COLORADO PARKS AND WILDLIFE - AVIAN RESEARCH PROGRAM
Progress Report
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TITLE: Estimates and determinants of duck production in North Park, Colorado

AUTHORS: Adam C. Behney, James H. Gammonley, and Casey M. Setash

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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. Our first objective was to estimate the breeding population of ducks and evaluate the variation in abundance across wetlands. In 2022, we surveyed 120 individual wetlands for breeding ducks. Summed across all sites, we observed 3,388 total indicated breeding pairs, including 763 mallards, 626 gadwall, 180 cinnamon teal, and 171 lesser scaup. The number of indicated breeding pairs was greatest on wetlands with more open water. Our second objective was to assess nesting characteristics of waterfowl throughout the park. We monitored 32 duck nests and 5 successfully hatched at least one egg. Another objective was to estimate duck production using brood surveys across the park. We conducted brood surveys on 119 wetlands and observed broods of 11 duck species. Duckling:pair ratio for all ducks ranged from 0 to 33 and averaged 1.80 (SD=4.16) ducklings/pair. Our last objective was to use banding data to obtain demographic estimates and the contribution of North Park ducks to hunting opportunity. In 2022 we banded 982 ducks during preseason banding operations. At the time of this report, 105 ducks we banded in 2018, 99 ducks we banded in 2019, 175 ducks we banded in 2020, 41 ducks we banded in 2021, and 93 ducks we banded in 2022 (total = 513) 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 miles^2 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 miles^2 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. geyeriana*). 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 mile^2) 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 2019-2022. 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 an airboat and spotlights at night on four sites. We marked ducks with standard U.S. Geological Survey (USGS) legbands and released them at their capture sites. 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 $\leq$ 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.

Banding

We trapped ducks on Arapaho NWR, Hebron Waterfowl Area, and Lake John State Wildlife Area during 30 July – 10 September, using swim-in traps baited with cracked corn at 7 wetland sites, each with 1 – 4 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. 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.

RESULTS AND DISCUSSION

Detection Probability

We conducted 268 dependent double observer surveys on basin wetlands in 2022. Out of 3,165 duck detections during these surveys, 54 were missed by the primary observer. The most parsimonious model of detection probability allowed detectability to vary among observers, species group (divers, large dabblers, small dabblers), and linearly with group size (Table 1). Estimated detection probability was between 0.98 and 1.00 for each combination of observer and species, at mean group size. Detectability increased with group size ($\beta_{group} = 0.19 \pm 0.09$). We conducted 118 independent double observer surveys on riparian areas, irrigation ditches, and hay fields. Out of 101 duck detections, 10 were missed by an observer. The best model of detection probability for independent double observer surveys allowed detectability to vary among species (2 groups: dabbling ducks versus diving ducks; Table 2). Estimated detection probabilities were 0.96 ± 0.02 for dabbling ducks and 0.75 ± 0.17 for diving ducks.

We conducted 175 independent double observer surveys for broods. Out of 5,884 duckling detections, 2190 were missed by an observer. The best model of brood detection probability included observer and species (large dabbler, small dabbler, diver; Table 3). Detection ± SE ranged from 0.63 ± 0.03 to 0.88 ± 0.01 among observers and species (Figure 1).

Breeding Duck and Pair Abundance

At 5 large reservoirs, we conducted 4 rounds of duck counts between 20-Apr and 15-Jun. Duck abundance decreased throughout the survey period, but we did observe a slight uptick during the last survey (Figure 2). We conducted 409 pair counts on 75 basin wetlands, 20 hay meadows, 13 riparian transects, and 12 irrigation ditch transects from 20-Apr until 24-Jun. Summed across all sites, we observed 3,388 total indicated breeding pairs of 16 duck species, including 763 mallards, 626 gadwall, 180 cinnamon teal, and 171 lesser scaup. We modeled pair abundance separately for these species in addition to all ducks combined. For all ducks combined, mallards, and cinnamon teal, a cubic effect of day was the most parsimonious time trend model; whereas, for gadwalls and lesser scaup, a quadratic time trend was best (Table 4). Total pair abundance across species declined early in the breeding season and then was relatively stable through June, whereas, individual species pair abundance varied through time (Figure 3). We then added vegetation variables to the best time trend model. For all ducks combined and each species separately, open water was an important, positive, predictor of pair abundance (Table 4, Figure 4). For gadwall, percent shrub/scrub (negative relationship) and robust emergent vegetation (positive relationship) were also important predictors of pair abundance (Table 4, Figure 4).

Brood Abundance/Productivity

We conducted 328 brood counts at 119 sites from 25-Jul through 2-Sep. We observed broods of 11 duck species with gadwall being the most common followed by lesser scaup, mallard, and cinnamon teal. Summed across surveys and sites, we observed 6,263 ducklings (986 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, lesser scaup, and cinnamon teal. For all ducks combined, date in cubic form ($date^3$) was the best temporal trend of duckling abundance, which peaked in early August (Table 5, Figure 5). Percent of the site that was flooded positively influenced duckling abundance (Figure 6). For gadwall, mallards, and cinnamon teal, a quadratic time trend ($date^2$) was best, whereas for lesser scaup a cubic trend was the best temporal predictor of duckling presence (Table 5). Duckling presence for gadwall, mallards, lesser scaup, and cinnamon teal peaked in early to mid-August (Figure 7). Percent of the site that was flooded was the best habitat variable predicting gadwall, mallard, and cinnamon teal duckling presence (Table 5) and presence was positively related to percent flooded (Figure 8). Percent herbaceous vegetation was best in predicting lesser scaup duckling presence (Table 4) and was negatively related to duckling presence (Figure 9).

