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TITLE: Estimates and determinants of duck production in North Park, Colorado

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ABSTRACT

Assessing waterfowl use and productivity throughout the Intermountain West can inform habitat management practices across various land use regimes. The North Platte River Basin (hereafter, North Park) in north central Colorado has historically held important breeding and stopover habitat for ducks and is expected to become increasingly important as water demands increase across the state. In 2018, we began a study to examine duck breeding populations and production in North Park, in relation to wetland habitat conditions. During the 2021 field season, our first objective was to estimate the breeding population of ducks and evaluate the variation in abundance across wetlands. We surveyed 117 individual wetlands for breeding ducks. The number of indicated breeding pairs was greatest on wetlands with more open water. Summed across all sites, we observed 3,765 total indicated breeding pairs, including 1,049 gadwall, 648 mallards, 501 northern shovelers, 322 American wigeons, and 319 lesser scaup. Our second objective was to assess nesting characteristics of waterfowl throughout the park. We monitored 40 duck nests and 6 successfully hatched at least one egg. Another objective was to estimate duck production using brood surveys across the park. We conducted brood surveys on 74 wetlands and observed broods of 12 duck species. Duckling:pair ratio for all ducks ranged from 0 to 12.5 and averaged 0.86 (SD=2.24). An additional study objective was to use banding data to obtain demographic estimates and the contribution of North Park ducks to hunting opportunity. In 2021 we banded 608 ducks during pre-season banding operations. At the time of this report, 100 ducks we banded in 2018, 91 ducks we banded in 2019, 140 ducks we banded in 2020, and 21 ducks we banded in 2021 (total = 352) had been harvested by hunters and reported to the USGS Bird Banding Laboratory. We plan to continue annual data collection on this study through 2023.

INTRODUCTION

North Park (Jackson County) has historically been an important breeding area for ducks in Colorado (Kirkman 1956, Szymczak 1986, Colorado Division of Wildlife 1989, Sanders 1997, Runge 2011). In the 1970s and 1980s, duck hunters in numerous areas harvested ducks banded in North Park, but most species were harvested mainly in Central and Pacific Flyway states; in particular, mallards banded in North Park were harvested primarily in Colorado. Assuming these breeding population and harvest distribution patterns have remained consistent over time, maintaining or increasing duck production in North Park would benefit waterfowl hunters and non-consumptive users of waterfowl across Colorado and the surrounding region. However, no consistent monitoring of duck populations has been done in recent decades.

The Colorado Parks and Wildlife (CPW) Wetland Wildlife Conservation Program (Wetland Program) identifies North Park as an important wetland area in Colorado, and the Wetland Program has a specific goal to “maintain or increase the quantity and quality of spring migration and duck breeding habitat, and duck breeding populations and production in breeding areas important to Colorado” (Sullivan 2011). CPW and its Wetland Program partners have invested in numerous habitat conservation projects in

North Park, most of which are intended to improve habitat for breeding ducks. By annually quantifying wetland habitat conditions and the distribution, abundance, and productivity of ducks in North Park from spring arrival through brood production, we can improve our understanding of the contribution of different wetland habitats (and specific types of wetland conservation projects) to duck populations, and evaluate whether we are achieving the Wetland Program objectives for this priority area.

North Park is located in the Intermountain West Joint Venture (IWJV) and is typical of many montane basins distributed throughout the IWJV in the role that privately owned, irrigated lands play in providing wetland habitats. Although wetlands and deepwater habitats (Cowardin et al. 1979) comprise only about 20% of the North Park valley, 84% of these wetland acres are privately owned, and over 70% of these private wetland acres are irrigated for livestock pasture and hay production (Lemly and Gilligan 2012). This predominance of wetland resources on private lands is consistent across the IWJV (Peck and Lovvorn 2001, Copeland et al. 2010, Donnelly and Vest 2012a, 2012b), and highlights the need to understand and demonstrate the value of these managed wetland habitats for ducks and other wildlife. As increased development and demands for water occur throughout the West (Downard 2010), it is becoming more valuable to document the contributions these irrigated ranchlands make toward sustaining wildlife populations.

Although some information is available on the wildlife value of intermountain wetlands and some aspects of how these wetland systems function (Peck and Lovvorn 2001, Gammonley 2004), there are important gaps in our understanding of duck ecology in the intermountain West. Basic information about wetland habitats in North Park is available (Lemly and Gilligan 2012), but uncertainty exists about how breeding ducks respond to wetland conditions, and the optimal way to manage habitats to increase annual duck production. Habitat conservation activities are continuing, despite these uncertainties. We have established a long-term monitoring and research program to inform management decisions and reduce uncertainties (i.e., improve conservation program efficiencies) in North Park over time. Key stakeholders in this effort include CPW, Ducks Unlimited Inc., IWJV, private landowners, U.S. Fish and Wildlife Service, Bureau of Land Management, and the U.S. Forest Service. In addition, Colorado State University (CSU) is conducting research on fine-scaled habitat selection by mallards and gadwalls in North Park, and CPW and CSU are coordinating closely on these projects.

OBJECTIVES

- 1) Use satellite imagery and annual measures of hydrology, salinity, and vegetation composition and structure on a representative sample of wetlands to quantify wetland habitat conditions annually.
- 2) Use breeding pair counts, adjusted for detection probability, on a sample of wetlands to estimate overall breeding populations of ducks annually.
- 3) Assess nest site selection and nest survival for nests located on private and public land to estimate habitat effects on reproductive success.
- 4) Use brood counts, adjusted for detection probability, on a sample of wetlands to estimate duck production annually.
- 5) Use annual pre-season capture and banding of ducks to estimate annual survival rates, fidelity rates, harvest rates, and harvest distribution.

STUDY AREA

The North Park study area is located in Jackson County in northcentral Colorado. Jackson County is 1,621 miles² and is bounded by the Medicine Bow Mountains on the north and east, the Park Range on the west, and the Rabbit Ears Range on the south. Between these mountain ranges and their foothills, the “park” is a relatively flat area of about 600 miles² with rolling hills remnant of glacial retreat. Elevations in the county range from 7,800 to 12,953 feet. Jackson County includes the majority of the North Platte River Basin in Colorado. The Canadian, Michigan, Illinois, and North Fork of the North Platte rivers and Grizzly Creek flow from the surrounding mountains and join the North Platte River on its course to the north into Wyoming. North Park has a semi-arid climate characterized by long, cold winters and short summers, with a mean average annual temperature of 37°F in the town of Walden. With high summer

evapotranspiration rates and low precipitation (11 inches per year in Walden), run-off from snowmelt in the surrounding mountains is the main source of water for wetlands in the North Park valley.

North Park is located in the Southern Rocky Mountains Level III Ecoregion (Omernik 1987). Most of the valley floor is dominated by the Level IV Sagebrush Parks ecoregion. Upland areas are dominated by mountain sagebrush (*Artemisia vaseyanum*). Extensive riparian floodplains fill the valleys and predominately contain mixed willow species (*Salix monticola* and *S. geeyeriana*). Irrigated hay meadows are also a major land cover, covering approximately 13% of the basin, and are dominated by meadow foxtail (*Alopecurus pratensis*) or timothy grass (*Phleum pratense*). In the mountain foothills, vegetation transitions to forests dominated by aspen (*Populus tremuloides*) and lodgepole pine (*Pinus contorta*). In the higher subalpine zone, forests are dominated by subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*). Above treeline, vegetation consists of mixed grasses and forbs characteristic of high elevations.

