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Potential Applicability of Moist-soil Management Wetland as Migratory Waterbird Habitat in Republic of Korea

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이동성 물새 서식지로서 습윤토양관리 습지의 국내 적용 가능성

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Abstract

Inland wetlands in the Republic of Korea provide key breeding and wintering habitats, while coastal wetlands provide nutrient-rich habitats for stopover sites for East Asia/Australasia Flyway(EAAF) migrants. However, since the 1960's, Korea has reclaimed these coastal wetlands gradually for agriculture and urban expansion. The habitat loss has rippled across global populations of migrant shorebirds in EAAF. To protect a similar loss, the United States, specifically Missouri, developed the moist-soil management technique. Wetland impoundments are constructed from levees with water-flow control gates with specific soils, topography, available water sources, and target goals. The impoundments are subjected to a combination of carefully timed and regulated flooding and drawdown regimes with occasional soil disturbance. This serves a dual purpose of removing undesirable vegetation, while maximizing habitat and forage for wildlife. Flooding and drawdown schedules must be dynamic with constantly shifting climate conditions. Korea's latitude (N33° 25'~ N38° 37') is comparable to Missouri (N36° 69'~ N40° 41'); as such, moist-soil management could prove to be an effective wetland restoration technique for Korea. In order to meet specific conservation goals (i.e. shorebird staging site restoration), it is necessary to test the proposed methodology on a site that can meet the required specifications for moist-soil management. Moist-soil management has the potential to not only create key habitat for endangered wildlife, but also provide valuable ecosystem services, including water filtration.

Key words : Moist-soil Management, Wetland Restoration, Wildlife, Habitat

요 약

한국의 내륙습지는 동아시아-대양주 철새 이동경로 상 중요한 번식지 및 월동지를 제공하고 있고, 연안습지는 철새들에게 영양분이 풍부한 중간기착지를 제공하는 역할을 하고 있다. 하지만, 1960년대 이후, 한국은 농경지와 도심 확장을 위해 점진적으로 연안습지를 매립하였고, 야생생물 연안습지 서식지 손실로 인한 이동성 물새 개체수 감소를 야기 하였다. 미국(특히, 미주리 주)은 이러한 습지 야생생물 다양성 및 개체수 감소를 막기 위해 습윤토양관리 기법을 개발 하여 야생생물 서식지 보전과 개체수 관리를 하고 있다. 습윤토양관리 기법은 습지 야생생물의 서식지 조건을 최대한 충족하는 상태로 습지를 관리하여 서식지 수용력을 높이는 습지관리 기법이다. 습윤토양관리 지역을 조성하기 위해서는 제방과 물의 흐름을 조절할 수 있는 수문을 만들고, 토양, 지형, 가용한 수원 등을 관리 하여야 한다. 또한, 습윤토양관리 지역은 범람과 배수지역을 정기적으로 특정시기에 관리하고, 다년생 식물생장으로 인한 육상화 억제를 위해 일정기간 동안의 토양교란으로 서식지를 관리 하여야 한다. 이러한 관리 기법은 두가지 목적을 가지고 있는데, 하나는 원하지 않은 식물 생육 통제이고, 다른 하나는 야생생물의 서식지와 먹이원을 최대화 하기 위함이다. 범람과 배수 일정은 지역을 고려한 기후적인 변화에 맞도록 유동적으로 반영하여야

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한다. 한국의 위도는 미주리 주와 유사해서 습윤토양관리 기법이 한국에 맞는 효과적인 습지조성 및 관리기법으로 활용될 수 있을 것으로 기대된다. 특히, 이동성 물새(도요·물떼새) 중간기착지와 같은 서식지로의 중요한 역할을 하는 연안습지 인근지역에서 습윤토양관리 기법을 실험적으로 적용하여 한국의 여건(지리, 미기후, 생물종 분포 등)에 맞는지 세부적인 방법을 모색해 보는 연구가 필요하다. 습윤토양관리 기법은 멸종위기 야생생물들에게 주요 서식지를 조성해 줄 뿐만 아니라, 폭넓은 습지 생태계서비스 가치를 함께 제공해 줄 것이다.

