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., disking, 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

J.T. Anderson and C.A. Davis (eds.), *Wetland Techniques: Volume 3: Applications and Management*, DOI 10.1007/978-94-007-6907-6_4,

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 [*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

Fig. 4.1 (continued) (http://digitalmedia.fws.gov/). Figure is public domain in the USA. All Rights Reserved; **d**: Photo by Joshua Stafford; **e**, **f**: Published with kind permission of © Clayton Ferrell, U.S. Fish and Wildlife Service, New Johnsonville, Tennessee, USA 2013. All Rights Reserved)

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 $\leq$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.

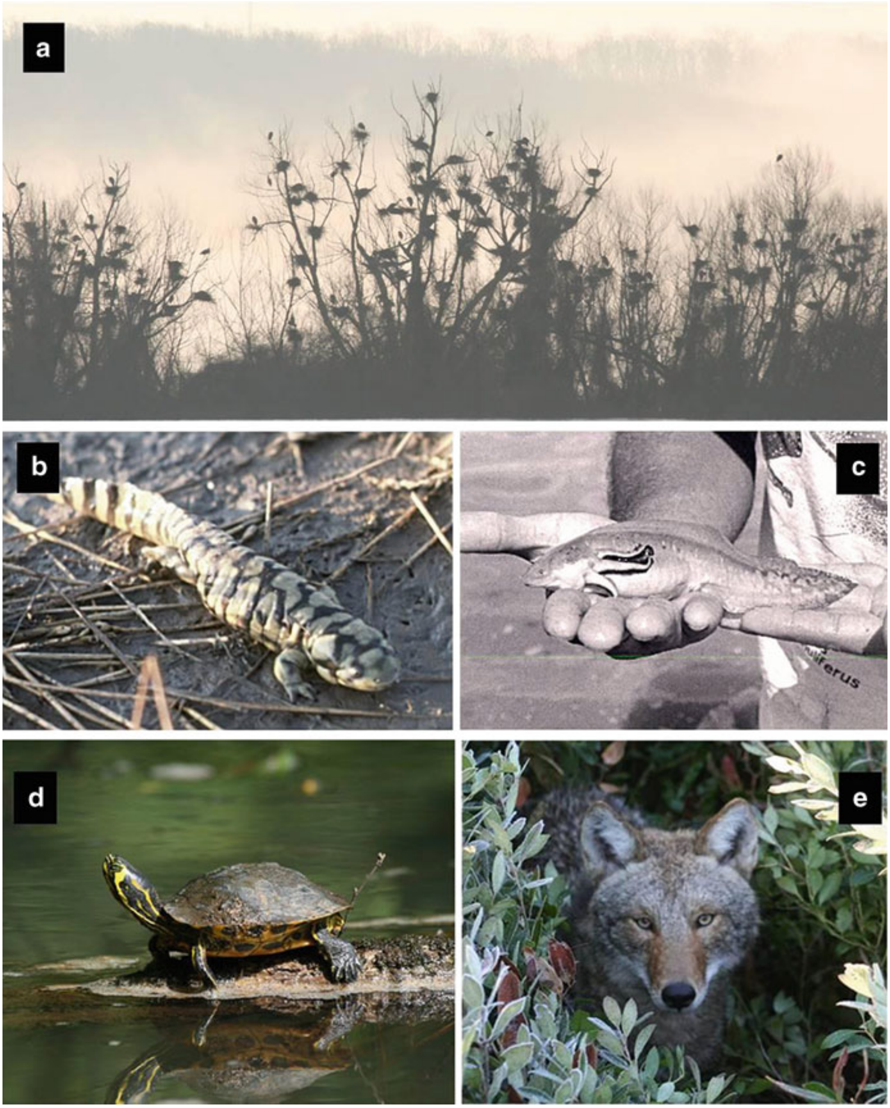


Fig. 4.2 (**a**) Many wading bird species nest in trees in large colonies called rookeries, (**b**) it is estimated that >40 % of salamander species are declining, (**c**) tiger salamander larvae can be voracious predators, (**d**) semi-aquatic turtle species need basking logs, and (**e**) various mammalian 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 clearcut 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),

Fig. 4.3 (**a**) Conversion of wetlands to agriculture is a leading cause of declining acreage, (**b**) the prairie potholes of North America provide habitat for numerous wildlife species, (**c**) an actively managed early successional wetland dominated by barnyardgrass (*Echinochloa crus-galli*), (**d**) fall disking to set back succession, (**e**) fall mowing open dense vegetation and create a hemi–marsh configuration following flooding, and (**f**) a passively managed moist-soil wetland dominated by perennial plants (Sources: **a**: Published with kind permission of © Scott Manley, Ducks Unlimited, Inc., Ridgeland, MS, USA 2013. All Rights Reserved; **b**: Published with kind permission of © Barry Pratt 2013. All Rights Reserved; **c**, **d**, **e**, **f**: Photos by Heath Hagy)

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 disking 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 disking 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 ($\geq$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.

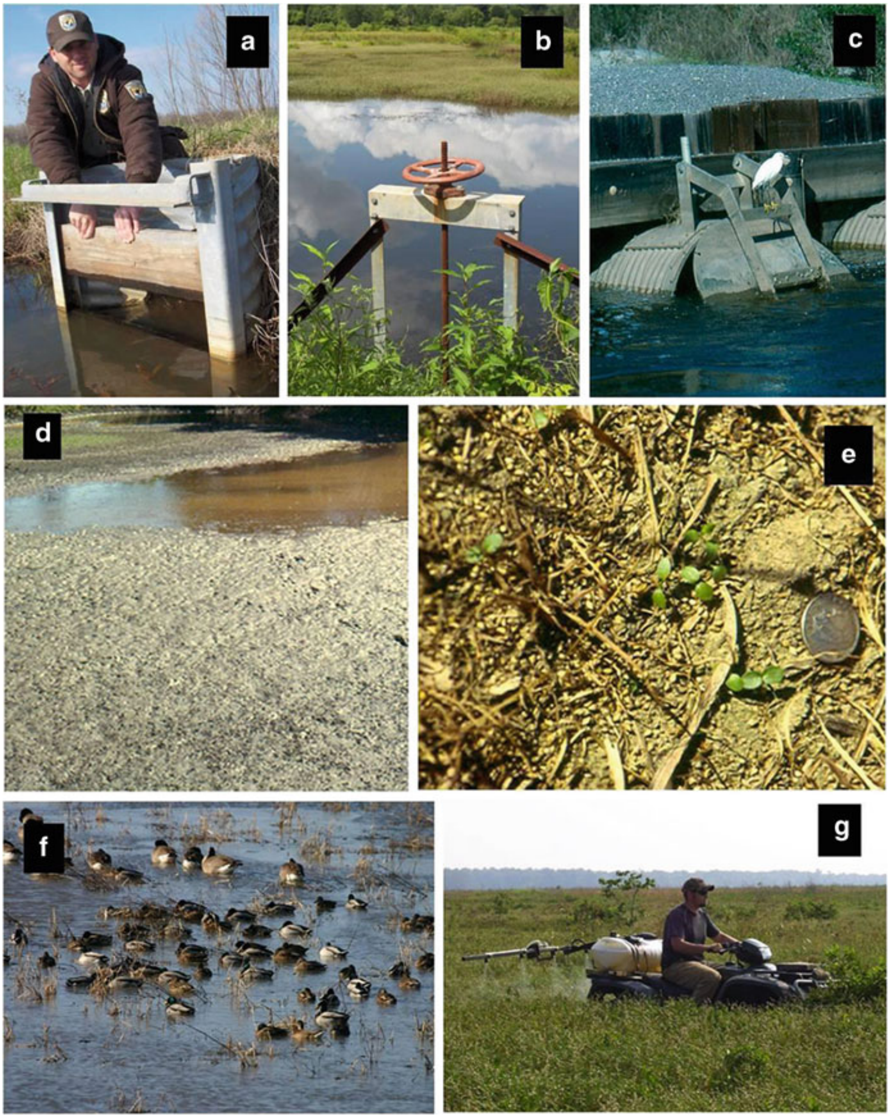


Fig. 4.4 (**a**) Drop-board, (**b**) screw gate, and (**c**) flap gate water control structures, (**d**) exposed mudflats are excellent foraging locations for shorebirds, (**e**) seeds on mudflats germinate and develop into moist-soil plants, (**f**) waterfowl can acquire high-energy seed and proteinaceous 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-latitudinal 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