Mean brood-pair ratio was greatest for gadwall and least for mallards (Table 6). Overall mean ± SD brood-pair ratio was 0.29 ± 0.70 and duckling-pair ratio was 1.80 ± 4.16 (Table 6).

Nest Density and Survival

We searched 1,311 ha for duck nests in 2022. We located 32 nests of eight species throughout the 2022 breeding season. Unadjusted nest density was 0.02 nests/ha in shrub-scrub habitat, 0.03 in riparian, 0 in hay meadows, 0.02 in graminoid meadows interspersed with shrubs, 0.04 in strictly graminoid meadows, 0.06 in emergent marsh, and 0 along irrigation ditches. All but three of these nests (90.6%) were located on Arapahoe NWR, with the others located on private, BLM, and SWA properties. Only five monitored nests successfully hatched at least one duckling in 2022, and most nests failed due to depredation (n = 20). The most parsimonious model explaining variation in nest survival included a covariate for nest initiation date (β = -0.07, SD = 0.23). None of the habitat predictors we included in a global model were associated with nest survival. At the mean nest initiation date, daily survival rate was 0.906 (SD = 0.018) equating to overall nest success of 0.05 (SD = 0.03) across species and habitats.

Banding Summary

During pre-season trapping operations (15 August – 16 September) we banded 982 ducks of 11 species (Table 6). Our pre-season trapping effort was comprised of 300 trap-days with baited swim-in traps (70% of the banded sample), and 4 nights of spotlighting from an airboat (30% of the banded sample). Mallards comprised the majority (62%) of our banded sample. We captured gadwall (20% of the banded sample) primarily (94%) with spot-lighting. We banded 38 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, 105 ducks we banded in 2018, 99 ducks we banded in 2019, 175 ducks we banded in 2020, 41 ducks we banded in 2021, and 93 ducks we banded in 2022 (total = 513) had been harvested by hunters and reported to the USGS Bird Banding Laboratory, including 402 mallards, 58 gadwall, 5 cinnamon teal, 7 unidentified teal (likely cinnamon teal), 11 shovelers, 7 green-winged teal, 7 wigeon, 2 pintails, 2 Mexican ducks, 7 lesser scaup, 3 redhead, and 2 canvasback. Among mallards, juveniles and adult males have been harvested at higher rates than adult females (Table 7). Most mallards (73.6%) were harvested in Colorado, in 36 different counties (Table 8). Mallards banded in North Park during 2018-2022 were also harvested in 13 other states, including 58 different counties, and the provinces of Alberta and Saskatchewan 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 2022.

Model	**K**	**ΔAIC$_c$**	**w$_i$**
Observer (6 levels) + species (3 levels) + group size	9	0.0	0.7
Observer (6 levels) + species (2 levels) + group size	8	2.2	0.2
Observer (6 levels)	6	13.0	0.0
Observer (6 levels) + species (2 levels)	7	14.6	0.0
Observer (6 levels) + species (3 levels)	8	14.8	0.0
Group size	2	39.2	0.0
Species (2 levels) + group size	3	40.8	0.0
Species (3 levels) + group size	4	41.1	0.0
Species (2 levels)	2	61.0	0.0
Null	1	61.1	0.0
Species (3 levels)	3	61.9	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 2022.

Model	**K**	**ΔAIC_c**	**w_i**
Species (2 levels)	2	0.0	0.3
Null	1	1.4	0.2
Species (2 levels) + habitat type	4	1.7	0.1
Species (3 levels)	3	1.9	0.1
Habitat type	3	2.6	0.1
Species (2 levels) + habitat type + group size	5	3.6	0.1
Observer	6	3.7	0.1
Species (2 levels) + habitat type + group size + observer	10	6.0	0.0

Table 3. Model selection results for duck brood detection probability using independent double observer sampling in North Park, Colorado during 2022.

Model	**K**	**ΔAIC_c**	**w_i**
Observer + species (3 levels)	8	0.0	1.0
Observer	5	66.2	0.0
Habitat type + species (3 levels)	7	201.0	0.0
Species (3 levels)	4	201.5	0.0
Species (2 levels)	3	205.1	0.0
Habitat type	4	263.5	0.0
Null	1	264.6	0.0

Table 4. Model selection results for indicated breeding pairs/survey based on date and vegetation characteristics of sites in North Park, Colorado during the 2022 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	1.0
	Date (cubic) + robust emergent	6	234.4	0.0
	Date (cubic) + bare ground	6	324.6	0.0
	Date (cubic) + shrub/scrub	6	332.0	0.0
	Date (cubic) + herbaceous emergent	6	339.7	0.0
	Date (cubic)	5	341.4	0.0
	Date (linear)	3	356.1	0.0
	Date (quadratic)	4	358.1	0.0
	Null	2	363.4	0.0
Gadwall				
	Date (quadratic) + shrub/scrub	5	0.0	0.6
	Date (quadratic) + open water	5	0.7	0.4
	Date (quadratic) + robust emergent	5	9.9	0.0
	Date (quadratic)	4	13.0	0.0
	Date (quadratic) + herbaceous emergent	5	13.6	0.0
	Date (quadratic) + bare ground	5	14.1	0.0
	Date (cubic)	5	15.0	0.0
	Date (linear)	3	17.9	0.0
	Null	2	18.7	0.0
Mallard				
	Date (cubic) + open water	6	0.0	1.0
	Date (cubic) + robust emergent	6	141.1	0.0
	Date (cubic) + herbaceous emergent	6	167.2	0.0
	Date (cubic)	5	233.0	0.0
	Date (cubic) + bare ground	6	233.1	0.0
	Date (cubic) + shrub/scrub	6	235.0	0.0
	Date (quadratic)	4	307.1	0.0
	Date (linear)	3	324.1	0.0
	Null	2	336.2	0.0
Cinnamon teal				
	Date (cubic) + open water	6	0.0	0.2
	Date (cubic) + robust emergent	6	0.1	0.2
	Date (cubic) + bare ground	6	0.8	0.2
	Date (cubic) + shrub/scrub	6	0.9	0.2
	Date (cubic)	5	1.4	0.1
	Date (cubic) + herbaceous emergent	6	2.8	0.1

