Chapter 12
Wetlands Restoration and Mitigation

Robert P. Brooks and Naomi A. Gebo

Abstract For decades, scientists, managers, policy makers, and practitioners have sought to improve the design and performance of mitigated and restored wetlands. Progress has been made, but further improvements are needed. In this chapter, we provide a historical context, review the mitigation process, summarize the literature on mitigation and restoration of wetlands, and make the case for using natural reference wetlands as templates for designing mitigation and restoring projects and assessing their performance. Two case studies conducted by Riparia at Penn State are used to demonstrate the value of a reference-based approach. A comparison of scores from Habitat Suitability Index models between reference and created wetlands shows that the latter are either not equivalent, with created sites scoring lower, or habitats are shifted toward species in the wildlife community that favor open water or emergent conditions. In the second study, scores of hydrogeomorphic (HGM) functional models are compared between reference wetlands and mitigation sites, showing that average performance is often significantly lower for several functions across multiple HGM types. Finally, we describe how a set of variables from Riparia's database of reference wetlands can be used to improve the outcome of mitigation and restoration projects.

R.P. Brooks (✉)
Riparia, Department of Geography, Pennsylvania State University, 302 Walker Building,
University Park, PA 16802, USA
e-mail: rpb2@psu.edu

N.A. Gebo
704 Rogers Street, Columbia, MO 65201, USA
e-mail: naomi.gebo@gmail.com

R.P. Brooks and D.H. Wardrop (eds.), *Mid-Atlantic Freshwater Wetlands: Advances in Wetlands Science, Management, Policy, and Practice*,
DOI 10.1007/978-1-4614-5596-7_12,

12.1 Introduction

Striving to improve the *performance* of wetland projects has been a goal of *mitigation*, *restoration*, *creation*, *construction*, and *enhancement* efforts since the inception of these practices (see Sect. "Glossary" for definitions of underlined terms). The call to improve the performance of mitigation projects began in earnest with the release of The Conservation Foundation's report on Protecting America's Wetlands: An Action Agenda in 1988, which recommended both a no net loss policy for existing wetland area and function, and a long-term gain in wetland area and function. This report also stated the need for developing technical guidance for designing and replacing wetlands and their inherent functions, but for years, the "no net loss" portion has been applied to acreage only (not function), and the "gain" portion of the recommendations has not been effectively applied to either acreage nor function.

The state-of-the-science in wetlands restoration and creation was summarized in an edited volume by Kusler and Kentula (1990). This was soon followed by the National Research Council's report (1992) that called attention to the gaps in our knowledge about restoring wetlands and other aquatic ecosystems. A variety of works aimed at guiding practitioners on how to "build a better wetland" (Cole et al. 1997) followed, such as Hammer (1992) and Marble (1992). Yet, the focus of these and most other publications was on the creation, restoration, or enhancement of many freshwater, emergent marshes, for which *design* and construction techniques are well established (e.g., Cole et al. 1996). Thus, the majority of wetlands were of this type, whether they were built as mitigation projects, as *voluntary*, incentive-driven projects on private lands, or as wildlife enhancements designed and constructed by conservation organizations, such as Ducks Unlimited (www.ducks.org).

What was obviously needed was a process by which more in-kind replacement could be proposed and designed. To achieve this, two things were necessary: a classification system that had a functional basis, and a process by which one could recognize relevant models for restoration or creation. These needs were met by a series of papers such as Brinson and Rheinhardt (1996), which recommended the study of comparable, natural, reference wetlands to guide the process of designing and constructing mitigation projects. The concept was that wetlands classified differently either by their hydrogeomorphic (HGM) characteristics (i.e., water sources, hydrodynamics, landscape position, Brinson 1993) or their vegetation characteristics (e.g., aquatic bed, emergent, shrub, trees, Cowardin et al. 1979), would vary in their design parameters and construction specifications.

The limits of replicating or replacing wetlands "in kind" (of the same type) or "off site" (some distance from the wetland being replaced, but usually within the same watershed) and their associated ecosystem services have been extensively cited and debated (e.g., Race and Fonsec 1996; Mitsch and Wilson 1996; Zedler and Callaway 1999, National Research Council 2001, U.S. General Accounting Office 2002; Environmental Law Institute 2004, 2005; Hoeltje and Cole 2007; Hossler et al. 2011), culminating in the release of the so called “Mitigation Rule” by the U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers in 2008 (33 C.F.R. 332.3(c); USEPA 2008). These revisions encourage states to carry out mitigation in a watershed context, prioritizing mitigation projects on a watershed basis to the extent appropriate and practicable. States are expected to establish monitoring programs and measureable performance standards for mitigation wetlands. At present, the science and practice of restoration and mitigation are on the cusp of demonstrating how these sites can be more like their natural counterparts, and thus, deliver the level of structure and function that the profession and public expect.

This chapter provides a summary of research conducted by Riparia (http://www.riparia.psu.edu) that focuses on providing information that can improve practice. Following a brief synopsis of the state-of-the-science, we address specific measures related to both the design of projects and evaluation of their performance. Because understanding terminology precisely is a key to assessing wetlands mitigation, a glossary of *italicized* terms is provided at the end of this chapter for the convenience of readers. Throughout this chapter, we will use “mitigation” when referring generically to *restoration*, *creation*, *construction*, and *enhancement*.

12.2 The Mitigation Process

Mitigation and restoration activities should not be conducted in a vacuum, where the landscape and wetland types are not known. Based on studies conducted by personnel from Riparia and others from the early 1990s, we began to recommend that wetlands mitigation be conducted using a defined process to assess the type and location of wetland restoration or creation, in order to achieve maximum likelihood of effective function (Kentula et al. 1992; Brooks 1993). We were influenced, in part, by findings of Gwin and Kentula (1990) and Kentula et al. (1992b), which demonstrated that wetlands created for purposes of mitigation, were not mimicking natural wetlands found in the landscapes of Oregon where those studies were conducted. As a consequence, the profile of natural wetlands (i.e., wetland abundance by wetland type) found in a given landscape would likely shift to a new profile comprised of dissimilar or unrecognizable types of wetlands (e.g., Bedford 1999), with a resultant shift in functions and values provided by those wetlands.

To further the compatibility of mitigation decision-making and current wetlands science, Brooks et al. (2006) diagrammed an overall planning process where the general objective was to have no net reduction in ecological integrity. Restoration was considered as the last part of a sequence that would likely involve an inventory of existing wetland resources and assessment of target resources, before prioritizing sites for restoration based on their landscape position, conservation status, and restoration potential (Table 12.1).

