Using river flow management to improve wetland habitat quality for waterfowl on the Mississippi River, USA

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Abstract

In an effort to improve wetland conditions on the highly regulated Upper Mississippi River, the U.S. Army Corps of Engineers conducted an experiment that involved using navigation dams to restore the stable, summer low water portion of the natural flow regime that would expose soil and permit establishment of moist-soil plant species. Plant response was measured and waterfowl surveys and behavioural observations were conducted to evaluate the ability of river flow management to improve habitat quality for migrating waterfowl. A total of 15 plant species were recorded in plot transect surveys conducted during 1999, none in 2000 and 17 in 2001. Species in the genera *Polygonum*, *Echinochloa*, and *Cyperus* were most common, occurring in > 75% of sample plots. River stage management produced an estimated 2,541 kg ha^{-1} of moist-soil plant seed in 1999, 0 kg ha^{-1} in 2000 and 3,336 kg ha^{-1} in 2001, and seed species composition varied between years. Eighteen species of duck were observed during spring surveys. Duck abundance was lowest in the spring following the failed plant year. Dabbling ducks overwhelmingly used the moist-soil vegetation zone more than open water in 1999 (94.0% of all ducks), and Green-winged Teal *Anas crecca*, Mallard *A. platyrhynchos* and Northern Pintail *A. acuta* spent between 31–46% of their time feeding. River flow management can be used to improve wetland conditions for waterfowl on a large regulated river like the Mississippi.

Key words: feeding effort, Mississippi River, moist-soil plants, river level management, waterfowl.

Anthropogenic actions have substantially changed system structure and function on the Upper Mississippi River ecosystem. Levee construction and the addition of 26 locks and dams have changed the Upper Mississippi River from a free-flowing river-floodplain into a series of managed pools with constricted flow and controlled flooding (Chen & Simons 1986; Johnson *et al.* 1995; Patrick 1998). Because of these modifications, the natural hydroperiod characteristic of the system has been altered, changing ecosystem function (Junk *et al.* 1989). In fact, the hydroperiod behind the dams on the Upper Mississippi River is often inverted; that is, low pool elevations occur during spring periods of relatively high flow, and low river flows in summer now correspond to higher pool levels. The ability of wetland plants to persist in this altered landscape and the suitability of these altered habitats for wetland birds such as waterfowl is unclear.

The Upper Mississippi River has been altered to provide flood protection, increase agricultural production in the floodplain, and facilitate navigation. Attempts to improve ecosystem function must operate within the bounds of these other societal priorities. In 1994, the U.S. Army Corps of Engineers (USACE, the agency in charge of managing the Upper Mississippi River system) conducted a water management experiment in an attempt to increase wetland habitat quantity and quality while maintaining adequate river levels for summer navigation by commercial shipping. Termed Environmental Pool Management (EPM), the objective was to use the navigation dams to alter river flows and maintain a period of low water long enough to create conditions suitable for the germination, growth, and maturation of herbaceous annual plant species (*i.e.* moist-soil plants; Busse *et al.* 1995). EPM is based on successful wetland management principles (Fredrickson & Taylor 1982); however, these principles have not been applied to a large regulated river like the Mississippi, and it was unclear if the river stage could be lowered and stabilised or how wetland plants would respond.

If wetland plants do respond to EPM, this would improve the habitat quality for migratory waterfowl. The floodplains of the Mississippi and nearby Illinois River have historically provided habitat for large numbers of migratory waterfowl, but numbers have declined as the system has been increasingly modified (Havera 1999). Management actions that restore the growing conditions required by moist-soil plants can provide direct benefits to waterfowl by producing seeds, tubers, and aquatic macroinvertebrates (Bellrose 1941; Kadlec 1962; Harris & Marshall 1963; Voigts 1976; Murkin *et al.* 1982; Murkin & Kadlec 1986). The objectives of the study presented here were to measure plant response on mudflat habitats exposed by EPM, to quantify the wetland plant seeds produced by the responding vegetation, and to estimate waterfowl use and behaviour in areas influenced by EPM.

