TITLE

The American Pond Belt: An untold story of conservation challenges and opportunities

AUTHORS

Timothy M. Swartz[1,2] *, James R. Miller[2,3]

[1] Center for Biodiversity, Department of Biology, Temple University, Philadelphia, PA 19140, USA
[2] Department of Natural Resources and Environmental Sciences, University of Illinois at Urbana-Champaign, Urbana, IL 61820, USA
[3] Program in Ecology, Evolution, and Conservation Biology, University of Illinois at Urbana-Champaign, Urbana, IL 61820, USA
* Correspondence: timothy.swartz@temple.edu

ABSTRACT

Over the past century, millions of farm ponds have been constructed in the eastern Great Plains, U.S.A. Built to provide water for livestock and reduce soil erosion, ponds also provide habitat for native species in agricultural landscapes that historically lacked natural wetlands. Because this role in supporting biodiversity has been chronically underappreciated, approaches to managing these ponds effectively for conservation remain poorly developed. Here we discuss the historical context of pond construction, the role of ponds in agriculture, and their present distribution across the American Pond Belt. Based on our review of their ecology and threats, we argue that farm pond conservation should focus on enhancing pondscapes – networks of ponds covering a range of successional stages – to support the broadest array of biodiversity at a landscape scale. We conclude by highlighting the role of scientists, agency personnel, policymakers, and landowners in the future conservation of pondscapes in the American Great Plains.

IN A NUTSHELL

- The millions of farm ponds that have been built to support agriculture in the central United States represent an untapped resource for conservation.
- Their potential value as biodiversity hotspots is the result of habitat succession over relatively short periods time, with many ponds progressing to late successional, biodiverse habitats within decades.
- Unfortunately, farm ponds are not federally protected as wetlands and many prevailing management practices threaten their capacity to support native biodiversity.
- Conservation efforts should focus on preserving late successional ponds in order to maintain diverse pondscapes comprising sites across a range of successional stages.
- Key avenues for advancing farm pond conservation include: increasing research attention from scientists to identify prospects for improved management; establishing channels for exchanging knowledge with the landowners who can effect change on the ground; and pursuing legislative action to codify the value of these conservation resources.

KEY WORDS

Farm ponds, farmland ponds, pondscapes, wetland conservation, aquatic biodiversity, novel ecosystems

MAIN TEXT

INTRODUCTION

Habitat loss in agricultural landscapes is at the root of many biodiversity losses. In the Great Plains of the United States, expansion of row crop production and livestock grazing has reduced habitat for grassland birds (Sauer et al. 2017), pollinators (Koh et al. 2016), and amphibians (Gallant et al. 2007). Wetlands in the region have been particularly impacted. Several states have lost the majority of their historical wetland acreage since the 1800s (Dahl 1990). Losses have exceeded 48% in Kansas, 52% in Texas, 87% in Missouri, and 89% in Iowa (Dahl 1990). These patterns reflect the age-old trade-off between habitat for native species and agricultural production, but they do not tell the whole story.

Even as natural wetlands were lost, millions of farm ponds, typically < 1 ha in size, were being built throughout the Great Plains (Chumchal and Drenner 2015). Like others around the globe, these ponds are built to support rural enterprise (Smith et al. 2002), but their value is not limited to agricultural functions. They also provide habitat for native species when properly managed. Indeed, human-constructed ponds in Europe and the United Kingdom are considered crucial to biodiversity conservation (Ruggiero et al. 2008, Miracle et al. 2010, Sayer et al. 2012). Farm ponds in the U.S. currently lack similar recognition, despite providing most of the aquatic habitat present in some areas (Dahl 1990, Smith et al. 2002, Gallant et al. 2011).

