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Moist-soil Plant Seed Production for Waterfowl at Chautauqua National Wildlife Refuge, Illinois

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ABSTRACT.—The Illinois River Valley (IRV) is a critical ecoregion for migratory waterfowl. Significant wetland loss occurred in this region in the early 20th Century, and remaining wetlands are subject to additional degradation via sedimentation, summer flooding from the Illinois River and invasive species. Managed moist-soil wetlands may provide quality foraging habitat for migrating waterfowl, but contemporary estimates of seed production and carrying capacity do not exist for the IRV. We evaluated seed production and carrying capacity of a 931-ha moist-soil wetland at Chautauqua National Wildlife Refuge in central Illinois during falls 1999–2001. Seed production varied annually (329–1231 kg/ha), but overall was greater than previously published estimates for other areas of North America. Estimated carrying capacity across years was 6.760 ± 411 (SE) duck use-days/ha; this value was 1.5–15.4 times greater than other published carrying capacity estimates for harvested corn, rice and soybeans. We recommend continued regional-scale research to estimate foraging carrying capacity of moist-soil wetlands for waterfowl in mid-latitude regions, such as the IRV or upper Mississippi River.

INTRODUCTION

Management of moist-soil wetlands is an effective strategy to provide foraging habitat for migrating and wintering waterfowl (Low and Bellrose, 1944; Fredrickson and Taylor, 1982; Reinecke *et al.*, 1989; Kaminski *et al.*, 2003). Management strategies generally include manipulation of hydrology, vegetation or seed banks to encourage growth of seed-producing wetland vegetation (Low and Bellrose, 1944; Fredrickson and Taylor, 1982). Research in the Mississippi Alluvial Valley (MAV) documented greater forage abundance in moist-soil wetlands than harvested croplands (Reinecke and Loesch, 1996; Penny, 2003; Reinecke and Hartke, 2005). Additionally, waterfowl densities may be greater in moist-soil wetlands than flooded croplands, possibly indicating preference for these habitats or suitability beyond foraging alone (Reinecke *et al.*, 1992; Twedt and Nelms, 1999). Finally, moist-soil plant seeds provide essential amino acids not found in crop foods (Loesch and Kaminski, 1989) and have average true metabolizable energy values similar to agricultural seeds (Checkett *et al.*, 2002; Kaminski *et al.*, 2003).

Occurrence of quality waterfowl foraging habitats in key migrational regions may promote good body condition prior to arrival at wintering areas (Fredrickson and Drobney, 1979; Reid *et al.*, 1989) and during spring migration (Heitmeyer, 1985; LaGrange, 1985). In the mid-continent region of the United States, the Illinois River Valley (IRV) represents an important ecoregion for migrating and wintering waterfowl. Historically, the IRV was a 172,000 ha floodplain, consisting of mast-producing bottomland hardwoods [*e.g.,* pin oak (*Quercus palustris*)], moist-soil, emergent marsh and open-water areas (Bellrose *et al.*, 1983; Havera *et al.*, 1995; Havera, 1999). These bottomlands flooded seasonally, providing vast high quality foraging habitat for spring- and fall-migrating waterfowl. Indeed, over

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1.6 million mallards (*Anas platyrhynchos*) were counted in the IRV during an aerial survey on 15 November 1948 (Havera *et al.*, 1995; Havera, 1999). However, the IRV experienced extensive wetland drainage for agriculture during the 20^{th} Century, and approximately 74,000-ha of waterfowl habitat remain in this region (Havera, 1999:91). Exacerbating wetland loss, most remaining wetlands in the IRV have been further degredated or lack productivity due to extensive sedimentation, and colonization by invasive plants [*e.g.,* willow (*Salix* spp.) and cocklebur (*Xanthium* spp.)] and animals [*e.g.,* common carp (*Cyprinus carpio*)]. Many of these wetlands also lack protection from the Illinois River during summer, when floods frequently kill emerging moist-soil plants (Bellrose *et al.*, 1983; Havera, 1999).

Despite landscape-scale modifications, the IRV remains critical habitat for migrating waterfowl annually [Upper Mississippi River and Great Lakes Region Joint Venture (UMRGLRJV) Board, 1998; Havera, 1999]. For example, peak aerial counts averaged 391,000 (163,000–720,000) waterfowl during 1993–2003 (M. M. Horath, pers. comm.). Additionally, the UMRGLRJV of the North American Waterfowl Management Plan specifically relies on the IRV and other migratory focus areas to meet foraging requirements of 8.9 million waterfowl during a 30-d fall migration period (UMRGLRJV Board, 1998).

