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ORIGINAL PAPER

Differences in aquatic communities between wetlands created by an agricultural water recycling system

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Abstract Establishment of an agricultural water recycling system known as the wetland reservoir subirrigation system (WRSIS) results in the creation of two different types of wetlands adjacent to agricultural fields. Each WRSIS consists of one treatment wetland designed to process agricultural contaminants (WRSIS wetlands) and one storage wetland for holding subirrigation water (WRSIS reservoirs). Previous WRSIS related research has focused on the filtration ability and development of aquatic plants within WRSIS wetlands. The fauna of the WRSIS reservoirs and how its aquatic community structure compares with WRSIS wetlands is unknown. We compared fish, amphibian, and reptile community structure between WRSIS wetlands and reservoirs in northwestern Ohio. Fishes, amphibians, and reptiles were sampled by seining, hoop netting, and gee minnow trapping in three WRSIS wetlands and three WRSIS reservoirs in June of 2006, 2007, and 2008. No difference in species richness, abundance, percent fish, percent reptiles, fish abundance, or reptile abundance occurred between the smaller shallower WRSIS wetlands and the deeper larger WRSIS reservoirs. Percent amphibians and amphibian abundance was greater in WRSIS wetlands than reservoirs. Jaccard's index scores ranged from 0 to 0.5 and indicated species composition differed between WRSIS wetlands and reservoirs. Our results assisted with the development of design and management criteria incorporating wetland size, hydrology, and upland habitat intended to enable WRSIS wetlands to function primarily as amphibian habitat and the reservoirs to function as fish habitat.

Keywords Fishes · Amphibians · Reptiles · Wetland creation · Agriculture · Subirrigation

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Introduction

Agricultural land use and drainage practices have increased nutrient, pesticide, and sediment loadings and reduced the amount wetlands and riparian forests within agricultural watersheds (Naiman et al. 1993; Zedler and Kercher 2005; Kalita et al. 2006). Nutrient inputs from the midwestern United States have been identified as a significant contributor to the formation of the dead zone in the Gulf of Mexico and the current and historical water quality issues in the Great Lakes (Richards et al. 2002; Mitsch and Day 2006; Nobiesz et al. 2010). Large-scale wetland creation and restoration has been proposed as a solution for reducing agricultural nutrient inputs (Mitsch and Day 2006). However, the midwestern United States contains the largest concentration of tile-drained cropland in the United States (Smith and Pappas 2007). The widespread use of tile drains requires special consideration

in choosing locations for wetland creation and restoration. One proposed solution is the creation of wetlands designed to intercept and treat agricultural runoff from tile drains (Osborne and Kovacic 1993; Mitsch and Day 2006). The creation of wetlands adjacent to agricultural fields in the midwestern United States also has the capability of providing habitat for wetland-dependent animals that have been impacted by habitat destruction resulting from agriculture. Despite these potential ecological benefits landowners and producers may be hesitant to create or restore wetlands because of potential income loss as a result of converting agricultural fields to wetland habitat (Czartoski et al. 1995). Thus, created wetland designs capable of providing agricultural benefits and ecological benefits are more likely to be broadly adopted and implemented by the agricultural community. To meet this challenge a water recycling system known as the wetland reservoir subirrigation system (WRSIS) was developed (Czartoski et al. 1995; Allred et al. 2003).

WRSIS consists of two different types of wetlands (i.e., WRSIS wetlands and WRSIS reservoirs) that are connected to each other and the agricultural fields by a network of subsurface pipes (Fig. 1). WRSIS wetlands are treatment wetlands designed to process agricultural chemicals, whereas the WRSIS reservoirs

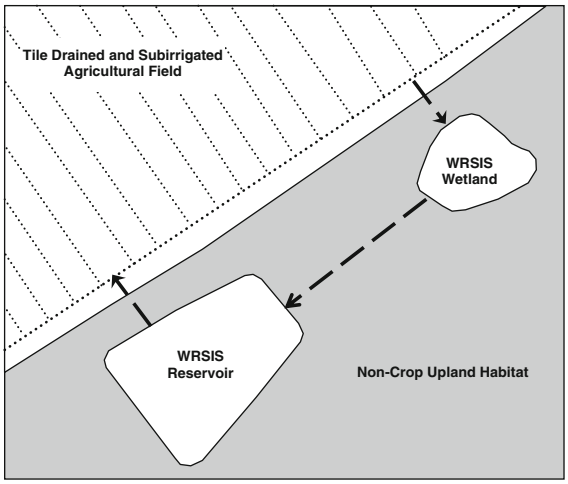

Fig. 1 Diagram of aerial view of WRSIS showing the two created wetland types and how they are connected with each other and the adjacent agricultural fields via a network of subsurface pipes. *Dotted lines* within the agricultural fields depict the subsurface pipes. The *dashed arrows* also represent subsurface pipes and the direction of the water flow through the system