We argue that farm pond ecosystems are an untapped resource for biodiversity conservation in the United States, especially in the agricultural landscapes of the American Great Plains where they are most abundant. Their role in watershed hydrology, sediment capture, and geochemistry has been noted (Smith et al. 2002, Boyd et al. 2010, Biggs et al. 2016), but they have been chronically understudied and undervalued by conservation ecologists (Leja 1998, Downing 2010). Furthermore, though their wetland-like characteristics are sometimes acknowledged in technical literature (NRCS 2006, Perry et al. 2015), farm ponds remain in a precarious legal state and are not subject to federal wetland protections (see Clean Water Act 1972, Clifford and Heffernan 2018). There are no regional or nationwide strategies in place to conserve these ecosystems and protect their biodiversity.

Here, we synthesize knowledge of U.S. farm pond ecology and outline how management, research, and outreach could help conserve their biodiversity. We begin by reviewing the history and distribution of farm ponds in the American Great Plains. Next, we describe their ecology, including links between successional processes and community composition. We then examine several key threats to farm pond biodiversity, including habitat degradation by cattle and fish, terrestrialization, and renovation by landowners. This is followed by an exploration of how a 'pondscape' approach to monitoring and managing these sites could improve their conservation value (after Boothby 1997). We conclude by describing the roles of key partners in advancing these efforts.

HISTORY & DISTRIBUTION

Farm ponds are a defining feature of modern Great Plains landscapes. Now numbering in the millions (Smith et al. 2002, Chumchal and Drenner 2015), the first ponds were built in the region less than a century ago as simple soil management tools. An extreme drought in the 1930s decimated crops throughout the Great Plains and much hilly, erosion-prone farmland was abandoned (Peters et al. 2007). Loose soil from these lands was then swept up into enormous dust storms that blew across the region during the Dust Bowl (Peters et al. 2007). The environmental calamity of this period ultimately catalyzed nationwide efforts to reform land use (McLeman et al. 2014) and a newly-expanded U.S. Department of Agriculture added farm ponds to its array of soil conservation tools (Compton 1952, Leja 1998). Farm ponds serve two primary purposes (Fig. 1a & b). They provide water for livestock, allowing high-erosion cropland to be converted to more resilient pasture (Compton 1952). They also capture sediment-laden runoff and prevent the formation of gullies (Leja 1998, Renwick et al. 2006). Separate from these key functions, farm ponds provide a variety of non-agricultural services, like recreational fishing

(USFWS 1956). They are also estimated to collectively capture around 30 million tons of carbon each year (Renwick et al. 2006). Their contribution to the aesthetic properties of rural landscapes has been noted as well (Greenland-Smith et al. 2016), with pond number and quality even hypothesized to signal the social status of their owners (Hawley 1973).

Due to their numerous benefits, farm ponds have been constructed at exceedingly high densities in the central United States. Their numbers peak in the Pond Belt, a region stretching from south-eastern Texas to southern Iowa (Fig. 2a; Chumchal and Drenner 2015, Swartz and Miller 2019), where natural ponds and wetlands were historically scarce (Fig. 2b; Smith et al. 2002, Tiner 2003, Gallant et al. 2011). This high concentration of ponds has been ascribed to a range of topographic, climatic, and agronomic factors (Fig. 3a; Hawley 1973). Whatever the cause, the result has been a systematic redistribution of aquatic habitat and the creation of new biodiversity hotspots throughout the Pond Belt region (Smith et al. 2002).

DESIGN, ECOLOGY, & SUCCESSION

The design and function of newly constructed farm ponds reflects the agricultural role they are built to serve. Reliable water storage is foremost among these functions and is maintained by building ponds with steep banks and deep basins (Deal et al. 1997, Renwick et al. 2006, Chumchal and Drenner 2015). This design prevents the dramatic seasonal fluctuations in water level that characterize natural wetlands, like the prairie potholes of the northern Great Plains (see Winter 1989). Water permanence, in turn, shapes the biological communities of farm ponds (Fig. 3b; Chumchal and Drenner 2015). In permanent ponds, emergent vegetation is confined to pond edges where the water is most shallow. The deep basins provide abundant habitat for many large, predatory vertebrates. These include fish stocked as game (bluegill

[*Lepomis macrochirus*] and largemouth bass [*Micropterus salmoides*]) as well as turtles (*Chrysemys* spp.) and frogs (*Lithobates* spp.) that naturally colonize the pond (Fig. 4a).