Study area

The Upper Mississippi River extends 1,370 km from Lake Itasca in north-central Minnesota to its confluence with the Ohio River near Cairo, Illinois. The watershed

($444,185 \ km^2$) drains most of Minnesota, Wisconsin, Iowa, and Illinois, along with portions of Missouri, South Dakota, and Indiana. The study was conducted in Pool 25, a 51.6 km stretch of the Mississippi River, and its associated floodplain between Lock and Dam 25 (river km point 388.4) and Lock and Dam 24 (river km point 440.0), covering an area of 6,506 ha. The study areas were within 5 km of Lock and Dam 25. At full pool, the river level is 132.3 m (according to National Geodetic Vertical Datum; NGVD) at Lock and Dam 25, with 130.9 m NGVD being the lowest river elevation that maintains the 2.25 m deep channel needed for navigation (Wlosinski 1996). Pool 25 contains a mosaic of habitats including bottomland forest, backwater lakes, side channels, and arable areas (U.S. Army Corps of Engineers 1996). The study sites were located in the backwater slough at Jim Crow Island, the downstream, side-channel tip at Turner Island, and within the backwater area of the Batchtown State Fish and Waterfowl Management Area (hereafter Batchtown). Earlier work indicated that these areas contained the bulk of exposed soils during low river stages (Wlosinski *et al.* 2000).

Environmental pool management

Pool 25 is managed using hinge point control, which means a primary objective is to keep the river stage constant at the mid-point (*i.e.* half-way between the two dams) of the pool (Sparks 1995). As spring snow melt increases river discharge, dam gates at the upper and lower ends of the pool are opened to increase water passage down river. Effectively the pool is put on "tilt", and the elevation gradient from the upper to the lower pool more closely tracks the slope of the river channel. As the river stage declines in the lower reaches of the pool, soils in floodplain and off-channel areas are exposed, creating conditions that allow germination of moist-soil plants. As river discharge declines, dam gates are closed, which restricts river discharge and the river stage behind the dam rises (*i.e.* the influence of the natural river gradient is lessened). Under this management regime, soils were rarely exposed long enough to allow for the survival and maturation of moist-soil vegetation. The goal of EPM was to maintain a period of stable river stage, below full pool, in the lower reaches of Pool 25 for at least 30 days, which would allow moist-soil vegetation to germinate and reach heights that would enable them to persist on returning the river to full pool levels. The management prescription called for the river then to be raised at a rate ≤ 6 cm per day (132.3 m; Busse *et al.* 1995). If the river stage rises too soon and too quickly it can cover and kill young plants. The USACE has attempted to implement EPM each year since 1994.

Methods

Data from USACE were used to construct a hydrograph for the lower reach of Pool 25 for three growing seasons (1999–2001). To classify the extent and duration of drawdown, the number of consecutive days that the river stage was held below 132.3 m (full pool) and 130.9 m was summed. The rate that the river stage rose from low to full pool following a period of stable river levels was calculated as: (full pool elevation – minimum sustained river stage)/number of days to reach full pool, where the minimum sustained river stage was defined as the river stage that the water managers attempted to maintain for a 30-day period during each year.

The plant community was characterised by recording presence and estimating percent cover (to nearest 10%) for each species occurring in 0.5 m^2 plots located along 13 transects (one at Jim Crow Island, one at Turner Island and 11 in Batchtown). Each transect was taken in a line perpendicular to the shoreline (and elevation contour). Sampling stations along each transect were located at elevations corresponding to 5, 20, 35, 50, and 75 cm below full pool; specific sites were determined by tossing a 0.5 m^2 sampling frame on the ground. In 2000 and 2001, vegetation composition data were collected in the 11 transects established in the Batchtown area during 1999. After the first year, GPS was used to relocate the start of each transect, with notes from 1999 specifying the distance of each plot along the transect being used to locate the sampling stations. Collection of data commenced approximately 3 weeks after the river stage reached minimum water surface elevation. This date was too early to identify all plants to species level, so in some cases plants were only identified to genus. We chose to sample plants within three weeks of germination because of uncertainty regarding the timing of re-flooding and the risk of not collecting any data if re-flooding occurred earlier than anticipated.

Seed biomass produced by Nodding Smartweed *Polygonum lapathifolium* (L.), Red-rooted Nutsedge *Cyperus erythrorhizos* (Muhl.), Sprangletop *Leptochloa panicoides* (J. Presl), Rice Cutgrass *Leersia oryzoides* (L.), and Millet *Echinochloa crusgalli* (L.) was estimated using regression relationships between seven measurements of plant structure (*e.g.* plant height) and seed head characteristics (*e.g.* length and width) and seed biomass (Laubahn & Fredrickson 1992). Plant measurements were collected on mature plants, starting approximately three weeks after river level returned to full pool elevation and after plants had set seed. Measurements were taken in 0.25 × 0.25 m plots located randomly along the length of the same transects used to characterise species composition (n = 232 plots in 1999; n = 120 plots in 2001).

