Wintering Waterfowl Use of Wetlands in Delta National Forest, Mississippi

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Abstract: Bottomland hardwood forests in the southeastern United States provide important food and other socio-physiological resources for several wintering duck species. Duck presence and abundance in these wetlands can be influenced by periodicity and extent of flooding, disturbance from anthropogenic activities, and availability and coverage of certain vegetative communities. We tested if presence of flooding, anthropogenic disturbance, and certain vegetation types influenced wintering duck presence and abundance in Delta National Forest (DNF; Mississippi), the only National Forest which is entirely bottomland hardwood forest. Across 17 surveys of 65 randomly selected wetlands in the DNF in winter 2012–2013, the most abundant duck species included wood duck (*Aix sponsa*, 60%), gadwall (*Mareca strepera*, 20%), and mallard (*Anas platyrhynchos*, 18%). Hooded mergansers were rare (*Lophodytes cucullatus*, 2%), and American wigeon (*M. americana*), northern shoveler (*Spatula clypeata*), and ring-necked ducks (*Aythya collaris*) were detected in only one survey. Wood ducks, mallards, and gadwall increased in presence or abundance in relation to flooding and generally decreased in presence or abundance in relation to human disturbance. Wood duck and gadwall presence was associated with wetlands containing duckweed (*Lemna minor*), and wood duck and mallard abundance increased with wetland area. Wood duck, gadwall, and hooded merganser abundance was also associated with wetland coverage of 60–70% shrub cover. We encourage managers to flood existing green-tree reservoirs in the DNF or capture flood waters naturally and then hydrologically manage these areas according to flooding prescriptions that safeguard bottomland hardwood forest tree health. We also encourage managers to limit unnecessary human disturbance to waterfowl. Managers should also reduce dense shoreline or other scrub-shrub areas to 60–70% which should attract ducks to wetlands within DNF as well as promote waterfowl forage through the augmentation of annual seed producing plants.

Key words: bottomland hardwood forest, gadwall, hooded mergansers, mallards, wood ducks

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The Mississippi Alluvial Valley (MAV) encompasses approximately 10 million ha in portions of seven U.S. states extending from southern Illinois southward to the Gulf of Mexico (Reinecke et al. 1989). Historically, the MAV was predominately hardwood forest in floodplains of the Mississippi River and its tributaries and largely served as ancestral wintering habitat for North American mid-continent mallards and other waterfowl (Nichols et al. 1983, Reinecke et al. 1989, Saucier 1994, Gardiner and Oliver 2005). Nearly 75% of the forested landscape of the MAV has been cleared for flood control, dam construction, and conversion to agriculture and urbanization (Fredrickson 2005, Gardiner and Oliver 2005, King et al. 2005, Oswalt 2013). These transformations have greatly modified hydrology of the MAV and subsequently influenced waterfowl distribution and resource use (Heitmeyer 2001, 2006; King et al. 2006; Pearse et al. 2008, 2012).

In the MAV, forested and other palustrine wetlands form a wetland complex that provides resources important to wintering waterfowl (Reinecke et al. 1989, Pearse et al. 2012). Forested wetlands are diverse and range from seasonally-flooded red oak (*Quercus* spp. [*Erythrobalanus*]) dominated stands to semi- to permanently-flooded bald cypress (*Taxodium distichum*)–water tupelo (*Nyssa aquatica*) forest and associated scrub-shrub (e.g., buttonbush [*Cephalanthus occidentalis*] and eastern swamp privet [*Forestiera acuminate*]). When inundated, flooded oak flats provide nutrient-rich foods such as acorns, aquatic invertebrates, samaras, and seeds of herbaceous plants especially beneficial for mallards (*Anas platyrhynchos*) and wood ducks (*Aix sponsa*) (Delnicki and Reinecke 1986; Fredrickson and Heitmeyer 1988; Foth et al. 2014, 2018; Straub et al. 2016, 2019). In contrast, bald cypress and tupelo-gum communities and associated semi-permanent wet-

