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Body Mass and Body Condition Variation of Mallards (Anas platyrhynchos) Within and Among Winters Within the Lower Mississippi Alluvial Valley

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Body Mass and Body Condition Variation of Mallards (*Anas platyrhynchos*) Within and Among Winters Within the Lower Mississippi Alluvial Valley

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ABSTRACT

Most North American waterfowl overwinter in southern North America before migrating back to breeding grounds in the northern US and Canada. These species face the challenge of needing to maintain or increase their body mass during an environmentally difficult winter period. Successful body mass maintenance during the winter period has major ramifications not only for their winter survival but for their fitness across the entire year. Recent research in Europe and the western United States suggests that the body mass of mallards (*Anas platyrhynchos*) has increased from the late 1960s to early 2000s. However, the factors responsible for increases in mallard body mass remain unknown. Because research has shown that mallard body mass and condition is directly proportional to energy acquired across the landscape, conservation agencies attempt to provide high-energy habitat such as woody wetlands, herbaceous wetlands, and open water areas for waterfowl to feed, rest, and complete other important life-cycle activities. Additionally, managers have tried to increase the amount of flooded agricultural grain across the landscape, as crops like rice can provide waterfowl with a source of high-energy food, especially in important overwintering waterfowl areas such as the Lower Mississippi Alluvial Valley (LMAV). However, long-term trends in mallard body mass, as well as the relationship between body condition of mallards and landscape composition has yet to be assessed in the LMAV.

To assess mallard body mass over time in the LMAV, we collected measurements from hunter-harvested mallards across the LMAV of Arkansas and Mississippi during duck hunting seasons from 1979-2021. We measured body mass, wing length, and aged and sexed each bird. We then developed four age-sex linear mixed effects models (LMM) analyzing changes in body mass across years. We also analyzed body mass within a winter period across the day of duck season, as well as in relation to cumulative rainfall, river flooding, and a weather severity index (WSI). We determined that mallard body mass has increased within the LMAV from 1979-2021. Within years, body mass generally decreased over the course of the hunting season. Mallard body mass generally increased when rainfall and river flooding increased. However, there was generally no relationship with mallard body mass and WSI.

Using Arkansas mallard measurements from duck hunting seasons 2019-2020 and 2020-2021, we calculated body condition indices (BCI) for each bird using the residuals from a mass by wing length regression for each age-sex class. We then used an LMM to analyze changes in mallard BCI in relation to landscape variables known to influence mallard body mass or BCI within a 30-km radius of each harvest site. Landscape variables included proportion of water cover, rice, soybeans, woody wetlands, herbaceous wetlands, open water areas, and areas of human disturbance. We found that mallards with high BCI came from areas with higher proportions of water cover, woody wetlands, and open water. However, mallards with lower BCI came from areas with higher proportions of herbaceous wetlands and human disturbance. We suggest managers restore, protect, and increase food resource availability in wetlands including bottomland hardwood forests

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I would like to thank the U.S. Geological Survey (USGS) Cooperative Fish and Wildlife Research Unit system, those associated with Ducks Unlimited, the U.S. Fish and Wildlife Service, the AGFC, Arkansas Audubon Society Trust, Rich-N-Tone Calls, and Leggett family for funding support, supplies, field assistance, and housing during data collection. USGS Arkansas Cooperative Fish and Wildlife Research Unit Administrative Analyst, Diane Moler, deserves a special thanks for her help with administrative work.

I would also like to thank all duck clubs, public land hunters, duck processing businesses, and volunteer data collectors for helping us acquire mallard measurements. I thank our technician, Jacob Hewitt, for helping collect several hundred mallard measurement samples from 2019-2021. Dr. Kenneth J. Reinecke and Dr. Brad Dabbert deserve a special thanks for donating mallard body mass data to our project where collections took place from 1979-2004.

Finally, I would like to thank my family and friends who have supported me throughout the course of my work. I thank my mother and father, Deborah and Robert Veon, for supporting my dream to become a waterfowl and wetland scientist. My father exposed me to the world of waterfowl hunting and my mother always made sure I had what I needed to continue to participate in the tradition. I would like to thank my sister, Greer Veon, for always providing writing advice when needed, as well as a place to stay while commuting between campus and field sites. I thank Harper Purifoy for her continued support both in and outside of field season. Harper always made sure I had what I needed for long field days and was never afraid to help. Additionally, the following individuals also deserve recognition for their knowledge, support, and friendship over the course of my master's degree: Andrhea Massey, Ellery and Elliot Lassiter, Reilly Jackson, Nathaniel Mull, Leah Bayer, Will Kirkpatrick, and Connor Gale.

DEDICATION

I would like to dedicate this thesis to those of the waterfowl hunting community. Several of these individuals gave us access to harvested birds, volunteered to help record data, suggested new sample sites, and sometimes even opened their homes and dinner tables to us. Without their participation and hospitality, this project would not have been possible.

EPIGRAPH

“A duck call in the hands of the unskilled is one of conservation’s greatest assets.”

-Theophilus Nash Buckingham

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INTRODUCTION

Long-Term Monitoring of Body Mass and Body Condition in Waterfowl

Overwintering waterfowl must maintain their body mass to meet energetic needs during the winter period (Loesch et al. 1992). Waterfowl can maintain body mass by having access to adequate foraging and roosting habitat across the landscape (Delnicki and Reinecke 1986; Reinecke et al. 1988; 1989; Frederickson and Taylor 2007). Waterfowl that successfully maintain their energy stores are more likely to be in a better body condition, and will be more equipped to survive the winter, properly time important life-cycle events (e.g., molt cycles, pair formation), as well as prepare for the challenges of spring migration (Bergan and Smith 1993; Dujins et al. 2017; Owen and Cook 1977; Hepp 1986; Miller 1985) and subsequent breeding activities (Devries et al. 2008). Thus, body mass and resulting body condition in waterfowl can be important indicators of waterfowl population health and waterfowl resource provision across the landscape.

However, few studies have measured long-term trends in waterfowl body mass, but all suggest body mass has increased in several species of waterfowl from the late 1960s to early 2000s, and that waterfowl in more recent decades may be of a better body condition than those of previous decades. In the Northwest European Flyway, researchers found that mallards (*Anas platyrhynchos*) and European green-winged teal (*Anas crecca*) increased in mass by between 7.3% and 11.7% from the 1960s to the 2000s. The authors speculated that the increases in mass could be due to waterfowl spending less energy on thermoregulation due to a more benign winter climate. Furthermore, increases in mass may be the result of more rainfall and flooding over time, thus, increasing access to food. Additionally, researchers believe that the intensification of wetland management practices as well as the increase in protected areas over time could have resulted in increases in waterfowl body mass (Guillemain et al. 2010). Waterfowl body mass and resulting condition has also increased in the Central Valley (California, USA) for several duck species. Researchers speculate increases in mass are due to improved habitat management. Over the 20-year study period, wetland enhancement programs in the Central Valley area improved post-harvest flooding of crop fields, like rice; better managed the productivity of natural seeds in wetlands; and increased the amount of available roosting habitat. Thus, waterfowl at the end of the study period were able to spend less time searching for and traveling between resources to maintain energy requirements as opposed to waterfowl in previous time periods (Fleskes et al. 2016).

On the contrary, other studies suggest that body mass increases in waterfowl are more likely a function of distributional shifts of subpopulations or the genetic swamping of wild populations by hand-reared waterfowl. In the Mediterranean Flyway (Europe), researchers found that mallards have shortened their migration distances (Gunnarsson et al. 2012). Additionally, mallards within this area have increased in body mass. Because shorter migration distances require less energy use, it is thought that the shifts in distributions are possibly responsible for the increases in body mass (Gunnarsson et al. 2011). Additionally, this area was subject to mallard stocking of hand-reared mallards. Because hand-reared mallards are usually of a larger size than wild mallards (Harrison 1966; Greenwood 1975; Figley and VanDruff 1982; Byers and Carey 1991; Dubovsky and Kaminski 1994), the introgression of hand-reared mallards could be responsible for the increases in mass (Gunnarsson et al. 2011).

Waterfowl Management in Relation to Mallard Body Mass and Body Condition in the Lower Mississippi Alluvial Valley

Because waterfowl body mass is directly proportional to energy acquired (Labocha and Hayes 2012), the quality and quantity of food resources that management agencies provide can influence waterfowl body mass and their resulting body condition (Rave and Baldassarre 1991). Additionally, habitat that allows waterfowl to sufficiently rest and avoid disturbance will prevent waterfowl from engaging in unnecessary behaviors (e.g., swimming, flying) and wasting energy. Thus, waterfowl management is centered upon the premise that maximizing the amount of food on the landscape, while regulating human disturbance (Fredrickson and Taylor 2007; Reinecke et al. 1989) will increase mallard body condition. Therefore, waterfowl using managed habitats should assimilate more energy, resulting in a higher body condition index (BCI) value.

Management of habitat for overwintering waterfowl body condition is especially important in the Lower Mississippi Alluvial Valley (LMAV). The LMAV is 26.7 million acres in size and spans from the upper Midwest to southern portions of the Mississippi Flyway (Oswalt 2013). In particular, the Arkansas portion of the LMAV is a point at which many rivers converge, and this attracts some of the highest densities of overwintering waterfowl in North America. For this reason, conservation agencies like the U.S. Fish and Wildlife Service and Arkansas Game and Fish Commission spend millions of dollars each year to protect, restore, and manage habitat for waterfowl in this region.

Several types of habitats that are managed in the Arkansas LMAV for waterfowl and can influence mallard body mass or body condition. For example, this area is known worldwide for its once vast bottomland hardwood forests that provide waterfowl with high-energy mast in the form of acorns (Allen 1980; Dabbert and Martin 2000; Heitmeyer and Fredrickson 1990: Miller et al. 2003: Reinecke et al. 1989), macroinvertebrates in the leaf litter that provide valuable proteins (Foth et al. 2014; Fredrickson and Heitmeyer 1988; Krapu and Reinecke 1992; Fredrickson and Batema 1992), as well as offer waterfowl areas to roost and avoid hunting pressure which contributes toward energy conservation (Reinecke et al. 1989). Herbaceous wetlands, in the form of moist soil units, are also managed to provide waterfowl with a variety of vegetative matter and seeds packed with unique, essential vitamins and amino acids (Checkett et al. 2002), as well as aquatic invertebrates for dietary proteins (Fredrickson and Taylor 1982; Anderson and Smith 1999; Gray et al. 1999). Open water lakes are also areas of management interest as they allow waterfowl to have good visibility to locate and avoid predators, shallow water shorelines for foraging, and areas for roosting (Chabreck et al. 1989; Rave 1987; Tamisier 1978). Waterfowl also benefit from flooded agricultural fields, like rice, as they offer high energy food resources for waterfowl. However, not all commercial crops are beneficial to waterfowl. Soybeans, sometimes utilized by waterfowl, do not provide much nutrition. If digested, soybeans can sometimes cause impaction and increase mortality among waterfowl (Ringleman 1990). Additionally, because areas with high human disturbance can cause waterfowl to alter their behavior (Burger and Gochfeld 1998; Pease et al. 2005; Riddington et al. 1996) and waste energy (Knapton et al. 2000; Taylor et al. 2010), conservation agencies also manage waterfowl refuges, which are habitats closed to human access during the winter period (Bellrose 1954; Madsen 2004). Waterfowl use a variety of these habitat types to maintain energy stores required during different life cycles events across the winter.

Objectives

Long-term body mass trends, specifically for mallards, have yet to be assessed within the LMAV. Additionally, because recent assessments show the LMAV is below goal levels of food energy provision for ducks (LMVJV 2015), it is important for conservation agencies to understand how the body condition of waterfowl is responding to a lack in resources so they may be able to manage the landscape appropriately. Therefore, I conducted the studies below to assess how body mass in hunter-harvested mallards has changed from 1979-2021 within the

LMAV, as well as analyzed the environmental and landscape variables that could be responsible for observed trends in mallard body mass and body condition.

The objectives of my study were to: 1) to measure variation in overwintering mallard body mass within the LMAV based on intrinsic factors such as age and sex, as well as extrinsic factors such as temperature, rainfall, river height, day, and year; 2) to explore landscape cover within the vicinity of mallard harvest sites that promotes high BCI in mallards; and 3) identify areas within the Arkansas LMAV that will promote better body condition among waterfowl.

Chapter One of my thesis addresses my first objective. Chapter Two will examine my second and third objectives. Chapter One is formatted with the intent of publication in the *Journal of Wildlife Management* with Dr. Brett A. DeGregorio, Luke W. Naylor, Dr. Kenneth J. Reinecke, Dr. Brad C. Dabbert, Dr. Dean W. Demarest, Dr. Kevin M. Hartke, and Dr. David G. Krementz. Chapter Two is also formatted with the intent of publication in the *Journal of Wildlife Management* with Dr. David G. Krementz, Luke W. Naylor, and Dr. Brett A. DeGregorio.

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CHAPTER I

WINTER MALLARD (*ANAS PLATYRHYNCHOS*) BODY MASS TRENDS FROM 1979 – 2021 IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY

John T. Veon, Brett A. DeGregorio, Luke W. Naylor, Kenneth J. Reinecke, Brad C. Dabbert, Dean W. Demarest, Kevin M. Hartke, and David G. Krementz.

ABSTRACT

Body mass in overwintering waterfowl is an important fitness attribute as it relates directly to winter survival, timing of spring migration, and reproductive success the following spring. Recent research in Europe and the western United States suggests that the body mass of mallards *(Anas platyrhynchos)* has increased from the late 1960s to early 2000s. Some researchers hypothesize that increases in body mass are due to a more benign winter climate and increased food availability. Others suggest body mass has increased due to introgression of wild mallard populations by game-farm mallards or the shifting of wintering distributions northward. However, it is currently unclear if this phenomenon is occurring in other important waterfowl flyways. Here we analyze trends in mallard body mass in the Lower Mississippi Alluvial Valley from 1979-2021 to establish whether such changes have occurred. During Arkansas and Mississippi duck hunting seasons, we measured hunter-harvested mallards from hunting clubs, state and federal public duck hunting areas, and plucking stations. From 1979-2021, mallard body mass has increased by between 5.6 and 7.6 % among all age-sex classes. On average, mallards are increasing in mass by 1.5 % per decade. However, mallard body mass fluctuated within the wintering period and was quite variable between years. Mallards generally decreased in mass over the course of the waterfowl hunting season. Additionally, mallard body mass was influenced by rainfall, with ducks having larger body mass after periods of increased rainfall or river flooding, likely due to increased availability of food. Conservation agencies that promote flooding strategies to help waterfowl optimally access food resources may help promote a higher body mass in ducks

INTRODUCTION

Long-term monitoring of wildlife has revealed instances of body mass change coincident to landscape alterations, climate change, or genetic swamping from captive-bred individuals (Ktitrov et al. 2008; La Sorte et al. 2009; Reeves et al. 2020; Robel et al. 1979). For example, in Norway, changing forestry practices are thought to have led to decreases in moose (*Alces alces*) body size from the early 1970s to early 2000s (Bjørneraas et al. 2011; Lavsund et al. 2003). Additionally, the body mass of wood rats (*Neotoma* spp) in New Mexico, USA has decreased from 1989-1996 as minimum and maximum temperatures increased over the course of the study period (Smith et al. 1998). Wacker et al. 2021 was able to demonstrate that farm raised Atlantic salmon (*Salmo salar*), which escaped into River Atla in Norway, were able to breed with wild salmon. After 20 years, introgressed Atlantic salmon in the river were of a larger body size than those of non-introgressed salmon (Wacker et al. 2021).