are storage wetlands for holding subirrigation water (Fig. 1). Surface and subsurface runoff from the agricultural fields is directed into the WRSIS wetland (Fig. 1). Submersible pumps are used to transfer water from WRSIS wetland into WRSIS reservoir (Fig. 1). WRSIS reservoirs store water and submersible pumps are used to reapply treated water back onto the agricultural fields via subirrigation (Fig. 1). The use of two wetland cells is a commonly used created wetland design within North America (Kennedy and Mayer 2002). Reuse of water is commonly incorporated into the design of wetlands intended to treat animal waste, but not cropland runoff (Stone et al. 2004). WRSIS and modified versions of the original design have been implemented in Ohio, Illinois, Michigan (Holcomb 2008), Canada (Ontario and Nova Scotia, Tan et al. 2007; Haverstock et al. 2008), and China.

Previous research conducted within WRSIS in North America has evaluated agricultural production and water chemistry benefits. Corn and soybean yields increased with implementation of WRSIS in Michigan (Holcomb 2008), Ohio (Allred et al. 2003; Baker et al. 2004), and Canada (Tan et al. 2007). Decreases in nutrient concentrations at the outflows of the WRSIS wetlands have also been documented in Ohio (Baker et al. 2004), Michigan (Holcomb 2008), and Canada (Haverstock et al. 2008). Total suspended sediments in Ohio (Baker et al. 2004) and *Escherichia coli* in Canada (Haverstock et al. 2008) also decreased at the outflows of WRSIS wetlands. However, there is only limited information on the potential decreases in agricultural contaminants that could occur as a result of the entire WRSIS system (i.e., both WRSIS wetlands and reservoirs) as only one study in Canada has documented decreases in nutrients leaving the WRSIS reservoir (Haverstock et al. 2008). Ecological research involving plants and animals has only been conducted in Ohio and focused mostly on documenting biota within WRSIS wetlands (Luckeydoo 1999, 2002; Luckeydoo et al. 2002, 2004, 2006; Moody and Rife 2004). Seventy-seven vascular plant species have been documented from three Ohio WRSIS wetlands and 45% were wetland plants (Luckeydoo et al. 2006). Fifty seven algae genera, 61 invertebrate taxa, and 51 vertebrate species have been documented from two Ohio WRSIS wetlands (Luckeydoo 2002; Moody and Rife 2004). However, the fauna of WRSIS reservoirs and how its aquatic community

structure compares with WRSIS wetlands is unknown. Understanding how WRSIS wetlands and reservoirs differ is needed to appreciate the potential ecological benefits of the entire WRSIS, not just one component of the system.

Fishes, amphibians, and reptiles are important components of wetland ecosystems. Wetland destruction and habitat degradation have been attributed as one of the primary contributing factors in the worldwide declines exhibited by these animals (Gardner et al. 2007; Jelks et al. 2008). Future wetland creation efforts that incorporate design criteria specifically intended to benefit the aquatic biota are needed. Yet, there is only a limited amount of information on agricultural wetland creation design guidelines in the midwestern United States to benefit these aquatic animals because wetland design typically focuses on nonpoint pollution control or providing waterfowl habitat (Crumpton 2001; Kennedy and Mayer 2002; Porej and Hetherington 2005). We sampled fishes, amphibians, and reptiles from WRSIS wetlands and reservoirs within three WRSIS in northwestern Ohio to address the research question: *"What is the difference in aquatic community structure between WRSIS wetlands and reservoirs?"* We then considered the implications of our results for developing design and management criteria capable of benefiting fishes, amphibians, and reptiles within these created agricultural wetlands.

Methods

Study area descriptions

Three WRSIS sites located in Fulton County (41° 36′25.87″ N, 83° 25′7.16″ W), Defiance County (41° 20′12.59″ N, 84° 25′ 55.93″ W), and Van Wert County (40° 53′ 4.58″ N, 84° 33′ 58.02″ W) in northwestern Ohio were chosen as study sites. The mean distance among the three WRSIS locations was 65 km (range 48–94 km). All sites are located in the Maumee River watershed that was once part of the Great Black Swamp that was drained for agriculture (Luckeydoo 1999). Streams and rivers in the Maumee River and other parts of northwestern Ohio are currently heavily impacted by the agricultural land use that dominates throughout this region (Ohio EPA 2010). All WRSIS sites are located adjacent to agricultural fields that undergo corn (*Zea mays*) and soybean (*Glycine max*) rotations.

