A Manual for Calculating

Duck-Use-Days

To Determine Habitat Resource Values and Waterfowl Population Energetic Requirements in the Mississippi Alluvial Valley

Prepared For:

U. S. ARMY CORPS OF ENGINEERS
MEMPHIS DISTRICT

Greenbrier Wetland
Services Report 10-01

Mickey E. Heitmeyer

MAY 2010

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AND
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IN THE MISSISSIPPI ALLUVIAL VALLEY

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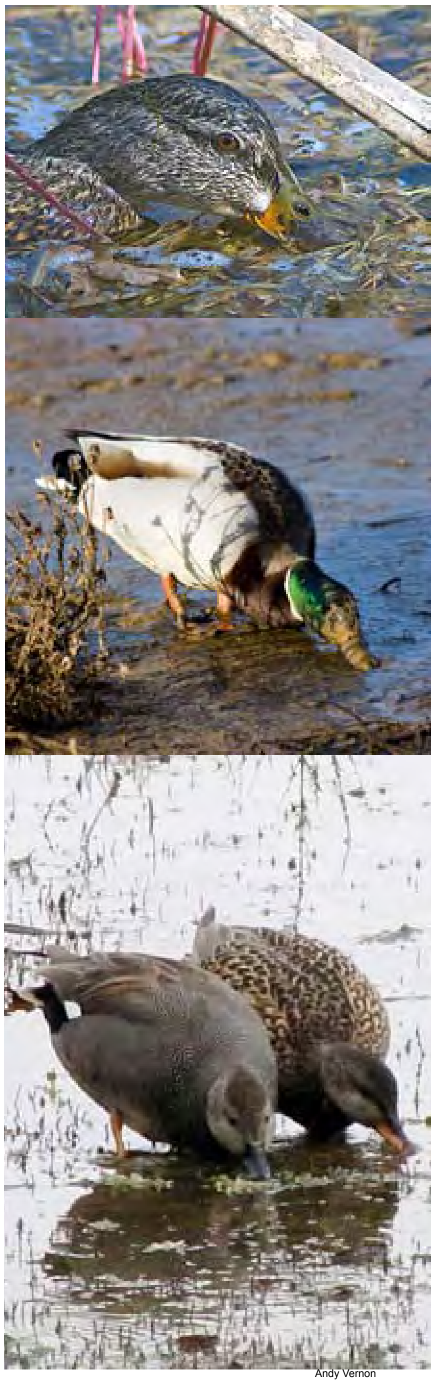
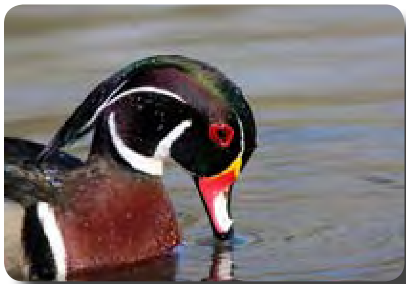
EXECUTIVE SUMMARY



Andy Vernon

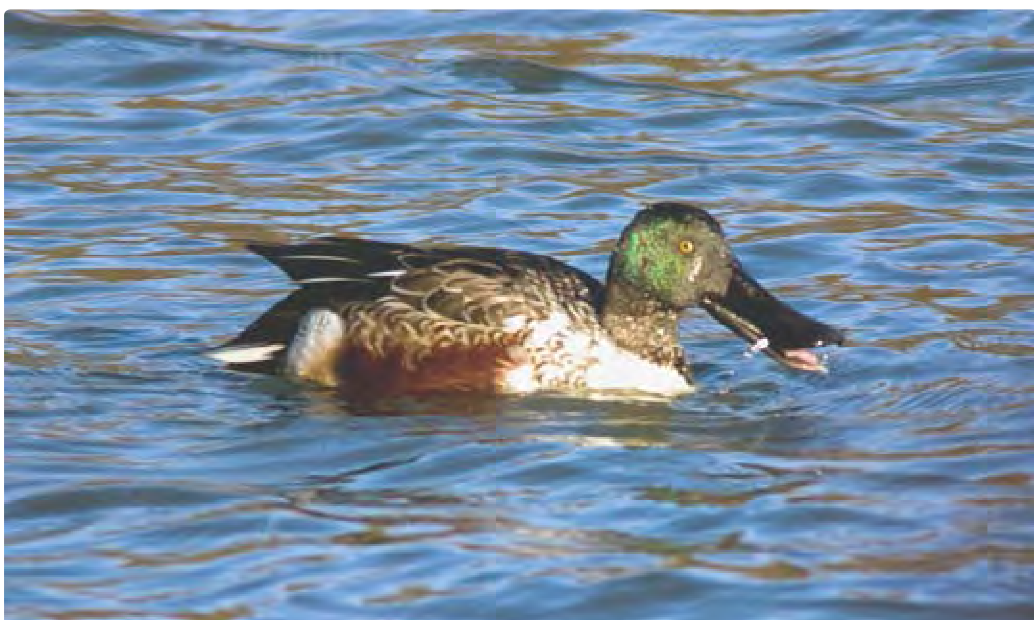
This manual provides quantitative methods to estimate duck-use-days (DUD), based on daily energy requirements of waterfowl species, to determine incremental benefits, and impacts, of land and water resource development projects on waterfowl habitats and populations in the Mississippi Alluvial Valley (MAV) during the nonbreeding period September through March. The manual uses the basic concepts of estimating DUD's from resource abundance in the MAV developed by the Lower Mississippi Valley Habitat Joint Venture and expands data and model equations using contemporary data on: 1) daily energetic expenditure of waterfowl species commonly present in the MAV during the nonbreeding period; 2) estimates of resource values and dynamics in a complete array of MAV habitats and management scenarios; 3) estimates of energy values of specific foods relative to different species; and 4) seasonal and annual probabilities of foods being available to waterfowl.

The primary habitat types in the non-coastal part of the MAV are: 1) Bottomland Hardwood Forest, 2) Floodplain Forest, 3) Riverfront Forest, 4) Seasonal Herbaceous including Bottomland Prairie, 5) Persistent Emergent, 6) Shrub/Scrub, 7) Dead Timber, 8) Open Water/Aquatic, and 9) Agricultural Fields. Major food groups in these habitats are 1) mast; 2) invertebrates and zooplankton; 3) seeds



from herbaceous and aquatic plants; 4) below-ground tubers, roots, and rhizomes; 5) above-ground browse; 6) aquatic plants and algae; 7) small vertebrates; and 8) agricultural grains and browse.

Five model equations are provided that calculate DUD's for various combinations of species, habitats and foods. These equations also provide a method to account for the probability of food types being available for various time periods from September through March. Specific project-specific data that must be obtained prior to using the manual model equations include number and species of waterfowl present on the site; habitat types and management of each respective habitat area; composition, stand density, and tree size for forested habitats; and frequency and duration of flooding by area and habitat type.



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INTRODUCTION

Land and water resource development projects conducted by the U.S. Army Corps of Engineers (USACE) and other agencies/ entities often need a quantitative methodology to determine incremental benefits, and impacts, of project features on waterfowl habitats and populations. Furthermore, waterfowl managers require information to determine potential carrying capacity of local and regional landscapes (Prince 1979), set habitat and acre goals for conservation areas such as North American Waterfowl Management Plan (NAWMP) Habitat Joint Ventures (e.g., Heitmeyer 1989, Loesch et al. 1994, Reinecke and Baxter 1996), determine impacts and mitigation requirements for land and water development projects (Phillips 2003), and evaluate the effectiveness of management actions and techniques (Fredrickson and Taylor 1982, Reinecke et al. 1989, Laubhan and Fredrickson 1992, Anderson and Smith 1999, Gray et al. 1999).

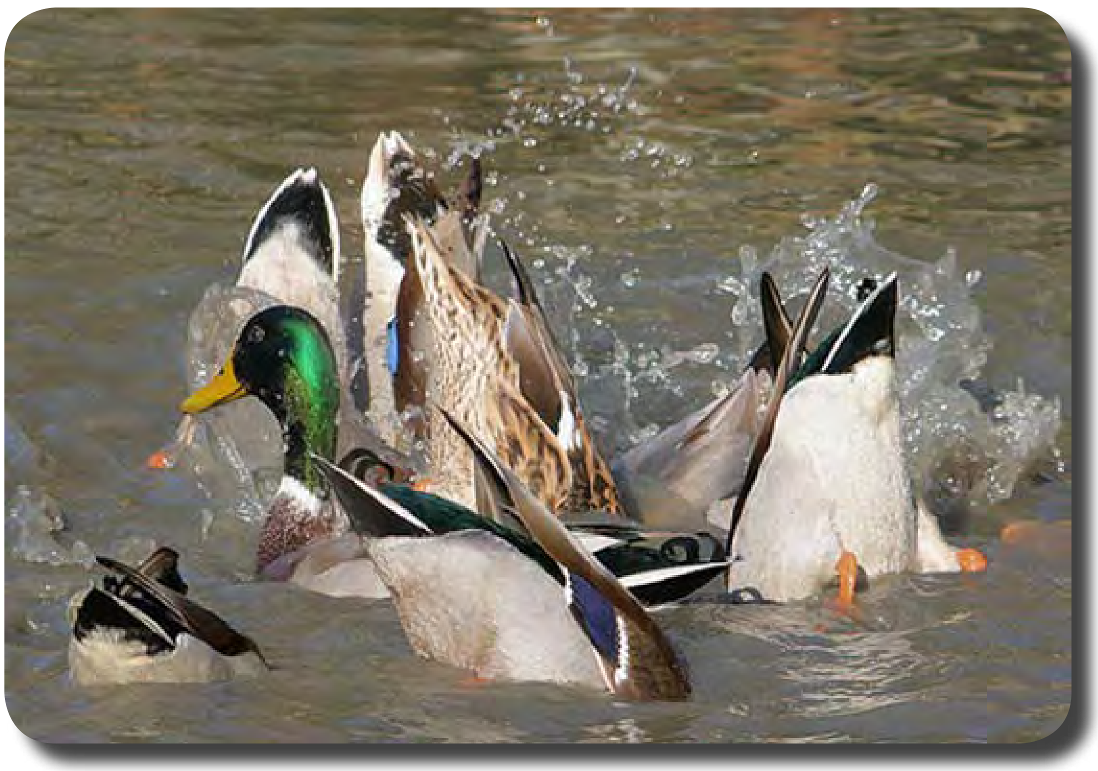
The basic question asked by the above interests is:

"How many individual waterfowl will an area/habitat type support during a particular period?"

The answer to this fundamental question requires information on:

1. The daily nutrient requirements of waterfowl species present during different periods of the year and annual cycle events they are engaged in.
2. The amount of resources potentially present in an area by habitat type.
3. The availability of resources in an area by habitat type related to waterfowl species foraging capabilities and climatic/hydrological events.

Historically, waterfowl managers have estimated habitat values and waterfowl population requirements by determining daily and period-specific energy use of birds present, or anticipated, in an area and the carrying capacity of habitats in that area (e.g., Prince 1979). The concept of "duck-energy-days", commonly referred to as "duck-use-days" (DUD), represents the energy needs of one individual waterfowl for one day. Waterfowl use of habitats and resources in an area depends on many factors, however, daily energy requirements represents an essential currency and continuity between an animal and its environment and can be quantified in an objective manner (King 1974). Estimates of DUD vary in relation to: 1) species and sex, mean body mass, and annual cycle events of waterfowl; 2) area of specific habitats; 3) amount of food produced and available to waterfowl in various habitat types; 4) nutritional composition of food types; 5) the efficiency of waterfowl in converting food nutrients to metabolizable energy; 6) environmental/climatic conditions; 7) decomposition rates of food types; 8) consumption of foods by non-waterfowl species, and 9) densities of food at which waterfowl cease foraging due to low foraging efficiency (often referred to as a "giving up density").



OBJECTIVES AND GENERAL ASSUMPTIONS

The objective of this manual is to identify quantitative methods to estimate DUD's, based on daily energy requirements of waterfowl species, to determine incremental benefits, and impacts, of land and water resource development projects on waterfowl habitats and populations in the Mississippi Alluvial Valley (MAV) during the nonbreeding period (September-March). The September to March time period is used to represent the non-breeding period because migrant waterfowl generally arrive and stay in the MAV during this time; only a very small number of some migrant species such as blue-winged teal, shoveler, and ruddy duck are present in the MAV outside of this time in August and April (Bellrose 1980). This manual is not intended to represent energy needs of waterfowl breeding in the MAV, including some species such as wood ducks, hooded merganser, and some locally-nesting mallards that may initiate nesting as early as February or March.

The MAV is defined as the historic and contemporary geomorphic surfaces formed by fluvial dynamics of the historic Mississippi River from ca. Cape Girardeau, Missouri to the northern extent of the Deltaic and Chenier Plains (Fig. 1). Many studies of food production and availability in the MAV are from northern parts of the MAV and no data are provided in this manual from coastal wetlands. Consequently, DUD equations provided in this manual may be most precise for the Upper portions of the MAV, but other areas, including sites outside of the MAV, also can use model information if the habitats in the area are similar to those in the MAV. For

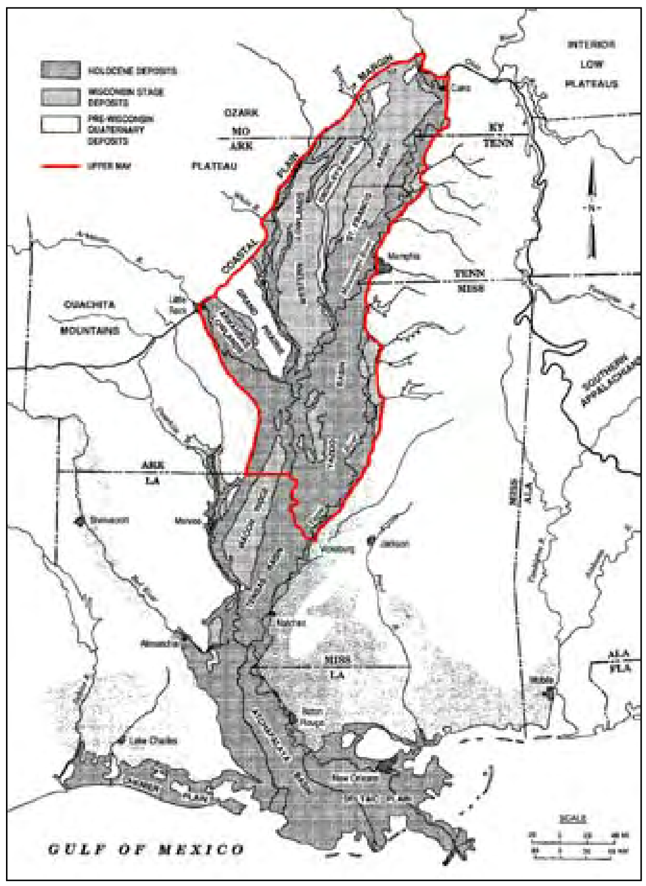


Figure 1. The Mississippi Alluvial Valley, showing Quaternary geomorphic surfaces and delineation of the Upper MAV regions pertaining to the Duck-Use-Day manual (modified from Saucier 1994).

example, floodplains in non-MAV portions of the Red, Arkansas, Pearl, Obion, Forked Deer, Hatchie, Black and other rivers have forested habitats similar to MAV regions that are used by large numbers of nonbreeding waterfowl.

This manual uses the basic concepts of estimating DUD's from resource abundance in the MAV developed by the Lower Mississippi Valley Habitat Joint Venture of the NAWMP (Loesch et al. 1994, Reinecke et al. 1989, Reinecke and Loesch 1996) and expands data and model equations using contemporary data on: 1) daily energetic needs of waterfowl species commonly present in the MAV during the nonbreeding period; 2) estimates of resource values and dynamics in a complete array of MAV habitats and management scenarios; 3) estimates of energy values of specific foods relative to different species; and 4) seasonal and annual probabilities of foods being available to waterfowl.

Generally, this manual provides estimates of abundance and availability for specific foods and habitats based on published scientific literature, but some data come from currently unpublished or limited access sources. An attempt was made to review all pertinent literature and report sources, but some information may not have been identified, and future studies and publications likely will help refine estimates. Estimates of food abundances reported in the field studies considered in this manual often varied substantially, and ranges of values and error probability were not always reported. This manual provides estimates of food abundance and availability to be used in model equations based on statistical means/medians of similar studies and/or data from more comprehensive and long-term investigations. For some foods and habitats, few data/studies were available and estimate values were chosen based on assumed relationships of other similar foods or habitats. The manual recognizes that some level of stochasticity exists for the estimates used in the DUD models; however, the range of probability expectation undoubtedly varies among foods and habitats because of the sometimes substantial differences in the study estimates. Consequently, it is difficult to suggest exact probability values, such as standard of errors, for the selected estimates of specific foods and habitats. Recognizing this important statistical caveat, generally, combined data from field studies used in developing model values had standard error levels that were < 20% level (e.g., Wehrle et al. 1995).

Project-specific information including number and species of waterfowl present; area, type, and management of habitats; composition, density and size of trees in forested habitats; and occurrence, frequency and duration of flooding by area and habitat type is required prior to using the model equations provided in this manual. Many techniques are available to obtain these data, and it is outside the scope of this manual to review all techniques or to recommend specific methodologies. Likely, techniques may vary from site to site based on project goals and objectives, site conditions, and resources. At the very least, project-specific data collection and analyses should clearly state the assumptions of data collection methods.

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DAILY ENERGETIC REQUIREMENTS OF WATERFOWL

Daily energy requirements of wild waterfowl during the nonbreeding season are based on the strong relationship between body mass and basal metabolic rate (BMR) within and among species of birds (Lasiewski and Dawson 1967, King 1974, Aschoff and Pohl 1970, Calder 1974, Prince 1979, Daan et al. 1989, Miller and Eadie 2006). Models of daily energy expenditure, and specific annual cycle events, of free-living waterfowl have been developed, assuming that total daily energy cost is some multiple of BMR (e.g., Fredrickson and Drobney 1979, Drent and Daan 1980, Pienkowski et al. 1984, Daan et al. 1990, Heitmeyer 2006a). Alternatively, Resting Metabolic Rate (RMR) is a statistic that accounts for varying conditions individual birds are exposed to in experimental "test" situations (Schmidt-Nielsen 1984, Bennett and Harvey 1987) and may be more appropriate for estimating DUD's of wild waterfowl (Miller and Eadie 2006).

BMR and RMR of waterfowl have been estimated from equations related to:

1. Non-passerine birds, where BMR (kcal/day) = $73.5W^{0.734}$ (Aschoff and Pohl 1970), and where W is body mass of birds in kg.
2. Mallards in experimental and wild settings, where BMR = $87.9W^{0.734}$ (Prince 1979), where W is body mass of birds in kg.
3. Literature calculations of allometric equations from regression of RMR on body mass for many waterfowl species (Miller and Eadie 2006).

The latter allometric analyses represent the most comprehensive evaluation of RMR among many waterfowl species; the equation for combined waterfowl species is:

RMR (kJ/day) = $422W^{0.74,}$
where W is body mass in kg.

This translates into an equivalent equation for kcal as:

RMR (Kcal/day) = $100.7W^{0.74,}$
where W is body mass in kg
and assuming that
kJ = 4.185kcal
(Gabrielsen et al. 1991).

This allometric equation estimating RMR for all waterfowl species, suggests former estimates of RMR and thus daily energy expenditures calculated from the Prince (1979) and Aschoff and Pohl (1970) equations may be underestimated by 25-30% during the nonbreeding period. This manual, therefore uses the Miller and Eadie (2006) allometric equation for all waterfowl species to estimate DUD's of waterfowl in the Upper MAV and uses kcal as the energy currency to model DUD because of the traditional use and convenience/availability of energy information expressed in kcal in the scientific literature pertaining to waterfowl.

Daily existence energy (DEE) requirements of wild waterfowl are actually some multiple of RMR because costs of various daily activities such as flight, swimming, courtship, nutrient deposition, molt, etc. exceed resting metabolism (Prince 1979). Prince (1979) suggested that DEE for wild waterfowl was about 3.4 times BMR/RMR, however this DEE estimate does not account for increased daily energy (and specific nutrient) needs during physiological processes related to productivity (King 1974, Ricklefs 1974) and energy expensive annual events such as nutrient deposition prior to, or immediately after, migration, pairing, and molt that occur during the nonbreeding season in the Upper MAV (Heitmeyer 1988a,b; Fredrickson and Heitmeyer 1988, Heitmeyer 2002). Many activities in the nonbreeding season involve substantial flying (Dugger 1990, Cox and Afton 2000, Davis et al. 2009), which is 10-12 times BMR, and extensive swimming (up to 5 times BMR), and foraging often occupy up to 80% of diel activities during some periods in winter (Prince 1979, Heitmeyer 1985, Paulus 1988). Field data from mallards in the Upper MAV during winter suggest that use of the 3.4x multiplier for RMR to estimate DEE may be underestimated by 33-39%, based on Prince's (1979) equation of BMR (Heitmeyer 2006a). Adjusting former BMR estimates (Prince 1979) to the more contemporary RMR estimates (Miller and Eadie 2006), and accounting for additional energy requirements of waterfowl during migration, molt, and pairing during winter, suggests DEE of waterfowl during the nonbreeding season is at least 4x RMR.