Table 12.1 Integrated tasks for wetland monitoring matrix (WMM): inventory, assessment, and restoration at three levels of effort

	Inventory	Assessment	Restoration
Level 1: Landscape	Use existing map resources (NWI) of wetlands for priority watersheds	Map land uses in watersheds; compute landscape metrics and initial condition	Produce synoptic watershed maps of restoration potential with multiple sites
Level 2: Rapid	Enhance inventory using landscape-based decision rules classify by NWI and HGM types	Rapid site visit and stressor checklist; determine condition based on human disturbance score	Select sites for restoration; examine levels of threat from surroundings
Level 3: Intensive	Map wetlands intensively for a portion of area; verify inventory; classify by NWI and HGM types	Apply HGM and IBI models to selected sites to assess condition based on reference sites and data	Focus on specific sites for restoration; design projects with reference data sets using performance criteria matrices

Modified from Brooks et al. (2006)

The mitigation process, as recommended, consists of seven major steps (Brooks 1993):

1. Conduct a functional assessment of the wetland to be impacted (assuming there is a need for direct replacement), considering the functional needs for the region of interest.
2. Set site-specific objectives for the project in cooperation with stakeholders, which could include agency personnel, landowners, cosponsors, and/or citizen groups.
3. Select and acquire access to a suitable site.
4. Design conceptual plans based on site conditions and project-specific objectives with input from stakeholders.
5. Prepare construction plans, specifications, and budget.
6. Implement construction and maintenance activities.
7. Prepare as-built condition plans for baseline information, and implement monitoring protocols for evaluation reports.

An underlying tenet of our work has been the critical need to mirror methods used to assess wetland condition (step 1) vs. those used to measure performance (step 7). In plain language, with few exceptions, one must measure the same parameters in the same way when assessing natural wetlands and when evaluating performance of mitigation projects (Kentula et al. 1992; Brooks 1993; Brooks et al. 2005, 2006). Inherent in this tenet, is that practitioners need design and performance criteria, specific to different wetland types that are based on measurements obtained from natural reference wetlands of the intended type, in order to construct and monitor projects, respectively. Unfortunately, design and performance criteria, based on specific types of wetlands occurring in different ecoregions, have not been widely available.

12.3 State-of-the-Science in Wetlands Restoration and Mitigation

Performance “curves”, as a concept, were recommended by Kentula et al. (1992a) to document the progression of ecological function(s) within a mitigated wetland over time against findings for reference wetlands within a region. In the mid-1990s, actual performance matrices were compiled for the hydrologic, soil, vegetation, and wildlife components of wetlands in central Pennsylvania in a report that was narrowly distributed, and hence, those data were not widely used. These matrices were structured to provide detailed information (e.g., means, ranges, and species) by HGM subclass to aid in designing mitigation projects for specific wetland types. In addition, when characteristics of natural wetlands were compared to those of mitigation sites, large differences were found that highlighted the poor performance of the mitigation sites.

Further studies by Riparia personnel, reported in Bishel-Machung et al. (1996), Stauffer and Brooks (1997), Cole and Brooks (2000), Cole et al. (2001), Brooks et al. 2002, Campbell et al. (2002), Walls et al. (2005), and Cole et al. (2006), demonstrated the consistent failure of mitigation sites to replicate the structure and function of natural reference sites. For example, mitigation sites had soils with coarser texture, and lower amounts of organic matter, silt, and clay. This was most likely caused by the common practice of excavating to subsoil, without replacing topsoil removed from the sites. Soil bulk densities were higher in mitigation sites, reflecting inappropriate construction practices, such as allowing compaction by heavy, earth-moving machinery. Comparatively, the Munsell chroma of matrices from soils of mitigation sites were brighter than those of reference wetlands, suggesting that insufficient time had transpired for saturation or inundation to occur, which would force the reduction of iron that leads to duller colors. Campbell et al. (2002) found that in created sites up to 18 years since construction, organic matter failed to accrete over time so as to match that of comparable HGM types. They also found that vascular plant richness and total cover were both greater in reference versus created wetlands, and invasive plants were more prevalent in the latter. Basin *morphometry* also varied, with reference wetlands displaying more complex perimeter-to-area relationships than in mitigation sites. This points to the tendency of creating geometric shapes during the wetland construction practices because they are less expensive and simpler to build.

Cole and Brooks (2000) concluded that while created wetlands can meet jurisdictional requirements, their hydrologic behavior is not necessarily the same as that defined by a naturally occurring HGM subclass. Differences in subclass have implication for function. Cole et al. (2002) found that for specific HGM subclasses and settings in Pennsylvania and Oregon, wetlands, which depend on surface water additions (for one HGM subclass), are more likely to have different wetland functions than wetlands that are hydrologically supported by regional water tables (for a different HGM subclass). Such variations in hydrologic regime can lead to differences in the water depth and/or duration of soil saturation, and thus change a wetland’s dependence from that of one dominated by anaerobic soil conditions to one

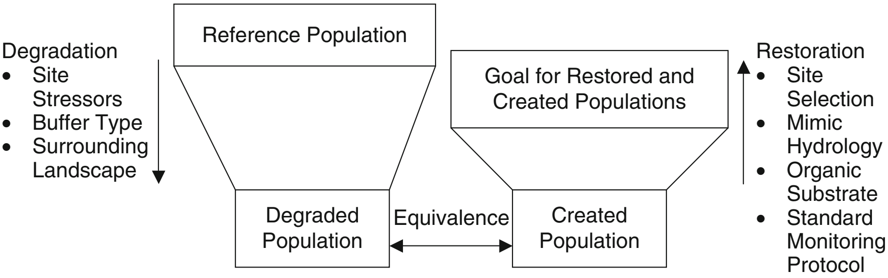

Fig. 12.1 Conceptual model of wetland degradation and restoration showing the equivalence of characteristics for populations of degraded and created populations, and how data from reference wetlands could be used to improve the performance of mitigation projects (modified from Brooks et al. (2005))

reflective of aerobic conditions. This would certainly have an effect on the formation of hydric soil indicators.

This body of work led to the formulation of a conceptual model of how the state-of-the-practice for creation, restoration and mitigation projects was resulting in wetlands that were equivalent in condition and/or function to highly degraded natural wetlands (Brooks et al. 2005). A conceptual model of the issues (Fig. 12.1), along with examples of how mitigation sites failed to match the characteristics of reference wetlands, led to their suggestion to “build a better wetland” by using reference wetlands to generate design and performance criteria that are specific to different types of wetlands.

More recently, Moreno-Mateos et al. (2012) compared over 621 wetland mitigation projects worldwide to 556 reference wetlands, concluding that recovery was slow and incomplete. The net result over time is a net loss of wetland ecosystem services. Larger restoration projects in warmer climates, and those controlled by the dynamics of rivers and tides, approached the level of ecosystem services provided by natural reference sites more rapidly than others. The focus of their meta-analysis was on restored wetlands ($n=401$), and less so on created wetlands ($n=220$, those built from scratch, which are typical of mitigation projects).