Some of the strongest evidence for body mass change over large time scales comes from waterfowl. For example, Guillemain et al. 2010 showed that the body mass of mallards (*Anas platyrhynchos*) and European green-winged teal (*Anas crecca*) in Europe increased between 7.3% to 11.7% from the 1960s to the 2000s. The authors hypothesized that these changes could have been caused by climate change and local habitat management. Waterfowl body mass has also increased over time for several duck species in California, USA (Fleskes et al. 2016). The authors suggest that the observed increases in waterfowl body mass can be explained by increases in waterfowl food resources and wetland area. However, there are other potential explanations such as stocking programs using heavier, hand-reared mallards to supplement wild mallard populations as well as shifts in winter distributions of subpopulations leading to increased body mass in mallards (Gunnarsson et al. 2011). Given these similar trends on different continents, it is likely that this phenomenon of waterfowl increasing in body mass over time occurs in additional regions. Elucidating the extent of these changes will be important for understanding how wildlife are responding to a changing world.

Understanding long-term changes in body mass for waterfowl is complicated by the fact that body mass varies both year-to-year and within years in relation to several intrinsic and extrinsic factors. Waterfowl body mass can be affected by endogenous regulation due to specific life cycle events as well as age and experience. For example, female mallards during certain molt stages, specifically the mid-pre-breeding molt stage, were lower in lipid mass than other females in other molt stages (Heitmeyer 1988). In the same study, females who completed breeding pair formation with males contained greater lipid masses than females who failed breeding pair formation. Mallard body mass also varies across the wintering period, driven by physiological processes (Heitmeyer 1988; Loesch et al. 1992), perhaps as a mechanism to attain optimal spring departure weights for efficient, fast migration (Lindström and Alerstam 1992). Other researchers have shown that older ducks have greater body mass because they are more efficient foragers than younger individuals (Hohman and Weller 1994). Waterfowl body mass can also be affected by exogenous factors such as food availability and climate. Dabbling ducks like mallards forage in shallow marshes, flooded fields, and floodplains for aquatic invertebrates, rice, soybeans, mast, and seeds of moist-soil plants (Delnicki and Reinecke 1986; Miller et al. 2003; Reinecke et al. 1989). Because duck body mass is directly proportional to energy acquired (Labocha and Hayes 2012), the quality and quantity of available food resources can alter waterfowl body mass (Rave and Baldassarre 1991). Food availability for dabbling ducks varies across the winter period as foods are consumed, decompose, or become available/unavailable based on rising or receding water levels driven by rainfall and flooding (Behney 2020; Hagy and Kaminski 2012;

Poysa 1983). Temperatures can further impact duck body mass by either making food unavailable under ice or by thermally stressing animals and increasing their metabolism (McKinney and McWilliams 2005; Schummer et al. 2010).

Here, we assess body mass trends in hunter harvested mallards across four decades (1979-2021) within the LMAV, as well as explore the factors responsible for those trends. Our overall goal was to evaluate if mallards have increased in body size as has been reported in Europe (Guillemain et al. 2010; Gunnarsson et al. 2011) and in the western United States (Fleskes et al. 2016), but to also explore other factors influencing changes in body mass within and among years. Our specific objective is to quantify variation in winter body mass of mallards in the LMAV based on intrinsic factors such as age and sex, as well as extrinsic factors such as temperature, rainfall, river height, day, and year. We predict that overall body mass has increased over time as has been seen in other regions such as western Europe and the western United States (Fleskes et al. 2016: Guillemain et al. 2010; Gunnarsson et al. 2011). We also predict that this overall trend will be complicated by natural variation in weather within years such that mallards will be heaviest when food availability is increased due to higher levels of winter rain and river flooding (Delnicki and Reinecke 1986; Reinecke et al. 1988), as well as being heaviest when weather is mild relative to years with severe winter weather that can lead to increased physiological stress and reduced food availability (McKinney and McWilliams 2005; Schummer et al. 2010; Whyte and Bolen 1984).

METHODS

Study Area

The Lower Mississippi Alluvial Valley (LMAV) is the largest floodplain in the USA and spans 26.7 million acres across portions of seven states within the Mississippi Flyway (Oswalt

2013). The LMAV is made up of many river systems used by waterfowl as they migrate south for the winter. As a result, the LMAV supports some of the highest densities of waterfowl in North America (Bellrose et al. 1976). Additionally, the LMAV contains rich alluvial soil which makes it a productive agricultural region for crops like rice that are a valuable waterfowl food source (National Fish and Wildlife Foundation 2019; Nelms et al. 2007). Our study area spanned the entirety of the LMAV of Arkansas, as well as some sites within the LMAV in Mississippi (Figure 1.1).

Body Mass Measurements

Body measurements were collected from several different published (Dabbert et al. 1997; Dabbert and Martin 2000; Delnicki and Reinecke 1986) and unpublished studies the authors have collectively conducted from 1979-2021. Thus, sample site locations and methodology were not standardized across different time periods. We included body mass measurements of mallards collected during the Mississippi duck hunting seasons of 1979-1980 through 1982-1983, as well as Arkansas duck hunting seasons of 1990-1991, 1999-2000 through 2003-2004, 2015-2016, 2016-2017, 2019-2020, and 2020-2021. We collected data from both public and private lands. We selected field sites based on availability of harvested mallard samples from hunters, but also in an attempt to obtain a wide geographic distribution of mallard samples across the Arkansas and Mississippi LMAV. In later years, we focused efforts on collecting samples from as wide of a geographic area as possible and sampling areas not previously visited. We sampled ducks at hunting lodges, public waterfowl hunting areas, as well as duck cleaning businesses. Body mass measurements from 1979-1983 were previously collected by Delnicki and Reinecke (1986) and measurements from 1990-1991 were previously collected from Dabbert et al. (1997) and Dabbert and Martin (2000) (Table 1.1). From 1979-1980 through 1982-1983, we measured mallards killed by hunters at Hillside National Wildlife Refuge (NWR), Panther Swamp NWR, Delta National Forest, and private hunting clubs in Holmes, Humphreys, Sharkey, and Yazoo Counties in west-central Mississippi. From 1990-1991, we harvested and measured mallards from Bayou Meto Wildlife Management Area (WMA) and the White River NWR. From 1999-2000 through 2003-2004, we obtained body mass data for mallards at a duck cleaning business in Stuttgart, Arkansas in the Grand Prairie region of east-central Arkansas. During 2015-2016 and 2016-2017, we collected mallard body mass measurements from harvested mallards on private farmland in east-central Arkansas. During 2019-2020 and 2020-2021, we collected mallard body mass measurements from harvested mallards on private land and public waterfowl hunting areas (WMAs and NWRs) across the north, central, and south LMAV of Arkansas. All mallards were aged and sexed using plumage dimorphism and feather morphology characteristics (Carney 1992; Krapu et al. 1979).

Body Mass Analyses

To explore mallard body mass change over time and in response to intrinsic and extrinsic factors, we used linear mixed effects models (LMMs) in R Computing Software (package lme4 in R Studio 1.2.5042; 2020). Because mallards display sexual dimorphism with males being larger than females (Bellrose 1980), and by age with adults being larger than juveniles (Hohman and Weller 1994), we analyzed each sex and age group separately. For all four models, we used mallard body mass as the response variable, and we used location as our random variable to control for variation across sites. We used Year as our first fixed factor to explore how mallard body mass has changed over the course of the study (1979-2021). However, we should note that the duck hunting season spans calendar years (often Nov-Feb). Thus, our use of the term Year refers to the duck hunting season initiating in November of that year and spanning to February of the next calendar year. We expected that mallard body mass would increase from 1979 to present as has been reported for mallards in Europe and the Central Valley of the U.S.

Additionally, we explored several other extrinsic fixed factors to assess how they also are related to mallard body mass fluctuations. These extrinsic factors include Day of Season, Cumulative Rainfall, River Gage Height, and Weather Severity Index (WSI). Day of Season refers to each chronological day of the duck hunting season. We included Day of Season because mallard body mass is known to fluctuate over the course of the winter (Loesch et al. 1992; Pawlina et al. 1993). We used a modified Julian day with the earliest date that a mallard was harvested across the study labeled as day 1 (November 19th) and each subsequent day numbered sequentially until day 83 (Feb 13th), the latest date a bird was harvested. We expected body mass to be negatively correlated to the day of hunting season as food resources become scarcer as winter progresses (Eadie et al. 2008). To assess the relationship of Cumulative Rainfall and WSI to mallard body mass, we collected climate variables from nearby National Oceanic and Atmospheric Administration (NOAA) weather stations. We obtained daily measures of precipitation (cm) and minimum and maximum temperature (°C). We used data from Yazoo City, Yazoo County, Mississippi (station name: Yazoo City 5 NNE) for winters 1979-1980 through 1982-1983 and Arkansas (station names: Stuttgart 9 ESE, Des Arc, Searcy, Georgetown, Pine Bluff, Augusta, Wynne, Alicia, Keiser, Eudora, Monticello Municipal Airport, Marianna, Arkansas Post, Rohwer, Paragould, and Pocahontas) for winters 1990-1991, 1999-2000 through 2003-2004, 2015-2016, 2016-2017, 2019-2020, and 2020-2021 based on proximity of harvest site to closest weather station. We calculated 3-day cumulative rainfall prior to mallard harvest to explore the relationship of rainfall with waterfowl body mass. We expected body mass to be positively related to precipitation because flooding increases available foraging habitat (Reinecke et al. 1988). We then calculated daily average temperature for each day of the season and used these values to calculate the 3-day average of daily average temperatures prior to mallard harvest. Finally, we calculated WSI using our 3-day average temperature values (by modifying the WSI equation from Schummer et al. 2010) to evaluate the relationship of weather severity and mallard body mass before harvest.

$$\begin{aligned} WSI = \big(&-1 * Average\ of\ Previous\ 3 - day\ Average\ Daily\ Temperature\ (C°)\big) \\ &+ (Number\ of\ Days\ Consecutively\ \leq 0\ C°) \\ &+ (Snow\ Depth\ (cm\ x\ 0.394)\ on\ Day\ of\ Harvest) + (Consecutive\ days \\ &\geq 2.54\ cm\ of\ snow) \end{aligned}$$

We predicted that during extreme weather events, mallards will have higher metabolic needs and potentially reduced access to food resources, and thus lower body mass (Whyte and Bolen 1984). Finally, River Gage Height refers to river gage height data (m) that was collected from the USGS Lower Mississippi-Gulf Water Science Center for Mississippi winters 1979-1983 (gage name: Big Black River near Bovina) and for Arkansas winters 1990-1991,1999-2000 through 2003-2004, 2015-2016, 2016-2017, and 2019-2020, and 2020-2021 (gage names: Black River near Corning, Black River at Pocahontas, Black River at Black Rock, Cache River at Egypt, White River at Newport, White River at Georgetown, Cache River near Cotton Plant, White River at DeValls Bluff, L'Anguille River near Colt, L'Anguille River near Palestine, Bayou Meto near Lonoke, Bayou Bartholomew at Garrett Bridge, and Bayou Bartholomew near McGehee). Gage data was retrieved from river gages that were nearest to our sample sites to examine the relationship of daily river height on harvested mallard body mass. Similar to rainfall, we expect that mallard body mass will be highest when river levels are high because of increased foraging habitat. After developing all variables, we checked for collinearity using Pearson's correlation coefficient. No predictor variables were highly correlated (≥ 0.7

correlation), and thus, all were retained for analyses. Among predictor variables, only Cumulative Rainfall did not meet assumptions of homogeneity of variances. Therefore, Cumulative Rainfall was log transformed to better meet assumptions.

Determining Rate of Change (%) of Body Mass Over Time

To better explore the magnitude of body mass change over time for each age-sex class, we binned duck body mass into decadal groups and calculated the rate of change in body mass between decadal groups. We used the following time periods: Decade 1 = 1979-1980 through 1988-1989, Decade 2 = 1989-1990 through 1998-1999, Decade 3 = 1999-2000 through 2008-2009, Decade 4 = 2009-2010 through 2018-2019, and Decade 5 = 2019-2020 through 2020-2021. We chose to bin body mass measurements among decadal groups because our data were collected during sampling periods separated by uneven gaps of time. We then calculated pair-wise changes in average body mass across these time periods using variations of the following rate of change equation from Hopkins (1992):

$$\%\ Average\ Body\ Mass\ Growth\ Between\ Individual\ Decades = \left(\frac{Avg.\ Body\ Mass\ Decade\ (D) - Average\ Body\ Mass\ of\ Previous\ Decacde\ (D-1)}{Average\ Body\ Mass\ of\ Previous\ Decade\ (D-1)}\right) * 100$$

$$\%\ Average\ Body\ Mass\ Growth\ per\ Decade = \frac{Sum\ of\ \%\ Change\ Between\ All\ 5\ Chronological\ Decade\ Pairs\ (1\ \&\ 2, 2\ \&\ 3, etc.)}{5}$$

We should note, binning of body mass measurements by decadal groups was only used to calculate the rate of change of body mass over time. Binning was not used to analyze trends in body mass overtime within LMMs.