	Date (quadratic)	4	20.7	0.0
	Date (linear)	3	21.1	0.0
	Null	2	23.6	0.0
Lesser scaup				
	Date (quadratic) + open water	5	0.0	1.0
	Date (quadratic) + bare ground	5	39.0	0.0
	Date (quadratic) + robust emergent	5	43.8	0.0
	Date (quadratic) + herbaceous emergent	5	47.2	0.0
	Date (quadratic)	4	47.5	0.0
	Date (cubic)	5	48.4	0.0
	Date (quadratic) + shrub/scrub	5	49.3	0.0
	Date (linear)	3	70.3	0.0
	Null	2	115.7	0.0

Table 5. Model selection results for duckling abundance and brood presence based on date and vegetation characteristics of sites in North Park, Colorado during the 2022 breeding season. For all ducks, we modeled duckling abundance, whereas, for gadwall, mallard, lesser scaup, and cinnamon teal, 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 (cubic) + per. flooded	12	0.0	1.0
	Date (cubic) + per. shrub	12	121.6	0.0
	Date (cubic) + per. herbaceous	12	139.4	0.0
	Date (cubic) + per. robust emergent	12	139.9	0.0
	Date (cubic)	10	142.0	0.0
	Date (cubic) + per. emergent	12	144.3	0.0
	Date (cubic) + per. submergent	12	144.8	0.0
	Date (quadratic)	8	145.3	0.0
	Date (linear)	4	404.4	0.0
	Null	3	621.7	0.0
Gadwall				
	Date (quadratic) + per. flooded	5	0.0	1.0
	Date (quadratic)	4	9.1	0.0
	Date (quadratic) + per. submergent	5	9.7	0.0
	Date (quadratic) + per. shrub	5	10.0	0.0
	Date (quadratic) + per. robust emergent	5	10.1	0.0
	Date (quadratic) + per. emergent	5	10.8	0.0
	Date (quadratic) + per. herbaceous	5	11.1	0.0
	Date (cubic)	5	11.2	0.0
	Null	2	11.4	0.0
	Date (linear)	3	13.1	0.0
Mallard				
	Date (quadratic) + per. flooded	5	0.0	0.7
	Date (quadratic) + per. shrub	5	3.4	0.1
	Date (quadratic) + per. herbaceous	5	4.9	0.1
	Date (quadratic)	4	5.7	0.0
	Date (quadratic) + per. emergent	5	6	0.0
	Date (cubic)	5	7.7	0.0
	Date (quadratic) + per. submergent	5	7.8	0.0
	Date (quadratic) + per. robust emergent	5	7.8	0.0
	Date (linear)	3	10.0	0.0
	Null	2	11.5	0.0
Lesser scaup				
	Date (cubic) + per. herbaceous	6	0.0	0.6

	Date (cubic)	5	4.0	0.1
	Date (cubic) + per. submergent	6	4.2	0.1
	Date (quadratic)	4	4.4	0.1
	Date (cubic) + per. shrub	6	5.4	0.0
	Date (cubic) + per. flooded	6	5.8	0.0
	Date (cubic) + per. emergent	6	5.8	0.0
	Date (cubic) + per. robust emergent	6	5.9	0.0
	Date (linear)	3	12.4	0.0
	Null	2	13.0	0.0
Cinnamon teal				
	Date (quadratic) + per. flooded	5	0.0	0.6
	Date (quadratic) + per. submergent	5	2.7	0.1
	Date (quadratic) + per. shrub	5	4.2	0.1
	Date (quadratic)	4	4.7	0.1
	Date (cubic)	5	4.9	0.0
	Date (quadratic) + per. robust emergent	5	5.6	0.0
	Date (quadratic) + per. emergent	5	6.5	0.0
	Date (quadratic) + per. herbaceous	5	6.6	0.0
	Null	2	7.5	0.0
	Date (linear)	3	8.8	0.0

Table 6. Brood and duckling-pair ratios with associated standard deviation and minimum and maximum values across sites in North Park, Colorado during 2022.

	Brood-pair ratio				Duckling-pair ratio			
Species	Mean	SD	Min	Max	Mean	SD	Min	Max
Cinnamon teal	0.09	0.32	0.00	2.00	0.58	2.47	0.00	20.00
Mallard	0.07	0.21	0.00	1.07	0.54	1.54	0.00	8.00
Gadwall	0.38	0.83	0.00	4.00	2.64	5.90	0.00	29.00
Lesser scaup	0.13	0.43	0.00	3.00	0.90	3.25	0.00	23.00
All ducks	0.29	0.70	0.00	6.00	1.80	4.16	0.00	33.00

Table 6. Numbers of ducks banded in North Park during pre-season capture efforts in 2022. 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	68	239	95	186	6	10	604
Gadwall	23	18	29	38	37	55	200
Shoveler	3	2	13	13	8	9	48
Cinnamon/blue-winged teal[a]	3	1	20	12	1	1	38
Lesser scaup	1	0	8	4	4	15	32
American wigeon	6	7	4	4	6	3	30
Green-winged teal	2	3	0	4	0	1	10
Mexican duck	0	8	0	1	0	0	9
Redhead	2	3	0	0	1	2	8
Pintail	0	0	2	0	0	1	3
Total	108	281	171	262	63	97	982

[a]We could not reliably distinguish between cinnamon and blue-winged teal for locals and females.