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lands often contain floating and submersed aquatic vegetation foraged by primarily herbivorous gadwall (*Mareca strepera*) and American wigeon (*M. americana*). Exploitation of these food resources allows waterfowl to increase nutrient reserves and progress through pre-basic molt, which subsequently prepares them for spring migration, reproduction, and potentially enhanced recruitment (Heitmeyer and Fredrickson 1981, Kaminski and Gluesing 1987, Heitmeyer 1988, Richardson and Kaminski 1992, Osnas et al. 2016). In addition to food resources, the physical structure of bottomland hardwood forests provides ducks with micro-habitats for isolation, loafing, courtship, thermal cover, and temporary escape cover from predation, waterfowl hunting, vehicular activity, and other disturbances (Fredrickson and Heitmeyer 1988, Korschgen and Dahlgren 1992, Madsen 1995). Additionally, palustrine emergent wetlands containing both emergent vegetation and open water attract an abundance and diversity of breeding and non-breeding waterfowl and other waterbirds (Weller and Fredrickson 1974; Kaminski and Prince 1981, 1984; Murkin et al. 1982; Smith et al. 2004; Rehm and Baldassarre 2007). This plant-water dynamic may also increase diversity and abundance of aquatic invertebrates (Murkin et al. 1982, Batzer et al. 2006) and provide resources for migrating, wintering, pair-bonding, pre-breeding, and breeding ducks (Kaminski and Prince 1984, Kaminski et al. 1993, Murkin et al. 1997, Smith et al. 2004, Webb et al. 2010).

Delta National Forest (DNF) is the largest contiguous bottomland hardwood forest in Mississippi and the second largest publicly owned tract in the MAV (Gardiner and Oliver 2005). Moreover, DNF is the only national forest in the United States that is exclusively a bottomland hardwood forest. Wetland managers and waterfowl hunters have questioned recent decreases in duck abundance in the DNF and other southern wintering grounds (Meehan et al. 2021). Thus, we sought to investigate the influences of the following three factors on the presence and abundance of wintering ducks in the DNF: 1) resource pulses due to forest inundation, 2) human disturbance, and 3) wetland landcover composition. Previous waterfowl research in the DNF focused solely on impounded green-tree reservoirs (GTRs) (Kaminski et al. 1993, Sherman et al. 1995), whereas we studied the larger wetland complex of non-impounded wetlands. Based on previous research in palustrine emergent wetlands, we predicted that presence and abundance of wintering ducks in the DNF would increase during natural flood events, at low or no human disturbance, and in wetlands with about 50% open water and 50% scrub-shrub.

Study Area

The DNF is located in Sharkey County in west-central Mississippi (32° N, 90° W; Figure 1) and contains 24,684 ha of bottomland hardwood forest owned and managed by the U.S. Forest Service and Mississippi Department of Wildlife, Fisheries, and Parks (Gardiner and Oliver 2005). Areas for waterfowl in the DNF include the Big Sunflower and Little Sunflower rivers, lakes containing bald cypress and water tupelo, scrub-shrub swamps dominated by buttonbush and eastern swamp privet, naturally flooded red oak (*Quercus texana, Q. phellos*) flats, and six GTRs (Wehrle et al. 1995, Straub et al. 2019). The US Forest Service closed water-control structures in GTRs on alternate years, coinciding with autumn tree dormancy, to provide flooded habitat for waterfowl and duck hunting. During our study, GTRs were not artificially flooded; therefore, they only were inundated during overbank flooding from the aforementioned rivers. Annual rainfall in the region averages 127–152 cm and ambient temperatures from November–March average 7.8 °C to 12.2 °C (NOAA 2020).

