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Ecological Separation of Mallards (Anas Platyrhynchos) and American Black Ducks (Anas Rubripes) In the Adirondack Park of New York State

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ECOLOGICAL SEPARATION OF MALLARDS (*Anas platyrhynchos*) AND AMERICAN BLACK DUCKS (*Anas rubripes*) IN THE ADIRONDACK PARK OF NEW YORK STATE

by:

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The American black duck is a large–bodied native dabbling duck in the northeast United States and Canada which has declined > 50% to ~ 500,000 breeding pairs since the 1950s. Concurrently mallards have replaced black ducks in Atlantic flyway breeding habitats. I used Bayesian statistical modeling to test for differences in mallard and black duck occupancy and productivity between and within beaver–modified wetlands and lakes in the Adirondack Park of New York. Mallard occupancy was ≥ 6.7% greater than black duck in all habitats surveyed. I further propose that mallards may outproduce black ducks in years where wetlands experience negative environmental effects such as drought or absence of beaver. I also compared the utility of drones to ground observers to survey black ducks, and discovered drones detect black ducks and other secretive waterfowl more reliably. However, when considering all ducks present, overall detection probability was similar between methods.

Key words: Adirondack Park, American black duck, *Anas rubripes*, *Anas platyrhynchos*, breeding habitat, mallard, New York, occupancy, time-to-detection

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CHAPTER 1: INTRODUCTION

Inherent to the process of speciation is the assumption of niche differentiation. Competitive exclusion principle states that when two species experience enough niche overlap, one will eventually outcompete the other for their shared resources unless some degree of resource partitioning or niche differentiation thereafter develops (Gause 1934). This concept is as widely varied as the life histories of the species involved and is difficult to test, but has been documented in various ecological systems (Pianka 1972, Bryce et al. 2001). In waterfowl, Gurd (2008) suggested sympatric species were not partitioning their shared primary food resources, but rather only their secondary food sources (Nudds 1983). Even when two species do not directly compete, the presence of one can cause the other to recuse itself from high quality patches of habitat or require more energy to defend territories that inevitably will not be spent on reproduction or collecting resources (Coulter and Miller 1968, Pianka 1972, Fretwell 1972, Merendino et al. 1993, Merendino and Ankney 1994). An example of this was identified by Coulter and Miller (1968) who demonstrated that adding mallard nests to islands in Lake Champlain appeared to prevent black ducks from initiating nests on the islands, suggesting the two species see the other as conspecifics (Seymour 1992, McAuley et al. 1998). Mallards and black ducks have some differentiation in diet and feeding habits which English et al. (2020) suggested explained the capacity of mallards and black ducks to coexist during winter at the Atlantic coast of Canada. Ultimately, some level of niche differentiation is needed between mallards and black ducks for them to co–exist (Gause 1934).

A Century of Black Duck – Mallard Population Dynamics and Interactions

The American black duck population decreased by approximately half between the 1950s and 1990s before stabilizing, but remains 22% below the United States Fish and Wildlife Service population goal of 640,000 breeding pairs (USFWS 2011, 2017). As such, black ducks are a species of High Priority Greatest Conservation Need in New York (SGCN1; NYSDEC 2015) and have species–specific conservation plans for recovery elsewhere in eastern North America (USFWS 2011). Concurrent with these changes, mallards colonized portions of the black duck range (Heusmann 1991). Hypotheses for decline in black duck abundance include loss and modification of breeding and wintering habitat, overharvest, hybridization, and competitive exclusion by mallards (Goodwin 1956, Ankney et al. 1987, Longcore et al. 1998, Mank et al. 2004, Petrie et al. 2012) although decline by hybridization has been recently refuted (Lavretsky et al. 2019; 2020).

Prior to the 1900s, mallards primarily occupied western grasslands and black ducks occupied eastern forests in North America (Eaton 1910). Landscape change decreased forested wetlands that are often selected by black ducks, favored expansion of the mallard range in eastern areas traditionally dominated by black ducks, and, through general homogenization of land cover types, increased likelihood of interaction between mallards and black ducks (Heusmann 1974, Heusmann 1991, Harrigan 2006, USFWS 2017, Bleau 2018). Game–farm mallards have also been actively released by public and private entities for the purpose of sport hunting to supplement the wild mallard population in eastern North America (Heusmann 1991). In many areas, mallards have replaced black ducks as the primary breeding waterfowl, with black ducks primarily continuing to exist during the breeding period in relative isolation from mallards in northeastern forested zones of North America (Heusmann 1974, Heusmann 1991, Baldassarre 2014). In some areas of the northeastern United States, breeding black ducks continue to exist in areas of dense forest with abundant wetland cover and limited human encroachment (Petrie et al. 2012, Macy and Straub 2016).

New York's Adirondack Waterfowl Breeding Grounds

The Adirondack Park (here–on AP) is the largest publicly protected area in the contiguous United States and was designated a World Biosphere Reserve in 1989. The AP provides substantial habitat for breeding black ducks with more than 3,000 lakes and abundant beaver–modified wetlands (Brown and Parsons 1979, Dwyer and Baldassarre 1994, Macy and Straub 2016). Despite the potential abundance of waterfowl breeding habitat in the AP, few studies have estimated the abundance, relative productivity, and occupancy of mallards and black ducks within its boundary. Eaton (1910) described the mallard as a transient visitor to New York State, with few exceptions breeding in central New York counties. Eaton (1910) described black ducks as the most common dabbling duck, specifying its weariness of human disturbance. Benson (1968) found the mallard to be a rare visitor to the AP. An extensive study of waterfowl use in beaver–modified wetlands during the mid–1970s in the AP indicated they provide nesting and brood rearing habitat for black ducks, hooded mergansers, and wood ducks, but not mallards (Brown and Parsons 1979).

More recently, mallards and black ducks have been found sympatric in the AP, and studies have not detected competitive exclusion (Dwyer and Baldassarre 1994, Macy and Straub 2016). Dwyer and Baldassarre (1994) only included palustrine wetlands (excluding palustrine needle–leaved) in their sample frame because of the infrequent use of lacustrine wetlands by mallards and black ducks in the AP. Macy and Straub (2016) found the two species were sympatric, but suggested mallards tolerated recreational activity more than black ducks in lakes of the AP.

Competition Between Mallards and Black Ducks in the AP

Droke (2018) detected that New York wintering mallards left for their breeding grounds up to a month before sympatric black ducks in some years. If black ducks cede the most favorable breeding habitats to earlier arriving mallards (Seymour 1992, Merendino et al. 1993) because they recognize them as conspecifics (Petrie et al. 2012); migration timing, nest initiation, and tolerance for human activities could be important factors affecting relative changes in distributions of breeding mallards and black ducks. Although many researchers have found no difference in reproductive parameters between mallards and black ducks (Longcore et al. 1998, Maisonneuve et al. 2000, Petrie et al. 2000), Petrie et al. (2012) found that interference competition may be occurring where productivity parameters may be similar, but competitive exclusion or displacement of black ducks by mallards may be inhibiting breeding altogether (Merendino et al. 1993, Merendino and Ankney 1994). The propensity of mallards to tolerate anthropogenic environments (Diefenbach and Owen 1989, Macy and Straub 2016) and black duck avoidance of mallards and humans (Coulter and Miller 1968, Spencer 1986, Macy and Straub 2016) suggests interference competition or competitive exclusion by displacement may be contributing to black duck decline given the positive effects lake–nutrient loading has on duckling production (Staicer et al. 1994, Longcore et al. 1998).

Pilot Study 2016–2018

In contrast to the relatively accessible areas studied in Dwyer and Baldassarre (1994), Staicer et al. (1994), and Macy and Straub (2016); remote beaver–modified wetlands are surveyed less during contemporary large–scale waterfowl surveys despite the abundance and use of that cover type by breeding black ducks in the AP (Brown and Parsons 1979). Few studies have directly surveyed these areas to compare mallard and black duck abundance and productivity since

Brown and Parsons (1979), in part, because of the logistical challenges of surveying remote wetlands.

As an extension of prior studies (Brown and Parsons 1979, Dwyer and Baldassarre 1994, and Macy and Straub 2016), I developed a pilot study in coordination with the New York State Department of Environmental Conservation and followed a similar methodology to Brown and Parsons (1979) to survey waterfowl in the AP. Our interest for the pilot study was to determine the feasibility of deploying a large–spatial scale study to determine use of beaver–modified wetlands by black ducks relative to other waterfowl to estimate breeding pair abundance and productivity, as well as compare spatial use and productivity of these wetlands between mallards and black ducks. Additionally, I investigated a sample of remote and human influenced lakes in the AP. For my previous and future study, lakes include open water habits > 12 ha that do not rely on beaver modification to remain viable waterfowl habitat.

Pilot study results suggested the black duck is relatively uncommon across the landscape, although black ducks were present and breeding more frequently than mallards on remote beaver–modified wetlands in the eastern–central portion of the AP, and less frequently than mallards on human influenced lakes. Our pilot study estimates of black duck abundance resulted in high variance and a broad confidence interval because of relatively small sample sizes and few black ducks were detected on pilot study wetlands.

Goal and Objectives

Rarer species often require unique methods for study, therefore I aimed to apply novel field and analytical techniques to provide wildlife managers with information that refines and updates conservation knowledge of breeding black ducks and local heterospecific waterfowl in the AP. Use of a multi–species occupancy model featuring Bayesian analyses and time to detection is useful to generate reliable unbiased estimates of population parameters within a 95% credible interval (Kéry and Royle 2008; 2015). I used this statistical framework to 1) assess the occupancy and general habitat use of waterfowl in AP beaver–modified wetlands and 2) compare beaver–modified wetlands to developed and undeveloped lakes (Staicer et al. 1994, Longcore et al. 1998) to test for differences in mallard and black duck occupancy in the context of an increasingly developed AP (Holland 2011). These estimates are useful for updating the knowledge of AP black duck for their conservation.

I also used a Bayesian statistical framework in the form of a linear mixed model (Kéry 2010) to test for differences in mean brood size between mallards and black ducks comparing lakes and wetlands to compare productivity in the AP (Petrie et al. 2000). Finally, I explored the feasibility and utility of Small Unmanned Aerial Services (SUAS) to survey waterfowl on a subset of AP beaver–modified wetlands and compared SUAS survey performance with successive traditional ground surveys conducted as part of this larger study frame. I used an N–mixture model (Kéry 2010) in a Bayesian statistical framework to estimate and compare detection probabilities between the ground and aerial surveys, and review black duck–specific detection cases to assess SUAS effectiveness and practicality as a survey method for black ducks in the AP.

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CHAPTER 2: FACTORS AFFECTING OCCUPANCY OF A SUITE OF WATERBIRDS IN ADIRONDACK WETLANDS, WITH A FOCUS ON MALLARDS AND AMERICAN BLACK DUCKS

ABSTRACT The American black duck is a large–bodied dabbling duck native to the northeast United States and Canada which has declined in abundance by > 50% since the 1950s. Concurrent with these changes, mallards have replaced black ducks in many Atlantic flyway breeding areas. The Adirondack Park (AP) of New York, USA, is a 2.4 million ha matrix of deciduous and coniferous forests with thousands of lakes, bogs, wetlands, and cold–water riverine systems that provide habitat for breeding black ducks. I tested for differences in occupancy among beaver–modified wetlands (n = 181), undeveloped lakes (n = 83) and developed lakes (n = 127) for mallards and black ducks in the AP, May −July 2019 −2020. I conducted 30 min counts including 7 waterbird species in a multispecies occupancy model for mallard and black duck because additional species decreased variance of estimates. I used time–to–detection to account for detection probability while also allowing for single site visits which increased site sample size. I found mallard occupancy was ≥ 6.7% greater than black ducks in all combinations of year and strata, with the greatest difference (13.7% ± 0.06 SD) at developed lakes. This is a historically significant result as previous studies suggested mallards were rare or otherwise sympatric with black ducks. I postulate mallard niche is wider than black ducks in AP breeding habitat because mallards use human environments more than black ducks, which provides a source population from increasingly developed AP lakes.

KEY WORDS Adirondack Park, American black duck, *Anas platyrhynchos, Anas rubripes,* mallard, time–to–detection, multispecies occupancy.

Conservation of freshwater wetlands for birds is important for waterfowl and other waterbirds, but also to a broad diversity of other species including humans (Gray et al. 2014). Up to 40% of the world's animals and 75% of North American birds use wetlands at some point in their lives (Gray et al. 2014). Despite only composing 4% of the earth's surface (Mitsch and Gosselink 2000) wetlands offer > 40% of the realized ecosystem services (Costanza et al. 1997). For humans, wetlands can clarify and purify groundwater and runoff, contribute to groundwater recharge, provide shoreline protection, and help control floodwaters. Wetlands also provide breeding habitat for many species of fish, birds, mammals, and other wildlife. Arguably the most iconic amongst these species of plants and wildlife are the diversity of waterfowl that depend on wetlands for breeding and brood rearing in the warm summer months in North America.

The American black duck (*Anas rubripes*, hereon black duck) is a large–bodied monochromatic duck species native to northeastern North America. The black duck population decreased by about 50% between the 1950s and 1990s before stabilizing but remains 22% below the United States Fish and Wildlife Service population goal of 640,000 breeding pairs (USFWS 2011, 2017). As such, black ducks are a species of High Priority Greatest Conservation Need in New York (SGCN1; NYSDEC 2015) and have species–specific conservation plans for recovery elsewhere in eastern North America (USFWS 2011). Concurrent with these changes, mallards (*Anas platyrhynchos*) colonized portions of the black duck range (Heusmann 1991). Hypotheses for decline in black duck abundance include loss and modification of breeding and wintering habitat, overharvest, hybridization with mallards, and competitive exclusion by mallards (Goodwin 1956, Ankney et al. 1987, Longcore et al. 1998, Mank et al. 2004, Petrie et al. 2012).

Prior to the 1900s, mallards primarily occupied western grasslands and black ducks occupied eastern forests in North America (Eaton 1910). Landscape change decreased the availability of forested wetlands in eastern North America, favored expansion of the mallard range eastward, and through general homogenization of land cover, increased likelihood of interaction between mallards and black ducks (Heusmann 1974, Heusmann 1991, Harrigan 2006, USFWS 2017, Bleau 2018). In many areas, mallards have replaced black ducks as the primary breeding waterfowl, generally in a west to east manner. In some areas of the northeastern United States, breeding black ducks continue to exist in areas of dense forest with abundant wetland cover and limited human presence (Petrie et al. 2012, Macy and Straub 2016).

The Adirondack Park (AP) located in northern New York state is the largest publicly protected area in the contiguous United States and was designated a World Biosphere Reserve in 1989. The AP provides breeding habitat for waterbirds with > 3,000 lakes and abundant beaver–modified wetlands (Brown and Parsons 1979, Dwyer and Baldassarre 1994, Macy and Straub 2016). Despite the potential abundance of waterfowl breeding habitat in the AP, few studies have estimated the abundance, relative productivity, and occupancy of mallards and black ducks within the AP boundary. In the late 19th and early 20th century, the mallard was a transient visitor in New York state and the AP during migration, whereas the black duck was the most common dabbling duck (Eaton 1910, Benson 1968). An extensive study of waterfowl use of beaver–modified (*Castor canadensis*) wetlands during the mid–1970s in the AP indicated they provide nesting and brood rearing habitat for black ducks, hooded mergansers (*Lophodytes cucullatus*), and wood ducks (*Aix sponsa*), but rarely mallards (Brown and Parsons 1979). More recently, mallard and black duck were sympatric in the AP during the breeding season, and studies have not detected competitive exclusion (Dwyer and Baldassarre 1994, Macy and Straub 2016). I felt it timely to conduct additional assessment of mallard and black duck occupancy because mallards became the most common breeding duck in the northeastern United States and portions of southeastern Canada in the past 20 years.

For mallard and black duck to co–exist in the AP in perpetuity, some level of niche differentiation must exist (Mayr 1970, Schoener 1974, Nudds 1983). However, if the mallard niche overlaps with that of the black duck and mallards are behaviorally dominant, black ducks might be excluded from favorable breeding habitat by mallards (Seymour 1992, Merendino et al. 1993, Petrie et al. 2012). Therefore migration timing, nest initiation, and tolerance for human activities could be important factors governing relative changes in abundance between mallards and black ducks.

Although many researchers have detected no difference in reproductive parameters between mallards and black ducks (Longcore et al. 1998, Maisonneuve et al. 2000, Petrie et al. 2000), Petrie et al. (2012) found that interference competition may be occurring where productivity parameters are similar. Possibly, conventional observational studies are not detecting competitive exclusion of black ducks from some breeding areas by mallards because it is occurring at subtle temporal and spatial scales (Merendino et al. 1993, Merendino and Ankney 1994, Petrie et al. 2012). Given the ability of mallards to breed in anthropogenic environments more readily than black ducks (Diefenbach and Owen 1989, Macy and Straub 2016) and the potential for mallard behavioral dominance (Coulter and Miller 1968, Seymour 1992), interference competition or competitive exclusion by displacement of breeding black ducks by mallards could negatively affect black duck occupancy and productivity. The artificial improvement of anthropogenic ecosystems by human–sourced nutrient loading can have positive effects on duckling production, potentially further contributing to mallard dominance in regions where black ducks breed (Staicer et al. 1994, Longcore et al. 1998).

In contrast to the relatively accessible areas studied in Dwyer and Baldassarre (1994), Staicer et al. (1994), and Macy and Straub (2016); beaver–modified wetlands are surveyed less during contemporary large–scale waterfowl surveys despite their use by breeding black ducks in the AP (Brown and Parsons 1979). Few studies have directly surveyed these areas to compare mallard and black duck abundance and productivity since Brown and Parsons (1979), in part, because of the logistical challenges of accessing these beaver–modified wetlands. Dwyer and Baldassarre (1994) only included palustrine wetlands (excluding palustrine needle–leaved) in their sample frame because they noted infrequent use of lacustrine wetlands by mallards and black ducks. In contrast, Macy and Straub (2016) found the two species were sympatric on lacustrine cover types and suggested mallards tolerated recreational activity more favorably than black ducks.

Black ducks are relatively uncommon in the AP, although they were present and breeding more frequently than mallards in 2016 and 2017 on a small sample of remote beaver–modified wetlands in the eastern–central AP, and less frequently than mallards on human influenced lakes (NYSDEC unpublished data). Rarer species often require detection corrected methods for study (Mackenzie et al. 2005), therefore I used a time to detection model (Garrard et al. 2008) to account for imperfect detection probabilities of waterbirds in my study. I incorporated presence–absence data for multiple waterbird species (Garrard et al. 2013) to precisely estimate occupancy probability of mallard and black duck. My aim was to produce estimates able to detect differences in occupancy between mallard and black duck among beaver–modified wetlands and undeveloped and developed lakes (Kéry and Royle 2015, Halstead et al. 2018). Common waterbirds (e.g., Canada goose, common loon) were included in my model to inform occupancy by less common species (e.g., black duck) and validate the modeling process by comparing known habitat use patterns of species with results (e.g., I expected common loons [*Gavia immer*] occupancy of open water sites to be greater than other cover types). I also investigated inclusion of percentage open water in the survey and percent emergent vegetated shoreline because these metrics affect selection of breeding and brood rearing habitat by waterbirds (Kaminski and Prince 1981, Staicer et al. 1994, Dyson et al. 2018). These estimates can provide wildlife managers with information that refines and updates conservation knowledge of AP breeding black ducks and local heterospecific waterfowl. I predicted that mallards would occupy developed lakes more than black ducks because mallards tolerate human disturbances. I also predicted that black ducks would occupy undeveloped and beaver–modified wetlands more than developed lakes because of their reluctance to occupy sites near human disturbances during the breeding season.

METHODS

Study Area

The AP is a 2.4 million ha mosaic of private (55%) and public (45%) lands in northern New York state, subject to varying degrees of regulation by the Adirondack Park Agency (APA). The AP has similar geologic and ecologic conditions to Canada's boreal forest and its extensive forest cover is characterized as a transition between northern hardwoods (maple–beech–birch) and northeastern spruce–fir (Bryce et al. 2010). Geology is greatly shaped by glaciation and the granite upwelling of the AP mountains, providing numerous lakes, wetlands, bogs, and cold–water river systems throughout the AP (Bryce et al. 2010). Beaver–modified wetlands typically have greater emergent vegetation, cover, and invertebrate productivity (Kirby 1988, Dwyer and Baldassarre 1994, Seymour and Jackson 1996) than lakes, and previous AP waterfowl studies suggested lake use by waterfowl was limited (Dwyer and Baldassarre 1994). Beaver were increasingly rare in the AP during the mid–20th century, and a 4–year beaver trapping moratorium was instituted in some parts of the AP to restore beaver abundance (Parsons and Brown 1978). Since that time, beaver abundance has fluctuated but beaver–modified wetlands are common throughout the AP (Brown and Parsons 1979). A 2016 – 2018 pilot study began in beaver–modified wetlands in the northeastern portion of the AP (n = 22 wetlands), expanded the next year to include much of the eastern AP (n = 45), and in 2018 surveys included all ecozones of the AP (n = 97; Fig. 2.1). I used the results of this pilot study to select sample sizes, to refine my sampling frame, and to determine informative Bayesian priors in subsequent analyses.

