on brood survival and habitat use are unknown. To determine if forestry influences black duck brood habitat use, I conducted brood surveys in commercial forests of New Brunswick, Canada. Black duck broods were commonly observed and present on 14 of 25 study wetlands. Broods moved between wetlands during the brooding period and >1 brood were observed using the same wetland on numerous occasions, but on different survey days. Brood size decreased from 7.28±2.28 at age class I (n=7) to 5.00±0.78 at age class III (n=10). Apparent brood survival was 0.585. I used a generalized linear model approach to model habitat variables with brood presence or absence. None of the predictors (proportion of intact forest within 1000m of the wetland edge in a ten- and twenty-year period, distance to road, distance to stream, wetland area, wetland classification, and main wetland vegetation type) influenced brood presence. Black duck broods made extensive use of wetlands in the study area, and forestry did not appear to influence their habitat selection. Future forestry operations in the study area should occur at or below current intensity to continue to provide protection to brood-rearing wetlands and maintain wetland connectivity.

Keywords: Acadian forest, anthropogenic development, brood-rearing, disturbance, recruitment

Introduction

The Acadian forest has experienced intensive commercial forest harvesting and is facing increased anthropogenic development (Loo and Ives 2003). The Acadian forest is within the breeding range of the American black duck (*Anas rubripes;* black duck), which has been designated a priority management species in eastern North America following steep population declines of >50% from 1950-1980 (Maisonneuve et al. 2006). Black duck populations remain below former levels, and the *Conservation Action Plan for the American Black Duck* recognizes that forest harvesting is a potential threat to breeding black duck abundance (Devers and Collins 2011). Black ducks may be at risk of extirpation in commercial forests because of a loss of landscape suitable for occupancy (Higdon et al. 2006). Between the first (1986-1990) and second (2006-2010) Maritimes Breeding Bird Atlases there was a decline in the probability of occurrence of black ducks in the province of New Brunswick (NB), Canada where it may still be subject to local threats (Stewart et al. 2015). One of the most effective methods to increase local waterfowl populations is to undertake management actions that increase local recruitment (Anderson et al 1997). However, this is difficult when the habitat use of breeding individuals in the area is largely unknown.

Survival and selection of high-quality habitat during the brood-rearing period are important to ensure recruitment into the population (Dyson et al. 2018). The influence of anthropogenic disturbance on vital rates of breeding waterfowl in forested areas is largely unknown (Roy 2018). Black ducks are considered intolerant of disturbance, and the effects of anthropogenic disturbance on population changes are unknown (Longcore et al. 2000). Commercial forest harvesting may impact brood distribution because of challenges travelling overland between wetlands that are not connected by streams or rivers, by altering wetland dynamics, direct disturbance by active operations, and post-harvest by people using the infrastructure to access previously remote areas. Numerous brood studies have focused on the wetland specific habitat characteristics of black duck brood-rearing areas, brood movement in estuary habitats, and comparisons with mallard (*A. platyrhynchos*) broods (Reed 1975, Ringelman and Longcore 1982, Merendino et al. 1995, Seymour and Jackson 1996, Longcore et al. 1998, Petrie et al. 2000), but research on habitat surrounding black duck brood-rearing areas is lacking, specifically information on anthropogenic disturbance.

Because of the importance of brood-rearing wetlands to recruitment, and the lack of current information about inland, forest-dwelling black duck brood habitat selection in the Acadian forest, and how commercial forestry affects black duck brood distribution, I conducted brood surveys in commercially forested area of NB. I hypothesized that commercial forestry alters black duck brood wetland selection and predicted that black duck broods would be found on wetlands less affected by commercial forestry.