핵심용어 : 습윤토양관리, 습지복원, 야생생물, 서식지

1. Background

The Republic of Korea has a rich array of inland and coastal wetlands that exceed >19,000 ha. Inland, there are fourteen Ramsar-designated natural and man-made wetlands that serve as breeding and wintering habitat for waterbirds, including 95% of the world's Baikal teal (*Anas formosa*) population (Yu et al., 2014; Ramsar, 2017). Korea has one of the world's five major intertidal mud flats alongside the Yellow Sea, with eight coastal wetlands, comprised of intertidal marshes, estuarine waters, freshwater lagoons, as well as sand, shingle, or pebble shores (Kim, 2010; Ramsar, 2017). These coastal wetlands are vital stopover sites and bottleneck over 2 million migrant waterbirds along the EAAF, which extends from the Alaskan Arctic and Russia to Australia and New Zealand (Lee and Miller-Rushing, 2014; Nam et al., 2015; Studds et al., 2017). In order to survive the extensive flight, migrants must refuel at these staging sites to feed on nutrient-rich tubers, sprouts, roots, aquatic plants, invertebrates, fish and amphibians (Jiang et al. 2015). Pristine wetlands were once well-equipped to meet the nutritional demands of migrants and residents; however, reclamation projects have resulted in a loss of >30% of Korea's tidal flats since the 1980's at a >1% annual rate (Murray et al., 2014).

The Saegmangeum Reclamation project is a clear example of the staging site loss of waterbird populations in EAAF (Yang et al., 2011; MacKinnion et al., 2012; Lee and Miller-Rushing, 2014). The project damaged 401 km^2 of premier shorebird tidal flat habitats. These tidal flats supported over 30% of the globally vulnerable great knot (*Calidris tenuirostris*) population during northbound migration. High concentration of endangered spotted greenshank (*Tringa guttifer*) and critically endangered spoon-billed sandpiper (*Eurynorhynchus pygmeus*) also relied upon the area during southward migration (Barter, 2002; Lee and Miller-Rushing, 2014). As a result, the global population of EAAF shorebirds has declined by 20% since its completion, illustrating that an environmental threat to any part of a migrant's life cycle impacts the global population as a whole (Yang et al., 2011; Runge et al., 2015). Yang et al. (2011) hypothesized that in the face of habitat loss, shorebirds will shift to the closest alternative. However, global declines indicate that the Yellow Sea may be filled to capacity and further wetland degradation will continue to reduce waterbird populations (Rogers et al., 2006; Yang et al., 2011; MacKinnion et al., 2012). Overall, dependence upon the Yellow Sea is considered the leading contributor to shorebird loss in the EAAF (Studds et al., 2017).

In order to prevent further declines, remaining wetlands must be maintained and degraded sites restored where possible. To some degree, agricultural fields may serve as surrogate habitats (Hands et al., 1991; Ma et al., 2010; Nam et al., 2015). However, grain yields cannot fully meet the energetic demands required for migrant waterbirds whereas native wetland plants provide essential amino acids (Baldassarre et al., 1983; Lane and Jensen 1999; Bowyer et al., 2005; Straub, 2008; Nam et al., 2015). Row crops serve as artificial wetlands for shorebirds, but are not likely to have the same density or diversity of invertebrates as natural wetlands (Hands et al., 1991; Ma et al., 2010). In light of the overwhelming loss of >50% of the world's wetlands, several countries have implemented environmental protection legislation that prevent further destruction and promote restoration through carefully constructed management plans, such as the United States' "No Net Loss of Wetlands" policy (Lee et al., 2015). In addition to the government's resolve to halt further losses, the US Fish and Wildlife Service has developed a comprehensive, and cost-effective, plan to restore wetlands and provide optimal foraging conditions for waterbirds (Fredrickson and Taylor, 1982; Lane and Jensen, 1999; Lyons et al., 2016).

Fredrickson and Taylor (1982) spent decades observing different flooding and drawdown regimes in an attempt to promote desirable, naturally-occurring wetland vegetation for migratory waterfowl, which has led to the development of moist-soil management (Lane and Jensen, 1999). Moist-soil management is defined as the seasonal flooding and drawdown of shallow water impoundments in order to maximize foraging and coverage for wetland-dependent species (Lane and Jensen, 1999; Anderson and Smith, 2000).