Anthropogenic hydrologic alterations in the North Platte River basin began in the 1880s, with shallow ditches constructed throughout much of North Park to expand the floodplain resources for cattle pasture and hay production. Existing irrigated land is still concentrated near the rivers and their broad, meandering, floodplains. Each spring, landowners divert snowmelt surface water from streams and flood irrigate their lands for hay and cattle, which has created additional wetland acres over many years (Peck and Lovvorn 2001). Groundwater pumping is relatively limited in North Park; only 130 active water wells are reported in North Park and many of these are under 120 feet deep (Colorado Division of Water Resources 2011).

Walden is the largest town in North Park with a population of 608; a total of 1,394 people (<1 person per mile²) live in Jackson County (U.S. Census Bureau 2017). Public lands in North Park are managed by CPW, the State Land Board, the U.S. Fish and Wildlife Service (Arapaho National Wildlife Refuge), the Bureau of Land Management, and the U.S. Forest Service.

METHODS

At five large reservoirs (Walden Reservoir, Cowdrey Reservoir, Lake John, Muskrat Reservoir, and 18 Island), we counted ducks weekly from mid-May through mid-July to understand how waterfowl abundance in North Park changes throughout the summer. Observers drove around the site and counted the number of each species of duck present.

We conducted duck pair counts on basin wetlands, reservoirs, and sections of ditches and riparian areas across public and private land in North Park. The methods we used for each count depended on the type of site. On riparian areas and ditches, we conducted independent double observer surveys to estimate detection probability. We randomly selected 500-m sections of riparian corridors along the primary river channel or ditch running through Arapahoe NWR and private lands. Two observers conducted each survey, walking on opposite river banks and feigning data-taking behaviors to maintain independence. Following completion of the survey, observers compared notes and determined if any ducks were missed by either observer which was used to estimate detection probability. For all detections, observers noted the social status of ducks (paired, lone male, etc.).

We found that the frequent movement of ducks within basin wetlands and reservoirs impeded the mapping process necessary to conduct independent double observer pair counts. Therefore, we conducted dependent double observer (Nichols et al. 2000) surveys on basin wetlands. Dependent double observer surveys involved two observers, one primary and one secondary. The primary observer scanned through the site noting the species and social status of each duck seen. The secondary observer recorded data but also scanned the site and made note of any ducks missed by the primary observer. With this system, the secondary observer sees all the ducks seen by the primary observer plus any missed by the primary observer.

For counting broods, we used independent double observer surveys. Two observers in separate vehicles counted all ducklings by species and age at each site. At the end of the surveys, they compared notes and noted any ducklings missed by either observer.

We searched nest plots in flood-irrigated hay meadows on private and public land throughout the breeding season. Some of these plots were associated with restoration projects being conducted by Ducks Unlimited from 2019-2021. We therefore located nests associated with flood irrigation to evaluate the importance or impact of flood irrigation on nesting waterfowl.

We trapped ducks during 30 July – 10 September, using swim-in traps baited with cracked corn at 7 wetland sites, each with 1 – 2 traps per site (Mauser and Mensik 1992). We also captured ducks using and airboat and spotlights on one site during one night. We marked ducks with standard U.S. Geological Survey (USGS) legbands and released them at their capture sites. In coordination with a CSU research project, we also marked 2 mallards captured in swim-in traps, and one mallard captured on its nest, with Ecotone Kite-L GPS-GSM transmitters (12-14 g). We classified captured ducks to species, age, and sex using plumage characteristics and cloacal examination. We classified age as local, hatch year, or after hatch year. We defined local birds as unfledged ducklings that we could reasonably assume had hatched locally, and only attached bands to ducklings with legs large enough to hold a legband. We recorded the band number of all recaptured ducks. We reported information on ducks we banded to the USGS Bird Banding Laboratory.

STATISTICAL ANALYSES

Breeding Pair Abundance

We assessed detection probabilities from our dependent double observer surveys for the most prevalent duck species using Huggins closed capture models (Huggins 1989, Huggins 1991). We included a two-occasion encounter history, with the first occasion indicating whether the primary observer saw an individual and the second occasion indicating whether the secondary observer (i.e. the person recording any birds missed by the primary observer) saw that same individual. We set recapture probability (c) = 1 since the protocol for dependent double observer assumes that the secondary observer observes all individuals observed by the primary observer. This allowed for two possible encounter histories: 11 or 01, indicating that both observers saw an individual or that the primary observer missed an individual seen by the secondary observer, respectively. Potential covariates for detection probability included site, observer, time of day, social grouping (i.e. whether the observation was of a lone drake, pair, etc.), group size, and date. We defined a group as any individuals ≤ 5 m apart for a majority of the survey time. Groups could include multiple species and individuals of varying social status. We then used the species-specific estimates of detection from the top model to derive estimates of abundance for the four target species across all survey sites and types. We used an average estimate of detection to derive abundance for the remaining duck species. We estimated duck abundance (calculated as indicated breeding pairs; hereafter IBP) at the wetland level in order to ascertain the variation in densities among wetlands. We then used linear models to assess relationships between pair abundance and habitat characteristics of surveyed wetlands. We evaluated single-covariate models only, using covariates expressing the percentage of the surveyed wetland that was made up of open water, herbaceous emergent vegetation, robust emergent vegetation (e.g., bulrush and cattails), and shrub-scrub vegetation (e.g., willows, greasewood, etc.). We compared these to an intercept-only null model and models incorporating linear, quadratic, and cubic time trends.

Brood Abundance/Productivity

We assessed detection probability from our independent double observer surveys of duck broods using Huggins closed capture models (Huggins 1989, Huggins 1991) in Program MARK. We set $c_2=p_2$ to represent the fact that the likelihood of the second observer detecting a particular brood did not depend on whether the first observer detected it (Pagano and Arnold 2009). We incorporated species, species group (dabbling ducks, teal, diving ducks), and duckling age class as individual covariates. We pooled ducklings into age classes I, II, or III because we did not believe detection would vary within each of those age classes (Gollop and Marshall 1954). We then used detection estimates from the top model to adjust brood counts and estimate abundance of each age class across species. For each pond, we calculated a duckling:pair ratio by dividing the maximum estimate of duckling abundance at that pond in

each of the three age classes by the maximum estimate of indicated breeding pairs at that pond throughout the breeding season. We also calculated a brood:pair ratio using maximum brood abundance divided by the maximum pair abundance, where a brood is defined as a group of ducklings associated with a single pair (Pagano et al. 2014). We then used linear models to assess relationships between duckling abundance and habitat characteristics of surveyed wetlands. We evaluated single-covariate models only, using covariates expressing the percentage of the surveyed wetland that was open water, herbaceous emergent vegetation, robust emergent vegetation, and shrub-scrub vegetation. We compared these to an intercept-only null model.