Methods

Study Area

Wetlands surveyed for broods were located north of Doaktown, NB (46.620N, -66.124W). The area is in the Acadian forest ecozone, which is characterized by the predominance of red spruce (*Picea rubens*), black spruce (*P. mariana*), yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*), and balsam fir (*Abies balsamea*; Loo and Ives 2003). The area is predominantly crown land which is managed by a few commercial forestry licensees responsible for large contiguous tracks of forest. The majority of brood-rearing habitat in this area consists of numerous smaller wetlands including swamps, marshes, bogs, and beaver ponds, and a few larger lakes. The Dungarvon and Bartholomew rivers run north through the survey area, as well as numerous permanent and semi-permanent streams. Protected riparian buffer areas range from the minimum required size of ≥30m for wetlands ≥1ha (NB Clean Water Act 1989) to >1000m and varies if harvest near the wetland is unfeasible due to forest value and logistical constraints. Seventeen species of waterfowl potentially occur in this area, of which the black duck is the most abundant breeding species (Stewart et al. 2015).

Brood Observations

I conducted brood surveys during the black duck brood period, from 1 June - 15 August 2018 at 14 wetlands that were surveyed 4-5 times each on a semi-regular schedule. Surveys were conducted at daybreak or before 0900h to coincide with peak brood activity (Ringelman and Flake 1980). These wetlands were haphazardly chosen from a selection of wetlands in the study area that were accessible (<1km from a road) and representative of wetlands in the broader area. Large lakes (>20ha) were excluded because of difficulties surveying the entire area. One to three wetlands were surveyed per day based on wetland area by one to five observers. Brood observations were recorded with species, number of ducklings, and age class (I-III; Southwick 1953). Opportunistic brood observations were recorded at additional wetlands that were not regularly surveyed or if a brood was observed on a wetland outside the survey period.

Habitat Characteristics

I obtained forest and wetland habitat characteristics from the NB Department of Energy and Resource Development (DERD) forest inventory database. This GIS layer contains spatial information derived from air photo interpretation and a subset of polygons ground-truthed by DERD staff. Forest polygons contain information on harvest block harvest method, extent, year, and tree species. Wetland polygons contain information on wetland boundaries, wetland and vegetation types (Table 4.1), and water regime. This layer also contains information on road and stream extents. The average home range size of an incubating black duck female is approximately 1000m^2 (Ringelman et al. 1982a, Lemelin et al. 2007) and females are likely to use a wetland close to their nesting site to raise a brood. Black ducks have been found to react differently to harvest within 10- and 20-year time periods (Börger and Nudds 2014). Therefore, I determined the amount of harvest that has occurred within a ten- and 20-year period within 1000m of a wetland edge using ArcMap 10.4.1 (ESRI 2016). Using the “generate near table” function I determined the distance from a wetland to the closest road and stream. I then used the “buffer” tool to create a 1000m buffer around each wetland and used the “erase” tool to remove any harvest. I did this twice, removing harvest within ten years and removing harvest within 20 years. I then divided the area of the buffer without the harvest block by the total area of the buffer to determine the amount of intact forest.

Statistical Analysis

I used a generalized linear model approach to determine the effect of predictors on black duck distribution using the lme4 package (Bates et al. 2015) in the program R 3.4.3 (R Core Team 2017). A generalized linear model is an appropriate method to analyze non-normal data (Dobson and Barnett 2008). I used a binomial family to fit black duck brood presence (1) or absence (0) and created a set of 20 biologically appropriate candidate models (Anderson et al. 2000). I used Akaike's Information Criterion corrected for small sample size (AICc) to assess which model in the set best explained brood presence (Hurvich & Tsai 1989). Models with ΔAICc of 2-4 were considered to have little to moderate support and models with ΔAICc < 2 were considered strongly supported. I tested numerical predictors for multicollinearity using Pearson's correlation coefficients. All *r* values were above the threshold for collinearity (>0.7; Table 4.2), and no pairs were eliminated (Dormann et al. 2012).