The artificial flooding regimes are often accompanied by mechanical soil management (Lane and Jensen, 1999; Strader et al., 2005). Moist-soil management has shown to provide diverse aquatic invertebrate communities and nutrient-rich browse, tubers, and seeds from native aquatic vegetation (Lane and Jensen, 1999; Anderson and Smith, 2000). Fredrickson and Taylor (1982) observed that moist-soil management areas had significantly greater (>80%) species richness compared to adjacent row crops (Lane and Jensen, 1999). The United States' success in active management of artificial and restored wetland sites have provided a comprehensive framework with the potential to be adapted to similar ecosystems in other countries. In light of Korea's loss of key tidal flats and other wetlands, it is vital to utilize active management techniques to mitigate past, present, and future damages with clear and precise target goals (Kim, 2010). Moist-soil management allows for wetland managers to deploy site- and target-specific regimes, which would prove advantageous for Korea's current environmental issues. For the current paper, we outline the general methodology of moist-soil management and its potential application in Korea to restore optimal habitat for migrant and wintering waterbirds.

2. Introduction of moist-soil management

Moist-soil management has a broad set of general tactics and principles that can be applied to multiple scenarios, but specifics in regards to timing must coincide with regional hydrologic conditions and climate (Lane and Jensen, 1999). It is important to note, yearly weather conditions are variable; management strategies must be dynamic to respond accordingly. Further, decisions must stem from a comprehensive knowledge of the site's natural history; agronomists, engineers, hydrologists, and wetland ecologists need to collaborate during all phases of development. Managers must also acknowledge the unique, inter-specific needs of different waterbirds throughout their life cycle (breeding, wintering, and migration), and accommodate potential conflicts in management decisions according to species needs (Ma et al., 2010; Gillespie and Fontaine, 2017). For example, wetland managers in Missouri frequently target waterfowl conservation for moist-soil management regimes, of which requires water depths of around 15 cm with annual vegetation (MDC, 2017). However, members of Rallidae depend upon dense, perennial vegetation and depths of 0 – 11 cm and sandpipers occupy sparsely vegetated mudflats (Gillespie and Fontaine, 2017; Fournier et al., 2017). Therefore, depending on timing, it may become necessary to manage several units independently to address all requirements. In the following sections, we present the moist-soil management guidelines outlined by the U.S. Army Corps of Engineers and the Missouri Department of Conservation (MDC) (Lane and Jensen, 1999; MDC, 2017). In terms of climate and migration onset, we determined Missouri to be a reasonable comparison to Korea's seasonal conditions (KMA, 2017; Decker, 2017). In addition, the majority of active management regimes implemented in the United States are based upon the MDC wetland conservation efforts implemented in 1989 (Norrgard, 2010).

3. Practice of moist-soil management

3.1 Site selection and design

The design and location of impoundment sites will vary with management goals and region. Regardless, there are multiple factors that must be taken into consideration: water source, soil type, impoundment size, topography, number of individual units, water control system, levee construction, and waterbird concentrations. Impoundment size can vary, but individual basins should be no smaller than 1 ha and no larger than 400 ha. It is also recommended that total management area not exceed 1,500 ha. These constraints are well within the limits of Korea's wetlands. Upo Wetland is the largest wetland in the country (~230 ha) and comprised of four separate regions: Mokpo, Jkokjibeol, Sajipo, and Upo (Kim et al., 2014). Smaller impoundments are easier to control with exact water conditions, but can be expensive to develop. In contrast, larger areas are more difficult to manage, but less sensitive to disturbance and have greater biodiversity. In order to retain water, impoundments should be built with clay, silt, loam, or very fine sand. To ensure water coverage throughout the impoundments, basins elevation gradients should be <1% to ensure water coverage throughout the flat. Small undulations in the basin topography are beneficial and create microhabitats that increase plant and animal diversity (Lane and Jensen, 1999).

The impoundment is contained by external walls (levees) that should be built from a clay or clay-silt soil. These materials are highly compactable and less likely to shrink and swell. The minimum dimensions should be at least 3 m across the top with a slope of 3:1 to 5:1 for all external levees (Fig. 1). Height is dependent upon flooding regimes and if the region is prone to natural flooding events. Levees must be able to withstand damage from water, rodents, ice, and the weight of heavy machinery required for maintenance and disturbance regimes (i.e. mowing). To resist erosion, levees should be seed with warm- and/or cool-season grass. Internal levees should follow natural contours of the local topography and ideally would be built to standards comparable to their external counterparts (Lane and Jensen, 1999). It is speculated that an individual wetland cannot meet all requirements (i.e. roosting, foraging, nesting, and others.) of all occupant waterbirds (Ma et al., 2010; Twedt, 2013; Nam et al., 2015; Fournier et al., 2017). Thus, it is recommended that multiple, complimentary impoundments within different treatments are placed within a 16 km radius of each other (Lane and Jensen, 1999; Ma et al., 2010). For example, Gillespie and Fontaine (2017) suggest that providing interspersed mudflat and shallow water mosaics among impoundments that favor waterfowl would prove beneficial for sandpipers.