Defiance WRSIS was constructed 1995 and involved the creation of the wetland and reservoir. Construction of the Fulton WRSIS was completed in 1996 and involved creating a wetland and linking it with an existing reservoir that was constructed in 1976. Van Wert WRSIS was initially developed in 1996 by constructing a wetland and linking it with an existing reservoir. The Van Wert wetland was redesigned in 2003 so the original wetland now contains one wetland and a new reservoir. The original Van Wert reservoir is still connected to the newly modified system, but it is no longer an operational part of the system and was not sampled as part of this research. Each WRSIS wetland was created in a location that was previously row crop for at least 20 years prior to construction (Luckeydoo et al. 2004). Defiance reservoir and the newly created Van Wert reservoir were also previously row crop prior to construction. Fulton reservoir was previously pasture prior to construction. No wetland plants were planted as part of the WRSIS construction and wetland vegetation establishment relied on resident seed bank and delivery of seed from outside sources (Luckeydoo et al. 2006). WRSIS wetlands and reservoirs were separated by a mean distance of 85 m (range 6–205 m).

Mean water depths and water surface area were greater (Two factor block design analysis of variance (ANOVA), $P < 0.05$) in WRSIS reservoirs than wetlands (Fig. 2). Both habitat types consisted mostly of open water habitat with only a limited amount of emergent aquatic plants (Fig. 2). Physicochemical variables of water temperature, pH, conductivity, and dissolved oxygen were similar between WRSIS wetlands and reservoirs (Table 1). Turbidity was greater (Two factor block design ANOVA, $P < 0.05$) in WRSIS wetlands than reservoirs (Table 1). Concentrations of commonly used agricultural pesticides and nitrogen were also similar between wetland types (Table 1). Terrestrial habitat immediately surrounding WRSIS wetlands and reservoirs consisted of mostly of herbaceous vegetation due to periodic mowing and herbicide applications (Luckeydoo 1999; Moody and Rife 2004). In general, both WRSIS wetlands and reservoirs are unconsolidated bottom wetlands consisting mostly of open water habitat and differ primarily in habitat size with WRSIS reservoirs being on average 6.5 times greater in water depths and 2.5

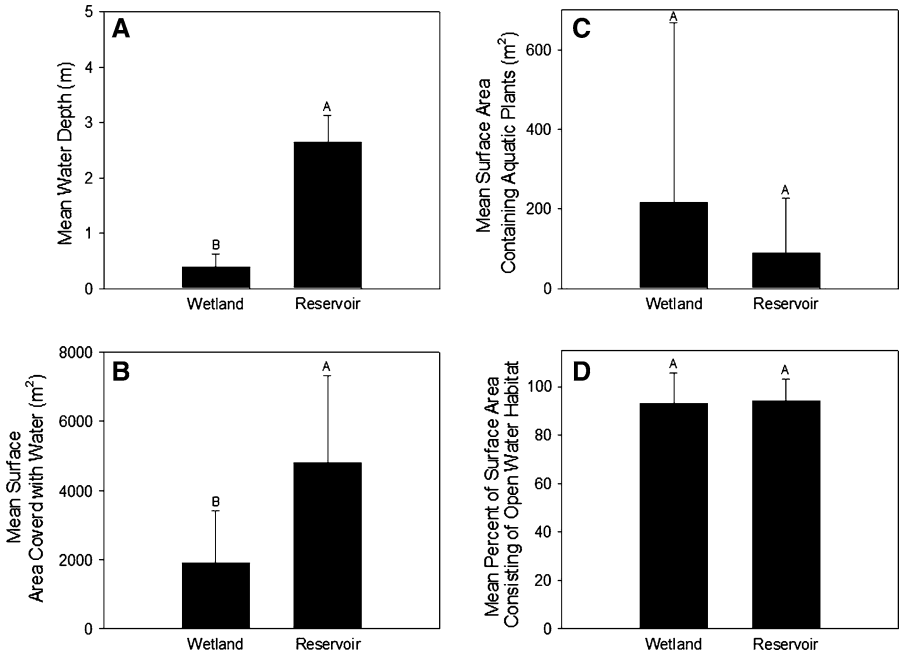

Fig. 2 Mean and SD of water depth (**a**), surface area covered with water (**b**), wetted surface area containing emergent aquatic plants (**c**), and percent of wetted surface area consisting of open water habitat (**d**) in WRSIS wetlands and reservoirs in northwestern, Ohio, 2006–2008