Results

One to five waterfowl broods were observed at every wetland surveyed; black duck broods were observed at 12 of these 14 wetlands (Table 4.3). Black duck broods were opportunistically observed at 2 additional wetlands. On one occasion during a survey, a female black duck flew into a wetland vocalizing repeatedly and exhibiting behaviour consistent with a female looking for a brood when returning from a recess. I counted this as an observation of a brood and assumed the ducklings were hidden in vegetation. Because black duck broods were observed at most of the wetlands surveyed semi-regularly, I included an additional seven wetlands in the analysis that were visited numerous times (≥4; for other project purposes) from June to August but outside the daily survey period (0500-0900h). These wetlands never had a brood observed and rarely had waterfowl present, so although they were not visited during the peak brood movement period, I am confident they were not used by broods. In total, eighty-two waterfowl brood observations were made on 18 wetlands. Black duck broods were most commonly observed (n=13 wetlands). The mean number of black duck ducklings per brood declined as the ducklings aged, from 7.28(±2.28; age class I; n=7 observations) to 5.00(±0.78; age class III; n=10 observations). One class II black duck brood was observed with 14 ducklings, all similar in size. The maximum reported number of eggs in a black duck clutch is 15 (Longcore et al. 2000) so this female may either be very productive or have adopted ducklings from another female's brood. Other waterfowl species broods were often observed on the same wetlands as black duck broods. Hooded merganser (*Lophodytes cucullatus*; n=10 wetlands) and ring-necked duck (*Aythya collaris*; n=6 wetlands) broods were also commonly observed. Common goldeneye (*Bucephala clangula*; n=3 wetlands), green-winged teal (*A.* carolinensis; n=3 wetlands), Canada goose (*Branta canadensis*; n=3 wetlands), mallard (n=2 wetlands), and wood duck (*Aix sponsa*; n=2) broods were occasionally observed.

Hens were not marked, and the count and age of ducklings on a wetland varied between surveys indicating that more than one brood were using a wetland (although >1 black duck brood was never observed on the same wetland during a single survey) and that they moved between wetlands. Therefore, the assumption that broods made use of a single wetland (Ringelman and Longcore 1982) was not met and I could not calculate daily survival rates. However, following the methods of Ringelman and Longcore (1982) assuming 8.55 eggs are viable from each black duck nest and my mean class III brood size of 5.00, the apparent survival rate was 0.585.

Wetland area ranged from 0.2 to 16 hectares. Heavy rain and rapid snow melt caused widespread flooding in the early spring in the survey area. There was still snow cover in some areas until the first week of May. Freshwater marshes were the most common wetland type in the survey area and most surveys were conducted on this wetland type (n=17), followed by aquatic bed (n=3), large pond (n=2), and forested wetland (n=1). The most common vegetation type was shrub vegetation (n=8), followed by emergent vegetation (n=6), open-water vegetated (n=4), large pond (n=2), and forested softwood vegetation (n=3). The buffer within 30m of each wetland edge was intact or nearly intact (>92%) for the twenty years preceding the survey. The mean amount of intact forest within 1000m of a wetland edge decreased from 79±15% in the ten-year period preceding the survey to 63±15% in the twenty-year period preceding the survey. Thirteen wetlands were located on a stream system and the remainder were 108-930m from a river or stream. Four wetlands had a road immediately adjacent to the edge and the remainder were 16-513m from a road.

Four models were well supported and within 2ΔAICc of each other; the null model and models three, eight and nine (Table 4.4). The numerically lowest AICc value corresponded to model nine which retained the variables wetland area and the amount of intact forest within 1000m of the wetland edge within 20 years of the survey period. However, none of the models were considered to explain the variation in brood presence better than the null because they were within 2ΔAICc of the null.

Discussion

I found evidence of black duck broods using wetlands in commercially forested habitat, but my prediction was not supported, and I did not find an effect of commercial forest harvesting on their distribution. Breeding adult black duck distribution in the Acadian forest is relatively well known because it is surveyed annually during the helicopter-based waterfowl breeding pair survey in eastern Canada (Bordage et al. 2017), but I report here the first study of black duck brood wetland use in a commercially forested habitat of New Brunswick Acadian forest. This study provides a baseline for future waterfowl research in a key area of the black duck breeding range.