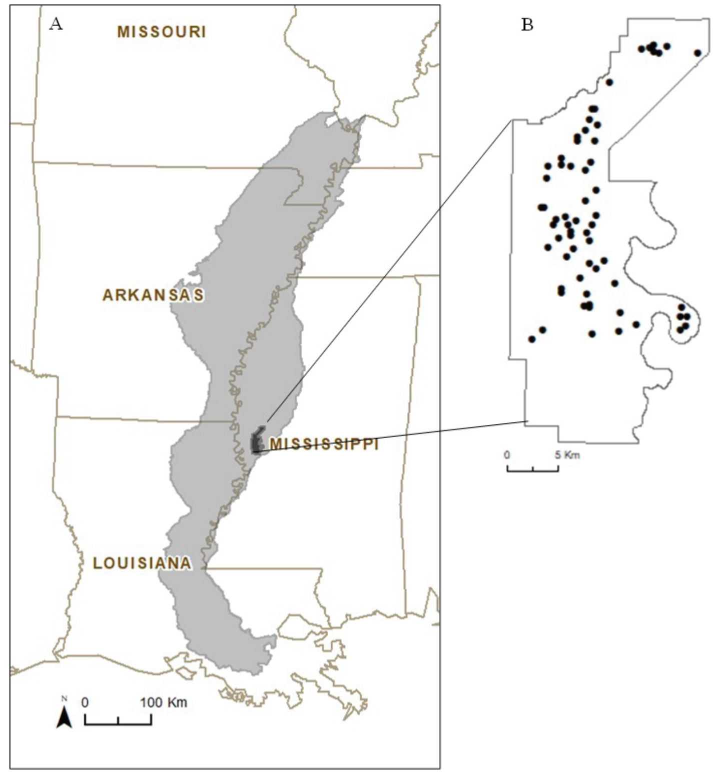

Figure 1. Location of a) the Delta National Forest (black) within the Mississippi Alluvial Valley (shaded region) and b) the 65 randomly selected wetlands surveyed for ducks during winter 2012–2013.

Methods

Wetland Sampling and Composition Determination

Using aerial imagery, we identified semi-permanent and permanent wetlands and associated sloughs in the DNF. For sloughs, we first partitioned these wetlands into ~400-m sections, as these lengths conformed to natural meanders of wetland areas and produced units possible to survey in entirety while walking, or from a pirogue when water depths precluded wading. In total, this created 257 wetlands and slough sections, of which we then randomly selected 65 (25%; Figure 1) to survey for waterfowl. We used mean wetland length as a radius to create a circular buffer from wetland centroids, encompassing an area of 37.4 ha around each of the 65 wetlands. After creating buffers, we used ArcMap v. 10 (ESRI, Inc., Redlands, California) to digitize the most contemporary photos available of DNF (30-cm resolution; Bing Maps 2011) and then categorize each 37.4 ha area around the selected wetlands into the following landcover types: hardwood forest, open water, scrub-shrub, roads, trails, levees, croplands, and openings (i.e., clear-cuts and clearings consisting of smaller canopy openings). We visited all 65 wetlands to ground-truth land features we observed in and around a specific wetland on aerial imagery. For all wetlands, we calculated the total area of bottomland hardwood forest, open water, and scrub-shrub wetlands and the proportional areas of scrub-shrub within the buffered area. We also computed the area of roads, levees, and cropland within the wetland buffer as well as the nearest linear distance to a road/trail from the wetland center.

Waterfowl Surveys

We conducted waterfowl surveys from mid-November 2012 to early March 2013, the period when wintering ducks typically occur in the MAV (Reinecke et al. 1989, Sherman et al. 1992, Pearse et al. 2008). During this period, we conducted 17 rounds of surveys, with each round lasting 4–9 days, the amount of time it typically would take for three observers to visit all wetlands. Each survey of a wetland was conducted by a single individual. The surveyors alternated wetlands in a random sequential order to limit sampling temporal and spatial bias and disturbance, with all three observers counting ducks on wetlands independently each day to maximize sampling effort.

We conducted waterfowl surveys from sunrise to sunset and limited them to days without heavy rain, dense fog, or other inclement conditions that inhibited visual detections of birds (Ralph et al. 1995, O'Neal et al. 2012). To conduct a survey, a surveyor quietly entered into a wetland's perimeter and traversed their way around the wetland, counting ducks by species, mostly as the ducks flushed. Additionally, when hardwood forest within the buffered wetland area (i.e., the 37.4 ha) became inundated, the presence of flooding was recorded and ducks observed in the flooded timber contiguous with survey wetlands were counted. Though we were unable to fully account for observational differences among surveyors in the field, we assumed our counts were accurate indices of duck abundance. Given that herbaceous vegetation in wetlands was dominated by duckweed (*Lemna minor*), we noted whether duckweed was present (i.e., any quantity observed by surveyor) or absent at each wetland during each survey. Additionally, we recorded any potential disturbance to waterfowl (e.g., hunting or vehicular activity) that was occurring within ~100 m of the wetland. To further assess flooding events, we used recorded water levels of the Big Sunflower and Little Sunflower rivers from the U.S. Army Corps of Engineers river gages at Holly Bluff and Riverside, Mississippi, respectively (U.S. Army Corps of Engineers 2013).

