The Effects of Seasonal Flooding on Seed Availability for Spring Migrating Waterfowl

ANDREW K. GREER,1,2 Cooperative Wildlife Research Laboratory, Southern Illinois University Carbondale, Life Science II 252, Carbondale, IL 62901, USA
BRUCE D. DUGGER,3 Cooperative Wildlife Research Laboratory, Southern Illinois University Carbondale, Life Science II 252, Carbondale, IL 62901, USA
DAVE A. GRABER, Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201, USA
MARK J. PETRIE, Ducks Unlimited, 1101 SE Tech Center Drive, Suite 115, Vancouver, WA 98683, USA

ABSTRACT We hypothesized the seed biomass available to migrating waterfowl would be higher in spring- versus fall-flooded wetlands. To test this hypothesis we conducted an experiment using 5 pairs of wetland impoundments in northern Missouri, USA (2000–2002). We strategically assigned one impoundment of each pair to either a fall or spring treatment group. We estimated seed biomass in fall and in spring by clipping seed heads and collecting soil cores at 20 random locations within each impoundment. We placed exclosures near each fall sample site in spring-flooded impoundments to estimate seed loss from granivorous birds and rodents. Despite similar biomass in fall between treatments (P = 0.64), overwinter seed loss was greater in fall-flooded (79%; 1,324 ± 195 kg/ha) than in spring-flooded (31%; 653 ± 130 kg/ha) impoundments (P = 0.009). Considering barnyard grass or millet (Echinochloa spp.) only, seed loss was higher in fall-flooded than in spring-flooded impoundments (P = 0.05). Spring biomass estimates were similar inside versus outside exclosures (P = 0.63) indicating loss to granivorous birds and rodents was limited. Our results suggest that fall flooding reduces seed availability for spring migrating waterfowl. We recommend spring flooding be used in areas where impoundment water levels can be manipulated to increase seed availability for spring migrating waterfowl. (JOURNAL OF WILDLIFE MANAGEMENT 71(5):1561–1566; 2007)

DOI: 10.2193/2006-376

KEY WORDS impoundment management, moist-soil, seed deterioration, seed loss, seed predation, spring migration, waterfowl, wetlands.

Wetlands at mid latitudes of North America provide important stopover habitat for millions of migratory waterfowl each fall and spring (Bellrose 1980). Wetland loss and degradation along these migration corridors prompted investigations of migrating and wintering waterfowl ecology and wetland habitat management (Low and Bellrose 1944, Korschgen 1955, Meeks 1969). These studies revealed insights about waterfowl habitat requirements and provided recommendations for managing habitat to meet the nutritional and behavioral needs of waterfowl during fall migration (Fredrickson and Taylor 1982, Reid et al. 1989). However, few studies have investigated the effects of spring habitat management on migrating waterfowl, even though resources acquired during spring migration may affect recruitment (Krapu 1981). Studies have documented seasonal shifts in habitat use from fall to spring (Heitmeyer and Vohs 1984), use of newly flooded habitats in spring (LaGrange 1985), and smaller waterfowl population sizes on managed refuges in spring compared to fall (D. A. Graber, Missouri Department of Conservation [MDC], unpublished data). These studies suggest waterfowl use different areas during spring migration but the underlying reason for this pattern is unclear. Historically many midcontinent wetlands became available in spring following winter precipitation, spring snowmelt, or over-bank flooding of major rivers (Galat and Lipkin 2000). Thus, compared to fall-flooded habitat, spring-flooded habitat may contain different food resources critical to migrating birds.

If spring-flooded wetlands are disproportionately more important during spring migration compared to fall-flooded wetlands, the underlying mechanism may be the quantity and quality of seed resources available to birds. Waterfowl require carbohydrates and lipids to satisfy energetic demands of migration and moist-soil seeds may help to meet these requirements (Checkett et al. 2002). Large numbers of foraging waterfowl may deplete food resources in fall- and winter-flooded wetlands (Jemison and Chabreck 1962, Prevost et al. 1978, Naylor 2002, Rutka 2004). In contrast, wetlands that remain dry during fall and winter do not receive extensive use by waterfowl and may provide an abundance of residual seeds when these habitats are flooded in spring. Furthermore, nutritional value of seeds may be greater in spring-flooded wetlands compared to fall-flooded wetlands (Neely 1956, Nelms and Tweedt 1996).