In their study, the recovery of ecosystem services in all major categories was always less than those of comparable reference wetlands even after significant periods of time, ranging from <10 to >100 years; wildlife and fisheries, aquatic insects and other invertebrates, and plants do not reach full functional equivalency. Biogeochemical functions also failed to reach the levels found in natural reference wetlands; soil organic matter averaged 62% of reference wetland values and nitrogen accumulation still only averaged 74% of reference wetland values after 50–100 years, and was substantially less over shorter time periods.

Similarly, Gebo and Brooks (2012) compared HGM functional assessments of 222 reference wetlands (spanning an anthropogenic disturbance gradient) from Riparia’s Pennsylvania collection to 72 mitigation wetlands sampled in 2007 and 2008 from three categories—Pennsylvania Wetland Replacement Program sites,

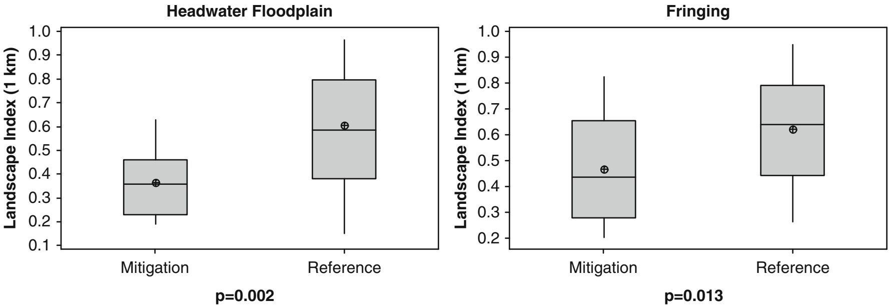

Fig. 12.2 Boxplots (mean, median, standard deviation, range) depicting the difference in Landscape Index score between reference and mitigation wetlands; headwater floodplain and fringing wetlands subclasses (Gebo 2009)

Pennsylvania Department of Transportation mitigation banks, and permit required compensatory mitigation sites. Overall, mitigation sites displayed lower potential to perform characteristic wetland functions than reference wetlands. Depressions show the greatest discrepancy, while fringing sites along lakes showed the least amount of difference from reference scores. The majority of mitigation sites fell within the range of reference function for their HGM subclass, indicating that they are at least equivalent in functional capacity to some naturally occurring wetlands. However, creating wetlands that function at a lower level like those of disturbed natural wetlands should not be considered an optimal mitigation or restoration endpoint (Brinson and Rheinhardt 1996, Zedler 1996).

The data reported here show some examples of functional assessments where mitigation projects scored lower than reference wetlands (Gebo 2009; Gebo and Brooks 2012). Gebo (2009) examined both the landscape setting (Fig. 12.2) and site-level conditions (Fig. 12.3) for mitigation projects and reference wetlands. For both landscape and site comparisons, most functions of mitigation sites scored significantly lower than those of reference wetlands.

For the majority of mitigation wetlands studied by Gebo (2009) and Gebo and Brooks (2012), fewer than 10 years had passed since initial site construction. Hossler et al. (2011) found that created wetlands, even those monitored several decades after construction, were not reaching equivalent patterns of nutrient cycling when compared to natural wetlands, thus raising concerns about long-term success. Other authors have expressed similar performance concerns regarding spatial patterns and temporal lags for mitigation projects designed to meet functional equivalency with natural wetlands (e.g., Gutrich and Hitzhusen 2004; Bendor 2009).

Overall, low functional capacity at mitigation and restoration sites is likely tied to continued problems of attaining hydrologic equivalence. This conclusion is supported by the finding that fringing sites, associated with adjacent deep water aquatic systems, had the most consistently high level of functional potential of all the mitigation sites studied in Pennsylvania (Gebo and Brooks 2012). Trying to mimic the hydrologic regimes of groundwater supported wetlands or mature floodplain forests

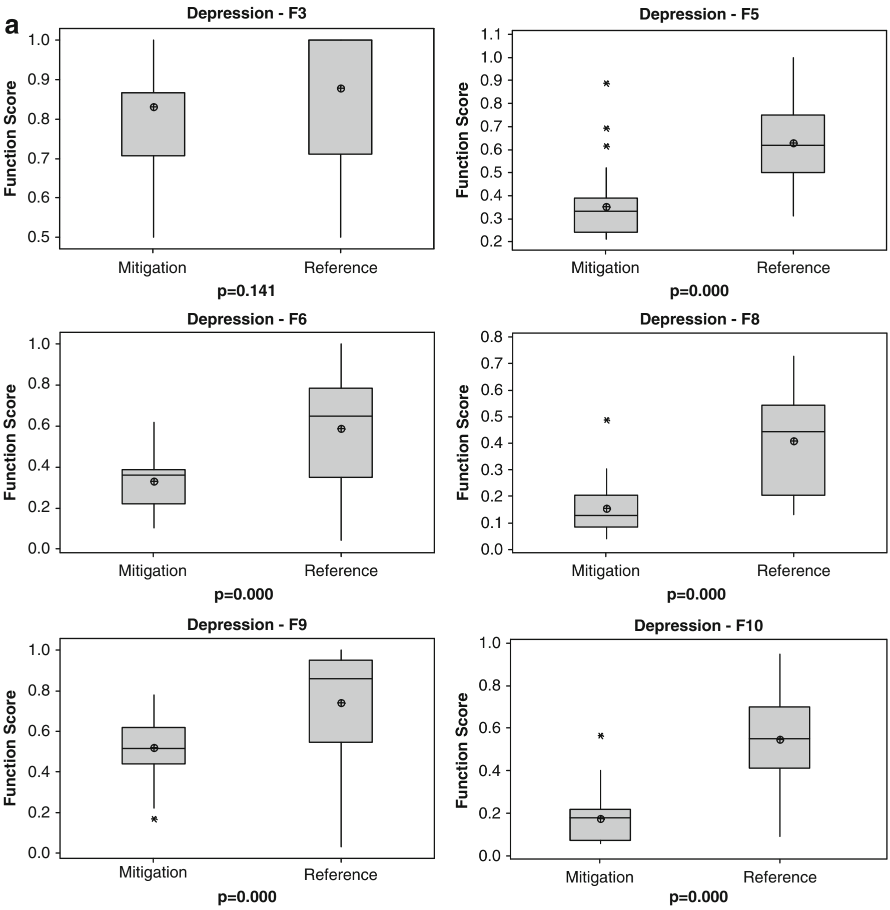

Fig. 12.3 (**a**–**d**) Boxplots (mean, median, standard deviation, range) comparing selected functional capacity index scores for mitigation sites and reference wetlands classified as: (**a**) depression (permanent, seasonal, and temporary), (**b**) fringing (lacustrine), (**c**) headwater floodplain (riverine upper perennial), and (**d**) slope. Functions included here are: F1 (energy dissipation/Short-term surface water detention), F2 (long-term surface water storage), F3 (Maintain characteristic hydrology), F5 (removal of imported inorganic nitrogen), F6 (solute adsorption capacity), F7 (Retention of inorganic particulates), F8 (export of organic carbon), F9 (maintain characteristic native plant community composition), F10 (maintain characteristic detrital biomass), F11 (vertebrate community structure and composition) (see Brooks 2004, Gebo 2009)