Table 1 Means (SD) of water chemistry variables from WRSIS wetlands and reservoirs in northwestern Ohio. Bolded values are those that differ significantly ($P < 0.05$) between WRSIS wetlands and reservoirs

	Wetlands	Reservoirs
Water temperature (°C)	25.2 (2.1)	24.6 (1.2)
pH	8.5 (1.0)	8.2 (1.3)
Conductivity (microsiemens/cm)	297.4 (153.8)	289.5 (68.1)
Dissolved oxygen (mg/L)	8.9 (2.8)	8.7 (1.8)
Turbidity (NTU)	**50.6 (62.6)**	**8.3 (5.8)**
Atrazine (μg/L)	0.81 (1.22)	0.25 (0.14)
Metolachlor (μg/L)	0.07 (0.39)	0.00 (0.00)
Simazine (μg/L)	0.35 (0.66)	0.07 (0.08)
Chlorothalonil (μg/L)	0.02 (0.06)	0.03 (0.08)
Metalaxyl (μg/L)	0.09 (0.15)	0.04 (0.10)
Malathion (μg/L)	Not detected	Not detected
Ammonium (mg/L)	0.34 (0.95)	0.05 (0.08)
Nitrate plus nitrite (mg/L)	3.04 (6.15)	0.52 (2.57)

* Physicochemical variables were measured concurrently with fish, amphibian, and reptile sampling in June 2006, 2007, and 2008 using a multiparameter meter. Weekly grab samples for pesticide and nutrient measurements were collected in the summer (May to July) 2008 and 2009. Standard laboratory protocols were used for pesticide and nutrient measurements and details are available in Smiley et al. (2009b)

times greater in water surface area than WRSIS wetlands (Fig. 2).

Fish, amphibian, and reptile sampling

Fishes, amphibians, and reptiles were sampled by seining, hoop net trapping, and gee minnow trapping during a two week sampling period in June 2006, 2007, and 2008. Three seine hauls were conducted in each WRSIS wetland and WRSIS reservoir with a 10 m × 2 m seine (3.2 cm mesh size) once during each two week sampling period. Hoop net and gee minnow trap sampling was conducted twice during each sampling period. One hoop net (0.9 m hoops, 1.8 m length,

2.54 cm mesh size) and one gee minnow trap (23 cm × 45 cm, two 2.54 cm openings on each end, 0.6 cm mesh size) were set in each wetland. All traps were baited with sardines. Traps were set for two nights in each week (total 4 trap nights for each sampling period). Each day the traps were examined and all captured animals were identified, enumerated, and released.

The sampling effort for each gear type was the same for all wetland types during all years. Our sampling protocol was designed to ensure that our sampling efforts were the same among wetland types and sampling periods. This is especially critical in comparisons of different sized habitats. Additionally, we used three different sampling methods so our results are not influenced by the sampling biases of a single sampling method (Smiley et al. 2009c). It was not possible for us to sample the entire area of each of the WRSIS wetlands and reservoirs due to large size and depths within some of our sites. However, we distributed our sampling throughout each site and among different microhabitat types. For example, we ensured that individual seine hauls were not immediately adjacent to each other, but were conducted in different locations within a site that represented different microhabitat types. Additionally, hoop nets and gee minnow traps were always placed in different locations as hoop nets were placed within deeper water areas lacking emergent aquatic plants and gee minnow traps were placed within shallow areas having emergent aquatic plants. We also changed the position of the hoop net and gee minnow traps each week to ensure our sampling was not confined to a single location within the sites.

Data analyses

We used a two factor block design analysis of variance (ANOVA) coupled with the Tukey test to examine if community characteristics of species richness, FAR (fish, amphibian, and reptile) abundance, percent fish, percent amphibian, percent reptiles, fish abundance, amphibian abundance, and reptile abundance differed between WRSIS wetlands and reservoirs. Species richness is the number of fish, amphibian, and reptile species captured. FAR abundance is the number of fishes, amphibians, and reptile captured. The percent fish, percent amphibian, and percent reptile is the number a particular vertebrate class (i.e., fish, amphibian, or reptile) captured/FAR abundance. The abundance of fish, amphibian, and reptiles is the number of captures for each vertebrate class. The assumptions of normality and equal variance were not met for five community variables (percent fish, percent amphibian, percent reptile, amphibian abundance, and reptile abundance). Therefore, the two factor blocked design ANOVA was conducted with rank transformed values because a nonparametric analogue to this test was not available. Rank transformation is commonly recommended in these situations and its use with a parametric test is the equivalent of conducting a nonparametric two factor blocked design ANOVA (Conover 1999). The two factor blocked design ANOVA tests were conducted with SAS System for Windows version 8 (SAS Institute 1999). We used a significance level of $P < 0.05$ for all statistical tests. We also used the Jaccard's index (Magurran 1988) to examine if species composition of aquatic communities differed between wetland types. Specifically, we compared species composition within each WRSIS location in each year and then calculated the mean Jaccard's index from all nine comparisons. Jaccard's index scores are calculated based on presence and absence data and ranges from 0 (complete dissimilarity) to 1 (complete similarity). We followed Matthews et al. (1988) considered Jaccard's index values > 0.7 as similar. We also summarized individual species abundances (number of captures) and occurrences (number of times a species was present within three sites over a three year period) in each WRSIS wetland type to qualitatively describe species composition differences.