DEE's for waterfowl species commonly present in the MAV were calculated from published body mass and RMR equations (Table 1). Mean body mass of species was calculated from data in Bellrose (1980). Estimated mean body masses were weighted by percentage of the species in the Upper MAV that were juveniles (estimated at 80% adult from Raftovich et al. 2009) and male:female proportions of species groups (55% male in *Anas* and *Aix*; 65% in *Aythya, Bucephla,* and *Mergus*; and 50% in geese, Bellrose et al. 1961,

Table 1. Mean weighted body mass (kg), estimated resting metabolic rate (RMR in kcal/day), and daily existence energy (DEE in kcal/day) of common waterfowl species present in the Mississippi Alluvial Valley during the nonbreeding season. See text for calculations.

Species	Weighted Body Mass	RMR	DEE
Ducks			
Canvasback	1.22	116.66	466.64
Mallard	1.17	113.11	452.44
Redhead	1.03	102.93	411.72
Northern pintail	0.94	96.19	384.76
Gadwall	0.89	92.38	369.52
American wigeon	0.79	84.58	338.32
Lesser scaup	0.79	84.58	338.32
Ring-necked duck	0.71	78.16	312.64
Hooded merganser	0.70	77.34	309.36
Wood duck	0.67	74.87	299.48
Northern shoveler	0.65	73.21	292.84
Bufflehead	0.44	54.85	219.40
Blue-winged teal	0.42	52.99	211.96
Green-winged teal	0.31	42.33	169.32
Geese			
Giant Canada goose	5.17	339.64	1,358.56
Interior Canada goose	3.17	236.49	945.96
White-fronted goose	2.63	205.97	823.88
Lesser snow goose	2.51	198.97	795.88
Ross' goose	1.68	147.83	591.32

Bellrose 1980). DEE was assumed to be 4x RMR, which probably is very conservative, based on the extensive literature documenting large amounts of time nonbreeding waterfowl spend in energetically expensive activities such as flying, swimming, and courtship in generally colder temperature periods of late fall, winter, and early spring (e.g., Paulus 1988). These DEE calculations (Table 1) provide the basis for estimating energetic requirements of waterfowl in the MAV and subsequent calculations of DUD.

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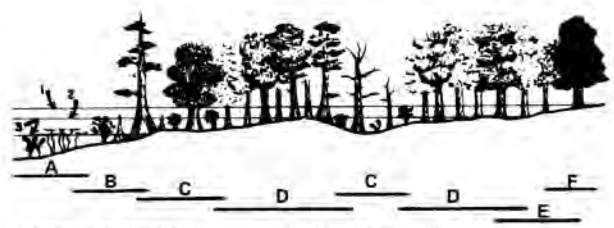
HABITAT TYPES, RESOURCE ABUNDANCE, AND AVAILABILITY TO WATERFOWL

HABITAT DESCRIPTIONS

The primary habitat/community types in the non-coastal part of the MAV are: 1) Bottomland Hardwood Forest (BLH), 2) Floodplain Forest, 3) Riverfront Forest, 4) Seasonal Herbaceous including Bottomland Prairie, 5) Persistent Emergent, 6) Shrub/Scrub, 7) Dead Timber, 8) Open Water/Aquatic, and 9) Agricultural Fields (e.g., Fredrickson 1979, Heitmeyer 2008a). Certain of these habitat types have subdivisions, for example agricultural cropland might be flooded or dry corn, soybeans, grain sorghum (milo), rice, etc. Brief descriptions of these habitats are provided below:

BLH

BLH includes a gradient of forest types (Fig. 2) related to elevation and frequency of flooding in MAV floodplains and Holocene terraces (Fredrickson 1979; Heitmeyer et al. 1989, 2002, 2006; Heitmeyer 2006b, Klimas et al. 2009). Cypress-Tupelo habitats occur in the lowest elevations and are flooded for extended periods during the year and occasionally are flooded year round. Flooding usually is at least 3 months duration and soils are saturated almost constantly. Vegetation in Cypress-Tupelo habitats is tolerant of flooding but needs occasional drying periods for regen-



Duration of Flooding	Woody Vegetation
A - Permanent	Common baldcypress, *Taxodium distichum*
B - Semi-permanent	Common baldcypress Water tupelo, *Nyssa aquatica* Water elm, *Planera aquatica* Common buttonbush, *Cephalanthus occidentalis*
C - 3-8 Months	Common baldcypress Overcup oak, *Quercus lyrata* Red maple, *Acer rubrum* Water hickory, *Carya aquatica* Possumhaw holly, *Ilex decidua*
D - 1-6 Months	Willow oak, *Q. phellos* Pin oak, *Q. palustris* Cherrybark oak, *Q. pagoda* Sugar hackberry, *Celtis laevigata* American sweetgum, *Liquidambar styraciflua* Blackgum tupelo, *Nyssa sylvatica*
E - 0-2 Months	American sweetgum Blackgum tupelo Sugar hackberry Shagbark hickory, *Carya ovata* American elm, *Ulmus americana* Swamp chestnut oak, *Q. michauxii*
F - Once in 10 years	American sweetgum Shagbark hickory White oak, *Q. alba* Flowering dogwood, *Cornus florida*

Figure 2. Schematic cross-section of forested wetlands in the Upper Mississippi Alluvial Valley, showing the distribution of woody plants relative to flooding regimes. 1 = 10-year flood frequency, 2 = mean annual high water level, 3 = mean annual low water level. A = permanently flooded, B = 6-10 months annual flooding, C = 3-6 months annual flooding, D = 1-6 months annual flooding, E = 0-2 months annual flooding, and F = 5-10 year flood frequency. Modified from Fredrickson 1979 and Batema et al. 2005.

eration. Baldcypress and water tupelo are dominant species. Cypress/tupelo habitats occur in a variety of locations including abandoned channels, isolated depressions, deep swales in point-bar deposits, and along drainages (Klimas et al. 2009).

Low BLH occurs in low elevations that typically flood each year and have extended soil saturation. Flooding and soil saturation is not as extended as in Cypress-Tupelo sites and low BLH habitats typically are flooded for 1-3 months usually from December to March. Low BLH habitats are almost entirely within the 2-year flood frequency zone predominantly on backswamp deposits, swales in point bars, and abandoned courses. Dominant vegetation includes green ash, cedar elm, water hickory, overcup oak, water locust, buttonbush, and swamp privet (Heitmeyer et al. 2006).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Intermediate BLH habitats occur in floodplain locations that are flooded on average for a few weeks to 1-2 months annually during the dormant season and early spring. Soil saturation in these sites often is extended for 2-3 months. Most Intermediate BLH are between the 2-5 year flood frequency zone and some higher sites may not flood every year. Intermediate BLH is present mostly in backswamp and higher point bar surfaces and on the edges of some abandoned courses (Klimas et al. 2009). Dominant vegetation in Intermediate BLH sites includes sugarberry, American elm, Nuttall oak, pin oak, willow oak, and sweetgum.

High BLH habitats occur in the highest elevation floodplain and natural levee sites that, at least historically, were flooded for up to a few weeks during some years, usually during high flow events on the Mississippi River and its tributaries. High BLH occasionally may go several years between flood events, however, soils are saturated for some periods annually (Heitmeyer et al. 1989). High BLH commonly are called "flats" or "terrace hardwoods" and they occur mostly on higher elevation point bars, older floodplain terraces, and natural levees (Klimas et al. 2009). Generally, the dividing point between Intermediate and High BLH is the 5-year flood frequency contour. Dominant species in High BLH includes water oak, willow oak, cherrybark oak, Delta post oak, hickories, and sweetgum.

BLH in the MAV is present in naturally flooded and managed flooded conditions. Greentree reservoirs (GTRs) are tracts of BLH that have at least some water-control infrastructure (usually levees and water-control structures) capable of intentionally flooding and holding surface water on the site (Fredrickson and Batema 1992). Water supply to GTRs is variable and includes both natural runoff and overbank flooding and external water sources from wells or pumps. Typically, GTRs are intentionally flooded in fall prior to, or during, waterfowl hunting seasons and water is drained from these sites from late winter through spring. Individual GTRs employ various water regime schedules, and current management philosophy suggests later and shorter duration flooding that emulates natural hydrology within regions (e.g., Heitmeyer et al. 2004).

Floodplain Forest

Floodplain Forest historically covered large expanses of MAV floodplains on point bar surfaces and along tributary streams (e.g., Heitmeyer 2008a). This forest type represents a transition zone from early succession Riverfront Forest located on coarse-sediment chute and bar surfaces to BLH forests that occurred in clay-type soils in backswamps and floodplain depressions. Most Floodplain Forest is within the 1-2 year flood frequency zone and is dominated by elm, ash sweetgum, sugarberry, and box elder, but includes many other minor species depending on elevation and soil type. Higher elevation ridges and older remnant natural levees often contain pecan, pin and swamp chestnut oak, honey locust, and scattered hickory. Low swales contain a mix of more water tolerant species such as willow, cottonwood, maple, and sycamore on coarser sediments to oak, ash, sweetgum, and inclusions of tupelo and baldcypress in swales with clay-type soils. Almost all Floodplain Forest in the MAV is naturally flooded from overbank flows of drainages.

Riverfront Forest

Riverfront Forest (also called River-Edge Forest in some older botanical literature) is present on chute and bar surfaces, some point bar areas, near the current channels of the Mississippi and tributary rivers, and along the edges of some abandoned channels in the MAV (Heitmeyer et al. 2002, Heitmeyer 2008a). These geomorphic surfaces contain recently accreted lands and are sites where river flows actively scoured and deposited silt, sand, gravel, and some organic material within the last decade or so. This forest type is dominated by early succession species such as willow and silver maple in low elevations to elm, ash, cottonwood, sycamore, pecan, and sugarberry on ridges. Swamp white oak and pin oak occasionally are present in some higher elevations, but these species have high mortality during extended flood events and oak patches usually are small and scattered. Shrubs and herbaceous vegetation are sparse in these habitats near rivers, but dense tangles of vines, shrubs, and herbaceous vegetation are present on higher elevations away from the river where alluvial silts were deposited. Riverfront Forest is within the 1-year flood frequency floodplain in most MAV areas (Klimas et al. 2005, Heitmeyer 2008).

Seasonal Herbaceous and Bottomland Prairie Wetlands

Seasonal Herbaceous and Bottomland Prairie habitats are present in small depressions, old Holocene terraces, intervening valley train ridges, and floodplain edges in the MAV (Heitmeyer et al. 2000, Heitmeyer 2008a). These sites contain saturated soils


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and short periods of surface flooding that support annual and perennial herbaceous and grass species. Some Seasonal Herbaceous wetlands are small basin depressions that receive water mainly from surface sheetflow runoff following local rains. These wetlands typically are flooded for short periods each year from winter to early summer depending on timing of rainfall and occasional overbank/backwater flooding from local drainages. A gradient of vegetation species occurs from low depressions, which contain a wide diversity of annual and perennial herbaceous "moist-soil" plants to higher grassland that contains many prairie type species. Soils on prairie terraces often have an impermeable clay layer 18-24 inches below the surface, which allows seasonal basins to hold water while simultaneously retarding tree growth.

Seasonally flooded impoundments (often called "moist-soil" impoundments) are commonly used in the MAV to promote and sustain seasonal herbaceous plant communities (Fredrickson and Taylor 1982). These impoundments typically have water-control infrastructure that allows managers to intentionally flood and drain the site to create various soil and flooding conditions that facilitate germination of desired plants and discourage other plants that are less valuable for waterfowl. Many disturbance techniques are used in these impoundments including flooding/drainage, soil tillage, burning, and mowing. The intensity of management in moist-soil impoundments often is great.

Karen Kyle

Persistent Emergent

Small areas of some non-forested wetlands in the MAV contain Persistent Emergent vegetation communities. This habitat type is a relatively minor component of the MAV landscape, and usually is restricted to isolated areas or narrow bands along the edges of larger Open Water/Aquatic sites where semipermanently flooded water regimes occur. If water regimes become more permanent then the sites transition into Open Water/Aquatic habitats with occasional small inclusions of residual Cypress-Tupelo, Persistent Emergent, or S/S plant species. Moreover, most semipermanently flooded areas in the MAV support Cypress-Tupelo or S/S habitats and do not become populated with Persistent Emergent species. Examples of Persistent Emergent habitats in the MAV are bands of water willow along the edges of Reelfoot Lake (Smith and Pitts 1981), isolated stands of giant cutgrass in Monopoly Marsh on Mingo National Wildlife Refuge (U.S. Fish and Wildlife Service 2007), and narrow bands of cattail or river bulrush along some drainage ditches and older abandoned channels in the northern MAV (Heitmeyer 2008a).

Shrub/Scrub

Shrub/Scrub (S/S) communities contain woody shrub species in areas that have extensive flooding, but some annual drying in most years (Heitmeyer et al. 1989). S/S often occurs as narrow bands along the edges of depressions, abandoned channels, and sloughs/swales. This zone represents the transition area from more frequently and prolonged flooding to higher and drier BLH and other forest communities. S/S habitats typically are flooded a few inches to 2-3 feet for extended periods each year except in extremely dry years. These habitats are dominated by buttonbush, swamp privet, willow and other shrubs.

Dead Timber

As the name implies, Dead Timber habitats are former forest areas that have died and the dead trees are in various degrees of decomposition (e.g., Heitmeyer et al. 1989). The typical cause of death in these former forest areas is extended flooding for several years during the growing season (Heitmeyer et al. 1989, Heitmeyer 2006b). As forest canopy decreases and flooding is prolonged, the vegetation in Dead Timber sites usually changes to S/S, herbaceous, and aquatic-type communities. Vegetation composition can range from dense buttonbush to open water with abundant submerged aquatic vegetation. Dead Timber sites include beaver ponds, blocked drainages, impounded forest areas, and other inundated forest areas.

Open Water/Aquatic

Many areas within the MAV contain deeper water areas that are flooded for extended periods in all but the driest years (Fredrickson and Heitmeyer 1988). These sites usually do not support herbaceous, persistent emergent or woody plant species because of the prolonged yearly flooding. These habitats often contain abundant submerged aquatic vegetation, floating-leaved plants, and algae. These habitats often are in abandoned channels (oxbows) of historic drainages, deeper depressions in Holocene floodplain scoured areas, and backwaters/side chutes of current drainages.

Agricultural Fields

Agricultural habitats used by waterfowl in the MAV are mostly grain fields that have been harvested or are intentionally left unharvested. Typical grain crops in the MAV include

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corn, soybeans, milo, rice, and wheat. Small areas of cropland may be unharvested in winter because of climatic events (e.g., floods) or intentional provision of food for waterfowl on public or private lands. Some agricultural fields are intentionally flooded during fall and winter to provide waterfowl foraging habitat using water-control infrastructure used in crop production (e.g., rice levees and checks) or small berms/structures installed in fields. The proportion of agricultural fields intentionally flooded in the MAV is < 10% of all fields (Uihlein 2000).

POTENTIAL FOOD ABUNDANCE IN HABITATS

Availability of food to waterfowl in MAV habitats varies among species depending on their behavioral/morphological adaptations and also among seasons and years depending on annual temperature and rainfall, growing season days and latitudinal position, timing of floods or droughts, depth of water, consumption by other wildlife (e.g., blackbirds), and composition of vegetation/invertebrates. Waterfowl foods in MAV habitats are classified in the following groups:

1. Mast (hard and soft)
2. Invertebrates and zooplankton
3. Seeds from herbaceous and aquatic plants

Table 2. Primary use of food types[a] by waterfowl during the nonbreeding season in the Mississippi Alluvial Valley (adapted from Bellrose 1980, Fredrickson and Heitmeyer 1988, Heitmeyer 2002).

Species	HSD	AQSD	Mast	BEGD	ABGD	AQP	INV	SMV	AGR	AGB
Ducks										
Mallard	x		x	x			x		x	
Pintail	x			x			x		x	
Gadwall	x	x				x	x			
American wigeon	x	x			x	x	x		x	x
Northern shoveler	x						x			
Blue-winged teal	x	x					x			
Green-winged teal	x	x					x		x	
Wood duck	x		x	x			x			
Canvasback		x		x		x	x			
Redhead		x				x	x			
Lesser scaup	x	x					x			
Ring-necked duck	x	x					x			
Bufflehead	x	x					x			
Hooded merganser							x	x		
Geese										
Canada goose	x			x	x				x	x
White-fronted goose				x	x				x	x
Lesser snow goose				x	x				x	x
Ross goose				x	x				x	x

[a] HSD – herbaceous plant seeds, AQSD – aquatic plant seeds, Mast – acorns and pecans, BEGD – below ground tubers, etc., ABGD – above ground browse, AQP – aquatic plants, INV – invertebrates, SMV – small vertebrate, AGR – agricultural grains, AGB – agricultural browse.

4. Below-ground tubers, roots, rhizomes
5. Above-ground browse
6. Aquatic plants and algae
7. Small vertebrates
8. Agricultural grains and browse

The relative preference/consumption of these food groups and use of habitats varies among waterfowl species (Table 2) and the annual event individual waterfowl are engaged in (e.g., Heitmeyer and Fredrickson 1990, Heitmeyer 2002). Recognizing foraging dynamics and differences among waterfowl species is important because not all foods present in MAV habitat types are consumed by, or available to, all species. Consequently, calculating DUD's for waterfowl in the MAV requires matching abundance and availability of specific food types by habitat type (Table 3) to appropriate species (Table 2). For example, food abundance and habitat values for hooded mergansers primarily are a function of small vertebrate and invertebrate foods in forest and Open Water/Aquatic habitats. In contrast, green-winged teal use mostly seed and invertebrate foods in Seasonal Herbaceous Wetlands.

General Data Considerations for Estimating Food Abundance

MAV habitats provide abundant and diverse foods, with specific potential

Table 3. Presence of major food types[a] consumed by waterfowl during the nonbreeding season in the Mississippi Alluvial Valley in relation to habitat type (adapted from Fredrickson and Heitmeyer 1988, Heitmeyer et al. 2005).

Habitat[b]	HSD	AQSD	Mast	BEGD	ABGD	AQP	INV	SMV	AGR	AGB
BLH–NF	x		x	x			x	x		
BLH-GTR	x		x	x			x	x		
Cypress-Tupelo		x		x		x	x	x		
Floodplain forest	x		x	x			x	x		
Riverfront forest	x		x	x			x	x		
Dead timber	x	x		x	x	x	x	x		
Shrub/scrub	x	x		x	x	x	x	x		
SHM-managed	x	x		x	x	x	x	x		
SHM-unmanaged	x	x		x	x	x	x	x		
Persistent Emergent	x	x				x	x			
OW-AQ		x				x	x	x		
Agricultural	x						x		x	x

[a] HSD – herbaceous plant seeds, AQSD – aquatic plant seeds, Mast – acorns and pecans, BEGD – below ground tubers, etc., ABGD – above ground browse, AQP – aquatic plants, INV – invertebrates, SMV – small vertebrate, AGR – agricultural grains, AGB – agricultural browse.
[b] BLH-NF – bottomland hardwood forest naturally flooded, BLH-GTR – bottomland hardwood forests greentree reservoir, SHM – seasonal herbaceous, OW-AQ – open water/aquatic.

waterfowl forage items being provided in various habitats (Table 3). Unfortunately, few long-term studies have estimated annual production of various food types in MAV habitat types. Consequently, estimates of food production and availability often are based on short time periods, period-specific habitat conditions (e.g., flooding regimes, management practices, plant species composition), or similar habitats in non-MAV locations that may or may not accurately reflect representative conditions throughout the MAV or long-term dynamics of production. Furthermore, studies and estimates of annual production of specific types of foods (e.g., small vertebrates, zooplankton, algae, submerged aquatic plants, above-ground browse) are lacking for many, or all, habitats. Generalizing annual production data within habitat types given the heterogeneity of geographies within the MAV also is difficult, and extremes of production (either good or poor) are associated with many abiotic and biotic factors. Recognizing the many caveats of production data, means and ranges of production from various studies are presented where available and an attempt is made to provide a reasonable, usually presumed to be conservative, estimate of average potential annual food production among habitat types. Undoubtedly, future investigation will refine, and provide, more accurate and reliable quantification of, these estimates.

Hard and Soft Mast

Forest communities in the MAV produce abundant hard and soft mast. The composition of forest communities greatly affects amount and distribution of these foods. For example, red oak composition, tree size, health, and flooding regime (managed and natural) affect acorn production (e.g., see review in Brakhage 1966, McQuilkin and Musbach 1977). Acorns are a primary food for several waterfowl species in the MAV (Table 2), with smaller acorns being preferred at least

Table 4. Average annual production of pin oak acorns (kg/ha) in a greentree reservoir (GTR) and naturally flooded stand of bottomland hardwood forest in southeast Missouri related to stocking density and size of pin oak trees in the stand (data adapted from McQuilkin and Musbach 1977).