RESULTS AND DISCUSSION

Detection Probability

We conducted 147 dependent double observer surveys on basin wetlands in 2021. Out of 2,086 duck detections during these surveys, 36 were missed by the primary observer. The most parsimonious model of detection probability allowed detectability to vary among observers (two groups: obs A, B, C vs. obs D) and linearly with group size (Table 1). Detection probability was 0.993 and 0.974 for the two levels of observer held constant at mean group size. Detectability increased with group size ($\beta_{group} = 0.28 \pm 0.15$). We conducted 113 independent double observer surveys on riparian areas, irrigation ditches, and hay fields. Out of 258 duck detections, 20 were missed by an observer. The best model of detection probability allowed detectability to vary among habitat types, species (3 groups: small dabbling duck, larger dabbling duck, diving duck), and linearly with group size (Table 2). Estimated detection probabilities were generally high, ranging from 0.91 to 1.00 (Fig. 1). Detectability decreased with group size ($\beta_{group} = -0.59 \pm 0.18$).

We conducted 199 independent double observer surveys for broods. Out of 1,394 duckling detections 518 were missed by an observer. The only model of brood detection probability to outperform the null model included wetland type (AIC_c weight = 1). Detection \pm SE was greatest in hay meadows (1.0 ± 0.00), followed by riparian (0.98 ± 0.02), basin (0.77 ± 0.01), and reservoirs (0.70 ± 0.04).

Breeding Duck and Pair Abundance

At 5 large reservoirs, we conducted 3 rounds of duck counts between 23-Apr and 15-Jun. Duck abundance decreased throughout the survey period (Fig. 2). We conducted duck pair counts on 68 basin wetlands, 18 hay meadows, 13 riparian transects, and 13 irrigation ditch transects from 22-Apr until 18-Jun. Summed across all sites, we observed 3,765 total indicated breeding pairs, including 1,049 gadwall, 648 mallards, 501 northern shovelers, 322 American wigeon, 319 lesser scaup, and 182 cinnamon teal. We modeled pair abundance separately for these species in addition to all ducks combined. For all ducks combined, gadwall, mallards, and cinnamon teal, a cubic effect of day was the most parsimonious time trend model (Table 3). For northern shovelers, a linear time trend was best and for lesser scaup, a quadratic time trend was best; whereas, the null model outperformed any time trend for American wigeon (Table 3). Total pair abundance across species was relatively stable throughout the breeding season but decreased in June, while individual species temporal trends were more variable (Figure 3). We then added vegetation variables to the best time trend model. For all ducks combined, as well as for gadwall, mallard, cinnamon teal, and northern shoveler individually, percent open water was the best habitat variable and was positively related to pair abundance (Table 3, Figure 4). For American wigeon and lesser scaup, scrub/shrub vegetation was best and negatively related to pair abundance (Table 3, Figure 4).

Brood Abundance/Productivity

We conducted 201 brood counts at 74 sites from 12-Jul until 16-Aug. We observed broods of 12 duck species with gadwall being the most common followed by mallard, and cinnamon teal. Summed across surveys and sites we observed 1459 ducklings (267 broods). On average, we conducted three brood surveys per site. Similar to the analysis for pair counts, we modeled duckling abundance for all duck species combined. For the species specific analyses, an excess of counts with zero ducklings observed necessitated modeling presence/absence of broods rather than duckling abundance for mallards, gadwall,

and northern shovelers. For all ducks combined, date in quadratic form was the best temporal trend of duckling abundance, which peaked in early August (Table 4, Figure 5). Percent of the site that was flooded positively influenced duckling abundance; whereas, percent herbaceous vegetation negatively impacted abundance (Figure 6). For gadwall, a cubic time trend was best, whereas for mallards a quadratic trend, and for northern shovelers, the null model was best (Table 4). Gadwall duckling abundance peaked in late July, decreased, and then increased again in mid-August; whereas, mallard duckling abundance had a more gradual peak in late July (Figure 7). Percent herbaceous vegetation was the best habitat variable predicting mallard duckling presence (Table 4). Percent submergent vegetation was best in predicting gadwall and northern shoveler duckling presence (Table 4). The probability of mallard duckling being present on a site decreased with percent herbaceous vegetation (Figure 8). Gadwall and northern shoveler duckling presence increased with percent submergent vegetation on a site (Figure 8).

Mean brood-pair ratio was greatest for cinnamon teal and least for lesser scaup (Table 5). Overall mean \pm SD brood-pair ratio was 0.15 ± 0.37 and duckling pair ratio was 0.86 ± 2.24 (Table 5).

Nest Density, Survival, and Habitat Selection

We searched 131 plots across three privately-owned ranches, Arapahoe National Wildlife Refuge, Lake John State Wildlife Area, and Hebron Slough Waterfowl Area within areas that were managed via flood irrigation. Plots ranged from 0.45-123.55 ha (\bar{x} = 8.58 ha) and we rope-dragged on foot, with ATVs, or searched systematically on foot to locate duck nests. Plots consisted of flooded and dry hay meadows ($n=18$), flooded and dry uncut/nongrazed meadows interspersed with shrubs ($n=75$), expanses of shrub/scrub (primarily greasewood and basin sagebrush; $n=3$), irrigation ditches ($n=6$), reservoir perimeters ($n=4$), and the perimeter of riparian areas ($n=23$). Preliminary results indicate that the top three observed nesting species (mallards, gadwall, and cinnamon teal) all selected nest sites with high visual obstruction (i.e., high vegetation density surrounding the nest), indicating that tall, dense ground vegetation may be important for nesting ducks. We did not detect an effect of the other measured covariates (e.g., percent of each of the following at the nest site: litter, grass, forbs, shrubs, sedges, or rushes) on where each of these three species selected nest sites.

We located 40 nests of six species throughout the 2021 breeding season. A large portion (82.5%, $n=33$) of these nests were located on Arapahoe NWR while 15% ($n=6$) were associated with working lands and 2.5% ($n=1$) were located at Lake John State Wildlife Area. Over the four years the study has been taking place, nest density has been highest in different habitat types each year. Typically riparian areas (mean = 1.09 nests/ha), irrigation ditches (mean = 0.58 nests/ha), and graminoid meadows (mean = 0.42 nests/ha) have exhibited the highest density of nests across all years. Nest density was highest in riparian areas (3.14 nests/ha) in 2021, followed by hay meadows (0.31 nests/ha), irrigation ditches (0.33 nests/ha), graminoid meadows interspersed by shrubs (0.15 nests/ha), purely graminoid meadows (0.13 nests/ha), and shrub-scrub habitat (0 nests/ha). Future analyses will explore how nest density is impacted by local weather conditions and whether that might explain the disparity between densities within the same habitat type across years. Only six nests successfully hatched at least one duckling in 2021, and most nests were depredated by nest predators (e.g., common raven, coyote, etc.). Nest survival did not vary by habitat type and averaged 0.28 (SE = 0.17) across species and habitats.

We deployed cameras at six duck nests during summer 2021. Five of the six nests failed and one was successful. Of the five failed nests, we were able to capture pictures of ravens depredating three. We were not able to identify what depredated the remaining two nests.