Statistical Analysis

We used a two-part hurdle modelling approach (Cameron and Trivedi 1998, Martin et al. 2005) to examine duck species presence/absence (i.e., 1 or 0) and abundance (as indexed by our counts) in relation to environmental variables within a generalized linear mixed model framework. The first part of model examined the probability of observing 0 ducks (i.e., absence) using a Bernoulli distribution. The second part of the model examined abundance when waterfowl were present (i.e., ≥1 duck counted). For the four predominant species (wood duck, mallard, gadwall and hooded merganser [*Lophodytes cucculatus*], see Results), we included in each model the presence (or absence) of flooding beyond scrub-shrub wetland into surrounding areas, and the presence (or absence) of duckweed. For variables related to possible anthropogenic disturbance, we included presence (or absence) of disturbance, distance to the nearest road, and proportion of human modified land within the wetland buffer. For wetland composition variables, we included total wetland area, the proportion of scrub-shrub, and a quadratic term for scrub-shrub given that ducks may respond to some optimum percentage of scrub-shrub. All models included survey and observer as random effects to account for the repeated sampling of wetlands and surveyor bias, respectively. Due to overdispersion in the count model for wood duck and mallard abundance, we performed modeling using a negative binomial distribution, while we used a Poisson distribution for gadwall and hooded merganser (Cameron and Trivedi 1998, Martin et al. 2005). We examined significant and marginally significant results ($0.05 < \alpha < 0.10$). We performed analyses using R package glmmTMB (Brooks et al. 2017) in R v. 3.6.0 (R Core Team 2019).

Results

Survey wetland segments averaged 345 ± 29.3 m (SE) in length, with relative precision (coefficient of variation = 8.5%), suggesting consistency in length among the 65 wetlands. Among 17 rounds of surveys (1105 total surveys), we counted 6718 ducks within the 65 wetlands and another 2551 ducks within adjoining flooded bottomland hardwood forest (9269 total ducks; Table 1). The latter duck counts were not included in analyses because they occurred

Table 1. Total counts ($n = 9269$ ducks) of wood duck (*Aix sponsa*), mallard (*Anas platyrhynchos*), gadwall (*Mareca strepera*), and hooded merganser (*Lophodytes cucullatus*) in the Delta National Forest, Mississippi, winter 2012–2013 for each survey. Number of ducks detected in adjoining flooded bottomland hardwood forest are in parentheses.

Survey	Date	Wood duck	Mallard	Gadwall	Hooded merganser	Total
1	16 Nov 2012	193	0	1	13	208
2	26 Nov 2012	212	1	2	10	225
3	3 Dec 2012	169	2	6	13	190
4	8 Dec 2012	342	4	2	6	354
5	14 Dec 2012	231	0	2	12	245
6	19 Dec 2012	337	0	5	5	347
7	26 Dec 2012	325	0	8	6	339
8	2 Jan 2013	430 (21)	4	20 (10)	7	461
9	8 Jan 2013	575 (180)	11 (3)	43	18 (4)	647
10	14 Jan 2013	621 (478)	133 (124)	18 (12)	2 (2)	774
11	22 Jan 2013	463 (319)	354 (307)	1	6 (1)	824
12	28 Jan 2013	297 (97)	140 (113)	41 (1)	10 (3)	489
13	3 Feb 2013	370 (52)	190 (63)	189 (15)	7	756
14	8 Feb 2013	408 (140)	623 (269)	203 (35)	9	1243
15	14 Feb 2013	217 (81)	129 (69)	542 (60)	13 (5)	901
16	20 Feb 2013	214 (34)	57 (8)	244 (25)	10	525
17	25 Feb 2013	134 (13)	36 (4)	561	6 (2)	741

within and beyond our consistent survey area. Frequently occurring and abundant species were wood ducks (42% frequency of occurrence, 60% relative abundance, respectively), mallards (10%, 18%), gadwall (6%, 20%), and hooded merganser (7%, 2%). While we also detected American wigeon, northern shoveler (*Spatula clypeata*), and ring-necked ducks (*Aythya collaris*), we only detected them during one survey and therefore excluded them from analyses.

The Big and Little Sunflower rivers crested their banks and inundated approximately half of the DNF from 11 January to 3 February 2013 and 13 February to 15 February 2013, coinciding with surveys 10–12 and 14–15, respectively (Table 1). When we recorded instances of flooding within wetlands, these events corresponded to times when the Big Sunflower River gages exceeded 26 m. While wood duck and hooded merganser use of the DNF was consistent throughout the study period, irruptive mallard and gadwall use began when overbank flooding inundated bottomland hardwood forest contiguous with survey wetlands in late winter-early spring (Table 1). Although spikes in duck numbers occurred in response to flooding, all wetlands had at least one record of duck use during the study.