The mean class III black duck brood size of 5.0 that I observed is similar to, but slightly lower than those reported in Maine (mean class III clutch size =5.26; Ringelman and Longcore 1982). However, this estimate is lower than the mean brood size at fledging reported by Seymour and Jackson (1996) at dispersed wetlands in Nova Scotia (1996; 7.05 individuals) and higher than that reported by Longcore et al. (1998; 3.95). My apparent brood survival of 0.585 is higher than duckling survival rates in an agricultural area of NB (0.50; Petrie et al. 2000) but lower than the class III brood survival rate in Maine (0.70; Ringelman and Longcore 1982). This indicates that black duck reproduction is similar in NB to other areas in the breeding range but varies spatially and by habitat. Although my survival estimates fall within the ranges reported for black ducks, they should be interpreted with caution as I did not mark individuals and apparent success can overestimate black duck recruitment (Ringelman and Longcore 1982).

In Nova Scotia, most black duck females moved their broods to an estuary marsh by the time they were 2-3 weeks old, even though freshwater marshes were available (Seymour 1984). My study system differs from other studies of black duck broods because it is over 100km from the core of my study area to the nearest estuary marsh. Given the variation in the number of ducklings and their age class observed on multiple wetlands, it seems likely that black ducks remain in the study area until fledging, likely moving between wetlands as food availability fluctuated.

I may not have found an effect from commercial forestry because the sample size was small, or there was not enough variation in the study area habitat to demonstrate an effect if present. I originally intended to determine brood survival rates on wetlands with different buffer sizes, so made repeated visits to wetlands instead of visiting a larger sample of wetlands. Determining brood survival in this manner would have been possible if broods did not make secondary movements, as was the case in a Maine study where only one brood was present on most wetlands, and it was possible to distinguish between broods using age class and brood size (Ringelman et al 1982). However, it became apparent that black duck broods used different wetlands in my study area throughout the brood-rearing period because duckling ages and numbers did not correspond between visits at all wetlands. It is also possible that I did not find an effect of forest variables because the scale at which I measured forest variables is not biologically relevant for the black duck parameters I was quantifying. Given the lack of previous research on black duck movements in the study area, I based the area around each wetland on black duck home range size in Maine (Ringelman 1982), which may not represent home range size of black ducks in New Brunswick. Conversely, I may not have found an effect of forestry on black ducks because of the widespread extent of forest harvesting in NB and the lack of available wetlands. The density of wetlands in NB is much lower than other areas of the black duck breeding range (Bordage et al. 2017) and black ducks may need to use less productive wetlands, or wetlands affected by forestry in this area.

Although I did not find an effect of commercial forest harvesting on the distribution of black duck broods, they likely provide important cover from predator and allochthonous nutrient input into wetlands. In the Great Lakes area, Dyson et al. (2018) suggest that woody vegetation in forested wetlands may have a positive influence on wood duck duckling survival. It is likely that given the widespread distribution and use of forested wetlands by black duck broods in the study area, that buffer areas are important for duckling survival and should be maintained. Future management actions would benefit from brood surveys conducted on more wetlands over a larger area. Given logistical constraints of accessing of the wetlands in remote areas of NB, the use of an aerial survey similar to the spring breeding pair survey would be beneficial. Additionally, research using current telemetry technology on a subset of black duck females would be beneficial to monitor black duck brood movement beginning at the nest site through to fledging to determine if commercial forestry affects these movements.