Banding Summary

During pre-season trapping operations (30 July – 10 September) we banded 608 ducks of 7 species (Table 6). Given the relatively dry conditions and poor production in 2021, we captured and banded relatively few total ducks, and very few local and hatch year ducks. Our pre-season trapping effort was comprised of 294 trap-days with baited swim-in traps (95% of the banded sample), and 1 night of spotlighting from an airboat (5% of the banded sample). Mallards comprised the majority (82%) of our

banded sample. We captured gadwall (6% of the banded sample) primarily (92%) with spot-lighting. We banded 25 cinnamon and blue-winged teal (4% of the total banded sample); of these, we classified locals (young incapable of flight), hatch year females, and after hatch year females as unidentified teal, because we could not reliably distinguish between the two species in these cohorts. However, given the much higher proportion of cinnamon teal than blue-winged teal in the study area, we suspect that most of these unidentified teal were cinnamon teal.

At the time of this report, 100 ducks we banded in 2018, 91 ducks we banded in 2019, 140 ducks we banded in 2020, and 21 ducks we banded in 2021 (total = 352) had been harvested by hunters and reported to the USGS Bird Banding Laboratory, including 297 mallards, 32 gadwall, 5 cinnamon teal, 4 unidentified teal (likely cinnamon teal), 3 green-winged teal, 4 wigeon, 3 shoveler, 2 redhead, and 2 canvasback. Among mallards, juveniles and adult males have been harvested at higher rates than adult females (Table 7). Most mallards (72.6%) were harvested in Colorado, in 34 different counties (Table 8). Mallards banded in North Park during 2018-2021 were also harvested in 12 other states, including 50 different counties, and the province of Alberta in Canada (Table 8).

Future Work

We plan to continue annual field work through 2023.

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Table 1. Model selection results for duck detection probability on basin wetlands using dependent double observer sampling in North Park, Colorado during 2021.

Model	k	ΔAIC_c	w_i
Observer (2 levels) + group size	3	0.0	1.0
Observer (2 levels)	2	6.2	0.0
Group size	2	11.3	0.0
Null	1	16.8	0.0
Species (2 levels: dab vs. div)	2	18.0	0.0
Species (3 levels: big dab vs. small dab vs. div)	3	19.9	0.0
Social category	4	21.2	0.0
Species (17 levels: all species separately)	17	22.4	0.0

Table 2. Model selection results for duck detection probability on riparian areas, ditches, and hay meadows using independent double observer sampling in North Park, Colorado during 2021.

Model	k	ΔAIC_c	w_i
Habitat type + species (3 levels) + group size	7	0.0	0.8
Habitat type + species (3 levels) + group size + observer	10	3.0	0.2
Habitat type + species (3 levels)	6	9.8	0.0
Habitat type	4	12.6	0.0
Species (3 levels)	3	19.8	0.0
Observer	4	20.9	0.0
Species (2 levels)	2	22.2	0.0
Null	1	23.5	0.0
Species (14 levels)	14	34.7	0.0

Table 3. Model selection results for indicated breeding pairs/survey based on date and vegetation characteristics of sites in North Park, Colorado during the 2021 breeding season. Vegetation variables were added to the best time trend model. K indicates the number of parameters estimated in the model and w_i indicates the model weight.

Species	Model	k	ΔAIC_c	w_i
All ducks				
	Date (cubic) + open water	6	0.0	1.00
	Date (cubic) + shrub/scrub	6	19.8	0.00
	Date (cubic) + bare ground	6	35.8	0.00
	Date (cubic) + herbaceous emergent	6	156.1	0.00
	Date (cubic)	5	175.5	0.00
	Date (cubic) + robust emergent	6	175.7	0.00
	Date (quadratic)	4	176.0	0.00
	Null	2	176.6	0.00
	Date (linear)	3	178.5	0.00
Gadwall				
	Date (cubic) + open water	6	0.0	1.00
	Date (cubic) + bare ground	6	67.0	0.00
	Date (cubic) + herbaceous emergent	6	85.6	0.00
	Date (cubic)	5	90.8	0.00
	Date (cubic) + shrub/scrub	6	91.8	0.00
	Date (cubic) + robust emergent	6	92.2	0.00
	Date (quadratic)	4	97.4	0.00
	Date (linear)	3	114.6	0.00
	Null	2	127.6	0.00
Mallard				
	Date (cubic) + open water	6	0.0	1.00
	Date (cubic) + bare ground	6	41.2	0.00
	Date (cubic)	5	51.3	0.00
	Date (cubic) + herbaceous emergent	6	52.3	0.00
	Date (cubic) + shrub/scrub	6	53.0	0.00
	Date (cubic) + robust emergent	6	53.2	0.00
	Null	2	96.6	0.00
	Date (linear)	3	98.4	0.00
	Date (quadratic)	4	100.3	0.00
Northern shoveler				
	Date (linear) + open water	4	0.0	1.00
	Date (linear) + bare ground	4	16.0	0.00
	Date (linear)	3	17.8	0.00
	Date (linear) + herbaceous emergent	4	18.5	0.00

	Date (linear) + shrub/scrub	4	18.6	0.00
	Date (linear) + robust emergent	4	18.7	0.00
	Date (cubic)	5	19.0	0.00
	Date (quadratic)	4	19.4	0.00
	Null	2	63.5	0.00
American wigeon				
	Shrub/scrub	3	0.0	1.00
	Open water	3	54.8	0.00
	Bare ground	3	74.3	0.00
	Robust emergent	3	89.3	0.00
	Herbaceous emergent	3	91.4	0.00
	Null	2	92.5	0.00
	Date (linear)	3	93.5	0.00
	Date (quadratic)	4	95.3	0.00
	Date (cubic)	5	97.4	0.00
Lesser scaup				
	Date (quadratic) + shrub/scrub	7	0.0	0.92
	Date (quadratic) + bare ground	7	5.0	0.08
	Date (quadratic) + open water	7	58.1	0.00
	Date (quadratic)	4	84.4	0.00
	Date (quadratic) + robust emergent	7	84.8	0.00
	Date (cubic)	5	86.4	0.00
	Date (quadratic) + herbaceous emergent	7	86.4	0.00
	Date (linear)	3	109.2	0.00
	Null	2	257.0	0.00
Cinnamon teal				
	Date (cubic) + open water	6	0.0	0.99
	Date (cubic) + robust emergent	6	10.3	0.01
	Date (cubic) + herbaceous emergent	6	13.1	0.00
	Date (cubic)	5	14.3	0.00
	Date (quadratic)	4	14.8	0.00
	Date (cubic) + shrub/scrub	6	16.3	0.00
	Date (cubic) + bare ground	6	16.4	0.00
	Date (linear)	3	26.5	0.00
	Null	2	35.6	0.00

Table 4. Model selection results for duckling abundance and brood presence based on date and vegetation characteristics of sites in North Park, Colorado during the 2021 breeding season. For all ducks, we modeled duckling abundance; whereas, for gadwall, mallard, and northern shoveler, we modeled brood presence. Vegetation variables were added to the best time trend model. K indicates the number of parameters estimated in the model and w_i indicates the model weight.

