Chapter 4
Management of Wetlands for Wildlife

Matthew J. Gray, Heath M. Hagy, J. Andrew Nyman, and Joshua D. Stafford

Abstract  Wetlands are highly productive ecosystems that provide habitat for a diversity of wildlife species and afford various ecosystem services. Managing wetlands effectively requires an understanding of basic ecosystem processes, animal and plant life history strategies, and principles of wildlife management. Management techniques that are used differ depending on target species, coastal versus interior wetlands, and available infrastructure, resources, and management objectives. Ideally, wetlands are managed as a complex, with many successional stages and hydroperiods represented in close proximity. Managing wetland wildlife typically involves manipulating water levels and vegetation in the wetland, and providing an upland buffer. Commonly, levees and water control structures are used to manipulate wetland hydrology in combination with other management techniques (e.g., disk ing, burning, herbicide application) to create

Disclaimer: The use of trade names or products does not constitute endorsement by the U.S. Government.

M.J. Gray (✉)
Department of Forestry, Wildlife and Fisheries, University of Tennessee,
274 Ellington Plant Sciences Building, Knoxville, TN 37996-4563, USA
e-mail: mgray11@utk.edu

H.M. Hagy
Forbes Biological Station, Illinois Natural History Survey,
20003 CR 1770E, Havana, IL 62644, USA

J.A. Nyman
School of Renewable Natural Resources, Louisiana State University Agricultural Center,
Baton Rouge, LA 70803, USA

J.D. Stafford
U.S. Geological Survey, South Dakota Cooperative Fish and Wildlife Research Unit,
Department of Natural Resource Management, South Dakota State University,
Brookings, SD 57007, USA

desired plant and wildlife responses. In the United States, several conservation programs are available to assist landowners in developing wetland management infrastructure on their property. Managing wetlands to increase habitat quality for wildlife is critical, considering this ecosystem is one of the most imperiled in the world.

4.1 Introduction

Wetland ecosystems represent 4 % of Earth’s surface (Mitsch and Gosselink 2000), yet comprise approximately 45 % of the realized value of natural ecosystems (Costanza et al. 1997). Wetlands provide important functions such as filtering contaminants, removing nutrients and sediment from runoff, contributing to groundwater recharge, storing floodwater, stabilizing shorelines, and providing habitat for numerous fish and wildlife species (Mitsch and Gosselink 2000). Approximately 40 % of the world’s species depend on wetlands and three-quarters of the breeding bird species in North America use wetlands at some point during their life cycle. More than half of federally listed species (e.g., whooping cranes [Grus americana], bog turtles [Glyptemys muhlenbergii]) in the United States (U.S.) are dependent on wetlands. Many species of economic value and recreational interest also depend on wetlands (Mitsch and Gosselink 2000). For example, waterfowl hunting generates an estimated $87 million annually in Mississippi, U.S. (Grado et al. 2011). Over 90 % of shellfish species use coastal wetlands, and estuaries are important nurseries for many pelagic marine species (Mitsch and Gosselink 2000). Because of the numerous ecosystem services and importance to fish and wildlife, wetlands have been argued as one of the most important ecosystems on Earth (Mitsch and Gosselink 2000).

Wetland ecosystems are declining globally. Between 1993 and 2007, the global acreage of wetlands decreased by 6 % (Prigent et al. 2012). In the conterminous U.S., 53 % of wetland acreage has been lost since the early 1900s, with some states (e.g., California, Arkansas, Illinois) experiencing >90 % loss (Mitsch and Gosselink 2000). Continental estimates of degraded wetland acreage do not exist; however, it is reasonable to assume that most remaining wetlands are impacted to some degree by human land use. The reduction in wetland acreage and quality has caused population declines in many wetland-dependent taxa. For example, freshwater turtles and amphibians are the most imperiled vertebrate taxa in the world (Gibbons et al. 2000; Stuart et al. 2004). In this chapter, we outline common management techniques used to produce high quality habitats for various wetland wildlife species, with an emphasis on waterfowl in North America. Many of the techniques we discuss also improve wetland function by facilitating sediment and nutrient deposition, contributing to groundwater recharge, and reducing the likelihood of floods.
4.2 Principles of Wetland Management

Managing wetlands effectively for wildlife requires knowledge of wetland processes, plant and animal life histories, and habitat management techniques. Typically, wetland managers attempt to create water and soil conditions that favor plant communities that help wildlife meet annual life-cycle needs. The plant communities in wetlands exist along a successional gradient, hence management techniques often attempt to affect stages of vegetation succession, also known as seres. Even if plant species composition is ideal, wetlands need to be accessible to wildlife species; thus, managers may flood or perform manipulations that change the vegetative structure to facilitate access during critical time periods (e.g., breeding and migration). Thus, understanding the biological requirements of wetland-dependent species throughout the annual cycle is fundamental to identifying which techniques are most appropriate and when they should be applied. Historically, certain groups of wetland wildlife (e.g., waterfowl) received the majority of attention in wetland management. However, wetland managers in the twenty-first century need to be able to manage multiple wildlife communities simultaneously. That said, wetlands often cannot accommodate the needs of all target species at the same time, and management for some species may reduce habitat quality for others. Wetland managers often target management for priority species or those at greatest risk of loss. Below, we discuss characteristics of wetlands, processes of succession, and the life history needs of major wetland-wildlife communities.

4.2.1 Wetland Characteristics and Succession

The frequency, duration, timing, and depth of flooding can impact the density and richness of plant species that are present in a wetland. Like many ecosystems, wetland plant communities can proceed through vegetative succession in the absence of disturbance (van der Valk 1981). Succession in wetlands is largely mediated by hydrologic stress and disturbance and, in general, proceeds more quickly in temporarily flooded wetlands. In wetlands, early stages of succession are often dominated by grasses and sedges that reproduce annually and yield abundant seed. Later stages of succession are dominated by perennial plants (e.g., swamp smartweed \textit{[Polygonum hydropiperoides]} that predominantly reproduce vegetatively, have lower seed production, and often have allelopathic adaptations that inhibit growth of other plants (van der Valk and Davis 1980). Eventually, tree species that are adapted to wet conditions can establish and the system progress to a forested state. Development of a forested wetland is dependent on the availability of a seed source, water permanency, and climate, which vary annually and among geographic regions. Thus, natural wetland succession is driven by local and regional conditions and random processes (van der Valk 1981). One goal of wetland management is to use water and other stressors (e.g., mechanical disturbance, fire) to affect succession and create a plant community that helps animal species meet their annual life cycle needs.
Fig. 4.1 (a) Hunters in North America take advantage of migratory waterfowl using wetlands, (b, c) the majority of waterfowl production occurs in the north-central United States and Canada, (d) giant Canada geese establish resident populations and migrate only under extreme weather conditions, (e) shorebirds fly >10,000 km during migration, and (f) little is known about the habitat requirements of many waterbirds, including the king rail (Sources: a: Published with kind permission of © Barry Pratt 2013. All Rights Reserved; b: Published with kind permission of © Connie Henderson, Far Side of 50 Blog Spot 2013. All Rights Reserved; c: Published with kind permission of the U.S. Fish and Wildlife Service National Digital Library
4.2.2 Annual Cycle of Wetland Wildlife

A fundamental principle of natural resource management is providing quality habitat throughout the annual cycle for wildlife (Bolen and Robinson 2003). Species that use wetlands may be resident or migratory, thus management may be focused on a portion of or the entire year. To manage wetland wildlife effectively, a basic understanding of the life history and habitat requirements of the target species is required. Below is an overview of the life history and needs of major groups of wetland-dependent wildlife. For additional details, readers are encouraged to review life-history texts, such as Baldassarre and Bolen (2006) for waterfowl, Helmers (1992) for shorebirds, and Vitt and Caldwell (2008) for herpetofauna.

4.2.2.1 Waterfowl

Waterfowl (Anatidae) have complex life histories that evolved in response to seasonally abundant resources. In North America, most waterfowl breed at northern latitudes of the U.S. and throughout Canada, and migrate to the southern U.S., Mexico, and the Caribbean during autumn and winter. There are at least 60 species of waterfowl that commonly breed in North America, although management has focused historically on dabbling ducks (Anatinae, 11 species), because they are abundant and valued for hunting (Fig. 4.1a). Most dabbling ducks in North America migrate north to breeding grounds between February and April, during which time they formalize pair bonds and females build endogenous fat reserves that allow them to lay eggs after arrival. Depending on the species, endogenous reserves of females, and habitat conditions, nesting may be initiated within a week of arriving at a breeding site or occur after several weeks or months of feeding. In some species of ducks, females are philopatric and return to their natal wetland or a previous breeding site where they successfully hatched or fledged young. Nest site selection varies by species, but many dabbling ducks nest in uplands composed of grasses or short woody vegetation up to 2 km from a wetland. Additionally, some duck species nest in natural tree or artificial cavities (e.g., wood duck [Aix sponsa]) or opportunistically in emergent vegetation (e.g., ruddy duck [Oxyura jamaicensis]) or manmade structures over water (e.g., mallard [Anas platyrhynchos]). Egg laying usually occurs over a 7–14 day period, with one egg laid per day; incubation can be an additional 20–30 days (Fig. 4.1b).

Breeding waterfowl usually lead young away from the nest to a wetland within 24 h of hatching. Brood rearing varies interspecifically, but generally lasts...
50–70 days before ducklings reach 90% of adult mass and can fly (Fig. 4.1c). Male dabbling ducks do not participate in brood rearing and typically congregate on larger wetlands where they undergo pre-basic molt (wing and body). The resulting basic plumage is cryptic and aids concealment during the flightless period. Females undergo a partial pre-basic molt (wings only) while raising broods; their pre-basic body molt occurs in mid–late winter (Ringelman 1992), presumably due to fewer physiological demands at this time. Protein-rich aquatic invertebrates are an important diet component of adults during spring and summer when undergoing molt, egg laying, and brood rearing. Ducklings primarily consume proteinaceous aquatic invertebrates during their rapid development.

Most adult and juvenile waterfowl that breed in North America can fly by mid–August. Southward migration extends from August through December depending on species, weather patterns, food availability, and other factors. Blue-winged teal (A. discors) are the earliest fall-migrating species of waterfowl in North America. Mallards and Canada geese (Branta canadensis) tend to be facultative migrants and proceed south when available water freezes or food resources become low in the area they currently reside. The giant Canada goose (B. c. maxima) may overwinter in northern latitudes at sites with open water, and feed through the snow in harvested crop fields (Fig. 4.1d). Diet composition of dabbling ducks changes from primarily invertebrates in spring and summer to carbohydrate-rich seeds and agricultural grains during fall migration and winter (Heitmeyer 1988). In addition to food resources, migrating waterfowl require areas that lack human disturbance and have cover to escape inclement weather.

4.2.2.2 Shorebirds

Shorebirds are a group of avifauna (Order Charadriiformes) that is specialized to exploit seasonal wetlands, shorelines, tidal flats, and other areas of shallow or intermittent surface water (Fig. 4.1e). Shorebirds include many species groups, such as yellowlegs (Tringa spp.), dowitchers (Limnodromus spp.), plovers (Charadriinae), avocets (Recurvirostra spp.), and oystercatchers (Haematopus spp.). Of the 53 species considered under the U.S. Shorebird Conservation Plan, 28 (53%) are considered “highly imperiled” or of “high concern” (Brown et al. 2001). These birds vary considerably in their morphology, with diverse beak and body sizes and shapes that allow them to exploit aquatic invertebrates in a variety of wetland habitats and substrate types. Although life history strategies vary, the majority of shorebirds in the western hemisphere are known for their long-distance migrations (up to 32,000 km roundtrip) between Arctic breeding areas and wintering grounds in Central and South America. Similar to waterfowl, migration is an extremely energetically demanding life cycle event.

Migration chronology varies by species, but typically extends March–June (northward) and July–October (southward) in North America. In the mid-latitudinal U.S., shorebird abundance peaks in September, yet species richness is greater in August (Laux 2008; Wirwa 2009). Studies in Tennessee U.S. documented
greater abundance of long-distance migrants and species of conservation concern using wetlands in July and August compared to later months (Minser et al. 2011). The duration of stopovers at suitable habitats during migration varies by species and environmental conditions but probably is ≤10 days (Lehnen and Krementz 2005). Most shorebirds forage for invertebrates on mudflats or in shallow (<10 cm) water with no or sparse vegetation (Helmers 1992). In general, habitat for shorebirds is considered more limited during summer and fall migration than in spring due to precipitation patterns in temperate regions, which influences habitat availability.

### 4.2.2.3 Other Waterbirds

The “other” waterbirds that use wetlands include seabirds, coastal waterbirds, wading birds, and secretive marsh birds (Fig. 4.1f). For most species of waterbirds, there is little or no information describing habitat needs outside of the breeding season. Some waterbird species are colonial nesters that congregate at breeding sites in numbers ranging from dozens to thousands. Of the colonial nesting species, more than half require islands or isolated breeding habitats. In many cases, waterbirds depend on artificial structures provided by humans such as spoil islands, dikes, bridges, piers, and other created habitat. Secretive marsh birds (e.g., king rail, *Rallus elegans*) prefer dense emergent vegetation for nesting, whereas some species of wading birds (e.g., great blue heron, *Ardea herodias*) may build large nests in rookeries (Fig. 4.2a). Depending on the species, habitat acreage can be as important as vegetation structure or composition. Artificial wetlands such as rice fields, aquaculture ponds, urban parks, municipal treatment wetlands, retention ponds, and reservoirs can provide important resting and foraging habitat for waterbirds during winter and migration.

Waterbird management is complex due to international conservation issues such as wintering and breeding habitats located on different continents and the decline of interior and ocean fish stocks, which are important foods for some species. Furthermore, the feeding habits of waterbirds vary by species and region. Most species depend on marine or estuarine habitats for some time during their annual cycle. Interior species often congregate on aquaculture ponds or in large rookeries. Both of these activities have great potential to conflict with human uses, and may result in vegetative or structural damage, loss of economic resources, and legal or illegal culling. In general, wetland management for waterbirds focuses on providing suitable nesting habitat and available food resources. Management of amphibians is one technique that can be used to provide foraging areas for interior waterbirds. For seabirds, setting fishing gear at night and using gear that prevents bycatch are effective conservation strategies (Løkkeborg 2011; Croxall et al. 2012). Future research needs include precise estimates of population size for waterbird species, identifying factors affecting recruitment and survival, and understanding habitat requirements during migration.
Fig. 4.2 (a) Many wading bird species nest in trees in large colonies called rookeries, (b) it is estimated that >40% of salamander species are declining, (c) tiger salamander larvae can be voracious predators, (d) semi-aquatic turtle species need basking logs, and (e) various mammalian species can be found in wetlands, including coyotes (Sources: a: Published with kind permission of © Clayton Ferrell, U.S. Fish and Wildlife Service, New Johnsonville, Tennessee, USA 2013. All Rights Reserved; b, c: Photos by Matt Gray; d: Published with kind permission of © Sean C. Sterrett, University of Georgia, Athens, Georgia, USA. All Rights Reserved; e: Published with kind permission of © Joseph W. Hinton, University of Georgia, Athens, Georgia, USA 2013. All Rights Reserved)
4.2.2.4 Amphibians

Amphibians are one of the most imperiled vertebrate classes in the world, with one in three amphibian species in threat of extinction (Stuart et al. 2004). Thus, incorporating the needs of amphibians into at least a portion of wetland management plans is important. As with other wildlife, managing for amphibian populations requires knowledge of species life history. Amphibian breeding and developmental strategies are diverse (Wells 2007). In temperate regions, most amphibian species have a complex life cycle where larvae develop in water, individuals metamorphose, and juveniles and adults live in the terrestrial environment (Wilbur 1984). Thus, managing for amphibians requires suitable habitat in aquatic and terrestrial environments.