Tables

Table 4.1 Description of wetland and vegetation types derived from the New Brunswick Department of Energy and Resources forest inventory and landcover layer

Wetland Type	Description
Freshwater Marsh	wetlands dominated by rooted herbaceous plants and includes most typical marshes as well as seasonally flooded wet meadows
Aquatic Bed	wetlands dominated by permanent shallow standing water (<2 meters in depth during mid-summer) that may contain plants that grow on or below the surface of the water
Large Pond	Large, oligotrophic pond, vegetation limited to edges
Forested Wetland	forested areas with abundant standing water including the seasonally flooded forest of the Saint John River Valley and other floodplains

Vegetation Type	Description
Emergent Vegetation	common marsh plants include cattails, bur-reeds, various sedges, rushes and grasses like bluejoint and cordgrass spp., flowering herbaceous plants, goldenrods, asters and many others
Forest Softwood Vegetation	non-commercial or commercial softwood tree species such as cedar, tamarack and black spruce
Shrub Vegetation	dominant shrubs are willows, dogwoods, meadow sweet, bog rosemary, leatherleaf, Labrador tea and saplings of trees such as red maple (except alder)
Open Water Vegetated	open water <2m deep with vegetation present on top of or near the water surface
Large Pond	Open water >2m deep

Table 4.2. Correlation matrix of numerical predictor variables. No pairs had an r value >0.7. Therefore, no pairs were considered colinear and all combinations were considered for models.

	Intact 1000m forest (10 years)	Intact 1000m forest (20 years)	Wetland Area	Distance to Stream	Distance to Road
Intact 1000m buffer (10 years)	-	0.554	-0.063	0.193	0.045
Intact 1000m buffer (20 years)	0.554	-	0.056	0.017	0.240
Wetland Area	-0.063	0.056	-	-0.430	-0.134
Distance to Stream	0.193	0.017	-0.430	-	0.297
Distance to Road	0.045	0.240	-0.134	0.297	-

Table 4.3. Black duck and other waterfowl species brood presence on 23 wetlands in New Brunswick, Canada. Wetland and buffer attributes as well as distances to the nearest stream and road are displayed. Wetland and vegetation type descriptions are in Table 4.1

Wetland	Black Duck Brood Observed	Waterfowl Brood Observed (any species)	Wetland Type	Vegetation Type	Proportion of intact 1000m forest (10 years)	Proportion of intact 1000m forest (20 years)	Wetland Area (ha)	Distance to stream (m)	Distance to road (m)
BHB 11	no	no	Freshwater Marsh	Shrub Vegetation	0.65	0.34	2.43	388	92
BHB 14	no	no	Freshwater Marsh	Shrub Vegetation	0.80	0.63	1.22	0	0
BHB 2	no	no	Large Pond	Open Water	0.82	0.71	0.35	404	251
BHB 27	no	no	Aquatic Bed	Open Water Vegetated	0.98	0.49	0.20	930	225
BHB 6	no	no	Freshwater Marsh	Shrub Vegetation	0.82	0.66	5.58	0	264
Bliss 20	no	no	Freshwater Marsh	Forested Softwood Vegetation	0.94	0.69	0.67	0	90
Bliss 21	no	no	Freshwater Marsh	Shrub Vegetation	0.97	0.76	0.83	445	209
Bliss 5	no	yes	Freshwater Marsh	Shrub Vegetation	0.47	0.42	5.54	0	196
Bliss 6	no	yes	Freshwater Marsh	Emergent Vegetation	0.67	0.55	0.78	108	0
Haz 9	yes	yes	Freshwater Marsh	Forested Softwood Vegetation	0.86	0.76	1.08	121	156
Bliss ABDU 3	yes	yes	Freshwater Marsh	Emergent Vegetation	0.85	0.64	4.32	0	0
Bliss 1	yes	yes	Freshwater Marsh	Shrub Vegetation	0.81	0.81	3.40	357	89
BHB 8	yes	yes	Aquatic Bed	Open Water Vegetated	0.88	0.78	2.59	0	57
Bliss 14	yes	yes	Freshwater Marsh	Emergent Vegetation	0.81	0.59	8.53	0	283
Bliss 19	yes	yes	Freshwater Marsh	Shrub Vegetation	0.76	0.75	1.96	267	116
Bliss 2	yes	yes	Large Pond	Open Water	0.42	0.39	3.74	0	198
Bliss 24	yes	yes	Freshwater Marsh	Emergent Vegetation	0.94	0.62	2.51	0	129
Bliss 25	yes	yes	Freshwater Marsh	Shrub Vegetation	0.97	0.54	1.19	0	60
Bliss 4	yes	yes	Freshwater Marsh	Emergent Vegetation	0.92	0.72	16.28	0	16
Bliss 8	yes	yes	Freshwater Marsh	Forested Softwood Vegetation	0.80	0.80	10.98	0	135
FL 1	yes	yes	Aquatic Bed	Open Water Vegetated	0.69	0.62	1.94	431	0
Quarry 1	yes	yes	Aquatic Bed	Open Water Vegetated	0.72	0.72	1.73	222	282
WS 4	yes	yes	Forested Wetland	Emergent Vegetation	0.92	0.92	0.51	407	513