Species	Model	k	ΔAIC_c	w_i
All ducks				
	Date (quadratic) + per. flooded + per. herbaceous	7	0.0	0.81
	Date (quadratic) + per. flooded	6	2.9	0.19
	Date (quadratic) + per. herbaceous	6	11.8	0.00
	Date (quadratic)	5	16.2	0.00
	Date (quadratic) + per. robust emergent	6	16.4	0.00
	Date (quadratic) + per. emergent	6	18.0	0.00
	Date (quadratic) + per. submergent	6	18.1	0.00
	Date (cubic)	6	18.1	0.00
	Date (quadratic) + per. shrub/scrub	6	18.2	0.00
	Date (linear)	4	18.5	0.00
	Null	3	21.1	0.00
Gadwall				
	Date (cubic) + per. submergent	7	0.0	0.88
	Date (cubic) + per. emergent	7	5.9	0.05
	Date (cubic) + per. flooded	7	7.5	0.02
	Date (cubic)	6	7.6	0.02
	Date (quadratic)	5	7.7	0.02
	Date (cubic) + per. herbaceous	7	7.8	0.02
	Date (linear)	4	16.4	0.00
	Null	3	23.8	0.00
Mallard				
	Date (quadratic) + per. herbaceous	6	0.0	0.32
	Date (quadratic) + per. flooded	6	0.5	0.25
	Date (quadratic) + per. shrub/scrub	6	1.6	0.14
	Date (quadratic) + per. submergent	6	2.5	0.09
	Date (quadratic)	5	3.6	0.05
	Date (linear)	4	4.4	0.04
	Date (quadratic) + per. robust emergent	6	4.8	0.03
	Date (cubic)	6	4.8	0.03
	Null	3	5.0	0.03
	Date (quadratic) + per. emergent	6	5.4	0.02
Northern shoveler				
	Per. submergent	4	0.0	0.38
	Null	3	2.1	0.13

Per. emergent	4	2.5	0.11
Per. flooded	4	3.0	0.08
Per. shrub/scrub	4	3.3	0.07
Per. herbaceous	4	3.3	0.07
Date (linear)	4	4.0	0.05
Per. robust emergent	4	4.1	0.05
Date (quadratic)	5	4.9	0.03
Date (cubic)	6	5.6	0.02

Table 5. Brood and duckling-pair ratios with associated standard deviation and minimum and maximum values across sites in North Park, Colorado during 2021.

Species group	Brood-pair ratio				Duckling-pair ratio			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Cinnamon teal	0.15	0.29	0.0	1.0	0.76	1.55	0.0	8.0
Mallard	0.08	0.19	0.0	1.0	0.49	1.13	0.0	4.75
Gadwall	0.11	0.24	0.0	1.0	0.58	1.33	0.0	5.67
Lesser scaup	0.02	0.06	0.0	0.4	0.09	0.37	0.0	2.6
Northern shoveler	0.13	0.39	0.0	2.0	0.61	1.83	0.0	10.0
All ducks	0.15	0.37	0.0	2.0	0.86	2.24	0.0	12.5

Table 6. Numbers of ducks banded in North Park during pre-season capture efforts in 2021. LM = local male, LF = local female, HYM = hatch year male, HYF = hatch year female, AHYM = after hatch year male, and AHYF = after hatch year female.

Species	AHYF	AHYM	HYF	HYM	LF	LM	Total
Mallard	95	306	38	57	0	0	496
Gadwall	11	25	1	1	0	0	36
Cinnamon/blue-winged teal ^a	9	12	2	2	0	0	25
Green-winged teal	1	32	1	1	3	3	41
American wigeon	1	0	0	0	0	0	1
Northern pintail	4	0	2	0	0	0	6
Total	121	376	44	61	3	3	608

^aWe could not reliably distinguish between cinnamon and blue-winged teal for locals and females.

Table 7. Numbers of mallards banded in North Park during 2018-2021 in different age and sex cohorts and reported shot by hunters during hunting seasons through December 31, 2021.

Banded cohort	Band year	Number banded	Number harvested (% of banded sample)			
			2018-2019	2019-2020	2020-2021	2021-2022
AHY male	2018	168	10 (6.0%)	11 (6.5%)	5 (3.0%)	0
	2019	234	-	24 (10.3%)	8 (3.4%)	3 (1.3%)
	2020	246	-	-	16 (6.5%)	7 (2.8%)
	2021	306	-	-	-	12 (3.9%)
AHY female	2018	69	1 (1.4%)	2 (2.9%)	0	0
	2019	104	-	4 (3.8 %)	1 (1.0%)	1 (1.0%)
	2020	108	-	-	10 (9.3%)	2 (1.9%)
	2021	95	-	-	-	1 (1.1%)
HY male	2018	221	29 (13.1%)	13 (5.9%)	2 (0.9%)	2 (0.9%)
	2019	109	-	12 (11.0%)	6 (5.5%)	0
	2020	266	-	-	25 (9.4%)	14 (5.3%)
	2021	57	-	-	-	5 (8.8%)
HY female	2018	131	13 (9.9%)	5 (3.8%)	0	0
	2019	73	-	3 (4.1%)	1 (1.4%)	0
	2020	200	-	-	24 (12.0%)	4 (2.0%)
	2021	38	-	-	-	1 (2.6%)
L male	2018	12	1 (8.3%)	0	0	0
	2019	7	-	1 (14.3%)	0	0
	2020	25	-	-	5 (20.0%)	0
	2021	0	-	-	-	-
L female	2018	14	2 (14.3%)	0	0	0
	2019	11	-	1 (9.1)	0	0
	2020	28	-	-	3 (10.7%)	0
	2021	0	-	-	-	-
Total	2018	615	56 (9.1%)	31 (5.0%)	7 (0.7%)	2 (0.3%)
	2019	538	-	45 (8.4%)	16 (3.0%)	4 (0.7%)
	2020	873	-	-	83 (9.5%)	27 (3.1%)
	2021	496	-	-	-	19 (3.8%)

Table 8. Distribution by U.S. states and counties, and Canadian provinces, of the number (% of total) of direct (harvested during the hunting season immediately following banding) and indirect (harvested during hunting seasons one or more years after banding) recoveries of mallards banded in North Park, 2018-2021, reported by hunters through December 31, 2021.

State	County	Direct recoveries	Indirect recoveries
Colorado	Total	161 (78.2)	54 (61.7)
	Adams	3 (1.5)	2 (2.2)
	Alamosa	5 (2.4)	1 (1.1)
	Bent	2 (1.0)	1 (1.1)
	Boulder	4 (1.9)	2 (2.2)
	Chaffee	1 (0.5)	0
	Conejos	1 (0.5)	1 (1.1)
	Costilla	2 (1.0)	0
	Delta	0	1 (1.1)
	Dolores	0	1 (1.1)
	Douglas	1 (0.5)	0
	Eagle	7 (3.4)	0
	El Paso	1 (0.5)	0
	Fremont	1 (0.5)	1 (1.1)
	Garfield	1 (0.5)	0
	Grand	10 (4.9)	4 (4.4)
	Gunnison	1 (0.5)	0
	Jackson	54 (26.2)	6 (6.7)
	La Plata	1 (0.5)	1 (1.1)
	Larimer	3 (1.5)	1 (1.1)
	Las Animas	3 (1.5)	1 (1.1)
	Logan	0	2 (2.2)
	Mesa	2 (1.0)	1 (1.1)
	Montrose	0	2 (2.2)
	Morgan	5 (2.4)	3 (3.3)
	Otero	6 (2.9)	2 (2.2)
	Park	5 (2.4)	3
	Pitkin	1 (0.5)	0
	Prowers	1 (0.5)	0
	Pueblo	7 (3.4)	1 (1.1)
	Rio Grande	4 (1.9)	1 (1.1)
	Routt	4 (1.9)	1 (1.1)
	Saguache	6 (2.9)	1 (1.1)
Summit	1 (0.5)	0	
Weld	18 (8.7)	14 (15.6)	
Arizona	Total	2 (1.0)	0
	Coconino	1 (0.5)	0
	Maricopa	1 (0.5)	0
Kansas	Total	2 (1.0)	2 (2.2)
	Barton	1 (0.5)	0
	Hamilton	0	1 (1.1)
	Trego	1 (0.5)	1 (1.1)