Results

We captured five fish species, three amphibian species, and three reptile species from 6,085 captures. No significant differences (Two factor block design ANOVA, $P > 0.05$) in mean species richness and FAR abundance occurred between WRSIS wetlands and reservoirs (Fig. 3). Percent amphibians and amphibian abundance were greater (Two factor block design ANOVA, $P = 0.03$ for percent amphibians and amphibian abundance) in WRSIS wetlands than reservoirs (Fig. 4). Percent fish, percent reptile, fish abundance, and reptile abundance did not differ between WRSIS wetlands and reservoirs (Fig. 4).

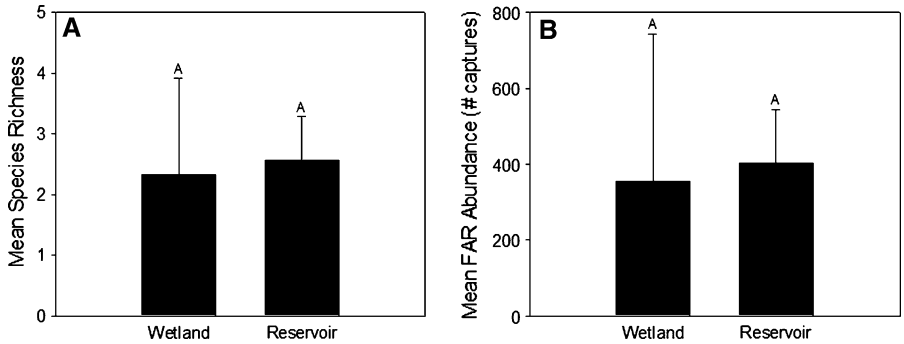

Fig. 3 Mean and SD of species richness (**a**) and fish, amphibian, and reptile (FAR) abundance (**b**) in WRSIS wetlands and reservoirs in northwestern, Ohio, 2006–2008

No significant effects (Two factor block design ANOVA, $P > 0.05$) of year or interaction of wetland type and year were observed for any community variable. Mean Jaccard's index score between wetland types was 0.18 and ranged from 0 to 0.5 (Table 2). All Jaccard's index scores were less than 0.7 and indicated species composition differed between WRSIS wetlands and reservoirs.

Green sunfish (*Lepomis cyanellus*), fathead minnow (*Pimephales promelas*), snapping turtle (*Chelydra serpentina*), and painted turtle (*Chrysemys picta*) were captured in both WRSIS wetlands and reservoirs (Table 3). Bullfrog (*Rana catesbeiana*), green frog (*Rana clamitans*), and leopard frog (*Rana pipiens*) were captured only in WRSIS wetlands (Table 3). Bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), black bullhead (*Ameiurus melas*), and eastern garter snake (*Thamnophis sirtalis*) were captured only in WRSIS reservoirs (Table 3). Green sunfish, leopard frog, and fathead minnow were the most abundant species captured in WRSIS wetlands (Table 3). Notably, we captured large numbers of fish larvae and tadpoles within the WRSIS wetlands (Table 3), but due to their small size we were unable to identify these animals to species level. Conversely, green sunfish, bluegill, and largemouth bass were the most abundant species captured in WRSIS reservoirs (Table 3).