Experimental Design

I randomly stratified a potential sample (n = 220) of beaver–modified wetlands in 5 ecozones of the AP (Edinger et al. 2014) in 2019 (Fig. 2.1) using wetlands from APA wetland shapefile attribute tables in combination with the National Agriculture Imagery Program (NAIP) August 2017 orthographic imagery in ArcGIS version 10.7 (ESRI, Redlands, CA). A power analysis (Cohen 1992, Steidl et al. 1997) of 2018 pilot study data indicated that a sample of 181 wetlands would be useful for detecting differences in occupancy among breeding waterbirds in the AP. I randomly selected proportionate samples of candidate wetlands based on the known available beaver–modified wetlands in each ecozone (total n = 220). Selection criteria for wetlands in this candidate list also included 1) permanently flooded, open–water, and beaver–modified wetlands with cover types of scrub–shrub, forested, emergent, and standing dead trees because they provided waterfowl habitat (Diefenbach and Owen 1989), 2) wetlands $\leq$ 1.6 km from accessible hiking trails or logging roads, 3) wetlands not visible from a paved road, and 4) wetlands on private lands with conservation easements or on public lands. Sites deemed inaccessible or otherwise uninhabitable to waterfowl when surveyed were removed from the sample.

I selected a sample of 55 lakes randomly from available AP lakes with access (i.e., public boat launches or trail access). I used AP lake bathymetry maps (NYSDEC 2005) to identify my candidate set of lakes because they showed public access points and human development, and I used this sample frame to include areas on lakes with and without human development. I considered lakes with substantial (>20%) littoral zones < 0.6 m deep and some level of human presence (e.g., development, campsites) (Macy and Straub 2016) as lacustrine dabbling duck habitat based on Staicer et al. (1994). Additionally, I included lakes with water quality data noted as mesotrophic or eutrophic (Laxson et al. 2019). Once lakes were selected, I reduced overlap between potentially territorial breeding pairs by generating random shoreline points separated by ≥ 1.6 km (Dwyer and Baldassarre 1994).

Beaver–modified wetlands in my sample frame can be categorized by dominant shoreline vegetation as forested, scrub shrub, or emergent, but typically have a combination of all three cover types. Most lake points in my sample frame (63%) were forested shoreline with little emergent or scrub–shrub vegetation. As such, to ensure beaver–modified wetlands and lakes surveyed areas were relatively comparable, I randomly selected one point of each of the shoreline types per lake; forested, emergent, and scrub–shrub wetland (n = 210 survey points). I discarded and reselected any randomly selected survey that occurred ≤ 1.6 km of an existing survey. When all three shoreline types were not available, I surveyed those that were present. For lakes ≥ 3 times larger than the suggested maximum home ranges for AP mallards (Dwyer and Baldassarre 1994), I increased my sample size proportionally.

Beaver–modified Wetland Surveys

Technicians and I surveyed wetlands (n = 187 of 220 candidate wetlands) for 30 min between sunrise and sunset from 13 May – 31 July 2019 and 14 May – 27 July 2020, which includes the territory defense, copulation, nesting, and brood–rearing periods in the AP (Dwyer and Baldassarre 1994, Baldassarre 2014). During surveys, we recorded the time to first detection of each waterfowl species to the nearest minute. Additionally, we recorded the observer's estimate of the percent open water in the survey area, and the percent of shoreline covered by emergent vegetation. We conducted surveys spatially among ecozones and temporally by time of day and across the sampling season as evenly as reasonably possible. We timed sampling of beaver–modified wetlands to maintain a relatively equal sample among morning ($\leq$ 1000 hrs), mid–day (1000 to 1500 hrs), and evening ($\geq$ 1500 hrs).

Lake Surveys

In 2019 and 2020, technicians and I surveyed 55 lakes (n = 210 survey points). We surveyed using binoculars and various boats anchored at offshore locations and recorded the same data as beaver–modified wetlands. We sampled lakes using the temporal and spatial scheme noted for beaver–modified wetlands. We recorded the presence or absence of shoreline development in lake surveys (i.e., docks, lawns, and human structures) as a categorical value (i.e., developed, or not). Covariate data for open water and emergent vegetation were recorded similarly to beaver–modified wetlands. The survey area from which these covariates were estimated on lakes was typically governed by natural features such as shoreline micro–topography (i.e., small peninsulas) and fallen trees that obstructed the farthest distance an observer could detect waterfowl (~400 m each direction).

Data Analysis

I used a static multi–species occupancy modeling framework with time to detection function for detection probabilities (Kéry and Royle 2008, 2015). I designated species as a random effect, nested within fixed effects for stratum (specified as beaver–modified wetland, undeveloped lake, or developed lake). The species included mallard, black duck, Canada goose (*Branta canadensis*), wood duck, hooded merganser, common merganser (*Mergus merganser*), and common loon which share relatively similar detectability traits (i.e., color, shape, size, crepuscular habit) (Garrard et al. 2013, Kéry and Royle 2015). I also included fixed effects of categorical year, continuous percentage open water, and continuous percentage emergent vegetation in the deterministic part of my occupancy model. I included percentage open water and emergent vegetated shoreline because these metrics have been shown to affect selection of breeding and brood rearing habitat by waterfowl (Kaminski and Prince 1981, Dyson et al. 2018).

I fit a single–visit, multispecies time–to–detection occupancy model in JAGS (Just Another Gibbs Sampler Version 4.3.0, Plummer 2003) using program R (R Version 4.0.3, www.r–project.org, accessed 8/17 2020), and package rjags (rjags Version 4–10, Plummer 2013) and created derived variables to compare occupancy of mallards and black ducks among treatments. The model structure was:

$$z_{ik} \sim Bernoulli(\psi_k)$$

$$d_{ik} \sim Bernoulli(\Theta_{ik})$$

$$TTD_{ik} \sim Exponential(\lambda_k)$$

$$\Theta_{ik} = z_{ik} * (TTD_{ik} > Tmax) + (1 - z_{ik})$$

where z_{ik} is the "true occupancy state" at site i for species k given mean occupancy probability for species k (ψ_k), d_{ik} is the censoring indicator (1 = no detection, 0 = detection) given the probability of censoring at site i for species k (Θ) which is 0 if the species was detected and 1 otherwise, TTD_{ik} is the observed time to detection given mean detection rate for species k (λ_k = 1/mean time to detection) *Tmax* is the maximum survey time, and $TTD_{ik} > Tmax$ = 1 if true and 0 if false. I modeled detection rate as a function of covariates using a log–link function, with a random effect of species k on the intercept of detection rate (α_λ) as:

$$Log\ (\lambda_k) = \alpha_{\lambda k}$$

$$\alpha_{\lambda k} \sim Normal\ (\mu_{\alpha\lambda},\ \tau_{\alpha\lambda})$$

$$\tau_{\alpha\lambda} \sim 1/\sigma_{\alpha\lambda}^2$$

With the following vague priors for the hyperparameters:

$$\mu_{\alpha\lambda} \sim Normal\ (0,\ 0.001)$$

$$\sigma_{\alpha\lambda} \sim Uniform\ (0,\ 100)$$

The derived mean time to detection is specified as:

$$TTD_k = 1\ /\ \lambda_k$$

and the derived mean probability of detection is specified as:

$$\bar{p}_k = 1 - exp\ (-\lambda_k * Tmax)$$

where $\bar{p}_k$ = the mean detection probability for species *k*.

I modeled occupancy probability as a logit–linear function of covariates and random effects of species on the intercept (α_ψ) and regression coefficients (β) as follows :

$$logit\ (\psi_{ik}) = \alpha_{\psi k} + \beta_{strat2k} * Strat2YN + \beta_{strat3k} * Strat3YN +$$

$$\beta_{yeark} * Year + \beta_{OWk} * OW + \beta_{Emk} * Em$$

where *Strat2YN* is a dummy variable for the fixed effect of undeveloped lake stratum, *Strat3YN* is a dummy variable for the developed lake stratum, *Year* is a dummy variable for 2020, *OW* is a continuous variable for percent unvegetated open water in the site, and *Em* is a continuous variable for the percent of shoreline dominated by emergent vegetation at survey sites.

The random effects for the intercept and beta parameters (i.e., regression parameter ϕ) for species k was specified as:

$$\phi_{\psi k} \sim Normal\ (\mu_{\phi\psi}, \tau_{\phi\psi})$$

$$\tau_{\phi\psi} \sim 1/\sigma_{\phi\psi}^2$$

With the following vague priors for the hyperparameters:

$$\mu_{\phi\psi} \sim Normal\ (0, 0.001)$$

$$\sigma_{\phi\psi} \sim Uniform\ (0, 100)$$

I created derived differences between occupancy (DDO) parameter estimates. I interpreted DDO estimates not overlapping 0 as a significant difference in occupancy probability between the two species of interest at 95% CI (Kéry 2010). I assumed that beta parameter estimates with 95% CI distributions for other fixed effects that did not overlap 0 to be significant (Kéry 2010). I derived mean occupancy estimates and 95% CI distributions among stratum for the 7 waterbird species in my study.

I originally used presence/absence data from only mallards and black ducks, however this model never converged for some parameters (i.e., Gelman–Rubin statistic > 1.1), even when allowed to run ≥ 3.5 million iterations. As such, data for the 5 additional species were included. These additional data further reduced the variance around estimates of time to detection and detection probability for mallards and black ducks by ≤ 31%, but had little effect on estimates of occupancy or variance around occupancy. Some species had < 40 detections (e.g., black ducks and common mergansers), and as a result even simple categorical covariates I included in the time to detection model made convergence difficult. As such, I did not include covariates in the time to detection part of the model, excluding a random effect for species.

RESULTS

Common loons (0.68 ± 0.11 SD, 0.22 ± 0.04 SD), mallards (0.18 ± 0.06 SD, 0.09 ± 0.02 SD), and common mergansers (0.06 ± 0.03 SD, 0.056 ± 0.019 SD) had the highest occupancy probabilities in developed and undeveloped lakes, respectively (Table 2.1, Fig 2.2). Occupancy probability for the remaining species in developed and undeveloped lakes was $\leq$ 0.05, with the lowest probability approaching 0 for hooded mergansers (0.001 ± 0.001 SD) in developed lakes (Table 2.1). Wetlands were occupied similarly by mallards (0.14 ± 0.02 SD), wood ducks (0.15 ± 0.02 SD), and hooded mergansers (0.14 ± 0.02 SD). Wetlands were occupied to a lesser degree, similarly by black ducks (0.051 ± 0.013 SD), common mergansers (0.047 ± 0.012 SD), and Canada goose (0.048 ± 0.012 SD). The lowest wetland occupancy was the common loon (0.028 ± 0.010 SD).

Mallards and black ducks overlapped 95% CIs for occupancy probability in some strata (Fig 2.2) but by < 25%. Mean occupancy probability for mallards was ≥ 6.7% greater than black ducks for all years and treatments (Table 2.1). Within–species DDO estimates suggested that mallard occupancy probability was 8.7% ± 4.1 SD lower in undeveloped lakes than developed lakes (Fig 2.3). All other within–species DDO estimates crossed 0 by small margins. Mallard and black duck occupancy were greater in wetlands and developed lakes than undeveloped lakes (Fig 2.3).

For Canada geese, mallards, and black ducks, the random effect was above the multispecies mean in developed lake environments relative to wetlands (Fig 2.4a). Wood duck occupancy was negatively associated with undeveloped lakes (Fig 2.4a) and developed lakes (Fig 2.4b) relative to wetlands. Wood duck occupancy was positively related with increasing percentage of emergent wetland vegetation (Fig 2.5b, Fig 2.6). Hooded merganser occupancy also was negatively associated with developed lakes (Fig 2.4a) and undeveloped lakes (Fig 2.4b) relative to wetlands, but did not show the same affinity for emergent vegetation as wood ducks (Fig 2.5b). For common loons, I detected that occupancy was positively influenced developed lakes (Fig 2.4a) and percentage open water (Fig 2.5a, Fig 2.6). Wood duck and hooded merganser occupancy had a negative relationship with developed lakes (Fig 2.4a). I found the beta parameter estimates for the effect of year were mildly variable amongst species and largely insignificant, however I left year in the model to account for interannual variation not otherwise modeled (Fig 2.5c).

Mean probability of detection ranged from 0.87 ± .052 SD for hooded merganser to 0.98 ± .02 SD for Canada goose (Table 2.2). Mean time to detection for those species was 14.7 ± 2.97 min and 7.7 ± 1.80 min, respectively. Detection probabilities and mean times to detection for mallards (p = 0.932, TTD = 11.1 min) and black ducks (p = 0.909, TTD = 12.4 min) were similar (Table 2.2), and derived tests for differences in TTD and p between these species were never found to be significant in any combination of model covariates or effects I tested.

DISCUSSION

My approach using a multi–species model with a time–to–detection probability function was effective for generating occupancy estimates with relatively good credibility for waterbirds in the AP despite few detections for some species. This method enabled me to meet my goal of increasing precision of estimates and detecting differences in occupancy between mallards and black ducks within and among habitat types. Results from the suite of five other waterbirds also provided validation that the ecological relationships detected for mallards and black ducks were likely biologically realistic. Hooded mergansers and wood ducks selected beaver–modified wetlands (Baldassarre 2014) and common loons and common mergansers occupied lakes or open water wetlands (McIntyre 1994, Mehner 2012, Spilman et al. 2014). The more generalist waterfowl species (i.e., Canada geese, black ducks, and mallards) occupied all study habitat types to a greater degree than wetland obligates (e.g., wood ducks, hooded mergansers) or piscivorous waterbirds (e.g., common loons, common merganser). Longer–term (i.e., additional years) datasets might allow for enough detections of black ducks to remove non–focal species from analysis, however they were especially useful to include in this analysis with only 2 years of detection data. Their inclusion is also useful for monitoring and managing populations of more than one species simultaneously.

Overall, occupancy was greater for mallards than black ducks in beaver–modified wetlands and lakes, which differs from prior findings in the AP that showed mallards were either rare or sympatric with black ducks in wetlands (Benson 1968, Brown and Parsons 1979, Dwyer and Baldassarre 1994), and in lakes (Macy and Straub 2016). Further, the difference in occupancy between mallards and black ducks was greater at developed lakes than other habitat types in my study, suggesting that human development of historically remote lakes could enable replacement of black ducks by mallards (Lehikoinen et al. 2016). Mallards need not be dominant or exclude other waterfowl from habitats to affect breeding black ducks, they simply need to fill niches that could be similarly used by black ducks during the breeding season (Coulter and Miller 1968, Petrie et al. 2012). In addition, the potential for mallards to be behaviorally dominant (Coulter and Miller 1968, Seymour 1992) and exploit greater niche space than black ducks could further provide an advantage to mallards (Diefenbach and Owen 1989, Lillie and Evrard 1994, Maisonneuve et al. 2006). In contrast to prior studies in the AP (Benson 1968, Brown and Parsons 1979, Dwyer and Baldassarre 1994, Macy and Straub 2016), I was able to identify differences between mallard and black duck occupancy for all combinations of year and habitat type. This is historically important because prior AP waterfowl studies suggested few examples of breeding AP mallards, and other ducks like hooded merganser, black duck, and wood duck were the most common breeding waterfowl for the last century (Eaton 1910, Benson

1968, Brown and Parsons 1979, Edinger et al. 2014). By the 1980's, mallards still had not colonized the AP as a substantial breeding participant (Brown and Parsons 1979, Heusmann 1991) despite their appearance in surrounding valleys. Just 15 years later, mallards and black ducks were sympatric with similar pair ratios and densities per km^2 in the western AP (Dwyer and Baldassarre 1994). My results suggest mallards are now more common than black ducks in the AP, and that greater use of developed lakes by mallards may provide an advantage relative to black ducks.

Compared to available prior AP waterfowl studies, my study samples sizes were substantially greater and spatially representative of the AP boundary. I did not include other ecosystems used by waterfowl in the AP, such as expansive geologically formed wetland basins and riverine areas, because of their difficulty in access and logistics of my sampling scheme. Despite their omission, some inference can be shared between riverine and geological wetlands and my study sites because their aquatic ecology and seasonal phenology are similar. Dwyer and Baldassarre (1994) determined that lakes were infrequently used by mallards and black ducks (< 5%), whereas I detected that developed lakes were the most occupied habitat type by black ducks, mallards, Canada geese, common loons, and common mergansers more so than undeveloped lakes. Further, the largest well–developed lake in the Dwyer and Baldassarre (1994) study area was a known mallard breeding site in my study.

Greater occupancy of developed lakes in my study may suggest a change in habitat quality between AP wetlands and lakes (Lehikoinen 2016). Further, dominance in sister–taxa can take decades to manifest into replacement of one species by the other after a period of sympatry (Mayr 1970, Nudds 1983) and this replacement can be habitat niche specific (Schoener 1974, Barnes and Nudds 1991). Despite the potential changes in lake occupancy in the 25 years since

Dwyer and Baldassarre (1994), wetlands were still important to mallards and black ducks, and were used similarly to developed lake sites. Even though vegetation is generally considered important for breeding and brood rearing for waterfowl (Kaminski and Price 1981, Staicer et al. 1994, Dyson et al. 2018) mallards and black ducks may still be meeting their nutritional needs in AP developed areas (Staicer et al. 1994), while potentially exploiting other advantages of human development (i.e., feeding of bread, shelter under porches and boat houses, lawns as a food source, predator avoidance). The general pattern of occupancy within mallards and black ducks was similar, indicating substantial niche overlap (Maisonneuve et al. 2006) and the only difference I found was greater mallard occupancy of undeveloped than developed lake sites. This largely agrees with previous findings that suggest mallards are more readily exploiting human influenced habitats (Morton 1998, Osborne et al. 2010, Macy and Straub 2016, Bleau 2018), and that black ducks generally avoid areas visible to human development (Diefenbach and Owen 1989, Macy and Straub 2016, Bleau 2018).

Invertebrates on breeding grounds are important to mallards and black ducks because they are the primary protein source for clutch formation and duckling growth (Krapu 1980, Reinecke and Owen 1981, Longcore et al. 2006, Baldassarre 2014). Prior studies have linked water chemistry with invertebrate density (i.e., phosphorous and PH), brood density (Staicer et al. 1994, Longcore et al. 2006), and brood size (Longcore et al. 1998). Over–eutrophication of wetlands from nutrients and climate warming trends has been suggested as a benefit to mallards while at the same time a deleterious effect on wetland obligate waterbirds that prefer specific successional stages (Lehikoinen 2016). Mallard success as a breeding generalist relative to other waterfowl species is supported by my occupancy results and in literature elsewhere (Lillie and Evrard 1994, Baldassarre 2014, Lehikoinen 2016).

The recent and increased pace of AP lakeshore development (~850 new building permits each year) has continued without strict standards for shoreline property lot–size despite the 1971 formation of the APA, which was aimed at regulating natural resource exploitation in the AP (Holland 2011). The latent (e.g., phosphorous) and unpredictable (e.g., nitrogen) effects of septic system effluent on littoral nutrient loading (Dennis 1986, Rakhimbekova et al. 2021) could have substantial long–term effects on AP littoral ecology (Laxson et al. 2019). Localized eutrophication paced by lakeshore development could partially explain the temporal series of studies cataloging colonization of the AP by mallards (Eaton 1910, Benson 1968, Brown and Parsons 1979, Dwyer and Baldassarre 1994) and, in this study, indications of an ongoing displacement or replacement of black ducks by mallards. Prior studies indicated that brood densities (Staicer et al. 1994) of black ducks were greater on human influenced lakes.