Stocking Density	Small-tree	Large-tree	Mean
GTR			
Low	140.84	177.45	159.20
Medium	132.87	164.29	148.58
High	187.97	199.69	193.83
Mean	153.89	180.44	167.17
Naturally Flooded			
Low	136.10	252.93	194.49
Medium	129.92	218.95	169.93
High	123.25	214.85	169.05
Mean	126.78	228.90	177.78

Table 5. Mean annual Nuttall oak acorn production in a greentree reservoir in western Mississippi in relation to tree size (adapted from Francis 1983).

	Tree Size			
Variable	Small	Medium	Large	Extra Large
Acorns/ft^3 tree crown	0.14	0.40	0.44	0.48
Dry wt (g)/ft^3 tree crown	0.32	1.08	1.03	1.08
Acorns/tree	104	638	790	1,225
Dry wt (g)/tree	229	1,535	1,576	2,990

Table 6. Mean annual Nuttall oak acorn production in naturally flooded and greentree reservoir (GTR) habitats in western Mississippi (adapted from Francis 1983).

Variable	Naturally flooded	GTR
Dry wt (g)/ ft^3 of crown	1.11	0.64
Number acorns/ft^3 of crown	0.44	0.29
Dry wt (g)/tree	2,232	933
Number of acorns/tree	958	422

by wood ducks (Barras et al. 1996). Typically, acorns that fall to the ground/water from pin, water, willow, southern red, Nuttall, and cherrybark oak trees are potential foods for some species, especially mallards and wood ducks (Heitmeyer 2002). Overcup oak acorns also are readily consumed by ducks if they are small enough for birds to assimilate. Data from overcup acorns in central Arkansas suggest about 20% of overcup acorns produced each year are small enough for mallards to eat (Heitmeyer, unpublished data).

Only one long-term study of pin oak acorn production has been conducted in the Upper MAV, and it included a highly managed GTR and nearby naturally flooded BLH tract in southeastern Missouri (Minckler and McDermott 1960, Minckler and Janes 1965, McQuilkin and Musbach 1977). Annual pin oak acorn production (sound, non-insect infested acorns) averaged 172 kg/ha for combined GTR and naturally flooded BLH areas from 1956 to 1969 (see Journal of Wildlife Management Errata: 1977 91:597), but varied from < 10 kg/ha to > 400 kg/ha during the period. Annual production averaged 179.9 kg/ha in GTRs and 191.6 kg/ha in naturally flooded BLH; size and density of red oak stands significantly influenced production (Table 4). The Missouri study did not estimate acorn production from non-pin oak species and therefore was not a complete accounting of total mast production potentially available to waterfowl in the study areas.


Mickey Heitmeyer

Table 7. Estimated acorn production (kg/ha) dropped to the ground for Nuttall, willow, and overcup oak in the East and West parts of the 640 greentree reservoir, Cornerstone Farms, Jefferson County, Arkansas (adapted from Heitmeyer and McGeorge 2009).

Area and Year	Nuttall	Willow	Overcup[a]	Combined
East				
2005	95.8	160.9	169.8	426.4
2006	124.2	219.3	81.5	425.0
2007	424.5	112.3	1.5	548.4
2008	66.4	55.1	3.8	130.8
Mean	177.7	136.9	64.1	382.6
West				
2006	128.0	155.2	0.6	283.9
2007	609.0	172.7	25.5	807.1
2008	212.1	74.0	0.3	286.5
Mean	316.4	134.0	8.8	459.2

[a] Estimate for overcup oak is adjusted for 20% of total acorn

Nuttall oak acorn production (extrapolated from data presented in Francis 1983) from naturally flooded and GTR sites in western Mississippi averaged about 200-250 kg/ha in a 5 year study and confirmed that acorn production was strongly related to tree size (Table 5) and flooding management (Table 6). This study also did not estimate acorn production from other oak species in natural stands.

In contrast to the Missouri and Mississippi studies, combined Nuttall, willow, and overcup oak (adjusted for size consumable by mallards) acorn production was estimated in a GTR in central Arkansas during four years, 2005-2008, and averaged 420 kg/ha/year, ranging from 131 to 807 kg/ha among years and locations (Table 7). The Arkansas study also documented that acorn production of

Table 8. Estimated mean annual acorn production (kg/ha) falling to the ground, of a size consumable to mallards and wood ducks, in bottomland hardwood forest stands in relation to whether the site was naturally flooded or in a greentree reservoir, density (basal area, ft^2 of red oak species), and average tree size used in duck-use-day models

Flooding regime and Basal area	Size of trees in a stand			
	Small	Medium	Large	Combined
Naturally flooded				
30-40	250	275	300	275
50-60	275	300	325	300
>75	325	350	375	350
Mean	283	308	333	300
Greentree reservoir				
30-40	200	225	250	225
50-60	225	250	275	250
>75	275	300	325	300
Mean	233	258	283	250

Nuttall, willow, and overcup oak was related to tree size, past water management, and stand density and composition.

All of the above acorn studies demonstrated that size and density of red oaks in BLH affects annual acorn production, consequently estimates of acorn production in BLH in the MAV must account for this covariance. Given the relative paucity of data on acorn production over widely divergent BLH areas in the MAV, this manual uses annual averages of acorn production based on management regime, tree size, and basal area in the areas studied to date (Table 8). Little or no acorn production occurs in Cypress-Tupelo, Dead Timber, or S/S habitats. Hard mast production in Floodplain and Riverfront Forest communities is unknown and depends on proportion of red oak, overcup oak, and pecan in sites. Extrapolating the above BLH data (Table 8) to Floodplain Forests that typically contains < 10% red oak and pecan (Heitmeyer 2008a), suggests hard mast production is < 50 kg/ha in these habitats. Riverfront Forest typically contains only scattered oak and pecan and 10 kg/ha hard mast production is suggested as a conservative estimate for this habitat.

No study to date has estimated pecan or soft mast (e.g., maple, elm samaras) production in MAV forests. Where ash and maple comprise larger parts of MAV forests, such as in Cypress-Tupelo, Riverfront Forest, Floodplain Forest and S/S, substantial soft mast is produced annually and is readily consumed by some duck species such as prebreeding wood ducks (Drobney and Fredrickson 1979). Likewise, GTRs that have been flooded for prolonged periods over many years often have expanded composition of ash and maple and produce considerable soft mast (Heitmeyer et al. 2004). Although no estimates of annual soft mast production are available from the MAV, this mast production occurs in spring and summer, and therefore is only available in small quantities to waterfowl during early spring and is considered a negligible food for nonbreeding waterfowl in this manual.

Aquatic Invertebrates and Zooplankton

Annual production of aquatic/benthic invertebrates in MAV habitats is variable among locations, seasons, years, management regimes, and plant composition (Batema 1987, Fredrickson and Reid 1988a, Magee et al. 1999, Batema et al. 2005). Naturally flooded BLH has relatively high production compared to most other MAV habitats apparently because of its seasonal hydroperiods, warm temperate climate, and large annual inputs to detrital litter (Krull and Hubert

Table 9. Estimates of annual production (kg/ha) of aquatic/benthic invertebrates during fall and winter in various habitats and locations in the Mississippi River Valley.

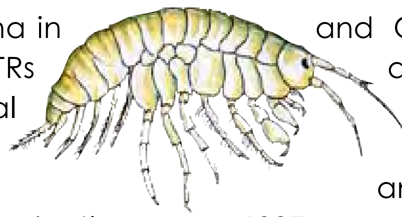
Habitat Type	Production	Reference
Naturally-flooded BLH	43.7-80.0	Wehrle et al. 1995
	38.9[a]	White 1982
GTR	41.6[a]	White 1982
	11.1	Duffy and LaBar 1994
	9.8-10.7	Wehrle et al. 1995
Clear cut BLH	0.4-2.7	Wehrle et al. 1995
Shrub/scrub willow-managed	110.0	Magee et al. 1993
Shrub/scrub willow-unmanaged	20-50	Magee et al. 1993
Dead Timber beaver pond	29.3	Duffy and LaBar 1994
Moist-soil impoundments	11.9-61.1	Augustin and Grubaugh Unpublished ms.
	19.0	Duffy and LaBar 1994

Table 10. Estimated annual production (kg/ha) of major food types[a] potentially available to be consumed by waterfowl during the nonbreeding season in the Mississippi Alluvial Valley in relation to habitat type and used in duck-use-day models.

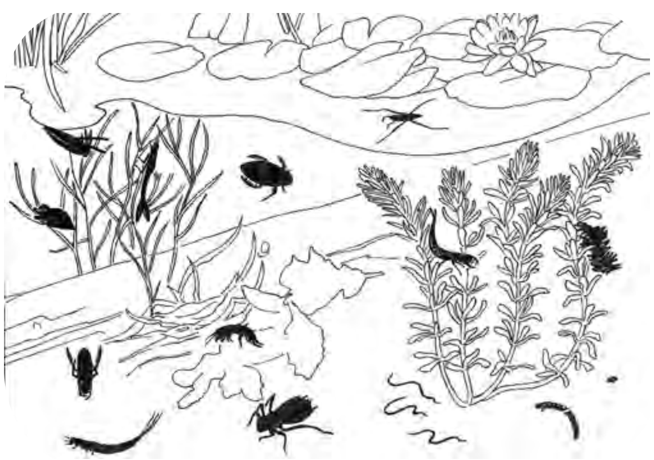
Habitat[b]	HSD	AQSD	Mast	BEGD	ABGD	AQP	INV	SMV	AGR	AGB
BLH–NF	[c]		[d]	[e]			40			
BLH-GTR	[c]		[d]	[e]			20			
Cypress-Tupelo		20				100	30			
Floodplain forest	[c]		50	[e]			30			
Riverfront forest	[c]		10	[e]			30			
Dead timber	150	20		[e]		100	30			
Shrub/scrub	150	20		[e]		100	50			
SHM-managed	[f]	[f]		[e]	50	50	50			
SHM-unmanaged	[f]	[f]		[e]	50	50	30			
OW-AQ	150	50				100	20			
Persistent Emergent	200	20				100	20			
Agricultural	10						5		[g]	[g]

[a] HSD – herbaceous plant seeds, AQSD – aquatic plant seeds, Mast – acorns and pecans, BEGD – below ground tubers, etc., ABGD – above ground browse, AQP – aquatic plants, INV – invertebrates, SMV – small vertebrate, AGR – agricultural grains, AGB – agricultural browse.
[b] BLH-NF – bottomland hardwood forest naturally flooded, BLH-GTR – bottomland hardwood forests greentree reservoir, SHM – seasonal herbaceous, OW-AQ – open water/aquatic.
[c] 21, 42, and 84 kg/ha for forests with 5%, 10%, and 20+% tree gaps and canopy openings.
[d] See Table 8.
[e] Assumed to be 10% of HSD seed production.
[f] See Table 12.
[g] Average of 290, 80, 150, and 150 kg/ha waste grain for corn, soybeans, milo, and rice, respectively, assuming 4% waste grain is left in fields immediately after harvest. Average of 300 kg/ha for winter wheat browse

1973, Batema et al. 2005). Naturally flooded BLH apparently has higher annual invertebrate production than GTRs (Table 9). Invertebrate production in MAV naturally flooded BLH ranged from ca. 20 kg/ha in southeastern Missouri (White 1982, 1985) to > 80 kg/ha at sites in the Delta National Forest of Mississippi (Wehrle et al. 1995). Production in GTRs at these locations averaged about 13.7 kg/ha in Missouri and 10.7 kg/ha in Mississippi. Another study of GTRs in Mississippi estimated annual production of aquatic invertebrates at 11.1 kg/ha (Duffy and LaBar 1994). Invertebrate production in clear-cut BLH in Mississippi averaged < 2 kg/ha (Wehrle et al. 1995) and Dead Timber beaver pond habitats had about 29 kg/ha production (Duffy and LaBar 1994). Willow-dominated wetlands that are similar to S/S and Riverfront Forest habitats in the MAV had about 110 kg/ha production in managed sites and 20-50 kg/ha production in unmanaged areas. Production in Cypress-Tupelo, Floodplain Forest and Riverfront Forest habitats likely is near or slightly lower than BLH (Sklar 1985, Gladden and Smock 1990).



Extrapolating data from the various studies, this manual uses 40 kg/ha as average invertebrate production in naturally flooded BLH, 20 kg/ha production in GTRs, 30 kg/ha in Dead Timber, Cypress-Tupelo, and Riverfront Forest habitats and 50 kg/ha in S/S communities (Table 10). Naturally flooded Floodplain Forest may be between BLH and more willow dominated sites and 30 kg/ha seems a reasonable estimate for these habitats (Table 10).



Aquatic invertebrate production in Seasonal Herbaceous, Persistent Emergent, and Open Water/Aquatic wetlands is quite variable depending on water regime, vegetation composition, and management (Fredrickson and Taylor 1982, de Szalay and Resh 1997, Magee et al. 1999). Estimates of aquatic invertebrate production in Seasonal Herbaceous wetlands in the MAV range from 12 to 60 kg/ha (Table 9). Apparently, actively managed moist soil impoundments produce more invertebrates than naturally flooded herbaceous wetlands (Magee et al. 1999, Fredrickson 1996, Batema et al. 2005). Little information is available on invertebrate production in Persistent Emergent or Open Water/Aquatic habitats in the MAV, but studies in similar habitats in northern areas indicate that more prolonged water regimes, including semipermanent flooding, reduces density, biomass, and diversity of dominant invertebrate taxa (Reid 1983, Neckles et al. 1990, Murkin and Ross 2000). Given the relatively sparse information from the MAV, this manual uses invertebrate production values of 50 kg/ha in actively managed moist-soil impoundments, 30 kg/ha in naturally flooded Seasonal Herbaceous wetlands, and 20 kg/ha in Persistent Emergent and Open Water/Aquatic habitats. Most agricultural fields have very depauperate invertebrate communities; e.g., flooded harvested soybean fields averaged less than 5 kg/ha in Tennessee (Augustin and Grubaugh, unpublished ms).

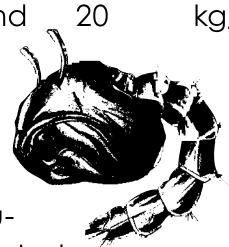


Table 11. Estimates of annual production (kg/ha) of seeds from herbaceous plants in managed and unmanaged seasonal herbaceous wetlands in various locations in the central United States.

Location	Plant seeds[a]	Mean or range	Reference
Managed Impoundments			
NW TX	Smartweeds	532-730	Haukos and Smith 1993
	Millet	346	
	Curly dock	1,233	
IL River Valley	Total	1,454	Bowyer et al. 2005
	Millet	3,155	Low and Bellrose 1944
	10 non-millet	653	Low and Bellrose 1944
SE MO	Total	1,629	Fredrickson and Taylor 1982
	Total	2,200	Davis *in* Fredrickson 1996
Central AR	Total	253-1,288	Moser et al. 1990
West MS	Total	331-1,084	Reinecke and Hartke 2005
Central MS	Total	550-2,050	Gray et al. 1999
Various MAV	Total[b]	238-1,985	Kross 2006, Kross et al. 2008a
Unmanaged or passively managed			
NW TX	Smartweeds	55-105	Haukos and Smith 1993
	Millet	45	
	Curly dock	703	
IL River Valley	Total	497	Bowyer et al. 2005
SE MO	Total	50-785	Fredrickson and Taylor 1982
Central MS	Total	100	Gray et al. 1999
NE LA	Total	226-312	McAbee 1994
Various MAV	Total[b]	437	Kross 2006, Kross et al. 2008a

[a] Smartweed is combined *Polygonum lapathifolium* and *Polygonum pensylvanicum*. Millet is combined *Echnichloa* species. Curly dock is *Rumex crispus*. Total is combined seeds measured or studied – see references.
[b] Combined seeds and tubers.

No estimates for zooplankton biomass are available for MAV habitats, but these animals represent important foods for shoveler and blue-winged teal (e.g., Taylor 1978, Heitmeyer 2002). Concentrations of Cladocera, Copepoda, Ostracoda, and *Nauplii* ranged from 29 to 864/L in GTRs and from 133 to 288/L in a Dead Timber reservoir in southeast Missouri (Wylie 1985). Zooplankton abundance in both habitats gradually increased from fall to spring. This manual does not include a separate estimate of annual zooplankton biomass among MAV habitats, but, zooplankton represents some unknown additional value of nonforested habitats to meeting DUD's of at least shoveler and blue-winged teal.

Current estimates of invertebrates in the MAV undoubtedly underestimate total invertebrate production and availability because they do not include zooplankton (see above) or terrestrial invertebrates such as insects, spiders, earthworms, etc. that occur in wetlands during certain seasons and events. For example, mallards consume large quantities of insects in Seasonal Herbaceous wetlands during fall and also forage extensively on many terrestrial species during winter floods in BLH (Heitmeyer 1985, Heitmeyer 2006a). Certain habitats that are at higher elevations and only occasionally flood such as High BLH and Floodplain Forest probably have high biomass of terrestrial invertebrates that may periodically be available to, and consumed by, waterfowl. Consequently, the above estimates of potential invertebrate biomass in the MAV may be quite conservative.

Seeds

Seeds from wetland plants comprise a large part of the diets of many waterfowl species in the MAV (Heitmeyer 2002). These seeds come from annual and perennial herbaceous, perennial emergent, and aquatic plants. Annual production of seeds potentially consumed by waterfowl varies greatly among MAV habitats in relation to amount and type of vegetation, hydrological regimes, management, climate, and nutrient composition of soils and water (Fredrickson and Taylor 1982). Generally, seed production is greatest in Seasonal Herbaceous communities and lowest in habitats with prolonged flooding regimes (such as Open Water/Aquatic, Persistent Emergent, Dead Timber) and large woody species components (such as forest and S/S communities).

Estimates of seed production in Seasonal Herbaceous wetlands in the Mississippi River Valley including the MAV have varied greatly, probably because of differences in location, vegetation composition and structure, hydroperiods, disturbance and management regimes, and estimation techniques (Table 11). Furthermore, studies often have grouped samples among locations, habitat and management types, and sampling methods and usually report cumulative means that mix divergent conditions. These estimates from both managed and unmanaged "moist-soil" areas ranged from 45 to 3,155 kg/ha (Table 11). Kross et al. (2008a) suggested using an average of 566 kg/ha for moist-soil impoundments in the MAV, but this average does not seem appropriate for all areas, management regimes or vegetation communities. The most comprehensive data set on herbaceous seed production is from southeast Missouri (Knauer 1977, Fredrickson and Taylor 1982, Kelley 1986, McKenzie 1987, Laubhan and Fredrickson 1992, Fredrickson 1996) where seed, browse, and tuber production was measured over many years, seasons, and management regimes. These studies and others (Reid 1983, Reid

Table 12. Estimated mean annual seed production (kg/ha) from herbaceous plants potentially available to nonbreeding waterfowl in seasonal herbaceous wetlands in relation to management intensity in the Mississippi Alluvial Valley.

Management Intensity[a]	Production
Intensive	1,000
Moderate	750
Low	562
Passive-unmanaged	422

[a] Intense management would include annual manipulations of soil, vegetation and water including tillage, mowing, burning, irrigation, fertilization, etc. Moderate management would include some annual manipulations of vegetation, soil, and water but not irrigation or fertilization. Low management would include at least some manipulations of soil, water, and vegetation at least every third year. Passive-unmanaged would include no intentional manipulations of soil, vegetation, or water.

et al. 1989, Fredrickson 1996, Gray et al. 1999, Bowyer et al. 2005, Kross et al. 2008a) indicate that annual production of moist-soil seeds is much higher in intensively managed impoundments than in unmanaged area (Table 11). Furthermore, time and type of disturbance greatly influences production. For example, seed production in impoundments in southeast Missouri averaged 1,960 kg/ha in the first year following disturbance and then declined to slightly less than 1,000 kg/ha by the third year post-disturbance (Fredrickson and Taylor 1982). Maximum overall average production in other intensively managed impoundments was 1,453 kg/ha in the Illinois River Valley (Bowyer et al. 2005), 1,184 kg/ha in several conservation areas in the MAV (Penny 2003), and 613 kg/ha in a central Arkansas (Moser et al. 1990). Other studies that did not separate data from intensive vs. more passive management estimated up to 2,200 kg/ha in Missouri (Davis, unpublished data cited in Fredrickson 1996), 1,084 kg/ha in Mississippi (Reinecke and Hartke 2005), and 2,332 kg/ha in several managed wetland areas in the MAV (Kross et al. 2008a). Collectively, these data indicate that intensively managed moist-soil impoundments average much greater annual production than Kross et al. (2008a) suggests, and that a conservative 1,000 kg/ha is a more accurate, and supportable, estimate for intensively managed moist-soil impoundments (Table 12).