Waterfowl were surveyed weekly from the last week in February to the first week in April during 2000–2002, the three springs that followed our summer growing seasons, using a total count methodology. While surveys in fall would have been preferable, waterfowl hunting during fall influenced bird distribution and researcher access to the study site. A survey route was established that included all side channel and backwater areas south of Hausgen Island; the route was chosen to minimise flushing birds to areas not yet surveyed and to ensure that areas covered by the plant transects were included in the survey. The route was navigated by boat and the abundance of each species was recorded, with the birds' flight direction also being noted to control for any double counting.

Behavioural observations were conducted to determine activity budgets for three species of waterfowl over a 6-week period in 1999 and again in 2000. Birds seen in spring 1999 were responding to habitat conditions created during 1998, a year in which plant response to the water levels was not quantified. However, a qualitative ground survey of the study area in 1998 indicated that plant response was similar to that recorded in 1999. Observations focussed on Green-winged Teal *Anas crecca* (L.), Mallard *A. platyrhynchos* (L.), and Northern Pintail *A. acuta* (L.), three species of duck that feed on seeds in moist-soil vegetation. Observations were made throughout the day between sunrise and sunset (CST) from duck blinds located throughout the study area using a 20–60 × spotting scope. Individuals were selected for observation by aiming the spotting scope at the centre of a flock and selecting the bird in the centre of the field of view. Each session lasted 15–30 min with bird behaviour recorded at 10 s intervals. If the original bird swam out of view before the end of the 30 min session, the observation was shifted to the nearest neighbour of the same species and sex as the focal individual (Losito *et al.* 1989). Behaviours were classified as feeding, comfort (preening, drinking, wing flapping and head shaking), locomotion (swimming and flying), agonistic (chasing and biting), courtship (including copulation), resting (inactive or sleeping), and alert (Dugger & Petrie 2000). If management created food resources of value, we hypothesise that birds should actively forage in the moist-soil vegetation zone. All means are reported ± s.e. unless otherwise indicated.

Results

Annual variation in river discharge influenced the ability of the USACE to meet the river stage criteria outlined by EPM (Fig. 1). Initiation of the stabilised low river stage period varied from early to mid June in 1999 and 2001. In 2000, the river stage dropped below full pool in late May; however, high river discharge overwhelmed capacity to maintain a low river stage and the river stage rose, exceeding full pool level. A subsequent drawdown of the river stage began in early July, but very little soil remained exposed for the specified 30 days. The elevation continuously exposed for at least 30 days varied by year (Fig. 2). The area of soil exposed for potential plant growth was most extensive in 1999 when areas 1.1 m below full pool were exposed for 30 days, followed by 1998 (0.8 m), 2001 (0.5 m) and 2000 (0.1 m). Re-flood rate varied from 5 cm/d in 2001 to 15.0 cm/d in 1999 and 22 cm/d in 2000.

In 1999, 15 plant taxa were recorded: *Polygonum*, *Echinochloa,* and *Cyperus* were the most common genera, occurring in 93.2%, 79.5%, and 76.7% of plots, respectively (Table 1). In 2000, the rise in river stage during June killed vegetation that had germinated; although waters receded again in July, soils were not exposed long enough for the moist-soil plants to become established. In 2001, 17 taxa of wetland plants were detected; as in 1999 *Cyperus* was abundant, occurring in 68.5% of samples, followed by pigweeds *Amaranthus* sp. and *Echinochloa* (Table 1). *Polygonum*, the most common plant in 1999, was found in only 27.8% of plots in 2001. We estimated that 2,541 kg ha^{-1} of moist-soil plant seed was produced in 1999, 0 kg ha^{-1} in 2000 and 3,336 kg ha^{-1} in 2001 (Table 2). Estimates of *C. erythrorhizos* were high in both years that seed was produced; however, while