Table 7. Numbers of mallards banded in North Park during 2018-2022 in different age and sex cohorts and reported shot by hunters during hunting seasons through December 31, 2022.

Banded cohort	Band year	Number banded	Number harvested (% of banded sample)				
			2018-2019	2019-2020	2020-2021	2021-2022	2022-2023
AHY male	2018	168	10 (6.0%)	11 (6.5%)	5 (3.0%)	0	1 (0.6%)
	2019	234	-	23 (9.8%)	8 (3.4%)	9 (3.8%)	2 (0.9%)
	2020	246	-	-	16 (6.5%)	14 (5.7%)	5 (2.0%)
	2021	306	-	-	-	22 (7.2%)	1 (0.3%)
	2022	239	-	-	-	-	14 (5.9%)
AHY female	2018	69	1 (1.4%)	2 (2.9%)	0	0	0
	2019	104	-	4 (3.8 %)	1 (1.0%)	1 (1.0%)	0
	2020	108	-	-	10 (9.3%)	2 (1.9%)	1 (0.9%)
	2021	95	-	-	-	2 (2.1%)	0
	2022	68	-	-	-	-	4 (5.9%)
HY male	2018	221	29 (13.1%)	12 (5.4%)	2 (0.9%)	5 (2.3%)	2 (0.9%)
	2019	109	-	12 (11.0%)	6 (5.5%)	0	2 (1.8%)
	2020	266	-	-	25 (9.4%)	22 (8.3%)	4 (1.5%)
	2021	57	-	-	-	6 (10.5%)	2 (3.5%)
	2022	186	-	-	-	-	31 (16.7%)
HY female	2018	131	13 (9.9%)	5 (3.8%)	0	0	0
	2019	73	-	3 (4.1%)	2 (2.7%)	0	0
	2020	200	-	-	23 (11.5%)	5 (2.5%)	3 (1.5%)
	2021	38	-	-	-	1 (2.6%)	1 (2.6%)
	2022	95	-	-	-	-	3 (3.2%)
L male	2018	12	1 (8.3%)	0	0	0	0
	2019	7	-	1 (14.3%)	0	0	0
	2020	25	-	-	5 (20.0%)	0	1 (4.0%)
	2021	0	-	-	-	0	0
	2022	10	-	-	-	-	1 (10.0%)
L female	2018	14	2 (14.3%)	0	0	0	0

	2019	11	-	1 (9.1)	0	0	0
	2020	28	-	-	3 (10.7%)	0	0
	2021	0	-	-	-	0	0
	2022	6	-	-	-	-	0
Total	2018	615	56 (9.1%)	30 (4.9%)	7 (0.7%)	5 (0.8%)	3 (0.5%)
	2019	538	-	44 (8.2%)	17 (3.2%)	10 (1.9%)	4 (0.7%)
	2020	873	-	-	82 (9.4%)	43 (4.9%)	14 (1.6%)
	2021	496	-	-	-	31 (6.3%)	4 (0.8%)
	2022	604	-	-	-	-	53 (8.8%)

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, 2018-2022, reported by hunters through December 31, 2022.

State	County	Direct recoveries	Indirect recoveries
Colorado	Total	211 (78.2)	85 (61.7)
	Adams	4 (1.5)	3 (2.2)
	Alamosa	4 (2.4)	5 (1.1)
	Bent	2 (1.0)	1 (1.1)
	Boulder	5 (1.9)	4 (2.2)
	Chaffee	1 (0.5)	0
	Conejos	1 (0.5)	1 (1.1)
	Costilla	2 (1.0)	1 ()
	Crowley	0	1 ()
	Delta	1 ()	2 (1.1)
	Dolores	0	1 (1.1)
	Douglas	1 (0.5)	0
	Eagle	7 (3.4)	0
	El Paso	1 (0.5)	0
	Fremont	0	1 (1.1)
	Garfield	3 (0.5)	0
	Grand	13 (4.9)	5 (4.4)
	Gunnison	2 (0.5)	0
	Jackson	77 (26.2)	10 (6.7)
	Kiowa	0	1 ()
	La Plata	1 (0.5)	1 (1.1)
	Larimer	6 (1.5)	1 (1.1)
	Las Animas	3 (1.5)	1 (1.1)
	Logan	2 ()	5 (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)	3 (2.2)
	Park	5 (2.4)	4 ()
	Pitkin	1 (0.5)	0
	Prowers	1 (0.5)	0
	Pueblo	8 (3.4)	1 (1.1)
	Rio Grande	4 (1.9)	2 (1.1)
	Routt	4 (1.9)	1 (1.1)
	Saguache	9 (2.9)	2 (1.1)
	Summit	2 (0.5)	0
	Weld	28 (8.7)	22 (15.6)
Arizona	Total	2 (1.0)	0
	Coconino	1 (0.5)	0
	Maricopa	1 (0.5)	0
Idaho	Total	0	2 ()
	Payette	0	1 ()
	Power	0	1 ()