In the context of Lavretsky et al.'s (2019; 2020) findings, game–farm mallards may be exploiting developed habitats to a greater degree than black ducks because of innate behavioral patterns. Tolerance for human activity has been suggested as inherited from captive reared Old–World mallards (Heusmann 1983, 1991, Hepp et al. 1998, Lavretsky et al. 2020), and my results suggest developed lakes are occupied by AP mallards more than black ducks. My results also indicate the current niche of AP mallards is much larger than that of black ducks, and that their niches overlap in traditional AP black duck breeding habitats (Benson 1968, Brown and Parsons 1979, Dwyer and Baldassarre 1994). This dynamic further establishes the possibility that developed lakes, with stable anthropogenic water levels and dependable food supply (i.e., human handouts and nutrient loading), may serve as a source for mallard population growth relative to wetlands more traditionally used by black ducks (Brown and Parsons 1979, Holt 1985, Pulliam 1988). Wetlands might be a population sink in years when environmental variables such as weather or beaver extirpation (Brown and Parsons 1979, Holt 1985, Pulliam 1988) reduce the availability or quality of beaver–modified wetlands as breeding habitats. This could be further complicated in years when lake–ice thickness and delayed ice–out dates temporarily prohibit initiation of nesting on lakes relative to wetlands. Examination of the anthropogenic exploitative nature of mallards in similar boreal ecosystems in Finland suggests the Old–World mallard (Lavretsky et al. 2019) is capable of outcompeting sympatric wetland obligate waterfowl using oligotrophic lakes as a key resource (Lehikoinen 2016).

Future studies investigating relationships between AP mallards and black ducks should focus on duckling productivity among habitats, relationships between breeding season parameters and nutrient loading in developed lakes versus undeveloped lakes and attempt to identify if a source–population effect from human development is benefitting mallards relative to black ducks (Holt 1985, Pulliam 1988). My results suggest lakefront development currently plays an important role as AP waterfowl breeding habitat.

MANAGEMENT IMPLICATIONS

My model demonstrates that a multispecies occupancy framework can be useful to generate estimates for relatively uncommon species such as black ducks in the AP, while also providing valuable occupancy estimates for sympatric species. If an aim of waterfowl managers is to sustain breeding black ducks in the AP, I propose the human–mallard interface in AP habitats will need to be discussed and the effects potentially mitigated. I also suggest that managers could apply harvest strategies to reduce the abundance of hybrid swarm, game farm × wild mallards in eastern North America with the aim of reducing competition with native black ducks for breeding habitat. The highly similar occupancy of habitats of these two species in the AP will likely foster a competitive release on breeding black ducks (Lavretsky et al. 2020). I suspect the subsequent back–replacement of mallards by black ducks in AP breeding habitats would follow because these two species occupy similar niches and treat each other as conspecifics (Petrie et al. 2012). Furthermore, the AP is a single stratum in the Atlantic Flyway Breeding Waterfowl Population Survey (Heusmann and Sauer 1997, 2000) with substantial variance around population estimates. My study sites and analysis framework offer managers a unique opportunity to accessibly monitor long–term trends in the populations of mallards, black ducks and other waterbirds in a semi–boreal ecosystem like those in the core breeding area of black ducks in Canada.

Given the nuanced differences of how each species reacts to disturbance, dealing with the interface of lakefront development and these two species will be a necessary component in the management of Adirondack waterfowl and the retention of the AP black duck. Curtailing lakefront development is likely severely unpopular with local municipalities and has proven to be the target of lobbying from development protagonists in the past. This lobbying effort was done to great effect at the time, and despite the ongoing formation of a regulatory agency intended to mitigate over–exploitation of AP natural resources (Holland 2011). Tackling nutrient loading may seem more attractive than reclassifying land use, however legacy phosphorous and the removal of nitrogen from septic effluent is widely considered impossible or ineffective to mitigate. Regardless, a necessary first step for expanding APA regulation in any of these areas will be to quantify the scale and impact of development in AP habitats.

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Table 2.1 Mean, SD, and quantiles of estimates of occupancy probability for 7 species of waterbirds from 2019 to 2020 in wetland sites, undeveloped lake sites, and developed lake sites in the Adirondack Park of New York, USA. SD is the standard deviation of the mean, q2.5, and q97.5 are their quantile estimates. Difference between q2.5 and q97.5 are the 95% credible interval for the specified estimate.

		Estimates			
Stratum	Species	Mean	SD	q2.5	q97.5
Wetland	American black duck	0.051	0.013	0.029	0.080
	Mallard	0.142	0.021	0.103	0.187
	Canada goose	0.048	0.012	0.027	0.075
	Wood duck	0.154	0.024	0.111	0.204
	Hooded merganser	0.139	0.023	0.098	0.189
	Common loon	0.028	0.010	0.012	0.050
	Common merganser	0.047	0.012	0.026	0.073
Undeveloped lake	American black duck	0.020	0.011	0.005	0.047
	Mallard	0.087	0.023	0.048	0.136
	Canada goose	0.019	0.010	0.004	0.044
	Wood duck	0.043	0.017	0.016	0.082
	Hooded merganser	0.011	0.009	0.001	0.033
	Common loon	0.223	0.038	0.153	0.300
	Common merganser	0.056	0.019	0.026	0.099
Developed lake	American black duck	0.035	0.024	0.007	0.096
	Mallard	0.175	0.056	0.084	0.299

Canada goose	0.050	0.032	0.010	0.133
Wood duck	0.011	0.007	0.003	0.028
Hooded merganser	0.001	0.001	0.000	0.004
Common loon	0.683	0.106	0.452	0.862
Common merganser	0.061	0.034	0.017	0.149

Table 2.2 Mean time–to–detection (TTD) and mean probability of detection (p) variance statistics for 7 species of waterbirds from 2019 to 2020 in wetland sites, undeveloped lake sites, and developed lake sites in the Adirondack Park of New York, USA. SD is the standard deviation of the mean, q2.5, and q97.5 are their respectively named quantile estimates. Difference between q2.5 and q97.5 are the 95% credible interval for the specified estimate.

		Estimate			
Parameter	Species	Mean	SD	q2.5	q97.5
TTD	American black duck	12.42	2.32	8.68	18.08
	Mallard	11.11	1.41	8.81	14.45
	Canada goose	7.75	1.80	5.15	12.06
	Wood duck	13.02	2.25	9.56	18.31
	Hooded merganser	14.77	2.97	10.12	20.76
	Common loon	11.42	1.66	8.60	15.58
	Common merganser	12.37	2.29	8.80	17.70
p	American black duck	0.909	0.040	0.810	0.968
	Mallard	0.932	0.023	0.875	0.967
	Canada goose	0.976	0.021	0.917	0.997
	Wood duck	0.899	0.039	0.806	0.957
	Hooded merganser	0.869	0.052	0.764	0.948
	Common loon	0.927	0.028	0.854	0.970
	Common merganser	0.910	0.039	0.816	0.967

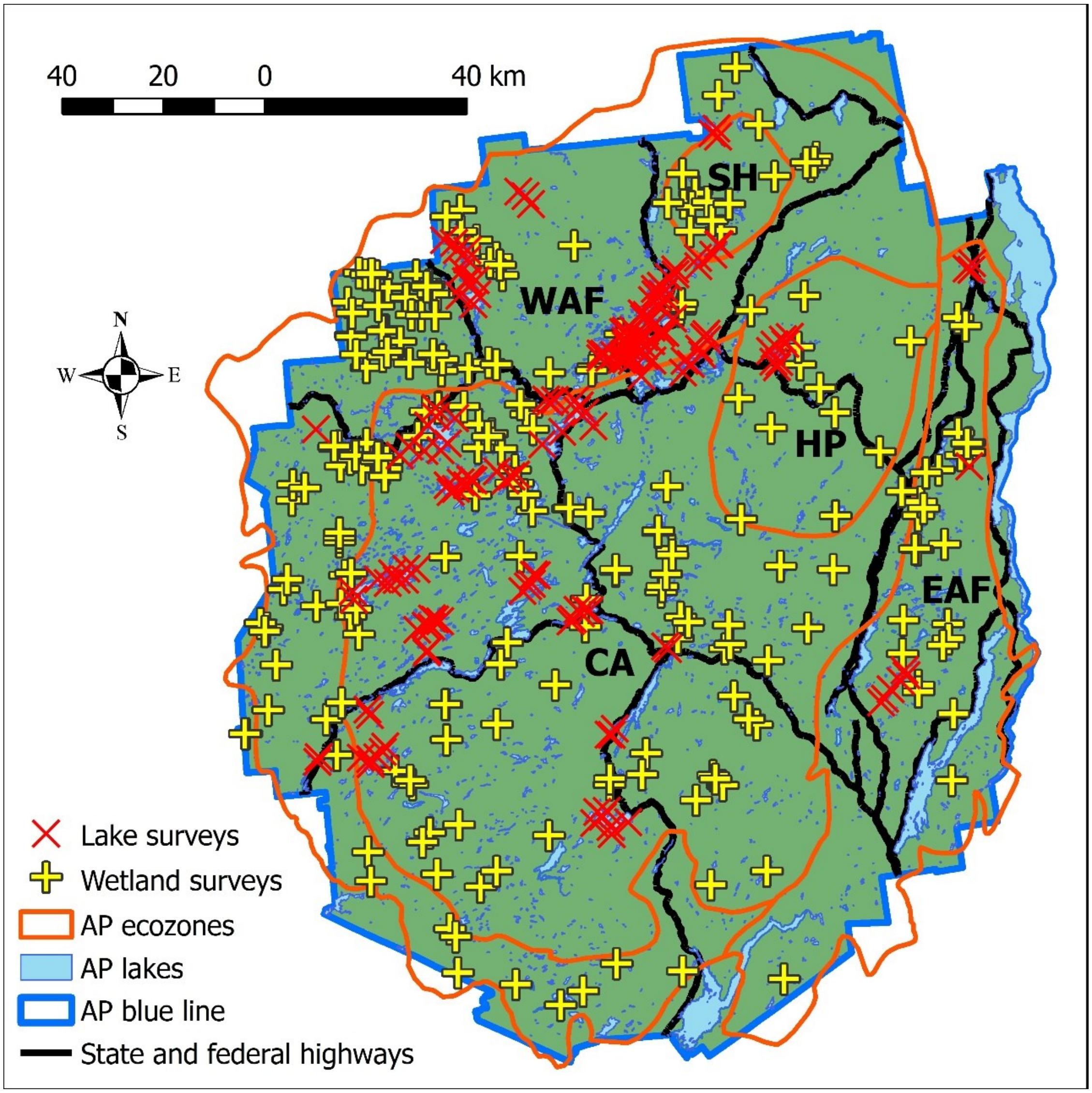

Figure 2.1. Map of beaver–modified wetland and lake surveys in the Adirondack Park (AP) of northern New York, USA, May – July 2019 and 2020. Ecozones are classified according to Edinger et al. (2014) and are denoted as Central Adirondack (CA), Western Adirondack Foothills (WAF), Sable Highlands (SH), High Peaks (HP), and Eastern Adirondack Foothills (EAF).

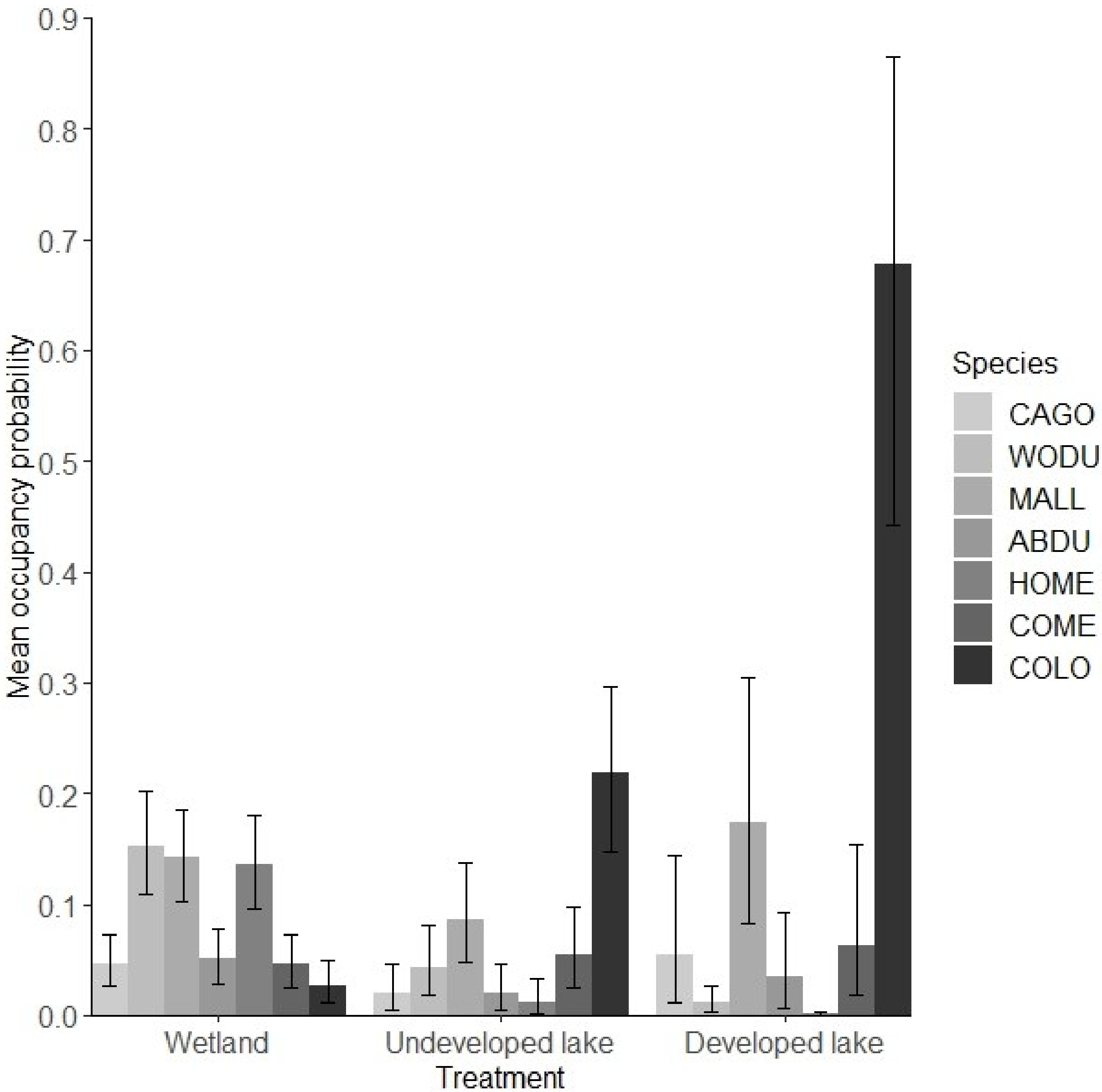

Figure 2.2. Mean occupancy probability with 95% credible intervals for 7 species of waterbirds in beaver–modified wetlands, undeveloped lakes, and developed lakes in the Adirondack Park, New York, USA, May – July 2019 and 2020. Alpha codes = CAGO – Canada goose, WODU – wood duck, MALL – mallard, ABDU – American black duck, HOME – hooded merganser, COME – common merganser, and COLO – common loon.

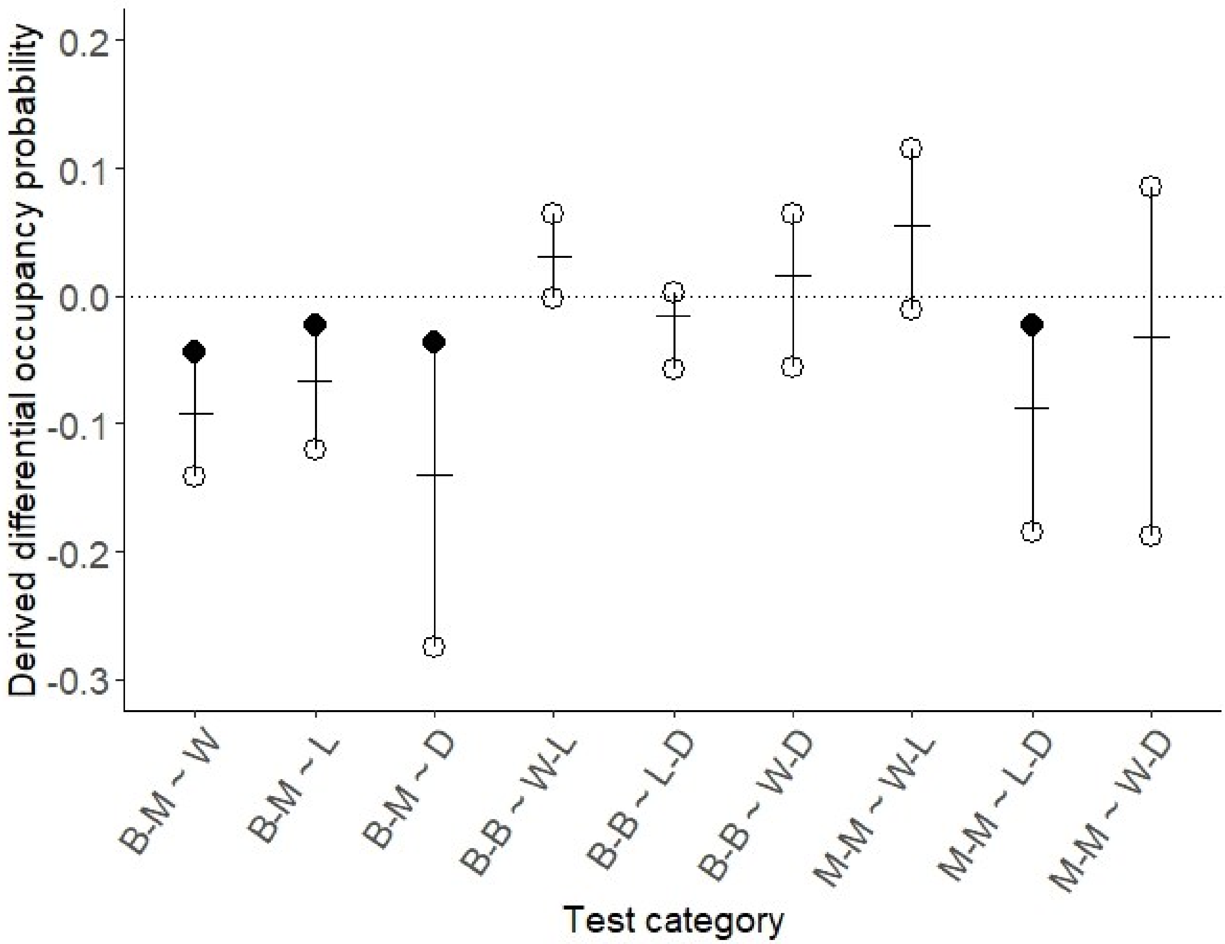

Figure 2.3. Derived difference in occupancy probability with 95% credible intervals for mallards and black ducks in beaver–modified wetlands (W), undeveloped lakes (L), and developed lakes (D) in the Adirondack Park, New York, USA, May – July 2019 and 2020. Test category is coded to denote differences between test categories including species (B = black duck, M = mallard), and treatment (L, W, or D). For example, B–M~W = the difference between mallard and black duck occupancy probability in wetlands). Black filled dots denote an estimate that does not overlap 0, indicating a significant result.