Table 4.4. AIC model selection to determine the effects of predictors on the presence or absence of black duck broods. Models are displayed in order of increasing AICc value. Models with ∆AICc< 2 were considered strongly supported and models with ∆AICc of 2-4 were considered to have little to moderate support. (Buff1000_20yr_prop = the proportion of intact forest within 1000m of the wetland edge within 20 years of the wetland being surveyed. Buff1000_10yr_prop = the proportion of intact forest within 1000m of the wetland edge within 10 years of the wetland being surveyed.

Model #	Model	AICc	∆AICc
9	ABDU ~ wetland area + Buff1000_20yr_prop	31.46215	0
3	ABDU ~ Buff1000_20yr_prop	32.07938	0.61723
8	ABDU ~ Wetland area	32.61936	1.15721
null	ABDU ~ 1	32.97956	1.51741
4	ABDU ~ stream distance	33.87563	2.41348
10	ABDU ~ wetland area + Buff1000_20yr_prop + road distance	34.06435	2.6022
13	ABDU ~ wetland area + Buff1000_20yr_prop + road distance	34.06435	2.6022
12	ABDU ~ wetland area + Buff1000_10yr_prop	34.82085	3.3587
17	ABDU ~ wetland area + stream distance	35.00873	3.54658
18	ABDU ~ wetland area + road distance	35.27069	3.80854
2	ABDU ~ Buff1000_10yr_prop	35.29494	3.83279
5	ABDU ~ road distance	35.38712	3.92497
14	ABDU ~ road distance + stream distance	36.42049	4.95834
7	ABDU ~ wetland type	39.42355	7.9614
6	ABDU ~ vegetation type	40.61151	9.14936
19	ABDU ~ Buff1000_20yr_prop + vegetation type	41.62245	10.1603
15	ABDU ~ wetland area + vegetation type	41.71739	10.25524
11	ABDU ~vegetation type + vegetation coverage	44.03726	12.57511
20	ABDU ~ Buff1000_10yr_prop + vegetation type	44.28887	12.82672
16	ABDU ~ wetland area + vegetation type + vegetation coverage	45.64447	14.18232

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Chapter 5. General Conclusion

This thesis explored how commercial forest harvesting might affect the distribution and productivity of an ecologically, economically, and socially important wildlife species in New Brunswick (NB), the American black duck (*Anas rubripes*). On a province-wide scale, using long term data, I examined whether harvest close to wetlands or the presence of mallards (*A. platyrhynchos*) could explain the presence of breeding black duck pairs on wetlands during the laying and incubation period of the breeding season. On a smaller spatial scale, in an actively commercially harvested forest, I examined how forest harvesting could affect black duck reproduction using artificial nests as a proxy for black duck nests. In this same area, I made observations of black duck broods to determine if harvest close to wetlands alters the distribution of black duck broods.