Although moist-soil wetlands are important foraging habitats for waterfowl in the IRV, we were unaware of contemporary published estimates of seed production and carrying capacity for moist-soil wetlands in the Mississippi Flyway north of the MAV (but *see* Low and Bellrose, 1944). These data are critical to evaluate management efforts to maximize foraging carrying capacity in the IRV. Additionally, such information is critical to evaluate waterfowl habitat conservation and restoration success relative to UMRGLRJV goals and objectives (UMRGLRJV Board, 1998).

We sampled a 931-ha moist-soil impoundment at Chautauqua National Wildlife Refuge (CNWR) in central Illinois during early autumn 1999–2001 to assess foraging carrying capacity. Our objectives were to: (1) estimate precisely (*i.e.,* CV $\leq$ 15%; Seber, 1982:64; Conroy *et al.*, 1988) production of moist-soil plant seeds at CNWR; (2) use these estimates to compute foraging carrying capacity for waterfowl; and (3) make management and research recommendations consistent with our results and other published literature.

STUDY AREA

Located in Mason County, Illinois, CNWR is considered the most important waterfowl refuge in the IRV with respect to use, and has been designated a Western Hemisphere Shorebird Network Site and a Globally Significant Bird Area (Fig. 1; Havera, 1999). Formerly, CNWR was a complex of bottomland lakes, sloughs and forest (Bellrose *et al.*, 1983). In the early 1900s the area was levied and drained for agriculture, but the Illinois River breeched the levee in 1926 and 1927, and the Chautauqua Drainage and Levee District was subsequently abandoned and purchased by the U.S. Biological Survey (Stall and Melsted, 1951; Bellrose *et al.*, 1983; Thompson, 1989). Restoration efforts repaired original levees intended for drainage and used them to retain water, thereby creating 1460 ha Lake Chautauqua. Cross-levees were built in the 1960s and late 1990s to divide the lake into two management units: a deep-water (north pool) and a moist-soil (south pool) wetland.

We conducted our research on the 931 ha south pool of Lake Chautauqua (hereafter, SP). This impoundment represented 31.1% of the total area of public waterfowl habitat in the IRV with levees capable of excluding the Illinois River during most floods. The SP also represented 4.6% of all public land in the IRV (Havera, 1999) and was managed as a moist-soil wetland for migratory waterfowl and other birds during our study. Renovations to the SP in the mid-1990s included installation of water control structures and construction of a drainage ditch, which enhanced the ability to manipulate water levels and reduce

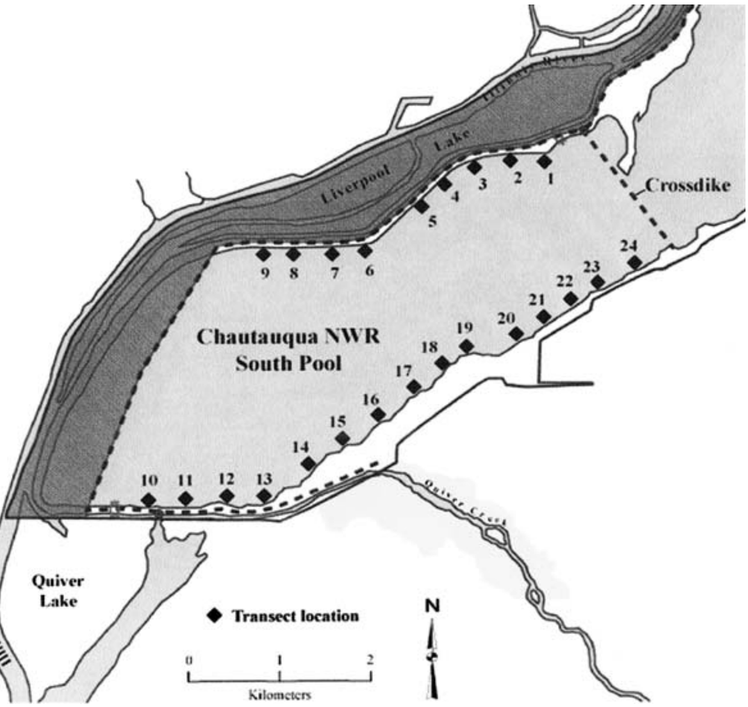

FIG. 1.—The South Pool of Chautauqua National Wildlife Refuge, Illinois, sampled to estimate moist-soil plant seed production during 1999–2001. Black diamonds denote transect locations

extensive growing season flooding, sedimentation and colonization by exotic vertebrate species from the Illinois River (Havera and Bellrose, 1985; Sager *et al.*, 1998).