Duck Presence/Absence

Flooding influenced wood ducks, mallards, and gadwall (Table 2), with a 93.2%, 65.7%, and 77.9% lesser likelihood of being absent from wetlands with flooding, respectively. Availability of duckweed influenced wood ducks and gadwall (Table 2), with a 55.0% and 86.9% lesser likelihood of their absence with duckweed, respectively. Anthropogenic-related variables influenced wood ducks (Table 2), with wood ducks being 48.4% more likely to be absent in wetlands with those influences. Wetland area influenced wood ducks, mallards, and gadwall, with a 33.0x, 31.6x, and 49.3x lesser likelihood of species absence in larger wetlands, respectively. Finally, the amount of scrub-shrub cover in a wetland influenced gadwall and hooded mergansers (Table 2), with gadwall and merganser less likely to be absent when there was scrub-shrub covered about 62% and 69% of the wetlands, respectively (Figure 2).

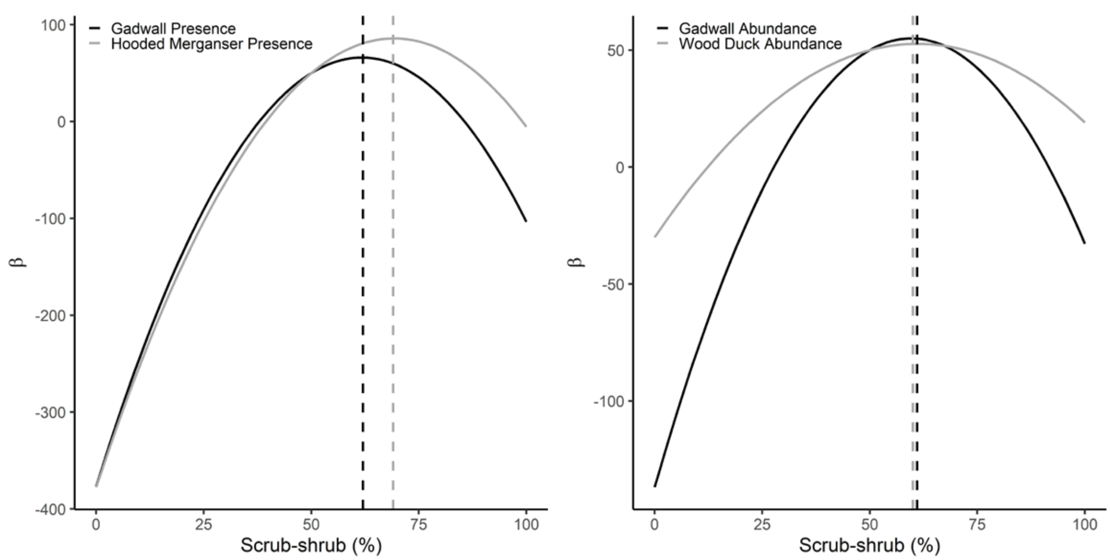

Figure 2. Optimum scrub-shrub cover (%) for gadwall (*Mareca strepera*) and hooded merganser (*Lophodytes cucullatus*) presence and indices of gadwall and wood duck (*Aix sponsa*) abundance in the Delta National Forest, Mississippi, winter 2012–2013. Vertical lines intersect scrub-shrub optimum values.

Table 2. Parameter estimates (*β*), *z*-values (*Z*), and *P*-values (*P*) for the analysis to evaluate the environmental variables and anthropogenic effects on the absence (i.e., the probability of obtaining a zero count) of wood duck (*Aix sponsa*), mallard (*Anas platyrhynchos*), gadwall (*Mareca strepera*), and hooded merganser (*Lophodytes cucullatus*) in the Delta National Forest, Mississippi, winter 2012–2013. Significant ($P < 0.05$) effects are bolded and marginally significant ($0.05 < P < 0.10$) effects are italicized.