Kansas	Total	2 (1.0)	2 (2.2)
	Barton	1 (0.5)	0
	Crawford	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)	1 ()
	Big Horn	0	1 ()
	Yellowstone	1 (0.5)	0
Nebraska	Total	4 (1.5)	4 (3.3)
	Garden	1 (0.5)	0
	Keith	2 (0.5)	1 ()
	Lincoln	1 (0.5)	1 (1.1)
	Morrill	0	1 (1.1)
	Scotts Bluff	0	1 (1.1)
New Mexico	Total	29 (12.1)	15 (11.1)
	Bernalillo	1 (0.5)	0
	Chaves	3 ()	0
	Dona Ana	1 (0.5)	1 ()
	Mora	0	1 (1.1)
	Otero	1 ()	0
	Rio Arriba	1 (0.5)	0
	Roosevelt	1 (0.5)	0
	San Juan	3 (0.5)	2 (2.2)
	Sandoval	0	1 (1.1)
	Santa Fe	1 (0.5)	0
	Sierra	2 (1.0)	3 (1.1)
	Socorro	8 (3.4)	6 ()
	Valencia	7 (3.4)	1 (1.1)
Nevada	Total	1 ()	1 (1.1)
	Lyon	0	1 (1.1)
	Nye	1 ()	0
Oklahoma	Total	3 (1.0)	6 (5.6)
	Caddo	0	2 (1.1)
	Carnegie	0	1 (1.1)
	Carter	1 ()	0
	Garfield	1 (0.5)	0
	Logan	0	1 (1.1)
	Oklahoma	0	2 (2.2)
	Pottawatamie	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	3 (1.0)	7 (3.3)
	Boxelder	0	2 ()
	Davis	0	1 (1.1)
	Duchesne	2 (0.5)	0
	Piute	0	1 ()
	Salt Lake	0	2 (1.1)
	Uintah	1 (0.5)	0
	Weber	0	1 (1.1)
Wyoming	Total	1 (0.5)	6 (2.1)
	Albany	1 (0.5)	3 (2.2)
	Goshen	0	1 ()
	Lincoln	0	1 (1.1)
	Sublette	0	1 (1.1)
Canada	Total	0	2 (1.1)
	Alberta	0	1 (1.1)
	Saskatchewan	0	1 ()
Total recoveries		264	138

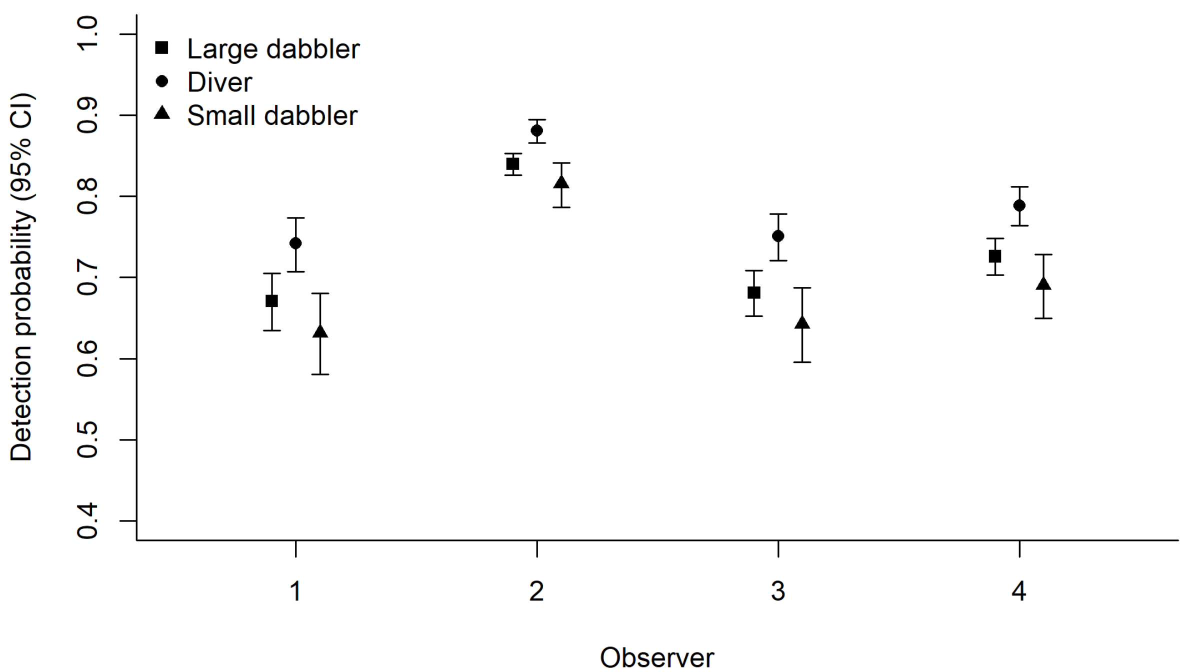

Figure 1. Brood detection probability among four observers and three species groups in North Park, Colorado, 2022.