Despite the care with which they are planned and constructed, farm ponds remain steep-sided and deep for only a short while. In just a few years, pond function changes as runoff erodes the banks and deposits sediment in the basin (Chumchal and Drenner 2015). This process of sedimentation-driven succession continues over the course of decades, gradually reducing water depth. At late successional stages, ponds shift to a semi-permanent or temporary (seasonal) state, with complete drying occurring every few years or even annually (Chumchal and Drenner 2015).

These hydrologic changes make a range of microhabitats available to wetland plants. The proliferation of seasonally exposed, shallow water areas favors rushes (Family Juncaceae), sedges (Cyperaceae), bur-reeds (Sparganiaceae) and other emergent plants (T.M. Swartz, *unpublished data*). The animal community shifts as well. Macrophyte-dominated ponds with seasonal hydroperiods are particularly valuable habitats for many organisms whose natural wetlands have been lost (Fig. 4b). Vegetated littoral zones offer foraging and reproductive habitat for amphibians and invertebrates (Porej and Hetherington 2005, Swartz and Miller 2019). Additionally, seasonal hypoxia and complete drying in shallow ponds can eliminate large predators, further benefiting many species (Lannoo 1998). Undoubtedly, bird and mammal populations also respond to this increased habitat diversity (Wait and Ahlers 2020), though more research is needed to address the ecology of these taxa in detail.

In some cases, diverse macrophyte-dominated habitats may not arise (Fig. 5a-f). Some ponds may instead exhibit a late-successional stage where woody vegetation encroaches on the pond edges and shades out other plants. Others may become completely overtaken by a native or hybrid cattail marsh (*Typha* spp.; Swartz et al. 2019a) as drier conditions prevail. With continued sedimentation, the site will fully “terrestrialize” and transition to forest or meadow (Renwick et al. 2006).

The role of an individual farm pond in providing habitat is enhanced by the presence of other ponds nearby, with each being unique in its successional stage and the range of biodiversity it supports. Throughout the Great Plains, pondscapes, or networks of ponds interconnected through dispersal (Boothby 1997), are in constant flux as new ponds are constructed and old ponds succeed and terrestrialize (Berg et al. 2016). This cycle occurs over relatively short time periods but metapopulation dynamics of the region’s wildlife have yet to receive detailed research attention. The factors that govern the pace of new pond colonization remain a noteworthy gap in our knowledge of these pondscapes.

THREATS

Despite their ecological complexity and potential to support native biodiversity, farm ponds in the United States are not afforded any of the protections granted to natural wetlands. This leaves them vulnerable to a number of threats posed by prevailing management practices.

Cattle

In some areas, nearly half of farm ponds provide water for livestock, principally cattle (Swartz et al. 2019a). Cattle can spend considerable time grazing along pond edges and loafing in the shallows (Trimble and Mendel 1995). While doing so, they trample the margins, uproot vegetation, and degrade water quality through defecation (Schmutzer et al. 2008). Cattle-accessible wetlands tend to have increased turbidity and higher concentrations of nitrogen and phosphorous (Trimble and Mendel 1995). This in turn can reduce richness and abundance of insects (Campbell et al. 2009) and limit the reproductive success, species richness, and survival of amphibians (Knutson et al. 2004, Schmutzer et al. 2008). Though the impacts of cattle can vary by species, livestock grazing is a particular threat to amphibians dependent on closed-canopy habitats (Howell et al. 2019). While fences can prevent much of this damage, they are often either not present or not effective (Swartz et al. 2019a), perhaps due to the expense of installation and upkeep.