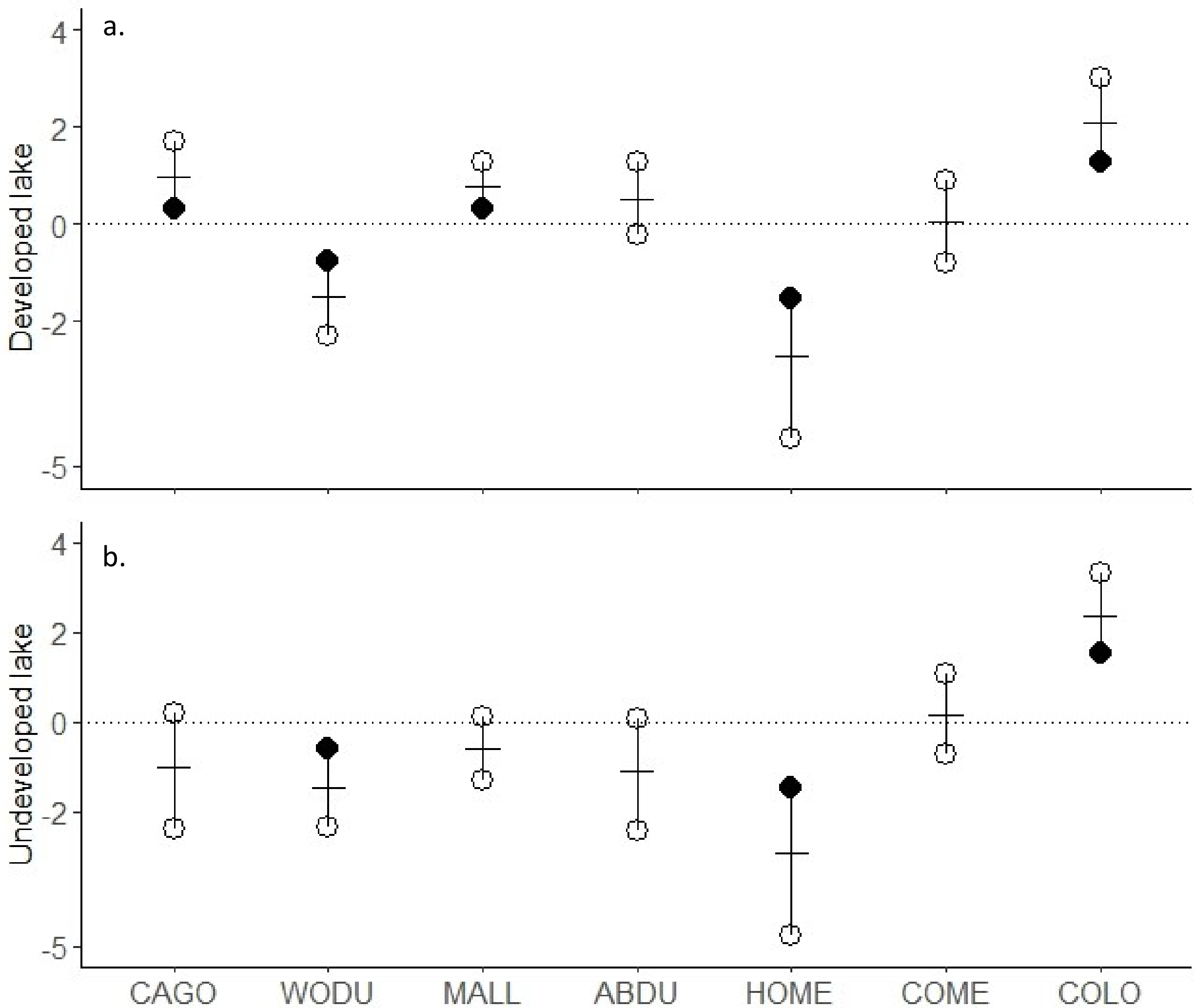

Figure 2.4. Beta parameter estimates with 95% credible intervals for the effect of developed lake (a) and undeveloped lake (b) treatment (i.e., stratum) relative to wetlands on occupancy probability of 7 species of waterbirds in the Adirondack Park, New York, USA, May – July 2019 and 2020. Alpha codes = CAGO – Canada goose, WODU – wood duck, MALL – mallard, ABDU – American black duck, HOME – hooded merganser, COME – common merganser, and COLO – common loon. Black filled dots denote an estimate that does not overlap 0, indicating a significant result.

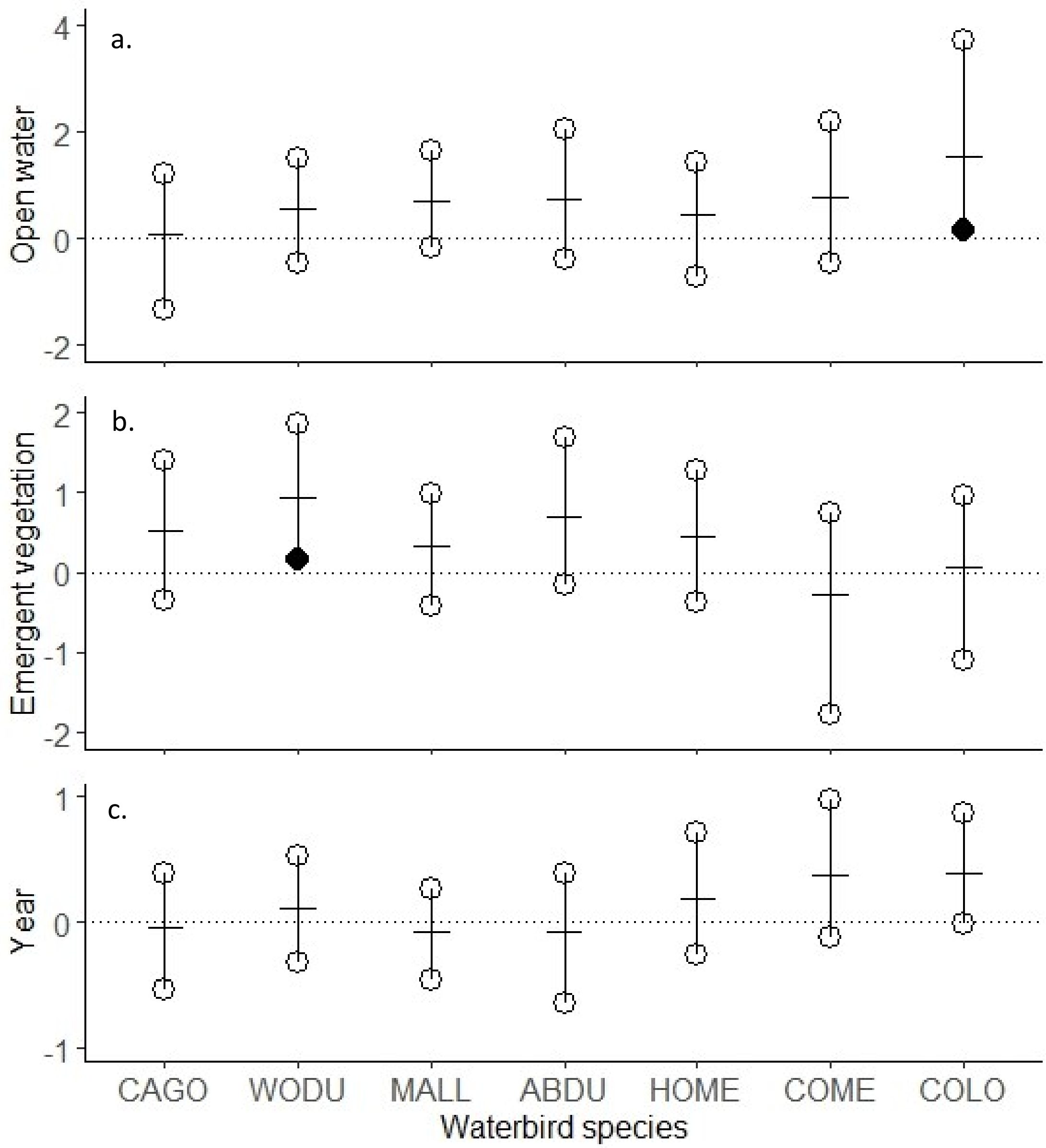

Figure 2.5. Beta parameter estimates with 95% credible intervals for the effect of (a) year, (b) percentage open water in site, and (c) percentage emergent vegetation as shoreline on occupancy probability of 7 species of waterbirds in the Adirondack Park, New York, USA, May – July 2019 and 2020. Alpha codes = CAGO – Canada goose, WODU – wood duck, MALL – mallard, ABDU – American black duck, HOME – hooded merganser, COME – common merganser, and COLO – common loon. Black filled dots denote an estimate that does not overlap 0, indicating a significant result.

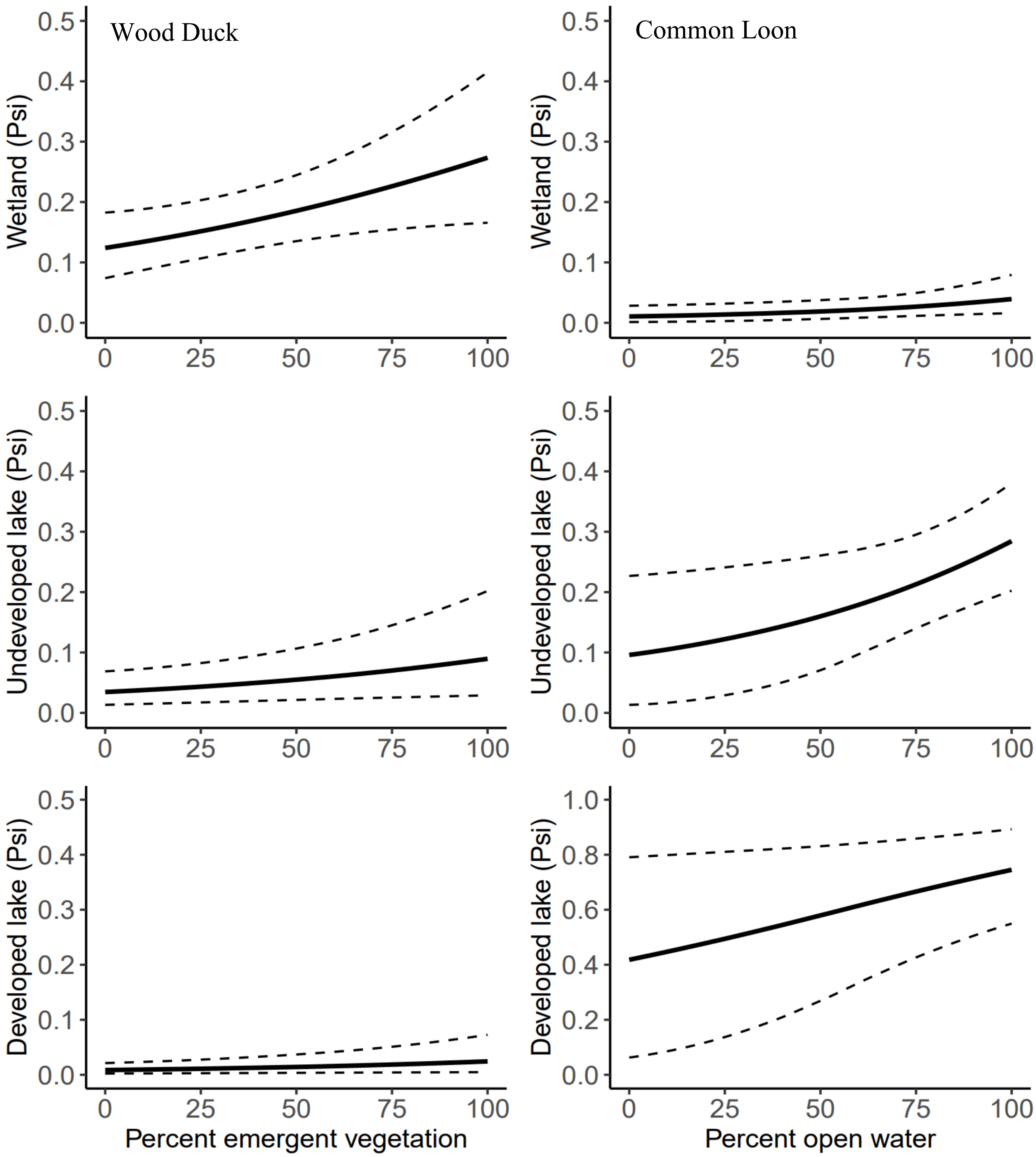

Figure 2.6. Covariate predictive plots with 95% credible intervals for the effect of percent shoreline as emergent vegetation on occupancy probability of wood ducks, and the effect of percent open water in survey site on occupancy probability of common loons in the Adirondack Park, New York, USA, May – July 2019 and 2020.

CHAPTER 3: EXAMINING UTILITY OF UNMANNED AERIAL VEHICLES TO SURVEY WATERFOWL IN FORESTED WETLANDS OF NORTHERN NEW YORK

ABSTRACT Unmanned aerial vehicles (UAV) are increasingly popular for wildlife studies because they offer many opportunities to resolve issues with land access, animal detectability, animal disturbance, survey reproducibility, and human safety. Waterbirds in wetlands with vertical structure that obstructs horizontal line–of sight are challenging to survey because detection is greatly reduced. The waterfowl species that inhabit densely vegetated wetlands are often secretive, and subject to being easily disturbed. Based on recent advances in integrated UAV camera systems, and recent research into colonial waterbirds in various environments, I hypothesized an off–the–shelf consumer grade UAV might be capable of collecting imagery and video that allow researchers to effectively detect, identify, and count waterfowl in beaver–modified wetlands of the Adirondack Park (AP), New York, USA. I evaluated this hypothesis by conducting successive ground and UAV surveys at 16 beaver–modified wetlands in the AP. I compared detection probability between methods while accounting for differences in covariates of the area surveyed by each method, and their corresponding survey–specific vegetation metrics. I analyzed the paired ground and UAV counts in an N–mixture model fit to a Bayesian statistical framework. I found no difference in detection probability between the UAV (p = 0.493 ± 0.247 SD) and ground survey (p = 0.452 ± 0.238 SD) after accounting for differences in vegetative cover and wetland area surveyed by these methods. However, review of raw video from the UAV detected more waterfowl in dense vegetation than the ground observer including 3 occasions where the UAV recorded black ducks not detected from the ground. Survey efforts were similar between methods, but UAV video includes additional viewing time.

KEY WORDS Adirondack Park, American black duck, *Anas platyrhynchos, Anas rubripes,* mallard, UAV, unmanned aerial vehicles.

UAVs may have advantages relative to traditional ground–based surveys including greater survey viewing angle, site access, and real–time collection of observational habitat data (Chabot and Bird 2015, Drever et al. 2015). UAVs have been applied to studies of rare and common species in terrestrial and aquatic environments (Watts et al. 2010, Brooke et al. 2015, Weissensteiner et al. 2015, McEvoy et al. 2016, Delparte et al. 2019). Application of UAVs to survey waterbirds has the potential to detect birds with various life history strategies and among a diversity of cover types (Chabot and Bird 2015, Hodgson et al. 2018). However, studies determining the utility of UAVs to survey waterbirds in wetlands surrounded by forest is limited to examples with few incidental trees in more arid environments relative to the dense older forests found in the northeastern United States. UAVs have been used to count nesting Canada geese (*Branta canadensis*) and snow geese (*Chen caerulescens*) as effectively and accurately as ground observers without noticeable disturbance (Chabot and Bird 2012). A thermal and visual sensor platform on a UAV was used in the grasslands of North America to effectively detect, monitor, and identify nests and broods of waterfowl (Bushaw et al 2020). In Australia, a medium format sensor on a large rotary wing UAV was used to identify between two similar species of dark plumage ducks while avoidance disturbance of birds during the non–breeding period (McEvoy et al. 2016). To my knowledge, no current publication has successfully used UAVs to survey waterfowl in a mountainous environment on wetlands surrounded by forest.

The American black duck (*Anas rubripes*; hereon black duck) declined in population in the eastern United States over the last century. Concurrent with that decline was an expansion in the range and population of mallards (*Anas platyrhynchos*). Black ducks are known to behave more secretively than mallards in relation to human development (Diefenbach and Owen 1989) and select forested wetlands (Kirby 1980; 1988) which can hinder large scale surveys (Merendino et al. 1995). Furthermore, breeding waterfowl often select brood–rearing habitat with abundant emergent vegetation (Cowardin and Blohm 1992), which can decrease probability of detections (Diem and Lu 1960). Therefore, the successful application of UAVs for surveying black ducks at a greater detection probability than ground surveys would enable more precise estimation of population trends in difficult–to–survey environments.

The Adirondack Park (AP) in northern New York, USA, has a diversity of waterfowl habitats including emergent wetlands, forested wetlands, glacial lakes, bogs, and riverine systems, all of which can be modified by beaver (*Castor canadensis*) activity. The cyclical occupancy of beaver–modified wetlands has long been recognized as beneficial to waterfowl (Nummi 1992, Kirby 1973). Its value to black ducks in densely forested areas of North America has also been well identified (Whitman 1978, Spencer 1986, Kirby 1980; 1988). Considering the abundance of beaver–modified wetlands and their importance to breeding waterfowl of the region, I aimed to determine if a high–resolution visible spectrum sensor on a consumer grade UAV would be useful to survey waterfowl in this habitat. Currently, this is the only study I am aware of that attempts to survey waterfowl in a densely forested and mountainous environment using a UAV. My objectives were to 1) determine if a UAV was able to identify black ducks and sympatric heterospecific waterfowl (hereon "ducks") at altitudes known to reduce disturbance (McEvoy et al. 2016) and avoid ground structure, 2) compare UAV survey performance to ground–survey methods, 3) compensate for inherent differences between ground and aerial survey methods, and 4) assess the chosen platform and flight strategy for species–specific cases of efficacy and recommend future strategies or points of study.

METHODS

Study Area

The AP, located in northern New York state, is the largest publicly protected area in the contiguous United States and is a designated World Biosphere Reserve in 1989. The AP has similar geologic and ecologic conditions to Canada's boreal forest and its extensive forest cover is characterized as a transition between northern hardwoods (maple–beech–birch) (*Acer* spp*.,* *Fagus grandifolia, Betula* spp.) and northeastern spruce–fir (*Picea* spp., *Abes balsamea, Tsuga canadensis*) assemblages (Bryce et al. 2010). Geology is greatly shaped by glaciation and the granite upwelling of the Adirondack mountains, and the AP provides numerous lakes, wetlands, bogs, and cold–water river systems (Bryce et al. 2010). The AP provides breeding habitat for black ducks with > 3,000 lakes and abundant beaver–modified wetlands (Brown and Parsons 1979, Dwyer and Baldassarre 1994, Macy and Straub 2016). Despite the potential abundance of waterfowl breeding habitat in the AP, naïve occupancy can be as low as 30% for beaver–modified wetlands (Chapter 2). Impediments to flying UAVs in the AP include mountainous topography (~1000 m prominence), trees > 33m in altitude above surface level (ASL), active military operations areas (MOAs), atmospheric weather conditions, and a matrix of private and publicly owned conservation lands with UAV and airspace use restrictions. Access to these wetlands using traditional ground–based approaches is physically difficult which can limit sample sizes, and the dense forests and vegetation in and around beaver–modified wetlands also often decreases detections (Diem and Liu 1960, Kirby 1980). Conventional aerial surveys of beaver–modified wetlands using manned aircraft are conducted rapidly and often fail to adequately detect the waterfowl present on wetlands (McAuley et al. 2004).

Experimental Design

I first applied basic photogrammetric calculations to manufacturer–provided specifications of modern consumer grade UAV and sensor combinations. I wanted to ensure an image resolution that made color and size details recognizable for identification of female mallards and black ducks in the breeding period, which may require collecting imagery with enough precision to identify bill color. I vetted identification capability by acquiring pilot licensing (FAA 14 CFR Part 107), access permits, suitable UAV equipment, and then employed them over known black duck habitat in central New York, USA, in March and April 2019. During the waterfowl brood rearing period (July 2020), I flew UAV surveys immediately after ground–based point counts in an existing wetland survey framework for waterfowl and analyzed the two counts for comparison of detection probability. In addition, I incorporated the covariates of survey area (ha of wetland) as "available" waterfowl habitat and percentage vegetative cover into estimates of detection probability and abundance, to control for the inherent relative differences between ground and UAV methods. I conducted surveys when allowed by MOA schedules, there was no precipitation, visibility was > 4.9 km, wind was < 24 km/h, and when high–angle sunlight did not impede detections.

Sensor Selection and Species ID Testing

AP beaver–modified wetlands are often surrounded by mature stands of mixed forests with white pine (*Pinus strobus*). My primary concerns for safely operating UAVs in the AP were trees that can often reach > 33m ASL in combination with the increasing elevation of topography surrounding wetlands. Additionally, I wanted to fly high enough to avoid waterfowl disturbance while still collecting imagery of the precision necessary for waterfowl identification. To accomplish this, I first determined the ideal ground–sampling distance (GSD; a linear measure of ground represented per image pixel) (Neumann 2004, 2008). I assumed the ideal GSD to be the resolution at which an individual pixel would likely capture the overall body color, speculum, tail feathers, bill color, or other features of individual waterfowl detections that could distinguish between female mallards and black ducks (*sensu* McEvoy et al. 2016). Using the LeMaster method book (LeMaster 1996), I measured the length and width of a black duck bill, as this was one of the finer scale detection differences available between species. I divided each dimension by 3 (i.e., allowing for partial color collection at all sides of a central pixel) to create a necessary image pixel size of one third the bill width and length of a black duck. Camera pixels are square, so I assumed the bill–width dimension mandated the desired GSD. This measurement then became my target GSD for differentiating between female mallards and black ducks.