RESULTS

In total from 1979-2021, we measured body mass of 6,307 mallards within the LMAV. Our mallard measurements included 2,765 adult males, 1,505 juvenile males, 912 adult females, and 1,125 juvenile females. On average, mallard body mass was generally the highest in sample year 2020-2021 among most age-sex classes (adult males = 1331.28 g ± 4.89 (SE), adult females = 1180.79 g ± 11.93 (SE), juvenile males = 1290.5 g ± 4.97 (SE)) as compared to other sample years, except for juvenile females being slightly heavier in 2015-2016 (1141.1 g ± 27.01 (SE)). Adult male (1167.22 g ± 13.53 (SE)) and juvenile female (988.86 g ± 33.02 (SE)) mallard body mass was lowest during 2016-2017. Juvenile male mallard body mass was lowest in 1990-1991 (1034 g ± 9.00 (SE)). Adult female mallard body mass was lowest in 1980-1981 (1051.15 g ± 6.57 (SE)) (Table 2.1).

Body Mass Change Over Time

We found that mallard body mass among all age-sex classes was significantly related to Year ($P < 0.01$), with all groups increasing in mass over time. Adult males ($\beta = 1.68$, CI = 0.94 – 2.43), juvenile males ($\beta = 2.91$, CI = 2.08 – 3.76), adult females ($\beta = 1.41$, CI = 0.59 – 2.22), and juvenile females ($\beta = 2.16$, CI = 1.13 – 3.21) all increased in body mass from 1979-2021. On average the rate of change of body mass from Decade 1 to Decade 5 was 5.6% for adult males, 6.9% for adult females, and 7.6% for juvenile males and females. Among all age-sex classes, increases in mallard body mass ranged on average between 1.2-1.9 % per decade (Figure 2.1; Table 3.1).

Although mallard body mass generally increased over the course of the study, body mass varied among years (Figure 3.1). For adult males and adult females ($P < 0.01$), as well as juvenile males ($P = 0.02$), body mass was related to Day of Season within a sample year. Mallard body mass generally decreased from the start to end of each hunting season for adult males (β = -0.8, CI = -1.05 – -0.55), adult females (β = -1.04, CI = -1.43 – -0.61), and juvenile males (β = -0.38, CI = -0.71 – -0.06). However, juvenile female mallard body mass was not significantly related to Day of Season (Table 3.1; Figure 4.1).

Body Mass Trends in Relation to Climate

It should be noted that *a priori* analyses indicated that Cumulative Rainfall and River Gage Height were not highly correlated (r = 0.24 – 0.27 among models). We observed that all age-sex classes were generally related to Cumulative Rainfall ($P \leq 0.039$ for adult males, and juvenile males and females). Body mass for adult males (β = 3.09, CI = 1.33 – 4.86), juvenile males (β = 2.53, 0.14 – 4.90), and juvenile females (β = 3.02, 0.30 – 5.84) increased as cumulative rainfall increased. However, there was no relationship between cumulative rainfall and adult female body mass ($P \geq 0.1$) (Table 3.1; Figure 5.1).

We also observed that mallard body mass was generally related to River Gage Height. Adult females ($P < 0.01$; β = 9.65, CI = 5.81 – 13.53) and juvenile females ($P < 0.01$; β = 9.32, CI = 5.24 – 13.36) increased in body mass as River Gage Height increased. There was a marginally significant relationship between adult male ($P = 0.084$) mallard body mass with River Gage Height, with adult males generally increasing in mass as River Gage Height increased (β = 2.14, CI = -0.27 – 4.61). However, juvenile male mallard body mass was not significantly related to River Gage Height ($P \geq 0.1$) (Table 3.1; Figure 6.1).

Mallard body mass among adult males and females, as well as juvenile males, was not significantly related to WSI ($P > 0.1$). However, body mass among juvenile females held a marginally significant relationship with WSI (P = 0.066) with juvenile females generally decreasing in mass as WSI increased (β = -1.62, CI = -3.36 – -0.09) (Table 3.1; Figure 7.1).

DISCUSSION

We found that mallard body mass has increased from 1979-2021. We documented a body mass increase of 5.6-7.6 % among all age-sex classes. This aligns with increases in body mass observed in both North America and Europe. In the Central Valley of the U.S., mallard body mass was 3.2-6.1% greater in 2006-2008 as compared to 1985-1993 and 1982-1984 respectively (Fleskes et al. 2016). In Europe, mallard body mass increases were ≥ 7.3 % among all age-sex classes collected in 2002-2008 as compared to 1952-1969 (Guillemain et al. 2010).

Increases in body mass have occurred in multiple regions, yet the underlying mechanism(s) has yet to be elucidated. Several primary hypotheses have emerged including climate change, genetic swamping of wild populations with captive bred individuals, wintering distributional shifts, and landscape alteration (Fleskes et al. 2016; Guillemain et al. 2010; Gunnarsson et al. 2011). First, we will explore the four hypotheses that attempt to explain mallard body mass increase over time. We will then investigate the trends of mallard body mass change within winters.

One factor that could be responsible for increases in waterfowl body mass is climate change. Recent weather data show that rainfall and river flooding have increased in variability from 1979-2021, while also indicating that rainfall and river flooding has increased on average and is predicted to continue to increase in future years (IPCC 2021; NOAA US Climate Extremes Index 2021). Because the amount of water across the landscape can affect the degree to which waterfowl can efficiently access food resources (Fredrickson and Taylor 2007), it is possible that increasing amounts of precipitation and river flooding could be increasing foraging habitat availability for mallards. Furthermore, temperatures are also increasing on average in Central North America (IPCC 2021; NOAA US Climate Extremes Index 2021). Because cold temperatures can inhibit access to food resources due to the presence of ice (Schummer et al. 2010), and colder temperatures require waterfowl to burn more energy for thermoregulation (McKinney and McWilliams 2005), it could be assumed that increases in temperatures could also increase food resource availability for waterfowl during the winter, as well as require waterfowl to burn less energy resulting in higher body mass.

Another factor that could be responsible for the observed increase in waterfowl body mass is the genetic swamping of wild strain mallards with domesticated mallard genes. In a recent study, nearly 40% of mallards sampled in the Mississippi Flyway had game-farm mallard DNA signatures (Lavretsky et al. 2019). Game-farm mallards are heavier and larger in size compared to North American wild-strain mallards (Harrison 1966; Greenwood 1975; Figley and VanDruff et al. 1982; Byers and Carey 1991; Dubovsky and Kaminski 1994). Thus, over time, genetic crossover of wild strain and game-farm-strain mallards could result in increased mallard body mass. Gunnarsson et al. 2011 showed that, in Europe, mallard body mass increased over a 30-year period of regular mallard stockings. European green-winged teal, which were not subjected to stocking programs in Europe, did not increase in body mass over the same 30-year period. A similar phenomenon has occurred in other species, such as Atlantic salmon (Wacker et al. 2021). While this link remains speculative and correlational, it is one of the hypotheses that would be most feasible to explore.

A third factor that could be responsible for mallard body mass increase over time is the shift in wintering distributions northward. Shorter migration distances should require less fat to be burned, resulting in a heavier morphology (Gunnarson et al. 2011). In the Northwest European Flyway, mallards experienced an increase in body mass as well as a shift northward in their migration distance in winter compared to earlier decades (Gunnarsson et al. 2012; Sauter et al. 2010). However, Green and Krementz (2010) found no evidence to support significant, directional changes in the latitude of mallard distributions within the Mississippi Flyway, as harvest distributions of mallards have not significantly changed. Their study did point to an overall broader distribution of mallard harvest across the Central and Mississippi Flyways, and it is possible this emerging trend has continued since the time of their study. While additional data might further refine our understanding of distributional shifts within the LMAV, we do not think this hypothesis is likely to account for the body mass changes we documented here because recent midwinter mallard distribution surveys suggest otherwise (AGFC 2021, unpublished report).

One final factor that could be responsible for mallard body mass increase over time is changing food availability caused by landscape alteration. Waterfowl habitat has continued to decline in the LMAV over time (LMVJV 2015). Recent studies have shown that bottomland hardwood forests may have reduced mast-producing potential due to declining tree health (AGFC 2017; T. Foti, Arkansas Natural Heritage Commission, personal communication; Nelms et al. 2007). Other reports indicate that the acreage of crops, such as rice which is utilized by waterfowl, has declined in Arkansas and Mississippi at a rate ≤ 2.6 % annually from 1995-2017 (McBride et al. 2018). The reasons for crop acreage decline are suggested to be the result from agricultural technological advancements (ie. planting earlier maturing crop strains) and practices (ie. stripper-header harvesting, fall tillage) that increase farmer yield per acre, requiring less acreage to be planted (Anders et al. 2008; McBride et al 2018). In addition to declines in the extent of important crops, food resources available in these fields have declined over time, most notably in rice fields (Stafford et al. 2006). Because mallard body mass has increased over time despite the general decline in wetland and agricultural habitat, we believe that landscape alteration is not fully responsible for the observed long-term increases in mallard body mass from 1979-2021 in the LMAV.

Detecting long-term trends in body mass change can be further complicated by body mass changes within a year or season. Although mallards increased in body mass over time, our results indicated that mallard body mass decreases over the course of each winter. This aligns with numerous studies that have shown mallard body mass declines from earlier and mid-winter periods to late-winter periods (e.g., Delnicki and Reinecke 1986; Loesch et al. 1992; Whyte et al.1986). Mallard body mass may decrease over winter as a result of pressure for birds to reach optimal (lower) spring departure weights as it is a more efficient migration strategy (Lindström and Alerstam 1992). However, decreasing body mass may also reflect decreasing food availability as food items are consumed or deteriorate over time (Greer et al. 2009).

Our results suggest that average body mass of mallards varied among years and was influenced by climate variables. The most reliable indicators of mallard body mass were rainfall and river gage height. These variables have long been associated with foraging habitat availability (Delnicki and Reinecke 1986; Frederickson and Taylor 2007; Guillemain et al. 2000). Increased area of surface water (from flooding or rainfall) could increase access to food resources; thus, mallard body mass could increase as a result. Interestingly, river gage height is not necessarily correlated with local rainfall, suggesting that factors occurring upstream from the focal areas or associated with water control regimes likely affect foraging habitat availability. Because it is beneficial to female mallards to pair early in the winter and as a result may have increased body mass (Heitmeyer 1988), and paired mallards are more likely to seek out forested wetland habitat for isolation where natural river flooding is more likely to occur (Harris et al. 1984; Heitmeyer 1985; Reinecke et al. 1989), this could explain how adult female mallard body mass is more likely to fluctuate in response to changing river levels rather than nearby rainfall. Due to there being more male mallards than hen mallards on average (Munro and Kimball 1982), the increased competition for male mallards to find a mate could explain why there was only a marginal relationship between adult male mallard body mass and river gage height. It is possible we could have collected a larger sample of measurements from unpaired male mallards that were more often using habitat where access might be governed by rainfall rather than river flooding (e.g., flooded agricultural fields) (Heitmeyer 1985; Reinecke et al. 1989). This case could further be supported by the fact that juvenile male mallard body mass was unrelated to river gage height. Juvenile males might be less successful in pair formation than adult male mallards (Heitmeyer 1995). Therefore, juvenile males may also spend more time in more open habitat where water levels may fluctuate primarily by local rainfall (e.g., agricultural fields) in search of a potential mate. Additionally, it could be noted that both adult females and juvenile females contained the smallest sample sizes of mallard body mass among age-sex cohorts, and thus, could also be responsible for differences in results.

Among adult males, adult females, and juvenile males, WSI appeared to have no relationship with mallard body mass. This does not align with traditional assumptions, where it is believed that severe cold weather could lead to insufficient access to food resources (Schummer et al. 2010) or increase metabolism, which could result in lowered body mass (McKinney and McWilliams 2005). Whyte and Bolen (1984) found that when feeding conditions are optimal, severe cold weather does not affect gains in lipids or body mass. Based on these studies, our results would suggest that food resources in the LMAV may be sufficient to counteract any effects from severe cold weather on mallard body mass. However, we did find that juvenile female body mass might decrease when WSI increases. This could most likely be explained by sensitivity of female mallard body mass fluctuation to intrinsic and extrinsic factors (Pattenden and Boag 1989) as well as juvenile female mallards engaging in activities that are more energetically costly (e.g., forming mating pairs in late winter, having larger home ranges in their first winter) than those of adults (Heitmeyer 1995; Jorde et al. 1984; Whyte et al. 1986). Thus, juvenile female mallards may initially expend more energy reserves during the winter than other age-sex groups. As a result, juvenile female mallards may experience increased mass loss during periods of intense thermoregulatory demand from colder weather.

We recognize that there are some potential biases of using hunter-harvested birds and non-standardized sampling methods among years. For example, it has been shown that hunter-harvested mallards tend to weigh less than mallards occupying undisturbed locations (Heitmeyer et al. 1993). This could have led to us collecting mallard measurements from a higher proportion of mallards that were more likely to die of natural causes. Additionally, mallard body mass was rounded to the nearest 10 g in years 1979-1983 and 2015-2017. This could have led to less precise body mass measurements within those years. Therefore, we emphasize that the results of our study are purely correlative. However, we would also like to recognize that to the best of our knowledge, this is the only comprehensive mallard body mass dataset that exists for the last 42 years within the LMAV, and our results are comparable to the results of other studies monitoring long-term trends in mallard body mass (e.g., Fleskes et al. 2016; Guillemain et al. 2010; Gunnarsson et al. 2011).

Management Implications

Our study shows strong evidence that mallard body mass has increased from 1979-2021 in the LMAV of Arkansas and Mississippi. Because the causal factors of body mass increase remain unknown, direct management recommendations are more difficult to elucidate. However, the links between climate and mallard body mass are likely to yield actionable possibilities. For example, managers seeking to increase the body mass of ducks could possibly accomplish this by manipulating surface water to provide access to shallow foraging areas, especially in periods of low rainfall. This may be particularly important late in the winter when food availability is likely most limited. Direct strategies for increasing the degree to which waterfowl can access food resources include gradually flooding food resources to ideal dabbling duck foraging water levels, and increasing the number of flooded impoundments as more waterfowl arrive in the wintering grounds (Frederickson and Taylor 2007). Ensuring the ability of river overflow events to inundate extensive area of unmanaged lands, thereby increasing resource availability, is important to maintain the ability of the LMAV to support mallard mass gains during winter. Other practices to improve late-winter food resource availability include incentivizing farmers to flood and leave crop stubble post-harvest for the duration of the fall and winter (Anders et al. 2008), purchasing and restoring natural wetlands (Fredrickson and Taylor 2007; Miller et al. 2003), and promoting natural flood regimes within bottomland hardwood forests to avoid tree stress and increase mast productivity (Nelms et al. 2007).