Most amphibians breed from March through July in temperate regions of the northern hemisphere, and larval development takes approximately 2 months (Wells 2007). Wetlands with permanent water often do not contain as diverse assemblages of amphibians as ephemerally-flooded ponds, because density of aquatic predators tends to be greater in the former. Fish and various species of aquatic insects are voracious predators on amphibian larvae (Wells 2007). Additionally, permanent wetlands attract amphibian species with larvae that overwinter (e.g., American bullfrog [Lithobates catesbeianus]) or opportunistically develop into aquatic adults (e.g., tiger salamander, [Ambystoma tigrinum]), which depredate eggs and larvae of other amphibian species (Fig. 4.2b, c).

Amphibian larvae can be negatively impacted by poor water quality (Wells 2007). In particular, excessive nitrogenous waste or fertilizers can decrease survival and growth or increase malformations and susceptibility to pathogens. Controlled studies suggest that >0.5, >2, and >30 mg/L of ammonia, nitrite, and nitrate, respectively, can negatively affect amphibian larvae (Jofre and Karasov 1999; Rouse et al. 1999). Low oxygen levels (<1 and <5 mg/L in lentic and lotic systems, respectively) can stress amphibian larvae. Various pesticides also are known to negatively affect amphibian larvae survival (Jones et al. 2009; Relyea and Jones 2009).

The majority of juvenile and adult amphibians in temperate regions use terrestrial habitat within 300 m of a wetland (Semlitsch and Bodie 2003). Terrestrial habitat is important for foraging, hibernation, estivation, and dispersal (Wells 2007). Most amphibians have thin, permeable skin that is prone to desiccation; thus, maintaining natural vegetation around wetlands is important. Unnatural edges (including roads) are known to deflect amphibian movements (Gibbs 1998). Silvicultural practices can negatively affect amphibians (Harpole and Haas 1999). For example, it may take >20 years before salamanders colonize an area that was clear-cut previously (Petranka et al. 1993; Homyack and Haas 2009). There are mixed results from studies investigating the effects of prescribed fire on amphibians (e.g., Ford et al. 2010; Matthews et al. 2010; Perry et al. 2012).

4.2.2.5 Reptiles

Reptiles that commonly use wetlands include aquatic turtles and snakes. The life history of many aquatic turtle species is opposite of amphibians in that they lay
nests in the terrestrial environment and spend much of their adult life in aquatic environment. Aquatic turtles (e.g., snapping turtle \(Chelydra serpentina\), soft-shell turtle \(Apalone ferox\)) depend on permanently flooded wetlands. Semi-aquatic turtles (e.g., painted turtle \(Chrysemys picta\), mud turtle \(Kinosternon subrubrum\)) prefer semi-permanent and permanent wetlands. These turtles forage in the water but spend significant amounts of time basking outside of the water (Fig. 4.2d). Most aquatic turtles in temperate regions of the northern hemisphere nest in grasslands between May and July within 200 m of wetlands (Nelms et al. 2012). Management for snakes typically involves providing foraging sites and hibernacula. Wetlands are natural foraging grounds for snakes, especially if amphibians and juvenile birds are present.

4.2.2.6 Mammals

Several mammalian species depend on wetlands during some part of the annual cycle or their lifetime, such as beaver \((Castor canadensis)\), muskrat \((Ondatra zibethicus)\), mink \((Neovison vision)\), nutria \((Myocastor coypus)\), river otter \((Lutra canadensis)\), and coyote \((Canis latrans)\) (Fig. 4.2e). Beaver create open water and forested wetlands by impounding streams, ditches, and other waterways with woody debris and mud. Beaver-created wetlands increase species richness and habitat heterogeneity in stream and riparian ecosystems important to fish, water-birds, amphibians, reptiles, and other mammals. Muskrats are also important environmental engineers, consuming various species of herbaceous plants and tubers, which affects succession and other wetland processes. Mink and river otters occur throughout streams and rivers of North America and consume crayfish, fish, amphibians, small mammals, insects, and a variety of other aquatic and terrestrial prey. Nutria are nonnative in North America and considered a nuisance species in coastal marshes in the southeastern U.S. Nutria forage on a wide variety of wetland vegetation and burrow extensively, which can degrade wetlands and cause levee breaks in managed impoundments.

Additional mammals such as black bear \((Ursus americanus)\), moose \((Alces alces)\), white-tailed deer \((Odocoileus virginianus)\), red wolves \((Canis rufus)\), and rabbits depend on wetlands. Black bears consume fish and vegetation found in and surrounding wetlands, and frequently select winter den sites in forested wetlands. In the northern U.S. and Canada, moose consume submerged aquatic vegetation, wade in wetlands to escape biting insects, and use scrub-shrub wetlands (i.e., stands of aspen \([Populus\) spp.] and willow \([Salix\) spp.] saplings near water) or emergent marshes. White-tailed deer consume wetland vegetation, use seasonal wetlands for cover, and depend on hardwood mast in many floodplain wetlands. Red wolves (once extirpated from the wild) use wetlands as foraging sites along the Atlantic Coast of North Carolina, U.S. Several species of shrews, moles, lemmings, mice, and rats use riparian areas and forested wetlands, and depend on wetland-associated...
amphibians and invertebrates for food. Swamp rabbits (Sylvilagus aquaticus) and marsh rabbits (S. palustris) depend on floodplain wetlands and coastal marshes in the southeastern U.S. Additionally, many other mammals depend directly or indirectly on wetlands for food or cover (Dickson 2001).

4.3 Wetland Management Techniques

Wetland management is the manipulation of ecosystem processes using prescribed techniques to create high quality habitat for target wildlife. Many techniques that are used to manage upland wildlife are used in wetlands, such as disking, burning, herbicide application, and providing food plots. Additionally, levees and water control structures can be used to manage hydrology, which is a primary driver of wetland characteristics. Although the cost of infrastructure development and maintenance is substantial, having the capability to drawdown or flood a wetland on a prescribed schedule is valuable if the goal is to maximize wildlife use. In coastal wetlands, tides and water salinity affect plant and wildlife responses, and are managed frequently. Some management (e.g., disking) and restoration (e.g., levee construction to restore hydrology) techniques are regulated if they occur within jurisdictional wetlands of the U.S., thus a federal or state permit may be acquired. In this section, we discuss federal wetland regulations in the U.S., and common approaches to managing interior and coastal wetlands.

4.3.1 Regulations and Permits

Wetlands continue to be lost throughout the world. Agriculture and urban development are the most significant threats to wetland loss, but conversion of shallow to deep water wetlands is a growing concern (Fig. 4.3a). In the U.S., wetlands in agricultural lands currently receive potential protection from the “swampbuster” provision of the federal Farm Bill, which withholds agricultural subsidy payments from farmers who drain, dredge, fill, or significantly alter wetlands with the intent of farming. The U.S. Department of Agriculture (USDA) Farm Service Agency, USDA Natural Resources Conservation Service (NRCS), and the U.S. Fish and Wildlife Service (USFWS) administer the swampbuster provision of the Farm Bill, which is reauthorized every 5 years. Because swampbuster is an incentive linked to subsidy payments, farmers that do not comply with it do not face criminal charges.

The other major federal wetland protection legislation in the U.S. is Section 404 of the Clean Water Act. This Act requires individuals, businesses, and organizations to obtain a permit before discharging dredged or fill material into navigable waters of the U.S. Navigable waters include major water courses (e.g., Mississippi River),
and all tributaries and associated wetlands that have a significant biological nexus with the primary water course (Leibowitz et al. 2008). Thus, under federal law, geographically isolated wetlands (e.g., prairie potholes, playa wetlands) are not protected currently. If wetland management involves soil disturbance (e.g., disking, levee construction) in a federally jurisdictional wetland, a permit is required. Fortunately,
wetland management and restoration activities are considered beneficial and included under “nationwide” permits, which are issued using a rapid and streamlined process. Most natural resource agencies have standing nationwide permits for ongoing management and conservation projects. The U.S. Army Corps of Engineers is responsible for enforcing the Clean Water Act and issuing Section 404 permits.

In Canada, as few as one-third of wetlands are protected by regulations (Rubec and Lynch-Stewart 1998), and regulations vary by province (Rubec and Hanson 2008). There is no single wetland protection program in Canada and many loopholes exist that allow drainage of wetlands on private lands (Stover 2008). In some areas, the Tile Drainage Act still subsidizes wetland drainage (Schulte-Hostedde et al. 2007). Internationally, the most important wetland protection measure is the Convention on Wetlands of International Importance, a treaty signed by approximately 160 nations in Ramsar, Iran in 1971. The Ramsar Convention designated and pledged protection of nearly 200 wetland complexes of international importance, but relies on individual countries to protect these sites.

4.3.2 Interior Wetlands

Interior wetlands comprise the majority of wetland acreage in North America, and include depressional and riverine wetlands that contain a variety of herbaceous and woody plant species associated with geographic region and site conditions. The most common wetland type in the conterminous U.S. is forested wetlands associated with rivers (Mitsch and Gosselink 2000), which are often called hardwood bottomlands. This wetland type provides habitats for a host of herpetofaunal, avian, and mammalian species, and can be managed using various silvicultural practices and flooding strategies. In southern Canada and the north-central U.S., millions of depressional wetlands, called prairie potholes, exist and contribute significantly to continental biodiversity. Wetlands with herbaceous vegetation that are semi-permanently or permanently flooded are often referred to as “emergent wetlands” whereas temporarily and seasonally flooded wetlands dominated by herbaceous vegetation are called “moist-soil wetlands”. Management typically involves a combination of strategic flooding and water drawdowns, mechanical manipulations (e.g., disking), and herbicide applications to create a target plant community. When hardwood bottomlands, moist-soil wetlands and emergent marshes are managed together as a wetland complex, they can provide habitat for a wide variety of avifauna, herpetofauna and mammals. Wetland managers also use food plots to provide additional high-energy food resources for wildlife. Ideally, wetland managers provide a combination of wetland and upland habitat types along with areas of minimal human disturbance (i.e., refuge) to meet the annual life-cycle needs for the greatest number of wetland-dependent species. In this section, we will discuss common techniques used to manage interior wetlands.
4.3.2.1 Prairie Wetland Management

Wetlands of the glaciated Prairies and Parklands of North America provide habitats for various species of wildlife and constitute an incredibly diverse, productive ecosystem (Fig. 4.3b). Because much of this region lies in the rain shadow of the Rocky Mountains, precipitation can vary considerably from year to year and is generally low (25–56 cm/year) compared to other regions in North America (Leitch 1989). Not surprisingly, precipitation and the subsequent effects on hydrology are the primary natural factors that influence the ecology of prairie wetlands. Wet-dry cycles result in transitions between annual and perennial plant communities. During successive years of above average precipitation, coverage of emergent vegetation in prairie wetlands decreases resulting in the appearance of a “lake-marsh” stage. During normal or below average precipitation, prairie wetlands often dry which accelerates decomposition and nutrient cycling, promotes seed germination, and increases coverage of herbaceous plants (van der Valk and Davis 1978; Murkin et al. 2000). The natural variability in prairie-wetland hydrology drives plant diversity and productivity, which influences wildlife use in this region. Shifts in precipitation patterns associated with global climate change are predicted to negatively impact some wildlife populations that use prairie wetlands (Johnson et al. 2005).

Because hydrology, driven by variability in weather patterns, shapes prairie wetland ecology, management of northern prairie wetlands typically mimics stages of this wet-dry cycle (Murkin et al. 2000). Prairie wetland managers often attempt to create an equal interspersion of open water and emergent vegetation (e.g., 50:50 ratio) called hemi-marsh conditions. Hemi-marsh conditions have been associated with high avian use and diversity as well as invertebrate abundance and diversity (Weller and Spatcher 1965; Kaminski and Prince 1981; Murkin et al. 1982). When managers are able to control wetland hydrology, northern prairie wetlands may be periodically (e.g., every 4–6 years) dewatered in May to reduce emergent monocultures of persistent emergent species, such as cattail (Typha spp.) and phragmites (Phragmites australis) (Merendino et al. 1990). Prolonged and deep flooding may also kill perennial emergent vegetation, and create the lake-marsh stage. Drawdowns allow annual plants to colonize mudflats, which produce abundant seed and tubers that are consumed by waterfowl when reflooded. When possible, managing several wetlands in close geographical proximity that are in different successional stages is ideal.

Where water control is unavailable, managers may use grazing, mowing, burning, or herbicide treatment to create openings in wetlands with dense stands of vegetation. The success of these techniques vary depending on timing, intensity, and geography (Linz et al. 1996; Hagy and Kaminski 2012b). If reducing vegetation cover is the primary goal, these techniques are typically more effective when flooding occurs subsequently over the plant stubble during the growing season.

Management of northern prairie wetlands can provide considerable resources for resident and migratory wildlife; however, habitat quality also depends on the composition of the adjacent uplands. Because many species of wetland wildlife
rely on uplands for breeding, foraging, or thermal cover, wetland buffers and adjacent uplands also should be managed. Maintenance of dense plant cover composed of native cool- and warm-season grasses within 2 km of a prairie wetland can have positive impacts on nesting waterfowl and songbirds (Higgins and Barker 1982; Chouinard 1999; Arnold et al. 2007). Although provision of quality upland nesting and wetland brood-rearing habitats promotes high survival and reproduction for waterfowl, the most common cause of nest failure is destruction by mammalian predators (Pieron and Rohwer 2010). In certain situations, managers can actively remove nest predators through trapping or shooting, resulting in increased nesting success (Duebbert and Lokemoen 1980; Garrettson and Rohwer 2001; Pieron and Rohwer 2010). However, trapping must be conducted annually, and the largest areas effectively trapped have been relatively small (e.g., 95 km$^2$).

Wetland managers also can use techniques to exclude predators from nests. The two most common predator-exclusion techniques are the provision of elevated nesting structures and the deployment of electrified fencing around upland nesting cover. Only a few species of waterfowl readily use overwater nesting structures, most notably mallards (e.g., Doty et al. 1975; Stafford et al. 2002) and Canada geese (e.g., Ball and Ball 1991; Higgins et al. 1986). Mammenga et al. (2007) summarized the results of several studies of mallards using overwater structures and reported that observed nest success was often $>70\%$. Overwater structures include round hay bales, upended culverts, horizontal cylinders stuffed with flax straw (i.e., “hen houses”), and many other platforms erected within wetlands (Haworth and Higgins 1993; Johnson et al. 1994; Stafford et al. 2002; Chouinard et al. 2005). Structures must be maintained annually by cleaning old nest materials, replacing surrounding cover, repairing mounting poles or structures damaged by ice, and removing or relocating structures that are not used or appear to attract predators (Stafford et al. 2002). Despite the successes of trapping predators and using overwater structures, conservation of large expanses of grasslands around wetland complexes has been described as the best approach to maximize the likelihood of nest survival (Stephens et al. 2005).