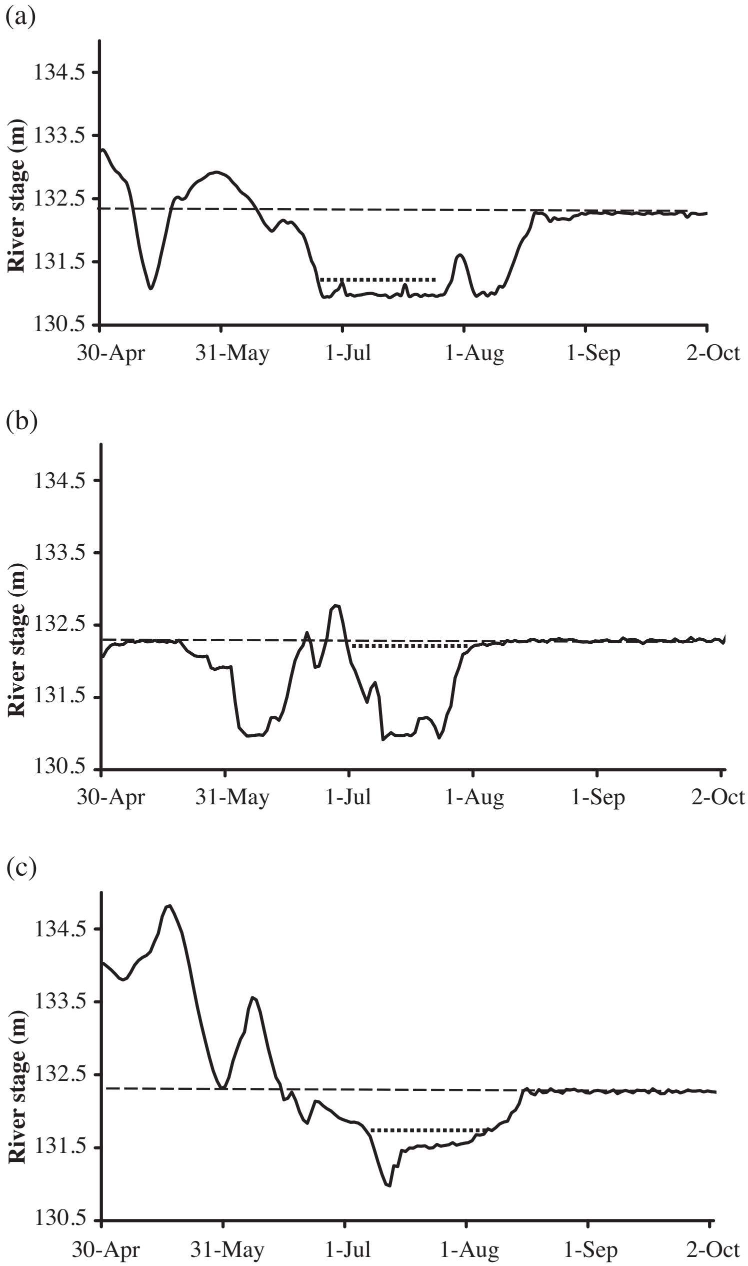

Figure 1. Hydrograph of river stage (solid line) on Pool 25, Upper Mississippi River, USA, during spring and summer in: (a) 1999, (b) 2000, and (c) 2001. Full pool river stage is indicated by the dashed line, and the elevation where soils were exposed for 30 days is marked by the dotted line.