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

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

[a]Kg/ha; To convert food available to lbs/ac, multiple kg/ha times 0.8922

[b]TME 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

[c]DEDs 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,

(continued)

Table 4.1 (continued)

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

[d]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)

[e]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)

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

[g]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)

[h]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)

[i]Based primarily on Stafford et al. (2006)

[j]Based on Foster et al. (2010a)

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

[l]Matthew McClanahan and Joshua Osborn, University of Tennessee, unpublished data

[m]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)

Table 4.1 (continued)

[n]We calculated DEDs for invertebrates separately from seeds and tubers and added those to this column. For moist-soil, we used our professional judgment to approximate 25 kg/ha of invertebrate mass based on nektonic estimates of Hagy and Kaminski (2012b; 2.5 kg/ha; MAV control plots) and Gray et al. (1999a; 4 kg/ha) and unpublished benthic estimates from the University of Tennessee (22 kg/ha). In harvested crops, we used 13.6 kg/ha for rice (Manley et al. 2004), 0.52 for grain sorghum (Wehrle 1992), 0.03 kg/ha in corn (Hagy et al. 2011a) and 10 kg/ha in flooded soybean (Whittington 2005). We used a mean TME value (0.95 kcal/g) based on the mean TMEs of invertebrates measured in 3 species of dabbling ducks (northern pintail [n = 3 taxa], blue-winged teal [n = 8 taxa], and American black duck [*Anas rubripes*; n = 4 taxa]) and reported in Appendix B in Cramer (2009) (see[h])

[o]One limitation of values in Table 4.1 is the estimate of DEDs for a specific wetland or agricultural field will only be impacted by acreage. Natural variation in available moist-soil seed, acorns and agricultural seed is expected among sites and years due to variation in abiotic and biotic factors (Gray et al. 1999a; Foster et al. 2010a). Moreover, wetland management can affect seed production, yet Table 4.1 predicts the same DED estimate every year for a specific site unless acreage changes. Onsite estimates provide a more accurate representation of seed yield at a particular site; however, existing models are only available for moist-soil wetlands (Gray et al. 2009). Yields for agricultural crops likely differ less than natural wetlands because of the standardization of modern production agriculture; hence, the values in Table 4.1 for agricultural seed are likely less variable than natural wetlands

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).

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

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)

(continued)

unharvested flooded corn would be needed (77,864 DED/ha [Table 4.1] $\times$ 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 in 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

(Neely 1962; Moore et al. 1999). 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

1980; Hatton et al. 1983; Bricker–Urso et al. 1989; Nyman et al. 1993a; Callaway et al. 1997; Neubauer 2008).

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).

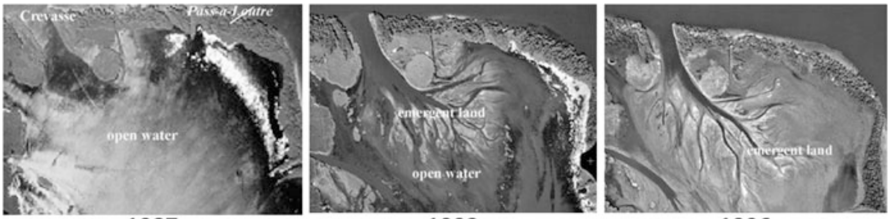
Fig. 4.6 (**a**) Cover burn set at Rockefeller Wildlife Refuge, Louisiana, U.S., (**b**) coastal marsh vegetation responding quickly after a cover burn, (**c**) creation of navigation channels through coastal wetlands causes saltwater intrusion and marsh loss, (**d**) exotic nutria (*Myocastor coypus*) 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).



1987 1993 1996

Fig. 4.7 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)

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 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 ($10 \times 1{,}000$ 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

Abernethy Y, Turner RE (1987) United States forested wetlands 1940–1980. Bio Sci 37:721–727

Able KW, Nemerson DM, Light PR, Bush RO (2000) Initial response of fishes to marsh restoration at a former salt hay farm bordering Delaware Bay. In: Weinstein MP, Kreeger DA (eds) Concepts and controversies in tidal marsh ecology. Boston, MA

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

Allen HH, Webb JW (1983) Erosion control with salt marsh vegetation. Symp Coast Ocean Manage 3:735–748

Allen HA, Clairain EV Jr, Diaz RJ, Ford AW, Hunt HL, Wells BR (1978) Habitat development field investigation, Bolivar Peninsula, marsh and upland habitat development site, Galveston Bay, Texas. U. S. Army Corps of Engineers, Waterways Experiment Station technical report D–78–15

Arnold TW, Craig–Moore LM, Armstrong LM, Howerter DW, Devries JH, Joynt BL, Emery RB, Anderson MG (2007) Waterfowl use of dense nesting covers in the Canadian Parklands. J Wildl Manage 71:2542–2549

Arthur SC (1931) The fur animals of Louisiana. Louisiana Department of Conservation, Bulletin 18, New Orleans, USA

Baldassarre GA, Bolen EG (1984) Field feeding ecology of waterfowl wintering on the southern high plains of Texas. J Wildl Manag 48:63–71

Baldassarre GA, Bolen EG (2006) Waterfowl ecology and management. Krieger Publishing Company, Malabar

Ball IJ, Ball SK (1991) Earth–filled culverts as nest sites for waterfowl. Prairie Nat 23:85–88

Ball IJ, Bauer RD, Vermeer K, Rabenbery MJ (1989) Northwest riverine and Pacific Coast. In: Smith LM, Pederson RL, Kaminski RM (eds) Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock

Ballard BM, Thompson JE, Petrie MJ, Checkett JM, Hewitt DG (2004) Diet and nutrition of northern pintails wintering along the southern coast of Texas. J Wildl Manage 68:371–382

Barney ES (2008) Change in availability and nutritional quality of postharvest waste corn on waterfowl staging areas near Long Point, Ontario. Thesis, University of Western Ontario

Barras SC, Kaminski RM, Brennan LA (1996) Acorn selection by female wood ducks. J Wildl Manage 69:592–602

Batema DL, Kaminski RM, Magee PA (2005) Wetland invertebrate communities and management of hardwood bottomlands in the Mississippi Alluvial Valley. In: Fredrickson LH, King SL, Kaminski RM (eds) Ecology and management of bottomland hardwood systems: the state of our understanding. University of Missouri-Columbia, Gaylord Memorial Laboratory Special Publication No. 10, Puxico, Missouri, USA

Bellrose FC, Anderson HG (1943) Preferential rating of duck food plants. Ill Nat Hist Surv Bull 22:417–433

Bellrose FC, Holm DJ (1994) Ecology and management of the wood duck. Stackpole Books, Mechanicsburg

Benoit LK, Askins RA (1999) Impact of the spread of *Phragmites* on the distribution of birds in Connecticut tidal marshes. Wetlands 19:194–208

Bolen EG, Robinson WL (2003) Wildlife ecology and management. Prentice Hall, Upper Saddle River

Bourn WS, Cottam C (1950) Some biological effects of ditching tidewater marshes. U.S. Department of the Interior, Fish and Wildlife Service Research Report 19

Boyer ME, Harris JO, Turner RE (1997) Constructed crevasses and land gain in the Mississippi River delta. Restor Ecol 5:85–92