METHODS

Survey design.—We used stratified random sampling to estimate moist-soil plant seed production in the SP (Thompson, 1992). It was our intent to increase precision of seed-production estimates by stratifying; thus, we allocated samples proportionally among three vegetation zones (Cochran, 1977). Specifically, we defined the following strata: (1) the 'moist-soil' stratum, which consisted primarily of seed-producing annual plants; (2) the 'willow' stratum, which consisted of wetland area dominated by black willow (*Salix nigra*) and; (3) the 'managed' stratum, which included wetland area where vegetation was actively manipulated by mowing or herbicide, primarily to control cocklebur and willow encroachment (2000 and 2001 only). We mapped vegetation and determined stratum sizes annually because timing, duration and extent of drawdown varied annually. Additionally, the managed stratum was not manipulated in 1999; however, we sampled portions of the area slated for management in 1999 to compare seed production in subsequent years when the stratum was actively managed. We refer to this stratum and year as "pre-treatment."

Vegetation mapping to estimate strata.—In 1999 we established 24 transects perpendicular to the north and south levees of the SP by dividing levees into 320 m sections and selecting a random meter location within each section using a random numbers table (Fig. 1). Each transect extended from the base of the levee to the center of the SP. We used the same transects in each year of study.

We mapped vegetation in late August to early September by traversing each transect in the SP, either on foot or with an airboat, until we reached open water or the center of the impoundment. We noted plant species composition while traversing transects and delineated vegetation zones when plant composition changed with respect to our three vegetation strata. Further, we noted dominant management practices (mowed or herbicide) when we encountered an area where vegetation had been actively managed during 2000 and 2001. We measured width of each vegetation zone along each transect to the nearest 1.0 m using a laser range finder (Bushnell Yardage Pro™ 800) when terrain was open and zone width ≥20 m; otherwise, we measured zone width with a measuring tape. We digitized vegetation zones in ArcView GIS 3.2 to estimate total surface area of strata in the SP (Environmental Systems Research Institute, 1996).

Estimating seed production.—We sampled seed production at 150, 296 and 317 sites in 1999, 2000 and 2001, respectively. We allocated samples proportional to stratum area in each year of study, as determined by previous vegetation mapping. Then, we used a random numbers table to select individual sample sites proportional to transect length within each stratum by assigning each sample location to a random distance (m) from the edge of the vegetation zone nearest the levee. At each randomly assigned location we identified all rooted vegetation within a 0.0625 m^2 PVC sampling frame (Laubhan and Fredrickson, 1992) following Mohlenbrock (1986). We estimated seed production for 16 moist-soil species regarded as quality waterfowl food (Bellrose and Anderson, 1943; Low and Bellrose, 1944; Fredrickson and Taylor, 1982); no other quality forage species were identified during sampling.

We initiated sampling in the SP in early October 1999–2001 when field observations indicated >90% of vegetation had reached maturity. Following the methods of Laubhan and Fredrickson (1992:330), we collected a seed head visually representative of the average of each of the 16 species within each plot to estimate seed production and counted all stems of each species in plots. Teal grass (*Eragrostis hypnoides*) was the most abundant species in 1999 and 2000, with densities commonly >5000 stems/m^2; therefore, we estimated teal grass stem density in 2001 using a circular 0.00811 m^2 subsample taken randomly within each plot. Finally, we recorded cocklebur stem densities to index abundance and evaluate management efforts to reduce this undesirable species in the managed stratum.

We air-dried seed heads for ≥2 mo prior to sorting (Sherfy and Kirkpatrick, 1999). We separated seeds from stems and chaff, and weighed them to the nearest 0.1 mg using an electronic balance. We multiplied seed mass from the representative seed head by the number of stems of that species per plot to extrapolate seed mass to plot area. We summed extrapolated seed mass across species to estimate total moist-soil plant seed production per plot.

We acknowledge two possible sources of bias in our seed production estimates. First, our use of Laubhan and Fredrickson's (1992) technique of selecting visually representative seed heads from plots (instead of at random) may have biased production estimates. We cannot account for this potential bias, but if we tended to select large or small seed heads production would be over or underestimated, respectfully. Second, our estimates of seed production were calculated from mass of air dried samples and may not be directly comparable to results from previous studies where seeds were oven dried prior to weighing. However, chemical composition data from Fredrickson and Reid (1988a) indicated that average moisture content of seeds of 4 common moist-soil species was 5.8%. Hence, we believe any bias of estimates due to residual moisture was minimal.