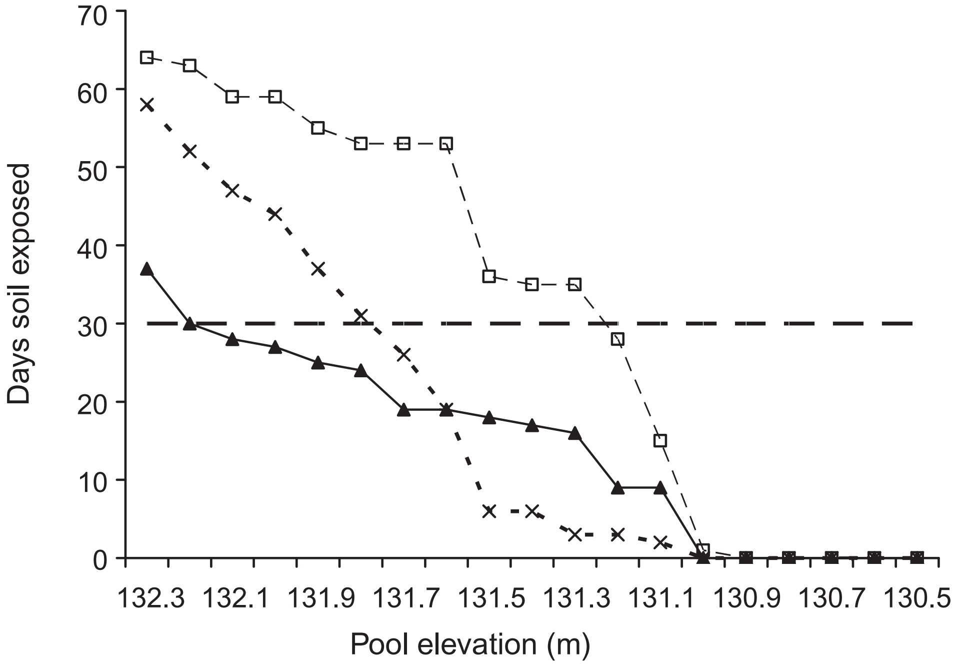

Figure 2. Relationship between duration of drawdown and river stage in Pool 25 of the Upper Mississippi River for three years: 1999 [□], 2000 [▲], and 2001 [×]. The area of soil exposed was most extensive in 1999 when river stage was held 1.1 m below full pool (132.3 m) for 30 days, and least extensive in 2000 when only soils 0.1 m below full pool were exposed for 30 days.

Polygonum was a co-dominant in 1999, it was much less common in 2001, having been replaced by *Echinochloa* and *L. panicoides*.

Six waterfowl surveys were conducted each spring except 2001, when fluctuating river stage permitted only three surveys. Eighteen species of duck were observed; mean counts were highest in 2000 (4,702 ± 2,621), followed by 2002 (1,275 ± 520) and 2001 (569 ± 377; Table 3). Dabbling ducks were more abundant than diving ducks except in 2001 and Mallard, Northern Pintail, and Green-winged Teal were the most abundant dabbling duck species (Table 3). In 1999, 94.0% of all ducks used the moist-soil vegetation zone and 99.2% of these were dabbling ducks. Combining years, the proportion of time spent feeding was 46% for Green-winged Teal (28 h of observation), 44% for Pintail (37 h) and 31% for Mallard (55 h). Foraging effort was less during 1999 than 2000 (Z = 3.19, P = 0.001) for Teal, but was similar between years for Mallard and Northern Pintail.

Discussion

The USACE is able to use the lock and dam system on the Upper Mississippi River to create a stable low river stage period that exceeds 30 days; this happened in three of

Table 1. Percentage of occurrence of plant taxa in sample plots (*n* = 65 in 1999, *n* = 55 in 2000 and 2001) located along transects placed in the Batchtown area of Pool 25, Mississippi River, USA in summers 1999 and 2001. Taxa known to be important food for waterfowl are given in bold. Measures are not given for 2000 because elevated water levels killed the vegetation that had germinated that year. Environmental Pool Management (EPM) began in 1994.

[a] Includes *Polygonum lapathifolium* and Large-seeded smartweed *P. pennsylvanicum*; [b] includes *Echinochloa crusgalli* and Rough Barnyard Grass *E. muricata*; [c] includes Chufa *Cyperus esculentus* and *C. erythrorhizos*; [d] includes *Populus* sp., *Acer* sp., and *Salix* sp.

Taxa	Year	
	1999	2001
Polygonum[a]	93.2	27.8
Echinochloa[b]	79.5	52.7
Cyperus[c]	76.7	68.5
Woody sp.[d]	26.0	–
Lindernia dubia	23.3	5.5
Leptochloa panicoides	23.3	10.9
Leersia oryzoides	20.6	9.1
Amaranthus rudis	16.4	59.3
Xanthium strumarium	11.0	3.6
Eragrostis hypnoides	4.1	20.4
Digitaria sp.	–	14.5
Ipomea purpurea	6.9	12.7
Ludwigia sp.	–	9.1
Scirpus fluvialis	–	5.5

four years in our study and 12 of the 13 years since EPM was implemented in 1994 (USACE unpubl. data). In contrast, during the 10 years prior to implementation of EPM, a hydrograph with features similar to EPM occurred in only one year (USACE unpubl. data). The extent and duration of the stabilised low-stage phase of the hydrograph varied with river conditions. Re-flood rates exceeded targets in three of four years, but this did not prevent establishment of moist-soil vegetation in either 1999 or 2001. The impact of the re-flood rate likely depends on the height of plants when re-flooding begins. In both 1999 and 2001, the prolonged low water period resulted in relatively mature plants before re-flooding began, which probably enabled the plants to survive a faster re-flood rate. The extent of the vegetation response varied with the water regime each year (J. Feddersen and B. Dugger, pers. obs.), but over 350 ha of vegetation cover may be created in Pool 25 (Wlosinski *et al.* 2000).