Brasher MG, Steckel JD, Gates RJ (2007) Energetic carrying capacity of actively and passively managed wetlands for migrating ducks in Ohio. J Wildl Manage 71:2532–2541

Brawley AH, Warren RS, Askins RA (1998) Bird use of restoration and reference marshes within the Barn Island wildlife management area, Stonington, Connecticut, USA. Environ Manage 22:625–633

Bricker–Urso S, Nixon SW, Cochran JK, Hirschberg DJ, Hunt C (1989) Accretion rates and sediment accumulation in Rhode Island salt marshes. Estuaries 12:300–317
Brown S, Hinkey C, Harrington B, Gill R (eds) (2001) The U.S. shorebird conservation plan. Manomet, MA
Brunson NW, Griffin JI (1988) Comparison of rice–crayfish and grain sorghum–crayfish double cropping systems. Aquaculture 72:265–272
Brusati ED, DuBowy PJ, Lacher TE Jr (2001) Comparing ecological functions of natural and created wetlands for shorebirds in Texas. Waterbirds 24:371–380
Burton EC, Gray MJ, Schmutzer AC, Miller DL (2009) Differential responses of postmetamorphic amphibians to cattle grazing in wetlands. J Wildl Manage 73:269–277
Bush Thom CS, La Peyre MKG, Nyman JA (2004) Evaluation of nekton use and habitat characteristics of restored Louisiana marsh. Ecol Eng 23:63–75
Byers SE, Chmura GL (2007) Salt marsh vegetation recovery on the Bay of Fundy. Estuar Coasts 30:869–877
Cahoon DR (1994) Recent accretion in two managed marsh impoundments in coastal Louisiana. Ecol Appl 4:166–176
Callaway JC, DeLaune RD, Patrick WH Jr (1997) Sediment accretion rates from four coastal wetlands along the Gulf of Mexico. J Coast Res 13:181–191
Canadian Wildlife Service and U.S. Fish and Wildlife Service (CWS) (1986) North American waterfowl management plan. Canadian Wildlife Service and U.S. Fish and Wildlife Service. Washington, DC
Chabreck RH (1979) Winter habitat of dabbling ducks: physical, chemical, and biological aspects. In: Bookhout TA (ed) Waterfowl and wetlands: an integrated review. North Central Section, The Wildlife Society, Madison
Chabreck RH (1988) Coastal marshes: ecology and wildlife management. University of Minnesota Press, Minneapolis
Chabreck RH (1989) Creation, restoration and enhancement of Northcentral Gulf coast marshes. In: Kusler JA, Kentula ME (eds) Wetland creation and restoration: the status of the science, vol I. Regional reviews. Environmental Protection Agency, Research Laboratory. EPA/600/3–89/038a. Corvallis, OR
Chamberlain RH, Barnhart RA (1993) Early use by fish of a mitigation salt marsh, Humboldt Bay, California. Estuaries 16:769–783
Chouinard KM (1999) Grassland songbird use of waterfowl nesting cover in southwestern Manitoba. Thesis, Humboldt State University
Chouinard MD, Kaminski RM, Gerard PD, Dinsmore SJ (2005) Experimental evaluation of duck nesting structures in prairie parkland Canada. Wildl Soc Bull 33:1321–1329
Combs DL, Fredrickson LH (1996) Foods used by male mallards wintering in southeastern Missouri. J Wildl Manage 60:603–610
Costanza R, D'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387:253–260
Craft C, Broome S, Campbell C (2002) Fifteen years of vegetation and soil development after brackish–water marsh creation. Restor Ecol 10:248–258
Cramer DM (2009) Estimating habitat carrying capacity for American black ducks wintering in southern New Jersey. Thesis, University of Delaware
Cross D, Vohs P (eds) (1988) Waterfowl management handbook. U. S. Fish and Wildlife Service, Fort Collins
Croxall JP, Butchart SHM, Laschelles B, Stattersfield AJ, Sullivan B, Symes A, Taylor P (2012) Seabird conservation status, threats and priority actions: a global assessment. Bird Conserv Int 22:1–34
Curole GP, Huval DL (2005) West Belle Pass Headland Restoration TE–23 (PTE–27) Comprehensive report No. 1. Louisiana Department of Natural Resources, Baton Rouge, Louisiana. Monitoring series No. TE–23–MSTY–0605–1. http://lacoast.gov/reports/cmp/TE23_Comp1.pdf. Accessed 17 Sept 2012

Dahl TE (2006) Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Fish and Wildlife Service, Washington, DC
Davis JB, Stephens SE, Leopold BD, Kaminski RM, Gerard PD (1999) Wood duck reproduction in small and large nest boxes in Mississippi: a continued experiment. Proc Southeast Assoc Fish Wildl Agencies 53:257–269
DeLaune RD, Nyman JA, Patrick WH Jr (1994) Peat collapse, ponding, and wetland loss in a rapidly submerging coastal marsh. J Coast Res 10:1021–1030
De Steven D, Lowrance R (2011) Agricultural conservation practices and wetland ecosystem services in the wetland–rich Piedmont–Coastal Plain region. Ecol Appl 21:S3–S17
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
Dickson JG (2001) Wildlife of southern forests: habitat and management. Hancock House Publishers, Ltd., Blaine
Dosskey MG (2001) Toward quantifying water pollution abatement in response to installing buffers on cropland. Environ Manage 28:577–598
Doty HA, Lee FB, Druse AD (1975) Use of elevated nest baskets by ducks. Wildl Soc Bull 3:68–73
Duebbert HF, Lokemoen JT (1980) High duck nesting success in a predator–reduced environment. J Wildl Manage 44:428–437
Durham RS, Afton AD (2003) Nest–site selection and success of mottled ducks on agricultural lands in southwest Louisiana. Wildl Soc Bull 31:433–442
Edwards KR, Proffitt CE (2003) Comparison of wetland structural characteristics between created and natural salt marshes in southwest Louisiana, USA. Wetlands 23:344–356
Eleuterius LN (1974) A study of plant establishment on dredge spoil in Mississippi Sound and adjacent waters. Gulf Coast Research Laboratory, Ocean Springs
Erwin RM, Beck RA (2007) Restoration of waterbird habitats in Chesapeake Bay: great expectations or Sisyphus revisited? Waterbirds 30:163–176
Ervin GN, Majure LC, Bried JT (2006) Influence of long–term greentree reservoir impoundment on stand structure, species composition, and hydrophytic indicators. J Torrey Bot Soc 133:468–481
Evans DM, Day KR (2002) Hunting disturbance on a large shallow lake: the effectiveness of waterfowl refuges. Ibis 144:2–8
Evans-Peters GR, Dugger BD, Petrie MJ (2012) Plant community composition and waterfowl food production on wetland reserve program easements compared to those on managed public lands in western Oregon and Washington. Wetlands 32:391–399
Faulkner S, Barrow W Jr, Keeland B, Walls S, Telesco D (2011) Effects of conservation practices on wetland ecosystem services in the Mississippi Alluvial Valley. Ecol Appl 21:S31–S48
Fell PE, Warren RS, Neiring WA (2000) Restoration of salt and brackish tidelands in southern New England: angiosperms, macro invertebrates, fish, and birds. In: Weinstein MP, Kreeger DA (eds) Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, Boston
Fennessy MS, Jacobs AD, Kentula ME (2004) Review of rapid methods for assessing wetland condition. U.S. Environmental Protection Agency Publication EPA/620/R–04/009, Washington, DC, USA
Fleming KS (2010) Effects of management and hydrology on vegetation, winter waterbird use, and water quality on Wetlands Reserve Program lands. Thesis, Mississippi State University, Mississippi
Flores C, Bounds DL, Ruby Douglas E (2011) Does prescribed fire benefit wetland vegetation? Wetlands 31:35–44
Fogarty MJ (1965) Biological studies within the coastal marsh area east of Calcasieu Lake. Masters thesis. Louisiana State University, Louisiana
Ford WM, Rodrigue JL, Rowan EL, Castleberry SB, Schuler TM (2010) Woodland salamander response to two prescribed fires in the central Appalachians. For Ecol Manage 260:1003–1009