TABLE 1.—Estimated mean production (kg/ha) of moist-soil plant seeds and duck use-days (DUD/ha) and standard error (SE), South Pool of Chautauqua National Wildlife Refuge, Illinois, 1999–2001

Year	Stratum	Area[a]	n[b]	$\bar{x}$	SE	DUD/ha[c]
1999	Pre-treatment	102	24	25	18	215
	Moist-soil	218	79	1748	228	14,964
	Willow	285	47	372	109	3188
	Total	605	150	809	97	6929
2000	Managed	166	109	476	62	4079
	Moist-soil	155	96	565	83	4840
	Willow	215	91	45	17	384
	Total	536	296	329	32	2815
2001	Managed	175	66	517	185	4426
	Moist-soil	459	180	2047	174	17,530
	Willow	217	71	82	33	700
	Total	851	317	1231	101	10,536
1999–2001	Managed[d]	171	175	497	98	4255
	Moist-soil	277	355	1454	99	12,444
	Willow	239	207	166	38	1424
	Total	664	722	790	48	6760

[a] Area of strata (ha)

[b] Sample size

[c] Assumed average TME for moist-soil plant seeds of 2.5 kcal/g and energetic requirements for a mallard-sized duck of 292 kcal/day (Reinecke *et al.*, 1989)

[d] The managed stratum was only manipulated in 2000–2001; thus $n = 2$ y for the managed pooled estimate

Statistical analysis.—Using extrapolated seed mass per plot as the sampled unit, we computed annual estimates of means and variances for moist-soil plant seed production in the SP using the SURVEYMEANS procedure in SAS v9.1 (SAS Institute, 2004). PROC SURVEYMEANS allowed for incorporation of strata and computed unbiased estimates of variances using Taylor series linearization (SAS Institute, 2004). We calculated mean moist-soil plant seed production across years as the grand mean ($\bar{\bar{x}}$) of annual production estimates. Additionally, we estimated variances of the pooled estimate, var($\bar{\bar{x}}$), as the sum of the annual variance estimates [var($\bar{x}_i$)] divided by n^2, where n equaled 2 y for the managed stratum and 3 y for all other estimates (Neter *et al.*, 1985:4). All means are reported ± 1 SE.

We used seed production estimates from SURVEYMEANS to estimate foraging carrying capacity for waterfowl in duck use-days (DUD), defined as the number of days an area of land could support a mallard-sized duck (Reinecke *et al.*, 1989). Our DUD calculation assumed an average true metabolizable energy for moist-soil plant seeds of 2.5 kcal/g (Kaminski *et al.*, 2003:546) and an average daily energy expenditure of a mallard of 292 kcal/day (Prince, 1979; Reinecke *et al.*, 1989).

RESULTS

Average estimated moist-soil plant seed production varied among years (329–1231 kg/ha; Table 1). Pooling across years yielded an overall estimate of 790 ± 48 kg/ha (Table 1). Precision of annual estimates was adequate based on our *a priori* standard of CV $\leq$ 15% (CV = 8.2–12.0%). Estimated seed production was greatest in the moist-soil stratum in all years (565–2047 kg/ha), and overall (1454 ± 99 kg/ha), and least in the pre-treatment stratum in 1999 (25 ± 18 kg/ha) and willow stratum in 2000 and 2001 [45 ± 17 kg/ha (2000) and

82 ± 33 kg/ha (2001); Table 1]. Averaged across years, seed production was 2.9 and 8.8 times greater in the moist-soil stratum than in the managed or willow strata, respectively.

Estimated average foraging carrying capacity for the SP ranged from 2815–10,536 DUD/ha (Table 1). Across years and strata, seed production in the SP yielded an estimated 6760 DUD/ha (Table 1). Of the 16 species monitored for seed production, teal grass, rice cutgrass (*Leersia oryzoides*) and red-root nutsedge (*Cyperus erythrorhizos*) dominated all strata based on stem density (Table 2). Additionally, these species were the dominant seed producers in the willow stratum. Estimated seed production in the managed stratum was greatest for teal grass, followed by rusty nutsedge (*C. ferruginescens*) and red-root nutsedge. In contrast, red-root nutsedge was the dominant seed producer in the moist-soil stratum, followed by hooded arrowhead (*Sagittaria calycina*) and rice-cutgrass.