### 4.3.2.2 Moist-Soil Management

Dr. Frank Bellrose of the Illinois Natural History Survey coined the phrase “moist-soil” to describe plants that grew on mudflats of seasonal wetlands along the Illinois River (Bellrose and Anderson 1943). This definition has been expanded to describe plant communities, wetland types, and management strategies in seasonally and temporarily flooded wetlands that contain annual and perennial grasses, sedges, and forbs (Fredrickson and Taylor 1982). Moist-soil plants thrive after a slow natural or managed drawdown of surface water exposes mudflats with rich seed banks. Management of moist-soil wetlands has become a common technique used by waterfowl biologists and conservation planners to help meet carrying capacity goals for waterfowl in North America (CWS 1986; Loesch et al. 1994). For example, in recent years, moist-soil management has been recommended to
compensate for decreased seed abundance in harvested agricultural fields (Fredrickson and Taylor 1982; Kross et al. 2008; Foster et al. 2010a; Schummer et al. 2012). Dr. Leigh Fredrickson (University of Missouri, retired) pioneered the use of wildlife management techniques in moist-soil wetlands for waterfowl and other wetland wildlife (Fredrickson and Taylor 1982). Since Dr. Fredrickson’s first manual (Fredrickson and Taylor 1982), a number of moist-soil management guides have been produced (e.g., Nassar et al. 1993; Strader and Stinson 2005; Nelms 2007; Strickland et al. 2009).

Moist-soil management can be a cost-effective habitat management strategy and implemented on idle croplands, aquaculture ponds, field margins, active crop fields after harvest, and public or private wildlife management areas to increase habitat and food for wildlife (Cross and Vohs 1988; Schultz et al. 1995; Marquez et al. 1999; Lyons et al. 2000; Dosskey 2001). Important foods for waterfowl and shorebirds in flooded moist-soil wetlands include seeds, tubers, and aquatic invertebrates. Wading birds may take advantage of amphibian larvae or small fish that may be present in moist-soil wetlands. Moist-soil wetlands also provide important ecosystem services such as improving water quality (Tockner and Stanford 2002; Vymazal 2007; Kröger et al. 2007, 2008; Manley et al. 2009; Jenkins et al. 2010). Moist-soil management techniques vary regionally due to hydrology regimes, soil types, cultural practices, and infrastructure. In North America, moist-soil management is most common in the Central Valley of California, Playa Lakes Region, Rainwater Basin of Nebraska, and the southeastern and midwestern U.S.

Moist-soil wetlands may be actively or passively managed, depending on management objectives and available resources. For moist-soil wetlands that are managed for waterfowl, a primary goal is to maintain early successional plant communities, because production of seeds and tubers by annual plants is greater than perennial plants (Gray et al. 1999a). In some regions of the U.S., unmanaged moist-soil wetlands will be rapidly colonized by woody vegetation (e.g., willows, ash [Fraxinus spp.], buttonbush [Cephalanthus occidentalis], maple [Acer spp.]), and progress toward a scrub-shrub or forested wetland. Moist-soil management often involves a combination of hydrology and soil or vegetation manipulations at prescribed intervals (Gray et al. 1999a). The timing and frequency of management activities determines whether moist-soil wetlands are actively or passively managed (Brasher et al. 2007; Fleming 2010; Evans-Peters et al. 2012).

Actively managed moist-soil wetlands are typically dominated by annual plants and maintained in early successional stages (Fig. 4.3c, Kross et al. 2008). Managers often disk, till, mow, or apply herbicides to reduce woody vegetation and perennial plants. Spring or early summer disking is the most common mechanical manipulation practice used to set back succession and produce annual plants (Fig. 4.3d). Manipulation frequency may vary depending on the plant communities present in wetlands, but typically occurs in at least 3-year intervals. For wetlands with herbaceous plants, 2–3 passes with an offset disk usually is sufficient to scarify soil (i.e., till) and set back succession. If woody plants become established, deep and repeated disking for several growing seasons or a combination of mowing and
disking may be necessary to restore annual plant communities (Strickland et al. 2009). Herbicides (e.g., imazapyr; glyphosate; 2,4–D) also can be used to control woody vegetation, but it may have residual effects on desirable vegetation. Maintaining early successional plant communities has been found to be more cost-effective than restoring late successional moist-soil wetlands to an early state (Strickland et al. 2009).

Fall manipulations of moist-soil wetlands can be used to increase food availability, create hunting areas, and set back succession. In southern latitudes of North America, dense stands of moist-soil plants can establish by the end of the growing season and prevent waterfowl from landing and acquiring food resources. Breeding and migrating waterfowl prefer wetlands with hemi-marsh arrangement of emergent vegetation and open water (Kaminski and Prince 1981; Smith et al. 2004; Moon and Haukos 2009). Dense stands of moist-soil vegetation can be partially mowed in autumn if vegetation is in early successional stages to create openings following flooding, thereby increasing access to food resources (Fig. 4.3e). If perennial herbaceous or woody vegetation is dominant, fall diskling can restore early successional plant communities in subsequent growing seasons (Gray et al. 1999a), but it may result in reduction of waterfowl foods during the winter immediately following the manipulation (Hagy and Kaminski 2012b). Thus, fall diskling should be used to set back succession only if a site is inaccessible earlier in the growing season, such as providing habitat for breeding waterfowl or amphibians. It is legal to hunt migratory waterfowl in moist-soil wetlands that are mechanically manipulated during fall and subsequently flooded as long as agricultural food plots (discussed later) are not manipulated.

Passive moist-soil management includes water drawdowns in mid or late summer with longer intervals (≥5 years) between soil manipulations (Fig. 4.3f). Passively managed wetlands may resemble emergent marshes and contain diverse plant assemblages representative of multiple vegetation seres. Typically, the goal of passive management is to provide habitat diversity for a variety of wetland-dependent wildlife, or may be a consequence of insufficient resources to perform active management. Although seed and tuber production for waterbirds is less in passively than in actively managed moist-soil wetlands, passively-managed wetlands often contain many obligate wetland plant species, increased vertical strata from young trees and shrubs, and grasses and sedges important to a wide variety of wildlife (Pankau 2008; Fleming 2010).

Whether actively or passively managed, manipulating hydrology in moist-soil wetlands is a common technique used to affect plant responses and manage succession. Managing water levels in wetlands is most easily achieved using levees that contain water control structures. Common water control structures include screw and flap gates and drop-board risers (Fig. 4.4a–c). Drop-board risers are often preferred because water levels can be micromanaged with boards of varying widths. Ideally, water is flowed into impoundments from a higher elevation via gravity. Gas and electric pumps can be used to move water against gravity and hydrologic gradients; however, costs can be significant.
Moist-soil impoundments are usually flooded through winter to provide habitat for migrating and wintering waterfowl. Timing of drawdowns is typically planned considering the existing plant community and life cycle needs of target wildlife.

Fig. 4.4 (a) Drop-board, (b) screw gate, and (c) flap gate water control structures, (d) exposed mudflats are excellent foraging locations for shorebirds, (e) seeds on mudflats germinate and develop into moist-soil plants, (f) waterfowl can acquire high-energy seed and proteinaceous aquatic invertebrates in flooded moist-soil wetlands, and (g) herbicide can be used to control invasive plants (Sources: a, b, c, d, e: Photos by Matt Gray; f: Photo by Joshua Stafford; g: Photo by Heath Hagy)

Moist-soil impoundments are usually flooded through winter to provide habitat for migrating and wintering waterfowl. Timing of drawdowns is typically planned considering the existing plant community and life cycle needs of target wildlife.
species (Fig. 4.4d, e). If wetlands are in late succession, managers may want to drain impoundments in early spring (March–May) to allow sufficient time for drying (usually 1 month) prior to disking (Fredrickson and Taylor 1982). Early drawdowns also will provide shallow-water habitat and mudflats for spring migrating waterfowl or shorebirds, but may have negative effects on resident wildlife seeking breeding habitats. If wetlands are in mid or early succession, drawdowns can be delayed until mid (June–July) or late summer (August–September), which can provide habitat for breeding amphibians, invertebrates, and waterfowl (e.g., wood duck). Drawdowns in late summer (August–September) will provide exposed mudflats for fall migratory shorebirds. In general, a minimum of 60 days is needed for moist-soil plants to reach maturity and produce seed; hence, drawdowns are typically completed by mid-September in the mid-latitudeal U.S. (e.g., Tennessee) to ensure enough time for plant growth and reproduction before frost. On management areas with >1 impoundment, staggering drawdowns from March–May and July–August will promote a diversity of habitat conditions for resident and migratory species. Drawdowns performed over 2–4 weeks increase the duration that seed and aquatic invertebrates are available for wetland wildlife, provide resident wildlife sufficient time to disperse, and will result in greater plant diversity for waterfowl (Fredrickson and Taylor 1982). In general, fast drawdowns (2–3 days) should be avoided unless management infrastructure is compromised (e.g., levee breach) or a slow drawdown is not feasible.

For moist-soil impoundments that are dewatered in early summer, flooding can begin in September to accommodate early migratory waterfowl (Fig. 4.4f). However, delaying flooding of the majority of impoundments until waterfowl abundance increases usually benefits the largest number of waterfowl species (Fredrickson and Taylor 1982). Managers of multiple impoundments (e.g., wetland complexes) also might consider permanently flooding one impoundment >90 cm to provide foraging habitat for diving ducks and roosting habitat for dabbling ducks and geese. Permanently flooded impoundments can be drained and rotated with a different impoundment every 5–7 years to allow decomposition of accumulated organic matter, removal of fish and other aquatic predators, and reestablishment of desirable early successional vegetation.

Similar to water drawdowns, flooding also can be used to control certain undesirable plants. For example, deep flooding with a late drawdown or over multiple years has been used to control reed canary grass (Phalaris arundinacea), willows, and other invasive species (Ball et al. 1989). A combination of mowing undesirable plants (e.g., cocklebur [Xanthium spp.], coffeeweed [Sesbania herbaceae]) followed by flooding over the stubble can be effective at preventing re-growth. Dynamic changes in flooding and drawdown may be an especially valuable management technique if herbicides and mechanical manipulations are not feasible.

Herbicide applications are another technique that can be used to control undesirable plants (e.g., red vine [Brunichia ovata], alligatorweed [Alternanthera philoxeroides]), especially when disking could segment and spread rhizomes, thereby increasing coverage. Many broadleaf plants are undesirable in moist-soil
wetlands because they shade and outcompete more desirable seed-producing grasses and sedges (Hagy and Kaminski 2012a, b). Broadleaf herbaceous plants can be killed with 2, 4-D herbicide without affecting most grasses and sedges (Strickland et al. 2009). Trees and shrubs can also be spot-sprayed using a foliar application or hack-and-squirt technique if stem diameters are large. The appropriate herbicide selection depends on the woody species and surrounding vegetation, but several formulations containing imazapyr or picloram are commonly used for woody vegetation (Strickland et al. 2009).

Herbicides may be applied using a variety of techniques ranging from aircraft to hand sprayers. For spot spraying small plots, areas difficult to access, or unevenly distributed plant groupings, a hand or backpack sprayer works well. For moderately sized areas (e.g., 0.5–4 ha), an ATV–mounted sprayer system with a boom is efficient (Fig. 4.4g). For large areas (e.g., >4 ha), a tractor-mounted spray system or aerial applications may be most efficient (Strickland et al. 2009). Regardless of the technique used, it is important that application equipment be calibrated correctly to deposit the appropriate label rate of herbicide with sufficient water coverage. Failing to calibrate equipment or apply the recommended solution per acreage could limit effectiveness of application, waste chemical and resources, or increase residual chemical in soil that hinders subsequent desirable plant response (Strickland et al. 2009). Moreover, certain herbicides can volatize and move onto adjacent agricultural crops or non-target vegetation, so adherence to label recommendations and application restrictions is essential.

Fertilizing vegetation in moist-soil wetlands can increase plant biomass and seed yield, but it is typically done conservatively so nutrient dynamics following flooding are not affected. Excess phosphorus and nitrogen can lead to blooms of bacteria and algae upon flooding if water temperature is relatively warm. Some managers report success controlling undesirable legumes (e.g., Sesbania spp.) by applying nitrogen fertilizers. However, fertilizer application to control some species does not guarantee that other undesirable species may not respond positively to excess nitrogen (e.g., Xanthium spp.).

Unlike coastal wetlands (discussed later), prescribed burning is used less than mechanical manipulations in moist-soil wetlands. Burning is often considered when moist-soil vegetation has been replaced by dense stands of cattails, phragmites, cordgrass (Spartina spp.), or other persistent emergent and perennial plant species. Burning or mowing can be used prior to disking moist-soil wetlands when extensive detritus prevents disking equipment from adequately scarifying soil. In coastal marshes, prairie potholes, or other managed wetlands where soil conditions, extended flooding, or other restrictions prevent disking, burning can be used to reduce emergent vegetation coverage (Lane and Jensen 1999). In Kansas, burning wetlands dominated by cattail had limited benefits on invertebrate production for migratory waterfowl (Kostecke et al. 2005). However, others have shown that burning increases invertebrate abundance in coastal marshes (de Szalay and Resh 1997). Burning controls persistent emergent vegetation best when used in combination with herbicide application or deep flooding. If burning is followed immediately by saturated soil conditions (i.e., not flooded or dry), cattail and other persistent emergent vegetation may recolonize rapidly.
Similar to burning, grazing is typically used in moist-soil or emergent wetlands that are dominated by tall or dense hydrophytes such as cattail and reed canary grass. Although cattle grazing and trampling is effective at reducing coverage of non-native or invasive species, cattle often graze desirable plants as well (Fig. 4.5a, Kostecke et al. 2004). Few studies have investigated proper stocking densities and durations in moist-soil wetlands to achieve desirable plant responses; thus, monitoring vegetation responses is important. Judicious use of cattle during autumn to reduce dense stands of moist-soil vegetation may be effective at creating a natural hemi-marsh following flooding. However, cattle can have negative impacts on resident wetland wildlife (e.g., amphibians, turtles, burrowing mammals, breeding marsh birds) by affecting water quality and vegetation cover or directly trampling individuals (Schmutzer et al. 2008; Burton et al. 2009). Thus, grazing during the growing season can be valuable for reducing emergent plant coverage, but may have negative effects on native plants and some wildlife species.