In Chapter Two, I show that recency of commercial forest harvesting affects breeding black duck distribution within ten years; black ducks were more likely to be present on larger wetlands in the presence of mallards where a larger proportion of the forest within 1000m was intact, but where harvest occurred near the wetland. Within a 20-year period after harvest, black duck presence was only influenced by wetland area and the presence of mallards, indicating that the effects of forest harvesting are for a limited period. The positive association I observed between breeding black ducks and forest harvesting may be because harvested areas provide attractive nesting cover as grass and shrub vegetation regenerates (Lemelin et al. 2007). This is likely short term because as tree species grow, they replace ground cover species. Black ducks and mallards were often present on the same wetlands, indicating that they are selecting the same habitats.

Mallards have been implicated in the black duck population decline through competition and hybridization (Conroy et al. 2002), and as their populations continue to expand eastward, they may pose a growing threat to breeding black ducks.

In Chapter Three, I show that predation rates on artificial nests designed to mimic black duck nests experienced low rates of predation. I did not find an effect of forestry on nest success, likely because of low predation rates. The success rates I found were within the range of those reported in the literature for black ducks, but much higher than dabbling duck nest success in the prairies and above the threshold necessary to maintain population size (Cowardin et al. 1985).

In Chapter Four, I show that black duck broods make extensive use of wetlands in commercial forests, but that their distribution does not appear to be affected by forestry. Apparent brood survival rates were similar to those reported in the literature but should be interpreted with caution as I did not mark individual broods.

I found evidence of commercial forestry affecting the distribution of black ducks during one of the most important habitat selection stages of the breeding period. Black ducks are preferentially selecting wetlands with forestry activities have occurred near them. However, given the low density of breeding black ducks in my study area, it is unlikely that nesting habitat is limiting for black ducks there. It is also unlikely that given the low rates of nest predation (Chapter 3) that black ducks are choosing nesting areas to limit nest predation. Survival and appropriate habitat selection at each stage of the breeding season is important for black ducks; a lack of quantity or quality during any of these three stages will limit black duck success (Kirby 1988).

I did not find evidence that the 30m buffer requirement is inadequate. I did find evidence of an effect from forestry within 1000m of the wetland edge, which may be more representative of the scale of forestry that affects wetland habitat, or the home range size of black ducks. I did not explicitly test the 30m buffer distance in Chapters Three and Four, but I found low nest predation rates indicating that nests were not subject to edge-related nest predation and found no apparent impact on brood distribution by forestry variables that were tested. Black ducks are considered to be wary (Longcore et al. 2000) but will only react to what they can see (Kirby 1988), so it is likely that this 30m buffer zone provides adequate visual obstruction to disturbance outside wetlands. Additionally, cover from trees in these riparian areas may provide important habitat for predator avoidance and shelter from severe weather (Ringelman and Longcore 1982, Dyson et al. 2018). Other breeding waterfowl studies in forest habitat have found higher brood survival on wetlands with more open water surrounded by less nesting habitat (Roy 2018). Therefore, forestry may provide increased nesting cover, but care must be taken to ensure that harvesting does not begin to compromise wetland health, wetland connectivity, or alter the complex of wetland, upland, and forest habitat for black ducks. In Chapter Four, I found that black duck broods move throughout the brooding period, so it is also important to maintain the connectivity of wetlands provided by permanent and semi-permanent streams.

Natural sources of landscape disturbance in the Acadian forest include those from forest fires and insect outbreaks (Wein and Moore 1977). Current forestry operations in NB are much more extensive than these historical landscape modifications, but the Boreal forest, which is to the north of the Acadian forest and very similar in structure with a similar historical disturbance regime, is considered relatively resilient to anthropogenic disturbance from forestry (Schmiegelow and Villard 2009). However natural disturbance in the Boreal forest is largely driven by stand replacement disturbance from forest fires, and natural disturbance in the Acadian forest is largely driven by gap replacement disturbance from insect defoliation (MacLean 2015). Silvicultural practices should seek to emulate natural disturbance and prevent homogenizing forest habitat (Schmiegelow and Villard 2009). Ringelman and Longcore et al. (1982) found that black ducks may prefer wetlands surrounded by broad leaved deciduous forest cover, a defining feature of the Acadian forest in which I studied them. However, the proportion of softwood and hardwood species in mixedwood forests is variable and given the economic value of softwoods, the number of mixedwood forests in the Acadian forest may decrease (Amos-Binks et al. 2010).