	Wood duck			Mallard			Gadwall			Hooded merganser		
Variable	**β**	***Z***	***P***	**β**	***Z***	***P***	**β**	***Z***	***P***	**β**	***Z***	***P***
Flooding presence	*–2.70*	*–1.65*	*0.10*	**–1.07**	**–3.02**	**0.003**	**–1.51**	**–4.19**	**<0.001**	–0.09	0.26	0.79
Duckweed presence	**–0.80**	**–2.80**	**0.005**	–0.31	–0.77	0.44	**–2.03**	**–5.03**	**<0.001**	0.18	0.56	0.57
Distance to road/trail (m)	0.05	0.40	0.69	–0.20	–1.36	0.17	0.05	0.37	0.71	0.19	0.95	0.34
Disturbance presence	**0.91**	**1.98**	**0.05**	1.34	1.59	0.11	–0.36	–0.13	0.89	–0.10	–0.15	0.88
Anthropogenic land (%)	–0.08	–0.66	0.49	–0.11	–0.97	0.33	0.16	0.80	0.42	0.93	0.94	0.35
Wetland area (m2)	*–0.40*	*–1.63*	*0.10*	**–0.38**	**–3.30**	**<0.001**	**–0.68**	**–4.98**	**<0.001**	0.13	0.59	0.55
Scrub-shrub cover (%)	–0.44	–1.07	0.29	–0.13	–0.21	0.83	**–2.73**	**–3.50**	**<0.001**	*–3.72*	*–1.85*	*0.06*
Scrub-shrub cover2	–0.34	0.29	0.77	0.01	–0.01	0.99	**3.40**	**4.10**	**<0.001**	**2.83**	**1.96**	**0.05**

Table 3. Parameter estimates (*β*), *z*-values (*Z*), and *P*-values (*P*) for the analysis to evaluate the environmental variables and anthropogenic effects on the index of abundance (i.e., counts >0) of wood duck (*Aix sponsa*), mallard (*Anas platyrhynchos*), gadwall (*Mareca strepera*), and hooded merganser (*Lophodytes cucullatus*) in the Delta National Forest, Mississippi, winter 2012–2013. Significant ($P < 0.05$) effects are bolded and marginally significant ($0.05 < P < 0.10$) effects are italicized.

	Wood duck			Mallard			Gadwall			Hooded merganser		
Variable	**β**	***Z***	***P***	**β**	***Z***	***P***	**β**	***Z***	***P***	**β**	***Z***	***P***
Flooding presence	**0.84**	**4.21**	**<0.001**	**2.06**	**6.01**	**<0.001**	**0.46**	**7.34**	**<0.001**	0.10	0.38	0.70
Duckweed presence	–0.30	–1.48	0.14	–0.67	–1.37	0.17	**1.16**	**6.83**	**<0.001**	–0.10	–0.37	0.71
Distance to road/trail (m)	0.03	0.33	0.75	*0.35*	*1.78*	*0.07*	**0.39**	**9.96**	**<0.001**	–0.04	–0.45	0.81
Disturbance presence	*–0.67*	*–1.71*	*0.09*	1.95	1.38	0.17	–3.71	–1.18	0.24	–0.28	–0.49	0.62
Anthropogenic land (%)	–0.01	–0.11	0.92	**0.24**	**1.99**	**0.05**	**–0.38**	**–3.01**	**0.003**	–0.36	–0.45	0.66
Wetland area (m2)	–0.01	0.14	0.89	**0.26**	**2.26**	**0.02**	**–0.14**	**–3.09**	**0.002**	–0.17	–0.82	0.41
Scrub-shrub cover (%)	0.49	1.54	0.12	0.52	0.77	0.44	**1.04**	**4.46**	**<0.001**	2.16	1.18	0.24
Scrub-shrub cover2	**–0.65**	**–2.21**	**0.02**	–0.76	–1.16	0.25	**–1.58**	**–4.96**	**<0.001**	–1.50	–1.18	0.24

Duck Abundance

Flooding also influenced waterfowl indices of abundance with more wood ducks, mallards, and gadwall occurring during flooding (Table 3). Gadwall was the only species primarily influenced by the availability of duckweed, where gadwall abundance increased with duckweed presence (Table 3). Gadwall abundance also was positively associated with increased distance to roads or trails, while wood duck abundance was negatively influenced by disturbance at or near a wetland (Table 3). Anthropogenic development influenced duck abundance, with mallard abundance positively and gadwall abundance negatively associated with increased percentage of development around a wetland (Table 3). Mallard abundance was positively associated, while gadwall abundance was negatively associated with wetland area (Table 3). Wood duck and gadwall abundance was greatest with an intermediate amount of scrub-shrub cover (60% and 61%, respectively; Table 3, Figure 2). We did not detect any relationships in hooded merganser abundance with any environmental or anthropogenic-related variables (Table 3).