Agricultural food plots are commonly used to increase energetic carrying capacity for waterfowl in moist-soil wetlands and provide food for other wildlife. Although moist-soil wetlands are nutrient- and energy-rich, planting agricultural crops in wetlands managed for moist-soil vegetation can increase foraging carrying capacity up to tenfold (Table 4.1). The most common agricultural crops planted for waterfowl in the Mississippi Alluvial Valley (MAV) are corn, rice, grain sorghum, Japanese millet, browntop millet, and soybeans (Hamrick and Strickland 2010). Corn and rice fields yield the most energy, but planting and maintenance is labor intensive and expensive. Japanese and browntop millet are the least expensive and can be seeded by broadcasting (i.e., scattering) onto mudflats, drilling, or seeding onto mowed vegetation or disked soil. Some wetland managers combine corn and moist-soil vegetation in a strategy known as “grassy corn” (Kaminski and Moring 2009). Grassy corn is produced by planting corn with wide row spacing (95 cm) and using minimal herbicides after initial sprouting. This arrangement provides ample space for moist-soil vegetation to grow between rows (Fig. 4.5b). Grassy corn, or other combinations of moist-soil vegetation and agricultural crops, provide energy-rich foods in association with natural foods (i.e., moist-soil seeds), which ensures a robust diet for waterfowl. If agricultural plots are manipulated (e.g., mowed, knocked down), they cannot be hunted legally during the same planting year, unless the manipulation is part of a normal agricultural practice (e.g., harvesting with a combine; U.S. Government Code of Federal Regulations 2009).

4.3.2.3 Bottomland Management

Forested wetlands comprise more than 50 % of freshwater wetlands in the U.S. (Dahl 2006). Bottomland forests are often dominated by long-lived hardwood trees that occur along rivers and streams or in vast floodplains (Fig. 4.5c). Most bottomland forests and floodplain wetlands in the U.S. occur in the Southeast where most have been drained, cleared, converted, or degraded (Abernethy and Turner 1987; Reinecke et al. 1989; King and Allen 1996; Mitsch and Gosselink 2000).
Fig. 4.5 (a) Cattle are useful in reducing vegetation structure, (b) incorporating agriculture in moist-soil wetlands to create “grassy corn”, (c) water levels fluctuate stochastically in hardwood bottomlands, (d) Mississippi State University developed a smaller wood duck box design: http://www.fwrc.msstate.edu/pubs/nest.pdf, (e) annual maintenance of wood duck boxes is necessary, and (f) the hack-and-squirt technique can be used to create snags or remove unwanted trees (Sources: a, b, d: Published with kind permission of © Rick Kaminski, Mississippi State University, Mississippi State, MS, USA 2013; c: Photo by Matt Gray; e: Photo by Heath Hagy; f: Published with kind permission of © Andrew Ezell, Mississippi State University, Mississippi State, MS, USA 2013. All Rights Reserved)
Table 4.1  Energetic carrying capacity of selected foraging habitats (expressed as duck-energy days/ha [DEDs]) for dabbling ducks

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Food abundance a</th>
<th>Foraging threshold a</th>
<th>Food available a</th>
<th>TME b,h,n</th>
<th>DED c,o</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Moist soil</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unmanaged</td>
<td>403</td>
<td>200</td>
<td>203</td>
<td>2.47</td>
<td>1,784</td>
</tr>
<tr>
<td>Managed</td>
<td>751</td>
<td>200</td>
<td>551</td>
<td>2.47</td>
<td>4,705</td>
</tr>
<tr>
<td>Restored WRP</td>
<td>306</td>
<td>200</td>
<td>106</td>
<td>2.47</td>
<td>970</td>
</tr>
<tr>
<td><strong>Harvested crops</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice i</td>
<td>80</td>
<td>50</td>
<td>30</td>
<td>3.34</td>
<td>384</td>
</tr>
<tr>
<td>Soybean j</td>
<td>45</td>
<td>50</td>
<td>0</td>
<td>2.65</td>
<td>3</td>
</tr>
<tr>
<td>Corn j</td>
<td>75</td>
<td>15</td>
<td>60</td>
<td>3.67</td>
<td>748</td>
</tr>
<tr>
<td>Milo l</td>
<td>156</td>
<td>50</td>
<td>106</td>
<td>3.49</td>
<td>1,258</td>
</tr>
<tr>
<td><strong>Unharvested crops</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice k</td>
<td>6,030</td>
<td>50</td>
<td>5,980</td>
<td>3.34</td>
<td>67,899</td>
</tr>
<tr>
<td>Soybean j</td>
<td>2,190</td>
<td>50</td>
<td>2,140</td>
<td>2.65</td>
<td>19,299</td>
</tr>
<tr>
<td>Corn l</td>
<td>6,260</td>
<td>15</td>
<td>6,245</td>
<td>3.67</td>
<td>77,864</td>
</tr>
<tr>
<td>Milo l</td>
<td>3,051</td>
<td>50</td>
<td>3,001</td>
<td>3.49</td>
<td>35,583</td>
</tr>
<tr>
<td>Millet l</td>
<td>1,300</td>
<td>10</td>
<td>1,290</td>
<td>2.61</td>
<td>11,472</td>
</tr>
<tr>
<td><strong>Bottomland hardwood</strong> m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 % red oak</td>
<td>12</td>
<td>10</td>
<td>2</td>
<td>2.76</td>
<td>56</td>
</tr>
<tr>
<td>20 % red oak</td>
<td>38</td>
<td>10</td>
<td>28</td>
<td>2.76</td>
<td>302</td>
</tr>
<tr>
<td>30 % red oak</td>
<td>64</td>
<td>10</td>
<td>54</td>
<td>2.76</td>
<td>547</td>
</tr>
<tr>
<td>40 % red oak</td>
<td>91</td>
<td>10</td>
<td>81</td>
<td>2.76</td>
<td>793</td>
</tr>
<tr>
<td>50 % red oak</td>
<td>117</td>
<td>10</td>
<td>107</td>
<td>2.76</td>
<td>1,039</td>
</tr>
<tr>
<td>60 % red oak</td>
<td>143</td>
<td>10</td>
<td>133</td>
<td>2.76</td>
<td>1,284</td>
</tr>
<tr>
<td>70 % red oak</td>
<td>169</td>
<td>10</td>
<td>159</td>
<td>2.76</td>
<td>1,530</td>
</tr>
<tr>
<td>80 % red oak</td>
<td>195</td>
<td>10</td>
<td>185</td>
<td>2.76</td>
<td>1,775</td>
</tr>
<tr>
<td>90 % red oak</td>
<td>222</td>
<td>10</td>
<td>212</td>
<td>2.76</td>
<td>2,021</td>
</tr>
<tr>
<td>100 % red oak</td>
<td>248</td>
<td>10</td>
<td>238</td>
<td>2.76</td>
<td>2,267</td>
</tr>
</tbody>
</table>

For simplicity, we rounded estimates of food available and DEDs/ha to the nearest whole number but calculated all estimates using the most accurate data available

aKg/ha; To convert food available to lbs/ac, multiple kg/ha times 0.8922

bTME in units of kilocalories per gram (kcal/g) is determined by feeding different foods to captive ducks and determining how much energy they retain and use to meet daily energy requirements

cDEDs calculated using the average number of dabbling ducks that can obtain daily energy requirements from 1 hectare (ha) of habitat for 1 day. Energetic requirements of dabbling ducks are based on calculations by Dr. Ken Reinecke (U.S. Geological Survey, retired) and Dr. William Uihlein (U.S. Fish and Wildlife Service) using eight common dabbling duck species. The simplest way to calculate DEDs/ac is to first calculate DEDs/ha, then transform the result from DEDs/ha to DEDs/ac. The following text describes the necessary steps. Ensure that processing, diet, and sampling bias adjustments are made to the gross abundance estimates prior to subsequent calculations (Hagy et al. 2011b; Hagy and Kaminski 2012a). To calculate DEDs/ha, first subtract the appropriate foraging threshold (kg/ha) from total food abundance (kg/ha) in a foraging habitat. We do this because ducks apparently cannot efficiently access food in habitats when food density is low and extensive searching, processing, or other costs outweigh potential energetic benefits of continued foraging. Thus, some unavailable residual density (Food Availability Threshold [FAT; Hagy 2010], Giving-up Density [Reinecke et al. 1989; Greer et al. 2009], Critical Food Density [van Gils et al. 2004]) remains, and this may vary among habitats (Rice = 50 kg/ha [Greer et al. 2009], moist-soil = 200 kg/ha [Hagy 2010], Japanese millet = 10 kg/ha [Hagy 2010], harvested dry corn = 15 kg/ha [Baldassarre and Bolen 1984]). If FAT is unknown, we suggest using 50 kg/ha for agricultural grains, 10 kg/ha for hard mast, and 200 kg/ha for natural seeds. After correcting food abundance for foraging threshold, multiple available food by 1,000,
which is the number of grams per kilogram (g/kg). The result is grams per hectare (g/ha) of available food. Then, multiple the g/ha of available food times the average TME available per gram of food (kcal/g). The result is in units of kcal/ha. Next, divide the number of kcal/ha by the average daily energy requirement (DER) of dabbling ducks for DEDs/ha. We have adopted a DER of 294.35 kcal/day as a good approximation (Reinecke and Uihlein 2006, Report to Waterfowl Working Group). Multiplying DEDs/ha times 0.4047 converts DEDs/ha to DEDs/ac. In cases where more than one food is available in a foraging habitat, DEDs are calculated as a sum of DEDs for the different foods. For example, a flooded impoundment may contain acreages of bottomland hardwoods, moist-soil vegetation, and food plots (e.g., flooded corn), and all can be included in estimates of available food and DEDs for that impoundment.

Our estimates of food availability in moist-soil wetlands include seeds, tubers, and aquatic invertebrates (added to DED separately because TME values are significantly different) that are likely consumed by ducks (Hagy and Kaminski 2012a) and are corrected for processing bias (Hagy et al. 2011b). We used the overall mean for seed and tuber abundance from fall or early winter from studies conducted in and nearby the MAV (i.e., Kross et al. 2008; Hagy and Kaminski 2012b; Olmstead 2010), corrected for potential negative sampling biases (i.e., 16%; Reinecke and Hartke 2005; Hagy et al. 2011b).

Hagy et al. (2011b) suggested increasing estimates of seeds and tubers from Kross et al. (2008) to 575 kg/ha and reducing that by 30% for diet bias to 402.5 kg/ha (Hagy and Kaminski 2012a). Then we suggest subtracting 200 kg/ha based on Hagy and Kaminski (2012) for FAT = 202.5 kg/ha (round to 200 kg/ha). “Unmanaged” is a slight misnomer, because some minimal level of management is necessary to maintain most moist-soil wetlands. However, this estimate was derived from state lands minimally managed compared to intensively managed moist-soil impoundments primarily located on USFWS National Wildlife Refuges and private lands (e.g., duck clubs, private waterfowl management areas).

Hagy and Kaminski (2012b) reported 751 kg/ha seed and tuber density and 1.8 kg/ha invertebrate density in managed, robust moist-soil wetlands in the MAV.

Data from moist-soil impoundments on Wetland Reserve Program easements in Mississippi and Arkansas that included some passive and active management (Fleming 2010; Olmstead 2010). For WRP, we used the mean masses of “beneficial seeds” (Lisa Webb, University of Missouri, personal communication: 263.5 * 1.16), corrected for processing bias (306 kg/ha), and subtracted FAT (306 – 200 = 106 kg/ha).

Based on Kaminski et al. (2003) – data from mallards if available. Assuming mean invertebrate TME is 0.952 kcal/g (mean from Fredrickson and Reid 1988; Jorde and Owen 1988; Sherfy 1999; Ballard et al. 2004).

Based primarily on Stafford et al. (2006).

Based on Foster et al. (2010a).

Based on two unharvested rice fields in Arkansas used in foraging experiment (Greer et al. 2009).

Matthew McClanahan and Joshua Osborn, University of Tennessee, unpublished data.

Hardwood bottomlands provide at least three food sources: invertebrates, seeds of non-woody plants (e.g., moist soil), and acorns. We assumed food availability in hardwood bottomlands included an average of 11.4 kg(dry)/ha of invertebrates (Batema et al. 2005; Foth 2011; Hagy et al. 2011a) and an amount of acorns proportional to the percentage of red oaks in the forest canopy. Estimates of hard mast from other species are not available and are not included in this table. To estimate availability of acorns, we used a predictive equation from Straub (2012; {Acorn abundance [kg/ha] = [261.92 * % red oak canopy] – 14.16}) and TMEs from Kaminski et al. (2003). There are no data available for hard mast foraging thresholds in flooded hardwood bottomlands; thus, we assumed that a threshold density would be less than other smaller and more cryptic seeds (Hagy 2010) and used best professional judgment to approximate a threshold of 10 kg/ha. We assumed negligible amount of moist-soil seeds are available in bottomland forests, given foraging thresholds may exceed 200 kg/ha and apparently no published estimates exist on the prevalence of canopy openings containing moist-soil vegetation in bottomland forests.

(continued)
The lower MAV once represented the largest bottomland hardwood forest in North America, but more than 75% has been cleared for agriculture and human development (MacDonald et al. 1979; Fredrickson 2005; King et al. 2006). Most of the remaining forested bottomlands have been degraded by selective removal of high value timber and mast producing trees (King and Allen 1996; Ervin et al. 2006). Further, flood control efforts along the Mississippi, Ohio, Missouri, and other major rivers have isolated bottomlands on floodplains and reduced flooding frequency and wetland function. As little as 10% of the Mississippi River floodplain remains connected to the river (Faulkner et al. 2011). Complete restoration of historical hydrological regimes and functions of bottomland forest wetlands is likely unachievable in most cases (Stanturf et al. 2001). Therefore, floodplain reforestation, forest management, and creation of impoundments are important strategies to improve function and wildlife habitat in bottomlands.

Management of bottomland forests can include both short- and long-term objectives. Short-term goals often include enhancing wildlife habitat and restoring some form of hydrology to floodplains. Short-term wildlife enhancements may include erecting nest boxes to provide nesting cavities for wood ducks, eastern screech owls (Megascops asio), hooded mergansers (Lophodytes cucullatus), pileated woodpeckers (Dryocopus pileatus), and other birds. Erecting nest boxes has been an important management technique for wood ducks (Bellrose and Holm 1994). Large (30 cm long × 30 cm wide × 61 cm high) and small (18 cm long × 30 cm wide × 43 cm high) box designs exist (Fig. 4.5d, Davis et al. 1999). Small boxes
were designed to reduce nest parasitism (i.e., dump nesting) by wood ducks. Boxes can be placed on posts over water or in random, inconspicuous locations in a bottomland forest. Boxes should be placed >1 m above high water levels to avoid inundation and include a predator guard to increase hatching success. Boxes should not be placed closer than 75 m to each other to minimize nest parasitism. Every winter or early spring, boxes should be cleaned and approximately 8 cm of wood shavings added to the box (Fig. 4.5e, Bellrose and Holm 1994). Other short-term enhancements to bottomland forests may include artificially flooding bottomlands during the winter using constructed levees, managing beaver populations to create and maintain natural impoundments, or planting cover crops in forest openings and on logging roads and levees to reduce sediment runoff and improve wildlife habitat. Creating streamside buffers using natural regeneration or plantings is often used to rapidly improve degraded streams and other waterways (Schultz et al. 1995; Marquez et al. 1999). Buffers provide habitat corridors for wildlife, reduce nutrient and soil runoff, and help reduce bank erosion during floods (Schultz et al. 1995; Dosskey 2001).