DISCUSSION

Managed moist-soil wetlands are important foraging habitats for fall-migrating waterfowl. Contemporary estimates of moist-soil plant seed production in the IRV are critical for conservation planning and evaluation. The only previous study of moist-soil seed production in the IRV documented 3155 kg/ha in millet stands, with average production of 653 kg/ha for 10 other species (Low and Bellrose, 1944). Fredrickson and Taylor (1982) found an average seed production of 1629 kg/ha in moist-soil impoundments in southern Missouri. Penny (2003) sampled moist-soil impoundments throughout the MAV and reported seed abundance averaged 611 ± 146 kg/ha. For conservation planning, the Lower Mississippi Valley Joint Venture assumes average seed production in moist-soil wetlands is 450 kg/ha (Reinecke *et al.*, 1989).

Previous studies documented considerable annual variation in moist-soil seed production. For example, moist-soil seed abundance ranged from 200–586 kg/ha during 2000–2001 in California's Central Valley (Naylor, 2002). Similarly, estimates of seed availability in Mississippi ranged from 331–1084 kg/ha in 2001–2002 and averaged 603 kg/ha (Reinecke and Hartke, 2005). Moser *et al.* (1990) documented 253–1288 kg/ha of moist-soil plant seeds in Arkansas impoundments during 1988–1990 ($\bar{x} = 613$ kg/ha). Our annual estimates of seed production also varied considerably (329–1231 kg/ha). We speculate variation in production was related to timing and duration of drawdown. Specifically, the SP was dewatered in 4 days in mid-July 1999 (a fast mid-season drawdown; Fredrickson and Taylor, 1982), 10 d in late-July to early-August 2000 (a fast late-season drawdown), and 19 d in early-mid July 2001 (a slow mid-season drawdown). Although we cannot infer cause-and-effect, our annual seed-production estimates appeared to coincide with recommendations of Fredrickson and Taylor (1982) in that a slow, mid-season drawdown promoted greatest seed production.

Our overall estimate of seed production ($\bar{x} = 790 \pm 48$ kg/ha) was slightly greater than reported previously. However, our estimates may not be directly comparable to previous research findings because we did not oven dry samples (*see* Methods) nor sample the seed bank as did other researchers (Naylor, 2002; Penny, 2003; Reinecke and Hartke, 2005). Our overall estimate of carrying capacity ($\bar{x} = 6760 \pm 411$ DUDs/ha) was slightly less than for playa wetlands in Texas ($\bar{x} = 7794 \pm 1806$ DUDs/ha; Anderson and Smith, 1999), but greater than most estimates for harvested croplands. For example, average carrying capacity in our study was 2.4 times greater than harvested corn fields and 15.2 times greater than harvested soybean fields in late autumn in Illinois (Warner *et al.*, 1989). Additionally, our carrying capacity estimates were 7.5 times that of harvested rice fields in the MAV (Stafford, 2004) and 1.5 times greater than harvested corn fields in Texas (Baldassarre and Bolen, 1984).

TABLE 2.—Estimated mean stem density (stems/m^2) and seed production (kg/ha) and standard error (SE) of 16 moist-soil plants by habitat stratum, South Pool of Chautauqua National Wildlife Refuge, Illinois, 1999–2001

	Stratum					
	Moist-soil		Managed[a]		Willow	
Species	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Amaranthus rudis						
Density	0.8	0.3	3.9	1.3	0.4	0.3
Production	7.9	4.7	14.4	6.6	2.5	2.2
Amaranthus tuberculatus						
Density	1.4	0.4	12.2	2.0	2.8	1.0
Production	10.1	5.6	37.5	12.6	11.5	6.4
Bidens cernua						
Density	8.4	2.0	0.0	0.0	5.7	3.2
Production	67.7	25.6	0.0	0.0	9.1	5.0
Bidens frondosa						
Density	<0.1	<0.1	0.0	0.0	0.1	0.1
Production	0.3	0.3	0.0	0.0	<0.1	<0.1
Cyperus erythrorhizos						
Density	61.6	9.3	60.5	8.9	8.6	2.8
Production	430.1	70.2	45.1	8.9	23.6	12.5
Cyperus esculentus						
Density	0.8	0.5	5.7	2.7	0.7	0.6
Production	1.3	1.0	6.2	3.9	0.4	0.4
Cyperus ferruginescens						
Density	33.8	5.4	81.4	12.3	7.5	3.3
Production	49.0	9.7	59.6	13.0	12.6	6.8
Cyperus strigosus						
Density	4.2	1.7	0.0	0.0	0.1	0.1
Production	25.8	12.5	0.0	0.0	<0.1	<0.1
Echinochloa crusgali						
Density	4.4	2.6	4.2	2.2	0.4	0.3
Production	28.2	16.8	7.5	5.7	<1.0	<1.0
Echinochloa walteri						
Density	17.1	3.8	0.6	0.4	2.6	1.3
Production	141.5	39.6	0.1	<0.1	7.5	5.9
Eragrostis hypnoides						
Density	806.2	83.2	3851.6	361.7	441.8	117.3
Production	124.5	16.9	305.8	71.8	27.1	7.4
Leersia oryzoides						
Density	135.8	13.3	21.8	4.1	36.7	8.7
Production	264.7	41.4	8.9	2.2	24.6	7.5