Discussion

Seasonal flooding of bottomland hardwood forest in DNF was a major influence on wood duck, mallard, and gadwall presence and indices of abundance, a trend typical of MAV systems in winter (Heitmeyer and Fredrickson 1981, Nichols et al. 1983, Conner and Sharitz 2005, Battaglia and Sharitz 2006, Heitmeyer 2006). As we observed, scrub-shrub wetlands proximal to hardwood forest can influence greater overall wetland use and provides additional habitat for ducks when the latter resource type floods. Winter floods are particularly important for mallards as flooding makes acorns, other seeds, and invertebrates available which enhances nutrient deposition, molt, and other important biological and behavioral processes of these birds (Nichols et al. 1983, Reinecke et al. 1988, Heitmeyer 2006), particularly in areas containing greater proportion of bottomland hardwood forests (Herbert et al. 2018, 2021). Benefits of wet winters are evident through carry-over effects on recruitment for mallards and other species (Heitmeyer and Fredrickson 1981, Kaminski and Gluesing 1987, Reinecke et al. 1988, Sedinger and Alisauskas 2014, Osnas et al. 2016). In our study, flood events, particularly in January and February, coincided with increases in wood ducks, mallards, and gadwall in scrub-shrub and nearby forested wetlands. Ducks continued to use survey wetlands but also capitalized on newly inundated areas, and wood ducks and mallards increased use of oak flats typical of a species' response to a resource-pulse (Heitmeyer 2006, Yang et al. 2008). In contrast, we did not observe gadwall responding to winter flooding of oak flats, but their abundances increased in late winter coinciding with flooding of wetlands. Given gadwall are primarily herbivores, wetlands provided environments for these birds to consume duckweed and submersed aquatic vegetation (Paulus 1982, McKnight and Hepp 1998, Gross et al. 2020). Wood ducks and mallards also consume duckweed (Drobney and Fredrickson 1979, Gruenhagen and Fredrickson 1990, Bellrose and Hom 1994); however, for these two species the only relationship we detected with duckweed presence was a positive association with presence of wood ducks. Wood ducks and mallards in winter primarily forage on acorns and invertebrates and less on aquatic plants (Drobney and Fredrickson 1979, Combs and Fredrickson 1996, Heitmeyer et al. 2005); therefore, a weak or lack of association with duckweed was not surprising for these species. Additionally, wood ducks and mallards typically forage in shallower areas where they can access seeds and benthos (<45 cm) and thus may avoid deeper wetlands that may contain duckweed in the DNF (Drobney and Fredrickson 1979, Reinecke et al. 1989, Hagy and Kaminski 2012).

Overall, estimates of ducks occupying DNF could be considered rather low given the size of the system. What is more difficult to reconcile is how potential factors contributed to use, or lack thereof, by ducks at DNF. For instance, habitat quality in terms of types, amount, and availability of forage were likely influential. Although beyond our control, the fact that dabbling ducks are decreasing in southern latitudes in recent winters may also have an important consideration (Meehan et al. 2021). Lastly, we view human disturbance at DNF as particularly important. The DNF has an extensive trail and road system and lacks designated sanctuaries for waterfowl from hunting and off-road vehicular disturbances (Brøseth and Pedersen 2000). Given the negative association of gadwall and the percentage of nearby anthropogenic lands and proximity to roads and trails, and of wood ducks and the amount of direct disturbance at some wetlands, these observations suggest non-regulated human activity influence use and abundance of some species of ducks in the DNF.

Research indicates that hunting and other recreational uses temporarily can disrupt activities of some wildlife species, including wintering ducks (Holbrook and Vaughan 1985, Korschgen and Dahlgren 1992, Laurance et al. 2006, Dooley et al. 2010, St. James et al. 2013) and that sanctuaries are important to waterfowl and other wildlife seeking safety (Korschgen and Dahlgren 1992; Madsen 1995, 1998). Per DNF regulations, off-road vehicles can travel designated trails and venture off trails up to ≤2.4 km to retrieve harvested white-tailed deer (*Odocoileus virginianus*); however, well-worn trails and off-road vehicles were frequently encountered throughout the forest, with no apparent relationship to deer harvest. In addition, small game hunting and hunting of wild hog (*Sus scrofa*) on foot and by horseback are permitted throughout the forest, which invoked additional disturbance. At 10 of the 65 wetlands, 3–6 disturbance events were observed during the 17 surveys, which only took 15–30 min per wetland. These detections suggested the actual number of disturbances per wetland would be greater during daylight hours of the hunting season. Additionally, lack of spatial or temporal sanctuary and predictable flooded hardwood forests for waterfowl may reduce waterfowl use of DNF. Lastly, the percentage of land around wetlands which contained roads, levees, and cropland proximal to surveyed wetlands also may be an important consideration for waterfowl management given an aversion to these aspects, which likely was not mutually exclusive from effects of trails and hunting activities.