Although long-term goals of bottomland management differ among natural resource agencies and private landowners, they often include improvement of tree canopies for provision of wildlife food and habitat, restoring natural hydrology, lessening dependence on intensive management techniques, and improving wetland function. Management can include building and maintaining impoundments to flood bottomlands more predictably or removing portions of flood control to allow natural hydrology to return to the site (Stanturf et al. 2001; De Steven and Lowrance 2011; Faulkner et al. 2011). Improving stream-floodplain connectivity is important for fish and amphibian populations (Henning 2004; Sullivan and Watzin 2009), and restores wetland functions such as sediment removal, soil stabilization, and nutrient cycling (Mitsch and Gosselink 2000).

Silvicultural activities can be an effective way to improve composition of bottomland forests (Schoenholtz et al. 2005). Many forests that have been previously harvested or regenerated from fallow agricultural fields contain few hard-mast producing trees such as oak (Quercus spp.) and hickory (Carya spp.). Using silvicultural practices to increase densities of mast and cavity producing tree species can be beneficial for waterfowl and other wildlife. Regeneration clearings can be made using selective timber harvest and small clear cuts during late spring or early summer after normal winter and spring flooding events have subsided. Small clear cuts (<2 ha) or hack-and-squirt chemical treatments that create dead snags and downed timber can benefit a variety of wildlife species, such as cavity nesting birds and mammals (Fig. 4.5f). Forest openings at least 80 m in diameter may increase use by some dabbling ducks (e.g., mallards) once flooded (Kaminski et al. 1993). Canopy gaps allow naturally regenerated or planted oak seedlings to flourish and eventually improve forest diversity. In even-aged stands with low species diversity, small clear cuts or forest management can improve forest health (Faulkner et al. 2011).

Regardless of the clearing or seedling regeneration strategy, competition from undesirable trees may be managed by manual thinning or herbicide application for
1–3 years after clearing (Guttery 2006). Regeneration clearings can also increase the number of strata in a forest and, over a period of years and several rounds of timber improvement, provide a diversity of habitats in multiple successional stages that are valuable to many different organisms, especially migratory birds. In bottomlands that flood regularly during winter, forest gaps can be maintained using periodic disking or herbicide, which also will encourage production of herbaceous moist-soil plants for waterfowl.

To provide bottomland wetlands that are more predictably available for migrating waterfowl, private landowners and public land managers have constructed greentree reservoirs (GTRs) by erecting levees with water control structures around mature or regenerating stands of bottomland trees (King and Fredrickson 1998). The first known GTR was constructed near Stuttgart, Arkansas, U.S. in the 1930s and used to provide consistent waterfowl hunting opportunities on private lands (Fredrickson and Batema 1992). Greentree reservoirs are flooded in winter to provide forested wetlands for waterfowl and other wetland-dependent wildlife, and drained prior to spring to reduce stress on trees. Water management is critical in GTRs because growing season flooding can have negative effects on mast production, seedling regeneration and tree growth, and result in forest composition shifting toward more flood-tolerant species that may be undesirable for certain management objectives (Malecki et al. 1983; Wigley and Filer 1989; Fredrickson and Batema 1992; Young et al. 1995; King et al. 1998; Guttery 2006). For example, growing season flooding in GTRs in the southeastern U.S. can result in a shift from desirable red oak species (e.g., Q. phellos) to overcup oak (Q. lyrata). Overcup oak acorns are large and have a cap that often encapsulates the acorn, which may negatively affect ingestion and digestion by waterfowl (Barras et al. 1996). Timber value of overcup oak also is less than many red oak species (Barras et al. 1996; Combs and Fredrickson 1996; Ervin et al. 2006). Gray and Kaminski (2005) recommended that a GTR be flooded no longer than 1 month during winter to minimize negative effects on desirable oak species.

### 4.3.2.4 Management of Agriculture Fields

Harvested and unharvested agricultural fields that are flooded can provide abundant, high-energy food resources for migratory waterfowl (Twedt and Nelms 1999; Manley et al. 2004, 2005). Rice is one of the most beneficial agricultural crops for wildlife because production involves the creation of impoundments that are shallowly flooded to suppress weeds and enhance rice growth. When rice fields are flooded in summer, they can provide quality nesting, foraging, and brood rearing habitat for several species of birds, such as king rails, fulvous whistling ducks (Dendrocygna bicolor), purple gallinules (Porphyrio martinica), and mottled ducks (Anas fulvigula, Durham and Afton 2003). Flooded rice stubble also provides important foraging habitat for migrating and wintering waterbirds. The primary rice growing regions in North America are the Central Valley of California; coastal Texas and Louisiana; Lower Mississippi Alluvial...
Valley including portions of Louisiana, Mississippi, Arkansas and Missouri; and Grand Prairie Region of central Arkansas.

Rice seed remaining after harvest due to harvester inefficiency (i.e., waste rice), natural moist-soil plant seeds, and aquatic invertebrates are valuable food resources for waterfowl in rice fields (Manley et al. 2005; Stafford et al. 2006). Rice fields are typically drained in late summer as rice matures then harvested with conventional combines. After harvest, producers may re-flood fields to attract waterfowl for hunting or bird watching (Havens et al. 2009), increase decomposition of high cellulose straw (van Groenigen et al. 2003), reduce soil erosion, prevent winter weed growth, and reduce producer costs during the subsequent growing season (Manley et al. 2005, 2009). Flooding may occur at different times and rates depending on objectives. For example, some producers will flood their fields using pumps after harvest (e.g., September–December), whereas others will close water control structures so fields flood naturally from precipitation. Fallow and active rice fields also provide abundant habitat for crayfish, which can provide significant income for farmers in the southeastern U.S. (Brunson and Griffin 1988).

The amount and configuration of stubble left in agricultural fields after harvest can influence waterfowl use and food availability. Kross et al. (2008) and Havens et al. (2009) recommended partially burning or rolling standing rice stubble to create a mosaic of emergent vegetation and open water to attract dabbling ducks. Stafford et al. (2010) advised that irrigating rice stubble after harvest could produce a ratoon crop (i.e., second seed head from previously harvested plants) and increase available rice for waterbirds by 20-fold. Post-harvest irrigation and fertilization of other graminoid crops (e.g., grain sorghum) also can result in significant ratoon production (Wiseman et al. 2010).

Although rice is the most common agricultural crop that is grown in wetlands, several other crops may be planted to provide food for waterfowl. Corn and grain sorghum are planted frequently in managed impoundments to increase available food. Further, planting agricultural crops in impoundments that require soil disturbance to set back vegetation succession can improve moist-soil vegetation during the subsequent growing season. Soil tillage and herbicides required to produce crops usually kill perennial herbaceous and young woody vegetation. Thus, rotating an agricultural crop into all or a portion of a moist-soil impoundment once every 3–5 years increases food for waterbirds and may improve moist-soil seed production in subsequent years.

Unharvested agricultural fields or food plots typically need to be flooded to provide access to seeds for waterfowl; however, some waterfowl species will readily use harvested fields regardless of water presence. In the northern United States and southern Canada, agricultural seed left after harvest remains abundant in fields through winter if they remain untilled, and is often consumed by mallards, northern pintail (*Anas acuta*), and geese (Barney 2008; Sherfy et al. 2011). In the southeastern U.S., very little agricultural seed is available in harvested corn, grain sorghum or soybean fields by December when large numbers of migratory waterfowl arrive (Foster et al. 2010a). The fate of waste grain in harvested fields prior to the arrival of waterfowl depends on the crop type, with
corn seed depredated by various wildlife, and soybean and grain sorghum seeds germinating or decomposing (Foster et al. 2011).

Flooding agricultural fields increases rate of waste grain loss by 40–300 % due to decomposition; thus, managers can delay flooding until waterfowl arrive to increase food availability (Foster et al. 2010b). Unlike harvested fields, seed retention in unharvested fields through winter is high (Foster et al. 2010a) until they are flooded and made accessible to foraging waterfowl. Seed availability in unharvested agricultural fields is 20–80 times greater than in harvested fields in the southeastern U.S. (Table 4.1). Hence, use of agricultural food plots can significantly increase available energy on managed areas.

4.3.2.5 Monitoring Wetland Quality

Wetland quality for wildlife varies depending on management objectives and environmental factors. One of the most common quality indices used to guide wetland conservation for wildlife in North America is duck-energy days (DEDs) formally called duck-use days. The DEDs are an estimate of energetic carrying capacity of foraging habitats for dabbling ducks, and are defined as the number of ducks that a wetland can sustain for a certain period of time given the amount of available food and daily energetic requirements (Reinecke et al. 1989).

\[
\text{DED} = \frac{\text{Seed Production (kg[dry]/ha)} \times \text{TME (kcal/kg[dry])}}{\text{Daily Energy Requirement (kcal/day)}}
\]

To calculate DEDs, estimates of food availability, the true metabolizable energy (TME) of the food, and the daily energy requirement of waterfowl are required. The most variable component of the DED equation among waterfowl habitats is the amount of available food. Commonly, DEDs in wetlands and agricultural fields are calculated using seed availability estimates from previous large-scale studies (e.g., Kross et al. 2008; Foster et al. 2010a). These estimates are multiplied by the acreage of the habitat type (e.g., managed moist-soil, flooded unharvested corn) to generate an estimate of total DEDs in an area. There have also been numerous attempts to develop strategies for rapidly estimating seed production in moist-soil wetlands, including visual assessment (Naylor et al. 2005), seed vacuums (Penny et al. 2006), and models that use plant measurements (Laubhan and Fredrickson 1992; Gray et al. 1999b, c). Gray et al. (2009) demonstrated that the scanned area of a seed head was strongly correlated \((R^2 \geq 0.87)\) with seed mass produced by moist-soil plants. Moreover, processing time to receive a seed production estimate was only 15 s per plant. In their approach, average predicted seed mass per plant species is multiplied by average stem density per plant species and summed across plant species for an estimate of total seed production in a moist-soil wetland. The equations in Gray et al. (2009) predict aboveground seed production, hence may underestimate total seed availability given that ducks can sift mud and acquire
belowground seed. Recent data suggest that equations in Gray et al. (2009) may underestimate seed production 100–200 kg/ha (Gray and Hagy, unpubl. data), which can be used as a correction factor. The University of Tennessee Wetlands Program offers an inexpensive service to estimate DEDs in moist-soil wetlands by scanning seed heads submitted by biologists to predict seed yield (http://fwf.ag.utk.edu/mgray/DED/DED.htm).

Other measures of wetland quality depend on land management objectives. Fleming (2010) developed a floristic quality index for restored wetlands in the MAV representative of waterfowl foraging needs. Multiple researchers have developed indices based on plants that predict state of wetland restoration and use by wildlife guilds (Lopez and Fennessy 2002; Gray and Summers 2012). State and federal agencies have developed wetland quality indices that assess degradation risk using information on water and soil quality, wildlife habitat, and threat of conversion (Fennessy et al. 2004; Scozzafava et al. 2011). We refer the readers to Chaps. 1 and 2 of this book for additional discussions on wetland assessment strategies.

4.3.2.6 Managing Wetland Complexes and Herpetofauna

When managing wetlands for multiple taxonomic groups, it is important to provide a diversity of habitat types and ensure their availability during critical life cycle events. Natural wetlands and agricultural food plots are often managed for waterfowl during winter (Fredrickson and Reid 1988), but specific amount and interspersion of these habitat types is unknown (Pearse et al. 2012). Often, wetland managers estimate available DEDs and compare these values with estimates of waterfowl use to ensure they provide sufficient food resources. Acreages of moist-soil and hardwood bottomland wetlands tend to be fixed on management areas due to existing infrastructure; thus, agricultural food plots can be used to compensate for any DED deficits (see box inset).

Calculating Supplemental Food Needs

Suppose historical survey data indicate that on average 10,000 ducks/day use an area for 90 days = 900,000 total duck-days. If there are 200 ha of managed moist-soil (4,705 DED/ha [Table 4.1] × 200 ha = 941,000 total DEDs) and 20 ha of hardwood bottomlands with 30% red oak coverage (547 DED/ha [Table 4.1] × 20 ha = 10,940 total DEDs), there would be no need to plant crops based on the typical available energy in these natural habitats, because 951,940 DEDs exceed the anticipated use of 900,000 total duck-days. On the other hand, if only 100 ha of managed moist-soil wetlands were available (470,500 DEDs), total DEDs = 481,440 from moist-soil and hardwood bottomland wetlands, thus approximately 5.4 ha of additional

(continued)
unharvested flooded corn would be needed (77,864 DED/ha [Table 4.1] × 5.4 ha = 420,465 DEDs) to meet the energy demand of ducks using this area. We caution that DED estimates should be used only as a guide for managing waterfowl, because waterfowl and other wildlife need wetlands for several life cycle needs other than acquiring food resources.

However, waterfowl cannot persist on a diet composed solely of agricultural seeds (Loesch and Kaminski 1989); they must secure essential nutrients from natural seeds or aquatic invertebrates, or survival will be negatively impacted. Relatively few aquatic invertebrates exist in most flooded agricultural fields (Hagy et al. 2011a), which emphasizes the need to provide multiple wetland types in close proximity.

Another component of a wetland complex that targets waterfowl management is refuge. Refuge is an area or time period with limited human disturbance. Refuges are often important sites for waterfowl to rest, engage in courtship, and escape inclement weather. Refuges should include high quality food resources. For areas where hunting is allowed, refuges can encourage birds to remain locally and provide sustained harvest opportunities (Evans and Day 2002). Refuges can be spatial or temporal. Spatial refuges are a designated area where no hunting is allowed and human access is limited. Temporal refuges restrict human disturbance to certain days of the week or between morning and afternoon. Research is needed to determine the ideal amount or duration of refuge to maintain waterfowl use in an area. Some strategies worthwhile to investigate include 10, 25, and 50 % of an area dedicated to refuge. For temporal refuges, waterfowl use among areas with 1, 3, and 5 days per week of hunting could be compared. In most circumstances, continuously hunting all locations of a management area will negatively affect waterfowl use (Fox and Madsen 1997).