With this target GSD, I then compared the contemporary consumer grade (i.e., "off–the–shelf") UAV/sensor combinations available in January 2019. I only considered models requiring no custom programming or airframe modifications which also typically included fully integrated sensor payloads and real–time ground control station (GCS) video transmission systems. Densely forested environments typically require vertical takeoff and landing (VTOL) capabilities, and rotary–wing "quadcopter" type UAVs are most well suited for this strategy. As such, only VTOL capable aircraft platforms (mostly quadcopters) were considered. I selected the Inspire 2 airframe and Zenmuse X7 aerial sensor combination, with 16 mm and 50 mm aspherical (ASPH) lenses (24 mm and 77 mm spherical–lens equivalence) (DJI, Nanshan, Shenzhen, China). The Zenmuse X7 sensor is a "Super–35" sized 24–megapixel sensor measuring 23.5×15.7 mm.

An effective larger sensor and airframe combination were known to exist (McEvoy et al. 2016), however the expense, lack of portability, and lack of contemporary systems integrations (e.g., live video transmission and collision avoidance) was the motivating deciding factor against its use. I also preferred UAV airframes and navigation systems that had been well vetted for inherent errors by widespread consumer use.

I assembled, registered (FAA 14 CFR Part 48), updated, and calibrated the newly acquired aerial platform and sensor. I then deployed the UAV over known black duck habitat in the Northern Montezuma Wildlife Management Area (NMWMA) in Savannah, NY, USA, during the spring migration of March and April 2019. This is a New York State Department of Environmental Conservation (NYSDEC) owned property and required a NYSDEC UAV pilot license, in addition to a temporary revocable permit. Further testing to obtain a diversity of species detections using various flight strategies was conducted over flooded hardwoods and rice fields in Poinsett County, Arkansas, USA, February 2019, Lake Ontario, New York, USA March 2019, and the AP target wetlands, August 2019.

Flight Strategy, Imagery Collection and Review

I used the approximate flight strategy employed by McEvoy et al. (2016) by flying the aircraft as high above the wetland as imagery proved useful for identifying ducks, and most maneuvers such as VTOL, turning, or altitude change are conducted as far from the view of the wetland as possible to avoid causing disturbance to the birds. My method differed from McEvoy et al. (2016) and Drever et al. (2015) because I chose to collect a continuous reel of high–resolution video (4096 x 2160 pixels – hereafter 4K, and 6006 x 3200 pixels – hereafter 6K) in addition to 4K and 6K still images collected by prior studies. I used neutral–density optical filters to mitigate sunlight intensity when needed. Relatively linear–shaped wetlands with forested edges were flown at > 50 m ASL with a 50 mm focal length ASPH lens with mechanical leaf shutter. More circular, wider shaped wetland basins were flown > 30 m ASL with a 16 mm focal length ASPH lens.

Challenges securing permits in summer 2019 precluded my ability to conduct UAV surveys at a useful time in the 2019 waterfowl breeding period, however a subset of the selected AP wetlands were flown for testing in August 2019. During these flights, I tested autonomously programmed 50% overlap imagery in grid–style flights with the UAV camera aimed at nadir (Drever et al. 2015) in comparison to a hybrid method of manually flying grid–like patterns over wetlands (McEvoy et al. 2016) while allowing for some oblique camera viewing. For both flight strategies, I collected a continuous stream of 4K video (i.e., stored in onboard memory cards) while simultaneously collecting 4K and 6K still images of shaded forested shoreline and areas with dense aquatic vegetation. Still images were collected for any detections of waterfowl made during the GCS video feed, as well as other challenging detection environments such as dead forested wetlands and scrub–shrub shoreline. I used the Inspire 2 telemetry data (automatically plotted in a GCS on–screen map) to ensure full aerial–surface coverage of the wetland to be surveyed during the manual grid search method. Some wetlands were large enough to require battery changes to complete surveys of the wetland surface area. Telemetry data was also used to resume surveys where they were stopped, and ground surveyors observed for assumptions of closure between the surveyed and un–surveyed portions of wetlands.

In the lab, I reviewed video and imagery twice to detect and identify waterfowl. I recorded time of detection (i.e., survey effort time and video–index time), number of birds in each detection, demographic information, vegetative covariates, and if the UAV appeared to affect behavior. I recorded vegetation covariates from UAV video as an estimate of percentage of wetland with emergent vegetation above the water. This was included to model the effect of vegetation on detectability (Diem and Liu 1960, Kirby 1980) as well as its complimentary effect on abundance (Kirby 1980, Kaminski and Prince 1981, Dyson et al. 2018). I used VLC media player (VideoLAN, Paris, France) and 4K–ready computer monitors with substantial contemporary graphics processing hardware to effectively review, detect, and identify waterfowl in UAV imagery and video and found them essential to this process. I improved my ability to detect and identify waterfowl in videos by reducing playback by 1/3rd speed and zooming into images by ≤ 1000%.

Ground–based Wetland Surveys

I chose 16 AP beaver–modified wetlands in 2020 (Fig 3.1) with physical properties suitable for VTOL and maintaining visual line of sight (VLOS) that were already part of an existing ground–based waterfowl survey. At each wetland, observers surveyed for 30 min prior to the UAV flight from shoreline points with a secretive approach and the greatest visibility of wetland area. Ground and UAV surveys were conducted successively by the observer and the UAV pilot (myself in all cases) to synchronize the immediate transition of survey methods. Ground observers recorded the number, species, sex, and age of waterfowl in the wetland in a radius limited only by the extent of wetland visible from the survey point, and covariates for vegetation (relative to ground observer), and bird behaviors potentially associated with disturbance (i.e., flight, swimming away, hiding, change of activity). At the conclusion of the 30 min ground count, I launched the UAV and surveyed the wetland using the integrated camera system. During the UAV survey the ground observer watched for UAV disturbance of waterfowl and movements of waterfowl that might affect detection (i.e., during battery changes, disturbance behaviors). The pilot was not made aware of any detections recorded by the ground observer until after all flights had been completed.

Count Analysis and Detection Probability

I tallied counts conservatively (i.e., each brood or related group of ducks as a single detection) from each survey method to maintain model assumptions of independence of the counted individuals (Kéry 2010). I did not consider single adult or juvenile heterospecific waterfowl occurring in the same area as grouped, but conspecifics in arrangements of broods or pairs were counted as single detections. I combined all species of waterfowl detected and will discuss them hereafter simply as ducks because of small sample sizes for individual duck species. I analyzed count data using an adaptation of the binomial mixture model described by Kéry (2010) to model presence or absence of ducks from a binomial distribution, and their "true" count abundance from a Poisson distribution, considering the ground and UAV survey as two independent visits. The model was fitted in a Bayesian statistical framework using JAGS (Just Another Gibbs Sampler Version 4.3.0, Plummer 2003) called through program R (R Version 4.0.3, www.r–project.org, accessed 8/17 2020), and package rjags (rjags Version 4–10, Plummer 2013). I further parameterized this mixture model to account for wetland area, the availability of survey area for detection (i.e., method–specific survey area), and method–specific (i.e., UAV or ground) covariates for vegetated cover modeled to affect both presence and detection.

To model the "true" state of duck abundance, I specified the model equations as:

$$N_i \sim Poisson\ (\lambda_i)$$

$$\log(\lambda_i) = \log\ (Au_i) + \alpha_\lambda + \beta_\lambda * Vu_i + €_i$$

where N_i is the true abundance at site i, with a mean around λ_i (lambda = the Poisson intensity parameter). The deterministic equation for λ_i includes an offset for wetland area (Au_i), the intercept α_λ for λ, and the beta parameter (β_λ) for the effect of wetland vegetated cover (Vu_i) on duck abundance at site i. $€_i$ is an extra–Poisson variation parameter I included to compensate for overdispersion from zero–inflated data. I specified priors for the above parameters as:

$$€_i \sim \textit{Normal}\ (0, \tau)$$

$$\sigma \sim \textit{Uniform}\ (0, 100)$$

$$\tau = 1/(\sigma * \sigma)$$

$$\alpha_\lambda \sim \textit{Normal}\ (0, 0.001)$$

$$\beta_\lambda \sim \textit{Normal}\ (0, 0.001)$$

where $€_i$ is distributed normally around a mean of 0 and a precision of τ. σ (standard deviation of $€_i$) is distributed uniformly around a mean of 0 and a standard deviation of 100. I specified the observational model for replicated counts as:

$$C_i \sim \textit{Binomial}\ (p.e_i, N_i)$$

$$p.e_i = p_i * Av_i$$

$$\text{logit}(p_i) = \alpha_p + \beta_{pV} * Vp_i + \beta_{pObs} * Obs_i$$

where C_i (count data at observation i) is distributed binomial with a probability around $p.e_i$ (the probability of detection correcting for duck availability) given N detection trials at site of observation i. Availability (Av_i) = method–specific proportion of survey area covered, and was determined by using ArcGIS version 10.7 (ESRI, Redlands, CA) to delineate method–specific survey areas based on ground observer location, orthoimagery, and UAV flightpath and video. I specified the deterministic model for p_i (probability of detection) to include beta parameters for the effect (β_{pV}) of method–specific vegetated cover covariates (Vp_i) and beta parameters for the effect (β_{pObs}) of survey method (Obs_i) on detection probability for observation i. Priors for these parameters are specified as:

$$\alpha_p \sim \textit{Normal}\ (0, 0.001)$$

$$\beta_{pV} \sim Normal\ (0, 0.001)$$

$$\beta_{pObs} \sim Normal\ (0, 0.001)$$

where all coefficient priors were distributed normally with a mean around 0, and a SD around 1. I examined model estimates of detection probability between methods and generated predictive plots for the effect of vegetation on detection probability.

RESULTS

UAV Selection and Testing

Using the LeMaster method book (LeMaster 1996), I determined a female black duck bill was approximately 55 mm long and 23mm wide. I then determined my ideal GSD to be 7.6 mm. Using this GSD, I found that as of January 2019 the only UAV platform and sensor combination capable of obtaining this GSD and satisfy other mission criteria (i.e., portability, VTOL) was the Inspire 2 UAV and integrated Zenmuse X7 sensor. Test flights from NMWMA made it apparent (Fig 3.2) that mallards and black ducks could be readily distinguished from each other in imagery, video, and "live" on the GCS screen at altitudes > 50 m ASL with a 50 mm ASPH lens, especially when appearing together.

Further flights over NMWMA, Lake Ontario, and flooded rice and hardwoods in Arkansas suggested this UAV and sensor combination is capable of detecting and identifying Canada goose (*Branta canadensis*), wood duck (*Aix sponsa*), northern shoveler (*Spatula clypeata*), American wigeon (*Mareca americana*), northern pintail (*Anas acuta*), green–winged teal (*Anas crecca*), redhead (*Aythya americana*), ring–necked duck (*Aythya collaris*), long–tailed duck (*Clangula hyemalis*), bufflehead (*Bucephala albeola*), hooded merganser (*Lophodytes cucullatus*), common merganser (*Mergus merganser*), red–breasted merganser (*Mergus serrator*), ruddy duck (*Oxyura jamaicensis*), pie–billed grebe (*Podilymbus podiceps*), and great blue heron (*Ardea herodias*) in ideal lighting conditions at altitudes > 33 m ASL with a 50 mm ASPH lens.

Flight Strategy Testing, Image Collection and Review

I determined the geophysical properties (i.e., mountainous and forested) of AP beaver–modified wetlands and software issues with autonomous imagery collection precluded the use of the manufacturer–integrated autonomous flight software similar to the type used by Drever et al. (2015). Pre–programmed flight paths also were not able to adequately consider VLOS restrictions to the GCS in a densely forested environment, and view of the UAV often became obstructed by trees (sometimes at a similar altitude) when flying over the farthest portions of beaver–modified wetlands from the pilot. Onboard software did not allow for the discontinuous resumption of these programmed flight paths (i.e., waypoints) when VLOS interruptions occurred, and for legal compliance this method was deemed unsuitable. Additionally, color corruption errors in the encoding of autonomously collected still images suggested loss of image data and any included detections were likely. As such, my 2020 data collection flights were completed using the hybrid manual grid–like flight strategy.

During the 16 AP beaver–modified wetland flights, I collected 223 4K–videos totaling approximately 7.2 hrs of footage in addition to 1,865 4K and 6K–still images. I reviewed imagery twice during 60 hrs of viewing. The resulting file collection is approximately 432 gigabytes in storage size, a non–trivial volume considering my sample size (Table 3.1).

Count Analysis and Detection Probability

On 5 paired surveys, the UAV detected more ducks and on 4 surveys more groups than the ground observer, whereas on 4 paired surveys, the ground observer detected more total ducks than the UAV, and more groups on 2 of those occasions (Table 3.2). In 7 of 16 surveys, neither method detected ducks, and on one survey the UAV detected one duck while the ground observer saw none; however, the ground observer never detected ducks when the UAV found none (Table 3.2). In total, the UAV detected 44 birds in 20 independent groups, while the ground observer detected 20 birds in 11 independent groups (Table 3.2). Only 8 of 23 unique detections were shared by both methods, and only 16 of 54 individual ducks were detected by both methods (Table 3.2).

During the UAV portion of 2 different surveys, the ground observer detected waterfowl entering the airspace immediately above the wetland that landed in the survey area with the UAV present and operating nearby. On one such occasion, the UAV failed to detect that duck, but having occurred after the ground survey, was not included in the ground observer count for those surveys (Table 3.2). On 3 surveys, waterfowl not detected by the ground observer were black ducks obstructed by vegetation, 2 of which were broods. On one occasion, the UAV takeoff flushed a male black duck that was observed during the ground count, but I failed to detect it on video. Disturbance at the level of initiating a flight response only occurred on 4 occasions out of a total > 70 duck–group approaches in the AP and in test flights elsewhere.

I found no difference ($\Delta p = 0.042 \pm 0.155$) in detection probability between the UAV ($p = 0.493 \pm 0.247$ SD) and ground survey ($p = 0.452 \pm 0.238$ SD) after compensating for differences in wetland area surveyed by these methods (i.e., availability). I also found no effect of vegetated cover covariates on abundance ($\beta_{pV} = -0.477 \pm 2.610$ SD), or detection probability ($\beta_{\lambda} = 1.489 \pm 1.761$ SD). I estimated that total "true" abundance of ducks was $N = 57.676 \pm 54.36$ SD (Table 3.3).

DISCUSSION

My examination of raw detections by species suggests the UAV and ground observer are detecting ducks differently. Video review of UAV detections further suggests that emergent vegetation is less problematic for the UAV, while open water is more challenging. Like McEvoy et al. (2016), I think this is caused by ducks moving out from beneath the rotary wing UAV before it passes over them. Open water species like hooded and common mergansers (Baldassarre 2014) may dive or swim out of the UAV flightpath (McEvoy et al. 2016) more readily as that strategy suits the physical properties of their habitat selections (i.e., free space to move). I also suspect species favoring emergent vegetation like wood ducks (Davis et al. 2007, Dyson et al. 2018) and black ducks (Kirby 1980, Diefenbach and Owen 1989) might rely more on concealment within vegetated cover rather than fleeing. In some cases this is favorable for UAV detection relative to the ground observer. Wood ducks were commonly detected in relatively dense vegetation (i.e., sometimes impossible for ground observers to detect), and on several occasions were filmed leaving emergent vegetation for the upland portion of heavily forested shorelines to avoid the UAV path. In short, the UAV was more easily detecting secretive species, while the ground observer was more readily detecting species in open water. My evaluation of raw counts by species shows split evidence, but generally supports this theory. On the two surveys where the ground observer saw more groups than the UAV, one was a hooded merganser hen, and the other was a black duck drake. On 1 of 4 surveys where the UAV detected more groups than the ground observer, the extra group detected was a hooded merganser. On the remaining 3 surveys with more UAV group detections than the ground observer, 2 of 10 extra groups detected by the UAV were hooded mergansers, and the remaining 8 groups were wood duck, mallard, and black duck groups, respectively.

Given the raw counts, I was surprised to see no difference in detection probability between methods. I suspect the lack of significance in the effect of vegetation and observer on detection probability and vegetation on abundance is due to small sample size. I subsequently added a beta parameter term for the interactive–effect of observer and vegetation on detection probability and although it offered no further significance, the interaction dramatically reduced the burn–in and iterations necessary to reach model convergence, and further stabilized estimates of subsequent model runs. This suggests that further data are needed to quantify the interactive effect between observer specific detection probability and vegetation, but that the interaction is still functionally important to include in the model.

Further evidence of satisfactory model performance is suggested by the estimates of "true" total abundance produced by my model. Based on raw counts, 54 total ducks were present in our 16 wetlands. As previously mentioned, these wetlands are part of a larger (n = 397) existing waterfowl study, the analysis of which uses a time–to–detection as a function for detection probability. From this larger study, I estimated the rough mean (i.e., "duck") probability of detection for the 5 waterfowl species represented in this smaller UAV study as 0.918. A simple application of this rough mean detection probability (i.e., 54 ducks/0.918 = 58.82 ducks) suggests my UAV/ground analysis model was appropriately estimating method–specific detection probability and total abundance ($N = 57.7 \pm 54.4$) given the high variance likely driven by the thin, zero–inflated data used in the analysis.

Although this platform and sensor combination could identify differences between mallards and black ducks in imagery, it elicited unanticipated swimming response and awareness behaviors by target waterfowl. The ground observer and video reviewer frequently noted ducks swimming away from the space immediately beneath the flightpath of the UAV, sometimes in advance of the UAV, but most were still captured on video using the 16 mm ASPH lens. Some groups, most commonly broods, continued foraging behaviors uninterrupted despite the lingering presence of the UAV 30 m to 50 m above them. Magnitude of duck reaction to the quadcopter was inconsistent and difficult to predict, however all ducks that flushed were not bonded to a brood. This is partially a product of choosing a smaller sensor size than McEvoy et al. (2016), which required ≤ 30 m lower elevation flights as well as more flight paths per unit area surveyed in my study. Additionally, errors and shortcomings in the autonomous image collection systems provided by the UAV manufacturer were not able to sufficiently consider current VLOS regulations in a heavily forested environment. As such, I recommend a larger sensor size on a similarly portable quadcopter platform (not available as of late 2020), so pilots can maintain higher elevations while still collecting target–GSD imagery. I caution that the weight, physical size, battery needs, and expense of the platform and sensor combination employed by McEvoy et al. (2016) would have widely prohibited meaningful application to wetlands in densely forested ecosystems like this study. Increased sensor size in turn also improves VLOS with the GCS, reduces the number of flight lines, and reduces overall disturbance behaviors (McEvoy et al. 2016) similarly through greater altitude.

Recent advances in VTOL capable fixed–wing aerial platforms show a promising alternative to quadcopters in terms of flight duration (i.e., no battery changes) and in elevation (fully integrated full–frame sensors). As pointed out by Drever et al. (2015), flying high overlap imagery to collect detection data and habitat data simultaneously can be a potential useful tool in management, and fixed–wing aircraft are uniquely suited to high altitude (> 60 m ASL) mapping style missions. Furthermore, my initial testing of high overlap autonomous UAV surveys in AP wetlands suggested that method counted more waterfowl than the free search method, although as previously mentioned VLOS regulations prevented this method from being widely applied. Managers who wish to employ UAVs in less forested wetland environments (e.g., NMWMA) would likely benefit from the use of fixed–wing platforms given the current off–the–shelf availability for fully integrated large (i.e., > 32 megapixels) sensors (and the current lack of them for portable sized quadcopters). Despite the potential of VTOL capable fixed–wing UAVs, I caution some abilities to collect imagery while hovering and freedom of camera movement are still inherent to rotary wing UAVs relative to fixed–wing. Future studies should incorporate species into this model, especially in a sample size meaningful to detect method–specific and species–specific differences in detection probability given vegetative cover. Furthermore, advances in UAV technology (i.e., VTOL capable fixed–wing airframes with full–frame censors) and likely impending relaxations of VLOS regulations suggest UAVs will become increasingly useful in the immediate future. Habitat and population data collection co–surveys are currently and increasingly possible in any environment located in legally accessible airspace, forested or otherwise.

MANAGEMENT IMPLICATIONS

UAVs in their current and upcoming forms can serve as a useful tool for waterfowl managers surveying wetlands in densely forested ecosystems and other habitats. My results suggest detection probabilities between UAVs and traditional ground methods are similar, but that UAVs may be more capable of detecting secretive waterfowl than a ground observer and offer greater access to a variety of wetlands relative to ground surveys. UAVs could effectively replace ground observers on largescale wetland surveys, but perfect detection cannot be assumed, so survey designs that correct for detection probability must be used. Typically, the UAV could access a larger survey area than ground observers and, in some wetlands, collect survey data from a larger area faster. Ground and aerial surveys required similar total time spent surveying, however reviewing aerial imagery after UAV flights required substantially more labor than traditional ground surveys, but further offers the opportunity to review the data collected. Upcoming advances in automated imagery review software would be useful to reduce review time.