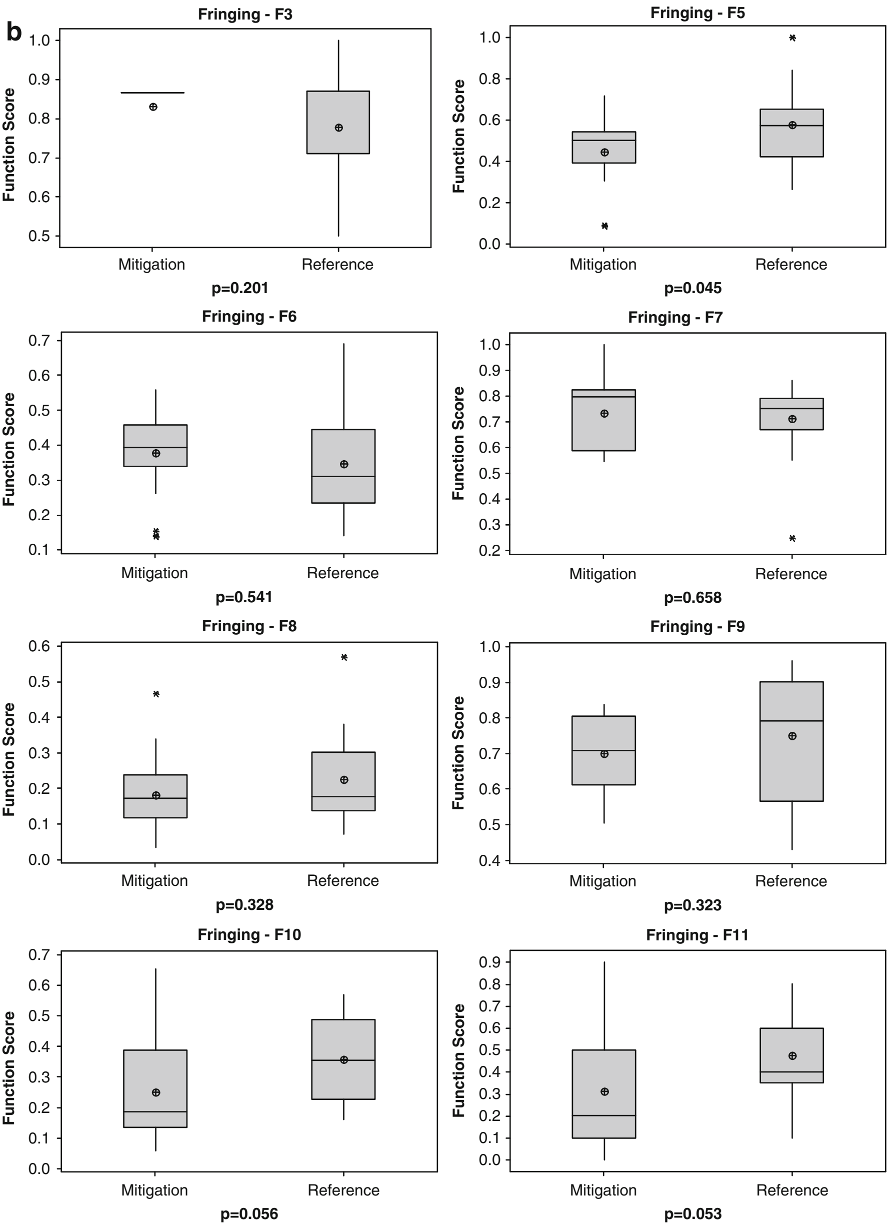

Fig. 12.3 (continued)

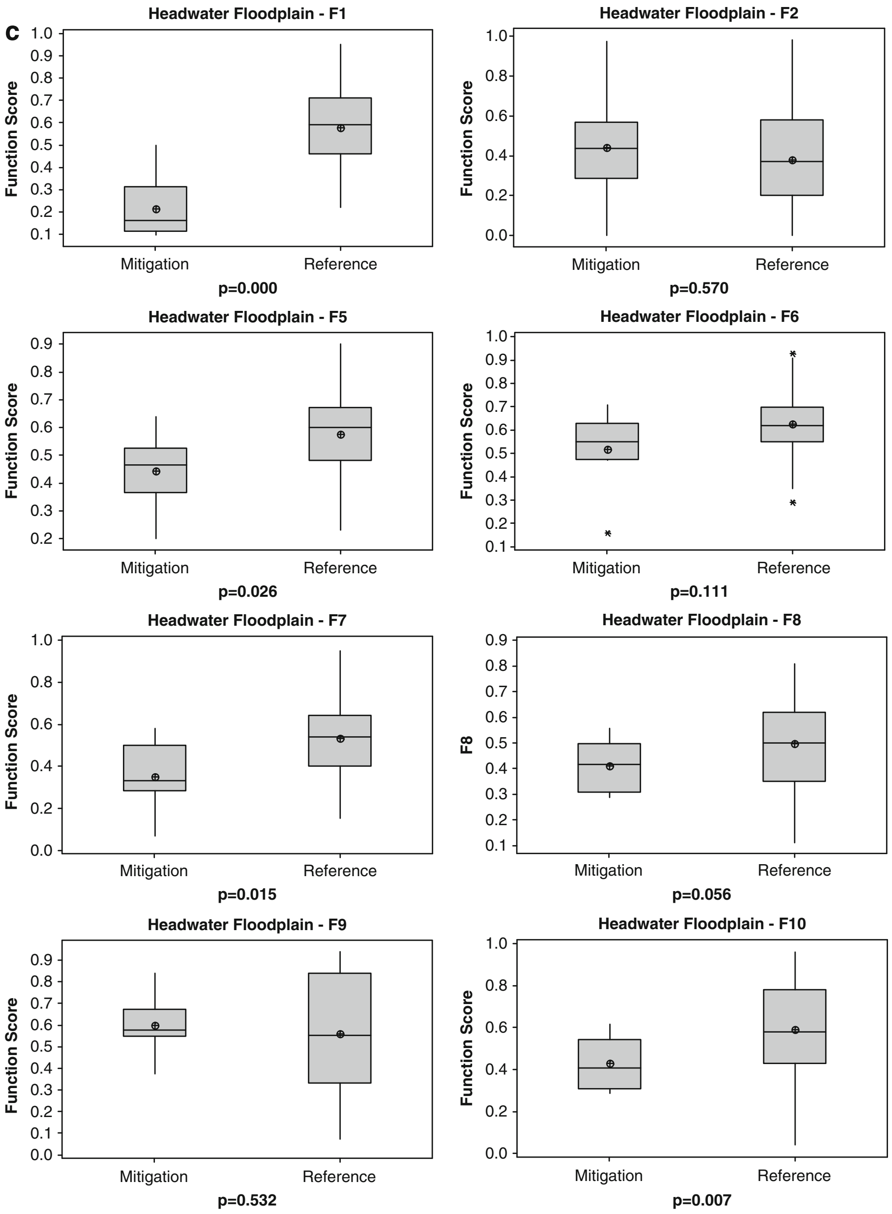

Fig. 12.3 (continued)