Twenty-first century wetland managers often are required to manage for species other than waterbirds. Many species of herpetofauna are declining worldwide, especially amphibians and freshwater turtles, thus natural resource agencies have started to manage for these groups. Managing for waterbirds can provide habitat for herpetofauna if done properly. Most amphibian species need available water from early spring through summer to provide breeding and larval habitat (Semlitsch 2000). Thus, if drawdowns are planned and providing habitat for amphibians is an objective, dewatering should be delayed until August. A late drawdown also will provide habitat for waterfowl broods during summer and expose mudflats in late summer for migrating shorebirds. Wetlands with emergent vegetation and that are devoid of fish tend to have high amphibian diversity (Semlitsch 2000), which can be promoted with drawdowns. Drawdowns that occur over 2–4 weeks will allow amphibian larvae to increase their developmental rate and metamorphose prior to complete dewatering. Amphibians are sensitive to water quality, thus if dissolved oxygen is low or nutrient concentrations are high (see life history discussion), water may be flowed into wetlands to improve water quality. Wetland managers can provide brush piles or logs in wetlands as basking sites to increase turtle habitat (Wolinsky 2006).
Most amphibians and turtles require undisturbed upland habitat for post-metamorphic stages and nesting, respectively. Semlitsch and Bodie (2003) suggested terrestrial buffers 300 m in width surrounding amphibian breeding sites; however, 100 m buffers may be sufficient for salamanders (Rittenhouse and Semlitsch 2007). Most freshwater turtles nest within 200 m of wetlands. Wetland managers also may establish undisturbed dispersal corridors (>100 m in width) between breeding sites to facilitate interdemic movement. Some forestry practices in terrestrial buffers can negatively affect herpetofauna (Harpole and Haas 1999). Group selection cuts (Homyack and Haas 2009), leaving slash and decomposing logs, and minimizing soil disturbance by using low-pressure tires and strategically placed skid trails can reduce the effects of silviculture on amphibians. Brush piles in the terrestrial environment also can serve as foraging locations and refugia for snakes.

4.3.3 Coastal Wetlands

Coastal wetlands differ greatly from interior wetlands primarily because of a combination of salinity, sulfur compounds, tidal range, plant and animal communities, and global sea-level rise. Most coastal wetlands in North America have emergent vegetation rather than trees, because few tree species can tolerate extended flooding and moderate salinity. An exception are mangroves, which are flood- and salt-tolerant trees that are primarily tropical and in the U.S. are limited to frost-free regions of coastal Texas, Louisiana, and Florida. Given the limited active management of mangroves, this section focuses on management of herbaceous coastal marshes.

Water quantity and quality is a primary driver of coastal wetland ecosystems. Water quantity has two components: (1) flood frequency (i.e., how often the soil surface is flooded), and (2) flood duration (i.e., how long the soil surface is flooded). Generally, marshes closer to the ocean flood more frequently but with less duration than marshes more inland. Water quality is determined by the balance between freshwater and seawater. Generally, marshes that are farther inland have lower salinity. Freshwater and tidal influxes interact to create a dynamic between flooding and salinity stress that lead to abrupt changes in vegetative composition and associated wildlife communities.

This section will discuss ways to manage salinity and water depth to create desired plant communities and wildlife responses in coastal wetlands. We also will discuss the usefulness of prescribed fire in managing coastal wetlands. Lastly, we address existing threats to coastal wetlands and some restoration techniques.

4.3.3.1 Salinity Management

For over a century, coastal wetlands have been drained and impounded for various human uses. Although levees can be used to manage water levels and salinity, they also can interfere with natural hydrology, which includes saltwater and freshwater influxes from tides and terrestrial runoff, respectively. In the early 1900s, many
coastal wetlands were impounded to increase waterfowl hunting opportunities. Impounding coastal wetlands typically results in vegetation composition changing to annual plant species that do not tolerate brackish salinity (0.5–30 ppt) or frequent flooding. More recently, coastal wetlands have been restored by breaking levees or installing culverts to partially mimic historical hydrology. These management practices have resulted in increased abundances of saltmarsh sharp-tailed sparrows (*Ammodramus caudacutus*), seaside sparrows (*A. maritimus*), semipalmated sandpipers (*Calidris pusilla*), and least sandpipers (*C. minutilla*) due to changes in perennial cover and increased mudflat area (Brawley et al. 1998).

In some coastal wetlands, such as in the Sacramento Delta and the Mississippi River Delta, U.S., levees or navigation channels prevent spring floods from supplying mineral sediments, nutrients, and freshwater to wetlands that formerly received them. Restoring spring flood waters increases habitat quality for wildlife (e.g., waterfowl, king rails) that prefer low salinity wetlands. Culverts and siphons can be used to pass freshwater from rivers through or over levees during flood stages. Diverted freshwater can revitalize marshes by depositing sediment and nutrients, and decreasing salinity (Lane et al. 1999). The impacts of freshwater diversion can be observed at three scales: (1) a small zone where there is an increase in sediments and nutrients and lower salinity, (2) a moderate zone where there is an increase in nutrients and lower salinity, and (3) a large zone that benefits from lower salinity only (Lane et al. 1999). Even in areas that experience only salinity reduction, plant growth usually increases because low salinity allows plants access to nutrients that are inaccessible when salinity is high (Merino et al. 2010).

Levees have been used to increase habitat quality for waterfowl by holding freshwater and excluding brackish water from coastal marshes. Typically, freshwater impoundments on the coast have high plant diversity and production, which attract waterfowl, if rainfall and freshwater inflow exceed evaporation (Chabreck 1979; Miller 2003; Sharp and Billodeau 2007a, b). However, this type of management can interfere with the ingress and egress of estuarine nekton (i.e., swimming organisms such as fish, shrimp, and crabs) between the marsh and coastal waters (Hoese and Konikoff 1995), which can lead to conflicts between agencies charged with promoting waterfowl versus estuarine fisheries.

### 4.3.3.2 Water-Level Management

Levees, culverts, and various types of water control structures have been used in coastal wetlands since the mid-1900s to create water conditions that benefit waterbirds (e.g., dabbling ducks, rails) and promote development of desirable vegetation (Griffith 1940; Landers et al. 1976). In impoundments with drawdown capability, managers use drawdowns to expose mudflats and increase growth of annual plants. Plant germination following drawdown in coastal wetlands is dependent on salinity (Landers et al. 1976). Even modest amounts of saltwater (e.g., salinity > 1 ppt) can prevent germination. Drawdowns in saline marshes result in acid-sulfate soils (e.g., “cat clays”) that can be toxic to vegetation for decades
Thus, as salinity increases, the utility of drawdowns decreases. As with moist-soil impoundments, vegetation in low salinity coastal impoundments will proceed through succession from annual to perennial plants. Coastal wetlands dominated by perennial plants typically are lower quality habitats for some waterbirds and fish (Bush Thom et al. 2004; O’Connell and Nyman 2010). To set back succession, infusion with saltwater can be used. For example, saltwater is introduced every 30–40 years for one growing season in freshwater impoundments at Rockefeller Wildlife Refuge in southwestern Louisiana, U.S., to kill perennial cattail and bulrush (e.g., *Schoenoplectus californicus*). When impoundments are drawn down and reflooded with freshwater, an interspersion of open water and emergent vegetation typically develops.

Drawdowns result in accelerated decomposition, thus a consequence can be soil subsidence. For some coastal wetlands, soil subsidence can be detrimental and result in complete loss of emergent vegetation. A general rule of thumb is that complete drawdowns should be avoided if depth of existing open water areas is less than the live root zone of adjacent emergent vegetation (McGinnis 1997). Thus, when drawdowns are performed in coastal wetlands, pools of water will typically remain throughout the wetland. Managers of coastal wetlands threatened by subsidence can reduce drawdown frequency to only a few per decade and duration of 2–3 months.

Some water control structures used in coastal wetlands lack the ability to allow for drawdowns. Weirs or sills resemble low levees made of sod, sheet pilings or rocks with the crest set at 15 cm below the elevation of the surrounding marsh to allow water to flow back and forth across the structures. These structures prevent marshes from completely draining, and can provide for important habitat for wintering waterfowl (Spiller and Chabreck 1975). Weirs with fixed crests stabilize water levels, decrease mineral sedimentation (Reed 1992), and increase abundance of submersed aquatic vegetation (Nyman and Chabreck 1996), but typically do not affect emergent plant communities (Nyman et al. 1993b) or marsh loss (Nyman et al. 1990a). In some cases, weirs and sills can increase marsh loss if vertical accretion in the marsh depends on mineral sedimentation (e.g., the southeastern and mid-Atlantic coast of the U.S.).

### 4.3.3.3 Vertical Accretion Management

Vertical accretion is an increase in marsh level due to an accumulation of mineral sediments (delivered by currents associated with rivers, tides, and storms) and organic matter produced by emergent plants typically growing in the wetland. It is often suggested that accretion depends mostly on mineral sediment accumulation (Hatton et al. 1983; Stevenson et al. 1985; Reed 1989; Nyman et al. 1990b). However, accretion in many tidal freshwater marshes (Neubauer 2008) and some brackish and saline marshes in New England and Louisiana, U.S., primarily depends on organic matter accumulation from plants (McCaffrey and Thomson
Wildlife management activities are preferred that minimize effects on the natural processes that contribute to vertical accretion in coastal wetlands. Levees, spoil banks, and fixed crest weirs can reduce or prevent natural sedimentation (Cahoon 1994; Reed et al. 1997). In wetlands with levees and water control structures, managers may open structures when sediment availability is greatest in adjacent water bodies, which generally occurs during spring when river discharge to coastal waters is greatest (Fig. 4.4c, Mossa and Roberts 1990). Coastal wetland managers also may wish to employ management practices that promote organic matter accumulation. Organic matter accumulation depends on the interaction between plant production and soil organic matter decomposition. Drawdowns will increase soil aeration, which will increase plant productivity but also increase soil organic matter decomposition. Coastal wetlands that are dry for extended durations due to draining or drought can decrease over a meter in elevation from organic matter decomposition (Bourn and Cottam 1950:5; Roman et al. 1984; Weifenbach and Clark 2000). It is possible that occasional drawdowns that are short in duration will increase plant productivity more than they increase soil organic matter decomposition; however, data on the ideal duration of drawdowns in coastal wetlands is lacking. Organic accumulation in coastal wetlands also can increase soil strength, which can reduce erosion (McGinnis 1997).

4.3.3.4 Prescribed Fire

Fire was a natural, regular disturbance in many coastal marshes (Frost 1995). The frequency at which natural fires spread into many coastal marsh areas has been reduced by roads and canals. Natural fires are most common in large expanses of coastal marsh dominated by saltmeadow cordgrass (*Spartina patens*) during late summer. Lightning strikes are the most common cause of natural fires in coastal marshes. Historically, Native Americans also regularly burned coastal wetlands. It is unlikely that early Europeans suppressed fire in coastal marshes, but prescribed fire was rare until the early 1900s when it was used initially to improve access for American alligator (*Alligator mississippiensis*) hunters and later used to improve habitat quality for muskrats and snow geese (*Chen caerulescens*, Nyman and Chabreck 1995). Legal liabilities have led some coastal marsh managers to use herbicides to simulate the effects of fire disturbance.

Water levels in a coastal marsh during a prescribed burn control the type of fire that occurs. Marsh fires can be classified as peat burns, root burns, or cover burns (Lynch 1941; Smith 1942; Uhler 1944; O’Neil 1949:93–107). Peat burns consume marsh soil where peat is drained or dry; they are not normally used as a management tool. The depth of the burn depends on soil moisture content and depth. Peat burns lower surface elevation and can convert emergent marsh to open water. Peat burns can be avoided by burning emergent vegetation only when the soil surface is flooded.
Root burns kill roots without consuming soil. Root burns occur when there is little or no water over the soil surface, there is an abundant fuel load, and the fire is slow moving. Few data exist on the effects of root burns on plant and wildlife responses.

Fires that remove aboveground biomass without killing roots or harming soils are classified as cover burns (Fig. 4.6a). Cover burns result from fires that occur when there is high soil moisture or when the soil surface is flooded a few cm deep. Emergent plant parts are burned, but soil and roots remain intact. Plants can quickly recover from cover burns if plant stubble is not subsequently covered by flood water (Fig. 4.6b). If plant stubble is flooded for several days to a week after a cover burn, the remaining vegetative stems and root stocks can be killed (Hoffpauer 1968). Cover burns are commonly prescribed during winter because they increase the abundance of wildlife food plants (Arthur 1931:262–265; Griffith 1940; Lynch 1941; Uhler 1944). One danger of late summer fires in coastal marshes in the southeastern U.S. is the possibility of flooding recently burned areas with saline water for days or weeks due to frequent tropical storm surges during that time of year. Cover burns also are prescribed to prevent shrubs from establishing and becoming dominant in low salinity coastal marshes. In most coastal marshes, prescribed burning is only required as frequently as needed to reduce fuel loads, woody encroachment, and the chance of unplanned burns. In general, prescribed cover burns are performed every 3–5 years (Flores et al. 2011), with 1/3 to 1/5 of a coastal marsh burned annually (Nyman and Chabreck 1995; but see Kern et al. 2012).

4.3.3.5 Loss of Coastal Wetlands

Loss of coastal wetlands has been occurring in North America and other regions of the world for centuries. Primary causes have been channelization and subsequent saltwater intrusion, sea-level rise, reduced sedimentation and vertical accretion, and introduced species (e.g., *Myocastor coypus*). As a consequence, many wetland dependent species have decreased in abundance, such as the seaside sparrow along on the Atlantic Coast (Benoit and Askins 1999) and the California clapper rail (*Rallus longirostris obsoletus*) on the Pacific Coast of the U.S. (Harding et al. 2001).

Ditches were excavated throughout the 1900s in coastal wetlands to increase access and for navigation (Fig. 4.6c). Ditch excavation significantly affects the natural hydrology within coastal wetlands. In particular, it often results in highly saline ocean water penetrating the wetland at greater distances and depth. Consequently, vegetation composition and wildlife use can be negatively impacted (Bourn and Cottam 1950). Vegetation coverage also can decrease and result in soil erosion or subsidence, which further facilitates saltwater intrusion as the elevation of the coastal wetland decreases. A classic example of the effects of ditching is the deepening the Calcasieu Ship Channel in Louisiana, U.S., which increased water depth 40 cm and water salinity in the Sabine National Wildlife Refuge wetlands (Fogarty 1965; Suhayda et al. 1989).
Fig. 4.6  (a) Cover burn set at Rockefeller Wildlife Refuge, Louisiana, U.S., (b) coastal marsh vegetation responding quickly after a cover burn, (c) creation of navigation channels through coastal wetlands causes saltwater intrusion and marsh loss, (d) exotic nutria (*Myocastor coypus*) can denude a coastal marsh and negatively affect wetland function, (e) dredging can be used to create coastal marsh in areas of subsidence, and (f) terrace construction is an effective technique to restore coastal marshes by increasing vertical accretion (Sources: a: Photo by Matt Gray; b: Photo by Andy Nyman; These photos were taken by Andy Nyman. d: Published with kind permission of the U.S. Geological Survey. Figure is public domain in the USA. All Rights Reserved; e: Published with kind permission of the U.S. Fish and Wildlife Service National Digital Library (http://digitalmedia.fws.gov/). Figure is public domain in the USA. All Rights Reserved)
Global sea-level rise is a consequence of atmospheric warming and melting of the polar ice caps. Sea-level rise combined with regional subsidence is called submergence, and averages 0.25–0.30 cm/year along most of the coastal U.S., but varies regionally (Titus 1996). For example, submergence during the late 1900s averaged 0.30–0.33 cm/year in coastal North Carolina (Kemp et al. 2009) but 1.17 cm/year in coastal Louisiana, U.S. (Penland and Ramsey 1990). Sea-level rise can be offset by vertical accretion. Vertical accretion in coastal wetlands is a natural process and most pronounced near rivers. For example, vertical accretion for a portion of the Mississippi River Deltaic Plain is 0.98 cm/year, yet less than the submergence rate (Nyman et al. 1993a). When submergence exceeds vertical accretion, the border of wetlands can migrate inland and upslope over former uplands (Phillips 1986), or wetlands are converted to open water resulting in loss (DeLaune et al. 1994).