Foster MA, Gray MJ, Kaminski RM (2010a) Agricultural seed biomass for migrating and wintering waterfowl in the southeastern United States. J Wildl Manage 74:489–495

Foster MA, Gray MJ, Harper CA, Walls JG (2010b) Comparison of agricultural seed loss in flooded and unflooded fields on the Tennessee National Wildlife Refuge. J Fish Wildl Manage 1:43–46

Foster MA, Gray MJ, Harper CA, Kaminski RM (2011) Post–harvest fates of agricultural seeds in Tennessee croplands. Proc Southeast Assoc Fish Wildl Agencies 64:81–87

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

Fox AD, Madsen J (1997) Behavioural and distributional effects of hunting disturbance on waterbirds in Europe: implications of refuge design. J Appl Ecol 34:1–13

Fredrickson LH (2005) Contemporary bottomland hardwood systems: structure, function and hydrologic condition resulting from two centuries of anthropogenic activities. In: Fredrickson LH, King SL, Kaminski RM (eds) Ecology and management of bottomland hardwood systems: the state of our understanding. University of Missouri–Columbia, Gaylord Memorial Laboratory Special Publication No. 10, Puxico, Missouri

Fredrickson LH, Batema DL (1992) Greentree reservoir management handbook. Gaylord Memorial Laboratory, Wetland management series 1

Fredrickson LH, Reid FA (1988) Waterfowl use of wetland complexes. Waterfowl management handbook – fish and wildlife leaflet 13.2.1. U.S. Fish and Wildlife Service, Washington, DC, USA

Fredrickson LH, Taylor TS (1982) Management of seasonally–flooded impoundments for wildlife. U.S. Fish and Wildlife Service Resource Publication 148, Washington, DC

Frost CC (1995) Presettlement fire regimes in southeastern marshes, peatlands, and swamps. In: Cerulean SI, Engstrom RT (eds) Proceedings 19th tall timbers fire ecology conference: fire in wetlands: a management perspective. Tall Timbers Research Inc., Tallahassee

Gabrey SW, Kinler N, Elsey RM (2009) Impacts of nutria removal on food habits of American alligators in Louisiana. Southeast Nat 8:347–354

Garrettson PR, Rohwer FC (2001) Effects of mammalian predator removal on upland–nesting duck production in North Dakota. J Wildl Manage 65:445–452

Gibbons JW, Scott DE, Ryan TJ, Buhlmann KA, Tuberville TD, Metts BS, Greene JL, Mills T, Leiden Y, Poppy S, Winne CT (2000) The global decline of reptiles, deja vu amphibians. BioScience 50:653–656

Gibbs JP (1998) Amphibian movements in response to forest edges, roads, and streambeds in southern New England. J Wildl Manage 62:584–589

Grado SC, Hunt KM, Hutt CP, Santos XT, Kaminski RM (2011) Economic impacts of waterfowl hunting in Mississippi derived from a state–based mail survey. Hum Dimens Wildl 16:100–113

Gray MJ, Kaminski RM (2005) Effect of continuous vs. periodic winter flooding on bottomland hardwood seedlings in Mississippi greentree reservoirs. In: Fredrickson LH, King SL, Kaminski RM (eds) Ecology and management of bottomland hardwood systems: the state of our understanding. University of Missouri, Gaylord Memorial Laboratory Special Publication Number 10, Puxico, Missouri

Gray MJ, Summers EA (2012) Standard bioassessment procedures for evaluating ecological restoration in southeastern hardwood bottomlands. University of Tennessee Institute of Agriculture Research Report 12–04

Gray MJ, Kaminski RM, Weerakkody G, Leopold BD, Jensen KC (1999a) Aquatic invertebrate and plant responses following mechanical manipulations of moist-soil habitat. Wildl Soc Bull 27:770–779

Gray MJ, Kaminski RM, Weerakkody G (1999b) Predicting seed yield of moist-soil plants. J Wildl Manage 63:1261–1268

Gray MJ, Kaminski RM, Brasher MG (1999c) A new method to predict seed yield of moist-soil plants. J Wildl Manage 63:1269–1272

Gray MJ, Foster MA, Peña Peniche LA (2009) New technology for estimating seed production of moist-soil plants. J Wildl Manage 73:1229–1232
Greer DM, Dugger BD, Reinecke KJ, Petrie MJ (2009) Depletion of rice as food of waterfowl wintering in the Mississippi Alluvial Valley. J Wildl Manage 73:1125–1133
Griffith RE (1940) Waterfowl management on Atlantic coast refuges. Trans North Am Wildl Conf 5:373–377
Guttery MR (2006) Evaluation of artificial regeneration of oaks, willow oak acorn production, light conditions following midstory control, and the effects of long–term annual flooding on forest vegetative composition in an Arkansas greentree reservoir. Thesis, Mississippi State University
Hagy HM (2010) Winter food and waterfowl dynamics in managed moist-soil wetlands in the Mississippi Alluvial Valley. Dissertation, Mississippi State University
Hagy HM, Foth JR, Kaminski RM (2011a) Invertebrate biomass in flooded corn and other wetlands managed for wintering waterfowl in the Mississippi Alluvial Valley. Proc Southeast Assoc Fish Wildl Agencies 65:56–61
Hagy HM, Straub JN, Kaminski RM (2011b) Estimation and correction of seed recovery bias from moist-soil cores. J Wildl Manage 75:959–966
Hagy HM, Kaminski RM (2012a) Apparent seed use by ducks in the Mississippi Alluvial Valley. J Wildl Manage 76:1053–1061
Hagy HM, Kaminski RM (2012b) Winter waterbird and food dynamics in autumn–managed moist-soil wetlands of the Mississippi Alluvial Valley. Wildl Soc Bull 36:512–523
Hamrick B, Strickland B (2010) Supplemental wildlife food planting manual for the Southeast. Mississippi State University Extension Publication 2111, Mississippi State, USA
Harding EK, Doak DF, Albertson JD (2001) Evaluating the effectiveness of predator control: the non–native red fox as a case study. Conserv Biol 15:1114–1122
Harpole DN, Haas CA (1999) Effects of seven silvicultural treatments on terrestrial salamanders. For Ecol Manage 114:349–356
Hatton RS, DeLaune RD, Patrick WH Jr (1983) Sedimentation, accretion, and subsidence in marshes of Barataria Basin, Louisiana. Limnol Oceanogr 28:494–502
Havens JH, Kaminski RM, Davis JB, Riffell SK (2009) Winter abundance of waterfowl and waste rice in managed Arkansas rice fields. Proc Annu Conf Southeast Assoc Fish Wildl Agencies 63:41–46
Haworth M, Higgins KF (1993) Waterfowl use and production from nesting baskets and bales in South Dakota wetlands. Prairie Nat 25:149–160
Heitmeyer ME (1988) Body composition of female mallards in winter relation to annual cycle events. Condor 90:669–680
Helmers DL (1992) Shorebird management handbook. Western Hemisphere Shorebird Reserve Network, Manomet
Henning J (2004) An evaluation of fish and amphibian use of restored and natural floodplain wetlands. Final Report EPA Grant CD–97024901–1. Washington Department of Fish and Wildlife, Olympia
Higgins KF, Barker WT (1982) Changes in vegetation structure in seeded nesting cover in the Prairie Pothole Region. U.S. Fish and Wildlife Service special scientific report wildlife 242, Washington, DC
Higgins KF, Miller HW, Kirsch LM (1986) Waterfowl nesting on an earth–filled cement culvert. Prairie Nat 18:115–116
Hoese HD, Konikoff M (1995) Effects of marsh management on fisheries organisms – the compensatory adjustment hypothesis. Estuaries 18:180–197
Hoffpauer CM (1968) Burning for coastal marsh management. In: Newsom JD (ed) Proceedings of the marsh and estuary management symposium. Louisiana State University, Baton Rouge
Homyack JA, Haas CA (2009) Long–term effects of experimental forest harvesting on abundance and reproductive demography of terrestrial salamanders. Biol Conserv 142:110–121
Jenkins WA, Murray BC, Kramer RA, Faulkner SP (2010) Valuing ecosystem services from wetlands restoration in the Mississippi Alluvial Valley. Ecol Econ 69:1051–1061