Kross et al (2008a) found that passively managed moist-soil habitats had about 35% less annual production than intensively managed sites. Penny (2003) found intensively managed sites had 2.5x the annual production of seeds and tubers than did unmanaged sites. Point estimates of energetic carrying capacity, based mainly on moist-soil seed production, was 1.4 times higher in actively- vs. passively-managed wetland impoundments in Ohio (Brasher et al. 2007). The degree of active management, using various amounts and times of tillage, mowing, burning, fertilization, and flooding/irrigation influences moist-soil seed production (e.g., Fredrickson and Taylor 1982). Data from Fredrickson and Taylor (1982) suggest about 25% reduction in production/year post-disturbance up to 3 years later. The reduced production in unmanaged sites and the annualized decline in production relative to management intensity produce similar rates of reduced production relative to management type and intensity (Table 12). Consequently, if these data are accepted as representative of moist-soil impoundments relative to management intensity, and that intensive management produces an average of ca. 1,000 kg/ha, then reasonable estimates of seed production in Seasonal Herbaceous wetlands in the MAV would be 750 kg/ha for moderate, 562 kg/ha for low, and 422 kg/ha for unmanaged (passive) areas (Table 12). Many unmanaged sites with more prolonged water regimes eventually resemble Persistent Emergent habitats. Seed estimates for Persistent Emergent habitats in the MAV are not available, but these communities typically succeed quickly to less diverse perennial plant species and with greatly reduced seed production (Strader and Stinson 2005). Consequently, recognizing the paucity of information, this manual uses an estimate of 200 kg/ha seed production for Persistent Emergent habitats.

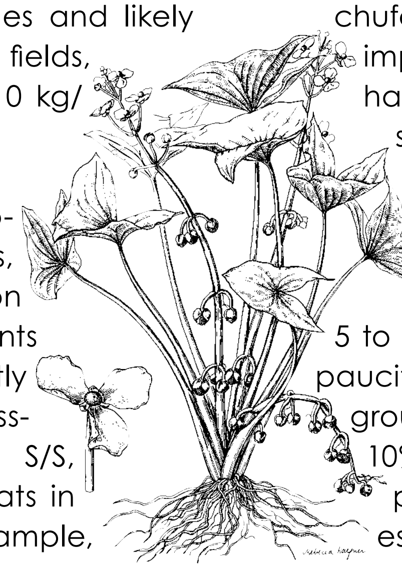
Seed production in forests comes mostly from herbaceous plants occupying tree gaps created by wind throw or death of single or multiple trees (e.g., Thompson 1980, Harrison and Chabreck 1988). These open areas cover 3-5% in naturally flooded BLH forests in the MAV (Heitmeyer et al. 1989), and if seed production is similar to unmanaged moist-soil impoundments (Table 12) then an annual production estimate for forests averaged across areas with ca. 20%, 10%, and 5% openings would be 84, 42, and 21 kg/ha, respectively. This range of relative "openness" and annual seed production in forests may be similar to that found in GTRs and Floodplain Forest communities. The only study that estimated seed production from willow-dominated wetlands was conducted in the Illinois River Valley and found an average of 166 kg seeds/ha/year (Bowyer et al. 2005). Consequently, a conservative value of 150 kg seeds/ha is recommended in this manual for S/S, Dead Timber, and margins of Open Water/Aquatic areas that experience mid-summer drawdowns that expose mud flats and stimulate moist-soil plant production (Table 10).

Some herbaceous seed production occurs in agricultural fields, depending on crop type, field management and production methods (e.g., use of herbicides, cultivation, etc.), and seed bank of fields. Estimates of moist-soil seed production in rice and soybean fields in northeastern Louisiana in the early 1990s ranged from 25 to 54 kg/ha in rice and 35-54 kg/ha in soybean fields (McAbee 1994). More recent estimates of seed production in rice fields in western Mississippi suggest low rates (e.g., 4 kg/ha) in contemporarily managed fields (Manley et al. 2004). Modern production methods in most agricultural crops in the MAV rely on heavy application of herbicides and likely reduce herbaceous plants in fields, consequently an estimate of 10 kg/ha is used in this manual.

In addition to seed production from herbaceous plants, considerable seed production also occurs from aquatic plants present in more permanently flooded habitats such as Cypress-Tupelo, Open Water/Aquatic, S/S, and Persistent Emergent habitats in the MAV (Wylie 1985). As an example, seeds from watershield are readily consumed by ring-necked ducks and pondweed seeds are consumed by several duck species (Fredrickson and Heitmeyer 1988, Heitmeyer 2002). Annual seed production from aquatic plants may exceed 300 kg/ha, but it is unknown how much is consumed by waterfowl. Consequently, 50 kg/ha is used as a very conservative estimate of potentially available aquatic plant seeds in Open Water/Aquatic habitats and 20 kg/ha is used for S/S, Cypress-Tupelo, Persistent Emergent, and Dead Timber habitats that contain abundant aquatic plants (Table 10).

Below-ground Roots, Tubers, Rootlets

Relatively little is known about annual production of below-ground biomass potentially consumed by waterfowl (e.g., Wills 1971, Kelley 1986). The best information on this production is from seasonally-flooded impoundments in southeast Missouri (Kelley 1986, McKenzie 1987, Kelley 1990, Kelley and Fredrickson 1991). These data and information extrapolated from Penny (2003) suggest that potential below-ground waterfowl forage from herbaceous plants, such as chufa, may be 10-20% of herbaceous plant seed production within an area. Production of chufa in intensively managed impoundments was nearly 366 kg/ha in shallowly disked and irrigated sites and as low as 15 kg/ha in deeply disked areas (Kelley and Fredrickson 1991). Roots, rhizomes, and tubers of other moist-soil plants ranged from 5 to 80 kg/ha (Kelley 1986). Given the paucity of information on these below-ground food types, this manual uses 10% of herbaceous vegetation seed production as a conservative estimate of below ground forage,



recognizing that species composition among areas will affect this production greatly (Table 10). Below-ground estimates from non-herbaceous habitats are unknown, but likely are not substantial.

Above-ground Browse

Although wetlands in the MAV are among the most productive ecosystems in the world in terms of above-ground vegetation biomass, much of this biomass is from woody plants (e.g., Conner and Day 1976, Wharton et al. 1982) and few duck species acquire substantial energetic or nutritional resources directly from consumption of plant material other than seeds and below-ground biomass of herbaceous plants (Heitmeyer 2002). Exceptions to this generalization are gadwall, wigeon, and geese than often consume stems and plant parts of herbaceous plants, such as spikerush, sedges, grasses, and forbs (Heitmeyer 2002). Total above-ground biomass of herbaceous plants in seasonal wetlands can exceed 5,000-10,000 kg/ha (Low and Bellrose 1944, Knauer 1977, Kelley 1990, Haukos and Smith 1993) but relatively few species provide potential browse used by certain ducks and geese. Data from control (non-managed) and treated (combinations of disking and irrigation) moist-soil impoundments in southeast Missouri indicated that above ground biomass of *Eleocharis obtusa*, a known browse species for geese and wigeon, averaged 63 kg/ha in control areas and 49 kg/ha in treated sites (Kelley 1986:36). In the absence of more comprehensive data, an average of 50 kg/ha may be reasonable for potential above-ground browse in habitats with substantial herbaceous plants, especially Seasonal Herbaceous Wetlands (Table 10). Wigeon, gadwall, and geese very rarely forage in forested habitats and above ground herbaceous biomass is not common in these habitats or in more permanently flooded areas such as S/S and Open Water/Aquatic habitats.

Aquatic Plants and Algae

Dense mats of submerged and floating-leaved aquatic plants and algae are common in certain habitats in the MAV (e.g., Wood 1972, Wylie 1985, Wylie and Jones 1986). Algae can be abundant in seasonally flooded nonforested habitats in the MAV, but aquatic plants are mostly limited to more permanently flooded areas. Total aquatic plant biomass in Open Water/Aquatic habitats in the MAV can exceed 25,000 kg/ha/year (Wood 1972). Annual algal production also is high in many MAV habitats (e.g., Wylie 1985). At any given time, algal biomass in freshwater wetlands may be 10-30 kg/ha (with total

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annual biomass adjusted for turnover rates > 10,000 kg/ha) depending on vegetation type, density, and hydrological regime (data summary in Robinson et al. 2000:168). As with above-ground biomass of herbaceous plants, relatively little of total aquatic plant/algae biomass may represent potential waterfowl forage. Wigeon, gadwall, redhead and canvasback are species that readily consume aquatic plants and some algae; other species have limited or incident intake of these foods. In the absence of having specific data on potential waterfowl forage from these aquatic foods, an estimate of 100 kg/ha aquatic vegetation is used in this manual for Open Water/Aquatic, S/S, Cypress-Tupelo, Persistent Emergent, and Dead Timber habitats and 50 kg/ha algae is used for Seasonal Herbaceous habitats. Forested habitats are assumed to have negligible potential waterfowl forage value from aquatic plants and algae.

Small Vertebrates

Small vertebrates represent important forage items for certain waterfowl species in the MAV, especially hooded mergansers (Table 2) Species groups commonly found in diets of hooded mergansers include anurans, salamanders, and small fish (Dugger et al. 1994). Many fish are present in permanently flooded MAV habitats and large numbers of several fish species access floodplain areas (forested and nonforested) to forage and spawn during flood events (Jackson 2005) and as nursery sites for larval and juvenile fishes (e.g., Stewart 1983, Sargent 1996). Annual productivity of fish in BLH floodplains may reach 2,000 kg/ha with swamp and shallow natural ponds/wetlands producing 5-200 kg/ha/year (Jackson 2005). Much of the annual biomass

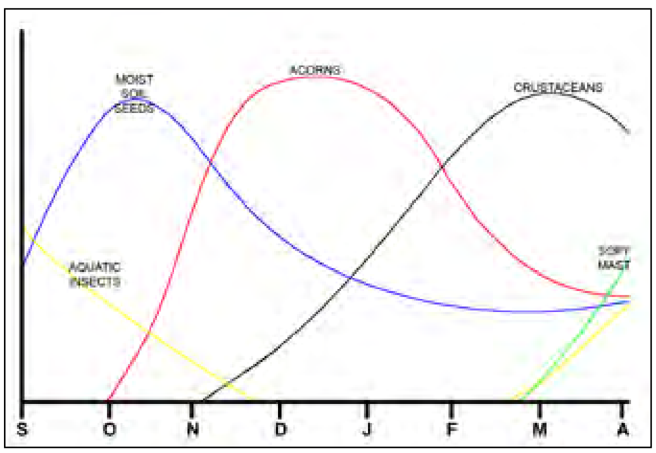

Figure 3. Availability of food resources in Upper Mississippi Alluvial Valley wetlands September to April. Modified from Fredrickson and Heitmeyer (1988).

is in larger fish that are not potential prey for mergansers; however, some component of this biomass does represent potential forage. Large numbers of frogs and amphibians occur in MAV habitats (Jones and Taylor 2005), but estimates of biomass and potential forage to certain waterfowl species are not available. Given the uncertainty in potential biomass as forage for waterfowl, no estimate of value is made toward calculating DUD values in this manual, however, it is noted that this forage component is substantial in many habitats, at least for hooded merganser.

Agricultural Grains and Browse

Large amounts of agricultural fields are present in the MAV and include primarily corn, rice, soybean, milo, and wheat crops. Additionally, domestic cultivars of millet (e.g., Japanese millet) are commonly grown on some wetland management sites for waterfowl food (e.g., Merz and Brakhage 1969). Almost all wheat grown in the MAV is winter wheat, so no grains are available during the nonbreeding period discussed in this manual. In contrast, winter wheat stem growth is readily available and consumed by some species, especially geese. Grain production in corn, soybean, and milo fields is variable throughout the MAV depending on location, field fertility, and production management. Generally, an average of 120, 30 and 60 bushels grain production/acre currently occurs for corn, soybeans, and milo, respectively, in the Upper MAV (U.S. Department of Agriculture, National Agricultural Statistics Service, http://nass.usda.gov). Corn and milo have 56 lbs/bushel and soybeans have 60 lbs/bushel, which translates to ca. 7,280, 2,000, and 3,700 kg/ha for corn, soybeans, and milo, respectively. Average rice yields in the MAV in the last decade have averaged about 6,300 kg/ha

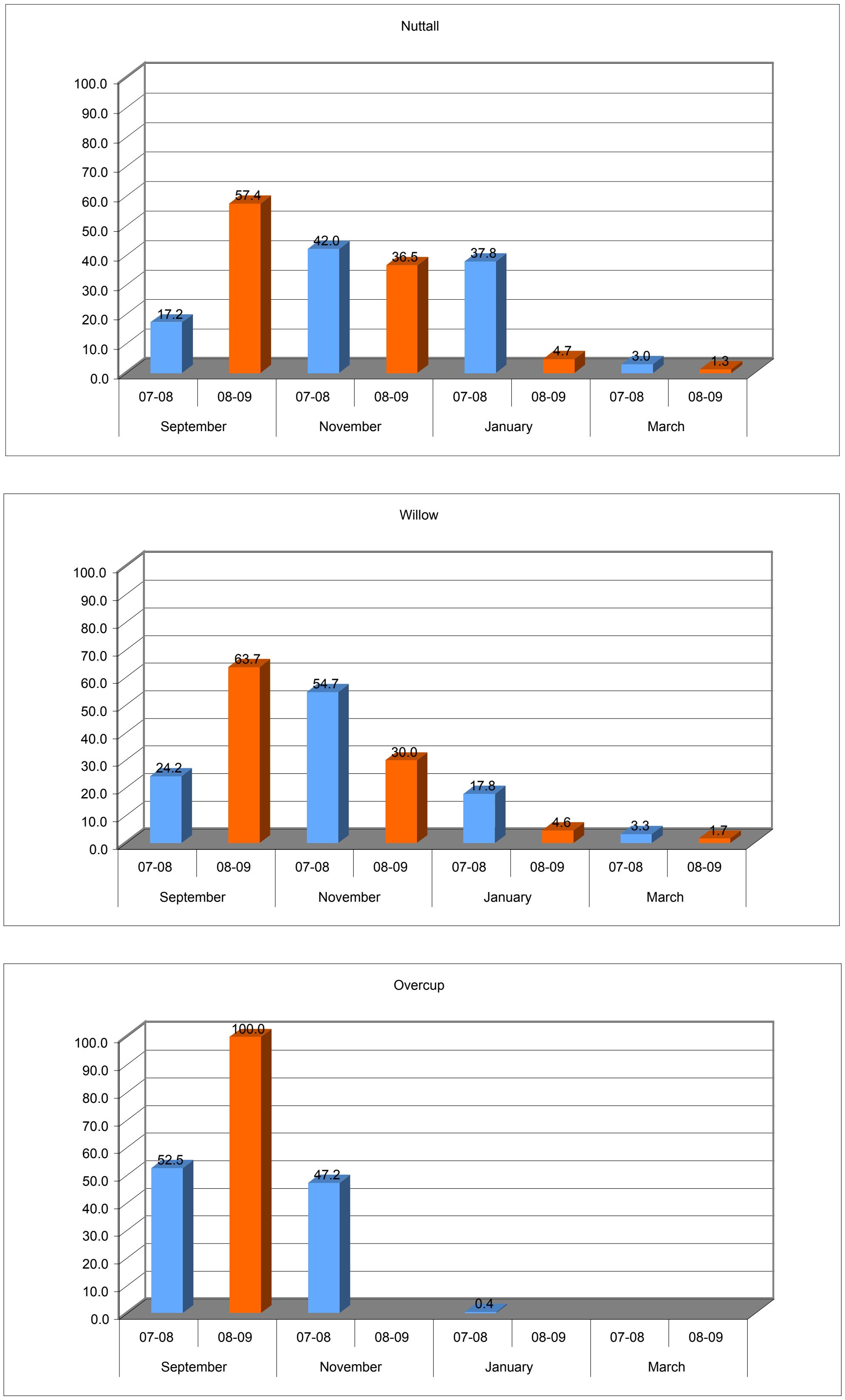

Figure 4. Mean percentage of Nuttall, willow, and overcup oak acorns falling from trees by the end of September, November, January, and March 2007-08 and 2008-09 in the 640 greentree reservoir on Cornerstone Farms, Arkansas (adapted from Heitmeyer and McGeorge 2009).

(Salton 2001, Stafford et al. 2006). Average annual millet production has been estimated at 1,500 kg/ha (Lower Mississippi Valley Joint Venture, unpublished estimate). Left unharvested, these potential waste grains may be present for waterfowl species that readily consume agricultural grains, including millet.

Recent studies have estimated harvest loss of 4-6% for rice and other grains in the MAV (Warner et al. 1989, Manley et al. 2004, Stafford 2006). Post-harvest management practices affect abundance of waste grains (e.g., Stafford et al. 2005, Kross et al. 2008b); leaving stubble undisturbed provides the most residual waste grain. For purposes of this manual it is assumed that 4% of waste grain is left in MAV crop fields immediately after harvest and that stubble is undisturbed (Table 10). Biomass of winter wheat during winter changes from germination through cumulative growth later in winter and spring. Geese and wigeon tend to forage on wheat later in winter, so estimated biomass during January and February seems appropriate to measure potential forage value. Estimates of this wheat biomass are sparse, but generally equate to ca. 300 kg/ha by late winter/spring (e.g., Kahl 1980, Kahl and Samson 1984).

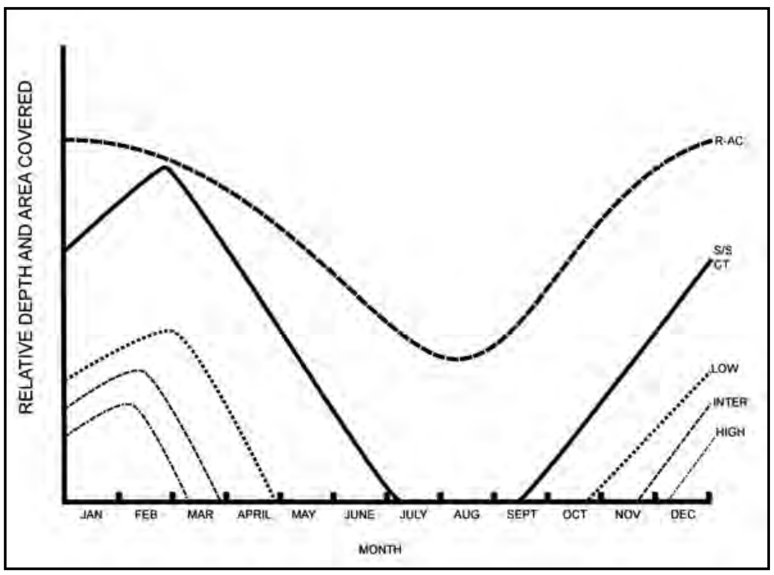

Figure 5. Relative annual flooding dynamics of habitat types in bottomland hardwood habitats in the Upper Mississippi Alluvial Valley (modified from Heitmeyer et al. 2005). LOW = low elevations dominated by overcup oak; INTER = intermediate elevations containing red oaks, sweetgum, and green ash; HIGH = high elevations near upland zones containing water, willow, and cherrybark oak and with hickory and sugarberry; S/S-CT = low elevation shrub/scrub and cypress/tupelo habitats; and R-AC = deeper depressions from remnant abandoned channels.

SEASONAL AND ANNUAL AVAILABILITY OF FOODS

Not all of the annual production of major waterfowl food groups in the MAV is available to nonbreeding waterfowl. Availability is influenced by:

- Chronology of seasonal production and presence in the foraging space of species
- Annual dynamics of extent and depth of flooding
- Decomposition and deterioration rates
- Consumption by nonwaterfowl species
- Disturbance or other factors preventing physical or behavioral access to foods
- Thresholds of foraging efficiency

Seasonal Food Availability

Potential seasonal availability of foods is determined by: 1) when production occurs and foods are in the foraging space of a species and 2) when the habitat becomes flooded, if flooding is a precursor to the food being accessible to a species. Foods that generally must be flooded before they become accessible to waterfowl species in the MAV are seeds; hard mast; below-ground tubers, roots, and rhizomes; aquatic plants and algae; invertebrates; and small vertebrates (Heitmeyer 2002). Above-ground and agricultural browse is accessible on dry, moist, and shallowly flooded surfaces. Agricultural grains are used more often when crop fields are shallowly flooded, but some species including mallard, pintail, and geese will readily forage in dry or moist fields, especially in late winter.

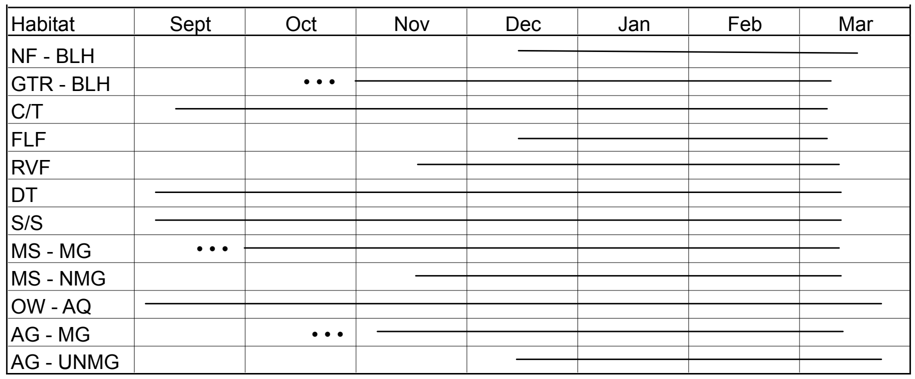

Figure 6. Average annual chronology of flooding of major habitat types in the Upper Mississippi Alluvial Valley. NF-BLH = naturally flooded bottomland hardwood forest; GTR-BLH = greentree reservoirs in bottomland hardwood forest; C/T = cypress/tupelo; FLF = floodplain forest; RVF = riverfront forest; DT = dead timber; S/S = shrub/scrub; MS-MG = managed moist-soil impoundments; MS-NMG = nonmanaged seasonally flooded herbaceous wetlands including moist-soil impoundments; OW-AQ = open water/aquatic; AG-MG = managed agricultural fields either harvested or unharvested; and AG-UNMG = unmanaged harvested agricultural fields.