Excessive herbivory by vertebrates is a conservation concern in coastal wetlands. For example, nutria were introduced into North America in the early 1900s for fur trade. This species consumes emergent vegetation at an unsustainable rate (Fig. 4.6d), which can result in subsidence. Programs have been developed to reduce nutria populations in Louisiana and Chesapeake Bay U.S. Reducing nutria populations has reduced wetland damage in Louisiana, U.S., without altering food habits of American alligators which opportunistically prey on them (Gabrey et al. 2009). Another species that has caused coastal marsh loss in North America is the snow goose. Snow goose populations have increased exponentially in North America since the 1990s (Alisauskas et al. 2011), possibly due to the expansion of rice farming in the southern U.S., which contributes to high winter survival. This species is gregarious and raises young in large flocks along the coastal marshes of James Bay and Hudson Bay, Canada. Overgrazing by snow geese has resulted in marsh subsidence and a change in vegetation to halophytic species (Srivastava and Jefferies 2002), which decreases habitat quality for various wetland dependent species (e.g., shorebirds).

4.3.3.6 Coastal Wetland Restoration

Coastal wetlands can be created by natural processes or anthropogenic modifications. The greatest challenge when creating a new coastal marsh is obtaining an appropriate surface elevation and flood frequency. Ideally, surface elevations will fall between high and low tide levels. Several excellent examples exist: tidal fresh marshes in the Bay of Fundy, Canada (Byers and Chmura 2007), Hudson River estuary, U.S. (Montalto et al. 2006), and cordgrass-dominated marshes on the Gulf of Mexico coast, U.S. (Nyman et al. 2009). Even when created at an appropriate elevation, decades may be required before a created wetland functions similar to an established wetland (Zedler 1993; Chamberlain and Barnhart 1993; Brusati et al. 2001; Craft et al. 2002; Levin and Talley 2002). There appear to be fewer differences between created and natural coastal wetlands when tidal or riverine energy, rather than dredging equipment, deposits the sediments (e.g., Poach and Faulkner 1998).
Below, we discuss natural (rivers and tides) and anthropogenic (dredging and terraces) techniques that can be used to create a coastal wetland.

Rivers can be used to create coastal wetlands in ways that mimic the natural processes of flooding, vertical accretion and erosion (Fig. 4.7, Kelly 1996). This technique is most commonly used in floodplain areas that were formerly wetlands but replaced by agricultural impoundments or open water due to unnatural rates of subsidence. The process involves creating openings in natural or artificial levees that permit water confined in river channels to enter adjacent shallow water areas where the unconfined water spreads, slows, and deposits sediments (Chabreck 1988). Such projects are called “sediment diversions,” even though they may actually be restoring historic river flow. Sediment diversions in the lower Mississippi River have increased the abundance of plants that are valuable waterfowl foods (Loga and Ensminger 1960), and have created wetlands at an average rate of 4.7 ha/year (Boyer et al. 1997). Although sediment elevation may increase in a diversion project, it may take >5 years for emergent plants to establish.

Similarly, tidal flow can be used to create wetlands where preexisting wetlands have been replaced by agriculture or salt production ponds. Restoring tidal flow to impounded, former wetlands is common on the Atlantic and Pacific Coasts of North America (Chamberlain and Barnhart 1993; Able et al. 2000), but less on the Gulf Coast because tidal energy and sediment availability are too low. Some coastal restorations have specific goals such as creating wading bird (Fell et al. 2000) or fish habitat (Simenstad et al. 2000), while others have been created by storms that breached levees (e.g., Byers and Chmura 2007). Success depends on sufficient tidal energy and sediments to result in vertical accretion. Success typically increases with surface elevation at time of restoration, sedimentation rate, and range of flooding tolerance by colonizing vegetation (Byers and Chmura 2007). On the Atlantic Coast, Perry et al. (2001) recommended grading sites to favor a low-elevation marsh rather than a high marsh to prevent establishment of phragmites, which can be invasive.

Sediment dredged from open water areas or navigation channels can be used to the raise elevation of the substrate under open water and create emergent wetlands (Fig. 4.6e). Sediments generally originate as a byproduct of dredging to maintain

![Fig. 4.7](image_url) These aerial photographs from Kelly (1996) show coastal wetlands that were created by the Mississippi River in the late 1900s following a sediment diversion, where the levee was breached to allow sediment to flow into a zone of open water (Published with kind permission of © Louisiana Department of Natural Resources, Baton Rouge, LA, USA 2013. All Rights Reserved)
depth of navigation channels (i.e., “beneficial use of dredged material” projects). Less often, dredging is conducted solely to obtain sediments for creating wetlands (i.e., “dedicated dredging” projects). Creating coastal wetlands with dredged material generally has been successful at creating new areas with emergent vegetation, but often the colonizing vegetation is less flood tolerant than intended because the elevation of the created wetland is too high (e.g., Curole and Huval 2005). In areas with firm substrates, success is greater than in areas where the substrate is poorly consolidated because the dredged material rapidly subsides (Chabreck 1989). Fine clays and silts in dredged material may remain unconsolidated long after placement and require a retaining structure for containment. In general, the final elevation of the wetland is more difficult to predict when dredged materials are fine clays and silts than when they are composed of sandy material (COE 1986). Wetlands created from dredged material typically have different soils and vegetation than natural wetlands, but those differences decline over decades (Edwards and Proffitt 2003). It is best if establishment of wetland plants on dredged material not be left to natural invasion because substantial erosion can occur before shorelines fully vegetate naturally (J.A. Nyman 2013, personal observation). Planting cordgrass is recommended for sites in intermediate and brackish marshes along the Gulf of Mexico (Eleuterius 1974). In more saline areas, smooth cordgrass (S. alterniflora) is to be planted below mean high tide, and cordgrass above mean high tide (Allen et al. 1978; Landin 1986). Fertilization is a common expense of these projects but does not appear to increase plant survival (Allen and Webb 1983), thus it may not be necessary. There are cases when sufficient seed sources and nutrients are available, making planting and fertilizing unnecessary (e.g., San Francisco Bay, U.S., Williams and Farber 2001). Shorebirds use natural and dredged wetlands similarly during migration, but not breeding (Brusati et al. 2001; Erwin and Beck 2007). Poor reproduction on dredged material has been attributed to high predation rates (Erwin and Beck 2007), but it is likely that other factors (e.g., sediment quality, topography) also influence reproduction in recently created coastal wetlands.

Terrace construction has been described as creating edge habitat in coastal wetlands. Terraces are constructed by dredging shallow open water areas and piling the dredged material in rows that are 5–20 m wide to form a linear, intertidal surface (Fig. 4.6f). Emergent vegetation (e.g., Spartina spp.) often is planted on the edges to accelerate the establishment of rooted vegetation. Terraces have been used frequently in coastal Louisiana and Texas, U.S., to slow erosion and increase accretion in adjacent wetlands. Terraces facilitate accretion by slowing wave and wind energy and allowing sediments to deposit. Unlike spoil banks, which are continuous and rise above normal tides, terraces are discontinuous and flood at high tide. It has been suggested that 1 ha of terrace (10 × 1,000 m) provides more fish and wildlife habitat than 1 ha (100 × 100 m) of created wetland because of the high ratio of edge to area with terraces (Rozas and Minello 2001; O’Connell and Nyman 2010). Several studies have documented increased abundances of submersed aquatic vegetation, invertebrates, fish and waterfowl associated with terraces (La Peyre et al. 2007; O’Connell and Nyman 2010).
4.4 Landowner Assistance Programs in the United States

Many federal, state, and non-governmental entities participate in wetland protection, restoration, and creation. Private landowners have many options available for obtaining technical assistance and compensation for protecting, restoring, and managing wetlands. The most prominent wetland programs in agricultural settings are administered by the USDA. The USDA provides technical and financial assistance to farmers through the Farm Service Agency’s Conservation Reserve Program (CRP) as well as the NRCS Wetlands Reserve Program (WRP) and Emergency Watershed Protection Program (EWPP). These programs provide cost-share for restoration, land rental payments for maintaining wetland improvement practices, or easement payments for long-term wetland protection. The USDA administers other programs, such as the Environmental Quality Incentives Program (EQIP) and the Wildlife Habitat Incentive Program (WHIP), that provide cost-share opportunities for landowners to install or implement practices which improve wildlife habitat and protect wetlands. The USFWS maintains the Partners for Fish and Wildlife Program (hereafter, Partners Program), which provides technical assistance to landowners seeking to improve wetland habitat for wildlife. The USFWS also purchases wetland easements to protect wetlands from draining, filling, and other modifications that could negatively affect their long-term function.

The WRP and CRP are currently active in most U.S. states. The CRP uses short-term contracts to establish conservation practices on private lands that improve water quality and wildlife habitat. Currently, there are 42 individual conservation practices within CRP, and many impact wetlands. For example, the farmable wetlands program can improve wetland habitats and reduce soil erosion and runoff through buffer installation (CP 28), adjacent upland conservation (CP41), and whole-wetland enrollment (CP 27, 39, 40). Other practices such as installation of filter strips in active working lands (CP21), grass in waterways (CP8), and riparian buffer protection and enhancement (CP22) provide a means to improve water quality and reduce soil loss. The WHIP and EQIP offer a wide variety of cost-share options to farmers and private landowners for improving conservation values on their lands without long-term contracts. For example, both programs could be used to install water control structures and weirs, plug ditches, remove exotic and invasive vegetation, and improve riparian areas by excluding livestock or planting soil-stabilizing vegetation. Similar to CRP, the WHIP and EQIP require short-term protection agreements with landowners in exchange for financial assistance to implement conservation practices.

The WRP protects, restores, and enhances functions and values of wetlands and adjacent uplands using mainly long-term easements (i.e., 30 year and perpetual). An easement is a binding agreement between the landowner and another party to sell certain values or rights associated with the land. Conservation easements often restrict future development and subdividing of lands, but allow landowners to retain most other rights and responsibilities (i.e., control of access, agriculture in designated areas, and mineral rights). The WRP restores wetlands on former
agricultural lands and can be tailored regionally to benefit wildlife and environmental needs. For example, in the MAV, landowners often plant most WRP lands to bottomland hardwood trees that are desirable mast producers for wildlife (e.g., oak trees) and construct impoundments with water control structures to allow management of herbaceous vegetation. In the Prairie Pothole Region of the northern Great Plains, U.S., WRP often includes plugging ditches that drain wetlands and protecting large amounts of associated upland habitats. In the midwestern U.S., WRP often includes a mix of bottomland forest plantings in stream and river bottoms, native grass planting in uplands, and removal of tile and other land drainage systems to restore hydrology. Similarly, EWPP can be used after natural disasters to remove infrastructure from floodplains and improve wildlife habitat and wetland function. The WRP, EWPP, CRP and other programs are often used in coordination or simultaneously to maximize landowner assistance and improve wetland function and values.

The USFWS Partners Program offers both technical and financial assistance to landowners to improve wildlife habitat. Although there are many practices implemented through the Partners Program, common examples include installation of fish passages, reconstruction of stream and riparian habitat, restoring wetland infrastructure, planting native bottomland trees, and removing exotic species. From 1987 to 2005, the Partners Program restored more than 30,000 ha of wetlands and 10,000 km of riparian and stream habitats. Often the Partners Program supplies the biological expertise needed by other organizations (e.g., NRCS) to implement wetland restoration programs (e.g., WRP). The USFWS also supplies direct financial assistance to landowners to improve wetlands and wildlife habitat (USFWS 2006). The USFWS administers the Small Wetlands Acquisition Program and the Wetland Easement Program which protects wetlands and upland habitats. The USFWS and other partners use funding from the purchase of Migratory Bird Hunting Stamps (i.e., duck stamps) and other sources to acquire waterfowl production areas in the Prairie Pothole Region of the U.S. The Partners Program typically requires short-term agreements with landowners to restore and improve wetland habitats. This program is often used to establish relations with private landowners, which can lead to later enrollment of their lands into permanent easement programs.

There are many other private land assistance programs administered by a large number of non-government organizations, state agencies, and other federal agencies. Many state agency’s natural resources departments administer state-funded landowner assistance programs similar to WHIP and EQIP. State agencies and non-governmental groups also commonly partner with NRCS to increase landowner compensation and technical assistance levels of federal programs. Non-government groups such as Ducks Unlimited, Trout Unlimited, Pheasants Forever, Quail Forever, the National Audubon Society, The Nature Conservancy, and many land trusts offer technical and financial assistance to landowners or offer their own conservation easements. An excellent first step in determining what landowner assistance programs may be most appropriate is contacting a local NRCS office, USFWS Partners Program biologist, or a state natural resources department.
References

Alisauskas RT, Rockwell RF, Dufour KW, Cooch EG, Zimmerman G, Drake KL, Leafloor JO, Moser TJ, Reed ET (2011) Harvest, survival, and abundance of midcontinent lesser snow geese relative to population reduction efforts. Wildl Monogr 179:1–42
Arthur SC (1931) The fur animals of Louisiana. Louisiana Department of Conservation, Bulletin 18, New Orleans, USA


de Szalay FA, Resh VH (1997) Responses of wetland invertebrates and plants important in waterfowl diets to burning and mowing of emergent vegetation. Wetlands 17:149–156


Eleuterius LN (1974) A study of plant establishment on dredge spoil in Mississippi Sound and adjacent waters. Gulf Coast Research Laboratory, Ocean Springs


Fogarty MJ (1965) Biological studies within the coastal marsh area east of Calcasieu Lake. Masters thesis. Louisiana State University, Louisiana

Foth JR (2011) Aquatic invertebrate biomass and community composition in greentree reservoirs and naturally flooded forests in the Mississippi Alluvial Valley and Interior Flatwoods. Thesis. Mississippi State University
Hagy HM, Kaminski RM (2012a) Apparent seed use by ducks in the Mississippi Alluvial Valley. J Wildl Manage 76:1053–1061
Kelly S (1996) Small sediment diversions. Louisiana Department of Natural Resources, Baton Rouge
King SL, Fredrickson LH (1998) Bottomland hardwood guidebook: the decision making process, design, management and monitoring of GTR’s. The Environmental Protection Agency, Dallas


Miller M (2003) CS–23 Hog Island Gully: west cove and headquarters canal structure replacement summary data and graphics. Louisiana Department of Natural Resources, Coastal Restoration Division, Baton Rouge, Louisiana
O’Neil T (1949) The muskrat in the Louisiana coastal Marsh. Louisiana Department of Wild Life and Fisheries, New Orleans


Reed DJ (1992) Effect of weirs on sediment deposition in Louisiana coastal marshes. Environ Manage 16:55–65


Sharp LA, Billodeau D (2007a) 2004 Operations, maintenance, and monitoring report for Cameron Creole Plugs (CS–17). Louisiana Department of Natural Resources, Coastal Restoration Division, Lafayette


Stover H (2008) A summary of Canadian and international wetland policy. Surplus Property Management Imperial Oil, Ltd., Calgary


Strickland BK, Kaminski RM, Nelms K, Tullos TA (2009) Waterfowl habitat management handbook for the lower Mississippi Alluvial Valley Mississippi State University Extension Service Publication 1864, Mississippi State, USA


Sullivan SMP, Watzin K, Tullos TA (2009) Waterfowl habitat management handbook for the lower Mississippi Alluvial Valley Mississippi State University Extension Service Publication 1864, Mississippi State, USA


Wehrle BW (1992) Invertebrate resources in Mississippi hardwood bottomlands, moist-soil habitat, and flooded cropland. Thesis, Mississippi State University

Student Exercises

The following are some brief ideas of classroom exercises for introducing students to wetland wildlife management.