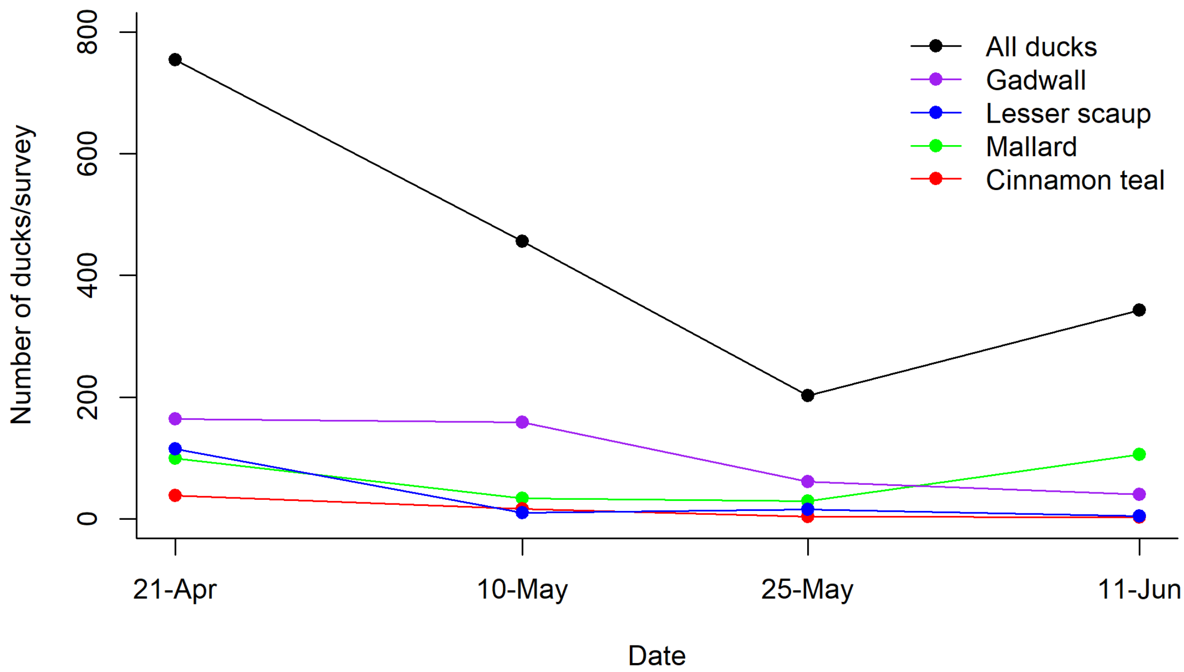

Figure 2. Number of ducks detected per survey for four surveys throughout the 2022 duck breeding season at five large reservoirs in North Park, Colorado.

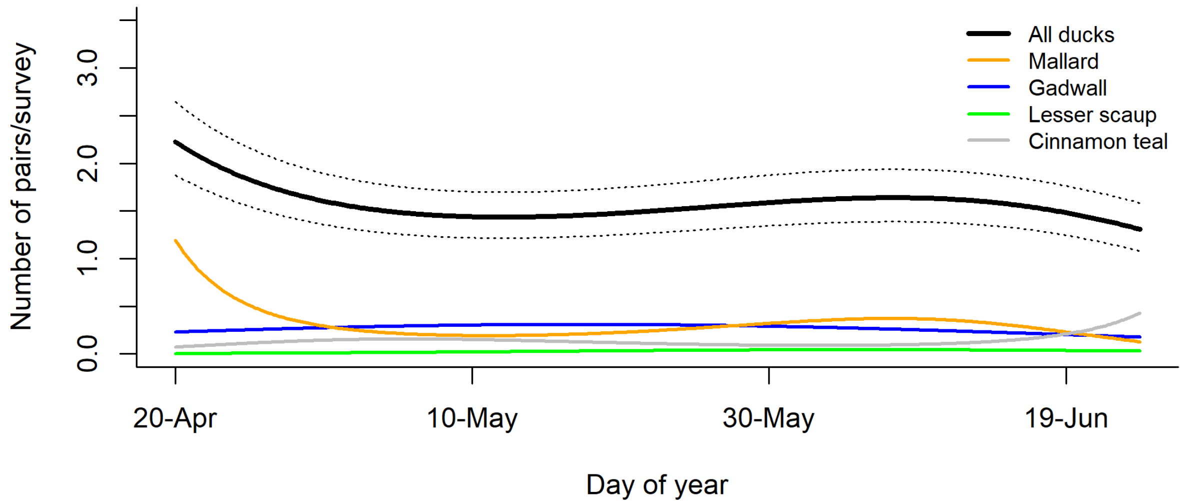

Figure 3. Number of indicated breeding pairs per survey for all ducks and select species throughout the 2022 duck breeding season in North Park, Colorado. Dotted lines indicate ± 1 SE.

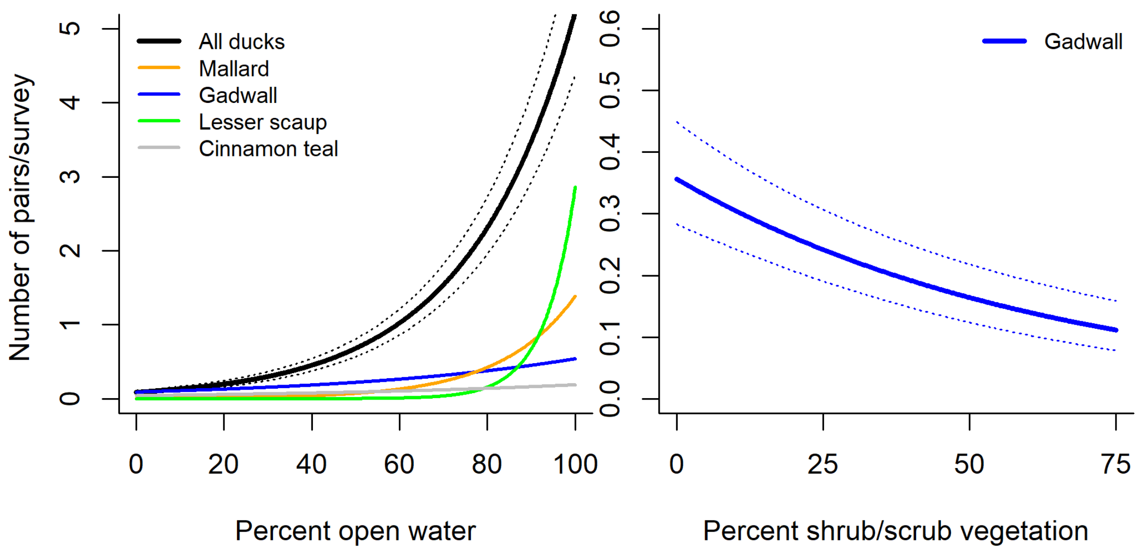

Figure 4. Effects of open water and shrub/scrub vegetation on duck indicated breeding pair abundance in North Park, Colorado during 2022. Dotted lines indicate ± 1 SE.