Seasonal production of foods that accumulates to some maximum potential available yield varies among food groups in the MAV (Fig. 3). By early fall (September-October) annual production of seeds, tubers, aquatic plants, wetland browse, and agricultural grains are near peak abundance. Acorn production also has peaked at this time, however, fall from trees is only 30-50% complete (Fig. 4); total acorn drop does not occur until late winter. Invertebrate production is composed of both aquatic and benthic invertebrates, which have different occurrence chronologies. Most aquatic insects are at peak levels in late summer and decline thereafter (e.g., Reid 1983). In contrast, most benthic invertebrates and zooplankton, especially in forested habitats, begin growth in late fall-early winter and peak in spring (e.g., White 1985, Wylie 1985). Annual production of small vertebrates, used by hooded mergansers and incidentally by other species probably begins in spring, peaks by fall, and declines through winter (e.g., Jones and Taylor 2005).

Estimates of carrying capacity for the entire nonbreeding season (September-March) can assume total maximum annual production for the food and habitat minus some loss from deterioration, consumption by nonwaterfowl species, and germination of seeds falling to the ground. In contrast, carrying capacity for individual months, or sets of months, must account for seasonal dynamics of both production and accessibility (e.g., flooding extent and depth). Natural dynamics of flooding regimes in the MAV are related to seasonal precipitation patterns, both locally and regionally, and subsequent surface flooding and water retention (e.g., Fig. 5). Some habitat types, including Cypress-Tupelo, Dead Timber, S/S, Persistent Emergent,

Table 13. Average deterioration rates (%/day) of various waterfowl foods following flooding (adapted from Neely 1956, McGinn and Glasgow 1965, Shearer et al. 1969, Fredrickson and Reid 1988b, Nelms and Twedt 1996).

Food Type	Deterioration Rate
Soybeans	0.76-1.083
Corn	0.36- 0.56
Rice	0.213
Red rice	0.102
Paspalum	0.133
Millet	0.259
Bristlegrass	0.261
Sesbania	0.268
Panic grass	0.364
Signalgrass	0.392
Morning glory	0.418

and Open Water/Aquatic typically are flooded the entire nonbreeding period (Fig. 6). Other habitats gradually become flooded when fall-winter precipitation increases; e.g., higher elevations of BLH are naturally flooded for only short durations in winter and early spring. Habitats that have artificial water management capabilities, such as GTRs, moist-soil impoundments, and agricultural fields may be flooded for much of the nonbreeding period depending on management objectives.

The amount of foods produced in MAV habitats that are not available to waterfowl because of water depths (either deep or dry) outside the foraging capability of species, germination, deterioration and consumption by nonwaterfowl is largely unknown. Consumption of acorns on the tree, prior to fall, from birds and squirrels may be 15-20% (Cypert and Webster 1948, Reid and Goodrum 1957). Furthermore, mammal and bird consumption of acorns in dry BLH may be high in some locations depending on abundance of consumers such as fall migrant blackbirds, rodents, turkey, deer, etc. (e.g., Dickson 2002, Bowman and Chamberlain 2002). Bird (nonwaterfowl) and small mammal consumption of moist-soil seeds may be quite high (> 50%) in some locations based on number, abundance, and energy needs/use of species. For example, large numbers of blackbirds, rails, snipe, and rodents are present in moist-soil impoundments immediately prior to and during flood up periods (Rundle 1980, Fredrickson and Taylor 1982). Likewise, blackbird and other animal consumption of waste agricultural grains and browse can be huge (e.g., Dolbeer 1980, Kahl 1980, Kahl and Samson 1984, Taylor 1957, Flegler et al. 1987). In contrast, nonwaterfowl consumption of aquatic plants/seeds, wetland browse, and below-ground tubers, etc. likely is quite low (e.g., Kelley 1986, McKenzie 1987).

Germination of seeds and agricultural grains falling to ground surfaces may also be substantial in some species and locations. For example, > 50% germination of fallen millet seeds from domestic cultivars in Central Arkansas and > 80% germination of waste corn in southeast Missouri in September was observed in early fall 2006-2008 (Heitmeyer, unpublished data).

Waterfowl foods in the MAV also deteriorate at different rates (Table 13). Some foods, such as soybeans decompose at very rapid rates, while others, such as algae mats and zooplankton populations also "turn over" quite rapidly (e.g., Wylie 1985, Robinson et al. 2000). In contrast, living aquatic invertebrates, living small vertebrates, acorns, and tubers decay slowly if at all during winter and spring. Estimates that assume a constant rate of deterioration suggest 10-15% dete-

Table 14. Estimated percentage of maximum annual production of major food types that is available to nonbreeding waterfowl in the Mississippi Alluvial Valley from September to March (based on seasonal dynamics, loss, and deterioration rates in Fredrickson and Taylor 1982; Fredrickson and Reid 1988b; Heitmeyer et al. 1989, 2005; Hubert and Krull 1973, Kelley 1986, Duffy and LaBar 1994, Heitmeyer and McGeorge 2009, Magee et al. 1993, Neely 1956, Nelms and Twedt 1996, Reid 1983, Shearer et al. 1969, Stafford et al. 2006, Wehrle et al. 1995, White 1982, Wood 1972, Wylie 1985, Brasher et al. 2007, Greer et al. 2007, Greer et al. 2009.

Food type	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Herbaceous seeds	90	80	70	60	50	40	30
Aquatic seeds	90	80	70	50	30	20	20
Below-ground tubers, etc.	90	100	90	90	90	90	80
Above-ground browse	80	70	60	50	40	50	60
Mast	30	50	80	90	80	70	50
Aquatic plants	80	60	40	20	20	20	40
Invertebrates	40	20	10	20	50	70	80
Agricultural grains	80	60	40	30	20	20	10
Agricultural browse	-	10	30	50	70	80	90

rioration rate/month from September through December (Fredrickson and Reid 1988b). The combined loss of post-harvest waste rice in western Mississippi from combined germination, deterioration, and consumption by nonwaterfowl species was estimated at 71% from September to early December (Stafford et al. 2006). Moist-soil seed losses in fall-flooded impoundments in Missouri averaged from 70-87% loss from September to February and 18-44% loss in spring-flooded impoundments (Greer et al. 2007).

Evidence exists that waterfowl may not continue to forage for specific foods in certain habitats if the quantity of food becomes low, or is difficult to obtain (e.g., Strong 1986, Tome 1989). The notion of a "threshold level", or "giving up density" at which a certain level of food reaches, and causes waterfowl to have reduced efficiency of feeding and thus abandonment of a site has been suggested (Reinecke et al. 1989) for certain MAV habitats. In rice fields, this "threshold" level may be 50 kg/ha (Stafford et al. 2006, Greer et al. 2009). It is doubtful that this threshold level (50 kg/ha) exists in all (or even any other) habitat/food types in the Upper MAV, because studies of wild waterfowl foraging behavior and food consumption indicate extensive foraging time and effort (up to 80% of diel time) in many habitats and seasons despite potentially low food abundance (e.g., Drobney and Fredrickson 1979, Heitmeyer 1985, Heitmeyer 1988a, Heitmeyer and Fredrickson 1990, Drobney 1980, 1990). Nonetheless, the potential for some "threshold" of varying levels may exist for various habitats. Recent sampling of moist-soil impoundments in the MAV found that 150-200 kg/ha of seeds may remain unconsumed in these wetlands by spring, suggesting that either the sites were not fully utilized by nonbreeding waterfowl, that seeds were not available to birds because of water levels or other deterrents to foraging, or that seed density declined to a point that foraging efficiency was inhibited and caused birds to discontinue use or foraging in an area (Hagy and Kaminski, unpublished data).

Given that some proportion of the annual potential maximum yield of waterfowl foods in the MAV is not available to, or used by, waterfowl in the nonbreeding season, and that this proportion changes among food types and season, this manual offers matrix estimates of percentage food availability by type and time (Table 14). This matrix combines the seasonal occurrence dynamics of production (see above) and cumulative effects of germination, deterioration, and consumption (including a giving up density) by nonwaterfowl species. Total combined monthly estimates for September through March are assumed to be 100% of total potential food yield from Table 10. Ratios of change were extrapolated from various literature sources, and additional field data undoubtedly will provide more accurate estimates in the future.

In addition to the above estimates of seasonal dynamics of food availability in the MAV, another important factor influencing accessibility of food is disturbance or other factors limiting either physical or behavioral access to foods. Access can be restricted because of water depth, species morphology, location and attributes of fields/tracts, competition from other species, predation risk, human-caused disturbance, etc. Disturbance from humans can occur from many factors including motor traffic (land and water), presence of humans or potential predators, aircraft, noises, etc. (Dahlgren and Korschgen 1992). Response and return times of mallards to experimental and naturally occurring disturbance on Mingo National Wildlife Refuge in southeast Missouri (Heitmeyer 1985, Raasch

1996), mallards and Canada geese on the Russell lakes Wildlife Management Area in Colorado (George et al. 1991), canvasbacks in Wisconsin (Kahl 1991), and spring staging snow geese (Belanger and Bedard 1989) suggest substantial impacts of disturbance on foraging behavior and habitat use of nonbreeding waterfowl. Actual effects of disturbance on food availability are not known in the MAV, and may be compensated by changed foraging time and behavior (e.g., shifts to nocturnal feeding, McNeil et al. 1992).

In the MAV, human disturbance from hunting may be a significant factor affecting waterfowl use of habitats (e.g., Heitmeyer 1985, Stafford et al. 2007, Davis et al. 2009). Waterfowl hunting seasons in the MAV in recent years have typically occurred from November to late January for ducks and dark geese and from November through March for white geese (USFWS 2009). The relative influence of hunting in limiting the availability of foods to waterfowl in the MAV is unknown, and likely varies greatly depending on location and intensity of hunting on a site. For example an area immediately adjacent to a sanctuary site that is hunted only for a few hours in the morning and only once or twice a week may be used extensively by waterfowl during nonhunting periods and potential food availability probably is not reduced. In contrast, a site that is substantial distance from a sanctuary and is hunted for most of the day several times a week, may be used infrequently by waterfowl during the day, or have use redistributed to nocturnal periods. Further, duck hunting effort varies widely among MAV states. Estimated hunter/days during the 2008-09 duck season ranged from 106,000 (an average of 7.12 days/hunter) in Kentucky to 520,100 (average of 8.9 days/hunter) in Arkansas (Raftovich et al. 2009). Limited data suggests that proportional use of hunted and nonhunted areas by mallards in some MAV areas varies inconsistently by time of day, seasons, and years (e.g., Davis et al. 2009). Given the uncertainty about, but presumption of at least some, effects of hunting on food availability in the Upper MAV during hunting seasons, this manual uses an average of 25% reduction in food availability for all food types in hunted sites during November to January in the MAV. This hunting period covers the periods of duck, white-fronted goose, and Canada goose seasons in the area. Conservation hunting seasons for white geese continue in the region in February and March, but most of this hunting occurs in dry harvested agricultural fields, and by relatively few hunters. This manual assumes that Conservation hunting of white geese has limited effect on food availability outside of duck hunting seasons because considerable data suggest waterfowl readily use areas hunted during the regular waterfowl seasons prior to, and after these seasons (e.g., Heitmeyer 1985, Dugger 1990, Havera 1999, Davis et al. 2009). However, if intense conservation hunting for white geese consistently occurs in wetland areas then some reduced availability of foods to, and use by, dabbling ducks may occur (e.g., Webb et al. 2010).

Annual Dynamics of Food Availability

The annual availability of most foods to waterfowl in MAV habitats depends on whether the site and foods become flooded. Some species may use some foods and habitats regardless of whether they are flooded or not, e.g., geese and wigeon grazing on winter wheat, but most waterfowl require that potential foods be flooded within their foraging depth, and thus become available to them, for some period of time that allows them to find and access the food. Certain data suggest that a flooding duration of at least 3-5 days may assure use by, and increased food value to, wintering mallards within constraints of other factors such as disturbance, etc. (Heitmeyer 2006a). If a minimum of 3 consecutive days of flooding is used as a criteria for foods to become available and used by nonbreeding waterfowl (excluding those species and habitats that do not require flooding to obtain specific foods) then the duration of at least 3 days flooding (0-100% of the total time period investigated) can be multiplied by the production and energy value of the food to determine the amount of food that is available.

Flooding in MAV habitats is caused by various conditions including, but not limited to: 1) natural headwater flooding (i.e., precipitation within a watershed that causes streams and other drainages to exceed bank full elevations and inundate off-channel, usually floodplain, areas; 2) natural backwater flooding (i.e., precipitation that causes a higher order stream/ drainage to exceed bank full elevations and causes water to back-up other lower order drainages and into upstream floodplains; 3) direct on-site precipitation; 4) blockages in drainages (i.e., natural and artificial obstructions including beaver dams, sediment and debris accumulation, dams, and weirs; and 5) artificial movement of water onto a site from pumping, water diversion, etc.

Table 15. Winter (Dec-Feb) flooding characteristics for river-gage stations in the Mississippi Alluvial Valley 1939-1940 to 1998-1999 arranged from most to least flooded[a], from The Journal of Wildlife Management, 2006.

	% yr flooded			Days flooded/ flood yr		Pulses/ flood yr		Days/pulse	
River-gage station	≥ 1	≥ 5	≥ 10 days	x	SE	x	SE	x	SE
Hatchie-Rialto, TN	91.7	90.0	83.3	41.2	12.1	1.7	0.4	24.0	10.2
White-Clarendon, AR	78.3	75.0	70.0	46.3	3.6	1.6	0.4	29.4	13.0
Obion-Bogota, TN	85.4	66.7	58.3	19.2	6.0	2.6	0.5	7.5	2.8
Big Black-Bovina, MS	73.3	68.3	50.0	20.5	7.8	1.5	0.3	13.3	5.4
Cache-Patterson, AR	66.0	55.0	48.3	23.4	9.0	1.7	0.4	13.5	6.6
St. Francis, St. Francis, AR	65.0	58.3	41.7	19.7	7.9	2.1	0.5	9.3	6.1
Ouachita-Camden, AR	65.0	61.7	40.0	14.5	4.7	2.0	0.5	7.5	2.5
Big Sunflower, Sunflower, MS	58.3	46.7	33.3	12.7	4.5	1.7	0.4	7.5	2.3
Boeuf-Ft. Necessity, LA	40.0	36.7	33.3	27.0	11.7	1.3	0.3	21.3	11.0
Ohio-Cairo, IL	35.0	35.0	25.0	17.7	6.7	1.3	0.2	13.7	6.0
Black-Corning, AR	53.3	35.0	20.0	8.7	3.9	1.8	0.5	5.0	1.9
White-Newport, AR	30.0	23.3	15.0	15.0	6.8	1.3	0.2	11.2	4.1
Mississippi-Memphis, TN	10.0	10.0	6.7	17.3	7.5	1.0	0.0	17.3	7.4
Mississippi-Vicksburg, MS	11.7	10.0	6.7	18.7	7.3	1.1	0.2	15.1	7.2
Tensas, Tendal, LA	26.7	11.5	5.0	6.3	2.9	1.3	0.3	4.8	1.8
Yazoo-Greenwood, MS	6.7	5.0	3.3	11.2	3.9	1.2	0.2	9.0	1.7
Mississippi-New Madrid, MO	3.3	3.3	3.3	38.5	5.3	1.0	0.0	38.5	5.3

[a] % of years when the station was flooded ≥ 10 days Dec-Feb.

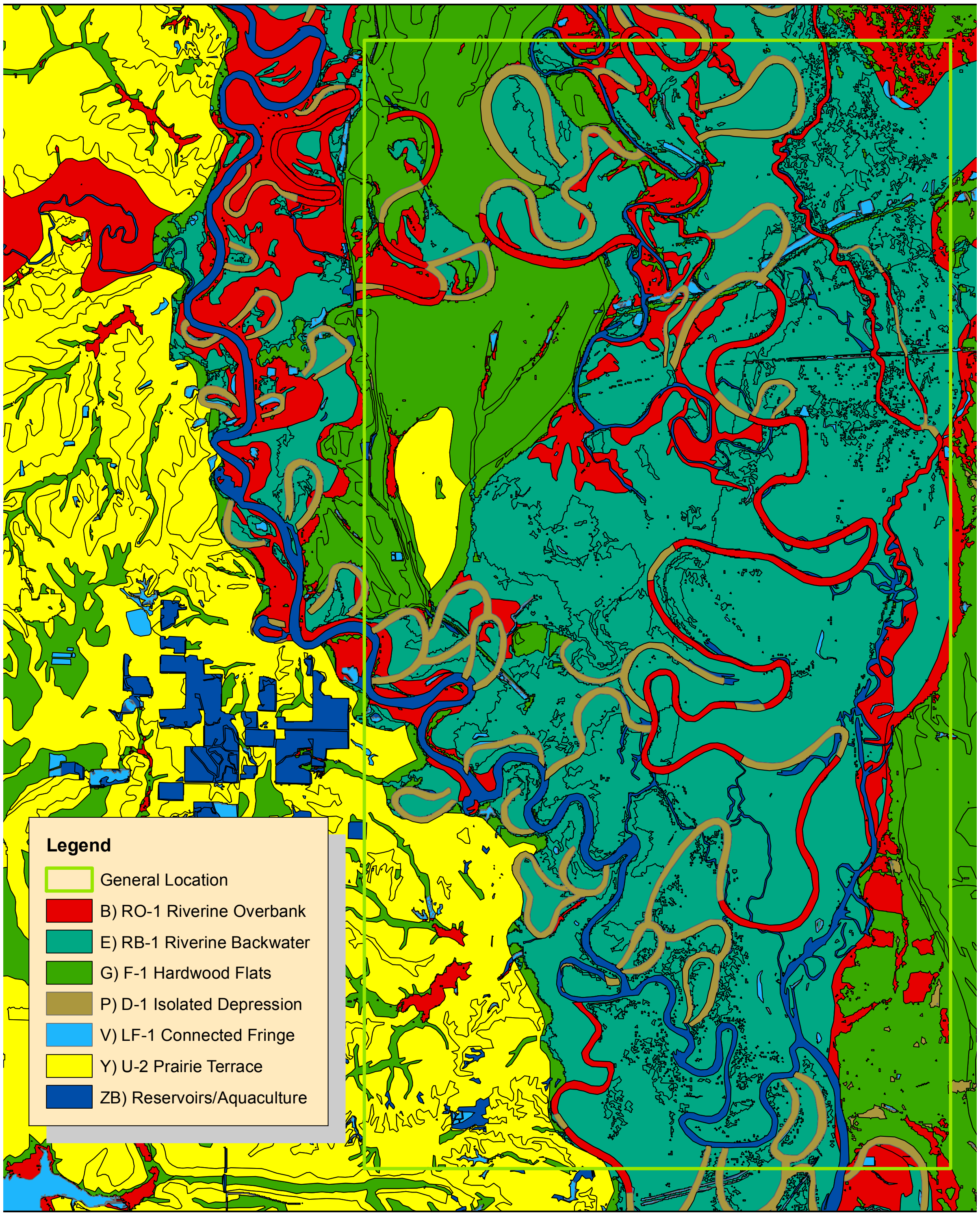

Figure 7. Example of a hydrogeomorphic map of potential forest vegetation communities based on flood frequency recurrence intervals in the Lower White River, Arkansas (from Heitmeyer 2008b).

Natural flooding of the MAV landscape during September-March is variable among years and locations. As indicated above, some habitats are flooded for extended to permanent periods each year, while others typically begin flooding in late winter or spring as precipitation, runoff, and overbank flooding of rivers and streams in the region increases. Also, some managed habitats (e.g., GTRs, moist-soil impoundments) are intentionally flooded almost every year (Fredrickson 1996, 2005). Overbank flooding is especially important to make forested, agricultural, and some other habitats available to wintering waterfowl (Reinecke et al. 1988, Heitmeyer 2006a). The frequency and duration of this winter flooding varies considerably among latitude and years. For example, overbank river flooding that lasts at least 5 days (a length of time that increases values to foraging mallards) ranges from about 3% of years along the Mississippi River in southeast Missouri and the Yazoo River in western Mississippi to about 90% of years along the Hatchie River in western Tennessee (Table 15).

River gauge data and general statistical practices can be used to determine flood duration within larger MAV floodplains. The USACE and the U.S. Geological Survey publish daily river stage data, and stage-discharge relationships, for many watersheds in the MAV and these are readily available at the following websites:

www.rivergages.com

http://waterdata.usgs.gov/nwis

Daily river stage data can be correlated to existing elevation data to determine the point where overbank flooding occurs and also the area of flooding for that day. Long-term trends over multiple days and years can be established to determine flood durations. Evaluation of differences in duration and area of 3-day and 5-day flood events in the MAV indicate little differences. For example, the difference between the median 3- and 5-day flooding durations for the Little Sunflower River gauge was only 0.16 feet, while the difference between maximum values was only 0.2 feet (D. Johnson, USACE, unpublished data from the Yazoo Basin, MS). Consequently, this manual recommends using the 3-day duration level as a predictor of food availability period. An example methodological sequence of hydrological analyses for calculating DUD is to:

1. Collect period of record (POR) river stage data for all gauges in the study area.

2. Determine maximum 3-day flooding duration by water year in the POR.

3. Determine frequency plotting positions by dividing n + 1 years by rank. As an example for a 49 year POR, the maximum annual 3-day duration would have a 50-year recurrence interval.