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TABLES

Table 1.1. General locations; sample period; land use types (state owned Wildlife Management Areas (WMA's), Federally owned National Wildlife Refuges (NWRs), private land, and duck processing businesses); and weight scale, body mass correction, and aging methodology of harvested mallards (*Anas platyrhynchos)* within the Lower Mississippi Alluvial Valley during study years 1979-1983, 1990-1991, 1999-2004, 2015-2017, 2019-2021.

Sample Years	1979-1983	1990-1991	1999-2004	2015-2017	2019-2021
States Sampled	Mississippi	Arkansas	Arkansas	Arkansas	Arkansas
Duration of Hunting Seasons Sampled	December & January	November – February	December & January	*2015-2016:* December & January *2016-2017:* November – January	November – February
Source of Ducks	National Wildlife Refuges, National Forest, Private Land	Wildlife Management Areas and National Wildlife Refuges	Duck Processing Businesses	Private Land	Wildlife Management Areas and National Wildlife Refuges, National Forest, Private Land
Weight Measurement Device	Spring Scale (nearest 10g)	Spring Scale (nearest g)	Battery Powered Electronic Balance (nearest g)	Spring Scale (nearest 10g)	Battery Powered Electronic Balance (nearest g)
Food Removed Before Weighing?	Yes	No	Yes	No	No
If No, How Food Was Corrected?	N/A	Subtracted weight of esophageal contents from raw mass of bird	N/A	N/A	All birds that had undigested esophageal contents were removed from analysis

Table 2.1. Average body mass measurements (rounded to nearest gram; plus/minus standard error (SE) rounded to nearest integer) and sample size from harvested mallards (*Anas platyrhynchos)* within the Lower Mississippi Alluvial Valley among hunting seasons within years 1979-1983, 1990-1991, 1999-2004, 2015-2017, 2019-2021.

	Males						**Females**					
	Adults			**Juveniles**			**Adults**			**Juveniles**		
Year	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*	$\bar{x}$	SE	*n*
1979-1980	1262	7	207	1220	12	71	1114	13	52	1088	12	64
1980-1981	1205	5	459	1134	13	64	1051	7	182	1001	10	82
1981-1982	1240	5	390	1144	25	18	1112	9	122	1004	21	26
1982-1983	1319	6	253	1239	24	16	1145	10	97	1101	26	16
1990-1991	1205	26	20	1034	9	2	1168	20	31	1068	36	13
1999-2000	1262	8	168	1173	9	118	1111	11	109	1029	8	122
2000-2001	1261	11	116	1205	8	111	1109	12	66	1053	9	115
2001-2002	1282	11	87	1216	14	41	1181	15	45	1070	11	76
2002-2003	1288	12	76	1228	13	48	1155	14	49	1082	13	49
2003-2004	1280	12	86	1209	13	55	1136	18	26	1037	10	74
2015-2016	1299	21	29	1253	21	29	1103	36	9	1141	27	10
2016-2017	1167	14	59	1164	19	24	1057	37	13	989	33	14
2019-2020	1299	5	391	1253	5	455	1158	12	53	1095	7	219
2020-2021	1331	5	424	1290	5	453	1181	12	58	1140	7	245

Table 3.1. Average % increase in body mass per decade and from 1979-2021, as well as results from general linear mixed effects models evaluating the influence of Year, Day, Cumulative Rainfall, Gage Height, and Weather Severity Index (WSI) on the body mass of mallards (*Anas platyrhynchos*) from 1979 – 2021 in the Lower Mississippi Alluvial Valley of Arkansas and Mississippi.

Age-Sex	Variable	*P*	F	β (95% CI)	Average % Increase in Body Mass
Adult Males	Year *	< 0.01	$F_{1,45} = 19.42$	1.68 (0.94 – 2.43)	From 1979-2021: 5.6 Per Decade: 1.2
	Day *	< 0.01	$F_{1,2127} = 40.23$	-0.81 (-1.06 – -0.55)	
	Cumulative Rainfall *	< 0.01	$F_{1,2453} = 11.75$	3.09 (1.33 – 4.86)	
	Gage Height	0.084	$F_{1,1624} = 2.98$	2.14 (-0.27 – 4.61)	
Juvenile Males	Year *	< 0.01	$F_{1,32} = 46.73$	2.91 (2.08 – 3.76)	From 1979-2021: 7.6 Per Decade: 1.9
	Day *	0.020	$F_{1,1261} = 5.42$	-0.39 (-0.72 – -0.06)	
	Cumulative Rainfall *	0.039	$F_{1,1094} = 4.29$	2.53 (0.14 – 4.90)	
Adult Females	Year *	< 0.01	$F_{1,24} = 11.09$	1.41 (0.59 – 2.22)	From 1979-2021: 6.9 Per Decade: 1.5
	Day *	< 0.01	$F_{1,700} = 27.85$	-1.07 (-1.46 – -0.64)	
	Gage Height *	< 0.01	$F_{1,305} = 23.39$	9.65 (5.81 – 13.53)	
Juvenile Females	Year *	< 0.01	$F_{1,34} = 16.40$	2.16 (1.13 – 3.21)	From 1979-2021: 7.6 Per Decade: 1.5
	Cumulative Rainfall *	0.032	$F_{1,999} = 4.61$	3.02 (0.30 – 5.84)	
	Gage Height *	< 0.01	$F_{1,722} = 20.15$	9.32 (5.24 – 13.36)	
	WSI	0.066	$F_{1,1059} = 3.39$	-1.62 (-3.36 – 0.09)	

FIGURES

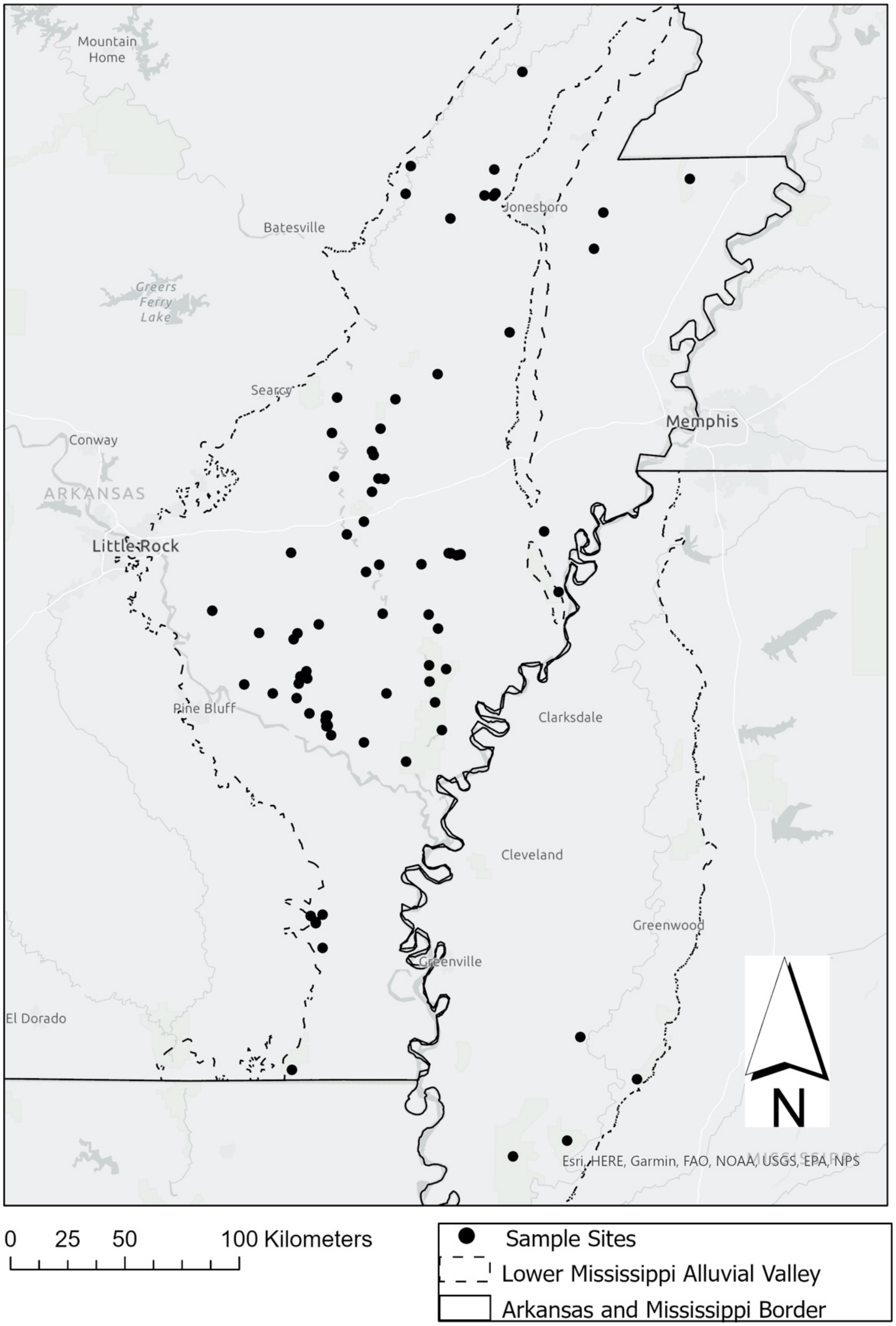

Figure 1.1. Map of field sites where body mass measurements were taken from hunter-harvested mallards (*Anas platyrhynchos*) across the Lower Mississippi Alluvial Valley of Arkansas and Mississippi from 1979-2021.

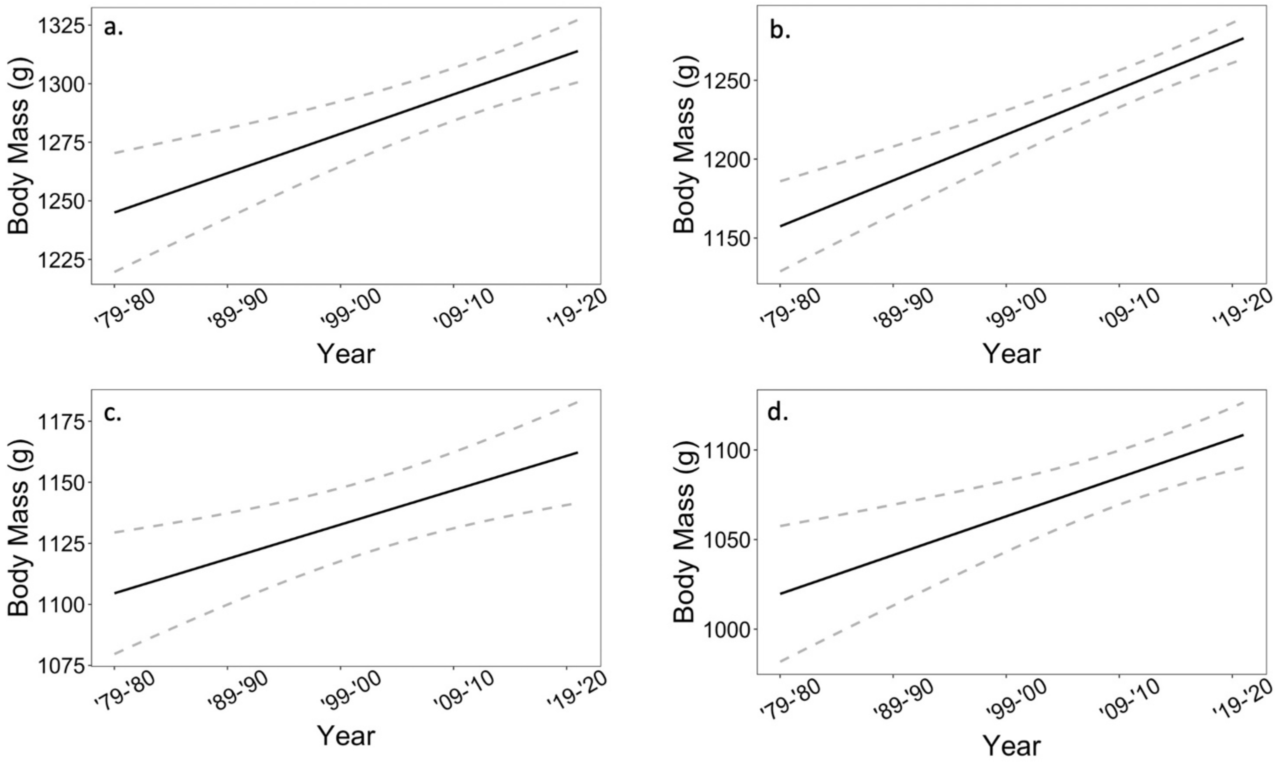

Figure 2.1. Predicted relationship of adult male (a), juvenile male (b), adult female (c), and juvenile female (d) mallard (*Anas platyrhynchos*) body mass with Year within the Lower Mississippi Alluvial Valley from 1979-2021. Solid black lines refer to estimated mean body mass and gray bands are upper and lower limits of the 95% CI.