Jofre MB, Karasov WH (1999) Direct effect of ammonia on three species of North American anuran amphibians. Environ Toxicol Chem 18:1806–1812
Johnson RR, Higgins KF, Ball IJ, Kohn SC (1994) Waterfowl productivity and use of nesting structures in the Prairie Pothole Region. Prairie Nat 26:187–194
Johnson WC, Millett BV, Gilmanov T, Voldseth RA, Gutenspergen GR, Naugle DE (2005) Vulnerability of northern prairie wetlands to climate change. BioScience 55:863–872
Jones DK, Hammond JI, Relyea RA (2009) Very highly toxic effects of endosulfan across nine species of tadpoles: lag effects and family–level sensitivity. Environ Toxicol Chem 28:1939–1945
Jorde DG, Owen RB Jr (1988) Efficiency of nutrient use by American black ducks wintering in Maine. J Wildl Manage 59:209–214
Kaminski RM, Moring R (2009) Grassy corn for wintering ducks. Delta Wildl 2009 (Spring):26–27
Kaminski RM, Prince HH (1981) Dabbling duck and aquatic macroinvertebrate responses to manipulated wetland habitat. J Wildl Manage 45:1–15
Kaminski RM, Alexander RW, Leopold BD (1993) Wood duck and mallard winter microhabitats in Mississippi hardwood bottomlands. J Wildl Manage 57:562–570
Kaminski RM, Davis JB, Essig HW, Gerard PD, Reinecke KJ (2003) True metabolizable energy for wood ducks from acorns compared to other waterfowl foods. J Wildl Manage 67:542–550
Kelly S (1996) Small sediment diversions. Louisiana Department of Natural Resources, Baton Rouge
Kemp AC, Horton BP, Culver SJ, Corbett DR, van de Plassche O, Gehrels WR, Douglas BC, Parnell AC (2009) Timing and magnitude of recent accelerated sea–level–rise (North Carolina, United States). Geology 37:1035–1038
Kern RA, Shriver WG, Bowman JL, Mitchell LR, Bounds DL (2012) Seaside sparrow reproductive success in relation to prescribed fire. J Wildl Manage 76:932–939
King SL, Allen JA (1996) Plant succession and greentree reservoir management: implications for management and restoration of bottomland hardwood wetlands. Wetlands 16:503–511
King SL, Fredrickson LH (1998) Bottomland hardwood guidebook: the decision making process, design, management and monitoring of GTR's. The Environmental Protection Agency, Dallas
King SL, Allen JA, McCoy JW (1998) Long–term effects of a lock and dam greentree reservoir management on a bottomland hardwood forest. For Ecol Manage 112:213–226
King SL, Twedt DJ, Wilson RR (2006) The role of the wetland reserve program in conservation efforts in the Mississippi River Alluvial Valley. Wildl Soc Bull 34:914–920
Kostecke RM, Smith LM, Hands HM (2004) Vegetation response to cattail management at Cheyenne Bottoms, Kansas. J Aquat Plant Manage 42:39–45
Kostecke RM, Smith LM, Hands HM (2005) Macroinvertebrate response to cattail management at Cheyenne Bottoms, Kansas, USA. Wetlands 25:758–763
Kröger R, Holland MM, Moore MT, Cooper CM (2007) Plant senescence: a mechanism for nutrient release in temperate agricultural wetlands. J Environ Pollut 146:114–119
Kröger R, Holland MM, Moore MT, Cooper CM (2008) Agricultural drainage ditches mitigate phosphorus loads as a function of hydrological variability. J Environ Qual 37:107–113
Kross J, Kaminski RM, Reinecke KJ, Penny EJ, Pearse AT (2008) Moist-soil seed abundance in managed wetlands in the Mississippi Alluvial Valley. J Wildl Manage 72:707–714
Landers JL, Johnson AS, Morgan PH, Baldwin WP (1976) Duck foods in managed tidal impoundments in South Carolina. J Wildl Manage 40:721–728
Landin MC (1986) Wetland beneficial use applications of dredged material disposal sites. In: Proceedings of the annual conference on wetlands restoration and creation 13:118–129
Lane JL, Jensen KC (1999) Moist-soil impoundments for wetland wildlife. U.S. Army Corps of Engineers technical report EL–99–11
Lane RR, Day JW Jr, Thibodeaux B (1999) Water quality analyses of a freshwater diversion at Caernarvon, Louisiana. Estuaries 22:327–336
La Peyre MK, Gossman B, Nyman JA (2007) Assessing functional equivalency of nekton habitat in enhanced habitats: comparison of terraced and unterraced marsh ponds. Estuar Coast 33:526–536

Laubhan MK, Fredrickson LH (1992) Estimating seed production of common plants in seasonally flooded wetlands. J Wildl Manage 56:329–337
Laux JW (2008) Waterbird responses to two east Tennessee River Valley reservoirs. Thesis, University of Tennessee
Lehnen SA, Krementz DG (2005) Turnover rates of fall–migrating pectoral sandpipers in the lower Mississippi Alluvial Valley. J Wildl Manage 69:671–680
Leibowitz SG, Wigington PJ Jr, Rains MC, Browning DM (2008) Non–navigable streams and adjacent wetlands: addressing science needs following the Supreme Court's Rapanos decision. Front Ecol Environ 6:364–371
Leitch JA (1989) Political overview of prairie potholes. In: van der Valk A (ed) Northern Prairie wetlands. Iowa State University, Ames
Levin LA, Talley TS (2002) Natural and manipulated sources of heterogeneity controlling early faunal development of a salt marsh. Ecol Appl 12:1785–1802
Linz GM, Blixt DC, Bergman DL, Bleier WJ (1996) Response of ducks to glyphosate–induced habitat alterations in wetlands. Wetlands 16:38–44
Loesch CR, Kaminski RM (1989) Winter body–weight patterns of female mallards fed agricultural seeds. J Wildl Manage 53:1081–1087
Loesch CR, Reinecke KJ, Baxter CK (1994) Lower Mississippi Valley joint venture evaluation plan. North American waterfowl management plan. U. S. Fish and Wildlife Service, Vicksburg
Loga EW, Ensminger AB (1960) Pass–a–Loutre waterfowl management area. In: Ninth Biennial report 1960–1961. Louisiana Wild Life and Fisheries Commission, New Orleans
Løkkeborg S (2011) Best practices to mitigate seabird bycatch in longline, trawl and gillnet fisheries – efficiency and practical applicability. Mar Ecol Prog Ser 435:285–303
Lopez RD, Fennessy MS (2002) Testing the floristic quality assessment index as an indicator of wetland condition. Ecol Appl 12:487–497
Lynch JJ (1941) The place of burning in management of Gulf coast wildlife refuges. J Wildl Manage 5:454–457
Lyons J, Trimble ST, Paine LK (2000) Grass versus trees: managing riparian areas to benefit streams of central North America. J Am Water Resour Assoc 36:919–930
MacDonald PO, Frayer WE, Clauser JK (1979) Documentation, chronology, and future projections of bottomland hard–wood habitat loss in the Lower Mississippi Alluvial Plain. U.S. Fish and Wildlife Service, Vicksburg
Malecki RA, Lassoie JR, Rieger E, Seamans T (1983) Effects of long–term artificial flooding on a northern bottomland hardwood forest community. For Sci 29:535–544
Mammenga PW, Flake LD, Grovijahn ME, Vaa SJ, Higgins KF (2007) Mallard use of elevated nesting structures: 15 years of management in eastern South Dakota. South Dakota Department of Game, Fish and Parks, Pierre, and South Dakota Agricultural Experiment Station, Brookings, Bulletin 752
Manley SW, Kaminski RM, Reinecke KJ, Gerard PD (2004) Waterbird foods in winter–managed ricefields in Mississippi. J Wildl Manage 68:74–83
Manley SW, Kaminski RM, Reinecke KJ, Gerard PD (2005) Agronomic implications of waterfowl management in Mississippi ricefields. Wildl Soc Bull 33:981–992
Manley SE, Kaminski RM, Rodriguez PB, Dewey JC, Schoenholtz SH, Gerard PD, Reinecke KJ (2009) Soil and nutrient retention in winter–flooded ricefields with implication for watershed management. J Soil Water Conserv 64:173–182
Marquez CO, Cambardella CA, Isenhart TM, Schultz RC (1999) Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA. Agrofor Syst 44:133–140
Matthews CE, Moorman CE, Greenberg CH, Waldrop TA (2010) Response of reptiles and amphibians to repeated fuel reduction treatments. J Wildl Manage 74:1301–1310
McCaffrey RJ, Thomson J (1980) A record of the accumulation of sediment and trace metals in a Connecticut salt marsh. Adv Geophys 22:165–236
McGinnis TE III (1997) Factors of soil strength and shoreline movement in a Louisiana coastal marsh. Thesis, University of Southwestern Louisiana
Merendino MT, Smith LM, Murkin HR, Pederson RL (1990) The response of prairie wetland vegetation to seasonality of drawdown. Wildl Soc Bull 18:245–251