Game and Bait Fish

The introduction of sport fish for recreational fishing has long been promoted by natural resource agencies (USFWS 1956, Perry et al. 2015). Unfortunately, many popular species, like bluegill and largemouth bass, are voracious predators that erode pond biodiversity (Lannoo 1996). Ponds with fish exhibit reduced amphibian reproductive success and abundance (Knutson et al. 2004). Even non-predatory bait fish may not be harmless. One common species, the fathead minnow (*Pimephales promelas*), can carry a parasitic copepod known to cause malformations in amphibian larvae (Kupferberg et al. 2009, Swartz et al. 2019b). Because of their potential to be predators, competitors, and disease vectors, introduced fish limit the potential for ponds to support many other organisms.

Terrestrialization and Renovation

The termination or interruption of successional processes also threatens pond biodiversity. If left unchecked, the sedimentation-driven succession that transformed a pond into a biodiversity hotspot will ultimately terminate in complete terrestrialization where the basin is filled with sediment and the site’s function as a pond ends (Renwick et al. 2006). While some ponds may persist for 60 years or longer (Swartz and Miller 2019), terrestrialization can occur in as few as 50 years (Renwick et al. 2006).

Although its rapid pace and potential for harm make terrestrialization noteworthy, it may rarely be allowed to play out unhindered. Pond renovation may pose a more urgent threat.

Indeed, only 5% of ponds built in central Texas during the 1950s had terrestrialized by 2012 (Berg et al. 2016). At the same time, 33% had been renovated, some several times (Berg et al. 2016). A similar pattern has been observed in Iowa (Swartz et al. 2019a). Landowners renovate ponds to restore agricultural function lost to decades of sediment accumulation, but the dredging involved in the process also scrapes away the aquatic ecosystem that had developed (Berg et al. 2016, Swartz and Miller 2019). Worryingly, renovation seems to occur just as ponds shift into late successional states (Swartz and Miller 2019). About 37% of ponds in southern Iowa are at least 40 years old and could be slated for renovation (Swartz et al. 2019a), suggesting that the risk posed by this practice may continue to grow.

CONSERVATION & MANAGEMENT

Currently, few conservation and management efforts stand between these threats and pond biodiversity. Existing guidelines provided by government agencies focus on maintenance practices that prolong pond lifespan (Deal et al. 1997) or sustain fish populations (e.g., Perry et al. 2015). Detailed instructions for promoting biodiversity are scarce (but see NRCS 2006). Moreover, it is unclear to what extent landowners actually implement recommended practices. The few studies available suggest that landowner investment wanes swiftly when construction is completed (Haley et al. 2012), with over half of Texas landowners spending just $50 or less per acre (Schonrock 2005).

Thus, many farm ponds follow trajectories not subject to human management. This ‘benign neglect’ may lead to positive conservation outcomes for some species of concern (see Swartz and Miller 2019), but targeted efforts are needed to harness the true potential of U.S. farm ponds to contribute to conservation.

Improved pond management should involve many of the actions taken to protect natural wetlands. For example, preventing cattle access and creating buffer strips will enhance water quality (Trimble and Mendel 1995, Semlitsch and Bodie 2003, Schmutzer et al. 2008). Though this could be accomplished with fencing (Giuliano 2006), the added expense could deter some landowners. Similarly, preventing fish stocking could bolster populations of many organisms, but angling remains a popular pond use (York 2019). Fortunately, effective habitat conservation would not necessarily require disrupting either fishing opportunities or water supplies. If cattle and fish are excluded from the smallest ponds (< 0.2 ha; Leja 1998), this could create more habitat for native species with minimal friction between management goals. These small ponds already provide poor fishing prospects and have limited water storage capacity (Leja 1998). For larger ponds, seasonally-inundated wetlands could be created below the embankments without interfering with other functions (Huggins et al. 2017). Overflow water leaving a pond via a pipe could sustain small wetlands (Fig. 6). Though limited in size, these wetlands would experience punctuated fluctuations in water level which could provide further habitat diversity, perhaps benefiting wetland plant communities.