The presence of moist-soil plants has been suggested as a useful indicator of habitat quality or restoration success on rivers whose hydroperiod is characterised by a summer low like the Mississippi River (Ahn *et al.* 2004). Seventeen taxa of moist-soil plants were recorded during two of three study years. In 2000, river stage was not stable long enough for plant establishment. Compared with an earlier assessment (Wlosinski *et al.* 2000), we found higher plant diversity and the presence of woody and perennial herbaceous species. Differences may reflect differences in sampling procedures (timing of sampling and sampling sites) or variation in the

Table 2. Estimated seed biomass (kg/ha) produced by moist-soil plants measured in Pool 25, Mississippi River, USA, during summers 1999 and 2001 (mean values; s.d. given in parentheses). Seed biomass estimates were calculated using the regression equations developed by Laubahn & Fredrickson (1992). [a] n = 232 plots; [b] n = 120 plots.

Taxa	**Year**			
	1999[a]		**2001[b]**	
Cyperus erythrorhizos	1,264	(1,995)	1,783	(2,868)
Echinochloa	114	(315)	909	(742)
Leersia oryzoides	12	(75)	36	(119)
Leptochloa panicoides	3	(15)	486	(953)
Polygonum lapathifolium	1,148	(990)	120	(239)
Total	2,541	(2,251)	3,336	(3,123)

plants' response to variation in hydroperiod among years (Fredrickson & Taylor 1982). Alternatively, differences between the studies may reflect plant succession. The presence of perennial species increases when wetlands have been under moist-soil management for > 4 years (Fredrickson & Taylor 1982). Although perennial species were not dominant at our sites, we did record Rice Cutgrass *Leersia oryzoides*, Eastern Cottonwood *Populus deltoides*, Red Maple *Acer saccharinum*, Willow *Salix* sp., and River Bulrush *Scirpus fluviatilis* on the study area. The absence of *Panicum* and Foxtail *Setaria* (found by Wlosinski *et al.* 2000) and occurrence of *Leersia* and *Scirpus* in our samples is consistent with successional change in the plant community since EPM started in 1994. Woody species (*e.g.* maples and willows) occurred less frequently in 2001 than 1999 suggesting that, while conditions suitable for germination may periodically occur, conditions may not be suitable for the long-term establishment of trees.

One goal of EPM was to increase the production of plant foods important for migratory waterfowl. Our estimate of seed production (2,541 kg ha^{-1} and 3,336 kg ha^{-1}) was similar to or higher than comparable estimates for high quality wetland habitat elsewhere in Illinois, Missouri and the Mississippi Alluvial Valley (range 496–2,920 kg/ha; Low & Bellrose 1944; Greer *et al.* 2007; Kross *et al.* 2008). Species-specific estimates of seed biomass changed greatly between years. The late drawdown in 2001 resulted in less *Polygonum* seed; however, this was offset by large increases in production of *Echinochloa* and *Leptochloa*

Table 3. Mean ducks counted (± s.e.) during weekly surveys of the lower reach of Pool 25, Mississippi River, USA, from late February–early April in 2000–2002 inclusive. [a] Includes Gadwall *Anas strepera,* American Wigeon *A. americana,* Blue-winged Teal *A. discors,* American Black Duck *A. rubripes* and Wood Duck *Aix sponsa.* [b] Includes Redhead *Aythya Americana,* Ruddy Duck *Oxyura jamaicensis,* Bufflehead *Bucephala albeola* and Hooded Merganser *Lophodytes cucullatus.*

Guild/Species	**Year**		
	2000	**2001**	**2002**
Dabbling ducks			
Anas platyrhynchos	2,194 ± 1,334	90 ± 27	491 ± 175
Anas acuta	947 ± 623	1 ± 1	412 ± 264
Anas crecca	645 ± 356	5 ± 5	26 ± 11
Other dabbling ducks[a]	454 ± 89	2 ± 2	43 ± 12
Total dabbling ducks	**4,243 ± 2,397**	**98 ± 32**	**1,187 ± 525**
Diving ducks			
Aythya affinis	645 ± 356	0	26 ± 14
Aythya collaris	238 ± 120	0	4 ± 2
Aythya valisineria	33 ± 33	57 ± 29	36 ± 11
Mergus merganser	4 ± 4	150 ± 260	12 ± 7
Bucephala clangula	2 ± 2	212 ± 367	3 ± 2
Other diving ducks[b]	44 ± 15	7 ± 3	8 ± 3
Total diving ducks	**459 ± 265**	**471 ± 378**	**88 ± 17**

seed. The abundance of all potential waterfowl foods (*e.g.* tubers) was not estimated; thus our assessment of food production may be conservative.