Waterbird Food Selection (Classroom, 30–60 min)

Overview: Wetland plants often serve as an indicator of habitat quality for wildlife. In particular, seed, tuber, and aquatic invertebrate abundance can be used to assess wetland quality for waterfowl and other waterbirds. The abundance and distribution of food resources are among the most important factors that influence habitat selection by migratory waterfowl. As energy needs change throughout the annual cycle (see chapter discussion), so do the types of food consumed by waterbirds.

Goal: The goal of this exercise is to expose students to the concept of diet analysis and food selection. Knowing foods selected by waterbirds can help guide wetland management practices and teach students about the diversity of foods necessary to provide quality habitat for migratory waterfowl.

Exercise: Each student should be given a plastic bag that represents a duck’s digestive system. In each bag, put various amounts of different candy types, where each candy type represents a different major food group for waterfowl (i.e., aquatic invertebrates, moist-soil seed, acorns, agricultural seed, aquatic plants, and fish). For example, gummie fish or goldfish crackers could represent fish,
different colors of malted eggs could represent different invertebrates, candy corn could represent agricultural seeds such as corn, and jelly beans could represent different species of moist-soil seeds. If edible items are a concern, actual seeds and preserved aquatic invertebrates can be used.

Instructions: Each student should count and weigh to the nearest 0.1 g each of the food types and calculate aggregate percent mass (i.e., mass of a food type divided by total mass of all food types); see example below. For simplicity, assume that all food types are equally available in the wetland (which is rare), and determine which food types were consumed in greater proportion to their availability (hence selected). Indicate which food types were avoided and which were selected. Considering which food types were selected, discuss what wetland management techniques could be used to encourage abundance of these food types. The discussion can be done orally as a class or in teams, or individually as a written assignment.

<table>
<thead>
<tr>
<th>Species</th>
<th>Mass (g) consumed</th>
<th>Aggregate (%) mass</th>
<th>Percent availability</th>
<th>Duck response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish</td>
<td>0.0012</td>
<td>0.1</td>
<td>12.5</td>
<td>Avoid</td>
</tr>
<tr>
<td>Invertebrate 1</td>
<td>0.0145</td>
<td>0.5</td>
<td>12.5</td>
<td>Avoid</td>
</tr>
<tr>
<td>Invertebrate 2</td>
<td>0.1542</td>
<td>4.8</td>
<td>12.5</td>
<td>Avoid</td>
</tr>
<tr>
<td>Natural seed 1</td>
<td>0.0002</td>
<td>0.1</td>
<td>12.5</td>
<td>Avoid</td>
</tr>
<tr>
<td>Natural seed 2</td>
<td>0.897</td>
<td>27.9</td>
<td>12.5</td>
<td>Select</td>
</tr>
<tr>
<td>Natural seed 3</td>
<td>1.546</td>
<td>48.2</td>
<td>12.5</td>
<td>Select</td>
</tr>
<tr>
<td>Agricultural seed 1</td>
<td>0.567</td>
<td>17.7</td>
<td>12.5</td>
<td>Select</td>
</tr>
<tr>
<td>Agricultural seed 2</td>
<td>0.0246</td>
<td>0.7</td>
<td>12.5</td>
<td>Avoid</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.2</strong></td>
<td><strong>100</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Duck-Energy Days (Assignment)**

Overview: Duck-energy day (DED) estimates are used to evaluate wetland management techniques (e.g., burning versus disking) and determine management area contributions to the North American Waterfowl Management Plan sustainability objectives for states (e.g., Tennessee) and regions (e.g., Mississippi Alluvial Valley).

Goal: The goal of this assignment will be to expose students to three common methods (i.e., constants, direct estimate, prediction) used for estimating DEDs. This assignment will provide an understanding of the number of dabbling ducks that can be energetically sustained in a wetland or agricultural field for a given amount of time. The skills developed during this assignment are commonly used by waterfowl biologists.

Instructions: Each student will be required to work four problems on estimating DEDs. All work must be shown to receive full credit; however, you may use spreadsheet functions to assist in calculations (if approved by the instructor). Partial credit will be given for computational but not procedural errors. For all problems, use the DED equation in this chapter, with daily energy requirement (DER) of waterfowl = 294 kcal/day.
1. Estimate the DEDs for the following management area using the food abundance (kg/ha) and true metabolizable energy (TME, kcal/g) estimates in Table 4.1 of this chapter (do not use the DED/ac pre-calculations).

<table>
<thead>
<tr>
<th>Management Area</th>
<th>Food Item</th>
<th>kg/ha</th>
<th>TME (kcal/g)</th>
<th>DED (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Agricultural</td>
<td>Rice (harvested)</td>
<td>100</td>
<td>40</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Soybean (harvested)</td>
<td>100</td>
<td>40</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Rice (unharvested)</td>
<td>100</td>
<td>40</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Soybean (unharvested)</td>
<td>100</td>
<td>40</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Corn (unharvested)</td>
<td>100</td>
<td>40</td>
<td>2.5</td>
</tr>
<tr>
<td>(b) Moist-soil wetland</td>
<td></td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c) Hardwood bottomlands</td>
<td>30 % BA red oaks</td>
<td>167</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60 % BA red oaks</td>
<td>167</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 % BA red oaks</td>
<td>166</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Express answers separately for a, b, and c. Then, comment on why differences may exist in energetic carrying capacity among these components of the waterfowl habitat complex (i.e., Part a vs. b vs. c), particularly reflecting on yield and TME of food items. Note that acreage among components is equal (500 ha).

2. Commonly, 50 kg/ha is subtracted from available food estimates prior to calculating DEDs. This amount of food has been called the giving-up density (GUD) or food availability threshold (FAT), and is considered the amount of food when most dabbling ducks quit foraging because it becomes too energetically costly to continue searching for food. This premise has foundation in optimal foraging theory. For Problem #1 (Part A), recalculate DEDs for harvested and unharvested soybean, and comment on difference in the number of ducks supported when GUD is considered in DED estimates.

3. Suppose that you directly estimated dry mass (g) of acorns in a bottomland using a standardized technique (e.g., plot sampling), and learned that acorn production for cherrybark oak, water oak and willow oak was 8, 3, and 0.75 g/m², respectively. Using Table 1 in Kaminski et al. (2003), estimate the number of wood ducks that could be energetically sustained on acorn resources alone if 75% of the bottomland was flooded for 50 days. Assume that acorn resources are accessible by wood ducks when the bottomland is flooded only. Total bottomland area = 1,052 ha. Discuss the relative contributions of each oak species to wood duck energy-days.


4. Given the following morphological measurements and using Gray et al. (1999b):

<table>
<thead>
<tr>
<th>Plant species</th>
<th>Moist-soil plant morphological measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HT</td>
</tr>
<tr>
<td>Fall panicum</td>
<td>1.25</td>
</tr>
<tr>
<td>Barnyardgrass</td>
<td>0.75</td>
</tr>
</tbody>
</table>
• First, estimate IV using the geometric equation for a cone given in footnote E in Table 1 of Gray et al. (1999b). Next, using the appropriate variables, estimate dry seed mass (g) per plant per species using Gray et al. (1999b) equations.

• Next, estimate total DED of this wetland (500 ha) using above predictions of seed yield/plant, an average density of eight plants/m² (for both species), and TME values (for mallards) in Kaminski et al. (2003).

• If this wetland is flooded for 110 days, how many mallards per day could be potentially sustained energetically in it on these seed resources?


5. Gray et al. (2009) discuss a rapid and accurate procedure for estimating seed production in moist-soil wetlands by scanning seed-head area (cm²). Seed-head area can be estimated using portable or desktop leaf-area scanner. Estimated area is entered into equations in Gray et al. (2009) to predict seed production (g/plant) and this value is multiplied by stem density estimated in the wetland. To facilitate calculations, a spreadsheet with these equations can be downloaded at: http://fwf.ag.utk.edu/mgray/DED/DED.htm.

Suppose average seed-head area per plant estimated using a LI-COR LI-3100 desktop scanner = 50 cm² for barnyard grass, 50 cm² for redroot flatsedge, and 50 cm² for curlytop knotgrass. Also, suppose that average density for each of these plant species = 1 plant/m². Using the spreadsheet, enter seed-head area and stem density for each plant species in the “desktop” scanner row for the appropriate plant species. Record the seed mass prediction (kg/ha) and DED estimate, and discuss why these values differ among plant species, considering that scanned area and stem density were identical. It has been suggested that total seed production $<200$ kg/ha represents poor seed yield, while $>600$ kg/ha is high seed production. How would you classify seed production in this wetland and what might be some causes for the existing seed production?


Managing Nuisance Canada Geese (Class Debate and Exercise, Two Class Periods)

Overview: Giant Canada geese (*Branta canadensis maxima*) were once relatively rare throughout mid-continental North America. However, harvest management, restoration efforts, and changes in agricultural practices have led to increases in Canada goose populations and conflicts with human land use. However, many individuals value Canada geese, so managing geese that are found to be a nuisance is not always a straight-forward process.
Goal: The goal of this exercise is to present students with a realistic situation where Canada geese are abundant and deemed problematic by some individuals but not others. Students will build logic and debating skills useful in resolving natural resource conflicts.

Exercise: Canada geese may be especially abundant near urban areas, where they may be largely undisturbed, yet these geese will also disperse to suburban or rural areas as populations increase. In this scenario, several farmers adjacent to moderate-sized city (e.g., population = 250,000) have requested removal of Canada geese that have bred in the area and are causing substantial damage to their emerging soybean crops. The farmers have requested the state natural resource agency destroy the birds immediately to stop their financial loss. Word of the farmers’ request has reached user groups, such as the local Ducks Unlimited chapter and bird watchers, who are upset about the possible removal of the geese. Local environmentalists on the other hand think it is a good idea to reduce population size because the geese and their young are defecating in a nearby water source, negatively affecting water quality, and serving as a possible source for harmful bacteria. The state natural resource agency has called a public hearing to discuss concerns on all sides before developing a conflict–resolution plan.

Instructions: Divide the class into four groups = farmers, bird watchers, local Ducks Unlimited chapter, and environmentalists. Each group is responsible for making an argument for why or why not the geese should be removed. It is recommended that each group be allowed 1 week to perform research and prepare their statement. The instructor (serving as the natural resource agency) will facilitate the discussion. After points are made by each group, the class needs to work together to develop a conflict-resolution plan. Innovative solutions are encouraged.

Biological Feedbacks from Nuisance Nutria
(Take-Home Exercise)

Overview: Nutria (Myocaster coypus) is an exotic rodent to North America that was introduced for fur trade. In Louisiana, this species has had significant effects on coastal marsh vegetation and ecosystem processes. The effect of a species on ecosystem processes is called a biological feedback. You will be required to read Carter et al. (1999) and discuss how nutria create a biological feedback and contribute to coastal marsh loss.

Goal: The goal of this exercise is to increase familiarity with coastal wetland function, reflect on management activities that might be effective at controlling nutria, and strengthen skills in reading and comprehending scientific papers.
Instructions: Review the three models (nutria, biomass, and area) proposed by Carter et al. (1999), and determine: (1) what factors are most influential in nutria contributing to marsh loss, and (2) what time of year is nutria herbivory most detrimental. If you were going to attempt to restore a marsh with high densities of nutria, what management techniques would you use and why?


\textbf{Moist-soil Management Prescriptions}

(Assignment or Take–Home Exam Question; Group or Individual)

Overview: As your first professional position as a wildlife biologist, you have been given the responsibility to manage a moist-soil complex with ten impoundments (see below). Each impoundment is 6 ha with a drop-board water control structure at its lowest end. Elevation changes gradually across each impoundment, encompassing four 0.3-m (1 ft) contours. There is a water supply channel that runs through the middle of the complex. Each impoundment can be flooded independently by allowing the water to flow through the water control structure; assume that water is not limiting. Impoundments are in different stages of vegetative succession (early, mid, and late). You can assume moist-soil seed production in the late, mid, and early successional impoundments is 200, 400, and 600 kg/ha. Historical surveys indicate that approximately 5,000 dabbling ducks will use the complex each day for 110 days during migration and winter. Occasionally, diving ducks (\textit{Aythya affinis}, \textit{A. collaris}) use the deeper ends of impoundments when they are flooded, and Canada geese roost in open water areas. The area is currently closed to waterfowl hunting but the director of your natural resource agency wants to open hunting on at least a portion of the area or during certain days of the week. You are responsible for crafting a management plan for this complex that provides habitat for breeding wood ducks and amphibians, migrating shorebirds, and migrating and wintering waterfowl. You also need to draft recommendations for hunting. Although the director is comfortable with managing this area for non-game wetland wildlife, the focus of management activities should be on waterfowl.

Goal: The goal of this exercise is to apply concepts and techniques in this chapter to a realistic scenario. This exercise will strengthen the understanding of wetland wildlife life cycle needs and how to use management techniques to meet those needs as well as public demands of hunting.
Instructions:

1. Assume that all impoundments are flooded in January, and describe specifically how you would manipulate the hydrology in each impoundment through one annual cycle to provide habitat for the aforementioned wetland wildlife. The date and rate of drawdown and flooding should be described, and correspond with activities proposed in (2). For each impoundment, indicate how your prescriptions will affect wildlife use.

2. Reflecting on the existing stages of succession in each impoundment, describe a 3-year rotational schedule for performing mechanical manipulations to set back succession. The date, acreage, and configuration of the manipulations should be described for each impoundment.

3. For impoundments that are drawn down in spring, assume that moist-soil vegetation structure is robust and coverage is 100% by the end of the growing season. Describe what techniques you plan to use to facilitate waterfowl access to these food resources.

4. For one of the late successional impoundments, assume that after performing your prescribed manipulation a dense stand of *Sesbania exaltata* establishes and is shading out beneficial moist-soil plants. What do you plan to do control this invasive plant?

5. Estimate the existing DEDs for this complex using Table 4.1 and the seed production estimates above, and compare it with expected dabbling duck use. At present, there are insufficient food resources from moist-soil seed production alone to energetically sustain 5,000 ducks/day for 110 days. Determine how many ha (or acres) of corn versus millet needs to be planted to meet the expected energy demand of dabbling ducks using this area. Second, describe where you intend to plant these food plots.