Missouri	Total	0	1 (1.1)
	Holt	0	1 (1.1)
Montana	Total	1 (0.5)	0
	Yellowstone	1 (0.5)	0
Nebraska	Total	3 (1.5)	3 (3.3)
	Garden	1 (0.5)	0
	Keith	1 (0.5)	0
	Lincoln	1 (0.5)	1 (1.1)
	Morrill	0	1 (1.1)
	Scotts Bluff	0	1 (1.1)
New Mexico	Total	25 (12.1)	10 (11.1)
	Bernalillo	1 (0.5)	0
	Chaves	2	0
	Dona Ana	1 (0.5)	0
	Mora	0	1 (1.1)
	Rio Arriba	1 (0.5)	0
	Roosevelt	1 (0.5)	0
	San Juan	1 (0.5)	2 (2.2)
	Sandoval	0	1 (1.1)
	Santa Fe	1 (0.5)	0
	Sierra	2 (1.0)	1 (1.1)
	Socorro	7 (3.4)	4
	Taos	1 (0.5)	0
	Valencia	7 (3.4)	1 (1.1)
Nevada	Total	0	1 (1.1)
	Lyon	0	1 (1.1)
Oklahoma	Total	2 (1.0)	5 (5.6)
	Caddo	0	1 (1.1)
	Carnegie	0	1 (1.1)
	Garfield	1 (0.5)	0
	Logan	0	1 (1.1)
	Oklahoma	0	2 (2.2)
	Pottawatomie	1 (0.5)	0
South Dakota	Total	0	1 (1.1)
	Fall River	0	1 (1.1)
Texas	Total	7 (3.4)	5 (5.6)
	Carson	1 (0.5)	0
	Crosby	0	1 (1.1)
	Haskell	1 (0.5)	0
	Hockley	0	1 (1.1)
	Hudspeth	1 (0.5)	1 (1.1)
	McCulloch	1 (0.5)	0
	Oldham	2 (1.0)	1 (1.1)
	Reeves	0	1 (1.1)

	Terry	1 (0.5)	0
Utah	Total	2 (1.0)	3 (3.3)
	Davis	0	1 (1.1)
	Duchesne	1 (0.5)	0
	Salt Lake	0	1 (1.1)
	Uintah	1 (0.5)	0
	Weber	0	1 (1.1)
Wyoming	Total	1 (0.5)	4 (2.1)
	Albany	1 (0.5)	2 (2.2)
	Lincoln	0	1 (1.1)
	Sublette	0	1 (1.1)
Canada	Total	0	1 (1.1)
	Alberta	0	1 (1.1)
Total recoveries		206	90

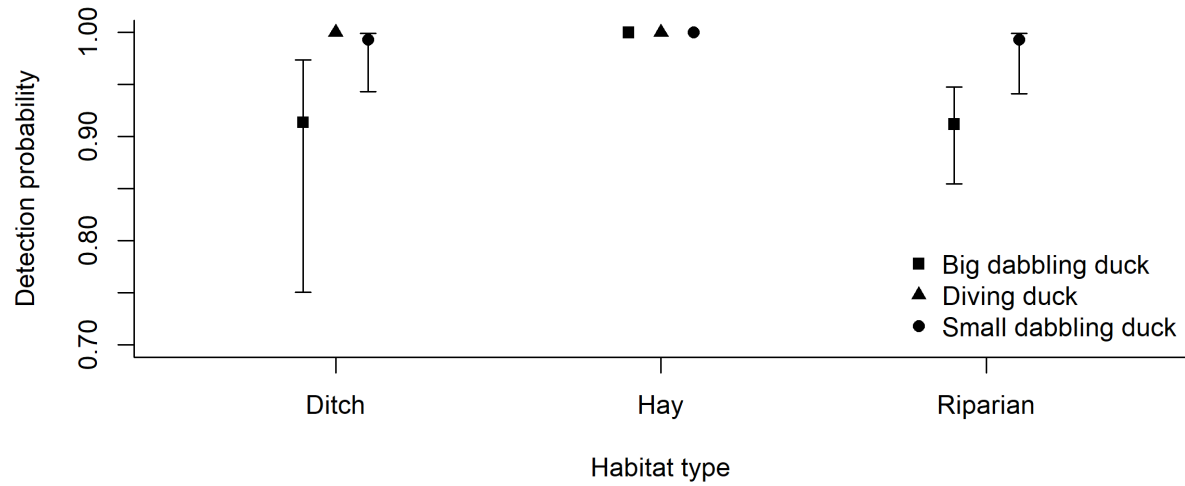


Figure 1. Estimated duck detection probability based on independent double observer surveys at ditches, riparian areas, and hay fields for big dabbling ducks, small dabbling ducks, and diving ducks in North Park, Colorado during 2021.

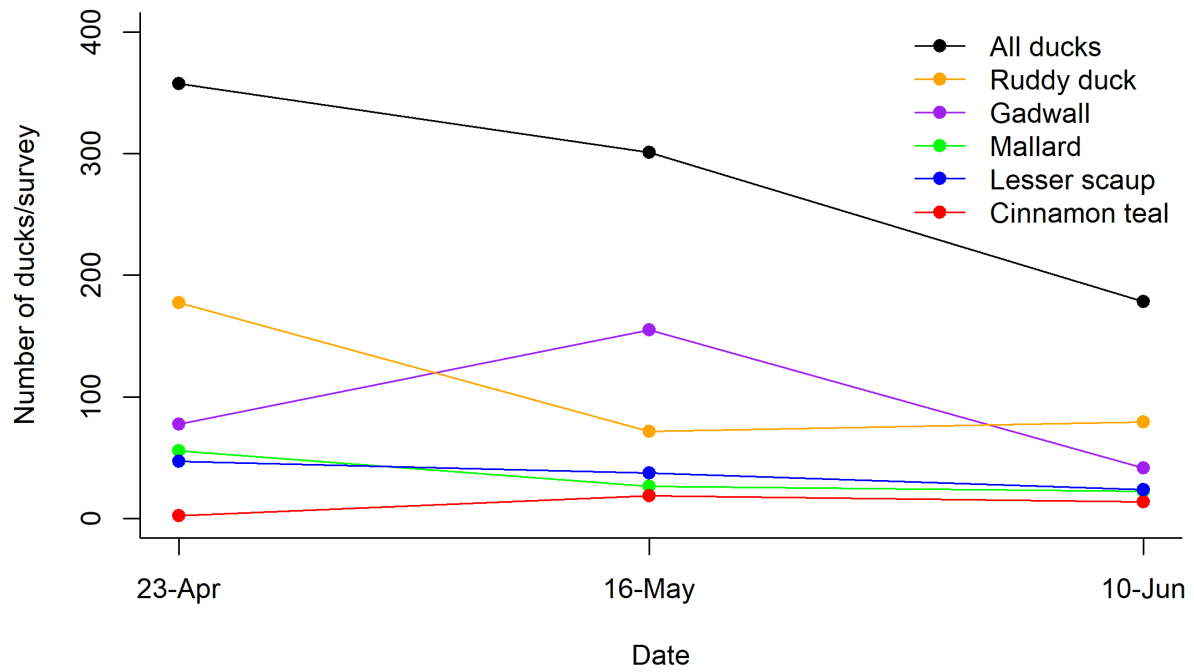


Figure 2. Number of ducks detected per survey for three surveys throughout the 2021 duck breeding season at five large reservoirs in North Park, Colorado.