The fluctuation in waterfowl numbers across years was consistent with changes in habitat conditions. Spring waterfowl abundance was highest in 2000 followed by 2002 and 2001. Low duck abundance in 2001, particularly dabbling ducks that rely on seeds produced by moist-soil vegetation, occurred following the failure of the moist-soil plant response in summer 2000. The reason for lower waterfowl abundance in 2002 compared to 2000 is less clear; however, food abundance is only one factor determining waterfowl use of a region during migration (Heitmeyer 1988; Havera

1999; Greer *et al.* 2007). In 1999, almost all ducks were using areas that supported vegetation the previous summer and behavioural observations indicated that feeding effort during 1999 and 2000 was at levels measured in other studies on major wintering and migration areas (Jorde 1981; Quinlan & Baldassarre 1984; Miller 1985; Gruenhagen 1987; Thompson & Baldassarre 1991; Rave & Baldassarre 1989).

Taken together, the data indicate it is possible to use the navigation dams along the Mississippi River to improve wetland habitat conditions for migratory waterfowl and we suggest that EPM continue. The USACE has demonstrated they have the capacity to apply this management technique to multiple river pools simultaneously. The focus in this paper was on a limited set of taxa (plants, ducks), but other research suggests that fish and invertebrates may benefit as well (Garvey *et al.* 2003). We suggest that an expanded effort to understanding the more complete picture of aquatic species response and interactions among species continue. For example, decreased *Polygonum* in 2001 changed the structural characteristics of the plant community. *Polygonum* has robust stalks and a large leaf surface area, and was frequently the only plant recognisable during waterfowl surveys in spring. The persistence of residual Smartweed vegetation may have important consequences for aquatic organisms using backwater areas in spring (Flinn *et al.* 2005). Furthermore, a decrease in the number of *Polygonum* leaves and stems during late summer after re-flooding influenced shading patterns that changed solar inputs into the water column, influencing key water quality parameters that possibly affected the structure and composition of the aquatic community (Garvey *et al.* 2003; Flinn *et al.* 2005). Additionally, the river hydrograph may still be inconsistent with the needs of some floodplain dependent fish that require a rise in river levels during spring or early summer to spawn (Garvey *et al.* 2003).

Finally, the hydrograph varied considerably among study years. However, year to year variation was historically part of the system and is desirable (Sparks 1995). Given that the main factors driving river floodplain function are known, but that there is a lack of specific details about the hydrologic needs for many species, variation in the timing, extent, and duration of the low river stage period provides the highest probability of meeting the habitat needs for a diverse community.

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References

Ahn, C., White, D.C. & Sparks, R.E. 2004. Moist-soil plants as an ecohydrologic indicator for recovering the flood pulse in the Illinois River. *Restoration Ecology* 12: 207–213.

Bellrose, F.C. 1941. Duck food plants of the Illinois River Valley. *Illinois Natural History Survey Bulletin* 21: 237–280.

Busse, D., Dalrymple, K. & Strauser, C.N. 1995. Environmental Pool Management. *In* Proceedings Fifty-first Annual Meeting of the Upper Mississippi River Conservation Committee, pp. 55–65. Upper Mississippi River Conservation Committee, Rock Island, Illinois, USA.

Chen, Y.H. & Simons, D.B. 1986. Hydrology, hydraulics, and geomorphology of the Upper Mississippi River System. *Hydrobiologia* 136: 5–20.

Dugger, B.D. & Petrie, M.J. 2000. Geographic variation in foraging patterns of pre-incubating female Mallards. *Canadian Journal of Zoology* 78: 2240–2243.

Flinn, M.B., Whiles, M.R., Adams, S.R. & Garvey, J.E. 2005. Macroinvertebrate and zooplankton responses to emergent plant production in Upper Mississippi River floodplain wetlands. *Archive fur Hydrobiologia* 162: 187–210.

Fredrickson, L.H. & Taylor, T.S. 1982. Management of seasonally flooded impoundments for wildlife. USFWS Resource Publication No. 148. United States Department of Interior, Fish and Wildlife Service, Washington DC, USA.

Garvey, J.E., Dugger, B.D., Whiles, M.R., Adams, S.R., Flinn, M.B., Burr, B.M. & Sheehan, R.J. 2003. Responses of fish, waterbirds, invertebrates, vegetation, and water quality to environmental pool management: Mississippi River Pool 25. Southern Illinois University Report to the U.S. Army Corps of Engineers. USACE, St. Louis District, USA.

Greer, A.K., Dugger, B.D., Petrie, M.J. & Graber, D. 2007. The effects of fall and spring flooding on the availability of seed resources for spring migrating waterfowl. *Journal of Wildlife Management* 71: 1561–1566.