Merino J, Huval D, Nyman AJ (2010) Implication of nutrient and salinity interaction on the productivity of *Spartina patens*. Wetl Ecol Manage 18:111–117

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

Minser WG, Gray MJ, Laux JW, Wirwa DW (2011) The value of transient mud. Wildl Prof 5:35–37

Mitsch WJ, Gosselink JG (2000) Wetlands. Wiley, New York

Montalto FA, Steenhuis TS, Parlange JY (2006) The hydrology of Piermont Marsh, a reference for tidal marsh restoration in the Hudson River estuary, New York. J Hydrol 316:108–128

Moon JA, Haukos DA (2009) Factors affecting body condition of northern pintails wintering in the Playa Lakes Region. Waterbirds 32:87–95

Moore PA Jr, Van Breemen N, Patrick WH Jr (1999) Effects of drainage on the chemistry of acid sulfate soils. In: Skaggs RW, Van Schilfgaarde J (eds) Agricultural drainage. American Society of Agronomy, Crop Science Society of America and Soil Science Society of America. Madison

Mossa J, Roberts HH (1990) Synergism of riverine and winter storm–related sediment transport processes in Louisiana's coastal wetlands. Transactions of the Gulf Coast Association of Geological Societies XL:635–642

Murkin HR, Kaminski RM, Titman RD (1982) Responses by dabbling ducks and aquatic invertebrates to an experimentally manipulated cattail marsh. Can J Zool 60:2324–2332

Murkin HR, van der Valk AG, Kadlec JA (2000) Nutrient budgets and the wet–dry cycle of prairie wetlands. In: Murkin HR, van der Valk AG, Clark WR (eds) Prairie wetland ecology: the contribution of the Marsh Ecology Research Program. Iowa State University, Ames

Nassar JR, Cohen WE, Hopkins CR (1993) Waterfowl habitat management handbook for the lower Mississippi Alluvial River Valley. Mississippi State University Extension Publication 1864

Naylor LW, Eadie JM, Smith WD, Eichholz M, Gray MJ (2005) A simple method to predict seed yield in moist-soil habitats. Wildl Soc Bull 33:1335–1341

Neely WW (1962) Saline soils and brackish waters in management of wildlife, fish, and shrimp. Trans North Am Wildl Conf 27:321–335

Nelms KD (2007) Wetland management for waterfowl: a handbook. Mississippi River Trust, Stoneville

Nelms KD, Porter MD, Gray MJ (2012) In: Neal W (ed) Small impoundment management in North America. American Fisheries Society, Bethesda, pp 391–420

Neubauer SC (2008) Contribution of mineral and organic components to tidal freshwater marsh accretion. Estuar Coast Shelf Sci 78:78–88

Nyman JA, Chabreck RH (1995) Fire in coastal marshes: history and recent concerns. In: Proceedings tall timbers fire ecology conference– fire in wetlands: a management perspective 19:135–141

Nyman JA, Chabreck RH (1996) Some effects of 30 years of weir management on coastal marsh aquatic vegetation and implications to waterfowl management. Gulf Mex Sci 14:16–25

Nyman JA, Chabreck RH, Linscombe RG (1990a) Effects of weir management on marsh loss, Marsh Island, Louisiana USA. Environ Manage 14:809–814

Nyman JA, Delaune RD, Patrick WH Jr (1990b) Wetland soil formation in the rapidly subsiding Mississippi River Deltaic Plain: mineral and organic matter relationships. Estuar Coast Shelf Sci 31:57–69

Nyman JA, Delaune RD, Roberts HH, Patrick WH Jr (1993a) Relationship between vegetation and soil formation in a rapidly submerging coastal marsh. Mar Ecol Prog Ser 96:269–279

Nyman JA, Chabreck RH, Kinler N (1993b) Some effects of herbivory and 30 years of weir management on emergent vegetation in a brackish marsh. Wetlands 13:165–175

Nyman JA, La Peyre MK, Caldwell A, Piazza S, Thom C, Winslow C (2009) Defining restoration targets for water depth and salinity in wind–dominated *Spartina patens* (Ait.) Muhl. coastal marshes. J Hydrol 376:327–336

O'Connell JL, Nyman JA (2010) Marsh terraces in coastal Louisiana increase Marsh Edge and densities of waterbirds. Wetlands 30:125–135

O'Neil T (1949) The muskrat in the Louisiana coastal Marsh. Louisiana Department of Wild Life and Fisheries, New Orleans

Olmstead VG (2010) Evaluation of management strategies on moist-soil seed availability and depletion on Wetland Reserve Program sites in the Mississippi Alluvial Valley. Thesis, Arkansas Tech University

Pankau AK (2008) Examining cost effectiveness of actively and passively managed wetlands for migrating and wintering waterfowl in southern Illinois. Thesis, Southern Illinois University

Pearse AT, Kaminski RM, Reinecke KJ, Dinsmore SJ (2012) Local and landscape associations between wintering dabbling ducks and wetland complexes in Mississippi. Wetlands 32:859–869. doi:10.1007/s13157–012–0317–5

Penland S, Ramsey KE (1990) Relative sea–level rise in Louisiana and the Gulf of Mexico: 1908–1988. J Coast Res 6:323–342

Penny EJ, Kaminski RM, Reinecke KJ (2006) A new device to estimate abundance of moist-soil plant seeds. Wildl Soc Bull 34:186–190

Perry JE, Barnard TA Jr, Bradshaw JG, Friedrichs CT, Havens KJ, Mason PA, Priest WI III, Silberhorn GM (2001) Creating tidal salt marsh in the Chesapeake Bay. J Coast Res 27:170–191

Perry RW, Rudolph DC, Thill RE (2012) Effects of short–rotation controlled burning on amphibians and reptiles in pine woodlands. For Ecol Manage 271:124–131

Petranka JW, Eldridge ME, Haley KE (1993) Effects of timber harvesting on southern Appalachian salamanders. Conserv Biol 7:363–370

Phillips JD (1986) Coastal submergence and marsh fringe erosion. J Coast Res 2:427–436