Discussion

Our results suggest the differences in habitat size between WRSIS wetlands and reservoirs did not influence fish, amphibian, and reptile species richness and abundance within WRSIS in northwestern Ohio. These results were surprising in light of the well-documented relationships of species richness and abundance with increasing habitat size for a wide range of taxonomic groups and ecosystems (Connor and McCoy 1979; Connor et al. 2000; Drakare et al. 2006), including fishes, amphibians, and reptiles within created agricultural wetlands (Smiley et al. 1999; Smiley et al. 2009a). Although species richness commonly increases with habitat size there have been studies where no relationships or negative relationships have been observed (Drakare et al. 2006; Watling and Donnelly 2006). Increases in habitat diversity with increases in habitat area has been attributed as a causal factor for species-area relationships (Connor and McCoy 1979; Drakare et al. 2006). WRSIS wetlands and reservoirs are relatively simple habitats structurally and perhaps the lack of increasing habitat diversity between wetland types results in a limited effect of wetland size. Increases in diversity with increasing habitat size may also occur as a result of greater colonization and decreased extinction probabilities with increasing habitat size (Connor and McCoy 1979; Drakare et al. 2006). WRSIS wetlands and reservoirs are isolated wetlands surrounded by agriculture. Isolation may result in similar colonization probabilities between habitat types and confound the effect of habitat size (Watling and Donnelly 2006).

Most species-area relationships are described for one taxonomic group (i.e., insects, fishes, etc.). Communities containing multiple taxonomic groups may exhibit different responses to increasing habitat size, especially communities containing a group of organisms capable of excluding other groups via competitive or predatory interactions. WRSIS wetlands and reservoirs were numerically dominated by fishes. Fishes were likely introduced into WRSIS

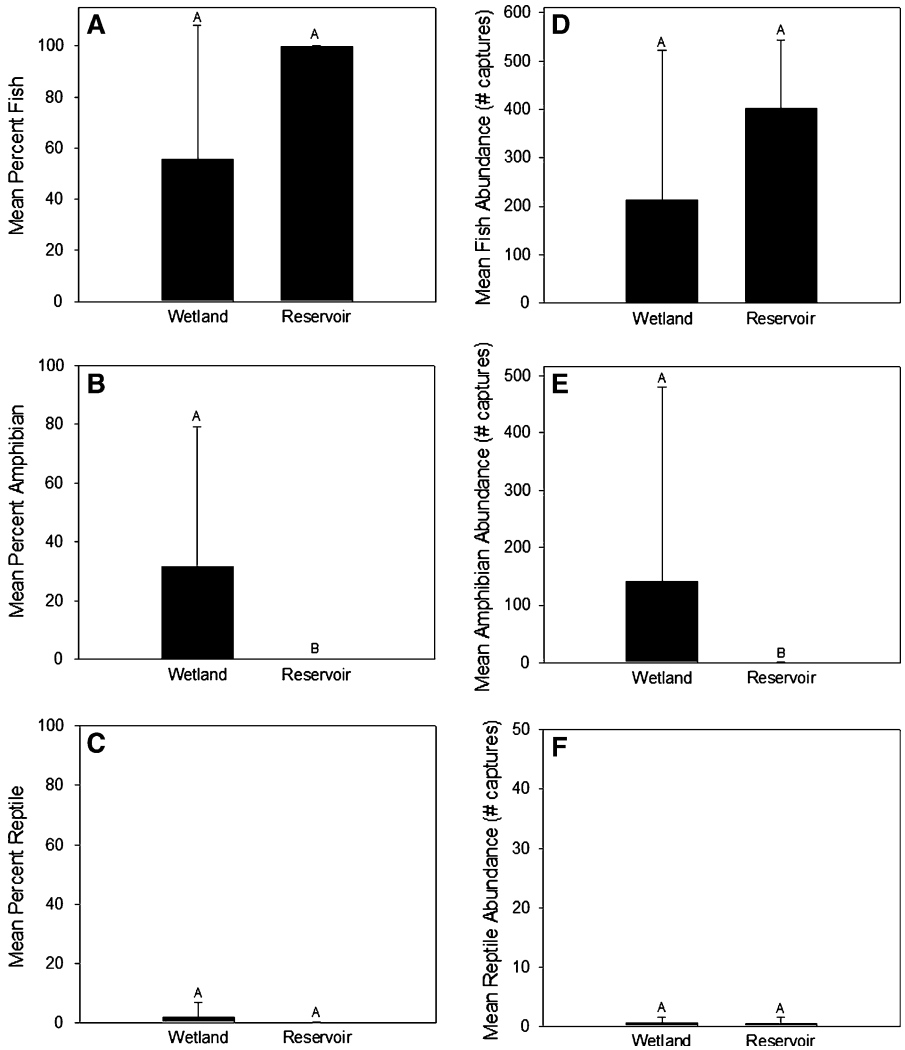

Fig. 4 Mean and SD of percent fish (**a**), percent amphibian (**b**), percent reptile (**c**), fish abundance (**d**), amphibian abundance (**e**), and reptile abundance (**f**) in WRSIS wetlands and reservoirs in northwestern, Ohio, 2006–2008