Despite the potential importance of spring-flooded habitats to spring migrating waterfowl, these wetlands have received little attention in the context of waterfowl life history requirements. Past studies have not compared seed biomass in fall-flooded and spring-flooded seasonal wetlands in spring. A comparison of food availability between fall-flooded and spring-flooded habitats is necessary to understand patterns in spatial distribution and abundance of waterfowl and improve habitat management and conservation planning for spring migrating waterfowl. In addition, the impact of granivorous rodents and birds on seed...
availability in seasonally flooded wetlands has not been documented. It is possible that foraging by rodents or other birds (Davison 1961, McGinn and Glasgow 1963) may deplete seeds before spring inundation, resulting in no net gain in seed availability for spring migrating waterfowl. We conducted an experiment to test the effects of fall and spring flooding on moist-soil seed availability for spring migrating waterfowl and to investigate the role of granivory in the overwinter seed loss within spring-flooded wetlands. We hypothesized that seed biomass would be greater in spring-flooded versus fall-flooded wetlands in spring.

STUDY AREA

We conducted our experiment in the Missouri River region of northwest Missouri, USA. Study areas included 4 areas owned and managed by MDC: Bob Brown Conservation Area (BBCA; 1,337 ha), Grand Pass Conservation Area (GPCA; 2,400 ha), Fountain Grove Conservation Area (FGCA; 2,897 ha), and Nodaway Valley Conservation Area (NVCA; 1,418 ha), and 2 National Wildlife Refuges: Squaw Creek National Wildlife Refuge (SCNWR; 2,907 ha) and Swan Lake National Wildlife Refuge (SLNWR; 4,443 ha). Each area consisted of a complex of impoundments (20–400 ha) with water control structures that provided independent water management capability. Impoundments were managed primarily as seasonally and semipermanently flooded moist-soil habitats. Other habitat types within the study areas included agricultural crops (corn, winter wheat, soybean), bottomland hardwoods, grasslands, and permanent aquatic habitat. Waterfowl hunting occurred on portions of all areas owned by the MDC, goose hunting was permitted in agricultural fields at SLNWR, and no hunting was allowed at SQNWR. All selected impoundments were closed to hunting except one impoundment at FGCA in year 2 when hunting was permitted until noon.

METHODS

We conducted our experiment during 2 field seasons (fall 2000–spring 2001 and fall 2001–spring 2002). Our experimental design consisted of 5 pairs of impoundments: 2 impoundments each at 4 sites and one impoundment at both BBCA and NVCA that we paired together. We designated one impoundment from each pair as a fall-flooded treatment and flooded it (Sep–Oct) prior to the onset of fall migration and within 2 weeks after we had collected samples. The second impoundment, designated as the spring-flooded treatment, remained dry during fall–winter and we flooded it (mid- to late Mar) before waterfowl arrived in spring. We strategically selected impoundments with independent water management capability and a history of good seed production to maximize the probability of maintaining treatment levels and of producing sufficient seed biomass that could be influenced by the flooding treatment. We selected new impoundments in year 2, and in 2 cases we reused impoundments from year 1 in year 2. The time of flooding had no effect on seed production the following year.

We collected samples (n = 20) from each impoundment twice, once in fall after seed senescence and prior to waterfowl arrival (7–19 Sep 2000 and 10–21 Sep 2001) and again in late winter prior to waterfowl arrival on spring migration (19 Feb–9 Mar 2001 and 11–22 Feb 2002). We collected samples along transects oriented through zones in each impoundment with appropriate water depths and plant communities (i.e., we did not sample zones of deep water and perennial vegetation that produced little seed). We randomly selected the first sample site along each transect then located each subsequent site at a fixed interval predetermined to span the impoundment. We marked fall sample sites with flagging tape and reused them for the spring sampling period.

During the fall sampling period, we characterized the plant community in each impoundment by identifying species occurring within a 0.0625-m² (25 × 25-cm) sampling frame and summarizing the data as percent occurrence for each plant taxa in each impoundment. To estimate aboveground seed biomass, we clipped all seed heads and inflorescences occurring within the sampling frame. Adjacent (<1 m) to the clip sample location, we estimated belowground seed biomass by collecting 2 soil cores (5 cm deep × 5-cm diam) and combining them into a single sample. In spring, we revisited each sample location and collected 2 soil cores adjacent to where cores were collected in fall (no inflorescences remained).