Pieron MR, Rohwer FC (2010) Effects of large–scale predator reduction on nest success of upland nesting ducks. J Wildl Manage 74:124–132

Poach ME, Faulkner SP (1998) Soil phosphorus characteristics of created and natural wetlands in the Atchafalaya Delta, LA. Estuar Coast Shelf Sci 46:195–203

Prigent C, Papa F, Aires F, Jiménez C, Rossow W, Matthews E (2012) Changes in land surface water dynamics since the 1990s and relation to population pressure. Geophys Res Lett. doi: 10.1029/2012GL051276

Reed DJ (1989) Patterns of sediment deposition in subsiding coastal salt marshes, Terrebonne Bay, Louisiana: the role of winter storms. Estuaries 12:222–227

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

Reed DJ, De Luca N, Foote AL (1997) Effect of hydrologic management on marsh surface sediment deposition in coastal Louisiana. Estuaries 20:301–311

Reinecke KJ, Kaminski RM, Moorhead DJ, Hodges JD, Nassar JR (1989) Mississippi Alluvial Valley. In: Smith LM, Pederson RL, Kaminski RM (eds) Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock

Reinecke KJ, Hartke KM (2005) Estimating moist-soil seeds available to waterfowl with double sampling for stratification. J Wildl Manag 69:794–799

Reinecke KJ, Uihlein WB (2006) Lower Mississippi Valley Joint Venture, waterfowl working group memorandum. U.S. Fish and Wildlife Service, Vicksburg

Relyea RA, Jones DK (2009) The toxicity of Roundup Original MAX® to 13 species of larval amphibians. Environ Toxicol Chem 28:2004–2008

Ringelman JK (1992) Identifying factors that limit duck production. U.S. Fish and Wildlife Service Waterfowl Management Handbook Leaflet 13.2.7

Rittenhouse TAG, Semlitsch RD (2007) Distribution of amphibians in terrestrial habitat surrounding wetlands. Wetlands 27:153–161

Roman CT, Niering WA, Warren RS (1984) Salt marsh vegetation change in response to tidal restriction. Environ Manage 8:141–150

Rouse JD, Bishop CA, Struger J (1999) Nitrogen pollution: an assessment of its threat to amphibian survival. Environ Health Perspect 107:799–803

Rozas LP, Minello TH (2001) Marsh terracing as a wetland restoration tool for creating fishery habitat. Wetlands 21:327–341

Rubec CD, Hanson AR (2008) Wetland mitigation and compensation: Canadian experience. Wetl Ecol Manage 17:3–14

Rubec C, Lynch–Stewart P (1998) Regulatory and non–regulatory approaches for the wetland conservation in Canada. Technical consultation on designing methodologies to review laws and institutions relevant to wetlands. Gland, Switzerland

Schmutzer CA, Gray MJ, Burton EC, Miller DL (2008) Impacts of cattle on amphibian larvae and the aquatic environment. Freshw Biol 53:26–13

Schoenholtz SH, Stanturf JA, Allen JA, Schweitzer CJ (2005) Afforestation of agricultural lands in the Lower Mississippi Alluvial Valley: the state of our understanding. In: Fredrickson LH, King SL, Kaminski RM (eds) Ecology and management of bottomland hardwood systems: the state of our understanding. University of Missouri–Columbia, Gaylord Memorial Laboratory Special Publication No. 10, Puxico

Schulte–Hostedde B, Walters D, Powell C, Shrubsole D (2007) Wetland management: an analysis of past practice and recent policy changes in Ontario. J Environ Manage 82:83–94

Schultz RC, Colletti JP, Isenhart TM, Simpkins WW, Mize CW, Thompson ML (1995) Design and placement of a multi–species riparian buffer strip system. Agrofor Syst 29:201–226

Schummer ML, Hagy HM, Fleming KS, Cheshier JC, Callicutt JT (2012) Moist-soil wetland plants of the Mississippi Alluvial Valley. University Press of Mississippi, Jackson

Scozzafava ME, Kentula ME, Riley E, Magee TK, Serenbetz G, Sumner R, Faulkner C, Price M (2011) The National Wetland Condition Assessment: National data on wetland quality to inform and improve wetlands protection. Natl Wetl Newsl 33:11–13

Semlitsch RD (2000) Principles for management of aquatic–breeding amphibians. J Wildl Manage 64:615–631

Semlitsch RD, Bodie JR (2003) Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conserv Biol 17:1219–1228

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

Sharp LA, Billodeau D (2007b) 2005 Operations, maintenance, and monitoring report for La. highway. 384 hydrologic restoration (CS–21). Louisiana Department of Natural Resources, Coastal Restoration Division and Coastal Engineering Division, Lafayette

Sherfy MH (1999) Nutritional value and management of waterfowl and shorebirds foods in Atlantic coastal moist-soil impoundments. Dissertation, Virginia Polytechnic Institute and State University

Sherfy MH, Anteau MJ, Bishop AA (2011) Agricultural practices and residual corn during spring crane and waterfowl migration in Nebraska. J Wildl Manage 75:995–1003

Simenstad CA, Hood WG, Thom RM, Levy DA, Bottom DL (2000) Landscape structure and scale constraints on restoring estuarine wetlands for Pacific coast juvenile fishes. In: Weinstein MP, Kreeger DA (eds) Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, Boston

Smith RH (1942) Management of salt marshes on the Atlantic coast of the United States. Trans North Am Wildl Conf 7:272–277

Smith LM, Haukos DA, Prather RM (2004) Avian responses to vegetative pattern in playa wetlands during winter. Wildl Soc Bull 32:474–480

Spiller SF, Chabreck RH (1975) Wildlife populations in coastal marshes influenced by weirs. In: Proceedings of the annual conference of the Southeastern Association of Game and Fish Commissioners 29:518–525

Srivastava DS, Jefferies RL (2002) Intertidal plant communities of an Arctic salt marsh: the influence of isostatic uplift and herbivory. Ecoscience 9:112–118

Stafford JD, Flake LD, Mammenga PW (2002) Survival of mallard broods and ducklings departing overwater nesting structures in eastern South Dakota. Wildl Soc Bull 30:327–336

Stafford JD, Kaminski RM, Reinecke KJ, Manley SW (2006) Waste rice for waterfowl in the Mississippi Alluvial Valley. J Wildl Manage 70:61–69

Stafford JD, Kaminski RM, Reinecke KJ (2010) Avian foods, foraging and habitat conservation in world rice fields. Waterbirds 33:133–150

Stanturf JA, Shoenholtz SH, Scheitzer CJ, Shepard JP (2001) Achieving restoration success: myths in bottomland hardwood forests. Restor Ecol 9:189–200