One major limitation to this study was the low density of breeding black ducks and logistical challenges while accessing wetlands. Navigating to most wetlands must be done on foot in a challenging landscape (wet and densely forested). This limits the number of wetlands that can be accessed during the breeding season. Many wetlands in the study area are beaver ponds, which are variable and change between years, so it is also difficult to determine where available habitat is located if aerial imagery is not up to date. Black ducks are also very cautious and flush when they detect a human presence, so care must be taken to approach wetlands stealthily. In addition, black ducks are very cryptic and camouflaged and may be missed during surveys. One way to overcome this challenge would be using satellite tracking technologies deployed early in the breeding season, when ducks can be captured on water, to track black duck movements through the breeding season when they are much more difficult to find. This technology would provide valuable information on exact black duck breeding locations and success, movement from the nest to wetlands, and of broods. An additional limitation to my study was the sole year in which I conducted field experiments and surveys (Chapters 3 and 4). Nest success and recruitment fluctuates between years (Ringelman et al. 1982). The spring of 2018 was very wet with extensive flooding, so my results may not accurately represent average black duck success and habitat use in years with different weather conditions.

In Chapters Three and Four, I demonstrate that black ducks are capable of high nest success and recruitment, above the threshold to maintain population levels (Cowardin et al. 1985). Given the high probability that most black duck offspring are recruited into the population in my study area, population trends should be stable or increasing. However, changes in the probability of detection of black ducks between the first and second Maritimes breeding bird atlases indicate that populations of black ducks in NB have declined. Based on the results of my study, it seems unlikely that this decline is driven by perturbations to breeding populations. Black ducks have high site fidelity and females typically return to their natal areas to raise young (Longcore et al. 2000), so it seems more likely that fewer black ducks are returning to these areas during the breeding season because of problems encountered during migration or on the wintering grounds. The major drivers implicated in the black duck population decline are breeding and wintering habitat loss, interactions with mallards, and overharvesting (Conroy et al. 2002).

My research indicates that although apparent breeding habitat losses have occurred from commercial forest harvesting, it is likely not a key factor in the black duck population decline in New Brunswick. Therefore, black duck distribution may also be affected by forest habitat variables I did not measure. My research also indicates that mallards and black ducks select similar habitats and that there may be potential for negative interaction to occur between the two species. Hunting restrictions were put in place in the 1990’s to reduce black duck harvest by 25% (Devers and Collins 2011). However, effects of harvesting pressure were inconclusive, and both the number of hunters and the number of black ducks being harvested declined, so in 2017 the adaptive harvest management model for black ducks liberalized seasons from a one bird a day to two bird a day bag limit (Government of Canada, 2017). There has been an increasing concern that overwintering black ducks are experiencing low survival rates and that quality and quantity of non-breeding habitat may be more significant in the population decline (English 2016). Black ducks typically make use of freshwater habitats during the breeding season and saltwater marshes while overwintering and more research is needed on survival rates of overwintering black ducks. My research did not investigate overwintering habitat or hunting but indicates that changes on the breeding grounds are likely not affecting black duck recruitment, and that there is potential for negative interactions with mallards.

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McLean, K., Pollard, B., McLellan, N., Nocera, J. 2019. The role of wetland buffer width in maintaining American black duck populations in New Brunswick commercial forests. Presentation at the University of New Brunswick Graduate Student Conference. Fredericton, NB.

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