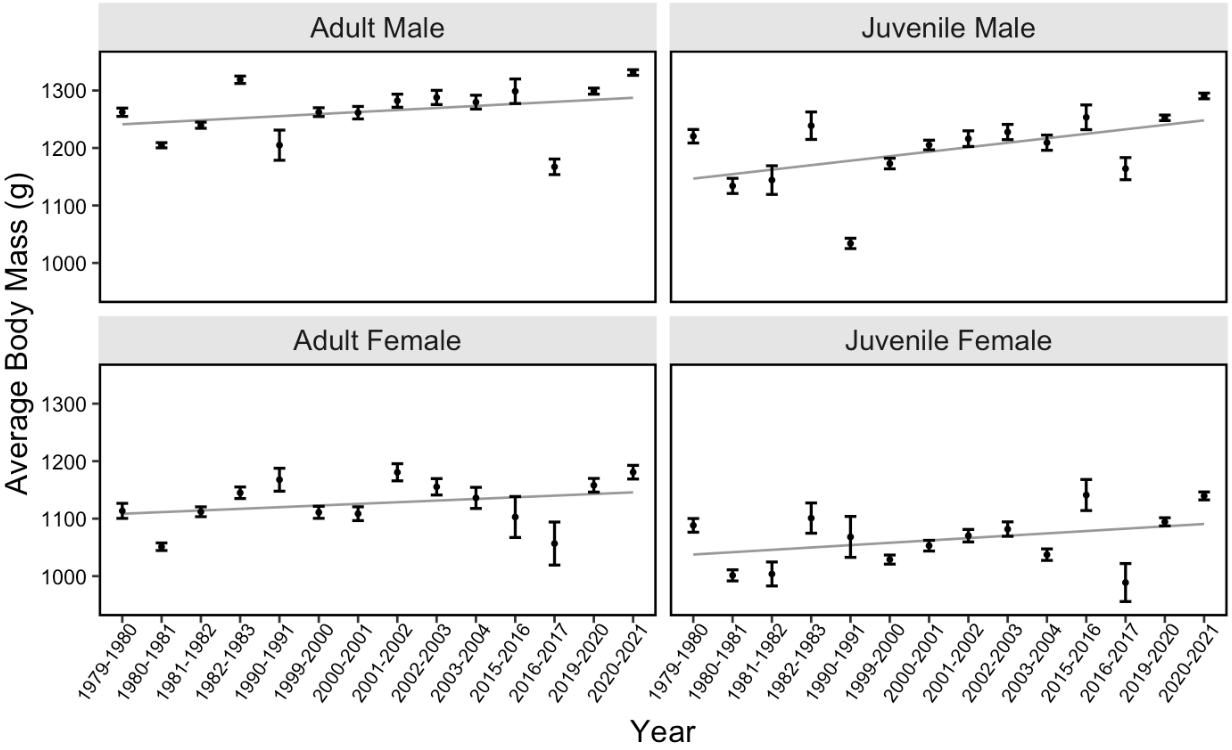

Figure 3.1. Average annual mallard (*Anas platyrhynchos*) body mass (points) with 95 % CI (error bars) among adult males, juvenile males, adult females, and juvenile females collected during waterfowl hunting seasons within the Lower Mississippi Alluvial Valley of Arkansas and Mississippi during 1979-1980 through 1982-1983, 1990-1991, 1999-2000 through 2003-2004, 2015-2016, 2016-2017, 2019-2020, and 2020-2021 (these graphs ignore years for which data was not collected).

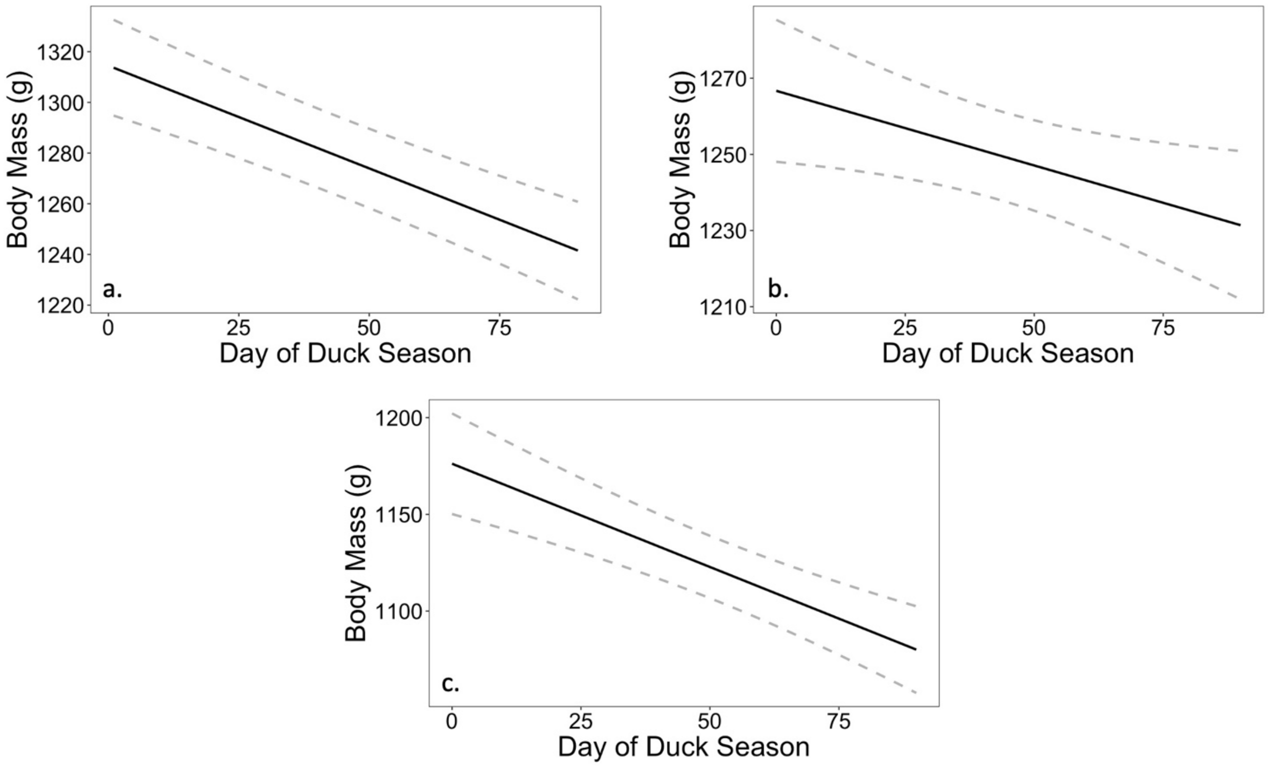

Figure 4.1. Predicted relationship of adult male (a), juvenile male (b), and adult female (c) mallard (*Anas platyrhynchos*) body mass with Day of Hunting Season within the Lower Mississippi Alluvial Valley from 1979-2021. Solid black lines refer to estimated mean body mass and gray bands are upper and lower limits of the 95% CI.

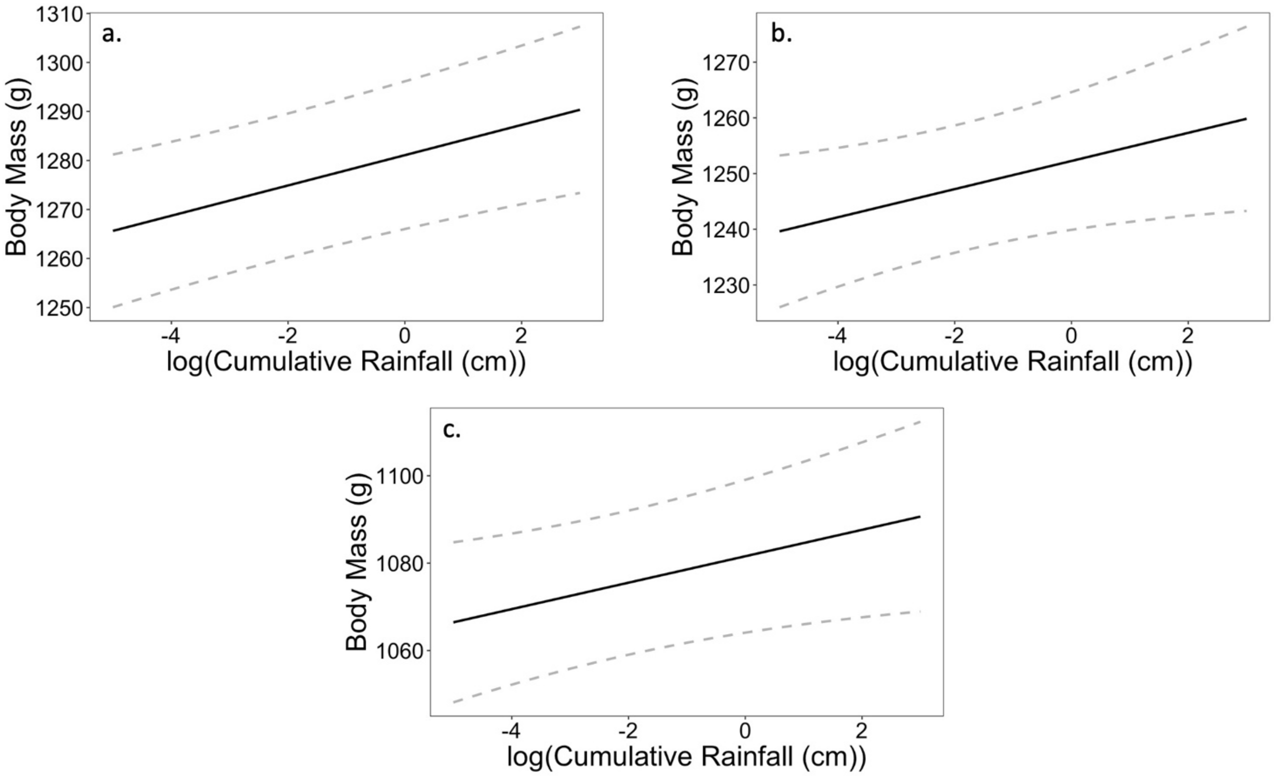

Figure 5.1. Predicted relationship of adult male (a), juvenile male (b), and juvenile female (c) mallard (*Anas platyrhynchos*) body mass with 3-Day Cumulative Rainfall previous to mallard harvest within the Lower Mississippi Alluvial Valley from 1979-2021. Solid black lines refer to estimated mean body mass and gray bands are upper and lower limits of the 95% CI.

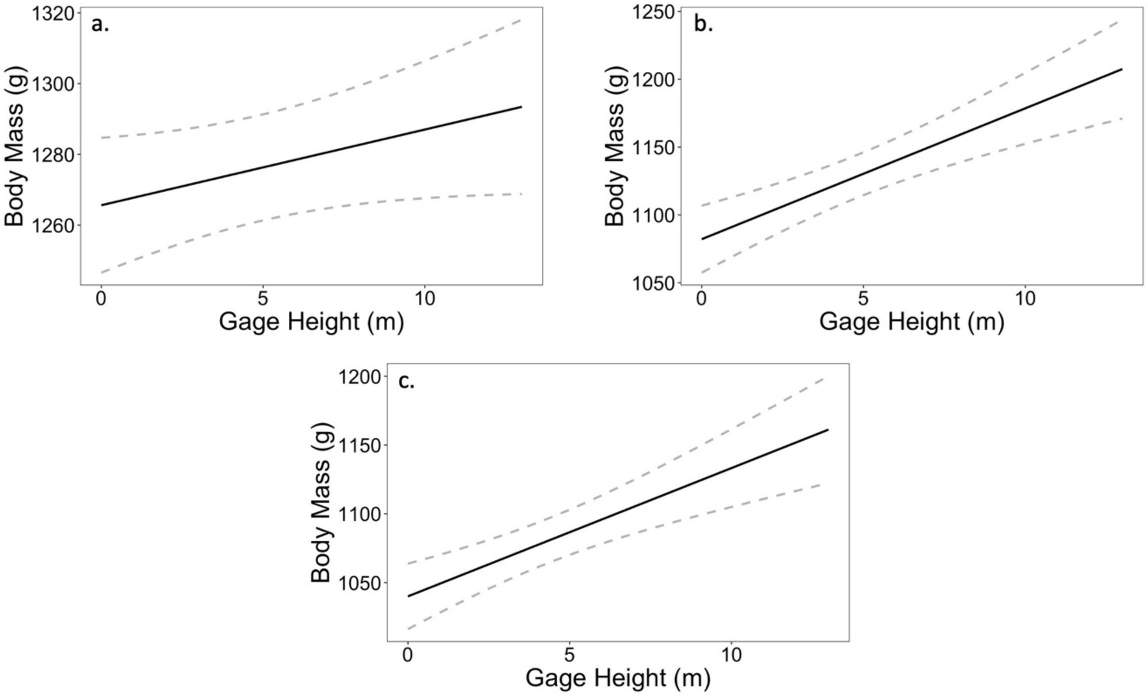

Figure 6.1. Predicted relationship of adult male (a), adult female (b), and juvenile female (c) mallard (*Anas platyrhynchos*) body mass with River Gage Height within the Lower Mississippi Alluvial Valley from 1979-2021. Solid black lines refer to estimated mean body mass and gray bands are upper and lower limits of the 95% CI.

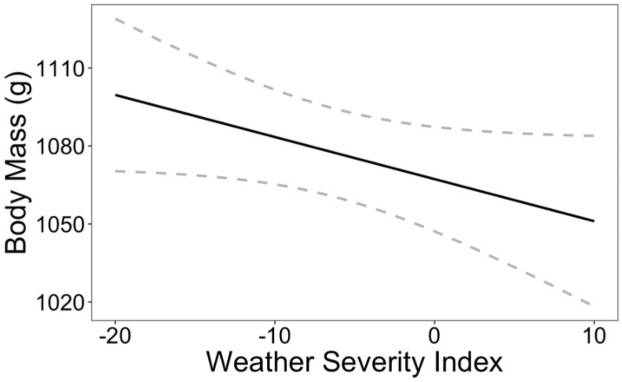

Figure 7.1. Predicted relationship of juvenile female mallard (*Anas platyrhynchos*) body mass with Weather Severity Index (WSI) within the Lower Mississippi Alluvial Valley from 1979-2021. Solid black lines refer to estimated mean body mass and gray bands are upper and lower limits of the 95% CI.

APPENDIX A: CO-AUTHORSHIP MEMO

UNIVERSITY OF ARKANSAS

J. William Fulbright College of Arts and Sciences
Department of Biological Sciences

November 11, 2021

I'm writing this memo in support of John Veon's thesis Chapter 1 entitled "WINTER MALLARD (ANAS PLATYRHYNCHOS) BODY MASS TRENDS FROM 1979 – 2021 IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY" This thesis chapter is intended for peer-reviewed publication with 8 co-authors including myself, Luke W. Naylor, Dr. Kenneth J. Reinecke, Dr. Brad C. Dabbert, Dr. Dean W. Demarest, Dr. Kevin M. Hartke, and Dr. David G. Krementz. As John Veon's major advisor, I confirm that John will be the first author and has conducted greater than 51% of the work for this paper.

Thank you

Brett DeGregorio

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CHAPTER II

EFFECTS OF LANDSCAPE COMPOSITION ON WINTER MALLARD (*ANAS PLATYRHYNCHOS*) BODY CONDITION IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY OF ARKANSAS

John T. Veon, David G. Krementz, Luke W. Naylor, and Brett A. DeGregorio

ABSTRACT

Overwintering waterfowl with a high body condition index are more likely to survive the winter, complete important life cycle events, and have increased productivity during the following breeding season. Body condition index in waterfowl should reflect the food and resting resources available to them locally. Some researchers suggest that increased surface area of water and low areas of human disturbance promote better body condition within waterfowl. Wetland habitat like woody wetlands, herbaceous wetlands, and open water may also promote better waterfowl body condition because they offer places to forage, rest, socially interact, and avoid disturbance. Agricultural habitat, like flooded rice, can improve lipid stores in waterfowl and could be beneficial to body condition. However, flooded soybeans may negatively impact body condition because they serve little nutrient value to ducks. Here, we analyze the effects of landscape composition on mallard (*Anas platyrhynchos*) body condition using a mass by wing length index (BCI) within the Lower Mississippi Alluvial Valley of Arkansas. We measured hunter-harvested mallards from hunting clubs and state and federal public duck hunting areas during the 2019-2020 and 2020-2021 Arkansas duck hunting seasons. We found that mallards collected from areas with high proportions of water cover, woody wetlands, and open water within a 30-km radius had higher BCI. Conversely, we found that mallards collected from areas with higher proportions of herbaceous wetlands or human disturbance had lower BCI. Management entities that can maintain water levels for waterfowl to efficiently access food resources, while providing ample habitat that allows for resting, loafing, and other life cycle events free of human disturbance, will most likely increase BCI among mallards.