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Table 3.1. Summary of survey effort and data collection for waterfowl point counts and unmanned aerial vehicle surveys (UAV) in 16 beaver–modified wetland sites in the Adirondack Park of NY, USA, 17 June 2020 to 20 July 2020. Survey effort is in minutes of active–searching video (EffortUAV) or minutes of ground observer observation (Effortg). Area of the UAV and ground surveyor (Areag) is reported in hectares.

Site	Videos	Images	$Effort_{UAV}$	$Effort_g$	$Area_{UAV}$	$Area_g$
1665	13	91	20.00	30	6.28	3.91
1646	76	66	13.75	30	0.85	0.47
17249	2	0	7.00	30	1.07	0.88
192460	3	86	13.50	30	2.23	1.86
1678	9	40	18.50	30	4.41	3.00
16510	12	65	22.75	30	3.57	2.18
181727	13	162	37.50	30	4.76	2.96
190317	22	135	44.90	30	13.16	9.05
190157	18	176	33.91	30	3.76	1.34
182032	12	176	32.33	30	7.76	6.33
190894	8	151	24.24	30	2.60	2.13
181836	11	197	35.16	30	9.45	3.28
192013	4	75	11.75	30	2.46	0.81
190704	2	16	3.50	30	3.05	3.05
190681	7	135	19.41	30	4.73	3.40
193788	11	288	51.64	30	5.59	4.66
Total	223	1859	389.84	480	75.71	49.29

Table 3.2. Summary of naïve detections for waterfowl point counts and unmanned aerial vehicle surveys (UAV), in beaver–modified wetland sites in the Adirondack Park of NY, USA, 17 June 2020 to 20 July 2020. Counts are separated by number of groups of ducks (Ng) detected by the UAV (NgUAV) compared to ground (Ngg) surveys and by number of birds detected (Nd). Shared indicates groups and ducks detected by both methods.

Site Name	Ng_{UAV}	Ng_g	Shared	Total	Nd_{UAV}	Nd_g	Shared	Total
1665	1	2	1	2	3	7	3	7
1646	0	0	0	0	0	0	0	0
17249	0	0	0	0	0	0	0	0
192460	0	0	0	0	0	0	0	0
1678	1	1	0	2	4	1	0	5
16510	0	0	0	0	0	0	0	0
181727	3	3	3	3	6	8	5	8
190317	4	1	1	4	17	5	5	17
190157	3	0	0	3	7	0	0	7
182032	0	0	0	0	0	0	0	0
190894	0	0	0	0	0	0	0	0
181836	1	1	1	1	1	3	1	2
192013	0	0	0	0	0	0	0	0
190704	1	0	0	1	1	0	0	1
190681	4	1	1	4	4	1	1	4
193788	1	2	1	2	1	3	1	3
Total	19	11	8	22	44	28	16	54

Table 3.3. Mean estimates and variance statistics for N–mixture model parameters from waterfowl point counts and unmanned aerial vehicle surveys (UAV) in beaver–modified wetland sites in the Adirondack Park of New York, USA, 17 June 2020 to 20 July 2020. q2.5 and q97.5 are their respectively named quantile estimates, overlap 0 is a logical argument for significance (i.e., FALSE = significant), and Rhat is the statistic to assess model convergence. Difference between q2.5 and q97.5 are the 95% credible interval for the specified estimate. Parameter name = N – total abundance across all sites, α_λ – intercept of abundance, β_λ – beta parameter for effect of vegetation on abundance, α_p – intercept of detection probability, β_{pV} – effect of vegetation on detection, βpObs – effect of UAV on detection, βpV*Obs – interactive effect of vegetation and observer, puav – UAV detection probability, pgrnd – ground surveyor detection probability, Δpu–g – derived differential parameter between methods of observation.

	N–mixture Model Estimates			
Parameter	Mean	SD	q2.5	q97.5
N	57.676	54.360	22.00	228.0
α_λ	–1.487	1.157	–3.451	1.122
β_λ	1.489	1.761	–2.144	4.704
α_p	–0.020	1.453	–2.927	2.711
β_{pV}	–0.477	2.610	–5.320	5.088
β_{pObs}	–0.631	1.322	–3.094	2.103
β_{pV*Obs}	1.832	2.293	–2.774	6.264
p_{uav}	0.493	0.247	0.068	0.910
p_{grnd}	0.452	0.238	0.062	0.914
$\Delta p_{u–g}$	0.042	0.155	–0.265	0.368

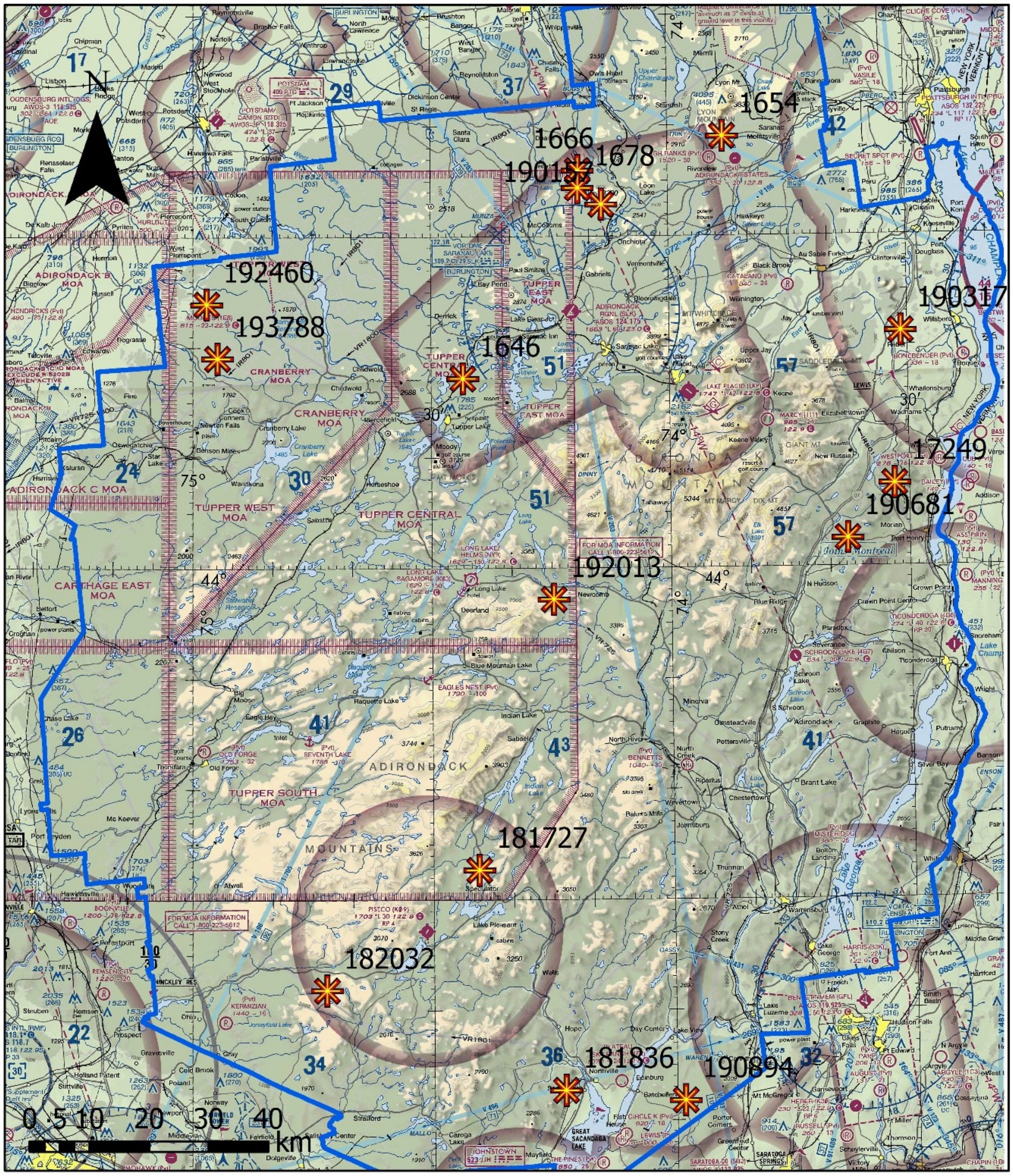

Figure 3.1. Map of beaver–modified wetlands flown as concurrent unmanned aerial vehicle surveys in the Adirondack Park (AP) of northern New York, USA, 17 June 2020 to 20 July 2020, and accompanying FAA airspace sectional charts. Blue line depicts the AP boundary.

Figure 3.2. Whole (top) and zoomed–inset (bottom) of test image containing sympatric mallards and black ducks in breeding plumage at Northern Montezuma Wildlife Management Area, Savannah, New York, USA, 27 March 2019. Image was captured with Inspire 2 unmanned aerial vehicle and Zenmuse X7 from > 45 m above surface level with a 50 mm aspherical lens.

CHAPTER 4: MEAN BROOD SIZES OF SYMPATRIC WATERFOWL IN THE ADIRONDACK PARK OF NEW YORK

ABSTRACT The American black duck is a dabbling duck native to eastern North America which has declined > 50% in abundance since the 1950s. Concurrently, mallards replaced black ducks in many Atlantic flyway breeding habitats. Previous studies have found breeding parameters similar between these species when sympatric. I used a linear mixed model in a Bayesian statistical framework to analyze brood size data from point–count surveys in lakes and wetlands of the Adirondack Park of New York State, that were collected as part of larger occupancy studies from 2013 and 2016−2020. I included Canada goose, wood duck, mallard, black duck, and hooded merganser because additional species of brood data were available, helped increase precision of estimates for my focal species of mallard and black duck, and furthered the significance of intraspecific tests. I tested for differences in mean brood size between and within mallards and black ducks relative to wetlands and lakes. I found greater productivity of mallards and black ducks in lakes relative to wetlands. Combined with greater occupancy of mallards than black ducks in lakes, this suggests mallards may outproduce black ducks by greater use of a more reliable (i.e., stable water levels and food resources) breeding habitat than black ducks.

KEY WORDS Adirondack Park, American black duck, *Anas platyrhynchos*, *Anas rubripes*, mallard, mean brood size, productivity.

The American black duck (*Anas rubripes*; here–on black duck) has declined significantly in the second half of the 20th century, concurrent with the increase in sympatric mallards (*Anas platyrhynchos*) (Heusmann 1974, 1991). This pattern continued through the southern breeding range of the black duck, to the effect of the mallard becoming the most common species. Many hypotheses are proposed for black duck decline, including introgressive hybridization (Ankney et al. 1987), competitive exclusion by mallards (Petrie et al. 2012, Merendino et al. 1993), and landscape scale habitat change (Diefenbach and Owen 1989, Maisonneuve et al. 2006). Nichols et al. (1987) concluded the cause of the decline must be driven by reproductive parameters, however future studies did not detect differences in clutch and brood sizes of sympatric mallards and black ducks (Krementz et al. 1992, Dwyer and Baldassarre 1994, Longcore et al. 1998, Maisonneuve et al. 2000, Petrie et al. 2000). Deviations from findings of identical reproductive parameters include greater black duck brood densities on freshwater lakes with human nutrient inputs (Staicer et al. 1994), and greater mean brood sizes of sympatric mallards and black ducks in similar nutrient–loaded lakes (Longcore et al. 1998) than habitats not impacted by humans in those studies.

The Adirondack Park (AP) is a 2.5 million ha protected area assumed to provide substantial breeding waterfowl habitat with > 3000 lakes and abundant geologic and beaver–modified wetlands. It consists of a mosaic of oligotrophic glacial lakes, bogs, beaver–modified wetlands, and cold–water river systems. However, breeding waterfowl occurrence in the AP is generally considered "rare" relative to other major breeding areas and > 60% of wetlands (NYSDEC, unpublished data) and > 90% of lakes may remain unoccupied in some years (Dwyer and Baldassarre 1994). As part of a larger ongoing effort to study the ecological separation of mallards and black ducks in the AP, I collected waterfowl brood data including number, age (Gollop and Marshall 1954), species, habitat type (i.e., wetland or lake), and date of detection for all waterfowl occurrences in this study frame. Small sample size precluded the application of broods in that larger occupancy analysis (Chapter 2), but here I analyze the sample of broods detected in that larger study, in combination with broods detected in previous AP breeding waterfowl studies collected in a similar randomly sampled structural framework.

Estimates from that larger study suggested greater occupancy probability of mallards than black ducks in human influenced lakes and beaver–modified wetlands. Given the differences in productivity (densities and ducklings/hen) between wetlands and human influenced lakes (Staicer et al. 1994, Longcore et al. 1998), I hypothesized that if mean brood sizes were greater at lake sites than wetland sites and mallard occupancy was greater than black ducks on lakes, this might offer mallards a slight advantage regionally in productivity relative to black ducks. Therefore, I aimed to test for differences in mean brood size between mallards and black ducks within strata (lakes and wetlands) and for each species between the strata. I incorporated the effects of species, stratum (i.e., wetland or lake), interval (i.e., days) between ice–out date and hatch date, brood age class, and year into my model estimates to compensate for differences in mean brood size inherent to those metrics (Arzel et al. 2014). Developed shoreline only occurs on lakes in this sample frame, so lakes are assumed to be the developed habitat in my analysis. However, undeveloped lakes are included but not modeled independently due to small brood sample sizes. I included Canada geese (*Branta canadensis*), wood ducks (*Aix sponsa*), and hooded mergansers (*Lophodytes cumulates*) because those data were available and offer some reference for assessing realism of model estimates. Additionally, species is a random effect, and inclusion of these data offers decreased variance of estimates.

METHODS

I used brood detections from single visit 30 min point counts at AP lake and wetland sites from 2019 and 2020 (described in Chapter 2). I improved species and stratum–specific sample sizes by also including first detections of broods from similar repeat–style counts on a subsample of the 2019 and 2020 wetlands completed June – August 2013 and 2016 − 2018 (Macy and Straub 2016; NYSDEC, *unpublished data*). To determine hatch date, I used species–specific breeding parameters (Baldassarre 2014) and brood age class as described by Arzel et al. (2014). Ice–out date was available for Mirror Lake, Lake Placid, NY, USA, (44.2884° N, 73.9819° W) as an index of ice–out for the AP (Arzel et al. 2014). I calculated ice–out interval as the difference between Julian hatch date of a brood, minus the Julian mean ice–out date for that year. I then fit these data to an adaptation of the analysis performed by Arzel et al. (2014). I parameterized a linear mixed model with brood size as the dependent variable and species nested in stratum, ice interval, brood age class, and year as random effects. To test for differences between and within species and strata, I specified my linear mixed model as:

$$BS_i \sim Normal\ (\mu_i, \tau)$$

$$\mu_i = \alpha_{spec.i} + \beta str_{spec.i} * Strata_i + \beta age_{spec.i} * Age_i + \beta ice_{spec.i} * Ice_i + \beta yr_{spec.i} * Year_i$$

where μ_i is the mean brood size of observation *i,* and the brood size (*BS*) of observation *i* is distributed normally around that mean, with a variance of tau (τ). Tau is derived from sigma (σ) where the prior is specified as distributed uniformly around a mean of 0 and a SD of 10. All random effects for species on brood size, and species–specific estimates for the random effect of strata, age, ice interval, and year on mean brood size were drawn from corresponding hyperparameters (μ_k). All priors for random effects were specified similarly to the random effect of species on brood size as depicted below:

$$\alpha_{spec.\mathrm{k}} \sim Normal\ (\mu_{spec.k}, \tau_{spec.k})$$

$$\mu_{spec.k} \sim Normal\ (0, 0.001)$$

$$\tau_{spec.k} = 1 / (\sigma_{spec.k} * \sigma_{spec.k})$$

$$\sigma_{spec.k} \sim Uniform\ (0, 10)$$

where $\alpha_{spec.k}$ is the intercept and the random effect of species k on mean wetland brood size of observation i, and is distributed normally around a mean of $\mu_{spec.k}$, (hyperparameter for random effect of species k on mean wetland brood size) and a precision of $\tau_{spec.k}$. $\mu_{spec.k}$ is distributed normally with a mean of 0 and a precision of 0.001. Parameters designed to test for significant differences in mean brood size between and within species and strata were specified in the derived quantities of this model, fit using program JAGS (Just Another Gibbs Sampler Version 4.3.0, Plummer 2003) called through program R (R Version 4.0.3, www.r–project.org, accessed 8/17 2020), and package rjags (rjags Version 4–10, Plummer 2013).

RESULTS

Sample sizes ranged from 9 broods in 2013 to 71 in 2018, while ice–out date ranged from April 6 in 2020 to May 4 in 2018 (Table 4.1). Mean brood size for mallards in wetlands was 4.35 ± 0.47 SD and 4.08 ± 0.46 SD for black ducks (Fig. 4.1). In AP lakes, mean mallard brood size was 6.00 ± 0.37 SD and 5.33 ± 0.55 SD for black ducks (Fig. 4.1). I detected differences in mean brood size between lakes and wetlands for wood ducks, mallards, and black ducks (Fig. 4.2), and mean brood size varied negatively with brood age (Fig. 4.3) and ice interval (Fig. 4.4) for all species. For mallards and black ducks, mean brood size was greater on lakes by 1.66 ± 0.56 SD and 1.25 ± 0.60 SD ducklings, respectively (Fig. 4.5). I also detected that mean brood size of black ducks on wetlands was 1.92 ± 0.58 SD less than mallards on lakes, whereas mean brood size of mallards on wetlands did not differ from those of black ducks on lakes (0.99 ducklings ± 0.75 SD; Fig. 4.5). There was no difference in the daily effect of ice–out interval on brood size between mallards and black ducks, however predictive plots suggest species–specific intercepts in mean brood size diverge in trend relative to increasing ice–out interval (Fig. 4.6). I found no effect of year for any species, and that variable was removed from the final model output and results for parsimony. The inclusion of additional species (Canada goose, wood duck, hooded merganser) reduced the standard deviation around black duck and mallard brood size estimates by ≤ 20%. Further, the increased precision was enough to enable the finding of greater black duck brood size on lakes relative to black ducks on wetlands (Fig. 4.5), whereas using a 2 species model could not identify that difference.

DISCUSSION

My results suggest that mallard and black duck mean brood size was greater on lakes than wetlands. Considering that mallards occupy lakes to a greater degree than black ducks (Chapter 2), this may provide a regional benefit to mallards relative to black ducks (Holt 1985, Pulliam 1988). Given the increasing rate of lakeshore development in the AP (Holland 2011), developed lakes may be increasingly important habitat for AP breeding waterfowl if there is indeed a unique and reliable productivity benefit to breeding there. I suggest the disturbance–adverse black duck (Diefenbach and Owen 1989) may be disadvantaged compared to the mallard's history of opportunism in anthropogenic environments (Heusmann 1974, 1991). Petrie et al. (2012) suggested a decrease in black duck breeding propensity rather than differences in breeding parameters (Dwyer and Baldassarre 1994, Longcore et al. 1998, Petrie et al. 2000, Maisonneuve et al. 2000), and my results also suggest similar brood sizes when mallards and black ducks are sympatric. My results differ from prior studies because I detected greater mallard occupancy and brood size in lakes relative to black ducks in wetlands (Chapter 2). Studies of sympatric mallards and black ducks have shown little habitat partitioning (Petrie et al. 2012, Macy and Straub 2016, Bleau 2018, Droke 2018; see Chapter 2). In this context, mallards appear capable of outproducing black ducks in AP lakes and wetlands in years when mallard productivity on lakes is greater than black ducks on wetlands, and that the inverse is not true. Predictive plots suggest ice–out interval is important to both species, but the mean brood size declines faster for black ducks than mallards as the duration of breeding season increases. This is possibly the effect of greater re–nesting effort of mallards than black ducks, a finding reported elsewhere in literature (Coulter and Miller 1968, Ankney et al. 1987, Dwyer and Baldassarre 1993, Petrie and Drobney 1997, Maisonneuve et al. 2000). If even a small fraction of mallards produced small late season broods from greater renesting effort relative to the black duck, this could potentially explain the greater mean brood size detected later in the summer.