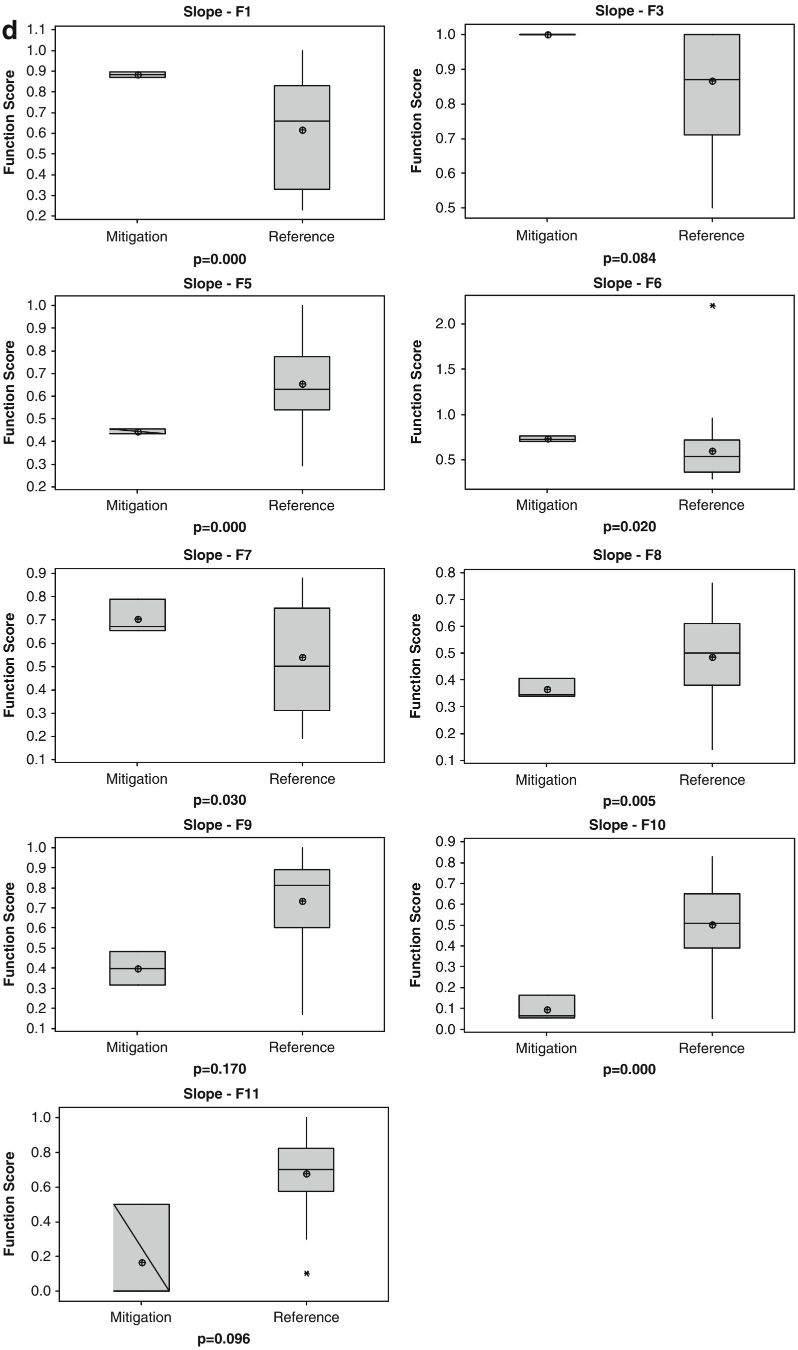

Fig. 12.3 (continued)

is far more difficult, and less likely to succeed, than creating emergent marshes using surface water sources.

12.4 Wildlife Habitat Community Profiles for Natural Reference and Created Wetlands

Wildlife managers and environmental professionals commonly use Habitat Suitability Index (HSI) models to evaluate potential habitat by individual species in single habitat types. During Riparia's studies of natural reference wetlands, we devised a standard means to compare habitat suitability across multiple types of freshwater, inland wetlands of the northeastern US. We developed a wildlife community habitat profile (WCHP) composed of ten species chosen to represent a range of taxa, trophic levels, and habitats (Brooks and Prosser 1995) (Table 12.2). HSI numerical scores (0–1 range) for each of the ten individual species were placed along a vegetation and moisture gradient from open water to forested wetlands, to create a unique wildlife profile. We then compared profiles between reference wetlands ($n = 38$) and created wetland projects ($n = 12$). Reference herbaceous wetlands were distinguished from reference wooded sites based on significant differences in HSI scores for each species comprising the profile. Species that use emergent wetlands scored equally well on reference herbaceous wetlands and created herbaceous sites, suggesting that wildlife habitat functions can be replaced reasonably well during

Table 12.2 Ten wildlife species used in the wildlife community habitat profile to evaluate reference and mitigation wetlands with Habitat Suitability Index (HSI) models

Common name	Scientific name	Taxonomic group	Trophic level
Open water (with some emergents allowed)			
Bullfrog	*Lithobates catesbeiana*	Amphibian	Carnivore
Muskrat	*Ondatra zibethicus*	Mammal	Herbivore
Emergent (with some open water or shrubs allowed)			
Meadow vole	*Microtus pennsylvanicus*	Mammal	Herbivore
Red-winged blackbird	*Agelaius phoeniceus*	Bird	Granivore
Scrub–shrub (with some emergents or forested wetland allowed)			
American woodcock	*Philohela minor*	Bird	Invertivore
Common yellowthroat	*Geothlypis thrichas*	Bird	Insectivore
Green-backed heron	*Butorides striatus*	Bird	Carnivore
Forested wetland (with some shrubs or emergents allowed)			
Wood duck	*Aix sponsa*	Bird	Herbivore
Wood frog	*Lithobates sylvatica*	Amphibian	Carnivore
Red-backed vole	*Clethrionomys* g. *gapperi*	Mammal	Herbivore

Table 12.3 Comparisons of median HSI scores for ten wildlife species among three wetland types