INTRODUCTION

Most North American waterfowl overwinter in southern North America before migrating back to breeding grounds in the northern U.S. and Canada. These species face the challenge of needing to maintain or increase their body mass during an environmentally difficult winter period (Loesch et al. 1992). During the winter, ducks must find and occupy areas that provide a number of resources with possibly the most important being access to abundant and nutritious food. Waterfowl that can meet energetic needs will most likely have a better body condition (Delnicki and Reinecke 1986; Owen and Cook 1977; Reinecke et al. 1988, 1989). Body condition can be defined as the fitness of an individual based on mass associated with energy reserves (Schulte-Hostedde et al. 2005). This fitness score is usually developed by an index that corrects raw body mass using a structural size component. Thus, a resulting higher score indicates higher fitness, and a lower score indicates lower fitness (Johnson et al. 1985; Harder and Kirkpatrick 1994; Schulte-Hostedde et al. 2005).

Body condition, as a function of mass and structural components, has been related to several factors that are linked to waterfowl fitness. For example, researchers have shown that early winter body condition can influence survival (Bergan and Smith 1993). Furthermore, waterfowl in poorer body condition are more likely to be infected by blood parasites, thus, potentially having an affect survival or productivity (Meixwell at al. 2016; Shutler et al. 1999). Individuals with lower body mass (which may result in a lower body condition) may have delayed courtship and breeding pair formation (Hepp 1986; Miller 1985). Additionally, better winter body condition in waterfowl increases the chances of survival and level of productivity during the following breeding season (Devries et al. 2008; Fowler et al. 2020; Heitmeyer and Fredrickson 1981; Warren et al. 2014). A better body condition can also shorten the timing of spring migration in migratory birds (Dujins et al. 2017), allowing migrants to reach the breeding grounds sooner, potentially increasing reproductive success (Elmberg et al. 2005; Rohwer et al. 1992).

One of the fundamental philosophies of waterfowl management is manipulating landcover to maximize the amount of available food on the landscape, while regulating human activity to reduce unnecessary energy use (Fredrickson and Taylor 2007; Reinecke et al. 1989). Therefore, conservation agencies expend substantial time and financial resources annually to manage overwintering waterfowl habitat to ensure adequate foraging and resting resources. Waterfowl using these managed habitats should assimilate more energy, resulting in a higher body condition index (BCI) value. The Lower Mississippi Alluvial Valley (LMAV) is one of the largest wintering areas for waterfowl in North America (Bellrose et al. 1976; Reinecke et al. 1989) and wintering ducks in this region forage and/or rest in woody wetlands such as flooded bottomland hardwood forests, herbaceous wetlands such as moist-soil impoundments, open water lakes, flooded agricultural crops, and waterfowl refuges with generally low levels of human disturbance (Reinecke et al. 1989). Woody wetlands can provide waterfowl with fatty metabolites in the form of acorns (Allen 1980; Dabbert and Martin 2000; Heitmeyer and Fredrickson 1990; Miller et al. 2003; Reinecke et al. 1989) as well as macroinvertebrates that provide valuable proteins (Foth et al. 2014; Fredrickson and Heitmeyer 1988; Krapu and Reinecke 1992; Fredrickson and Batema 1992). These forested habitats also offer a place for waterfowl to roost and potentially avoid hunting pressure and other predation risks which contributes toward energy conservation (Reinecke et al. 1989). Herbaceous wetlands provide waterfowl with a variety of vegetative matter and seeds that contain essential vitamins, minerals, and amino acids that are found in low quantities in other habitats (Checkett et al. 2002).

Herbaceous wetlands also provide waterfowl with aquatic invertebrates for dietary proteins (Fredrickson and Taylor 1982, Anderson and Smith 1999, Gray et al. 1999). Open water areas are favored by many waterfowl as they offer good visibility for locating predators, shallow water shorelines for feeding, and water for resting (Chabreck et al. 1989; Rave 1987; Tamisier 1978). Flooded agricultural fields containing rice, although not as nutrient diverse as herbaceous wetland vegetation and seeds, generally provide high energy per unit mass (Checkett et al. 2002; Kaminski et al. 2003). However, crops like soybeans decompose underwater rapidly, can cause fatal digestive issues, and contain digestive inhibitors that can reduce the amount of protein and other nutrient uptake by waterfowl (Ringleman 1990). Areas of high human disturbance can cause waterfowl to alter their behavior (Burger and Gochfeld 1998; Pease et al. 2005; Riddington et al. 1996), thus wasting energy and impacting lipid reserves (Knapton et al. 2000; Taylor et al. 2010). For this reason, conservation agencies also manage waterfowl refuges, which are habitats closed to human access during the winter period (Bellrose 1954; Madsen 2004). Waterfowl overwintering in the LMAV likely use a combination of these wetland habitat types throughout the course of the winter to meet nutritional demands required by different life cycle events (e.g., pair formation, molting).

The mallard (*Anas platyrhynchos*) is the most abundant waterfowl species overwintering in the LMAV (Bellrose 1976). Aside from being a popular resource among recreational hunters, mallards serve as a focal species of waterfowl management because their response to management is likely indicative of how other dabbling duck species respond (Gunnarsson et al. 2006; Newbold and Eadie 2004; Nichols et al. 2007; Reinecke et al. 1989). Despite management efforts to ensure sufficient food resources are provided to sustain a large and healthy population of mallards, the LMAV is currently estimated to not provide food for waterfowl at goal levels

(LMVJV 2015). In addition, food resources for mallards are unevenly distributed across the LMAV. Thus, the region of the LMAV in which waterfowl choose to winter and the landscape composition in those areas likely influences their BCI.

Here, we assess the relationship of a body mass by wing length BCI in hunter harvested mallards with landscape composition across the LMAV of Arkansas within two winter periods. Our overall goal is to explore landscape cover within the vicinity of each harvest site that promotes high BCI in mallards, as well as identify areas within the Arkansas LMAV that will promote better body condition among waterfowl. We predict BCI to be highest in areas with abundant woody wetlands, herbaceous wetlands, and overall water cover because these are typically associated with traditional mallard foraging habitats and are the target of management (Checkett et al. 2002; Fredrickson and Heitmeyer 1988; Fredrickson and Taylor 1982; Heitmeyer and Fredrickson 1990; Reinecke et al 1989). We also predict that mallards harvested from areas with a high proportion of rice fields will be in higher body condition because these foods are high in energy (Checkett et al. 2002; Kaminski et al. 2003). We also predict that the presence of open water areas that allow waterfowl to rest and avoid stress will also contribute to higher BCI (Chabreck et al. 1989; Reinecke et al. 1989). Finally, we predict that a high proportion of land cover consisting of low nutrition crops (e.g., soybean fields) or in areas with high levels of human disturbance will result in birds with lower BCI (Madsen 2004; Ringleman 1990).

METHODS

Study Area

The Lower Mississippi Alluvial Valley (LMAV) spans 26.7 million acres along the upper Midwest to southern portions of the Mississippi Flyway. Our study area spanned the entirety of the LMAV of Arkansas, which makes up 34% of the entire floodplain (Oswalt 2013) (Figure

1.2). Because the LMAV of Arkansas is a point at which many rivers converge, it attracts some of the highest densities of overwintering waterfowl in North America (Bellrose et al. 1976). Additionally, the LMAV of Arkansas contains flooded bottomland hardwood forests, which waterfowl use for food resources and other important life cycle events (Reinecke et al. 1989). The large density of rivers also provides the LMAV with rich alluvial soil which makes the area productive for agriculture. Waterfowl regularly forage in these agricultural fields if they flood during the winter (National Fish and Wildlife Foundation 2019; Nelms et al. 2007).

Body Condition Measurements

We collected hunter-killed mallard body measurements from private duck hunting clubs as well as public duck hunting areas. We focused on collecting body measurements from harvested ducks across as wide of a geographic range as possible within the LMAV, particularly during the second year of the study where we focused on collecting measurements from areas not sampled within the previous year. For each harvested mallard, we collected body mass measured to the nearest gram using an electronic scale. We used an ornithological wing ruler to measure wing length to the nearest millimeter (Carney 1992). Additionally, we aged and sexed each bird using plumage dimorphism and feather morphology characteristics (Carney 1992). We extracted the residuals from a mass by wing length regression separately for each age-sex class to calculate BCI for each bird. Although using body condition indices made up of structural components such as mass and wing length have received criticism (e.g., Green et al. 2001; Labocha and Hayes 2012; Schamber et al. 2009), indices using mass and wing length in migratory birds has been shown to be a reliable indicator of lipid and protein reserves (Johnson et al.1985; Whyte and Bolen 1984), winter survival (Bergan and Smith 1993), productivity (Devries et al. 2008), and locomotive performance (Dujins et al. 2017). Some researchers have also found that the use of a residual body condition index is the most reliable compared to alternative indices (Schulte-Hostedded et al. 2005).

Landscape Composition

We extracted landscape composition and human disturbance variables within a 30-km radius of each known harvest location. A 30-km radius buffer was chosen because research suggests that any waterfowl movement within 30-km is considered a local scale movement, while movement >30-km is considered a migration event (Beatty et al. 2014) and most mallards even have smaller home ranges within a 30-km radius (Allen 1987; H. Hagy, US Fish and Wildlife Service, personal communication). Furthermore, *a priori* analyses using data from telemetry marked mallards in Beatty et al. 2014 indicate that only 1.44% of mallards that winter in Arkansas will move outside of a 30-km radius before the spring (Beatty, unpublished data). Therefore, we had a high degree of certainty that a larger proportion of mallards used for our study had utilized the habitat within their respective location buffers before harvest. Additionally, because most waterfowl require anywhere from 4-72 hours to assimilate energy from the food they ingest (Charalambidou et al. 2005), we also had a high degree of certainty that mallards had assimilated energy from the vicinity of their harvest site at the time of collection; thus, their BCI would reflect recent energy assimilation.

We calculated 8 landcover variables that have been shown to, or predicted to, influence waterfowl body mass or BCI (e.g., Heitmeyer and Fredrickson 1990; Reinecke et al. 1989; Ringleman 1990; Taylor et al. 2010) and that were related to mallard foraging, resting, or human disturbance. The variables we calculated for each mallard harvest point were percentage of total water cover, woody wetlands, herbaceous wetlands, open water areas, flooded rice fields, flooded soybean fields, area of human disturbance, and percent area of lands managed by state or federal management agencies. We calculated percentage of total water cover using the Google Earth Engine Water Layer (GEE Water Layer 2019 & 2020, produced by the Intermountain West Joint Venture and Ducks Unlimited). We calculated the percent of woody wetlands, herbaceous wetlands, and open water using the National Land Cover Database Landcover Layer (NLCD 2019, produced by United States Geological Survey). We first overlayed the NLCD layer with the GEE Water Layer to ensure that we only included wetlands that were flooded and thus available to foraging ducks. We defined percent human disturbance as the combination of road density and development that was most likely to converge with waterfowl habitat. For this reason, we calculated percent human disturbance using "medium" disturbance cells from the Human Impact Avoidance Gap Analysis Project (produced in 2011 by the United States Geological Survey). To calculate the percent area of rice fields and soybean fields within each buffer, we used the United States Department of Agriculture Cropland Data Layer (USDA-CDL 2019 & 2020). However, we first overlayed this layer with the GEE Water Layer to ensure that we only included fields that were flooded during the study period. We chose to focus on rice and soybeans as they occur in large quantities within the LMAV of Arkansas (USDA Arkansas Field Office 2021) and are utilized as food resources by waterfowl. We also calculated the percent of area comprised of managed lands (e.g., state and federally managed) within each buffer using the Protected Areas Database of the U.S. (PAD-US 2.1, produced in 2020 by the United States Geological Survey). However, this layer was also first overlayed with the GEE water layer to ensure managed lands were flooded and accessible to foraging waterfowl. All landscape layers were generated using geographic information system software (ArcGIS Pro 2.8, Esri Inc, Redlands, CA, USA).

Analyses

To explore how landscape composition influenced mallard BCI, we used a linear mixed effects model (LMM). We first checked for collinearity using Pearson's correlation coefficient. Managed lands had a correlation coefficient of 0.78 with woody wetlands, so managed lands were excluded from our models. No other variables were highly correlated (≥ 0.7 correlation), and thus, all other variables were retained for analyses. We used BCI as the response variable and harvest site location as the random factor to control for variation across sites. We used % Total Water Cover, % Rice, % Soybeans, % Woody Wetlands, % Herbaceous Wetlands, % Open Water, and % Disturbance as fixed factors. We log transformed % Total Water Cover, % Soybeans, % Herbaceous Wetlands, % Open Water, and % Disturbance to better meet assumptions of homogeneity of variances. All analyses were conducted using R Computing Software (package lme4 in R Studio 1.2.5042; 2020).

To spatially project our results, we generated a 500 m x 500 m grid across the entirety of the LMAV of Arkansas. Using methods adapted from Lassiter et al. 2021, we then calculated the % landscape composition variable for each grid cell. We then reclassified each grid cell's % landscape composition to corresponding predictions of mallard BCI from the LMM analysis. These steps were completed individually for each statistically significant variable that influenced mallard BCI. Resulting mallard BCI prediction maps were then combined using the Weighted Sum Tool within ArcGIS Pro 2.8, where variables were ranked in the following order with the first receiving the most weight, based on suitability for waterfowl: % Total Water Cover > % Woody Wetlands > % Open Water > % Herbaceous Wetlands = % Human Disturbance (Allen 1987). Although important to waterfowl, herbaceous wetlands were ranked last due to only ~18% of herbaceous wetlands in the LMAV being intensively managed to provide high levels of food resource (B. Elliot, Lower Mississippi Valley Joint Venture, personal communication; NLCD 2019). Because there is limited information on habitat suitability based on human disturbance, % Disturbance was also ranked last.