We estimated the impact of granivorous rodents and birds on overwinter seed loss from spring-flooded impoundments by placing an exclosure (1 × 1.2 m) adjacent to each fall sample site (<1 m) immediately after fall sampling. Exclosures consisted of 4 wooden posts driven into the ground, supported by a square frame on top and metal window screening wrapped and stapled around the perimeter and top. We carefully bent down vegetation taller than 1 m inside the exclosure. We collected 2 soil cores from inside each exclosure during spring sampling and each core was located ≥20 cm from the inside edge of the exclosure.

We air dried clip samples for 2 weeks before processing them in the lab (Laubhan and Fredrickson 1992). After drying, we manually threshed seeds from inflorescences and sifted them through a series of graduated sieves (mesh sizes 10 [2.00 mm], 18 [1.00 mm], 25 [710 μm], 35 [500 μm], 45 [355 μm], and 60 [250 μm]) to separate seeds from the remaining plant material. Some nonseed material remained in each sample (e.g., awns), but separation methods and any minor bias remained consistent. For soil cores, we first washed them through 2 graduated sieves (mesh sizes 35 [500 μm] and 60 [250 μm]) and then placed the remaining contents onto a ceramic tray and dried them at 50°C for 24 hours (Laubhan and Fredrickson 1992). We then passed dried contents through another series of sieves (mesh sizes 10 [2.00 mm], 18 [1.00 mm], 25 [710 μm], 35 [500 μm], 45 [355 μm], and 60 [250 μm]) to separate seeds from other debris. For both clip and core samples, we sorted all
remaining seeds to genus or species using Martin and Barkley (1961) and Steyermark (1963), dried them at 50°C for 24 hours, and weighed them to the nearest 0.0001 g. We used weekly aerial survey data provided by MDC to characterize the timing of fall migration and to estimate waterfowl abundance and species composition on our study areas.

**Statistical Analysis**

We calculated seed biomass for each fall sample as the sum of the standardized (to kg/ha) clip and soil core estimates. We estimated fall seed biomass for each impoundment as the mean of the samples \( n = 20/\text{impoundment} \). In spring, we estimated seed biomass for each impoundment as the mean of the soil core estimates. We calculated seed loss for each impoundment as the difference in mean fall biomass and mean spring biomass. If this value was a negative number (loss was effectively zero, but sampling error led to a negative no.), we set the value to zero. We first estimated seed loss for all species combined as well as for the most common plant genera we encountered, barnyard grass \( (Echinochloa crus-galli \text{ and } E. muriata) \) and Japanese millet \( (E. frumentacea) \). We compared overwinter seed loss in spring-flooded \( n = 5 \) and fall-flooded \( n = 5 \) impoundments for both response variables using general linear models, including treatment (spring vs. fall flooding), year, and the treatment \( \times \) year interaction as explanatory variables (SAS Institute 1999).

To test the effect of granivory on overwinter seed loss from spring-flooded impoundments, we compared seed loss inside enclosures to seed loss outside enclosures (calculated above). We compared mean seed loss using general linear models, including treatment (inside vs. outside enclosure), year, and the treatment \( \times \) year interaction as explanatory variables. We performed all tests on untransformed data. Formal tests indicated the data were not normally distributed; however, analyses of variance are robust against departures from normality (Sokal and Rohlf 1995) and inspection of residual plots suggested variances were homogenous. We considered tests significant at \( \alpha < 0.05 \). We report all means (±SE).

**RESULTS**

The plant community in all impoundments was dominated by species of seed-producing plants that are commonly consumed by waterfowl (Table 1). In year 1, 15 plant taxa and in year 2, 17 plant taxa occurred in sample locations; 11 taxa were common to both years. Considering both years together, barnyard grass or millet occurred in 77.8% of our sample locations. During both years, waterfowl arrived in early October with peak populations occurring mid-late November. Waterfowl remained on our study areas until impoundments became covered with ice (11 Dec in yr 1 and 15 Jan in yr 2).