	Median HSI scores			Pairwise wetland type comparisons[b]		
Wildlife species	RH	RW	CH[a]	RH vs. RW	RH vs. CH	CH vs. RW[c]
Bullfrog	0.66	0.00	0.73	<0.05**	>0.15	<0.05**
Muskrat	0.63	0.27	0.73	>0.15	>0.15	>0.15
Meadow vole	0.61	0.50	0.60	>0.15	>0.15	>0.15
Red-winged blackbird	0.72	0.48	0.79	<0.05**	>0.15	<0.05**
Common yellowthroat	0.45	0.52	0.13	>0.15	<0.05**	<0.05**
American woodcock	0.37	0.44	0.20	>0.15	<0.05**	<0.05**
Green-backed heron	0.68	0.62	0.51	>0.15	0.07*	0.13*
Wood duck	0.32	0.33	0.34	>0.15	>0.15	>0.15
Wood frog	0.42	0.71	0.35	0.06*	>0.15	<0.05**
Southern red-backed vole	0.0.29	0.53	0.00	0.08*	<0.05**	<0.05**

[a,c] Wetland types and comparisons: reference herbaceous (RH), reference wooded (RW), created herbaceous (CH)

[b] Kruskal–Wallis, Bonferroni; p values are reported as >0.15 indicating no significance, *Significant difference for overall <0.15 (0.05 × 3) to >0.06 (0.02 × 3); **Highly significant difference for overall <0.05 (0.017 × 3)

creation of emergent marshes. Species dependent on forest and shrub wetlands scored poorly on created wetlands due to the absence of a wooded component on mitigation projects, which can only appear over time. This pattern is replicated for other functions, where herbaceous, emergent wetlands perform closer to the functional capability of natural wetlands than those dominated by woody vegetation.

The WCHP provides a consistent means to make quantitative and visual (by plotting a histogram of scores for the ten species) comparisons of habitat suitability among wetland types. Many of the variables assessed when applying the HSI models can be incorporated into designs for mitigation projects.

Median habitat scores for the bullfrog, wood frog, muskrat, meadow vole, red-winged blackbird, or the wood duck were not significantly different between reference herbaceous sites and created herbaceous sites. The common yellowthroat, American woodcock, green-backed heron, and southern red-backed vole, all showed significantly higher habitat values on reference herbaceous sites than on created herbaceous sites (Table 12.3).

Reference herbaceous sites scored significantly higher than the reference wooded sites for the bullfrog and red-winged blackbird, and reference wooded sites scored significantly higher than reference herbaceous sites for the wood frog and southern red-backed vole. No differences were observed in scores for species located in the middle portion of the vegetative profile; muskrat, meadow vole, common yellowthroat, American woodcock, green-backed heron, and the wood duck (Table 12.3).

Reference wooded sites had significantly higher scores than created herbaceous sites for species that require woody cover; common yellowthroat, American woodcock, green-backed heron, wood frog, and southern red-backed vole. Created herbaceous sites had significantly higher scores for the bullfrog and red-winged blackbird. No differences were found for the muskrat, meadow vole, and wood duck (Table 12.3).

Overall, reference herbaceous and created herbaceous sites provided equivalent wildlife habitat functions for six of the ten species. Habitat potential was poor for the four species which prefer some wooded cover; common yellowthroat, American woodcock, green-backed heron, and southern red-backed vole. If reference wooded wetlands are destroyed and replaced by mitigated wetlands dominated by herbaceous cover, a resulting shift in the wildlife community is likely to occur. Thus, while wetland practitioners are capable of producing equivalent habitat potential for species that require herbaceous, emergent marshes, there is little evidence of functional replacement of habitats for species that require the forest and shrub components of wetlands.

Given the overwhelming empirical evidence from these and many other studies by others that mitigation projects usually do not mimic the structure nor perform the functions of natural wetlands, and given the shift in policy accentuated in the release of the federal "Mitigation Rule," we focus the rest of this chapter on how to achieve the performance we desire.

12.5 Design and Performance Criteria

Following our basic premise of assessing mitigation projects and reference sites using comparable methods, we present a list of variables derived from assessments of natural wetlands that can then be used for evaluating the performance of wetland mitigation projects. The site data related to these measures are voluminous, and thus, are best served from a website (www.riparia.psu.edu) where characteristic measures can be selected by HGM types and for designated ecoregions. These initial data are primarily from Pennsylvania, but a summary of data from reference sites for the Mid-Atlantic Region is planned for distribution through the Riparia website. Because of their particular geographic origin, these data should be used with caution for other areas. Many of these variables, however, will have some relevance to wetlands of a particular type in many other physiographic regions. For readers interested in additional details about sampling and assessment methodologies, and how variables are scored and combined for HGM functional assessment models, refer to the appropriate sections of Brooks 2004 (Table 12.4) (relevant section available in pdf form at http://www.riparia.psu.edu)

Variables are divided into several categories:

1. Variables collected remotely or from GIS databases to assess the landscape around a site for assessment, design, or performance purposes
2. Variables collected at ground level primarily for design purposes
3. Variables collected at ground level for assessment or performance purposes

Once the purpose and objectives for a mitigation project are defined, site selection becomes a most critical next step. So, the first variables presented are used to assess the landscape surrounding a site. Mitigation projects located in an inappropriate place are likely to fail.

Table 12.4 Variables used to compare among natural wetland types and between reference wetlands and mitigation sites (see Brooks (2004) for additional details)

Variable	Design	Performance	Landscape
AQCON	X		
BIOMASS	X	X	
HERB% COV	X	X	
SHRB% COV	X	X	
TREE% COV	X	X	
CWD-BA	X	X	
CWD-SIZE	X	X	
EXOTIC		X	
FLOODP	[X]	[X]	
100FLOODPL			X
FWD	X	X	
GRAD	X	X	
HYDROCHA	[X]	[X]	
HYDROSTR			X
MACRO	X	X	
MICRO	X	X	
MPS			X
ORGMA	X	X	
REDOX		X	
REGEN		X	
ROUGH	X	X	
RDDEN			X
SDI			X
SNAGS	X	X	
SPPCOMP	X	X	
STR INDEX			X
NEAR DIST			X
TEXTURE	X	X	
UNDEVEL			X
UNOBSTRUC			X
URBAN			X
LDI			X
—			
WILDLIFE	X	X	X

HSI variables for ten species (Brooks and Prosser 1995; Brooks 2004)

Presumably, one aspect of effective project planning must include a decision on what type of wetland is to be built. Choosing a subclass based on both the physically oriented HGM system (Brinson 1993) and the vegetation-oriented Cowardin et al. (1979) system has worked well for our studies. We have developed a regional wetlands classification system for the Mid-Atlantic that pays homage to both systems, although HGM is emphasized (Brooks et al. 2011).