RESULTS

We measured 2,277 mallards within the LMAV of Arkansas during the 2019-2020 and 2020-2021 duck hunting seasons. Our measurements were from 807 adult males, 902 juvenile males, 107 adult females, and 461 juvenile females. We collected these samples from 47 hunting clubs or other private properties and 26 public hunting areas.

The proportion of landcover within harvest buffers aligned reasonably well with proportion of overall coverage of these landcovers across the LMAV. Among our variables, % Total Water Cover spanned the most area among our harvest-site buffers ($\bar{x}$= 25.45 %, ± 0.13 (SE)) as well as the LMAV ($\bar{x}$ = 26.45, ± 0.53 (SE)). The lowest coverage by a variable within our harvest site buffers ($\bar{x}$ = 0.26 %, ± 0.001 (SE)) and the LMAV ($\bar{x}$ = 0.27, ± 0.002 (SE)) was % Herbaceous Wetlands. In general, all landcover variables we examined occurred in harvest-site buffers at a similar proportion to their availability across the LMAV (Table 1.2).

Mallard BCI was significantly related to % Total Water Cover ($P < 0.01$, $F_{1,69} = 14.44$), % Woody Wetlands ($P < 0.01$, $F_{1,82} = 7.46$), % Herbaceous Wetlands ($P < 0.01$, $F_{1,58} = 12.90$), % Open Water ($P = 0.04$, $F_{1,49} = 4.42$), and % Disturbance ($P < 0.01$, $F_{1,59} = 9.66$). Mallard BCI was positively related to % Total Water Cover ($\beta = 1.66$, CI = 0.82 – 2.47), % Woody Wetlands ($\beta = 0.09$, CI = 0.02 – 0.16), and % Open Water ($\beta = 0.04$, CI = 0.01 – 0.70) such that BCI increased as these variables represented larger proportions of landcover surrounding the harvest location. Mallard BCI was negatively associated with the proportion of Herbaceous Wetlands ($\beta = -1.47$, CI = -2.22 – -0.61) and Disturbance ($\beta = -0.62$, CI = -0.98 – -0.23) surrounding the harvest locations. There was no relationship between BCI and % Rice or % Soybeans ($P > 0.05$) (Table 2.2; Figure 2.2).

DISCUSSION

Mallard BCI is an important predictor of fitness and is likely related to a combination of health, food availability, and stress-free resting sites (Delnicki and Reinecke 1986; Devries et al. 2008; Heitmeyer and Fredrickson 1981; Madsen 2004; Reinecke et al. 1988). We found that mallard body condition (BCI) was highest in areas with a large proportion of water cover, woody wetlands, and open water wetlands and lowest in areas with a high proportion of herbaceous wetland habitat or areas of high human disturbance. Contrary to our predictions, mallard BCI was unrelated to the proportional coverage of flooded rice or soybeans. These results indicate the importance of increased water cover, open water habitat, and woody wetland habitat, as well as the mitigation of human disturbance to body condition in mallards (Reinecke et al. 1988, 1989; Chabreck et al. 1989; Pease et al. 2005). Thus, understanding where waterfowl are meeting their resource needs can inform management practices, especially because bioenergetics modeling indicates that Arkansas does not currently provide waterfowl food resources at goal levels (LMVJV 2015).

Mallards are dabbling ducks and forage in shallow water where they eat seeds, hard and soft mast, agricultural waste grain, and invertebrates. As available water on the landscape increases (due to rain or flooding), foraging areas open to mallards because fields begin to hold standing water and the footprint of wetlands expand. Numerous studies support our results that mallard BCI or body mass increases with increasing water availability (Fredrickson and Taylor 2007; Guillemain et al. 2000; Reinecke et al. 1988). For instance, Delnicki and Reinecke (1986) found that mallards wintering in the LMAV were heavier (i.e., better condition) during wetter years than drier years, most likely the result of increased access to food resources. Similarly, Heitmeyer and Fredrickson (1981) found that winter precipitation was positively correlated with mallard productivity in the spring, suggesting that mallards were arriving in a better condition to engage in breeding behaviors.

Interestingly, our results showed that mallard BCI also increased when open wetlands such as large lakes and reservoirs were available within the surrounding landscape. Typically, these large and deep wetlands are not considered to be productive foraging grounds for dabbling ducks (Behney 2020). Although there is some limited food value to ducks along the shoreline, open water habitats likely contribute to high mallard fitness and BCI by offering locations to roost and loaf that are relatively free from human disturbance and predators (Reinecke et al. 1989). Some of the areas within Arkansas where mallards are predicted to have the highest BCI are associated with large open wetlands (e.g., reservoirs) on Big Lake National Wildlife Refuge/Wildlife Management Area, as well as some open water areas along the Cache River National Wildlife Refuge (Figure 3.2). These areas are likely beneficial to resting mallards because they provide a combination of open water and limited human disturbance, most likely from lower levels of development and being on wildlife refuges.

Arkansas is one of the most popular locations for waterfowl hunting, especially for the mallard hunting opportunities provided by its historically expansive bottomland hardwood forests (Guttery and Ezell 2006; Raftovich et al. 2021). Thus, it is unsurprising that individuals occupying areas with a high proportion of bottomland hardwoods were in better body condition than those with limited extent of these flooded forests (Bellrose 1976). Flooded bottomland hardwood forests provide both foraging and resting opportunities for mallards. They provide waterfowl with high energy mast in the form of acorns (Allen 1980; Dabbert and Martin 2000;

Heitmeyer and Fredrickson 1990; Miller et al. 2003: Reinecke et al. 1989) as well as valuable proteins and amino acids from macroinvertebrates harbored in the leaf litter and soil (Foth et al. 2014; Fredrickson and Heitmeyer 1988; Krapu and Reinecke 1992; Fredrickson and Batema 1992). Woody wetland complexes are also important to waterfowl during life cycle events beyond foraging. For example, woody wetlands offer mating pairs of mallards a place to avoid stress caused by courting parties that could occur on more open habitat (Heitmeyer 1985). Woody wetlands also offer waterfowl a place to roost and avoid predators (Fredrickson and Batema 1992). Thus, waterfowl occupying woody wetlands may be least likely to engage in energetically costly behaviors (e.g., excessively flying to avoid disturbance or predators, or to search for food), which may result in better body condition. Our results indicate that mallard BCI is likely high in areas with high densities of bottomland hardwood forests (Figure 3.2). It should be noted that bottomland hardwood forests can, at times, be heavily hunted throughout the Arkansas duck hunting season. These disturbances could potentially decrease mallard BCI. We suggest two possible reasons why mallards residing in or near these heavily hunted compounds may be of a better body condition. First, forested systems offer more cover, thus making it easier for ducks to avoid predators and lowering energetically costly vigilant behaviors (e.g., flying, swimming) (Fredrickson and Batema 1992; Knapton et al. 2000; Reinecke et al. 1989; Taylor et al. 2010). Second, ducks could be maintaining proper energy levels by day roosting away from these compounds when hunting pressure is high (typically in the morning) and returning to use woody wetland habitat in the afternoon, evening, and/or nighttime (Lancaster et al. 2015; Shirkey et al. 2020).

Herbaceous wetlands, some of which are moist-soil units, can offer waterfowl a wide variety of seeds and vegetative matter, as well as a variety of aquatic invertebrates that are valuable to waterfowl as a food resource (Anderson and Smith 1999; Checkett et al. 2002; Fredrickson and Taylor 1982; Gray et al. 1999). However, our results did not support our prediction that mallard BCI would increase as herbaceous wetland landcover increased. It is possible that our results are biased towards unmanaged herbaceous wetlands as most of the herbaceous wetlands in the region are not intensively managed for waterfowl (~ 82%) for food resources and may provide little food value to a duck (Reinecke et al 1989; B. Elliot, Lower Mississippi Valley Joint Venture, personal communication). Herbaceous wetlands that are not heavily managed by water manipulation and other management techniques could decrease in food resource productivity for waterfowl (Allen 1987; Reinecke et al. 1989), thus potentially resulting in lower BCI among nearby mallards. Additionally, most herbaceous wetlands are relatively small as compared to tracts of woody wetlands and open water wetlands, which could contribute to a greater degree of disturbance from hunters or other visitors (Fredrickson and Taylor 1982; Madsen 2004; Pease et al. 2005; Reinecke et al. 1989). As a result, disturbance could lead to unnecessary energy use by waterfowl, thus lowering BCI (Knapton et al. 2000; Taylor et al. 2010). Although we did not investigate the effects of hunting pressure disturbance on mallard BCI, our results did indicate that human disturbance in the form of road density and human infrastructure was negatively correlated with mallard BCI. Additionally, our predicted map of BCI shows that ducks harvested from or near areas of development are predicted to be in poor body condition (Figure 3.2).

Finally, we did not see changes in mallard BCI with changes in percent buffer of rice or soybeans despite our predictions that rice would be positively associated with BCI due to its high energy value and that soybeans would be negatively associated with BCI due to its low nutritional value (Checkett et al. 2002; Kaminski et al. 2003; Ringleman 1990). This can most likely be explained by changing agricultural practices such as planting earlier maturing rice variants, stripper-header harvesting, and fall tillage, all of which reduce the amount of actual waste rice present on the ground for ducks upon arrival to the wintering grounds (Anders et al. 2008). Once the remaining waste rice is inundated with water on the ground, ducks and other waterfowl may continue to reduce this resource over time. Crops like soybeans also degrade quickly compared to other natural seeds, thus, reducing availability further. For example, soybeans have been found to degrade the quickest among most agricultural grains, losing 1% of energy a day while flooded (Fredrickson and Reid 1988). Therefore, there may be an uneven distribution or actual availability in rice and soybeans among agricultural fields within our harvest site buffers. Although we selected rice and soybean cells that had at least 10% water cover, our water layer considers the presence of all water on the landscape during the winter (early Nov-early Feb). It is possible that the degree of flooding among crop fields could be highly variable across time (e.g., lose all water due to periods of drought, or become completely inundated due to controlled or natural flooding events). Thus, compared to natural wetlands, agricultural fields likely provide variable food resources that rapidly decline across the winter period.

It should be recognized that our results are purely correlative and not empirical. We only analyzed the relationship of landscape composition and mallard BCI but did not experimentally test what specific factors among the landscape influence changes in mallard BCI. It is also assumed that the 30-km buffer represents the area within which mallards have been assimilating energy from. However, it is possible ducks were moving beyond these buffers. Finally, we assume that the condition of the mallards we sampled are reflective of the quality of food resources within their respective buffer areas. Yet, our measurements ignore other ecological phenomena that could impact mallard BCI (e.g., density dependence, competition, etc.). Therefore, future studies that investigate specific factors within different habitat types that may influence mallard BCI may help to better understand the trends observed in our findings.

Management Implications

Our results indicate that mallard BCI is related to the availability of both foraging habitat as well as roosting, and/or loafing habitat relatively free from human disturbance. This highlights the need to protect and restore the once extensive bottomland hardwood forests that occurred in this region. Proper water management techniques across the landscape, if employed, could allow waterfowl to access food resources more efficiently. However, water levels in habitat that is sensitive to prolonged inundation, such as greentree reservoirs, should be monitored closely to protect the long-term health of these forests. In addition to foraging areas, mallards benefit from the presence of open water habitat. Although not as food dense as other habitats used by waterfowl, open water areas provide locations for roosting, loafing, and social interactions that are valuable to survival and reproduction. Additionally, our results may aid in locating areas in need of management efforts to improve mallard BCI.

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TABLES

Table 1.2. Average % coverage of Total Water, Rice, Soybean, Woody Wetlands, Herbaceous Wetlands, Open Water, and Disturbance (plus/minus standard error (SE)) with 30-km buffers surrounding all mallard (*Anas platrhynchos*) harvest locations and within the Arkansas portion of the Lower Mississippi Alluvial Valley (LMAV) during duck hunting seasons 2019-2020 and 2020-2021,

	30-km Buffer		**LMAV**	
Variable	$\bar{x}$	SE	$\bar{x}$	SE
% Total Water	25.17	0.60	26.45	0.53
% Rice	5.20	0.30	5.11	0.14
% Soybean	4.37	0.28	6.77	0.34
% Woody Wetlands	6.75	0.24	6.13	0.5
% Herbaceous Wetlands	0.26	0.01	0.27	0.002
% Open Water	2.57	0.16	2.91	0.03
% Disturbance	0.52	0.03	0.59	0

Table 2.2. Results from linear mixed effects model (LMM) evaluating the influence of % Total Water, % Rice, % Soybean, % Woody Wetlands, % Herbaceous Wetlands, % Open Water, and % Disturbance on body condition index (BCI) of mallards (*Anas platyrhynchos*) during duck hunting seasons 2019-2020 and 2020-2021 in the Lower Mississippi Alluvial Valley of Arkansas ("*" denotes a significant effect on mallard BCI).