Managing Pondscapes

Improving management at the level of individual pond is a critical first step, but a wider perspective is needed to address the challenge presented by succession-driven habitat development. Habitat availability should be assessed and managed at the level of a pondscape in order to maximize the range of biodiversity conserved (Boothby 1997). Given that only 16 to 34% of extant ponds are temporary (Chumchal et al. 2016, Swartz et al. 2019a) and just one-third exhibit more than trace amounts of macrophyte cover (Swartz et al. 2019a), the first step is to protect remaining non-permanent, vegetated ponds and prevent their premature renovation.

Boosting the number of these sites would benefit late successional communities. At the same time, early to mid-successional ponds should be allowed to progress gradually through succession with limited interference. New ponds appearing on the landscape would maintain a supply of early successional sites.

As ponds enter the final stages of succession and begin to terrestrialize or become overrun by trees and shrubs, managers should take action to restore pond function. Work implemented in eastern England, U.K., provides a compelling model of such efforts. To maintain a mosaic of successional states, ponds there are periodically dredged and overgrown, woody vegetation is removed (Sayer et al. 2012). This restores water depth and encourages the development of macrophyte communities (Sayer et al. 2012). Recently, there have been efforts to further boost pond numbers by excavating and restoring "ghost ponds" that have been infilled by farmers (Alderton et al. 2017). The success of these interventions is convincing: managed ponds boast increased invertebrate diversity (Sayer et al. 2012), aquatic plant communities buried by years of sediment emerge in re-excavated basins (Alderton et al. 2017), and terrestrial birds are bolstered by the insects produced by managed ponds (Lewis-Phillips et al. 2020). Notably, a growing number of local farmers have also become enthusiastic participants in the conservation and management of their own ponds (Sayer and Greaves In Press). Importing this approach to the U.S. could yield a substantial payoff.

Though coordination across property boundaries and between state and federal agencies would be necessary, pondscape-level conservation could provide sufficient flexibility to sustain both agricultural function and advance biodiversity conservation in the Pond Belt. Careful monitoring and assessment of pondscape composition could facilitate targeted interventions to ensure complementarity among individual ponds in terms of both biological communities (after

Briggs et al. 2019) and agricultural function at a landscape scale. Outreach efforts could focus on engaging landowners with many ponds on their properties. Some of these ponds are likely unnecessary for sustaining production and their owners may be willing to tolerate lower agricultural function to benefit biodiversity (Swartz et al. 2019a). A scheme patterned after the Conservation Reserve Program (U.S. Department of Agriculture 1985) or the Wetlands Reserve Program (NRCS 2015) could provide the financial incentive necessary to compensate landowners for letting ponds age past the point agricultural utility (see Swartz and Miller 2019).

A WAY FORWARD

Farm ponds, like most small water bodies, have suffered from a longstanding 'bigger-is better' bias among aquatic ecologists. Most freshwater conservation research has focused on lakes or rivers (Downing 2010) and research on ponds continues to stagnate worldwide (Biggs et al. 2016). Studies comprising the small but growing literature on farm ponds in the U.S. provide a foundation for understanding them as refuges for biodiversity. Nevertheless, their future conservation depends on these landscape features receiving increased attention from scientists and conservationists. Precisely defining the contribution of the Pond Belt to native species conservation at a national scale should be a research priority.

To affect conservation, a vibrant conversation among ecologists will need to be interwoven with a dialogue involving natural resource agencies (including NRCS). Agency employees are on the forefront of pond building and maintenance in the United States and engaging them is critical to moving beyond a view of farm ponds as mere agricultural tools. It will be necessary to first communicate that ponds with degraded agricultural function may in fact be prime wildlife habitat. Based on our own conversations with agency staff in Ringgold County, Iowa, we believe there is room to protect and improve habitat for wildlife while still working within agency mandates. Many considerations regarding pond placement and renovation are left up to the discretion of employees on the ground. Older, high-value ponds could be preserved by broadening the scope of factors considered when making these decisions.