Stephens SE, Rotella JJ, Lindberg MS, Taper ML, Ringleman JK (2005) Duck nest survival in the Missouri Coteau of North Dakota: landscape effects at multiple spatial scales. Ecol Appl 15:2137–2149
Stevenson JC, Kearney MS, Pendleton EC (1985) Sedimentation and erosion in a Chesapeake Bay brackish system. Mar Geol 67:213–235
Stover H (2008) A summary of Canadian and international wetland policy. Surplus Property Management Imperial Oil, Ltd., Calgary
Strader RW, Stinson PH (2005) Moist-soil management guidelines for the U.S. Fish and Wildlife Service Southeast Region. http://www.fws.gov/columbiawildlife/MoistSoilReport.pdf. Accessed 17 Sept 2012
Straub JN (2012) Estimating and modeling red oak acorn yield and abundance in the Mississippi Alluvial Valley. Dissertation, Mississippi State University
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
Stuart SN, Chanson JS, Cox NA, Young BE, Rodrigues ASL, Fischman DL, Waller RW (2004) Status and trends of amphibian declines and extinctions worldwide. Science 306:1783–1786
Suhayda J, Young M, Ren X (1989) Simulation study on natural and man–made changes in estuarine systems. In: Hamza MH (ed) Applied simulation and modeling. Acta Press, Anaheim
Sullivan SMP, Watzin MC (2009) Stream–floodplain connectivity and fish assemblage diversity in the Champlain Valley, Vermont, USA. J Fish Biol 74:1394–1418
Titus JG (1996) The risk of sea level rise. Clim Change 33:151–212
Tockner K, Stanford JA (2002) Riverine flood plains: present state and future trends. Environ Conserv 29:308–330
Twedt DJ, Nelms CO (1999) Waterfowl density on agricultural fields managed to retain water in winter. Wildl Soc Bull 27:924–930
Uhler FM (1944) Control of undesirable plants in waterfowl habitats. Trans North Am Wildl Conf 9:295–303
United States Army Corps of Engineers (COE) (1986) Beneficial uses of dredged material. U. S. Army Corps of Engineers, Chief of Engineers, EM1110–2–5026. Washington, DC
United States Fish and Wildlife Service (USFWS) (2006) Strategic plan: the partners for fish and wildlife program. Arlington
United States Government (2009) Code of federal regulations, Title 50, Part 20. www.gpoaccess.gov/cfr/. Accessed 17 Sept 2012
van der Valk AG (1981) Succession in wetlands: a Gleasonian approach. Ecology 62:688–696
van der Valk AG, Davis CB (1978) The role of seed banks in the vegetation dynamics of prairie glacial marshes. Ecology 59:322–335
van der Valk AG, Davis CB (1980) The impact of a natural drawdown on the growth of four emergent species in a prairie glacial marsh. Aquat Bot 9:301–322
van Gils JA, Edelaar P, Escudero G, Piersma T (2004) Carrying capacity models should not use fixed prey density thresholds: a plea for using more tools of behavioural ecology. Oikos 104:197–204
van Groenigen JW, Burns EG, Eadie JM, Horwath WR, van Kessel C (2003) Effects of foraging waterfowl in winter flooded rice fields on weed stress and residue decomposition. Agric Ecosyst Environ 95:289–296
Vitt LJ, Caldwell JP (2008) Herpetology: an introductory biology of amphibians and reptiles. Academic, New York
Vymazal J (2007) Removal of nutrients in various types of constructed wetlands. Sci Total Environ 380:48–65
Wehrle BW (1992) Invertebrate resources in Mississippi hardwood bottomlands, moist-soil habitat, and flooded cropland. Thesis, Mississippi State University
Weifenbach D, Clark N (2000) Three–year comprehensive monitoring report. Coast 2050 Region 4, East Mud Lake Marsh Management. Louisiana Department of Natural Resources, Coastal Management Division, Monitoring series CS–20–MSTY–0799–1. Baton Rouge, USA. http://www.savelawetlands.org/site/projects.html. Accessed 17 Sept 2012

Weller MW, Spatcher CS (1965) Role of habitat in the distribution and abundance of marsh birds. Iowa Agriculture and Home Economics Experiment Station, Special report 43, Ames
Wells KD (2007) The ecology and behavior of amphibians. University of Chicago, Chicago
Whittington MS (2005) Evaluation of aquatic macroinvertebrates available to wintering waterfowl in managed and natural wetlands in western Tennessee. Thesis, University of Tennessee
Wigley TB, Filer TH Jr (1989) Characteristics of greentree reservoirs: a survey of managers. Wildl Soc Bull 17:136–142
Wilbur HM (1984) Complex life cycles and community organization in amphibians. In: Price PW, Slobodchikoff CN, Gaud WS (eds) A new ecology: novel approaches to interactive systems. Wiley, New York
Williams P, Farber P (2001) Salt marsh restoration experience in San Francisco Bay. J Coast Res 27:203–211
Wirwa DW (2009) Waterbird use of Kentucky reservoir mudflats. Thesis, University of Tennessee
Wiseman AJ, Kaminski RM, Riffell SK, Reinecke KJ, Larson EJ (2010) Ratoon grain sorghum and other seeds for waterfowl in sorghum croplands. Proc Southeast Assoc Fish Wildl Agencies 64:106–111
Wolinsky S (2006) Farm pond ecosystems. Fish and Wildlife Habitat Management Leaflet 29. U. S. Department of Agriculture Natural Resources Conservation Service Wildlife Habitat Management Institute, Madison, Mississippi, and Wildlife Habitat Council, Silver Springs, Maryland
Young GL, Karr BL, Leopold BD, Hodges JD (1995) Effect of greentree reservoir management on Mississippi bottomland hardwoods. Wildl Soc Bull 23:525–531
Zedler JB (1993) Canopy architecture of natural and planted cordgrass marshes – selecting habitat evaluation criteria. Ecol Appl 3:123–138

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.

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

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).

		ha
(a) Agricultural		
1. Rice (harvested)	=	100
2. Soybean (harvested)	=	100
3. Rice (unharvested)	=	100
4. Soybean (unharvested)	=	100
5. Corn (unharvested)	=	100
(b) Moist-soil wetland	=	500
(c) Hardwood bottomlands		
1. 30 % BA red oaks	=	167
2. 60 % BA red oaks	=	167
3. 100 % BA red oaks	=	166

   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/m^2, 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.

Kaminski RM, Davis JB, Essig HW, Gerard PD, Reinecke KJ (2003) True metabolizable energy for wood ducks from acorns compared to other waterfowl foods. J Wildl Manage 67:542–550.

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

Plant species	Moist-soil plant morphological measurements					
	HT	ID	IL	IV	IN	PN	FW
Fall panicum	1.25	562	1,075	?	3	576	10
Barnyardgrass	0.75	240	265	?	2	52	69

- 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/m^2 (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?

Gray MJ, Kaminski RM, Weerakkody G (1999b) Predicting seed yield of moist-soil plants. J Wildl Manage 63:1261–1268.

5. Gray et al. (2009) discuss a rapid and accurate procedure for estimating seed production in moist-soil wetlands by scanning seed-head area (cm^2). 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 cm^2 for barnyard grass, 50 cm^2 for redroot flatsedge, and 50 cm^2 for curlytop knotgrass. Also, suppose that average density for each of these plant species = 1 plant/m^2. 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?

Gray MJ, Foster MA, Peña Peniche LA (2009) New technology for estimating seed production of moist-soil plants. J Wildl Manage 73:1229–1232.

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

<u>Overview</u>: 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.

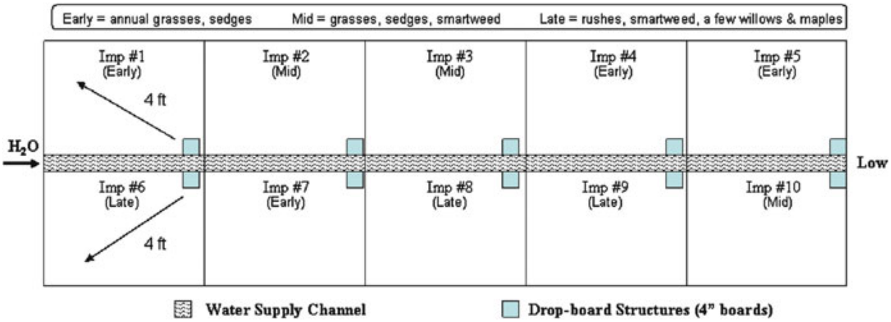
Instructions: Review the three models (nutria, biomass, and area) proposed by Carter et al. (1999), and determine: (1) what factors are most influential in nutria contributing to marsh loss, and (2) what time of year is nutria herbivory most detrimental. If you were going to attempt to restore a marsh with high densities of nutria, what management techniques would you use and why?

Carter J, Foote AL, Johnson–Randall LA (1999) Modeling the effects of nutria (*Myocaster coypus*) on wetland loss. Wetlands 19:209–219.

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 (*Aythya affinis*, *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.