4. Plot the 3-day duration frequency curve.

5. Use a selected mapping method to determine areal extent of the 3-day flood frequency events.

6. Obtain GIS land-cover information for the habitats present.

7. Tabulate the habitat-flood frequency information to determine the percentage habitat by flood frequency intervals.

8. Calculate annual waterfowl habitat by summing the habitat by weight flood frequency, e.g., 1-year by 1.0, 2-year by

0.5, 5-year by 0.2, etc. This calculation will yield average annual acres available for waterfowl foraging by habitat type.

9. Use tables in this manual to calculate kg/ha of specific foods available, total kcal of food available, and average annual DUD.

Another way to determine frequency of annual flooding is from flood-frequency or flooding recurrence interval mapping (Fig. 7). These recurrence intervals are determined from stage-discharge relationships developed from long-term gauge stations along major rivers and calculations of frequency that a specific discharge/stage that represents overbank flooding occurs (e.g., Heitmeyer 2008:55).

Obviously, knowing the frequency and duration that MAV habitats become flooded (at a depth that allows efficient foraging for various waterfowl species) or otherwise accessible to waterfowl is critical to determine how often specific foods and habitat types actually are available to nonbreeding waterfowl in the region. For example, excellent acorn production (say 500 kg/ha) might occur in a BLH site, but if this site is only inundated on average of 20% of years during some point in winter, then the annualized production available to waterfowl would be 100 kg/ha/year (i.e., 500 kg/ha times 0.2) In contrast, a poor moist-soil habitat that produces only a combined 100 kg/ha seeds, below-ground tubers, and invertebrates/year, but that is intentionally flooded every year, would have the same potential food availability (100 kg/ha) to waterfowl/year.

Another factor affecting annualized food production is whether habitats on a site are recently restored, or represent continuous habitat over time. For example, substantial areas in the MAV have been enrolled in the U.S. Department of Agriculture Wetland Reserve Program during the past decade and former croplands have been reforested or restored to other wetland communities (King et al. 2006). Sites that have been reforested to some component of red oak species may begin producing acorns within 20-30 years, but maturation to tree sizes and stand densities that produce larger quantities of acorns (Table 8) may take several decades. In contrast, newly restored BLH sites may produce large quantities of herbaceous plant seeds and tubers until trees shade out ground cover. Assessing food types and production in restored sites will require site-specific evaluation, and perhaps field data collection, to determine production dynamics.

ENERGY VALUES OF FOODS

Measurements of the amount of energy available to wild waterfowl from their diet typically are expressed as true metabolizable energy (TME) in kcal/g (Owen and Reinecke 1979, Miller and Reinecke 1984). Estimates of TME for most of the major food groups consumed by waterfowl in the Upper MAV are available from published literature (Table 16). Where multiple species are grouped within a category (e.g., moist-soil seeds), a general average of typical species is used to represent the group. Most foods consumed by waterfowl in the MAV range from 2.5 to 4.0 kcal/g with agricultural grains and below-ground tubers, etc. having the greatest energy concentration (Table 16).

Table 16. Estimated true metabolizable energy (TME, kcal/g dry mass) of major food types for nonbreeding waterfowl in the Mississippi Alluvial Valley.[a]

Food	TME
Seeds	2.50
Acorns	2.67
Below-ground tubers, etc.	4.00
Above-ground browse	2.50
Aquatic plants	2.50
Invertebrates	3.50
Small vertebrates	3.50
Corn	3.67
Soybeans	2.65
Milo	3.49
Rice	3.34
Winter wheat browse	2.50

[a] Extrapolated from data in Kaminski and Essig 1992, Kaminski et al. 2003, Buckley 1989,Checkett et al. 2002, Sherfy 1999, Petrie et al. 1998, Anderson and Smith 1997, Petrie 1994, Reinecke et al. 1989, Jorde and Owen 1988, Buchsbaum et al. 1986, Hoffman and Bookhout 1985, Hentges 1983, Mutzar et al. 1977, Sibbald 1976, Driver 1981, Driver et al. 1974, Sugden 1973, Sugden 1971, Scott et al. 1969, Harper and Daniel 1934, Dugger and Fredrickson 1996, Brasher et al. 2007

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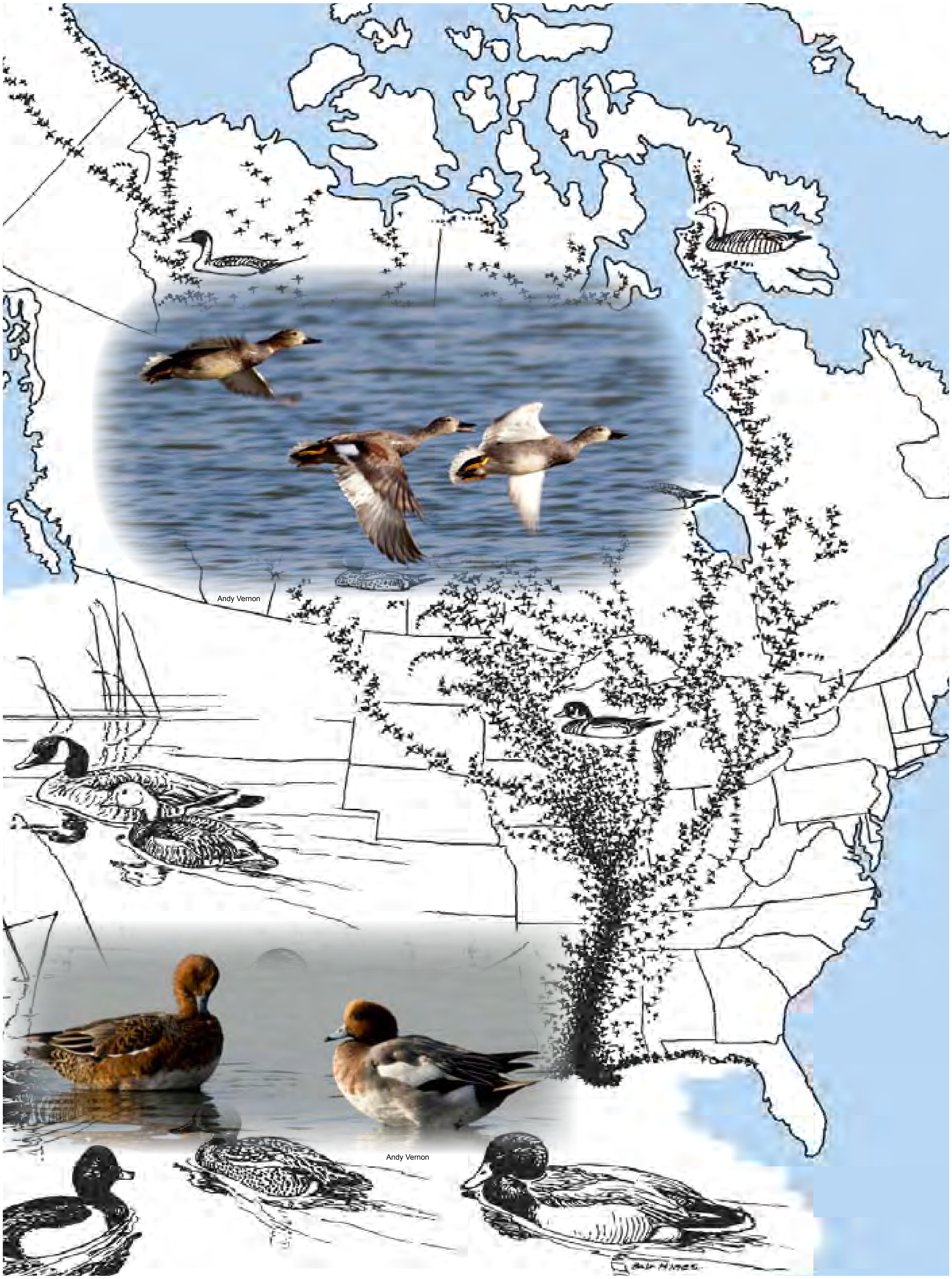

Andy Vernon
Andy Vernon

DUD MODEL EQUATIONS

DUD's of an area/habitat can be estimated using the model equations presented below. These equations rely on information on DEE's of waterfowl species and potential food abundance and availability presented in previous sections. Examples of calculations are provided for the equations to demonstrate use and possible inclusion of species, food, and availability data.

In its simplest form, the equation that estimates potential DUD's for one species in a single habitat area of one ha is:

1)

$$Species_{1...m}DUD = \frac{\sum(F_{1...j})(T_{1...l})}{D_{1...m}}$$

Where,

F = the potential food yield (g/ha) for food types $_{1...j}$ in the habitat type $_{1...k}$

T = TME (kcal/g) of specific food types $_{1...l}$

D = DEE of Species $_{1...m}$ in kcal/day and is 4x RMR

RMR = $100.7W^{0.74}$

and, W = weighted body mass of species $_{1...m}$ in kg

Maximum potential food yields of specific foods and habitats are presented in Table 10. Average TME of foods is presented in Table 16. DEE of species is presented in Table 1. Specific foods used by individual species are presented in Table 2.

This equation can then be multiplied by amount of area to obtain total DUD for a species/habitat in an individual tract (e.g., a field, wildlife management area, floodplain, etc.). This equation assumes that all potential food yield is present and available to waterfowl every year and month during the nonbreeding season. As such, it is overly simplistic and does not represent actual DUD's, only theoretical potential.

As an example, DUD values for mallards in 100 hectares of Dead Timber with:

1. A total of 185 kg/ha food (150 kg/ha seeds, 15 kg/ha tubers, and 30 kg/ha invertebrates from Table 10, excluding aquatic plant biomass assumed not used by mallards).

2. TME's of 2.5 kcal/g for seeds, 4.0 kcal/g for tubers, and 3.5 kcal/g for invertebrates.

3. Mallard DEE of 452.44 kcal/day

would equate to:

$$\frac{\text{100 ha x [seed value (150kg/ha x 2.5 kcal/g TME) + tuber value (15kg/ha x 4.0 kcal/g TME) + invertebrate value (30kg/ha x 3.5 kcal/g TME)]}}{\text{452.44 kcal/day}}$$

or,

$$\frac{\text{100 ha x 540,000 total kcal/ha}}{\text{452.44 kcal/day}} = \text{119,353 DUD's (mallards)}$$

If multiple habitats are involved in an area, then equation #1 becomes:

2)

$$Species_{1 \ldots m} DUD = \sum Habitats_{1 \ldots k} \left(\frac{\sum (F_{1 \ldots j})(T_{1 \ldots l})}{D_{1 \ldots m}} \right)$$

For example consider a site, used by mallards, that has the same 100 ha of Dead Timber described in the example for equation #1, but also with 100 ha of naturally flooded BLH with 50-60% basal area of red oaks, large tree size, and 5% canopy gaps and 100 ha of moderately managed moist-soil impoundments.

This site has the above calculated 54,000,000 kcal from Dead Timber and also:

100,682, 500 kcal from BLH calculated as:

100 ha [acorn value of 325 kg/ha (Table 8) x 2.67 TME + seed value of 21 kg/ha (based on 5% canopy gap) x 2.5 TME +2 kg/ha below-ground food (based on 10% of seed production – see text) x 4.0 TME + 30 kg/ha aquatic invertebrates x 3.5 TME (Table 10)]

and,

235,000,000 kcal from the moist-soil impoundment calculated as:

100 ha [seed value of 750 kg/ha (Table 12) x 2.5 TME + 75 kg/ha below-ground food (based on 10% of seed production (see text) x 4.0 TME + 50 kg/ha aquatic invertebrates x 3.5 TME (Table 10)]

Browse and aquatic plant production in this moist-soil habitat is not included because they are not readily used by mallards (Table 2).

In total, the 300 ha of Dead Timber, naturally flooded BLH, and moist-soil impoundments produced 386,185,000 kcal, which divided by the DEE of 452.44 kcal for mallards = 853,555 mallard DUD's

If a single habitat, but multiple species occur in an area, then the relative proportion (% composition of the waterfowl population) is determined and the predictive equation is:

3)

$$DUD = \sum S_{1\ldots m}\left[\frac{\left[\dfrac{\dfrac{D_{1\ldots m}}{\sum D_{1\ldots m}}\,\%composition\,S_m}{\sum \dfrac{D_{1\ldots m}}{\sum D_{1\ldots m}}\,\%composition\,S_m}\right] F_{jk}}{D_{1\ldots m}}\right]$$

For example, a hypothetical area with a total food yield available to all species of 100,000 kcal and a population comprised of 60% mallards, 15% pintail, 20% wood ducks, and 5% ring-necked ducks would have a kcal allocation of:

Mallard	67,000 kcal
Pintail	14,200 kcal
Wood Duck	14,800 kcal
Ring-necked Duck	3,900 kcal

and, based on their respective DEE's (Table 1), total DUD's by species would be:

Mallard	148.1
Pintail	36.9

Wood Duck	49.4
Ring-necked Duck	12.5
Total DUD	247

Finally, if multiple species and habitats occur in an area, then the predictive equation becomes:

4)

$$DUD = \sum Habitats_{1...k}\left(\sum S_{1...m}\left[\frac{\left[\dfrac{\dfrac{D_{1...m}}{\sum D_{1...m}}\%composition\, S_m}{\sum \dfrac{D_{1...m}}{\sum D_{1...m}}\%composition\, S_m}\right] F_{jk}}{D_{1...m}}\right]\right)$$

OR

$$DUD = \sum Habitats_{1..k}\,(Equation\#3)$$

As stated, the above equations represent potential maximum carrying capacity for areas/habitats by assuming all foods are present and available in all months and years. Clearly, for the reasons expressed in the above discussion of temporal and spatial dynamics and availability factors, the actual carrying capacity of areas/habitats is at some level below the maximum potential. In an attempt to represent "actual" carrying capacity of MAV landscapes, the above equations #1-4 can still be used, but food yield (F_{jk}) is calculated as:

5)

F_{jk} = Total Potential Yield of Food Type$_j$ for a Habitat Type$_k$
x TME (kcal/g) x % Availability (from Table 14)
x Annual Probability of Flooding/Accessibility
x % availability from Hunting/No hunting

For example, 100 ha of naturally flooded BLH habitat with a medium 50-60 basal area of red oak and medium size tree stand producing 300 kg acorns/ha, a TME value of 2.67 kcal/g for acorns, a total winter period, flooded for at least a 3-day duration with a 5-year (20%) flood frequency recurrence interval, and hunted would equate to:

100 ha x [300 kg/ha x 2.67 kcal/g TME x 1 (total winter availability) x 0.2 flood frequency x 1.0 hunting availability]

$$= \frac{16{,}020{,}000 \text{ kcal available}}{452.44 \text{ DEE for mallards}} = 35{,}408 \text{ mallard DUD/yr}$$

In this example, a 1.0 hunting availability value is used because the entire winter period is considered where birds potentially have access to undisturbed habitats and foods during non-hunting periods.

If only the combined months of December and January are used, when hunting occurs and reduces availability, with an average of 85% acorn availability in those months (Table 14), then the equation becomes,

100 ha x [300 kg/ha x 2.67 kcal/g TME x 0.85 (Dec-Jan availability) x 0.2 flood frequency x 0.75 hunting availability]

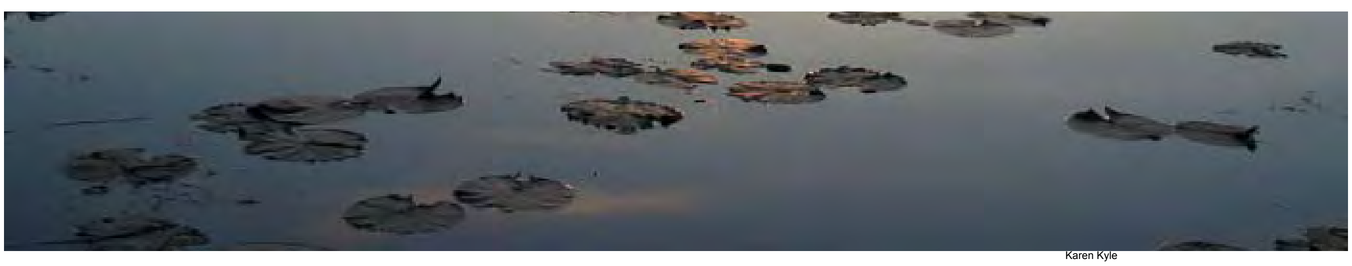
$$= \frac{10{,}212{,}750 \text{ kcal available}}{452.44 \text{ DEE for mallards}} = 22{,}573 \text{ DUD/yr}$$

For comparison, the DUD estimate of potential maximum carrying capacity assuming total production availability regardless of month, would have been:

100 ha x [300 kg/ha x 2.67 kcal/g TME x 1 (total winter availability) x 1 (flood frequency) x 1 (no hunting effects)]

$$= \frac{80{,}100{,}000 \text{ kcal available}}{452.44 \text{ DEE for mallards}} = 177{,}040 \text{ DUD/yr}$$

Clearly, inclusion of some real world estimates of food availability greatly reduces carrying capacity and DUD's in "actual" vs. "potential" scenarios. Presenting estimates in "actual" form using the food availability, Equation #5 will provide the most realistic evaluations of Upper MAV landscapes.



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Now consider a hypothetical "real world" water resources development project, where flood management is proposed for a 1,500 acre project area. The project area has the following attributes:

Flood Frequency During Jan-Mar	Harvested Soybeans	Dead Timber	BLH
1.0	100 ha	200 ha	200 ha
0.5	200 ha	-	100 ha
0.3	600 ha	-	100 ha

The BLH in this site are naturally flooded with 50-60% basal area, large tree size, and 5% canopy gaps. Mallards are the species of interest. For this site:

BLH would have:

- 325 kg/ha acorns (Table 8) x 2.67 kcal/g TME (Table 16) x an average of 70% availability for Jan-Mar (Table 14),
- 21 kg/ha herbaceous seeds (Table 10) x 2.5 kcal/g TME (Table 16) x an average of 40% availability for Jan-Mar (Table 14),
- 2.1 kg/ha below ground tubers, etc. (Table 10) x 4 kcal/g TME (Table 16) x an average of 90% availability for Jan-Mar (Table 14), and
- 40 kg/ha invertebrates (Table 10) x 3.5 kcal/g TME (Table 16) x an average of 70% availability for Jan-Mar (Table 14).

This equates to 645,825 kcal/ha for BLH

Dead Timber would have:

- 150 kg/ha herbaceous seeds (Table 8) x 2.5 kcal/g TME (Table 16) x an average of 40% availability for Jan-Mar (Table 14),
- 20 kg/ha aquatic plant seeds (Table 8) x 2.5 kcal/g TME (Table 16) x an average of 20% availability for Jan-Mar (Table 14),
- 15 kg/ha below ground tubers, etc. (Table 10) x 4 kcal/g TME (Table 16) x an average of 90% availability for Jan-Mar (Table 14), and
- 30 kg/ha invertebrates (Table 10) x 3.5 kcal/g TME (Table 16) x an average of 70% availability for Jan-Mar (Table 14).

This equates to 235,350 kcal/ha for Dead Timber

Soybeans would have:

- 10 kg/ha herbaceous seeds (Table 8) x 2.5 kcal/g TME (Table 16) x an average of 40% availability for Jan-Mar (Table 14),

- 5 kg/ha invertebrates (Table 10) x 3.5 kcal/g TME (Table 16) x an average of 70% availability for Jan-Mar (Table 14), and
- 80 kg/ha unharvested soybeans (Table 10) x 2.65 kcal/g TME (Table 16) x an average of 20% availability for Jan-Mar.

This equates to 64,650 kcal/ha for soybean fields

In the pre-project condition listed above, BLH would provide 180,831,000 kcal, Dead Timber would provide 47,070 kcal, and Soybeans would provide 24,567 kcal. Using the 452.44 DEE for mallards, the site would have a potential for 558,014 mallard DUD's

In the post-project development, this site now has the following attributes:

Flood Frequency During Jan-Mar	Harvested Soybeans	Dead Timber	BLH
1.0	100 ha	200 ha	200 ha
0.2	800 ha	-	200 ha

The food availability for the post-project habitats are the same as in the pre-project scenario, but acres and flood frequency now equate to 483,770 mallard DUD's, or a decrease of 74,244 DUD's. If this loss in DUD's is to be mitigated, then some scenario of increasing acres of other foraging habitats (e.g., moist-soil impoundments, reforestation, etc.) would be needed to avoid a net loss of habitat values for nonbreeding waterfowl in this example.