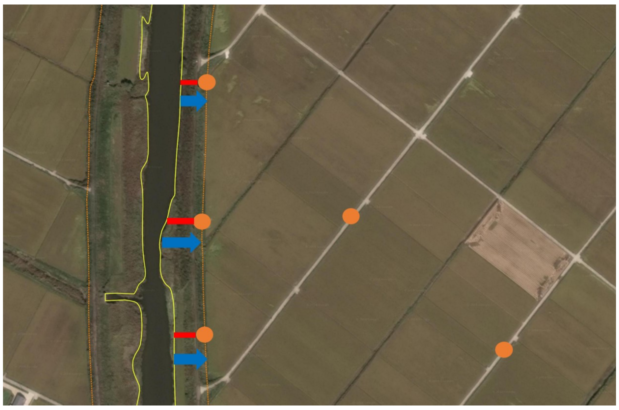

Fig. 1. Water impoundment design with river water source (yellow), water transport canals (red), and water control structures (orange). Water flow is indicated by blue arrows

3.2 Water quality and delivery system

Floodwater may be available through reservoirs, rainfall, groundwater, or river/stream sources. Reservoirs require greater expense, but allow for a ready source of water. Rainfall is the most cost-effective, but often difficult to predict. River or stream sources are more reliable, but still depend, in part, on rainfall events. If the impoundment location is prone to drought, this method could prove ineffective. Groundwater is a plentiful source of water, but requires greater expense through the use of a mechanical pumping system and the initial well drilling. In addition, groundwater sometimes lacks nutrients essential for vegetation. Before any water source is utilized, it is important to test for pollutants to avoid poisoning wildlife (Lane and Jensen, 1999; Naile et al., 2010).

Water delivery can be done through a gravity or header-ditch system. Gravity-based systems are cost-effective, especially in landscapes with a hills, mountains, or plateaus. The water flow is comparable of rice field terraces where the water initial fills the uppermost level before overflowing into the basin below. However, each terrace-level would be fitted with a water control structure. Flatter landscapes are suitable for header-ditch systems. Header-ditch systems have an adjacent ditch installed alongside the external levee with an internal, water control structure in each impoundment.

3.3 Flooding, drawdown, and disturbance regime

The goal of moist-soil management is to emulate natural hydrologic cycles while maximizing forage and habitat use for wetland-dependent species during seasonal events, such as the growing season and migration (Haukos and Smith, 1996; MDC, 2017). Therefore, the timing of flooding and drawdown is key to a successful management plan. The MDC (2017) recommends that impoundments remain flooded from the previous winter until May. Most waterfowl prefer 5 – 15 cm of water; however, many shorebirds require lower levels (Hands et al., 1991; Nam et al., 2015; Gillespie and Fontaine, 2017). At the end of May, drawdown should occur gradually, at an estimated rate of 2.54 cm per day, until the mud flat is exposed. The slow rate will allow moisture to remain in the soil for a greater period of time, which promotes greater diversity of desirable vegetation and prevents germination of unwanted perennials (MDC, 2017). The slow drawdown also presumably concentrates invertebrates and provides optimal habitat for staging waterbirds during spring (northbound) migration (April – June) (Anderson and Smith, 2000; Twedt, 2013). If water is removed at a rapid rate (2 – 3 days), vegetation will be more uniform and allow less desirable plants that require drier conditions (MDC, 2017).

From June – August, vegetation density will increase and produce high quality seeds. In addition, this period is the opportune time to complete any required construction or management along the levees as the soil is compact and dry enough to support heavy machinery (e.g. tractors) (Lane and Jensen, 1999). The MDC (2017) suggests that management areas should be disked every three to five years in order to prevent succession. For areas that cannot be disked, such as coastal wetlands, prescribed fire is another option for weed control (Gray et al., 2013). Controlled burns are an effective treatment that removes dense vegetation and opens up foraging habitats for marsh birds (Ma et al., 2010). Depending on management goals, gradual flooding should resume between early September and October. In Korea, migration occurs from late September – early November. Therefore, ideal flooding for the region would occur no earlier than mid-September (Fig. 2). As the summer vegetation dies off and decays, it serves as an