Wetland area and vegetative structure influence waterfowl use (Smith et al. 2004, Rehm and Baldassarre 2007, Schummer et al. 2012). Generally, increases in wetland area positively influence dabbling duck abundance during spring and winter (LaGrange and Dinsmore 1989, Webb et al. 2010, Pearse et al. 2012), a trend which was detected for mallards, wood ducks, and gadwall in the DNF. We could not adequately measure all possible disturbances and fully determine their impacts to duck use and distribution at DNF. However, we believe that larger wetlands may have served as a buffer to potential disturbances. Additionally, there were opposing effects on gadwall presence and abundance in relation to wetland area indicating there was likely some optimum area of waterbody for this species or that they may switch between wetlands with varying area. We also observed an optimum association with scrub-shrub wetlands for wood ducks, gadwall, and mergansers. For wood ducks, our results corroborate information from other studies (McGilvrey 1968, Parr et al. 1979). Presence and abundance of these species varied with generally intermediate coverage (~60%) of scrub-shrub similar to ducks and other waterbirds attraction to hemi-marshes containing relatively equal proportions of emergent vegetation and open water in a highly interspersed distribution (Weller and Fredrickson 1974, Kaminski and Prince 1981). Despite benefits of scrub-shrub, dense and impenetrable monocultures of vegetation preclude access by ducks. As scrub-shrub area increased beyond the 60–75% cover, dabbling ducks mostly become increasingly excluded from wetlands and intrinsic resources (Kaminski and Prince 1981, Kaminski et al. 1993, Linz et al. 1996). Hooded mergansers were associated with areas of greater scrub-shrub coverage (i.e., 69%). Additionally, while only wood ducks were typically observed in wetlands with >90% scrub-shrub, those occurrences were infrequent. As a result, forested wetland management in the DNF should include management to meet various species' needs, including reducing scrub-shrub in wetlands to levels of 60–70%, and ensuring wetlands contain dense scrub-shrub borders to buffer ducks from human disturbances and possibly predators.

In conclusion, our results support the established documented importance of bottomland hardwood forests to waterfowl (Fredrickson and Heitmeyer 1988, Heitmeyer 2006, Davis et al. 2009, Davis and Afton 2010, Lancaster et al. 2015), and we encourage management actions which are fundamental to improving conditions for waterfowl at the DNF: 1) maintain existing water management by Mississippi Department of Wildlife, Fisheries and Parks and partners and seek additional opportunity for such management to ensure seasonal flooded habitats and spatial sanctuaries for waterfowl, 2) ensure a viable complex of bottomland hardwood forests and semi-permanent scrub-shrub wetlands with 60–70% shrub cover, and 3) examine and consider modification of the DNF Motor Vehicle Use Map policy to minimize disturbance. Indeed, vehicle use policies may have to be amended if sanctuary or less disturbed areas for waterfowl are prioritized. Additionally, if spring drawdowns were possible, managers could partially remove scrub-shrub and potentially improve conditions for annual wetland grass and sedge communities (Harrison and Chabreck 1988, Kross et al. 2008). Improving water management conditions within the DNF to safeguard forest integrity and possibly promote annual herbaceous plant communities may be especially important given soybean is among the most available agricultural crops in the vicinity, and seeds of this legume have been shown to decrease body weight and survival of mallards during winter (Loesch and Kaminski 1989). Agriculture, particularly waste grain of nearby rice, form an important part of the wetland complex benefitting waterfowl at both local and regional scales (Stafford et al. 2006, Davis and Afton 2010, Pearse et al. 2012, Marty et al. 2020). Positive gains in wetland quality within the DNF will likely enhance the system's ability to attract wintering waterfowl, which may become increasingly important considering effects of climate warming on increasing northward wintering by ducks in North America (Meehan et al. 2021).

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