In fall, seed biomass estimates for each impoundment ranged from 2,719 ± 276 kg/ha to 961 ± 130 kg/ha. Across all years and treatments, species contributing the most to fall seed biomass were barnyard grass and Japanese millet \( (\bar{x} = 1,001 \pm 50 \text{ kg/ha}) \), smartweeds (water knotweed \( [Polygonum amphibium] \), swamp smartweed \( [P. hydropiper] \), curlytop knotweed \( [P. lapathifolium] \), Pennsylvania smartweed \( [P. pensylvanicum] \); \( \bar{x} = 355 \pm 32 \text{ kg/ha} \), and spikerushes (blunt spikerush \( [Eleocharis obtusa] \) and common spikerush \( [E. palustris] \); \( \bar{x} = 121 \pm 15 \text{ kg/ha} \)). For the fall sampling period, mean seed biomass per impoundment did not differ between years \( (P = 0.48; 1,615 \pm 65 \text{ kg/ha in 2000 vs. } 1,774 \pm 56 \text{ kg/ha in 2001}) \) or treatments \( (P = 0.64; 1,642 \pm 62 \text{ kg/ha for fall-flooded vs. } 1,747 \pm 60 \text{ kg/ha for spring-flooded}) \) and there was no treatment \( \times \) year interaction \( (P = 0.43) \).

Despite actions to maintain treatment levels, heavy rains and snow influenced flooding conditions in year 1. Specifically, 2 fall-flooded impoundments were flooded >1 m for periods in late fall and winter, and 4 spring-flooded impoundments were flooded in late January. Subsequently, cold temperatures froze the spring-flooded impoundments until sampling occurred about 30 days later, before birds returned in spring. In year 2, one spring-flooded impoundment was flooded for a period before spring sample collection because of a leak in a levee. Unlike year 1, waterfowl used this impoundment extensively before our spring sampling period.

Overwinter seed loss differed by flooding treatment in both years \( (F_{3,10} = 8.8, P = 0.009)) \), but the effect size was larger in year 2 than in year 1 (Table 2). When considering only barnyard grass, neither year \( (P = 0.63) \) nor treatment \( (P = 0.10) \) had an effect on overwinter seed loss. However, when we removed the one spring-flooded impoundment in year 2 that received bird use before we could sample,
barnyard grass seed loss was similar between years ($P = 0.89$) but differed by treatment ($F_{1,15} = 4.52$, $P = 0.05$) with higher loss in fall-flooded ($881 \pm 237$ kg/ha [83%]) than spring-flooded ($302 \pm 110$ kg/ha [31%]) impoundments for both years. In spring-flooded impoundments, there was no effect of exclosures on overwinter seed loss when all seed species were combined ($P = 0.63$) or when we analyzed barnyard grass separately ($P = 0.89$); however, overwinter loss was higher in year 1 than in year 2 for all species ($F_{3,16} = 6.49$, $P = 0.02$; Table 3). We suggest the difference in treatment effect between years was related to difficulties maintaining experimental controls, which resulted in reduced seed depletion in fall-flooded impoundments and increased loss from spring-flooded impoundments.

**DISCUSSION**

Our experiment demonstrated that, compared to fall flooding, spring flooding can increase seed availability for spring migrating waterfowl. Compared with seed losses of 70% and 87% in fall-flooded impoundments, seed loss from spring-flooded impoundments averaged only 44% and 18% in year 1 and 2, respectively. In year 1, data from paired experimental impoundments at 3 sites were consistent with the strong treatment effect in year 2; however, data from the remaining 2 pairs of impoundments showed little evidence of a treatment effect. Specifically, seed loss was relatively low in the fall-flooded impoundments at FGCA (57%) and BBCA (36%) compared with GPCA (89%), SCNWR (89%), and SLNWR (81%). Lower seed loss at FGCA and BBCA may have been the result of heavy rains that flooded sample locations >1 m deep, making seeds unavailable for foraging dabbling ducks that generally prefer depths between 10 cm and 30 cm (Fredrickson 1991, Riley and Bookhout 1993, Elphick and Oring 1998).

In contrast to fall-flooded impoundments, we suggest heavy winter rains caused higher seed loss (33–55%) in spring-flooded impoundments in year 1 because of increased seed decomposition. Instead of remaining dry throughout winter, most spring-flooded impoundments were at least partially flooded for a month prior to our sampling. Although ice cover prevented waterfowl from foraging in these impoundments, flooding likely increased seed decomposition. Most seed and plant deterioration occurs within the first 30 days under water (Neely 1956, Shearer et al. 1969, Schnauss 1976, Buckley 1989). Consistent with this explanation, seed loss in spring-flooded impoundments was similar inside and outside exclosures in year 1 and seed loss was higher in year 1 than in year 2 (Table 3).