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FIELD DATA REQUIRED FOR DUD MODEL EQUATIONS

In addition to the DEE and food abundance values summarized in this manual, the above DUD equations require field data on:

1. Number and species of waterfowl present in an area/region
2. Habitat types present, management, and the area of each
3. Composition, stand density, and tree size of forested habitats
4. Annual flood duration and frequency by area and habitat
5. Presence or absence of hunting

The number and species of waterfowl in an area/region usually can be determined from local surveys conducted by state/federal resource agencies. For example, the Missouri Department of Conservation conducts biweekly aerial surveys of key wetland areas in southeast Missouri each fall and winter and information is available at:

www.mdc.mo.gov

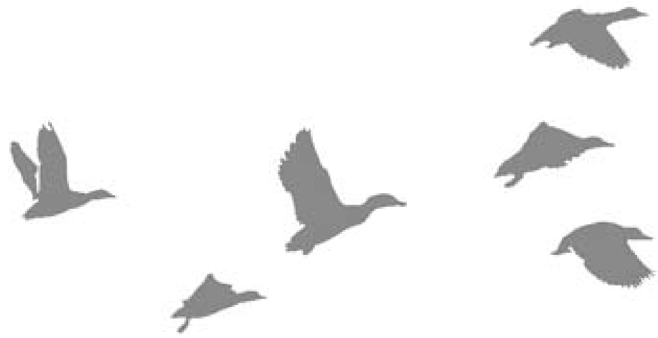
The U.S. Fish and Wildlife Service conducts an annual midwinter inventory of waterfowl throughout the United States each January and this information is available at

http://www.fws.gov/birddata/databases/mwi/mwidb.html

In the absence of more formalized surveys, local information can often be obtained by conducting ground surveys of important areas that represent a site.

Documentation of habitat types and areas usually can be done using various maps and photographs available for a site. In some cases, field reconnaissance may be needed to "ground-truth" interpretations from aerial images and identify specific habitat types. For example, Cypress-Tupelo habitats are commonly imbedded in BLH and may need to be mapped separately. Management of an area (used to distinguish GTRs in BLH habitats and moist-soil impoundments in Seasonal Herbaceous habitats) often can be determined by presence or absence of water-control structures and inquiries to local resource personnel. Documenting tree composition, stand density, and size of red oaks in MAV forests will require sampling that adequately represents the stand. Typically, measures are made on species composition, size (diameter at breast height), density (number of trees by species/ha) and other indicators of water stress, etc. using standard forest mensuration (e.g., Heitmeyer et al. 2004, Avery and Burkhart 2005, Heitmeyer 2008b). Annual flood frequency data and maps often are available for larger river floodplains from USACE District offices. Recurrence intervals of overbank flooding for general geographic areas also can be determined from river gauge data. Additionally, local flooding patterns may be determined in some cases from satellite imagery or other local records.

Documenting whether active hunting occurs in an area can be obtained from local information and certain published or electronically-available data (e.g., Missouri Department of Conservation, www.mdc.mo.gov).



Mickey Heitmeyer

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LITERATURE CITED

Anderson, J.T. and L.M. Smith. 1999. Carrying capacity and diel use of managed playa wetlands by nonbreeding waterbirds. Wildlife Society Bulletin 27:281-291.

Aschoff, J. and H. Pohl. 1970. Der Rueheumasatz von Vogeln als Funktion der Tageszeit und der Korpergrosse. Journal of Ornithology 111:38-47.

Augustin, J.C. and J.W. Grubaugh. Aquatic invertebrates in flooded agricultural and moist-soil habitats: implications for waterfowl management. University of Memphis, unpublished manuscript.

Avery, T.E. and H.E. Burkhart. 2005. Forest measurements, fifth edition. McGraw Hill Co., New York.

Barras, S.C., R.M. Kaminski and L.A. Brennan. 1996. Acorn selection by female wood ducks. Journal of Wildlife Management 60:592-602.

Batema, D.L. 1987. Relations among wetland invertebrate abundance, litter decomposition, and nutrient dynamics in a bottomland hardwood ecosystem. Ph.D. Dissertation, University of Missouri-Columbia.

Batema, D.L., R.M. Kaminski and P.A. Magee. 2005. Wetland invertebrate communities and management of hardwood bottomlands in the Mississippi Alluvial Valley. Pages 297-314 in L.H. Fredrickson, S.L. King and R.M. Kaminski, editors. Ecology and management of bottomland hardwood ecosystems: the state of our understanding. University of Missouri-Columbia, Gaylord Memorial Laboratory, Special Publication No. 10, Puxico, MO.

Belanger, L. and J. Bedard. 1989. Response of staging snow geese to human disturbance. Journal of Wildlife Management 53:713-719.

Bellrose, F.C. 1980. Ducks, geese and swans of North America, second edition. Stackpole Books, Harrisburg, PA.

Bellrose, F.C., T.G. Scott, A.S. Hawkins and J.B. Low. 1961. Sex ratios and age ratios in North American ducks. Illinois Natural History Survey Bulletin 27:391-474.

Bennett, P.M. and P.H. Harvey. 1987. Active and resting metabolism in birds: allometry, phylogeny, and ecology. Journal of Zoology, London 213:327-363.

Bowman, J.L. and M.J. Chamberlain. 2002. Squirrels. Pages 186-190 in J.G. Dickson, Editor. Wildlife of southern forests – habitat and management. Hancock House Publishers, Blaine, WA.

Bowyer, M.W., J.D. Stafford, A.P. Yetter, C.S. Hine, M.M. Horath and S.P. Havera. 2005. Moist-soil plant seed production for waterfowl at Chautauqua National Wildlife Refuge, Illinois. American Midland Naturalist 154:331-341.

Brakhage, G.C. 1966. Management of mast crops for wood ducks. Pages 75-80 in J.B. Trefethen, Editor. Wood duck management and research: a symposium. Wildlife Management Institute, Washington, DC.

Brasher, M.G., J.D. Steckel and R.J. Gates. 2007. Energetic carrying capacity of actively and passively managed wetlands for migrating ducks in Ohio. Journal of Wildlife Management 71: 2532-2541.

Buchsbaum, R., J. Wilson and I.Valiela. 1986. Digestibility of plant constituents by Canada geese and Atlantic brant. Ecology 67:386-393.

Buckley, D.E. 1989. The nutritional quality of selected rowcrop and moist-soil seeds for Canada geese. M.S. Thesis, University of Missouri-Columbia.

Calder, W.A. 1974. Consequences of body size for avian energetic. Pages 86-151 Pages 4-70 in R.A. Paynter, Jr., Editor. Avian energetics. Nuttall Ornithological Club No. 15, Cambridge, MA.

Checkett, J.M., R.D. Drobney, M.J. Petrie and D.A. Graber. 2002. True metabolizable energy of moist-soil seeds. Wildlife Society Bulletin 30:1113-1119.

Christisen, D.M. and L.J. Korschgen. 1955. Acorn yields and wildlife usage in Missouri. Transactions of the North American Wildlife Conference 20:337-357.

Conner, W.H. and J.W. Day, Jr. 1976. Productivity and composition of a baldcypress-water tupelo site and a bottomland hardwood site in a Louisiana swamp. American Journal of Botany 63:1354-1364.

Cox, R.R., Jr. and A.D. Afton. 2000. Predictable interregional movements by female northern pintails. Journal of Field Ornithology 69:276-287.

Cypert, E. and B.S. Webster. 1948. Yield and use by wildlife of acorns of water and willow oaks. Journal of Wildlife Management 12:227-231.

Dalhgren, R.B. and C.E. Korschgen. 1992. Human disturbance of waterfowl: an annotated bibliography. U.S. Department of the Interior, Fish and Wildlife Service Resource Publication 188, Washington, DC.

Daan, S., D. Masman and A. Groenewold. 1990. Avian basal metabolic rates: their association with body composition and energy expenditure in nature. American Journal of Physiology 259: R333-R340.

Daan, S., D. Masman, A. Strijkstra and S. Verhulst. 1989. Intraspecific allometry of basal metabolic rate: relations with body size, temperature, composition, and circadian phase in the Kestrel, Falco tinnunculus. Journal of Biological Rhythms 4:267-283.

Davis, B.E., A.D. Afton and R.R. Cox, Jr. 2009. Habitat use by female mallards in the Lower Mississippi Alluvial Valley. Journal of Wildlife Management 73:701-709.

de Szalay, F.A. and V.H. Resh. 1997. Responses of wetland invertebrates and plants important in waterfowl diets to burning and mowing of emergent vegetation. Wetlands 17:149-156.

Dickson, J.G. 2002. Wild turkey. Pages 108-121 in J.G. Dickson, Editor. Wildlife of southern forests – habitat and management. Hancock House Publishers, Blaine, WA.

Dolbeer, R.A. 1980. Blackbirds and corn in Ohio. U.S. Department of the Interior, Fish and Wildlife Service Resource Publication 136, Washington, DC.

Drent, R. and S. Daan. 1980. The prudent parent: energetic adjustments in avian breeding. Ardea 68:225-252.

Driver, E.A. 1981. Calorific values of pond invertebrates eaten by ducks. Freshwater Biology 11:579-581.

Driver, E.A., L.G. Sugden and R.J. Kovach. 1974. Calorific, chemical and physical values of potential duck foods. Freshwater Biology 14:281-292.

Drobney, R.D. 1980. Reproductive energetic of wood ducks. Auk 97:480-490.

Drobney, R.D. 1990. Nutritional ecology of breeding wood ducks: a synopsis for wetland management. Pages 77-82 in L.H. Fredrickson, G.V. Burger, S.P. Havera, D.A. Graber, R.E. Kirby and T.S. Taylor, editors. Proceedings of the 1988 North American wood duck symposium, St. Louis, MO.

Drobney, R.D. and L.H. Fredrickson. 1979. Food selection by wood ducks in relation to breeding status. Journal of Wildlife Management 43:109-120.

Dugger, B.D. 1990. Survival, habitat use, and movements of female mallards in Arkansas. M.S. Thesis, University of Missouri-Columbia.

Dugger, B.D., K.M. Dugger and L.H. Fredrickson. 1994. Hooded merganser. In A. Poole and F. Gill, Editors. Birds of North America 98. Academy of Natural Sciences of Philadelphia, Philadelphia, PA.

Dugger, K.M. and L.H. Fredrickson. Unpublished ms. Waterbird nutrition and the nutritional values of waterbird foods. University of Missouri-Columbia, Gaylord Memorial Laboratory Wetland Management Series No. 2, Puxico, MO.

Duffy, W.G. and D.J. LaBar. 1994. Aquatic invertebrate production in southeastern USA wetlands during winter and spring. Wetlands 14:88-97.

Flegler, E.S., H.H. Prince and W.C. Johnson. 1987. Effects of grazing by geese on winter wheat. Wildlife Society Bulletin 15:402-405.

Francis, J.K. 1983. Acorn production and tree growth of Nuttall oak in a green-tree reservoir. U.S. Department of Agriculture, Forest Service Southern Forest Experiment Station SO-289.

Fredrickson, L.H. 1979. Lowland hardwood wetlands: current status and habitat values for wildlife. Pages 296-306 in P.E. Greeson, J.R. Clark and J.E. Clark, editors. Wetland functions and values: the state of our understanding. Proceedings of a National Symposium of Wetlands, American Water Resources Association, Minneapolis, MN.

Fredrickson, L.H. 1996. Moist-soil management: 30 years of field experimentation. International Waterfowl Symposium 7:168-177.

Fredrickson, L.H. 2005. Greentree reservoir management: implications of historic practices and contemporary considerations to maintain habitat values. Pages 479-486 in L.H. Fredrickson, S.L. King and R.M. Kaminski, editors. Ecology and management of bottomland hardwood ecosystems: the state of our understanding. University of Missouri-Columbia, Gaylord Memorial Laboratory, Special Publication No. 10, Puxico, MO.

Fredrickson, L.H. and R.D. Drobney. 1979. Habitat utilization by postbreeding waterfowl. Pages 1190130 in T.A. Bookhout, ed. Waterfowl and wetlands – an integrated review. Proceedings of a symposium of the North Central Section of The Wildlife Society, LaCrosse Printing Company, La Crosse, WI.

Fredrickson, L.H. and T.S. Taylor 1982. Management of seasonally flooded impoundments for wildlife. U.S. Department of the Interior, Fish and Wildlife Service Resource Publication 148.

Fredrickson, L.H. and M.E. Heitmeyer. 1988. Waterfowl use of forested wetlands in southern United States: an overview. Pages 307-323 in M.W. Weller, Editor. Waterfowl in winter, University of Minnesota Press, Minneapolis.

Fredrickson, L.H. and F.A. Reid. 1988a. Invertebrate response to wetland management. U.S. Fish and Wildlife Service Leaflet 13.3.1.

Fredrickson, L.H. and F.A. Reid. 1988b. Nutritional values of waterfowl foods. U.S. Fish and Wildlife Service Leaflet 13.1.1.

Fredrickson, L.H. and D.L. Batema. 1992. Greentree reservoir management handbook. Wetland Management Series No. 1, University of Missouri-Columbia, Gaylord Memorial Laboratory, Puxico, MO.

Gabrielsen, G.W., F. Mehlum, H.E. Karlsen, O. Andresen and H. Parker. 1991. Energy cost during incubation and thermoregulation in the female Common eider Somateria mollissima. Norsk Plarinstitutt 195:51-62.

George, J.L., C.E. Braun, R.A. Ryder and E. Decker. 1991. Response of waterbirds to experimental disturbances. Proceedings Issues and Technology in the Management of Impacted Western Wildlife. Thoren Ecological Institute 5:52-59.

Gladden, J.E. and L.A. Smock. 1990. Macroinvertebrate distribution and production on the floodplains of two lowland headwater streams. Freshwater Biology 24:533-545.

Gray, M.J., R.M. Kaminski, G. Weerakkody, B.D. Leopold and K.C. Jensen. 1999. Aquatic invertebrate and plant responses following mechanical manipulations of moist-soil habitat. Wildlife Society Bulletin 27: 770-779.

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

Greer, D.M., B.D. Dugger, K.J. Reinecke and M.J. Petrie. 2009. Depletion of rice as food of waterfowl wintering in the Mississippi Alluvial Valley. Journal of Wildlife Management 73: 1125-1133.

Harper, H.J. and H.A. Daniel. 1934. Chemical composition of aquatic plants. Botanical Gazette 96:186-189.

Harrison, A.J., Jr. and R.H. Chabreck. 1988. Duck food production in openings in forested wetlands. Pages 339-351 in M.W. Weller, Editor. Waterfowl in winter, University of Minnesota Press, Minneapolis.

Haukos, D.A. and L.M. Smith. 1993. Moist-soil management of playa lakes for migrating and wintering ducks. Wildlife Society Bulletin 21: 288-298.

Havera, S.P. 1999. Waterfowl of Illinois: status and management. Illinois Natural History Survey Special Publication 21.

Heitmeyer, M.E. 2008a. An evaluation of ecosystem restoration options for the Middle Mississippi River Regional Corridor. Greenbrier Wetland Services Report 08-02, Blue Heron Conservation Design and Printing, LLC, Bloomfield, MO.

Heitmeyer, M.E. 2008b. Evaluation of baseline forest conditions within the Lower White River Floodplain: initial component of long-term monitoring plan for ivory-billed woodpecker, Grand Prairie Area Demonstration Project. Greenbrier Wetland Services Report 08-04, Blue Heron Conservation Design and Printing, LLC, Bloomfield, MO.

Heitmeyer, M.E. 2006a. The importance of winter floods for mallards in the Mississippi Alluvial Valley. Journal of Wildlife Management 70: 101-110 and 70:894.

Heitmeyer, M.E. 2006b. An evaluation of ecosystem restoration and management options for the Dave Donaldson/Black River Wildlife Management Area, Arkansas. University of Missouri-Columbia, Gaylord Memorial Laboratory Special Publication No. 11, Puxico, MO.

Heitmeyer, M.E. 2002. Waterfowl. Pages 209-223 in J.G. Dickson, Editor. Wildlife of southern forests – habitat and management, Hancock House Publishers, Blaine, WA.

Heitmeyer, M.E. 1989. Agriculture-wildlife enhancement in California: the Central Valley Habitat Joint Venture. Transactions of the North American Wildlife and Natural Resources Conference 54: 391-402.

Heitmeyer, M.E. 1988a. Body composition of female mallards in winter in relation to annual cycle events. Condor 90:669-680.

Heitmeyer, M.E. 1988b. Protein costs of the prebasic molt of female mallards. Condor 90:263-266.

Heitmeyer, M.E. 1985. Wintering strategies of female mallards related to dynamics of lowland hardwood wetlands in the Upper Mississippi Delta. Ph.D. Dissertation, University of Missouri-Columbia.

Heitmeyer, M.E., L.H. Fredrickson and G.F. Krause. 1989. Water and habitat dynamics of the Mingo Swamp in southeastern Missouri. Fish and Wildlife Research No. 6, U.S. Fish and Wildlife Service, Washington, DC.

Heitmeyer, M.E. and L.H. Fredrickson. 1990. Fatty acid composition of wintering female mallards in relation to nutrient use. Journal of Wildlife Management 54:54-61.

Heitmeyer, M.E., L.H. Fredrickson and S.L. King. 2000. An evaluation of ecosystem restoration options for the Grand Prairie region of Arkansas. U.S. Army Corps of Engineers, Memphis District, Memphis, TN.

Heitmeyer, M.E., L.H. Fredrickson, B. Ederington and S.L. King. 2002. An evaluation of ecosystem restoration options for the Bayou Meto Basin, Arkansas. University of Missouri-Columbia, Gaylord Memorial Laboratory Special Publication No. 5, Puxico, MO.

Heitmeyer, M.E., B. Ederington and L.H. Fredrickson. 2004. Bayou Meto Wildlife Management Area - Wetland Management Plan. University of Missouri – Columbia, Gaylord Memorial Laboratory Special Publication No. 7, Puxico, MO.

Heitmeyer, M.E., R.J. Cooper, J.G. Dickson and B.D. Leopold. 2005. Ecological relationships of warmblooded vertebrates in bottomland hardwood ecosystems. Pages 281-306 in L.H. Fredrickson, S.L. King and R.M. Kaminski, editors. Ecology and management of bottomland hardwood ecosystems: the state of our understanding. University of Missouri-Columbia, Gaylord Memorial Laboratory, Special Publication No. 10, Puxico, MO.

Heitmeyer, M.E., F.A. Nelson, and L.H. Fredrickson. 2006. An evaluation of ecosystem restoration and management options for the Duck Creek/Mingo Basin of southeast Missouri. University of Missouri-Columbia, Gaylord Memorial Laboratory Special Publication No. 12, Puxico, MO.

Heitmeyer, M.E. and W. McGeorge. 2009. Waterfowl habitat management at Cornerstone Farms, Jefferson County, Arkansas 2004-2008. Greenbrier Wetland Services Report 09-02, Blue Heron Conservation Design and Printing, LLC, Bloomfield, MO.

Hentges, J.R., Jr. 1983. Nutritional supplements for animals: vascular aquatic plants. In M.Recheigl, Jr., Editor. CRC Handbook of nutritional supplements. Volume II.

Hoffman, R.B. and T.A. Bookhout. 1985. Metabolizable energy of seeds consumed by ducks in Lake Erie marshes. Transactions of the North American Wildlife and Natural Resources Conference 50:557-565.

Hubert, W.A. and J.N. Krull. 1973. Seasonal fluctuations of aquatic macroinvertebrates in Oakwoods Bottoms Greentree Reservoir. American Midland Naturalist 90:351-364.

Jackson, D.C. 2005. Fisheries dynamics in temperate floodplain rivers. Pages 201-224 in L.H. Fredrickson, S.L. King and R.M. Kaminski, editors. Ecology and management of bottomland hardwood ecosystems: the state of our understanding. University of Missouri-Columbia, Gaylord Memorial Laboratory, Special Publication No. 10, Puxico, MO.

Jones, J.C. and J.D. Taylor, III. 2005. Herpetofauna communities in temperate river floodplain ecosystems of the southeastern United States. Pages 235-258 in L.H. Fredrickson, S.L. King and R.M. Kaminski, editors. Ecology and management of bottomland hardwood ecosystems: the state of our understanding. University of Missouri-Columbia, Gaylord Memorial Laboratory, Special Publication No. 10, Puxico, MO.

Jorde, D.G. and R.B. Owen, Jr. 1988. Efficiency of nutrient use by American black ducks wintering in Maine. Journal of Wildlife Management 52:209-214.

Kahl. R.B. 1980. Crop depredation by Canada geese in north-central Missouri. M.S. Thesis, University of Missouri-Columbia.

Kahl, R.B. 1991. Boating disturbance of canvasbacks during migration at Lake Poygan, Wisconsin. Wildlife Society Bulletin 19:242-248.

Kahl, R.B. and F.B. Samson. 1984. Factors affecting yield of winter wheat grazed by geese. Wildlife Society Bulletin 12:256-262.

Kaminski, R.M., J.B. Davis, H.W. Essig, P.D. Gerard and K.J. Reinecke. 2003. True metabolizable energy for wood ducks from acorns compared to other waterfowl foods. Journal of Wildlife Management 67:542-550.

Kaminski, R.M. and H.W. Essig. 1992. True metabolizable energy estimates for wild and game-farm mallards. Journal of Wildlife Management 56:321-324.