To emphasize the importance of location and landscape position, there are at least nine primary variables used to compute six metrics pertinent to selecting the location of a site in a landscape (see Brooks 2004 at http://www.riparia.psu.edu for definitions and sampling protocols):

1. Aquatic connectivity (VAQCON) is a composite variable comprised of three subvariables; occurrence of the site in a 100-year floodplain (V100FLOOD), stream density index (VSTR INDEX), and distance to the nearest National Wetlands Inventory mapped wetland (VNEAR DIST)
2. Gradient (VGRAD)
3. Number of hydrologic stressors (VHYDROSTRESS)
4. Average forest patch size within a 1-km radius circle (VMPS)
5. Road density with a 1 km radius circle around the site (VRDDEN)
6. Shannon diversity index (VSDI) for landscape categories within a 1-km radius circle around the site or Land Development Index (LDI) for a site
7. Undeveloped (VUNDEVEL) portions of landscape (a composite variable of VRDDEN and VURB)
8. Unobstructed portions of riverine floodplains (riverine types only; a composite variable of VRDDEN, VURB, and VHYDROSTRESS)
9. Percentage of urban land within a 1-km radius circle around the site (VURB)

Once a subclass is chosen, and a suitable location is secured, then the set of pertinent ground-based variables can be explored and translated into project-specific design criteria intended to produce a wetland that shares characteristics with its natural counterparts. Most importantly, the chosen location must have a hydrologic regime that provides the sources of water needed by that type of wetland, with sufficient quantities to meet frequency and duration requirements. For example, if on-site soils do not meet texture, nutrient, and/or organic matter content parameters, then it may be necessary to use soil amendments in appropriate quantities, usually computed volumetrically.

We recommend 17 variables collected at ground level for use in assessment, design, and performance purposes (see Brooks 2004 at www.riparia.psu.edu). Those variables with an "*" are only pertinent for measuring assessment and performance, as they are not particularly useful for design purposes. There are a few variables that are deemed to be important, but for which we do not have established field measurements to capture them, denoted by brackets [ ].

1. Biomass (VBIOMASS)—a metric composed of abundance and composition measures for herbaceous, shrub and tree strata within nested plots of different sizes.
2. Coarse woody debris—basal area (VCWD-BA)—measure of basal area for three diameter classes
3. Coarse woody debris—size (VCWD-SIZE)—abundance of three diameter classes
4. Exotic plants (VEXOTIC)—% of species list that are non-native
5. [Floodplain characteristics] (VFLOODP)—reserved until suitable measurements are developed
6. Fine woody debris (VFWD)—visual estimate of litter layer

7. [Hydrologic characteristics] (VHYDROCHAR)—reserved as a measurement; available hydrographs for designated HGM subclass should be examined
8. Hydrologic stressors (VHYDROSTRESS)—captured from the stressor checklist; obviously should be minimized for mitigation project planning and site location
9. Macrotopographic depressions (VMACRO)—number of topographic depressions in wetland (usually a floodplain) where standing water is more likely to occur
10. Microtopographic complexity (VMICRO)—used in the computation of VROUGH, an adaptation of Manning's roughness coefficient
11. Soil organic matter (VORGMA)—% soil organic matter usually in the top 5 cm of soil profile (amount at 20 cm depth may also be relevant)
12. Redoximorphic features (VREDOX)—Munsell chroma of soil matrix and mottles (if any) at 20 cm depth
13. Regeneration (VREGEN)—presence of dominant tree species in multiple strata
14. Roughness (VROUGH)—modified Manning's roughness coefficient
15. Snags (VSNAG)—density and diameter of erect dead woody material in three diameter classes
16. Species composition of flora (VSPPCOMP)—uses Floristic Quality Assessment Index (VFQAI) scores to reflect species composition of all vascular plants
17. Soil texture (VTEX)—measurement or observation of soil texture as a surrogate for mineral particle size and pore space

Additional characteristics that may be useful are detailed measures of the hydrologic regime, usually taken from automatic recording wells (see Chap. 4), and potential habitat characteristics, often derived from Habitat Suitability Models (HSI, see Brooks and Prosser 1995).

By designing mitigation sites with characteristics derived from reference wetlands of relevant HGM subclasses, practitioners are more likely to construct a project that will at least be on a performance trajectory to replace the ecosystem services of natural systems. As mentioned above, a searchable database based on reference wetlands is available at http://www.riparia.psu.edu, and we encourage users to design and construct restoration and mitigation projects based on these data. In time, we believe this will lead all of us toward "building better wetlands."

12.6 Glossary

Compensatory mitigation Creation, restoration, enhancement or preservation of a wetland designed to offset permitted losses of wetland functions in response to special conditions of a permit (National Research Council 2001)

Construction Activities resulting in the building of a wetland for restoration or mitigation purposes

Constructed wetlands Created for the primary purpose of contaminant or pollution removal from wastewater or runoff (Hammer 1997)

Creation Conversion of a persistent upland or shallow water area into a wetland (National Research Council 2001)

Design Plan for a mitigation project, usually based on measures of a wetland's intended structure and function

(Wetland) enhancement Refers to human activity that increase one or more functions of an existing wetland (National Research Council 2001)

Mitigation Similar to compensatory mitigation, but can include substitution of creation, restoration, enhancement or preservation of other aquatic or upland habitat types

Morphometry Topographic measures of a wetland's size, shape, slope and depth

Performance Measurable outcome of a mitigation project, usually based on assessment of a wetland's structure and function

(Wetland) preservation Refers to the protection of an existing and well-functioning wetland from prospective future threats (National Research Council 2001)

(Wetland) restoration To return a wetland from a disturbed or altered condition by human activity to a previously existing condition (National Research Council 1992)

Voluntary restoration Same as restoration, but landowner makes a conscious choice unrelated to permitting requirements

References

Bedford BL (1999) Cumulative effects on wetland landscapes: links to wetland restoration in the United States and southern Canada. Wetlands 19:775–788

Bendor T (2009) A dynamic analysis of the wetland mitigation process and its effect on no net loss policy. Landsc Urban Plan 89:17–27

Bishel-Machung L, Brooks RP, Yates SS, Hoover KL (1996) Soil properties of reference wetlands and wetland creation projects in Pennsylvania. Wetlands 16(4):532–541

Brinson MM (1993) A hydrogeomorphic classification for wetlands. Technical Report WRP-DE-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

Brinson MM, Rheinhardt R (1996) The role of reference wetlands in functional assessment and mitigation. Ecol Appl 6:69–76

Brooks RP (1993) Restoration and creation of wetlands. In: Dennison MS, Berry JF (eds). Wetlands: guide to science, law, and technology. Noyes, Park Ridge, NJ, 439pp.