TABLE 2.—Continued

	Stratum					
	Moist-soil		Managed[a]		Willow	
Species	x̄	SE	x̄	SE	x̄	SE
Leptochloa fascicularis						
Density	11.0	2.7	10.0	2.3	8.1	3.6
Production	23.5	7.6	5.5	1.9	5.1	2.5
Polygonum pennsylvanicum						
Density	<0.1	<0.1	0.0	0.0	0.2	0.1
Production	<0.1	<0.1	0.0	0.0	1.1	1.1
Sagittaria calycina						
Density	20.5	1.8	1.1	0.4	2.1	1.1
Production	399.5	60.4	1.2	0.7	5.3	3.3
Sagittaria latifolia						
Density	0.7	0.3	0.0	0.0	0.1	0.1
Production	4.8	2.0	0.0	0.0	0.0	0.0

[a] Values for the managed stratum represent only 2000 and 2001, when this area was actively manipulated

The moist-soil stratum contributed disproportionately to seed production and carrying capacity in the SP, although the managed stratum realized relatively great seed production. Although initially counterintuitive, seed production was less in the managed stratum than the moist-soil stratum because management was directed at reducing competition from invasive species, which was not a concern in the moist-soil stratum. Nonetheless, seed production per hectare in the managed area was 18.9 times greater in 2000 and 20.6 times greater in 2001 compared with 1999 (pre-treatment). Additionally, cocklebur stem densities in the managed stratum were 6 and 3 times greater in 1999 ($\bar{x} = 280 \pm 47$ stems/m^2) than in 2000 and 2001, respectively.

We did not explicitly estimate seed production relative to specific management techniques because refuge personnel conducted vegetation management when convenient, and treatments were difficult to delineate *a posteriori*. However, refuge personnel indicated that the majority of cocklebur and willow were controlled by mowing annually. Areas too wet to mow or containing unusually robust stands of cocklebur were typically sprayed with 2, 4-D. Because we did not evaluate spraying and mowing of undesirable vegetation through independent experiments we cannot infer causation about each practice. Nonetheless, it appears that mowing cocklebur and willow may increase seed production and additional benefits may be realized via herbicide treatment where mowing is difficult or inefficient. We recommend future research experimentally evaluate the effects of mowing and herbicide treatments for cocklebur and willow control in order to maximize seed production in moist-soil areas.

Although seed production was poor in the willow stratum, carrying capacity estimates for this zone may still exceed other estimates of waterfowl foraging habitats such as harvested soybeans (Warner *et al.*, 1989). Also, stands of willow may serve as windbreaks for waterfowl (Fredrickson and Reid, 1988b), reducing thermoregulatory costs during inclement weather (Magee, 1996), and may provide substrate for invertebrate production and emergent cover for protection from predators. Indeed, waterfowl commonly use the willow zone of the SP for roosting and shelter (M. M. Horath and A. P. Yetter, pers. obs.).

Although our estimates of seed production were precise, an estimate of food abundance for waterfowl applicable to the entire IRV is needed to evaluate foraging carrying capacity objectives relevant to regional conservation plans. Therefore, we recommend replicating our survey on other public and private lands in the IRV. Further, we recommend an experimental evaluation of timing and duration of drawdown on plant-seed production in the IRV to provide management guidelines for mid-latitude moist-soil wetlands. Finally, discing or tilling soil has been shown to increase seed production of moist-soil plants in other regions of North America (Gray *et al.*, 1999; Naylor, 2002); thus, we recommend experimental evaluation of the effectiveness of these practices to increase plant-seed production at mid- and northern latitudes.

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