Finally, the weaker treatment effect in year 1 may have been related to differences in plant species composition among treatments, years, or waterfowl preferences for specific seed species. Seeds differ greatly in their nutritional value, particularly related to energy content (Checkett et al. 2002), which could lead to selection or avoidance of some plant communities by waterfowl. Although diet studies suggest waterfowl use foods proportional to their availability at specific foraging sites (Miller 1986, Euliss and Harris 1987, Gruenhagen and Fredrickson 1990, Combs and Fredrickson 1996), decisions about site selection may be influenced by cues that include plant species composition (Cody 1985). Our analysis using only seeds of barnyard grass (species frequently consumed by waterfowl that has relatively high energy content [Checkett et al. 2002] and comprised 52% and 66% of total seed biomass in year 1 and 2, respectively) were similar to results for all seeds, suggesting plant community composition was not an important factor influencing seed loss.

Seeds in spring-flooded impoundments were relatively safe

<table>
<thead>
<tr>
<th>Plant taxa</th>
<th>Yr</th>
<th>n</th>
<th>$\bar{x}$ loss</th>
<th>SE</th>
<th>%Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>All seeds</td>
<td>1</td>
<td>5</td>
<td>1,071</td>
<td>346</td>
<td>-70</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5</td>
<td>1,578</td>
<td>134</td>
<td>-87</td>
</tr>
<tr>
<td>Barnyard grass (Echinochloa spp.)</td>
<td>1</td>
<td>5</td>
<td>714</td>
<td>395</td>
<td>-71</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5</td>
<td>1,048</td>
<td>287</td>
<td>-96</td>
</tr>
</tbody>
</table>

* We report data as both $\bar{x}$ (±SE) loss of biomass and $\%$ change in biomass (%Δ) for all seeds and separately for barnyard grass.

**Table 2.** Percent change (%Δ) in seed biomass (kg/ha) from fall (Sep) to spring (Feb) in wetland impoundments subjected to different flood regimes (fall-flooded [FF] vs. spring-flooded [SF]) in northern Missouri, USA, during 2000–2001 (yr 1) and 2001–2002 (yr 2).

<table>
<thead>
<tr>
<th>Plant taxa</th>
<th>Yr</th>
<th>n</th>
<th>$\bar{x}$ loss</th>
<th>SE</th>
<th>%Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>All seeds</td>
<td>1</td>
<td>5</td>
<td>1,071</td>
<td>346</td>
<td>-70</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5</td>
<td>1,578</td>
<td>134</td>
<td>-87</td>
</tr>
<tr>
<td>Barnyard grass (Echinochloa spp.)</td>
<td>1</td>
<td>5</td>
<td>714</td>
<td>395</td>
<td>-71</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5</td>
<td>1,048</td>
<td>287</td>
<td>-96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plant taxa</th>
<th>Yr</th>
<th>n</th>
<th>$\bar{x}$ loss</th>
<th>SE</th>
<th>%Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>All seeds</td>
<td>1</td>
<td>5</td>
<td>792</td>
<td>152</td>
<td>-44</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5</td>
<td>311</td>
<td>51</td>
<td>-18</td>
</tr>
<tr>
<td>Barnyard grass (Echinochloa spp.)</td>
<td>1</td>
<td>5</td>
<td>419</td>
<td>185</td>
<td>-48</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5</td>
<td>157</td>
<td>59</td>
<td>-13</td>
</tr>
</tbody>
</table>

* We report data as both $\bar{x}$ (±SE) loss of biomass and $\%$ change in biomass (%Δ) for all seeds and separately for barnyard grass.

**Table 3.** Overwinter loss of seed biomass (%Δ) for samples collected inside and outside exclosures within spring-flooded wetland impoundments on 5 managed wetland areas in northern Missouri, USA, during late winter (Feb–Mar) for 2 years (2000–2001).
from granivory and seed decomposition appeared to be the mode of seed loss in spring-flooded impoundments. Had seed loss been attributable to rodents, waterfowl, or other birds, we predicted seed loss would have been higher outside exclosures. This was only the case for the single spring-flooded impoundment in year 2 (GPCA) when flooding and use by waterfowl prior to spring sampling resulted in an 82% loss of seed biomass outside exclosures but only a 40% loss inside exclosures. In year 2, seed loss was <30% for 4 impoundments. Minimal seed loss is consistent with other research indicating moist-soil seeds lose <10% dry matter in nonflooded fields after 95 days (Buckley 1989).