MANAGEMENT IMPLICATIONS

Mallards on lakes, especially those influenced by human activities, may be capable of outproducing black ducks in all other AP breeding habitats over long periods of time. Reduced environmental stochasticity in human influenced lakes relative to wetlands, combined with greater mallard breeding presence in lakes may further advantage mallards relative to black ducks. Further, increasing human development on AP lakes may enhance traditionally poor waterfowl breeding habitat specifically for mallards as they appear to exploit breeding habitats heavily altered by human activities more readily than AP black ducks.

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Table 4.1. Summary of sample size by year, stratum, and species of 5 waterfowl from point counts in beaver–modified wetland and lake sites in the Adirondack Park of NY, USA from May to July in 2013, and 2016 to 2020. Mean ice–out date is derived from ice break–up records kept for Mirror Lake in Lake Placid, NY, USA. HDL is mean hatch date of lake broods and HDW is hatch date of wetland broods. Alpha codes = CAGO – Canada goose, WODU – wood duck, MALL – mallard, ABDU – American black duck, HOME – hooded merganser.

Mean ice–out date		Sample sizes and mean hatch dates by stratum at first detection				
Year	Ice−out	Species	Lake *n*	Mean HD Lake	Wetland *n*	Mean HD Wet
2013	22–Apr	CAGO	–	–	–	–
		WODU	–	–	–	–
		MALL	1	26–May	–	–
		ABDU	8	5–Jun	–	–
		HOME	–	–	–	–
2016	28–Mar	CAGO	–	–	1	7–May
		WODU	–	–	5	30–May
		MALL	–	–	0	0
		ABDU	–	–	4	6–Jun
		HOME	–	–	7	27–May
2017	16–Apr	CAGO	–	–	1	13–May
		WODU	–	–	5	18–Jun
		MALL	–	–	0	0
		ABDU	–	–	1	13–May

		HOME	–	–	9	3–Jun
2018	4–May	CAGO	–	–	3	27–May
		WODU	–	–	17	13–Jun
		MALL	–	–	3	22–May
		ABDU	–	–	3	26–May
		HOME	–	–	15	4–Jun
2019	22–Apr	CAGO	11	13–May	4	26–May
		WODU	5	10–Jun	5	13–Jun
		MALL	5	8–Jun	19	29–May
		ABDU	1	28–May	1	6–Jun
		HOME	1	6–Jun	10	31–May
2020	6–Apr	CAGO	10	16–May	2	6–May
		WODU	2	16–Jun	17	29–May
		MALL	14	25–May	6	4–Jun
		ABDU	1	18–May	4	7–Jun
		HOME	1	3–Jul	15	26–May

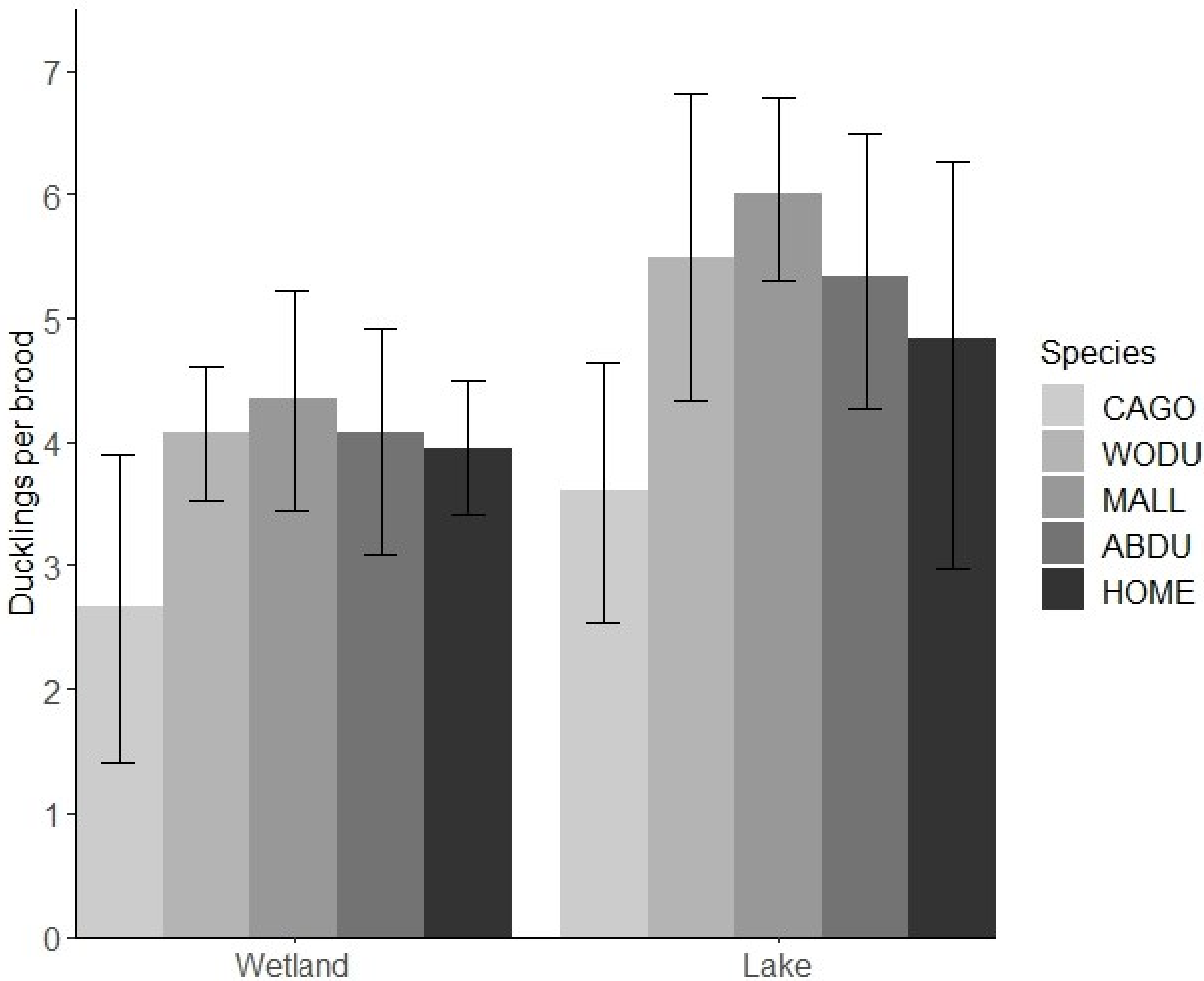

Figure 4.1. Model estimates of mean ducklings per brood with 95% credible intervals for 5 species of waterfowl in beaver–modified wetlands and lakes in the Adirondack Park, New York, USA, May – July 2013 and 2016 to 2020. Estimates were generated using a linear mixed model accounting for random effects of species, strata, age class, and interval of hatch date – ice break–up. Alpha codes = CAGO – Canada goose, WODU – wood duck, MALL – mallard, ABDU – American black duck, HOME – hooded merganser.

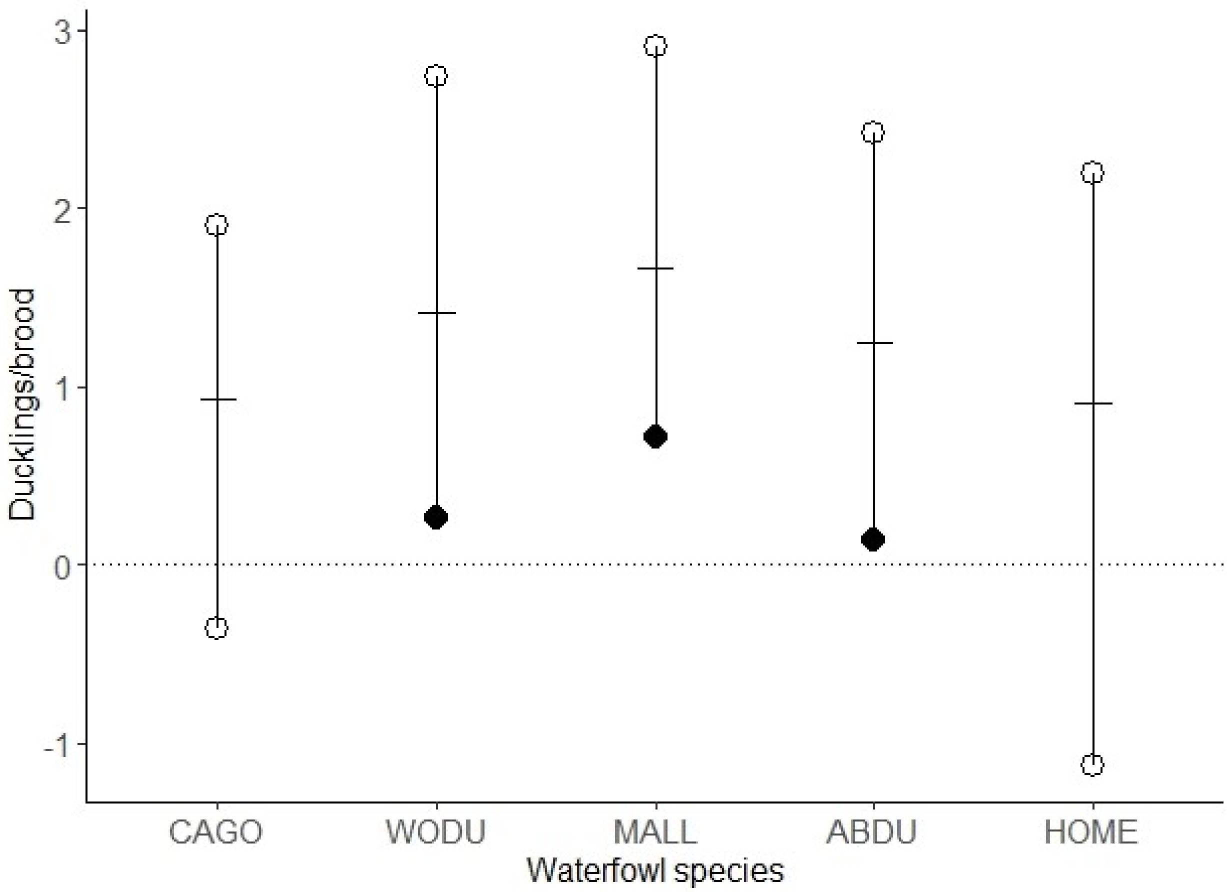

Figure 4.2. Beta parameters for the effect of lake stratum on mean ducklings per brood relative to wetlands, for 5 species of waterfowl in beaver–modified wetlands and lakes in the Adirondack Park, New York, USA, May – July 2013 and 2016 to 2020. Alpha codes = CAGO – Canada goose, WODU – wood duck, MALL – mallard, ABDU – American black duck, HOME – hooded merganser. Black filled dots denote an estimate that does not overlap 0, indicating a significant result.

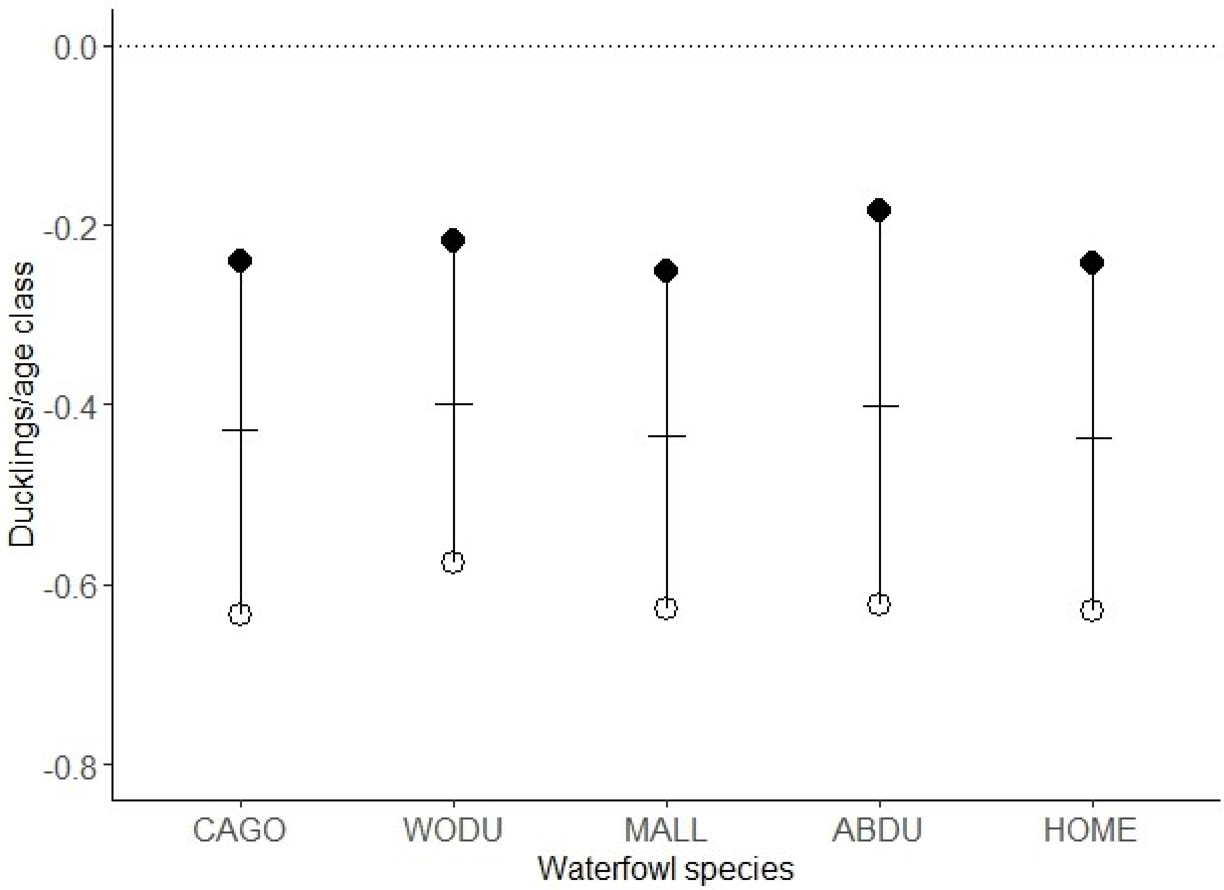

Figure 4.3. Beta parameters for the effect of age class on mean ducklings per brood for 5 species of waterfowl in beaver–modified wetlands and lakes in the Adirondack Park, New York, USA, May – July 2013 and 2016 to 2020. Alpha codes = CAGO – Canada goose, WODU – wood duck, MALL – mallard, ABDU – American black duck, HOME – hooded merganser. Black filled dots denote an estimate that does not overlap 0, indicating a significant result.

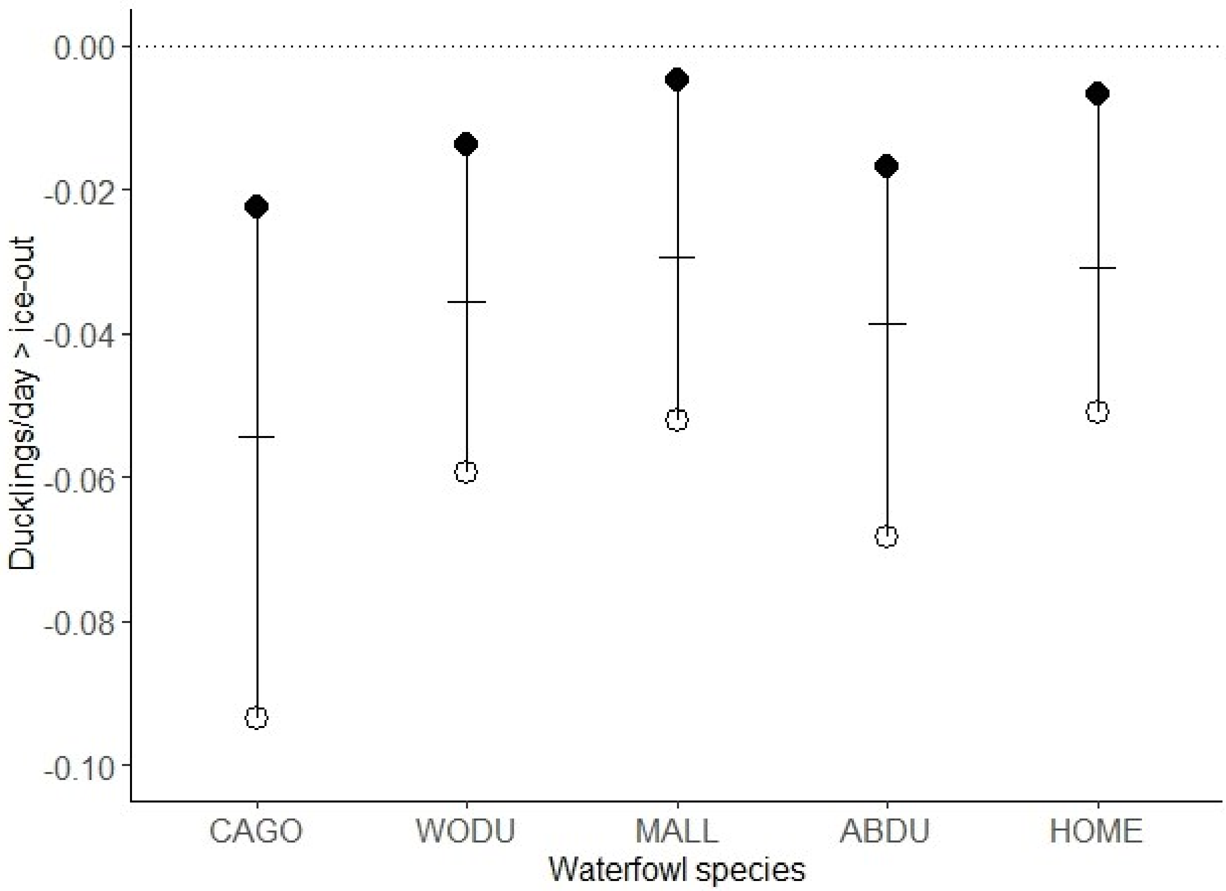

Figure 4.4. Beta parameters for the effect of hatching 1 day > ice–out date on mean ducklings per brood for 5 species of waterfowl in beaver–modified wetlands and lakes in the Adirondack Park, New York, USA, May – July 2013 and 2016 to 2020. Alpha codes = CAGO – Canada goose, WODU – wood duck, MALL – mallard, ABDU – American black duck, HOME – hooded merganser. Black filled dots denote an estimate that does not overlap 0, indicating a significant result.

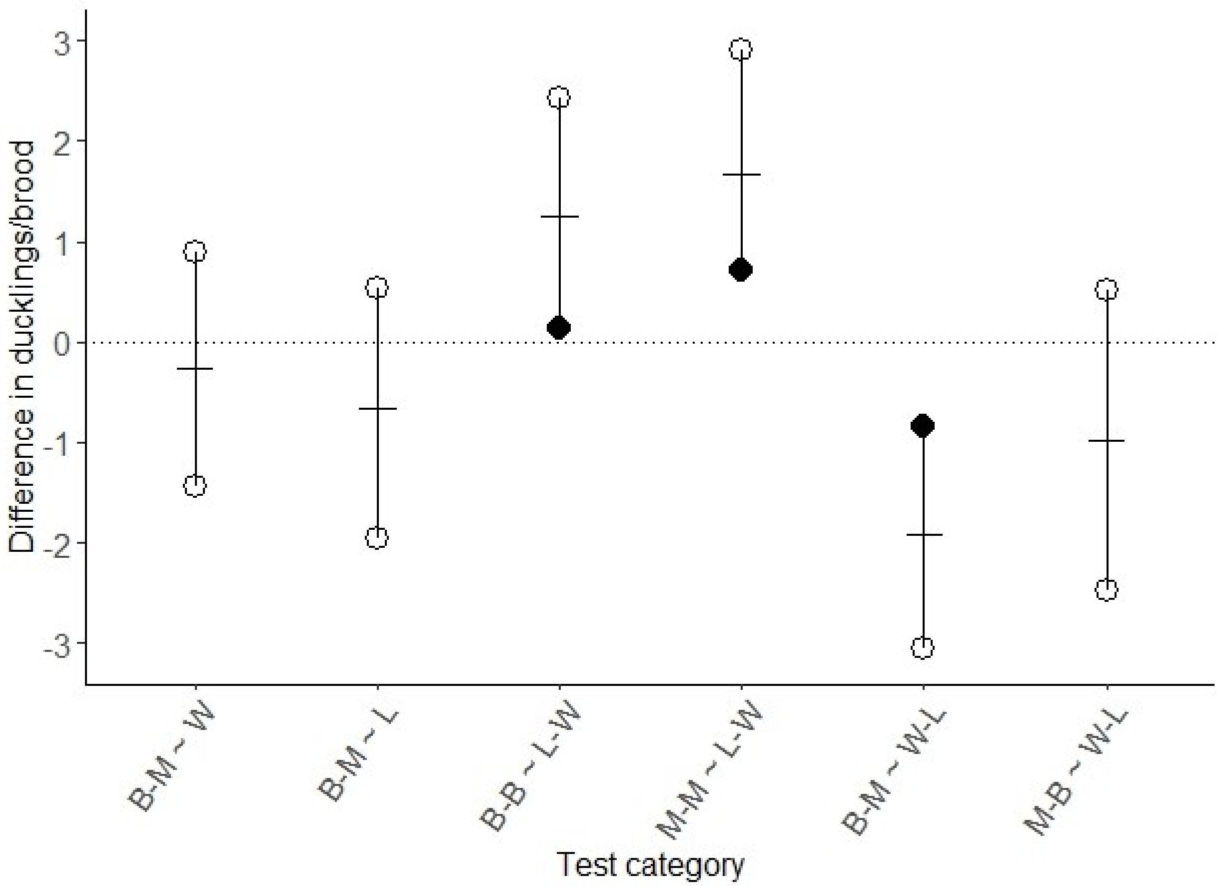

Figure 4.5. Derived difference parameters for mean ducklings per brood between and within mallards and black ducks in beaver–modified wetlands and lakes in the Adirondack Park, New York, USA, May – July 2013 and 2016 to 2020. Test categories = B–black duck, M–mallard, W–wetland, L–lake, and ~ – "distributed as…". Black filled dots denote an estimate that does not overlap 0, indicating a significant result.