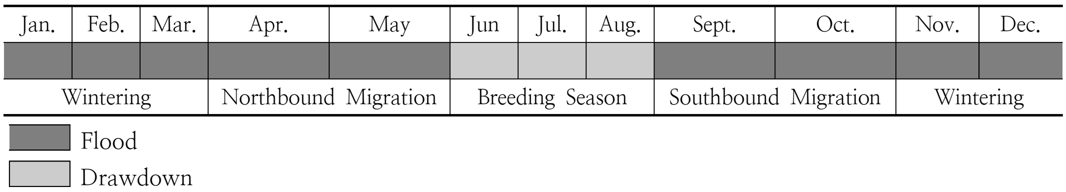

Fig. 2. Proposed flood/drawdown schedule for Korea in correspondence with waterbird migration and wintering events

excellent cover and food source for aquatic invertebrates of which becomes a vital resource for staging waterbirds during fall (southward) migration (Lane and Jensen, 1999; Anderson and Smith, 2000). In addition to staging migrants, many species of waterbirds, including Baikal Teals, will remain for the winter (Yu et al., 2014). Thus, the water levels should be maintained until the following spring (MDC, 2017).

3.4 Management evaluations

As mentioned prior, a successful wetland restoration requires multi-disciplinary efforts throughout the process and a strong support of baseline data detailing spatial and temporal ecological interactions. To meet target goals with active management, ecologists should follow a three-step approach: 1) monitor current resource states, 2) evaluate management results, and 3) revise management based on results (La Peyre et al., 2001). The baseline data for an effective moist-soil management regime resulted from decades of observations (Fredrickson and Taylor, 1982). While Korea is similar to Missouri in terms of seasonal timing and climate, it is important to ground any extensive wetland restoration efforts with localized, experimental results. Therefore, the logical next step would be to test the MDC (2017) recommendations initially with an experimental wetland plot capable of allowing exact water control in Korea. This would allow managers to refine a flood/drawdown regime that would maximize habitat use for target species.

With the aftermath of Saemangeum, one vital target goal would be the accommodation of migrant shorebirds that stage along the coastal wetlands. To maximize habitat use, managers might seek to create a diverse landscape through staggered drawdown periods in multiple impoundments, which would concentrate invertebrates and provide water level conditions for a diverse array of staging shorebirds, herons, and waterfowl (Watts et al., 2002). On a fine scale, the water breaks and flows will also create a diverse sediment topography that will reflect in benthic invertebrate community compositions and structure. This provides fueling opportunities for numerous species with unique foraging strategies (Gerritsen and Van Heezik, 1984; Choi et al., 2014).

Another goal, would be to focus on creating appropriate habitat for the large numbers of wildlife that rely upon Korea's inland wetlands during the winter (Kim et al., 2009; Kim et al., 2014). For example, if managing for Baikal teal habitat, it would be ideal to aim for deeper water, open water with emergent vegetation (Allport et al., 1991; Holopainen et al., 2015). In addition, maintaining for scarlet dwarf dragonfly (*Nannophya pygmaea*) habitat, *Juncus effuses* would have particular value to wetland managers aiming to maximize habitat use (Yoon et al., 2010; Yoon et al., 2011). Invertebrate surveys should also be conducted periodically. It would be important to monitor, not only the target species richness and diversity, but all major ecological aspects of a wetland. Managers should also take careful note of habitat use by wildlife (Lane and Jensen, 1999).

4. Potential application of moist-soil management wetland in Korea

Seasonal migration timing of waterbirds in Korea (e.g., Geum estuary) and Missouri (e.g., Grand Pass Conservation Area) was similar because migratory waterbirds use both areas as stopover habitats in the Flyway. Mean arrival date for waterbirds at Geum estuary (Korea, N36° 05'; Kang et al., 2015) and Grand Pass Conservation Area (Missouri, N39° 17', Ripper and Duke, 2013) was mid-April and mean departure date was late May. Sites within close proximity of the Geum estuary would be especially valuable to determine optimal conditions for East Asia/Australasia migrants in the fall that reply upon the mudflats as a staging site (Fig. 3). In addition, in the aftermath of Saemangeum, land managers might wish to make alternative habitats to increase carrying capacity for migrant shorebirds around Geum estuary.