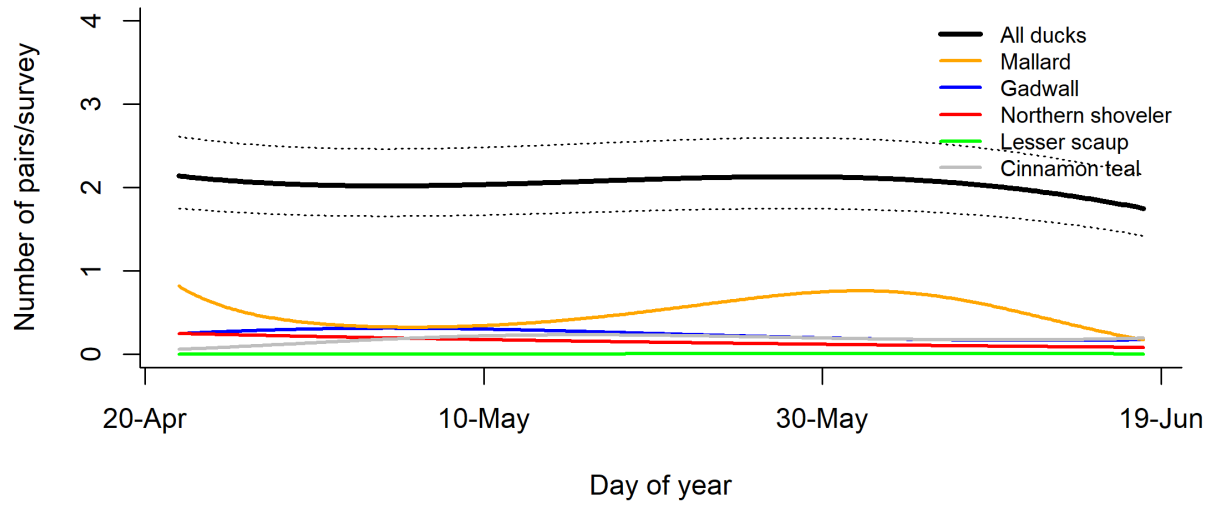


Figure 3. Number of indicated breeding pairs per survey for all ducks and select species throughout the 2021 duck breeding season in North Park, Colorado. Dotted lines indicate ± 1 SE.

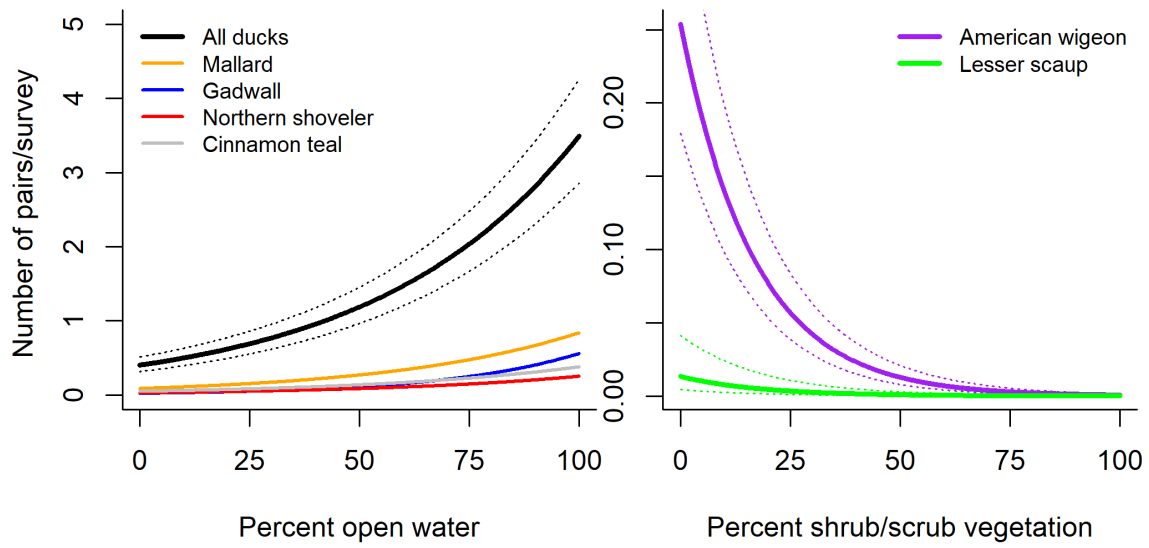


Figure 4. Effects of open water and shrub/scrub vegetation on duck indicated breeding pair abundance in North Park, Colorado during 2021. Dotted lines indicate ± 1 SE.

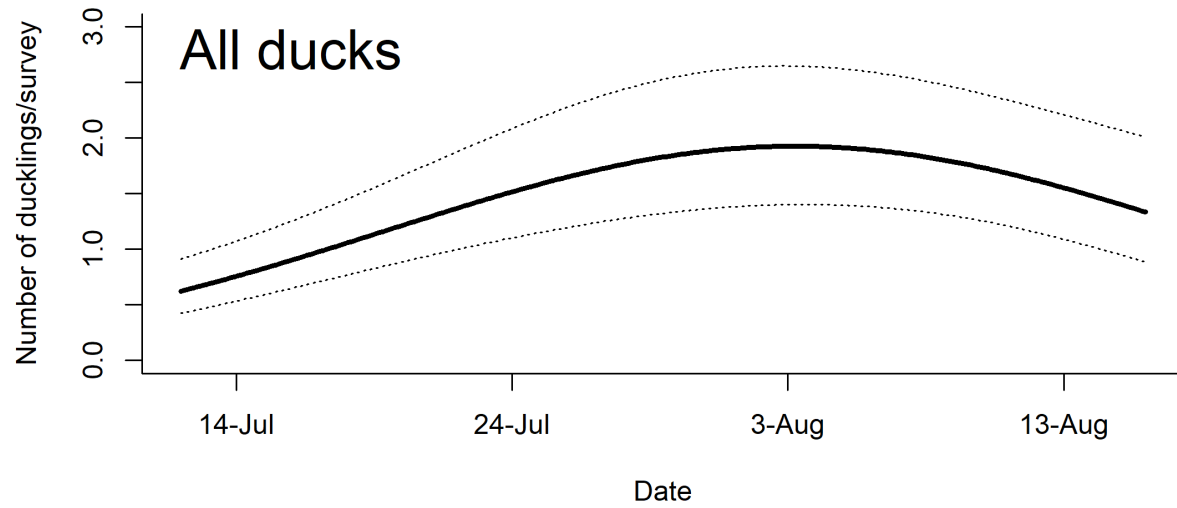


Figure 5. Model-estimated time-trend of duck brood abundance for all ducks combined throughout the 2021 breeding season in North Park, Colorado. Dotted lines indicate ± 1 SE.