Gruenhagen, N.M. 1987. Feeding ecology, behavior, and carcass dynamics of migratory female Mallards. M.Sc. Thesis, University of Missouri, Columbia, USA.

Harris, S.W. & Marshall, W.H. 1963. Ecology of water-level manipulations on a northern marsh. *Ecology* 44: 331–343.

Havera, S.P. 1999. Waterfowl of Illinois. Illinois Natural History Survey Special Publication No. 21. Illinois Natural History Survey, Champaign, Illinois, USA.

Heitmeyer, M.E. 1988. Protein costs of prebasic molt of female mallards. *Condor* 90: 263–266.

Johnson, B.L., Richardson, W.B. & Naimo, T.J. 1995. Past, present, and future concepts in large river ecology. *BioScience* 45: 134–141.

Jorde, D.G. 1981. Winter and spring ecology of mallards in south central Nebraska. Ph.D. Thesis, University of North Dakota, Grand Forks, USA.

Junk, W.J., Bayley, P.B. & Sparks, R.E. 1989. Flood pulse concept in river-floodplain systems. *In* D.P. Dodge (ed.), *Proceedings of the International Large River Symposium (LARS)*, pp. 110–127. Special Publication of Canadian Fisheries and Aquatic Sciences, Ottawa, Ontario, Canada.

Kadlec, J.A. 1962. Effects of a drawdown on a waterfowl impoundment. *Ecology* 43: 267–281.

Kross, J., Kaminski, R.M., Reinecke, K.J., Penny, E.J. & Pearce, A.T. 2008. Moist-soil seed abundance in managed wetlands in the Mississippi alluvial valley. *Journal of Wildlife Management* 72: 707–714.

Laubahn, M.K. & Fredrickson, L.H. 1992. Estimating seed production of common plants in seasonally flooded wetlands. *Journal of Wildlife Management* 56: 329–337.

Losito, M.P., Mirarchi, R.E. & Baldassarre, G.A. 1989. New technique for time-activity studies of avian flocks in view-restricted habitats. *Journal of Field Ornithology* 60: 388–396.

Low, J.B. & Bellrose, F.C. 1944. The seed and vegetative yield of waterfowl food plants in the Illinois River Valley. *Journal of Wildlife Management* 8: 7–22.

Miller, M.R. 1985. Time budgets of Northern Pintails wintering in the Sacramento Valley, California. *Wildfowl* 36: 53–64.

Murkin, H.R. & Kadlec, J.A. 1986. Relationships between waterfowl and macroinvertebrate densities in a northern prairie marsh. *Journal of Wildlife Management* 50: 212–217.

Murkin, R.M., Kaminski, R. & Titman, R.D. 1982. Responses of dabbling ducks and aquatic invertebrates to an experimentally manipulated cattail marsh. *Canadian Journal of Zoology* 60: 2324–2332.

Patrick, R. 1998. *Rivers of the United States. Volume 4a*. John Wiley and Sons, New York, USA.

Quinlan, E.E. & Baldassarre, G.A. 1984. Activity budgets of non-breeding green-winged teal on playa lakes in Texas. *Journal of Wildlife Management* 48: 838–845.

Rave, D.P. & Baldassarre, G.A. 1989. Activity budget of green-winged teal wintering in coastal wetlands of Louisiana. *Journal of Wildlife Management* 53: 753–759.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. *BioScience* 45: 168–182.

Thompson, J.D. & Baldassarre, G.A. 1991. Activity patterns of nearctic dabbling ducks wintering in Yucatan, Mexico. *Auk* 108: 934–941.

U.S. Army Corps of Engineers 1996. Batchtown habitat rehabilitation and enhancement project, Pool 25 Mississippi River. USACE Unpubl. Report, USACE, St. Louis District, St. Louis, Missouri, USA.

Voigts, D.K. 1976. Aquatic invertebrate abundance in relation to changing marsh vegetation. *American Midland Naturalist* 95: 313–322.

Wlosinski, J.H. 1996. Pool 25: Analysis of water levels and discharge. National Biological Service Report LTRMP 96-T001. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, USA.

Wlosinski, J.H., Rogala, J.T., Owens, T.W., Dalrymple, K.L., Strauser, C.N. & Atwood, E. 2000. Response of vegetation and fish during an experimental drawdown in three pools, Upper Mississippi River. U.S. Geological Survey Report LTRMP 2000-T001. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, USA.