The Geum estuary is filled with rice fields that have potential to serve as an experimental, moist-soil management wetland. The estuary would provide an accessible source of water to the potential moist-soil management area that effectively reflect natural conditions found within the

Fig. 3. Potential experimental site (red) adjacent to the Geum Estuary (blue), Republic of Korea (N36° 27', E126° 44')

ecosystem, including water and soil chemistry. In order to create a diverse array of foraging and roosting opportunities for migrant shorebirds, a manager would want to develop a mosaic of impoundments with different experimental treatments to test multiple flooding, drawdown, and disturbance regimes that would create optimal conditions for shorebirds with diverse life histories in a controlled setting. Moist-soil management's dynamic and flexible approach makes it an ideal management technique for different ecological systems and climates (Haukos and Smith, 1996; Norrgard, 2010; MDC, 2017). However, it is important to adjust timing of flooding and drawdown according a wetland's unique natural history. The methodology described in this manuscript provides baseline recommendations, but it is vital to ground any extensive wetland restoration efforts with localized, experimental results according to an area's natural history and target goal.

5. Conclusions

The rapid destruction of the EAAF's most important staging site through reclamation projects has left a definitive impact on global waterbird populations and illustrated the vulnerability of migrants at different stages of their life cycles (Yang et al., 2011; Runge et al., 2015). The declines also provided supporting evidence indicating that the Yellow Sea has reached carrying capacity. With this in mind, migrants cannot afford to lose additional habitat; yet, over 91% of the world's migrant birds are left vulnerable at one point or another in their annual cycle (Runge et al., 2015). Within the Yellow Sea, only 16% of the intertidal area is protected, with only 0.3% in South Korea (La Peyre et al., 2001). In the face of similar losses, the United States implemented several land management practices to restore degraded wetlands and maximize habitat value, with moist-soil management being among the most successful practices in the past thirty years. The technique allows for target-based management decision that embodies a dynamic approach for fluctuations in environmental conditions (Lane and Jensen, 1999). Moist-soil management's generalized construction parameters and intrinsic flexibility has potential for successful application in other distant regions, such as the Korean Peninsula. One distinct difference between the United States (e.g., Missouri) and Korea is wetland size. Missouri's largest wetland reserve program easement is 6,997 ha. In contrast, Korea's wetlands are <500 ha (Kim et al., 2014). In Korea, small mosaics of natural wetland systems with moist-soil impoundment may provide high quality habitat and forage for Korea's wildlife.

Since the 1960's, Korea has lost over >30% of its tidal wetlands with agriculture and reclamation projects (Kim, 2010; Murray et al., 2014; Studds et al., 2017). In the process, over 40% of the EAAF shorebirds lost critical staging habitat, which caused significant global declines, including 20% of the Great Knot population (Yang et al., 2011). It also reduced wintering habitat for over 95% of Baikal Teals (Yu et al., 2014). These global losses imply that the reduction in wetlands have pushed the remaining mudflats past carrying capacity. In light of continuing urban expansion, it is vital to mitigate against further habitat loss and seek alternative land management strategies in Korea. The United States faced a similar plight, but the combination of legislative policy and precise land management has allowed for the restoration of >36,000 ha of wetlands. Moist-soil management was a key tactic implemented during this period to maximize habitat use for wildlife, especially waterfowl, through a carefully timed flooding and drawdown regime that coincided with key events, such as fall migration. In order to preserve Korea's valuable, ecological integrity, it is important to seek similar tactics to preserve the remaining wetlands and restore reclaimed lands wherever possible. Thus, the logical next step would be to test moist-soil management techniques in Korea, preferably in a potential restoration site, in order to develop precise flooding, drawdown, and disturbance regimes that meet the country's target goals. Potential application of moist-soil management in Korea is highly conservative as we did not include wetland vegetation and animals in the United States and Korea. Thus, additional research is needed on detailed wetland wildlife characteristics. Potential application of moist-soil management in Korea is highly conservative as we did not include wetland vegetation and animals in the United States and Korea. Thus, additional research is needed on detailed wetland wildlife characteristics. A clear understanding of habitat environmental characteristics would help the long-term implementation of new wetland management strategy that includes habitat monitoring and conservation planning.

Habitats in moist-soil management area provide wildlife foods that are important waterbird diet and have become a significant part of management efforts on many wildlife refuges in USA. However, the manager of moist-soil management refuges may not make a step-by-step list that maximizes production on each moist-soil unit because moist-soil management is different in every location. The purpose of current paper is to provide the general methodology of moist-soil management and its potential application in Korea to restore optimal habitat for migrant and wintering waterbirds. Additional information on moist-soil management implementation in Korea would further enhance our understanding of this strategic methodology and refine our ability to predict successful introduction.

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