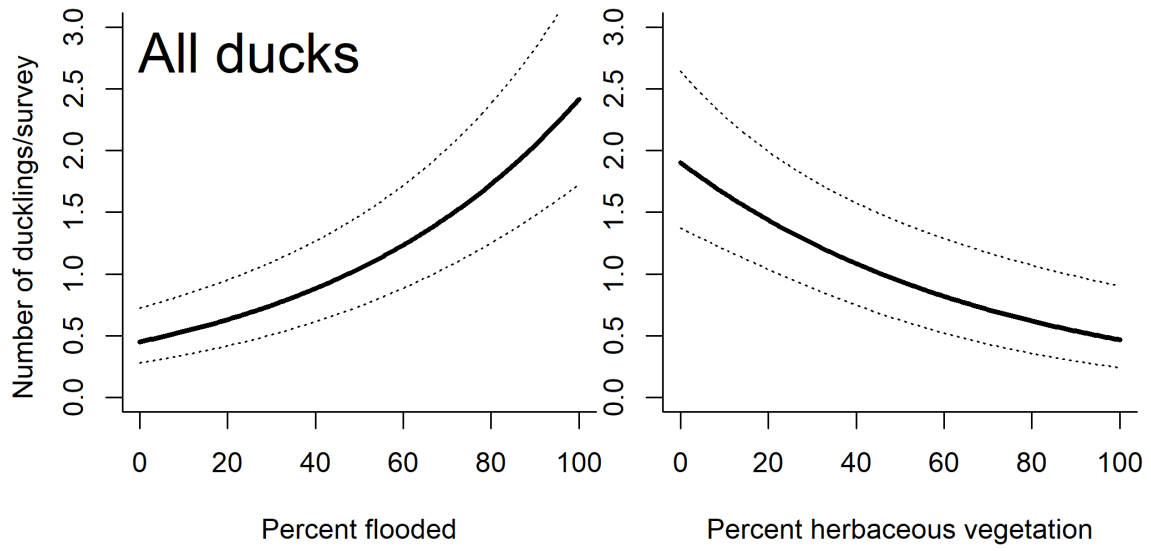


Figure 6. Model-estimated effects of the percent of a site that was flooded and covered with herbaceous vegetation on duckling abundance for all species combined in North Park, Colorado during 2021. Dotted lines indicate ± 1 SE.

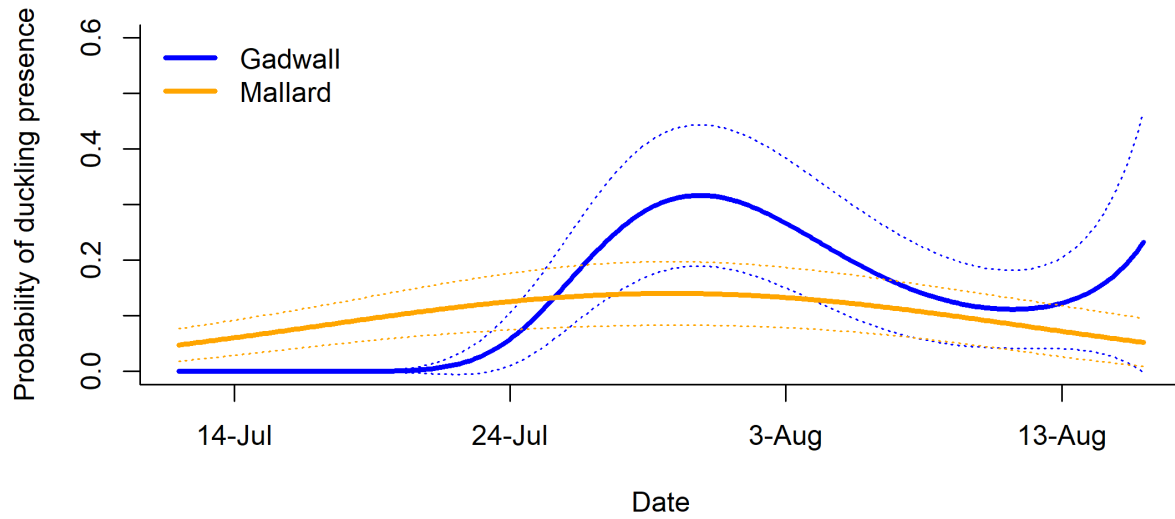


Figure 7. Model-estimated probability of duckling presence by date for gadwall and mallard across the 2021 breeding season in North Park, Colorado. Dotted lines indicate ± 1 SE.

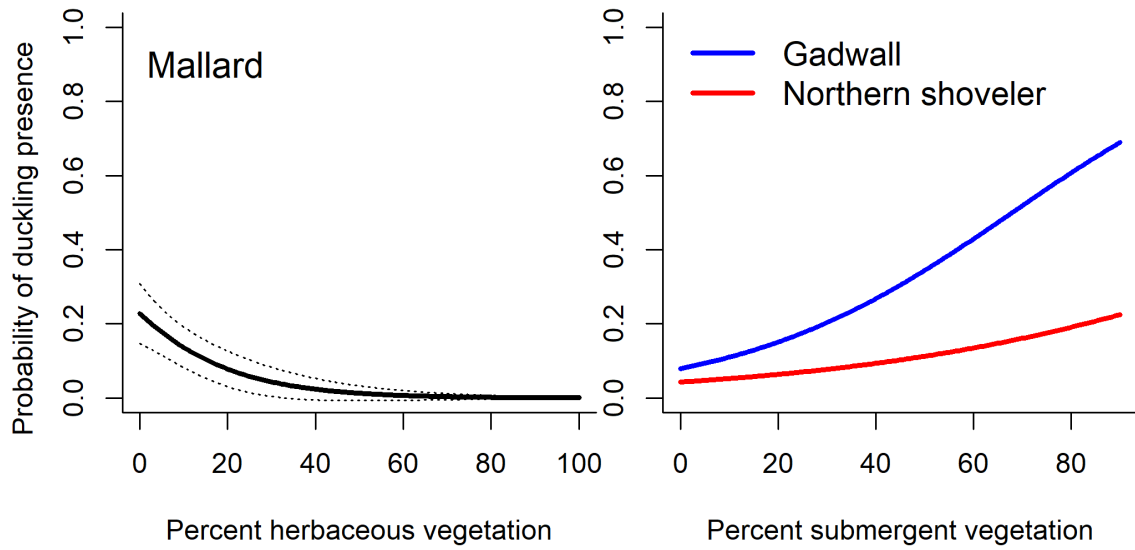


Figure 8. Model-estimated effects of herbaceous and submergent vegetation on mallard, gadwall, and northern shoveler duckling presence at sites in North Park, Colorado during 2021. Dotted lines indicate ± 1 SE.