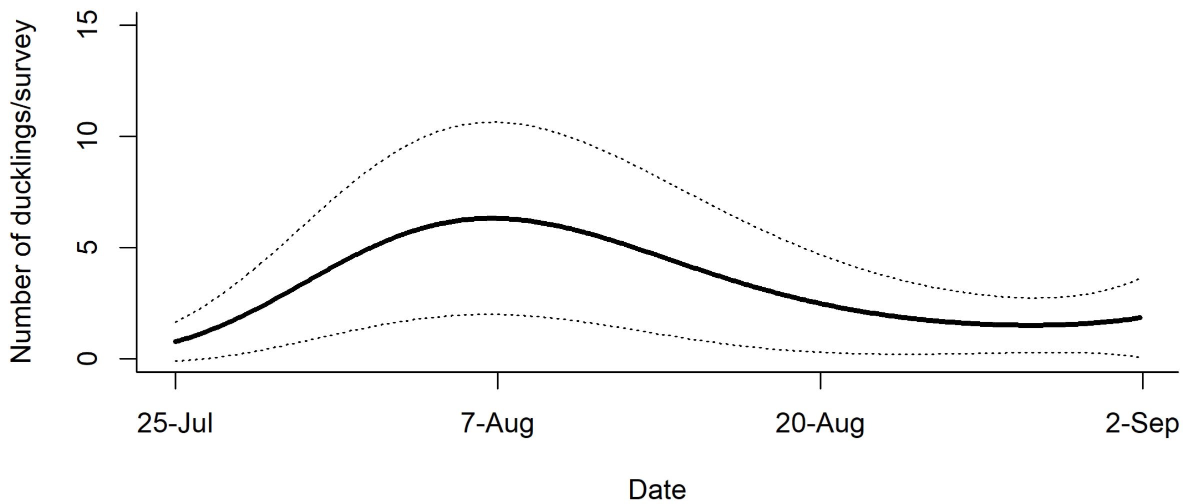

Figure 5. Model-estimated time-trend of duckling abundance for all ducks combined throughout the 2022 breeding season in North Park, Colorado. Dotted lines indicate ± 1 SE.

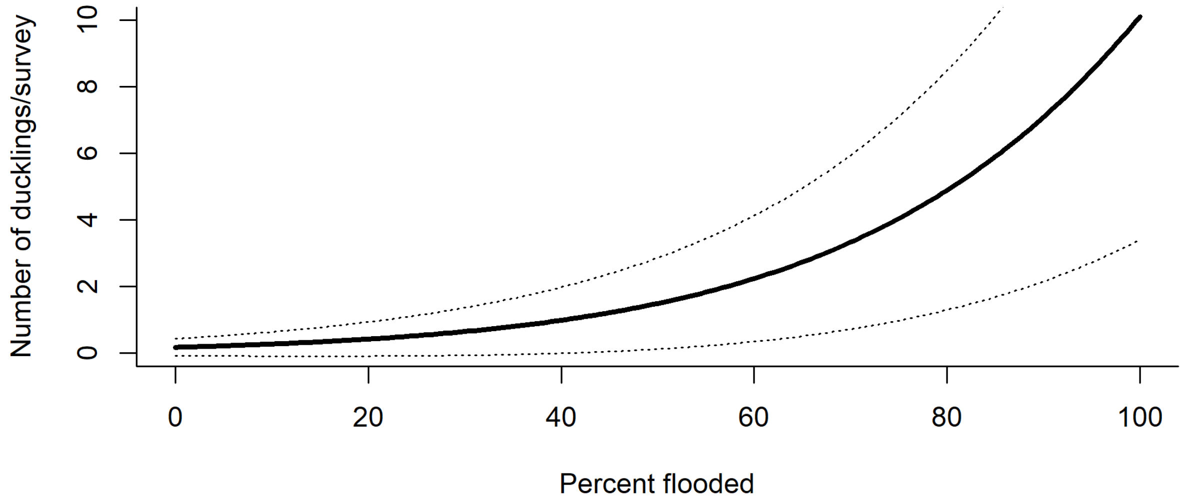

Figure 6. Model-estimated effects of the percent of a site that was flooded on duckling abundance for all species combined in North Park, Colorado during 2022. Dotted lines indicate ± 1 SE.