Table 2 Jaccard's index scores from comparisons of species composition between WRSIS wetlands and reservoirs in northwestern Ohio, 2006–2008

Comparison	Year	Jaccard's Index
Defiance Wetland and Reservoir	2006	0.00
Defiance Wetland and Reservoir	2007	0.00
Defiance Wetland and Reservoir	2008	0.13
Fulton Wetland and Reservoir	2006	0.00
Fulton Wetland and Reservoir	2007	0.00
Fulton Wetland and Reservoir	2008	0.20
Van Wert Wetland and Reservoir	2006	0.33
Van Wert Wetland and Reservoir	2007	0.50
Van Wert Wetland and Reservoir	2008	0.50

wetlands and reservoirs by humans for recreation and/or by water transfers between wetland types and from adjacent streams. It has been well documented that the presence of fishes within wetlands can have a negative influence on amphibian communities (Knutson et al. 2004; Porej and Hetherington 2005). When amphibian

Table 3 Abundance (occurrence) of fishes, amphibians, and reptiles documented in WRSIS wetlands and reservoirs in northwestern Ohio, 2006–2008. Abundance is the total number of captures from three sites within a wetland type over a 3 year period. Occurrence is the number of times a species was present within three sites within a wetland type over a 3 year period and the maximum occurrences possible is nine

	Wetlands	Reservoirs
Fishes		
Green sunfish (*Lepomis cyanellus*)	851 (6)	2675 (8)
Bluegill (*Lepomis macrochirus*)	0 (0)	568 (3)
Largemouth bass (*Micropterus salmoides*)	0 (0)	310 (3)
Fathead minnow (*Pimephales promelas*)	112 (3)	12 (4)
Black bullhead (*Ameiurus melas*)	0 (0)	1 (1)
Fish larvae	946 (2)	48 (1)
Amphibians		
Bullfrog (*Rana catesbeiana*)	25 (5)	0 (0)
Green frog (*Rana clamitans*)	6 (1)	0 (0)
Leopard frog (*Rana pipiens*)	156 (2)	0 (0)
Tadpole	1083 (4)	2 (1)
Reptiles		
Eastern garter snake (*Thamnophis sirtalis*)	0 (0)	1 (1)
Snapping turtle (*Chelydra serpentina*)	1 (1)	1 (1)
Painted turtle (*Chrysemys picta*)	4 (3)	2 (1)

diversity is examined across a range of habitat sizes with hydrological regimes ranging from ephemeral to permanent inundation amphibian diversity is the greatest at intermediate habitat sizes that undergo hydrological regimes capable of preventing the establishment of fish communities (Kolozsvary and Swihart 1999; Henning and Schirato 2006; Smiley et al. 2009a).

Despite the dominance of fishes we observed a greater abundance of amphibians in the smaller WRSIS wetlands. Differences in species composition between WRSIS wetlands and reservoirs were driven mostly by the presence of frogs within WRSIS wetlands, but not reservoirs. These results suggest the potential for WRSIS to provide habitat for different suites of aquatic communities. However, high quality wetlands within Ohio are characterized by having: (1) three or more species of pond breeding salamanders; (2) presence of spotted salamanders (*Ambystoma maculatum*) and/or wood frogs (*Rana sylvatica*); (3) $< 25\%$ of all captures are tolerant species (i.e., green frogs, bullfrogs, etc.); and (4) $> 50\%$ of all captures consist of sensitive species (i.e., wood frogs, spotted salamanders, etc.) (Micacchion 2011). Amphibian communities within WRSIS wetlands in contrast are more similar to those found in farm ponds in Ohio and are dominated by ranid frogs (Porej and Hetherington 2005). Thus, additional design and management criteria are needed to enable WRSIS wetlands to more effectively function as amphibian habitat and to ensure the creation of more distinct habitat types. Previous WRSIS management criteria have focused on developing subirrigation guidelines for increasing production (Allred et al. 2003) and specific management criteria for improving pollution control or aquatic habitat have not yet been developed.

Constructed treatment wetlands in North America average 230,000 m^2 and range in size from 1,000 to 4,860,000 m^2 (Kennedy and Mayer 2002). We first recommend newly created WRSIS wetlands and reservoirs are designed to have as large of surface areas as possible because WRSIS wetlands and reservoirs in our study are small treatment wetlands. Increasing the surface area will increase the amount of available habitat, increase the filtration ability of the WRSIS wetlands (Kadlec 1995), and will result in greater water storage for subirrigation purposes.