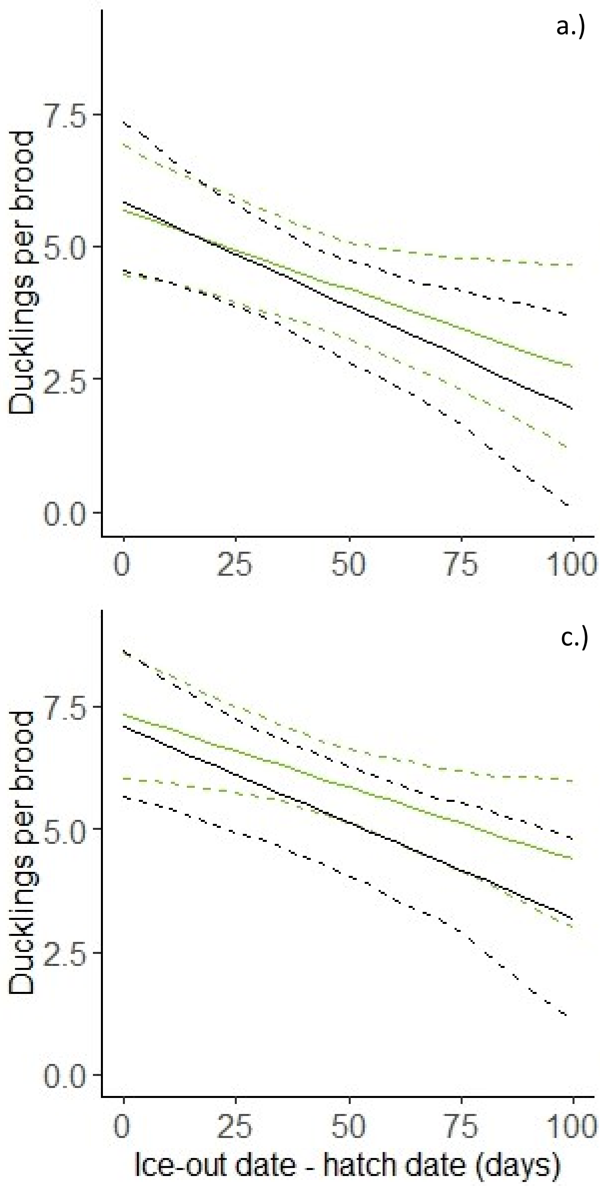

Figure 4.6. Predictive plot comparisons for the effect of interval (days) between hatch date and ice–out date on mean brood sizes of mallards (green) and black ducks (black) on wetlands and lakes in the Adirondack Park, New York, USA, May – July 2013 and 2016 to 2020. Predictive estimates are parameterized to account for mean age class. Brood size comparisons = a – wetland mallards vs. wetland black ducks, b – wetland mallards vs. lake black ducks, c –lake mallards and lake black ducks, and d – lake mallards vs. wetland black ducks.

CHAPTER 5: CONCLUSIONS

My multispecies occupancy model with a time–to–detection function for detection probability generated occupancy estimates for 7 waterbird species in the Adirondack Park (AP), while effectively capturing biological characteristics of their known life history strategies. I was able to use these estimates to test for differences occupancy of mallards and American black ducks among wetlands, undeveloped lakes, and developed lakes. In the AP, I detected that mallard occupancy was greater than black ducks among these habitat types. My results contrast with those of prior studies because they suggested that mallards were absent (Eaton 1910, Benson 1968, Brown and Parsons 1979), or more recently, equally abundant to black ducks on breeding areas in the AP (Dwyer and Baldassarre 1994, Macy and Straub 2016). The greatest difference I detected between mallard and black duck occupancy was on lakes with human development. This largely agrees with previous findings that suggest mallards use human influenced areas more (Morton 1998, Osborne et al. 2010, Macy and Straub 2016, Bleau 2018) than black ducks (Diefenbach and Owen 1989, Macy and Straub 2016, Bleau 2018).

In the context of Lavretsky et al.'s (2019; 2020) findings, mallards of game–farm ancestry may be exploiting developed lakes to a greater degree than black ducks because of innate behaviors making them tolerant of humans. Tolerance for human activity has been suggested as inherited from captive reared Old–World mallards (Heusmann 1983, 1991, Hepp et al. 1998, Lavretsky et al. 2020), and my results suggest developed lakes are used by AP mallards more than black ducks. My results indicate the current niche of AP mallards is much larger than that of black ducks, and furthermore that their niches overlap in traditional AP black duck breeding habitats (Benson 1968, Brown and Parsons 1979, Dwyer and Baldassarre 1994) where mallards were previously absent (Eaton 1910). Further, this dynamic establishes the possibility that human developed lakes, with stabilized water levels, may serve as a "source" for mallards relative to wetlands more traditionally used by black ducks which might act as a "sink" in years when beaver–modified wetlands are less available (Brown and Parsons 1979, Holt 1985, Pulliam 1988). On years when lake–ice depth and delayed ice–out date temporarily prohibits nesting on lakes relative to wetlands, lake mallards may complicate this by attempting to initially breeding in wetlands. Investigation into patterns of mallard occupancy in similar boreal ecosystems in Finland suggests the Old–World mallard is capable of outcompeting sympatric wetland obligate waterfowl using oligotrophic lakes as a key resource (Lehikoinen 2016). Considering Lavretsky et al. (2019; 2020), focusing on characteristics of the Old–World mallard and how it performs in this context may be more appropriate than literature from the prairie pothole region concerning the new–world mallard.

I also tested for differences in mean brood size between mallards and black ducks on lakes and beaver–modified wetlands while modeling the effect of age, year, species, ice–out date, and stratum on mean brood size. The two species produced similar sized broods within the same wetlands and lakes. However, I found significant differences in mean brood size of mallards and black ducks on lakes relative to mallards and black ducks on wetlands. Investigating the differences between wetlands and lakes suggested the mean mallard brood size on lakes relative to black ducks on wetlands was greater, and the opposite relationship was not true (i.e., wetland mallards relative to lake black ducks). Although these data are somewhat disparate, they offer the most comprehensive, structurally collected brood data for AP waterfowl in recent years, and the only data for AP waterfowl at a time when AP mallards have surpassed breeding black ducks in abundance (Dwyer and Baldassarre 1994, USFWS 2017).

Finally, I used unmanned aerial vehicles (UAV) to compare traditional ground–based point counts relative to this new aerial survey tool in an existing framework of AP wetland surveys and assessed case studies of detections. I found detection probabilities similar between the two methods while correcting for method–specific differences in survey area and vegetative cover. Furthermore, I found 3 cases in which black ducks could be detected by the UAV, but not by the ground observer. My review of footage and detections by species suggests UAVs are more well suited than ground observers for detecting secretive species of waterfowl that rely on dense vegetative cover to avoid perceived threats (Diefenbach and Owen 1989, Dyson et al. 2018).

Future Studies

The continuation of time to detection data, even at smaller sample sizes, would likely add information to the occupancy model that I applied in Chapter 2, such that more specific relationships might be clearer (Henry et al. 2020). Regardless, this method of multispecies occupancy with time to detection can be broadly applied elsewhere for waterfowl and is especially useful where rare species (< 5% occupancy) can be estimated with reasonable variance when modeled with sympatric heterospecifics. Additionally, a simple change of model parameters will modify the model I present in Chapter 2 to allow for estimations of abundance. A substantial effort in habitat mapping, remote sensed data collection, and mapping analysis would likely be required to extrapolate an accurate estimate of abundance. These mapping data are generally available for the AP, but not well updated.

The model I present here for UAV use can be more broadly applied to AP habitats and elsewhere, however I caution my UAV method and airframe are not well suited to study open water species on large bodies of water, but rather discreet areas of well vegetated wetlands.

Future studies of American black ducks, in the AP and elsewhere, would greatly benefit from a more detailed understanding of how development plays a role in niche differentiation between breeding AP waterfowl, and how that differentiation might be related to source–sink dynamics of mallards and black ducks in these habitats. A more substantive breeding survey with larger sample sizes, or longer running data sets that adequately model detection and attempt to capture the breeding parameter differences would also greatly benefit overall understanding of these two species.

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Veteran Pref: None

<u>Education</u>

State University of New York College of Environmental Science and Forestry, Syracuse, NY
– Master of Science in Fish and Wildlife Biology and Management (Exp. Jan. 2020 – passed defense)

State University of New York College at Plattsburgh, Plattsburgh, NY
– Bachelor of Arts in Environmental Science May 2014
– Study option in Env. Planning/Management & Minor in Geographic Information Systems

Oswego High School, Oswego, NY
– Baccalaureate (Honors) Diploma June 2004

<u>Certifications</u>

Class D driver's license: Issued by New York State
UAS pilot's license: Issued by US. Dept. of Trans. and Fed. Aviation Admin.
Firefighting:
IS700
S–130 Basic Wildland Firefighting
S–190 Intro to Wildland Fire Behaviour
ICS–100 Incident Command System overview
L–180 Human Factors in Wildland Fire Service
North American Banding Council
Bander Certified
NYSDEC:
Firearm Use Certified
Waterfowl ID
Hunter Safety Education
Remote Pilot License

<u>Recent Work Experience</u>

State University of New York – College of Environmental Science and Forestry
1 Forestry Drive, Syracuse, NY 13210
(315) 470–6500

Research Assistant – (9/1/18 – Present)
Supervisors: Dr. Jonathan Cohen and Dr. Michael Schummer
Duties include:
–Designing, planning, and executing a large–scale breeding waterfowl survey in remote mountain wetlands and lakes of New York State's Adirondack region, using a time–to–detection multispecies occupancy model in a Bayesian modeling framework.
– Close cooperation and coordination with the New York State Department of Environmental Conservation concerning a substantial number of staff, vehicles, and the associated equipment to conduct a large–scale waterfowl survey (2.4–million–hectare study area)
– Planning, permit and license acquisition, and execution of a study using unmanned aerial vehicles to survey waterfowl in remote wetlands, analyzed in a Bayesian modeling framework.
– Frequent use of ARCGIS v10.7 to discover remote wetlands, acquire geographic coordinates of wetlands, delineate wetland area, design, and develop daily operating maps for wetland

approach and waterfowl surveys, as well as spatial analysis of waterfowl habitat selection.
– Use of combined brood data to test for differences in productivity between Adirondack waterfowl species in a Bayesian linear mixed model.
– Image analysis and orthorectification using ARCGIS Drone2Map and other applications.
– Ingress and egress to remote wetlands and lakes on foot, bicycle, and boat using handheld GPS units.
– Identifying a diversity of waterfowl by species, sex, and age class of ducklings.
– Delegation of varying info, materials, tasks, and responsibilities to interns and NYSDEC staff.
– Use of Microsoft Excel, Program R, MARK, JAGS, and other statistical programs for data analysis.
– Condition, needs, and inventory assessment of equipment and materials necessary for waterfowl study, as well as maintaining and restoring equipment and small watercraft, as necessary.
– Inference of statistical results in terms of real management implications.
– Presentation of study to various interest groups including outside nonprofit organizations, other agencies and within DEC.

Teaching Assistant – General Ecology (Fall 2018) – Wildlife Habitat and Populations (Fall 2019)
Supervisors: Dr. Thomas Horton – General Ecology, Dr. Jonathan Cohen – Wildlife Habitat and Pop.
Duties include:
– Issuing, explaining, collecting, grading, and returning assignments as detailed by the course professor.
– Delivering laboratory lectures and assignments, followed by interpretation and assistance to class as needed.
– Delivering classroom lectures and presentations, participating, and organizing field exercises including class trips.
– Attendance, grade management, greeting guest speakers, and other preparatory and clerical work typical of college education settings.

New York State Department of Environmental Conservation, Bureau of Wildlife, Region 5
Wildlife Technician 1 (4/17/2017 – 9/1/2018)
1115 State Route 86, Ray Brook, NY 12977
(518) 897–1200
Supervisor: John O'Connor
Duties include:
– Planning and executing breeding waterfowl survey in remote mountain wetlands of New York State's Adirondack region.
– Identifying waterfowl species, gender, and age class of ducklings.
– Frequent use of ARCGIS v10.2 to discover remote wetlands, acquire geographic coordinates of wetlands, delineate wetland area, design and develop daily operating maps for wetland approach and waterfowl surveys, as well as spatial analysis of waterfowl habitat preferences.
– Planning, permit acquisition, and execution of pilot study using unmanned aerial vehicles to survey waterfowl in remote wetlands and ponds.
– Image analysis and orthorectification using ARCGIS Drone2Map.
– Delegation of varying info, materials, tasks, and responsibilities to interns and DEC staff.
– Use of Microsoft Excel and other statistical programs for data analysis and abundance indices.
– Inference of statistical results in terms of real management implications.
– Presentation of study to various interest groups including outside nonprofit organizations, other agencies and within DEC.
– Scouting, planning, preparing, and executing winter waterfowl banding stations/project for Mallard and American Black Duck in the northern Adirondack and Lake Champlain

regions.
– Ingress and egress to remote wetlands on foot and bicycle using handheld GPS units.
– Assisted with a variety of wildlife surveys and services including Atlantic flyway breeding waterfowl plot survey, woodcock surveys, tree bat surveys, winter raptor surveys, deer yard surveys, moose walk–in surveys, moose aerial surveys, nuisance bear trapping and handling, peregrine falcon surveys, nuisance wildlife permits, nuisance beaver trapping, pheasant stocking, and wetland delineation.

Wildlife Technician 1 (10/17/2016 – 3/9/2017)

1115 State Route 86, Ray Brook, NY 12977
(518) 897–1200

Supervisor: John O'Connor

Duties included:

– Acceptance, review, and issuance of species–specific furbearer trapping permits and associated database update and management
– Ingress and egress to remote camera station locations on foot and snowmobile using handheld GPS units
–Processing pine marten carcasses for tissue samples including muscle, reproductive, and tooth extractions
–Live trapping and processing pine marten for a variety of biometrics as well as mark–recapture ear tagging
–Installation, mid survey check, and removal of camera traps and bait stations for pine marten and fisher surveys in remote wilderness location
– Checking carcasses, furs, trapping logs, and issuance of pelt seals for furbearer game species.
– Frequent use of Microsoft Excel and Picture Information Extractor to "tag" camera trap images for species present, image time, other camera triggers, and associated database update and management.
– Frequent use of ARCGIS v10.2 to generate navigational maps for use installing and locating remote camera trap locations
– Assisted with a variety of wildlife surveys and services including moose walk–in surveys, moose and dear aerial surveys/transects (helicopter), nuisance bear trapping and handling, nuisance wildlife permits, waterfowl banding, winter waterfowl surveys, and wetland delineation.

Wildlife Technician 1 (4/17/2016 – 9/30/2016)

1115 State Route 86, Ray Brook, NY 12977
(518) 897–1200

Supervisor: John O'Connor

Duties included:

– Planning and executing breeding waterfowl survey in remote mountain wetlands of the Northern New York Adirondack region.
– Identifying waterfowl species, gender, and age class of ducklings
– Frequent use of ARCGIS v10.2 to discover remote wetlands, acquire geographic coordinates of wetlands, delineate wetland area, design and develop daily operating maps for wetland approach and waterfowl surveys, as well as spatial analysis of waterfowl habitat preferences.
– Ingress and egress to remote wetlands on foot and bicycle using handheld GPS units
– Assisted with a variety of wildlife surveys and services including Atlantic flyway breeding waterfowl plot survey, woodcock surveys, tree bat surveys, moose walk–in surveys, nuisance bear trapping and handling, peregrine falcon surveys, nuisance wildlife permits, pheasant stocking, waterfowl banding, and wetland delineation

U.S. Dept. of Agriculture, U.S. Forest Service, Shoshone Nat. Forest – Wind River Ranger District
Forestry Technician (Timber Sale Prep) GS–05 (6/1/2015 – 11/20/2015)

1403 W. Ramshorn Street, Dubois, WY 82513
(307) 455–2466

Supervisor: Skye Shaw
Duties included:

– Marking and traversing timber sale boundaries per written/verbal sylvicultural prescriptions
– Marking and cruising timber per written/verbal instructions and sylvicultural prescriptions
– Basic dendrometry using logger's tape, clinometer, and laser measuring devices
– Use of Trimble GPS to traverse unit boundaries and Allegro data recorders for tree tally/cruising
– Risk management pertinent to inherent work environment hazards
– Familiarization with contracts/task orders to understand technical data and project requirements
– Familiarization with Forest Service rules and requirements for creation of sale area maps
– Occasional use of ARCGIS 10 for timber sale area maps, skid–trail maps, and daily work maps
– Participation in the administration of sylvicultural contracts via delegation as an inspector for planting, spraying, and cone collection activities
– Occasional support of fire management activities as an initial attack firefighter (hand crew)

U.S. Dept. of the Interior, National Park Service, Bighorn Canyon Nat. Recreation Area
Seasonal Maintenance (8/2014 – 9/2014)

5 Yellowtail Drive, Fort Smith, Montana 59035

Supervisor: Curtis Rintz
Duties included:

–Used a variety of skills and equipment to maintain land and marine based structures, utility systems and other infrastructure within Bighorn Canyon NRA as a seasonal employee

Fogarty's Lake Flower Marina
Fiberglass and Gelcoat Technician (7/2013 – 5/2015)

260 Lake Flower Ave, Saranac Lake, NY 12983
(518) 891–2340

Supervisor: Terrance Fogarty
Duties included:

– Fiberglass, wood, and gelcoat repair & restoration on boats and boating equipment

Honors and Awards

– Eagle Scout Award
– International Baccalaureate Diploma (Oswego High School)
– SUNY Plattsburgh Dean's List Spring 2012, Fall 2012, Spring 2013, Fall 2013, Spring 2014

Publications

Macy, G. A. J., and J. N. Straub. 2016. Occupancy, detection, and co–occurrence of American black and mallard ducks in the Saranac lakes Wild Forest Area. Adirondack Journal of Environmental Studies 20:33–48.

Relevant Coursework

Undergraduate:

Intro to GIS, GIS Applications, Environmental Management, Environmental Conservation, Ecology, Environmental Technology 1 and 2, Biology, Introduction to Statisics, Forest Ecology and Management, Water Quality Modeling, Intro to Remote Sensing, Adv. Remote Sensing, Fish Ecology and Management, Wildland Fire, Environmental Law and Policy, Environmental Impact

Assessment, Outdoor Ethics, Environmental Planning, Waterfowl Occupancy Modeling, Chemistry, Physics, Geology, Atmospheric Processes

Graduate:

Sampling Methods, Intro to WinBUGS for Ecologists, Linear Regression, Intro to R and Reproducible Research, Wildlife Habitat and Populations, Waterfowl Ecology and Mgmt, Population Parameter Estimates in R and MARK, Seminars

Service Activities

– National Honor Society member
– Boy Scouts of America Volunteer

References

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