Brooks RP (ed) (2004) Monitoring and assessing Pennsylvania wetlands. Final Report for Cooperative Agreement No. X-827157-01, between Penn State Cooperative Wetlands Center, Pennsylvania State University, University Park, PA and U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington DC. Rep. No. 2004-3 Penn State Cooperative Wetlands Center, University Park, PA

Brooks RP, Prosser DJ (1995) Habitat suitability index models and wildlife community habitat profiles for use in Pennsylvania wetlands. Report No. 95-1, Penn State Cooperative Wetlands Center, University Park, PA, 27pp

Brooks RP, Devlin DA, Hassinger J, Brittingham MC, Hoover GA (1993) Wetlands and wildlife. College of Agricultural Sciences, Pennsylvania State University, PA, 55pp

Brooks RP, Wardrop DH, Cole CA, Reisinger KR (2002) Using reference wetlands for integrating wetland inventory, assessment, and restoration for watersheds. Pages 9–15 in R. W. Tiner (compiler). Watershed-based wetland planning and evaluation. A collection of papers from the Wetland Millennium Event, 6–12 August 2000, Quebec City, QC. Distributed by Assoc. State Wetland Managers, Inc., Berne, NY, 141pp

Brooks RP, Wardrop DH, Cole CA, Campbell DA (2005) Are we purveyors of wetland homogeneity?: A model of degradation and restoration to improve wetland mitigation. Ecol Eng 24(4):331–340

Brooks RP, Wardrop DH, Cole CA (2006) Inventorying and monitoring wetland condition and restoration potential on a watershed basis with examples from the Spring Creek watershed, Pennsylvania, USA. Environ Manage 38:673–687

Brooks RP, Brinson MM, Havens KJ, Hershner CS, Rheinhardt RD, Wardrop DH, Whigham DF, Jacobs AD, Rubbo JM (2011) Proposed hydrogeomorphic classification for wetlands of the mid-Atlantic region, USA. Wetlands 31(2):207–219

Campbell DA, Cole CA, Brooks RP (2002) A comparison of created and natural wetlands in Pennsylvania, USA. Wetlands Ecol Manage 10:41–49

Cole CA, Brooks RP (2000) A comparison of the hydrologic characteristics of natural and created mainstem floodplain wetlands in Pennsylvania. Ecol Eng 14(3):221–231

Cole CA, Serfass TL, Brittingham MC, Brooks RP (1996) Managing your restored wetland. College of Agricultural Sciences, Cooperative Extension, Pennsylvania State University, University Park, PA, 44pp.

Cole CA, Brooks RP, Wardrop DH (1997) Building a better wetland—a response to Linda Zug. Wetland J 10(2):8–11

Cole CA, Brooks RP, Wardrop DH (2001) Assessing the relationship between biomass and soil organic matter in created wetlands of central Pennsylvania, USA. Ecol Eng 17:423–428

Cole CA, Brooks RP, Shaffer PW, Kentula ME (2002) A comparison of the hydrology of wetlands in Pennsylvania and Oregon (USA) as an indicator of the transferability of hydrogeomorphic (HGM) functional models between regions. Environ Manage 30(2):265–278

Cole CA, Urban CA, Russo P, Murray J, Hoyt D, Brooks RP (2006) Comparison of long-term water levels of created and natural reference wetlands in northern New York, USA. Ecol Eng 27:166–172

Council NR (2001) Compensating for wetland losses under the Clean Water Act. National Academy Press, Washington DC, 322 pp.

Cowardin LM, Carter V, Golet FC, LaRoe ET (1979) Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31, U.S. Fish and Wildlife Service, Washington DC

Environmental Law Institute (2004) Measuring mitigation: a review of the science for compensatory mitigation performance standards. Environmental Law Institute, Washington DC, 281pp.

Gebo NA (2009) A landscape perspective for refining wetland mitigation in Pennsylvania, USA. Master's thesis, Ecology Program, The Pennsylvania State University, University Park, PA

Gebo NA, Brooks RP (2012) Hydrogeomorphic (HGM) assessment of mitigation sites compared to natural reference wetlands in Pennsylvania. Wetlands 32(2)321–331; DOI 10.1007/s13157-011-0267-3

Gutrich JJ, Hitzhusen FJ (2004) Assessing the substitutability of mitigation wetlands for natural sites: estimating restoration lag costs of wetland mitigation. Ecol Econ 48:409–424

Gwin SE, Kentula ME (1990) Evaluating design and verifying compliance of wetlands created under Section 404 of the Clean Water Act in Oregon. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR. EPS/600/3-90/061

Hammer DA (1992) Creating freshwater wetlands. Lewis, Boca Raton, FL, 298pp.

Hammer DA (1997) Creating freshwater wetlands, 2nd edn. CRC, Boca Raton, FL

Hoeltje SM, Cole CA (2007) Losing function through wetland mitigation in central Pennsylvania, USA. Environ Manage 39:385–402

Hossler K, Bouchard V, Fennessy MS, Frey SD, Anemaet E, Herbert E (2011) No-net-loss not met for nutrient function in freshwater marshes: recommendations for wetland mitigation policies. Ecosphere 2:1–36

Institute (2005) 2005 Status report on compensatory mitigation in the United States. Washington DC, 110pp.

Kentula ME, Brooks RP, Gwin SE, Holland CC, Sherman AD, Sifneos JC (1992) An approach to improving decision-making in wetland restoration and creation. Island, Washington DC, 151pp.

Kusler JS, Kentula ME (1990) Wetland creation and restoration: the status of the science. Island, Washington DC

Marble AD (1992) A guide to wetland functional design. Lewis, Boca Raton, FL, 222pp. (Originally published as a Federal Highway Administration document, FHWA-IP-090-10, in 1990)

Mitsch WJ, Wilson RF (1996) Improving the success of wetland creation and restoration with know-how, time, and self-design. Ecol Appl 6(1):77–83

Moreno-Mateos D, Power ME, Comin FA, Yochteng R (2012) Structural and functional loss in restored wetland ecosystems. PLOS Biology 10(1):e1001247

National Research Council (1992) Restoration of aquatic ecosystems. National Academy Press, Washington DC, 552pp.

Race MS, Fonsec MS (1996) Fixing compensatory mitigation: what will it take? Ecol Appl 6(1):94–101

Stauffer AL, Brooks RP (1997) Plant and soil responses to salvaged marsh surface and organic matter amendments at a created wetland in central Pennsylvania. Wetlands 17(1):90–105

U.S. Environmental Protection Agency (2008) Compensatory mitigation for losses of aquatic resources, final rule. http://www.epa.gov/owow/wetlands/pdf/ wetlands_mitigation_final_rule_4_10_08.pdf

U.S. General Accounting Office (2002) U.S. Army Corps of Engineers. Scientific panel's assessment of fish and wildlife mitigation guidance. GAO-02-574, Washington DC, 64pp.

Walls RL, Wardrop DH, Brooks RP (2005) The impact of experimental sedimentation and flooding on the growth and germination of floodplain trees. Plant Ecol 176:203–213

Zedler JB (1996) Ecological issues in wetland mitigation: an introduction to the forum. Ecol Appl 6:33–37

Zedler JB, Callaway JC (1999) Tracking wetland restoration: do mitigation sites follow desired trajectories? Restor Ecol 7(1):69–73