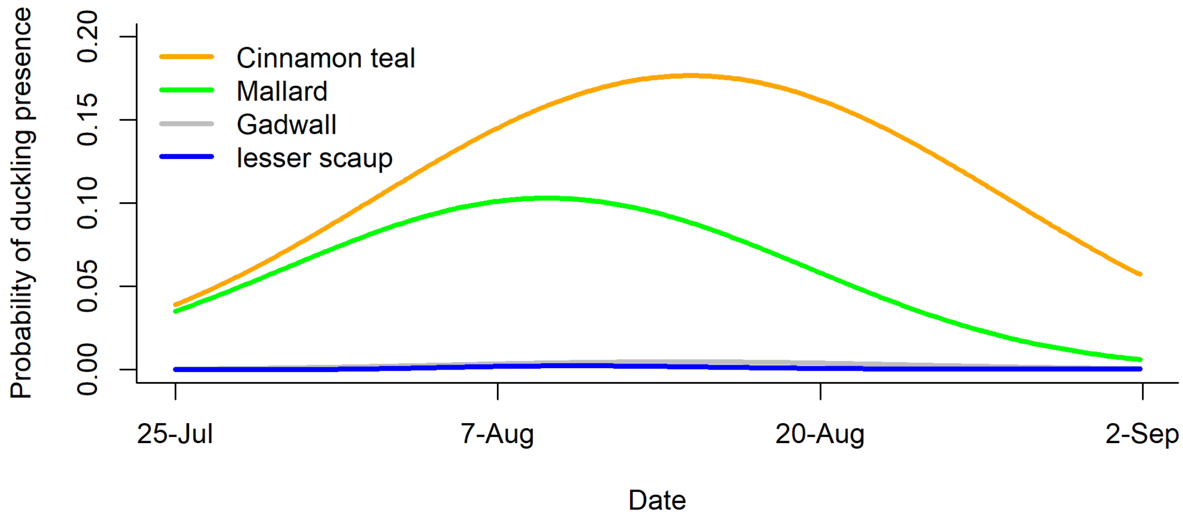

Figure 7. Model-estimated probability of duckling presence by date for cinnamon teal, mallard, gadwall, and lesser scaup throughout the 2022 breeding season in North Park, Colorado.

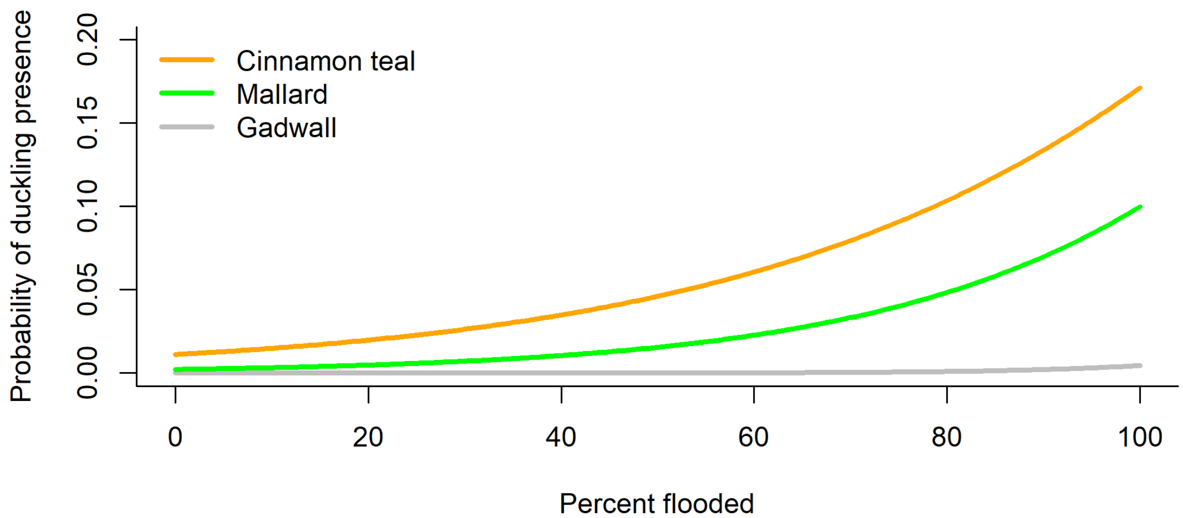

Figure 8. Model-estimated effects of percent of a site that was flooded on cinnamon teal, mallard, and gadwall duckling presence at sites in North Park, Colorado during 2022.

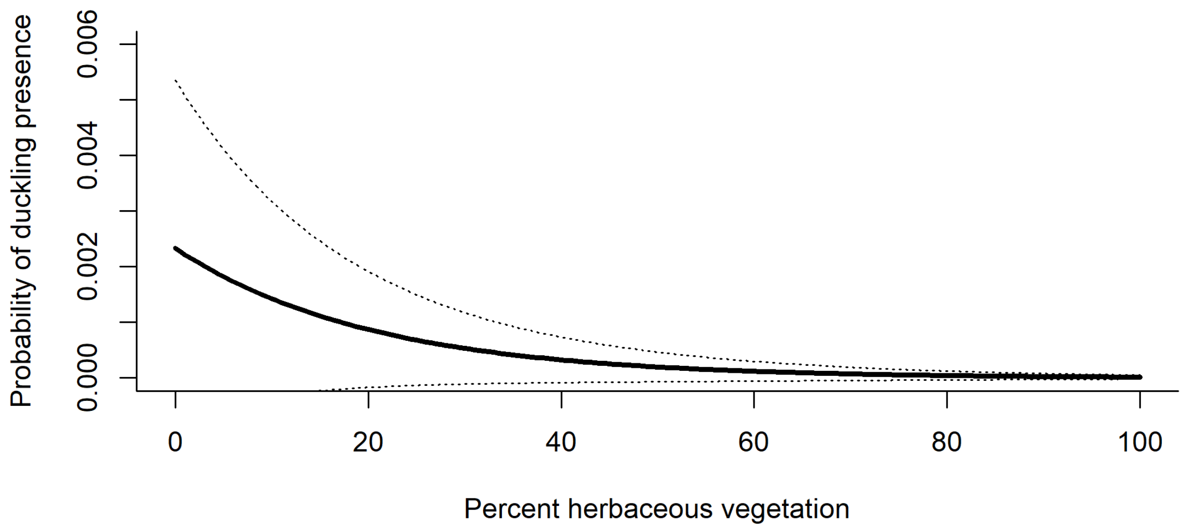

Figure 9. Model-estimated effects of percent herbaceous vegetation on lesser scaup duckling presence at sites in North Park, Colorado during 2022. Dotted lines indicate ± 1 SE.