Kelley, J.R., Jr. 1986. Management and biomass production of selected moist-soil plants. M.S. Thesis, University of Missouri-Columbia.

Kelley, J.R., Jr. 1990. Biomass production of chufa (*Cyperus esculentus*) in a seasonally flooded wetland. Wetlands 10:61-67.

Kelley, J.R., Jr. and L.H. Fredrickson. 1991. Chufa biology and management. U.S. Fish and Wildlife Service Leaflet 13.4.18.

King, J.R. 1974. Seasonal allocation of time and energy resources in birds. Pages 4-70 in R.A. Paynter, Jr., Editor. Avian energetics. Nuttall Ornithological Club No. 15, Cambridge, MA.

King, S.L., D.J. Twedt and R. Wilson. 2006. The role of the Wetland Reserve Program in conservation efforts in the Mississippi River Valley. Wildlife Society Bulletin 34:914-920.

Klimas, C., E. Murray, T. Foti, J. Pagan, M. Williamson and H. Langston. 2009. An ecosystem restoration model for the Mississippi Alluvial Valley based on geomorphology, soils, and hydrology. Wetlands 29:430-450.

Klimas, C.V., R.D. Smith and J. Raasch. 2005. Hydrogeomorphic classification of forested wetlands in the Lower Mississippi Valley: implications for restoration and management. Pages 77-92 in L.H. Fredrickson, S.L. King and R.M. Kaminski, editors. Ecology and management of bottomland hardwood systems: the state of our understanding. University of Missouri-Columbia, Gaylord Memorial Laboratory Special Publication No. 10, Puxico, MO.

Knauer, D.F. 1977. Moist-soil plant production on Mingo National Wildlife Refuge. M.S. Thesis, University of Missouri-Columbia.

Kross, J. 2006. Conservation of waste rice and estimates of moist-soil seed abundance for wintering waterfowl in the Mississippi Alluvial Valley. M.S. Thesis, Mississippi State University, Starkville, MS.

Kross, J., R.M. Kaminski, K.J. Reinecke, E.J. Penny and A.T. Pearse. 2008a. Moist-soil seed abundance in managed wetlands in the Mississippi Alluvial Valley. Journal of Wildlife Management 72:707-714.

Kross, J., R.M. Kaminski, K.J. Reinecke and A.T. Pearse. 2008b. Conserving waste rice for wintering waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 72:1383-1387.

Krull, J.N. and W.A. Hubert. 1973. Seasonal abundance and diversity of benthos in a Southern Illinois swamp. Natural History Miscellanea No. 190. The Chicago Academy of Sciences, Chicago, IL.

Lasiewski, R.C. and W.R. Dawson. 1967. A reexamination of the relation between standard metabolic rate and body weights in birds. Condor 69:13-23.

Laubhan, M.K. and L.H. Fredrickson. 1992. Estimating seed production of common plants in seasonally flooded wetlands. Journal of Wildlife Management 56: 329-337.

Loesch, C.R., K.J. Reinecke and C.K. Baxter. 1994. Lower Mississippi Valley Joint Venture evaluation plan. North American Waterfowl Management Plan, Vicksburg, MS.

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

Magee, P.A., F.A. Reid and L.H. Fredrickson 1999. Temporarily flooded wetlands of Missouri – Invertebrate ecology and management. Pages 691-710 in D.P. Batzer, R.B. Rader and S.A. Wissinger, editors. Invertebrates in freshwater wetlands of North America: ecology and management. John Wiley and Sons, New York.

Magee, P.A., L.H. Fredrickson and D.D. Humburg. 1993. Aquatic macroinvertebrate association with willow wetlands in northeastern Missouri. Wetlands 13: 304-310.

Manley, S.W., R.M. Kaminski, K.J. Reinecke and P.D. Gerard. 2004. Waterbird foods in winter managed ricefields in Mississippi. Journal of Wildlife Management 68:74-83.

McAbee, W.C. 1994. Waterfowl use and food availability on flooded croplands in northeast Louisiana. M.S. Thesis, Louisiana Tech University

McGinn, L.R. and L.L. Glasgow. 1965. Loss of waterfowl foods in ricefields in southwest Louisiana. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Agencies. 17:69-79.

McNeil, R., P. Drapeau and J.D. Goss-Custard. 1992. The occurrence and adaptive significance of nocturnal habitats in waterfowl. Biological Review 67:381-419.

McKenzie, D.F. 1987. Utilization of rootstocks and browse by waterfowl on moist-soil impoundments in Missouri. M.S. Thesis, University of Missouri-Columbia.

McQuilkin, R.A. and R.A. Musbach. 1977. Pin oak production on green tree reservoirs in southeastern Missouri. Journal of Wildlife Management 41: 218-225.

Merz, R.W. and G.K. Brakhage. 1964. The management of pin oak in a duck shooting area. Journal of Wildlife Management 28:233-239.

Miller, M.R. and J.M. Eadie. 2006. The allometric relationship between resting metabolic rated and body mass in wild waterfowl (Anatidae) and an application to estimation of winter habitat requirements. Condor 108:166-177.

Miller, M.R. and K.J. Reinecke. 1984. Proper expression of metabolizable energy in avian energetic. Condor 86:396-400.

Minckler, L.S. and R.E. McDermott. 1960. Pin oak acorn production and regeneration as affected by stand density, structure, and flooding. Missouri Agricultural Experiment Stations Research Bulletin 750.

Minckler, L.S. and D. Janes. 1965. Pin oak acorn production on normal and flooded areas. University of Missouri Agricultural Experiment Station Research Bulletin 898.

Moser, T.J., S.C. Yaich, G.A. Perkins and R.W. Milligan. 1990. Plant response to moist-soil management in southeastern Arkansas. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Agencies. 44:356-363.

Murkin, H.R. and L.C.M. Ross. 2000. Invertebrates in prairie wetlands. Pages 201-248 in H.R. Murkin, A.G. van der Valk and W.R. Clark, editors, Prairie wetland ecology: the contribution of the Marsh Ecology Research Program. Iowa State University Press, Ames.

Mutzar, A.J., S.J. Slinger and J.H. Burton. 1977. Metabolizable energy content of freshwater plants in chickens and ducks. Poultry Science 56:1893-1899.

Neckles, H.A., H.R. Murkin and J.A. Cooper. 1990. Influences of seasonal flooding on macroinvertebrate abundance in wetland habitats. Freshwater Biology 23:311-322.

Neely, W.W. 1956. How long do duck foods last underwater? Transactions of the North American Wildlife Conference 21:191-198.

Nelms, C.O. and D.J. Twedt. 1996. Seed deterioration in flooded agricultural fields during winter. Wildlife Society Bulletin 24: 85-88.

Owen, R.B., Jr. and K.J. Reinecke. 1979. Bioenergetics of breeding dabbling ducks. Pages 71-93 in T.A. Bookhout, Editor. Waterfowl and wetlands – an integrated review. North Central Section, The Wildlife Society, Madison, WI.

Paulus, S.L. 1988. Time-activity budgets of nonbreeding Anatidae: a review. Pages 135-152 in M.W. Weller, Editor. Waterfowl in winter. University of Minnesota Press, Minneapolis, MN.

Penny, E.J. 2003. Estimating moist-soil plant seed availability in the Mississippi Alluvial Valley. M.S. Thesis, Mississippi State University, Starkville, MS.

Petrie, M.J. 1994. True metabolizable energy of waterfowl foods. M.S. Thesis, University of Missouri-Columbia.

Petrie, M.J., R.D. Drobney and D.A. Graber. 1998. True metabolizable energy estimates of Canada goose foods. Journal of Wildlife Management 62:1147-1152.

Phillips, J.W. 2003. A waterfowl technical appendix for the Bayou Meto Basin, Arkansas, general reevaluation. U.S. Fish and Wildlife Service, Delta Sub office, Conway, AR.

Pienkowski, M.W., P.N. Ferns, N.C. Davidson and D.H. Worrall. 1984. Balancing the budget: measuring the energy intake and requirements of shorebirds in the field. Pages 29-56 in P.R. Evans, J.D. Goss-Custard and W.H. Hale, editors. Coastal waders and wildfowl in winter. Cambridge University Press, Cambridge, UK.

Prince, H.H. 1979. Bioenergetics of postbreeding dabbling ducks. Pages 102-117 in T.A. Bookhout, ed. Waterfowl and wetlands – an integrated review. Proceedings of a symposium of the North Central Section of The Wildlife Society. LaCrosse Printing Company, La Crosse, WI.

Raasch, J.D. 1996. Experimental disturbance of waterbirds on seasonally flooded impoundments in Missouri. M.S. Thesis, University of Missouri-Columbia.

Raftovich, R.V., K.A. Wilkins, K.D. Richkus, S.S. Williams and H.L. Spriggs. 2009. Migratory bird hunting activity and harvest during the 2007 and 2008 hunting seasons. U.S. Fish and Wildlife Service, Laurel, MD.

Reid, F.A. 1983. Aquatic macroinvertebrate response to management of seasonally-flooded wetlands. M.S. Thesis, University of Missouri-Columbia.

Reid, F.A., J.R. Kelley, Jr., T.S. Taylor and L.H. Fredrickson. 1989. Upper Mississippi Valley wetlands – refuges and moist-soil impoundments. Pages 181-202 in L.M Smith, R.L. Pederson and R.M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock, TX.

Reid, V.H. and P.D. Goodrum. 1957. Factors influencing the yield and wildlife use of acorns. Pages 46-63 in Proceedings of the 6th Annual Forestry Symposium, School of Forestry, Louisiana State University, Baton Rouge, LA.

Reinecke, K.J., R.M. Kaminski, D.J. Moorhead, J.D. Hodges and J.R. Nassar. 1989. Mississippi Alluvial Valley. Pages 203-247 in L.M Smith, R.L. Pederson and R.M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock, TX.

Reinecke, K.J., R.C. Barkley and C.K. Baxter. 1988. Potential effects of changing water conditions on mallards wintering in the Mississippi Alluvial Valley. Pages 325-337 in M.W. Weller, ed. Waterfowl in winter. University of Minnesota Press, Minneapolis, MN.

Reinecke, K.J. and C.K. Baxter. 1996. Waterfowl habitat management in the Mississippi Alluvial Valley. Pages 159-167 in J.T. Ratti, ed. Seventh International Waterfowl Symposium, Ducks Unlimited, Inc., Memphis, TN.

Reinecke, K.J. and C.R. Loesch. 1996. Integrating research and management to conserve wildfowl (Anatidae) and wetlands in the Mississippi

Alluvial Valley, USA. Gibier Faune Sauvage, Game and Wildlife 13:927-940.

Reinecke, K.J. and K.M. Hartke. 2005. Estimating moist-soil seeds available to waterfowl with double-sampling for stratification. Journal of Wildlife Management 69:794-799.

Ricklefs, R.E. 1974. Energetics of reproduction in birds. Pages 152-297 in R.A. Paynter, Jr., Editor. Avian energetic. Nuttall Ornithological Club, Cambridge, MA.

Robinson, G.C., S.E. Gurney and L.G. Goldsborough. 2000. Algae in prairie wetlands. Pages 163-200 in H.R. Murkin, A. G. van der Valk and W.R. Clark, editors. Prairie wetland ecology: the contribution of the Marsh Ecology Research Program. Iowa State University Press, Ames, IA.

Rundle, W.D. 1980. Management, habitat selection and feeding ecology of migrant rails and shorebirds. M.S. Thesis, University of Missouri-Columbia.

Salton, N.A. 2001. Arkansas rice production handbook. University of Arkansas Cooperative Extension Service publication MP192-10M, Fayetteville, AR.

Sargent, J.C. 1996. The importance of managed wetlands as fish nursery habitat in the Lower Missouri River floodplain. M.S. Thesis, University of Missouri-Columbia.

Saucier, R.T. 1994. Geomorphology and quaternary geological history of the Lower Mississippi Valley. Volumes I and II. U.S. Army Corps of Engineers, Waterways Experiment Station, U.S. Department of the Army, Vicksburg, MS.

Schmidt-Nielsen, K. 1984. Scaling: why is animal size so important? Cambridge University Press, Cambridge, UK.

Scott, M.L., M.C. Nesheim and R.J. Young. 1969. The nutrition of the chicken. M.L. Scott and Associates, Ithaca, NY.

Shearer, L.A., B.J. Jahn and L. Lenz. 1969. Deterioration of duck foods when flooded. Journal of Wildlife Management 33:1012-1015.

Sherfy, M.H. 1999. Nutritional value and management of waterfowl and shorebird foods in Atlantic Coastal moist-soil impoundments. Ph.D. Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Sibbald, I.R. 1976. A bioassay for true metabolizable energy in feeding stuffs. Poultry Science 55:303-308.

Sklar, F.H. 1985. Seasonality and community structure of the backswamp invertebrates in cypress-tupelo wetland. Wetlands 5:69-86.

Smith, W.L. and T.D. Pitts. 1981. Reelfoot Lake: a summary report. Tennessee Department of Public Health, Division of Water Quality Control, Nashville, TN.

Stafford, J.D., R.M. Kaminski, K.J. Reinecke, M.E. Kurtz and S.W. Manley. 2005. Post-harvest field manipulations to conserve waste rice for waterfowl. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 59:155-163

Stafford, J.D., R.M. Kaminski, K.J. Reinecke and S.W. Manley. 2006. Waste rice for waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 70:61-69.

Stafford, J.D., M.M. Horath, A.P. Yetter, C.S. Hine and S.P. Havera. 2007. Wetland use by mallards during spring and fall in the Illinois and Central Mississippi River Valleys. Waterbirds 30:394-402.

Stewart, E.M. 1983. Distribution and abundance of fishes in natural and modified bottomland hardwood wetlands. M.S. Thesis, University of Missouri-Columbia.

Strader, R.W. and P.H. Stinson. 2005. Moist-soil guidelines for the U.S. Fish and Wildlife Service Southeast Region. Division of Migratory Birds, Southeast Region, U.S. Fish and Wildlife Service, Jackson, MS.

Strong, A.M. 1986. Foraging decisions of captive mallards. M.S. Thesis, University of Missouri-Columbia.

Sugden, L.G. 1971. Metabolizable energy of small grains for mallards. Journal of Wildlife Management 35:781-785.

Sugden, L.G. 1973. Metabolizable energy of wild duck foods. Canadian Wildlife Service Progress Notes 35.

Taylor, T.S. 1978. Spring foods of migratory blue-winged teal on moist-soil impoundments. Journal of Wildlife Management 42:900-903.

Taylor, W.H. 1957. Utilization, preference and nutritional value of winter-green agricultural crops for goose food. M.S. Thesis, Virginia Polytechnic Institute, Blacksburg, VA.

Thompson, J.N. 1980. Treefalls and colonization patterns of temperate forest herbs. American Midland Naturalist 104:176-184.

Tome, M.W. 1989. Food patch depletion by ruddy ducks: foraging by expectation rules. Canadian Journal of Zoology 67:2751-2755.

Uihlein, W.B. 2000. Extent and distribution of waterfowl habitat managed on private lands in the Mississippi Alluvial Valley. Ph.D. Dissertation, Mississippi State University, Starkville, MS.

U.S. Fish and Wildlife Service. 2007. Mingo, Pilot Knob, Ozark Cavefish National Wildlife Refuges, Comprehensive Conservation Plan and

Environmental Assessment. U.S. Fish and Wildlife Service, Region 3, Minneapolis, MN.

U.S. Fish and Wildlife Service. 2009. Adaptive harvest management: 2009 hunting season. U.S. Department of the Interior, Washington, DC.

Warner, R.E., S.P. Havera, L.M. David and R.J. Siemers. 1989. Seasonal abundance of waste corn and soybeans in Illinois. Journal of Wildlife Management 53:142-148.

Webb, E.B., L.M. Smith, M.P. Vrtiska and T.G. LaGrange. 2010. Effects of local and landscape variables on wetland bird habitat use during migration through the Rainwater Basin. Journal of Wildlife Management 74:109-119.

Wehrle, B.W., R.M. Kaminski, B.D. Leopold and W.P. Smith. 1995. Aquatic invertebrate resources in Mississippi forested wetlands during winter. Wildlife Society Bulletin 23:774-783.

Wharton, C.H., W.M. Kitchens and T.W. Sipe. 1982. The ecology of bottomland hardwood swamps of the southeast: a community profile. U.S. Fish and Wildlife Service FWS/OBS-81/37, Washington, DC.

White, D.C. 1982. Leaf decomposition, macroinvertebrate production and wintering ecology of mallards in Missouri lowland hardwood wetlands. M.S. Thesis, University of Missouri-Columbia.

White, D.C. 1985. Lowland hardwood wetland invertebrate community and production in Missouri. Archive fur Hydrobiologia 103:509-533.

Wills, D. 1971. Chufa tuber production and its relationship to waterfowl management on Catahoula Lake, Louisiana. Proceedings of the Annual Conference of the Southeast Association of Game and Fish Commissioners 24:146-153.

Wood, K.G. 1972. Biological productivity of a swamp. Verh International Verein Limnology 18:121-125.

Wylie, G.D. 1985. Limnology of lowland hardwood wetlands in Missouri. Ph.D. Dissertation, University of Missouri-Columbia.

Wylie, G.D. and J.R. Jones. 1986. Limnology of a wetland complex in the Mississippi Alluvial Valley of southeast Missouri. Archive fur Hydrogiologia/ Supplement 74:288-314.

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APPENDIX A

Mathematical conversions used in calculating duck-use-days in the Mississippi Alluvial Valley.

Energy:
1 Kj = 4.185 Kcal

Mass and Area:
1 Kg = 2.2046 lbs
1 ha = 2.471 acres
1 lb/acre = 1.084 Kg/ha
1 Kg/ha = 0.892 lbs/acre

APPENDIX B

Common and scientific names of plant and animal species used in the text.

Waterfowl	
American wigeon	*Anas americana*
Blue-winged teal	*Anas discors*
Canvasback	*Aythya valisineria*
Green-winged teal	*Anas crecca*
Gadwall	*Anas strepera*
Hooded merganser	*Mergus cucullatus*
Lesser scaup	*Aythya affinis*
Lesser snow goose	*Anser caerulescens*
Mallard	*Anas platyrhynchos*
Northern pintail	*Anas acuta*
Northern shoveler	*Anas clypeata*
Redhead	*Aythya americana*
Ross' goose	*Anser rossii*
White-fronted goose	*Anser albifrons*
Giant Canada goose	*Branta canadensis*
maxima	
Interior Canada goose	*Branta Canadensis*
interior	
Bufflehead	*Bucephala albeola*
Trees	
Cherrybark oak	*Quercus pagoda*
Nuttall oak	*Quercus nuttalli*
Overcup oak	*Quercus lyrata*
Pin oak	*Quercus palustris*
Delta post oak	*Quercus stallata*
Southern red oak	*Quercus falcata*
Swamp chestnut oak	*Quercus michauxii*
Water oak	*Quercus nigra*
Willow oak	*Quercus phellos*
Red maple	*Acer rubrum*
drummondi	
Silver maple	*Acer saccharnum*
Hickory	*Carya* spp.
Green ash	*Fraxinus*
pennsylvanica	
Sugarberry	*Celtis laevigata*
Sycamore	*Plantanus occidentalis*
Black willow	*Salix nigra*
Box elder	*Acer nigundo*

American elm	*Ulmus americana*
Cedar elm	*Ulmus crassifolia*
Water tupelo	*Nyssa aquatica*
Baldcypress	*Taxodium distichum*
Cottonwood	*Populus deltoides*
Sweetgum	*Liquidambar*
styraciflua	
Buttonbush	*Cephalanthus*
occidentalis	
Swamp privet	*Foresteria acuminata*
Pecan	*Carya* spp.
Water locust	*Gledistsia aquatica*
Honey locust	*Gledistsia*
triancanthos	
Aquatic, Herbaceous and Emergent Plants	
Pondweed	*Potamogeton* spp.
Rice cutgrass	*Leersia oryzoides*
Panic grass	*Panicum*
dichotomiflorum	
Millet	*Echinochola* spp.
Foxtail bristlegrass	*Seteria italic*
Chufa	*Cyperus esculentus*
Spikerush	*Eleocharis* spp.
Sedge	*Carex* spp.
Common rush	*Juncus effuses*
Curly dock	*Rumex cripus*
Smartweed	*Polygonum* spp.
Tooth-cup	*Ammannia coccinea*
Morning glory	*Ipomoea coccinea*
Watershield	*Brassenia schreberi*
Cattail	*Typha* spp.
River bulrush	*Scirpus fluviatilis*
Water willow	*Dianthera ovata*
Agricultural crops	
Corn	*Zea mays*
Rice	*Oryza sativa*
Milo	*Sorghum* spp.
Soybeans	*Glycine max*
Wheat	*Triticum aestivum*

NOTES:


$Species_{1...m}DUD = \frac{\sum(F_{1...j})(T_{1...t})}{D_{1...m}}$
$Species_{1...m}DUD = \sum Habitats_{1...k}\left(\frac{\sum(F_{1...j})(T_{1...t})}{D_{1...m}}\right)$
$DUD = \sum Habitats_{1...k}(Equation\#3)$