Variable	*P*	F	β	95% CI
% Total Water *	< 0.01	$F_{1,69} = 14.44$	1.66	0.82 – 2.47
% Rice	0.08	$F_{1,63} = 3.12$	-0.06	-0.12 – 0.01
% Soybean	0.16	$F_{1,59} = 1.98$	-0.23	-0.53 – 0.07
% Woody Wetlands *	< 0.01	$F_{1,82} = 7.46$	0.09	0.02 – 0.16
% Herbaceous Wetlands *	< 0.01	$F_{1,58} = 12.90$	-1.47	-2.22 – -0.61
% Open Water *	0.04	$F_{1,49} = 4.42$	0.37	0.01 – 0.70
% Disturbance *	< 0.01	$F_{1,59} = 9.66$	-0.62	-0.98 – -0.23

FIGURES

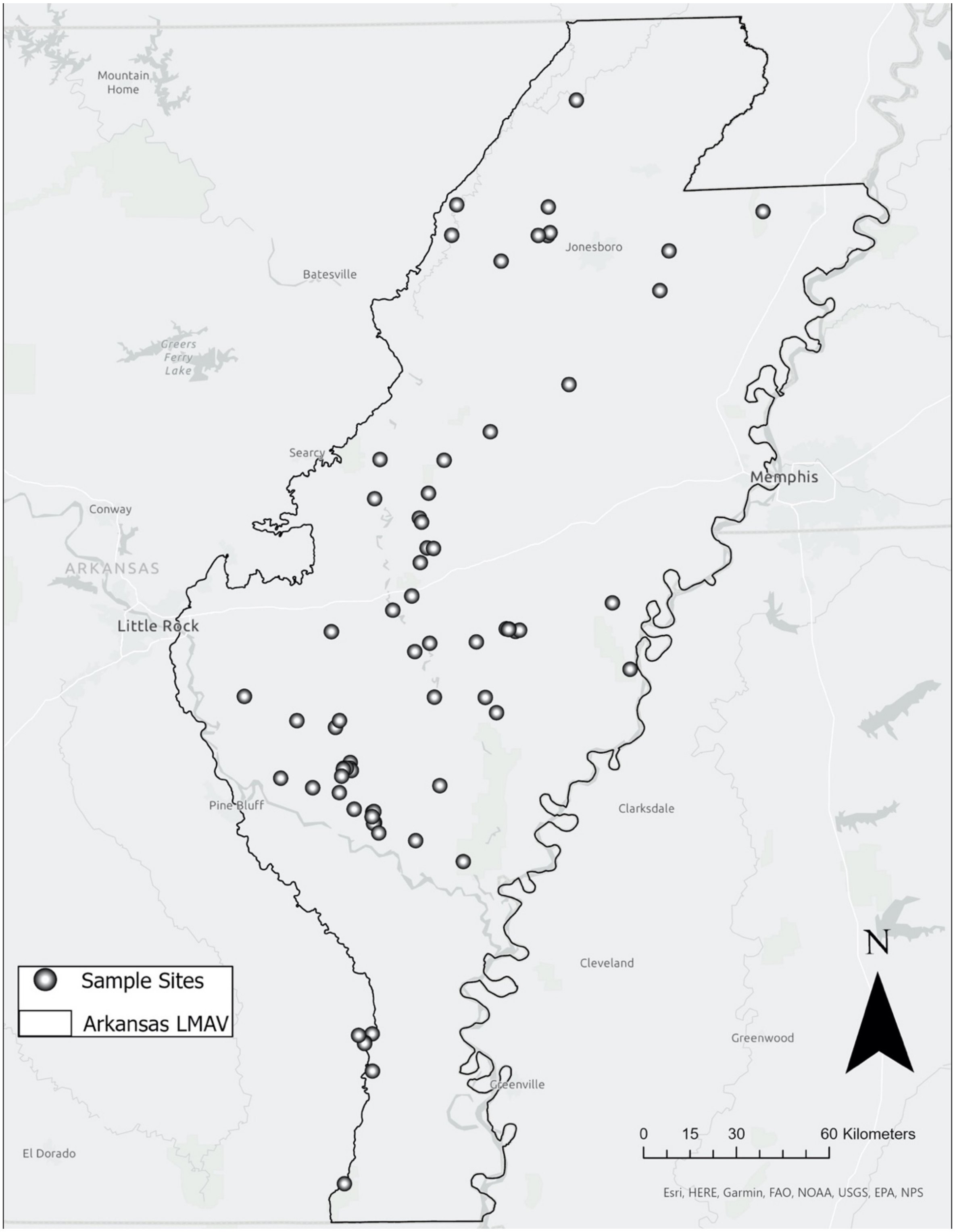


Figure 1.2. Harvest locations of mallards (*Anas platyrhynchos*) across the Lower Mississippi Alluvial Valley of Arkansas during suck hunting seasons 2019-2020 and 2020-2021.

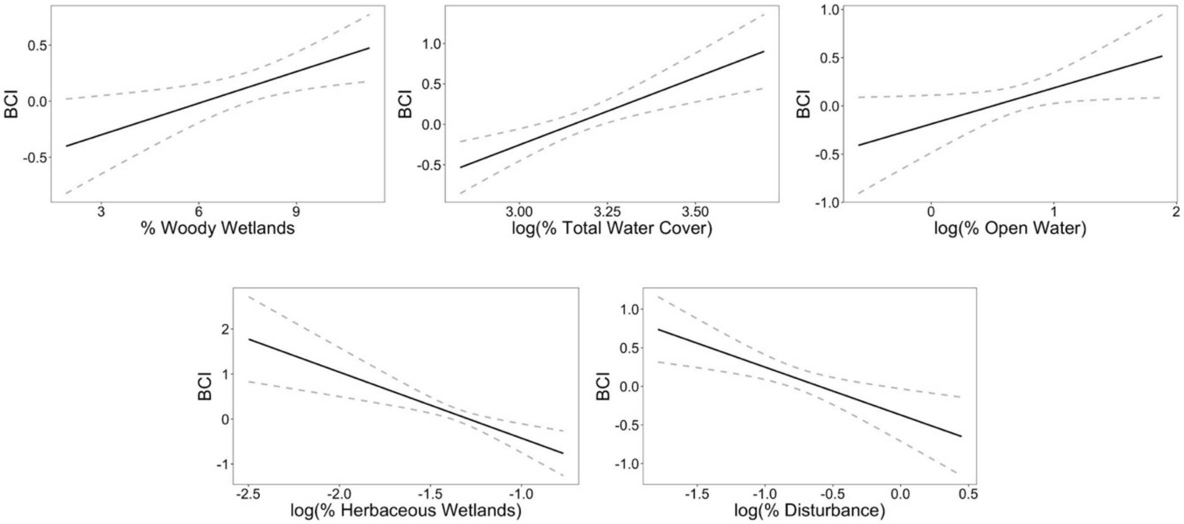
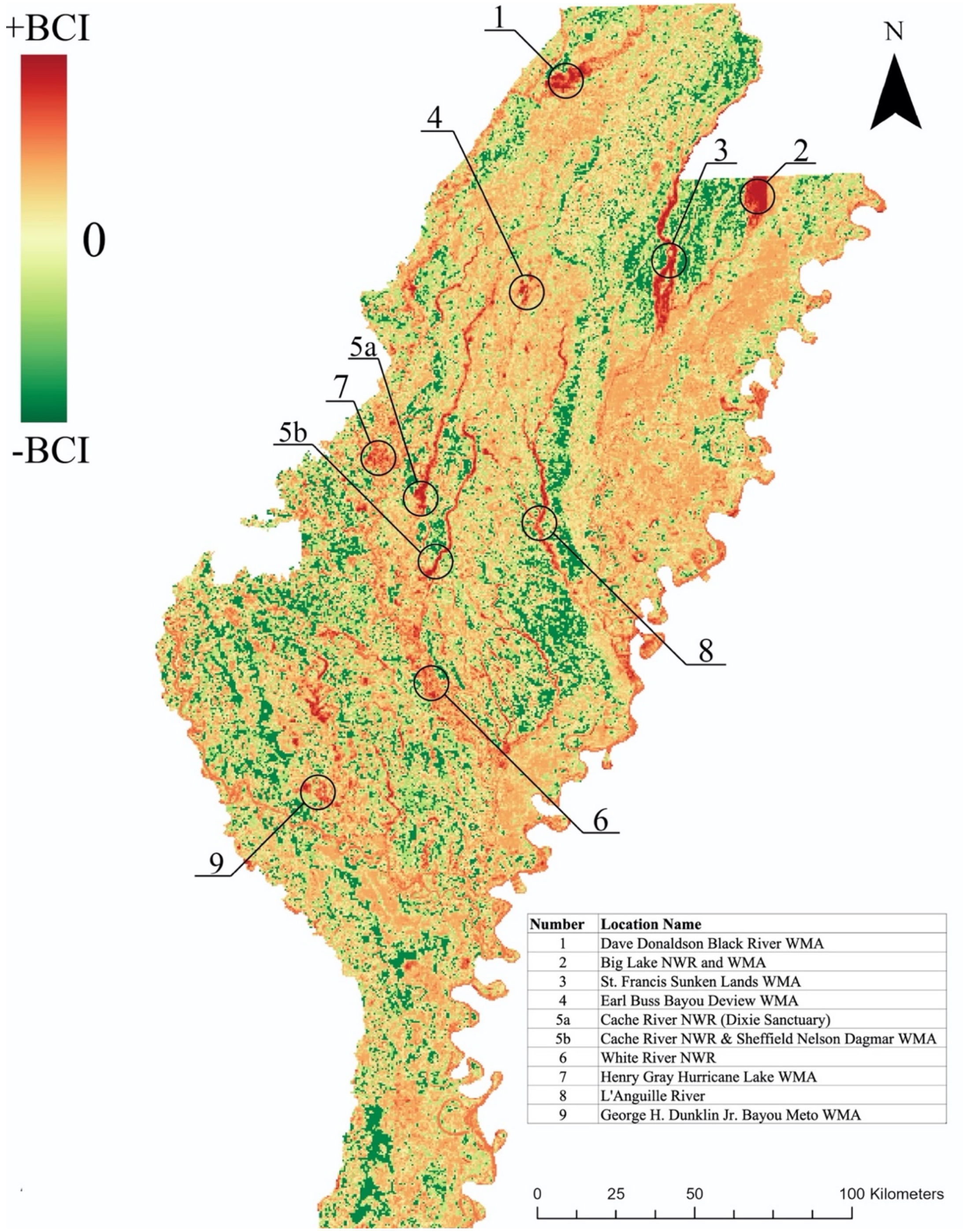


Figure 2.2. Predicted relationship of mallard (*Anas platyrhynchos*) body condition index (BCI) with % Total Water, % Woody Wetlands, % Herbaceous Wetlands, % Open Water, and % Disturbance within the Lower Mississippi Alluvial Valley of Arkansas during duck hunting seasons 2019-2020 and 2020-2021. Solid black lines refer to estimated mean BCI and gray dashed bands are upper and lower limits (using 95% CI).



Number	Location Name
1	Dave Donaldson Black River WMA
2	Big Lake NWR and WMA
3	St. Francis Sunken Lands WMA
4	Earl Buss Bayou Deview WMA
5a	Cache River NWR (Dixie Sanctuary)
5b	Cache River NWR & Sheffield Nelson Dagmar WMA
6	White River NWR
7	Henry Gray Hurricane Lake WMA
8	L'Anguille River
9	George H. Dunklin Jr. Bayou Meto WMA

Figure 3.2. Predicted relationships of mallard (*Anas platyrhynchos*) body condition index (BCI) with % Total Water, % Woody Wetlands, % Herbaceous Wetlands, % Open Water, and % Disturbance within the Lower Mississippi Alluvial Valley of Arkansas from hunting seasons 2019-2020 and 2020-2021. This map consists of a continuous color scale where more red areas refer to locations that are predicted to have mallards with high BCI (+ BCI), yellow areas refer to locations with average BCI (BCI = 0), and green areas indicate areas with predicted low BCI (- BCI). Each number label refers to examples (among others) of Wildlife Management Areas (WMA), National Wildlife Refuges (NWR), and/or other notable waterfowl habitat that promotes higher BCI in mallards.

APPENDIX B: CO-AUTHORSHIP MEMO

UNIVERSITY OF ARKANSAS

J. William Fulbright College of Arts and Sciences
Department of Biological Sciences

November 11, 2021

I'm writing this memo in support of John Veon's thesis Chapter 2 entitled "EFFECTS OF LANDSCAPE COMPOSITION ON WINTER MALLARD (ANAS PLATYRHYNCHOS) BODY CONDITION IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY OF ARKANSAS" This thesis chapter is intended for peer-reviewed publication with 4 co-authors including myself, Luke W. Naylor, and Dr. David G. Krementz. As John Veon's major advisor, I confirm that John will be the first author and has conducted greater than 51% of the work for this paper.

Thank you

Brett DeGregorio

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CONCLUSION

We demonstrate body mass of mallards (*Anas Platyrhynchos*) has increased over time (1979-2021). However, within winters, body mass declines over the course of the hunting season, most likely as resources become less available throughout the hunting season, and as waterfowl attempt to attain optimal spring departure weight. Body mass was observed to increase in the presence of increased rainfall and river flooding events; perhaps as increased water levels may increase access to food resources. Finally, mallards that were in a better body condition were associated with areas surrounding harvest sites containing higher proportions of water cover, woody wetlands, and open water, while mallards of a lower body condition were associated with areas containing higher proportions of herbaceous wetlands and human disturbance. Although we determined factors that influence mallard body mass within hunting seasons, the direct factors for why mallard body mass has increased over the past five decades remains a subject for additional research.

Although the direct factors for mallard body mass increases are unknown, the observed increases of mallard body mass show promising management possibilities. For example, if conservation agencies manipulate surface water to allow waterfowl to efficiently access food resources during the winter, the body mass of waterfowl could increase. This could be especially important during periods of drought or late in the winter when resources are scarcer (Fredrickson and Taylor 2007). Because river flooding is not always correlated to rainfall events, managers could ensure river overflow is able to flood large tracts of unmanaged lands to also provide waterfowl with more access to food resources to improve body mass. Additionally, programs that incentivize farmers to avoid fall tillage practices and ensure post-harvest flooding could increase the amount of agricultural waste grain across the landscape, thus providing waterfowl with more resources to improve their body mass (Anders et al. 2008).

Several habitat types and management strategies should be considered as conservation agencies attempt to increase waterfowl resources across the landscape. Our study highlights the importance of woody wetland habitat, some of which are managed as greentree reservoirs, to waterfowl due to its ability to provide high energy resources in the form of acorns (Allen 1980; Dabbert and Martin 2000; Heitmeyer and Fredrickson 1990; Miller et al. 2003: Reinecke et al. 1989), as well as areas for roosting, protection from predators, and social activities valuable to survival and reproduction (Reinecke et al. 1989). We recommend agencies continue to promote proper hydrology management techniques that allow waterfowl to access food resources efficiently but monitor water levels to avoid prolonged inundation in woody wetlands sensitive to flooding, like greentree reservoirs, to protect the long-term health of these forests. In addition to woody wetlands, our study indicates that ample open water habitat should be provided because mallards of higher BCI were found near this habitat type. Open water habitat provides waterfowl with locations for roosting, loafing, social interactions that are valuable to survival and reproduction, as well as some foraging opportunities near shorelines (Chabreck et al. 1989; Rave 1987; Tamisier 1978). Although we saw mallards with lower BCI located within or near higher proportions of herbaceous wetlands, the limited extent of this habitat (particularly intensively managed herbaceous wetlands) surely impacted our findings. Even so, we believe that herbaceous wetland restoration coupled with intensive food resource management may improve BCI among mallards using this habitat (Fredrickson and Taylor 2007; Miller et al. 2003; Reinecke et al. 1989). Finally, our study highlights the importance of mitigating human disturbance within or near wetlands to improve mallard BCI. In general, increasing availability of foraging habitat, as well as roosting and loafing habitat relatively free from human disturbance will most likely increase BCI among mallards, and potentially other waterfowl species.

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