Ours was the first study to document seed loss in seasonal wetlands on migration stopover areas for waterfowl. Mean seed loss in fall-flooded impoundments was 1,071 kg/ha (70%) and 1,578 kg/ha (87%) in year 1 and 2, respectively. Greater seed loss in year 2 may, in part, be related to warmer fall temperatures that allowed waterfowl to persist into early January, unlike year 1 when impoundments were frozen and inaccessible by early December. Seed loss from fall-flooded impoundments was greater than previously reported values for wintering areas in coastal Louisiana (14–17%; Jemison and Chabreck 1962) and California’s Central Valley (65%; Naylor 2002). Even though percent depletion in California was similar to seed loss for this study, total seed biomass depleted was less, just 130 kg/ha and 381 kg/ha over 2 winters (Naylor 2002).

Although we did not determine the proportion of seed loss directly attributable to waterfowl consumption, the dense concentration of waterfowl in study impoundments strongly implies seed predation by waterfowl. Waterfowl in fall-flooded impoundments were likely attracted to the high numbers of desirable seeds (95% of seed species frequently eaten by waterfowl [Bellrose and Anderson 1943, Korschgen 1955, Gruenhagen and Fredrickson 1990]), protection from disturbance and optimal foraging depths. Protection from hunting was probably not the reason for high seed loss however, as the single fall-flooded impoundment open to hunting (FGCA, year 2) experienced high depletion (92%) and birds will forage at night.

Seed decomposition is the other factor contributing to seed loss in fall-flooded impoundments. We did not quantify the amount of seed loss attributable to decomposition, but we routinely observed deteriorated seeds in samples from fall-flooded impoundments collected in spring but rarely in samples from spring-flooded impoundments. Work in the Lower Mississippi Valley demonstrated fall-flooded samples of moist-soil seeds lost 10–50% of their biomass after inundation (Nelms and Twedt 1996) and in Missouri decomposition was greater in flooded versus nonflooded wetlands (Buckley 1989).

MANAGEMENT IMPLICATIONS

Delaying flooding of seasonal wetland impoundments until spring is an approach managers may use to increase seed availability for spring migrating waterfowl. This management may provide a better balance of food resources required by spring migrating waterfowl. However, demands for fall-flooded habitat at state and federal waterfowl management areas may limit the amount of land that can be incorporated into a spring-flood regime. If true then private lands that naturally flood in spring are important and more work should be focused on understanding the role of these habitats in meeting the life history requirements of spring migrating waterfowl. Although not an experimental treatment, heavy rains and deeper flooding in some experimental impoundments in year 1 suggest that deep flooding in fall may be a mechanism for providing fall wetland habitat while protecting seeds from foraging dabbling ducks, increasing seed availability in spring.

ACKNOWLEDGMENTS

We are grateful to the following refuge managers and staff; R. Leonard (GPCA), D. Mengel (FGCA), M. Marks (BBCA, NVCA), C. Crisler (BBCA, NVCA), J. Guthrie (SLNWR), R. Bell (SCNWR), and F. Durbian (SCNWR). We thank D. Rutka, R. Weigt, R. Johnson, M. Booz, C. Leonard, B. Hopkins, M. Johnson, S. Finkbeiner, L. Kirk, F. Babineau, and J. Bovrette for field and laboratory assistance. Financial support was provided by MDC, United States Fish and Wildlife Service-Region 3, Ducks Unlimited, Cooperative Wildlife Research Laboratory, Southern Illinois University Carbondale, and Oregon State University.

LITERATURE CITED


Gruenhagen, N. M., and L. H. Fredrickson. 1990. Food use by migratory...


Korschgen, L. J. 1955. Fall foods of waterfowl in Missouri. Missouri Conservation Commission P-R Series No. 14, Columbia, Missouri, USA.


LaGrange, T. G. 1985. Habitat use and nutrient reserves dynamics of spring migratory mallards in central Iowa. Thesis, Iowa State University, Ames, USA.


Associate Editor: Keboe. 

1566 The Journal of Wildlife Management • 71(5)