In light of the negative impacts of fishes on amphibians we recommend the smaller WRSIS wetlands be managed as amphibian habitat having ephemeral hydrology regimes and the larger WRSIS reservoirs be managed as fish habitat with permanent hydrology regimes. Targeting these two taxonomic groups ensures the guidelines for wetland creation and management result in different hydrological regimes between WRSIS wetlands and reservoirs. Development of multiple agricultural wetlands in

close proximity that differ in hydrological regimes are much needed for the conservation of amphibians and reptiles (Semlitsch 2000; Bodie 2001; Kingsbury and Gibson 2002). Many constructed wetlands in the midwestern United States have permanent hydrological regimes (Porej and Hetherington 2005; Gamble and Mitsch 2009). Implementing variable hydrological regimes within WRSIS will also lead to the creation of a wetland type (i.e., ephemeral wetlands) critical for amphibian and reptile conservation in the midwestern United States (Kingsbury and Gibson 2002). The interconnectedness of WRSIS suggests the presence of fishes in the reservoirs represents a potential risk to amphibians within the wetlands even with the development of ephemeral hydrology regimes. Future water management strategies will also need to ensure that water from WRSIS reservoirs and/or adjacent streams is not introduced into the wetlands.

Establishment of proper hydrological regimes within created and restored wetlands is one of the most difficult tasks for managers (Kingsbury and Gibson 2002; Gamble and Mitsch 2009). The WRSIS system is unique in that hydrology management can be easily implemented due to the pumps and pipes capable of transferring water from WRSIS wetlands into the reservoirs and vice versa. In general, WRSIS wetlands should be allowed to completely dry out once a year in the summer and then contain water in the fall, winter, and spring (Kingsbury and Gibson 2002, Micacchion 2011). From March through June WRSIS wetlands should be completely inundated. Fluctuations of water levels are acceptable, but it is important not to let WRSIS wetlands dry out because this time period is the breeding period for most amphibians (Kingsbury and Gibson 2002, Micacchion 2011). Water levels should then be allowed to recede gradually in July with the goal of having the WRSIS wetlands completely dry by August. Implementing dry downs in August should provide late-breeding amphibians and those that require longer time periods to develop with an opportunity to complete their development (Kingsbury and Gibson 2002). Ensuring that the WRSIS wetlands are completely dry for at least one day will provide adequate time to kill off any fishes. Water levels can then be reestablished and hydrology fluctuations within WRSIS wetlands can occur as natural rainfall patterns allow. However, hibernating snakes and turtles require saturated soils to survive the winter, thus WRSIS wetlands should ideally be at or near capacity prior to the beginning of winter. Our experience with manipulating WRSIS water levels indicates that implementing this hydrology pattern within WRSIS wetlands is feasible, but research is critically needed to confirm if this pattern of hydrology will provide the greatest benefits for amphibians.

Implementation of summer dry downs within WRSIS wetlands will also increase their ability to process nitrogen within the runoff (Fink and Mitsch 2004). The influence of summer dry downs on the ability of WRSIS wetlands to uptake phosphorus is unclear as some suggest phosphorus uptake may decrease under a regime of flooding and drying (Fink and Mitsch 2004; Song et al. 2007) and others suggest it may increase (Patrick and Khalid 1974; Phillips 1998). The potential decline in phosphorus uptake as a result of altering the hydrology is not a risk if the WRSIS is managed as a closed system as designed and no water is released offsite. Also, the deep water reservoirs should be able to serve as an effective phosphorus sink. However, the filtration ability of reservoirs and the filtration ability of the entire WRSIS have not yet been quantified.

The WRSIS wetlands and reservoirs we sampled in this study have been managed as farm ponds and subjected to periodic mowing and herbicide applications (Luckeydoo 1999; Moody and Rife 2004). Development of upland habitat surrounding wetlands is a critical design feature needed for amphibians and reptiles (Semlitsch 2000; Bodie 2001; Kingsbury and Gibson 2002). Simply eliminating or reducing the frequency of mowing and herbicide application in the non-crop areas around the wetlands and reservoirs should enable increases in vegetative structure and/or woody vegetation to occur. Enhancement of the upland area adjacent to the WRSIS wetlands is especially critical as it will increase filtration of surface runoff prior to entry into the wetland and should enable development of vegetation along the shorelines that will assist with erosion control and provide habitat. Combined management of upland habitat and hydrology for the WRSIS wetlands provides the opportunity to create wetland habitat types that are rare in the midwestern United States (i.e., forested and grassland ephemeral wetlands) and critically needed for amphibian and reptile conservation.

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