Despite the potential for scientists and agency workers to facilitate conservation, these efforts will have sporadic support until policy changes codify their legitimacy and enhance their scope. For example, with no federal rules to regulate renovation, the persistence of old ponds of high biodiversity value is precariously dependent on landowners lacking interest or the ability to renovate them. The U.S. Clean Water Act (CWA; Clean Water Act 1972) is the primary tool used by the federal government to protect wetlands. However, extension of the CWA to include farm ponds would likely be neither successful nor ultimately helpful. Fallout from an effort in 2014 to refine the “Waters of the United States” rule highlights the serious political barriers to expanding oversight of rural waters (Layden 2014). An incentive program with voluntary enrollment could be a better option. The Wetlands Reserve Program (WRP) already provides a policy mechanism for mitigating the economic burden of restoring and protecting wetlands on private lands (NRCS 2015). Though farm ponds are human-constructed ecosystems, much could be gained by expanding the WRP to include them. Without financial reward, pond conservation may attract little buy-in from landowners. Local grassroots efforts patterned after the Norfolk Ponds Project (Sayer and Greaves In Press) could help fill the void temporarily, but we suspect that federal action will ultimately be required to conserve these ecosystems at a sufficient scale.

Barring such policy innovations, landowners will continue to have the final word on pond design and function. Their attitudes and beliefs about farm ponds thus remain central to preserving biodiversity. Moving forward, if pond conservation is to rely on voluntary management, substantial effort must be devoted to determining the factors that underlie landowner decisions. While a sizable number of landowners express favorable attitudes toward pond wildlife (Swartz et al. 2019a), their willingness to adopt conservation practices is unknown. Since ponds hold a unique position in the social fabric of rural areas (Hawley 1973) and farmers sometimes prefer the aesthetics of neatly manicured ponds to more natural-looking wetlands (Greenland-Smith et al. 2016), a variety of social and psychological factors likely have an important role in decision-making. Future research that illuminates these and other influences will be crucial for effective conservation.

Human-constructed ponds are a conservation resource that is just beginning to be recognized across the globe (Hill et al. 2018). We have outlined some of the areas where relationships could be formed to advance their conservation in the Great Plains. Certainly, there are countless other partnerships and avenues for research that could be equally fruitful, and we encourage their development. Given the sheer number of farm ponds in existence, both in the Pond Belt and beyond, even small steps toward evidence-based management could yield substantial benefits for biodiversity conservation.

ACKNOWLEDGEMENTS

We are exceedingly grateful to Jaime Coon and Scott Maresh Nelson for their input and feedback as we developed the ideas for this paper. This manuscript was much improved thanks to suggestions from Carl Sayer and two other anonymous reviewers. We also thank Chris Phillips and Robert Schooley for their helpful comments on earlier versions on this manuscript. We thank Shannon Rusk and Adam Gottemoeller for facilitating pond visits and providing valuable insights into technical aspects of farm pond construction and management. We thank Lynda Heller for contributing the pond illustration and Bridget Rogers and Byron Wolfe for technical support. T.M.S. was supported by the Jonathan Baldwin Turner Graduate Fellowship from the College of Agriculture, Consumer, and Environmental Sciences at the University of Illinois. A crowdfunding project through Experiment (www.experiment.com) made the drone images possible. This material is also based upon work that was supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number ILLU-875-918 and the Competitive State Wildlife Grants program grant U-D F14AP00012 in cooperation with the U.S. Fish and Wildlife Service, Wildlife and Sport Fish Restoration Program.

LITERATURE CITED

Alderton, E., C. D. Sayer, R. Davies, S. J. Lambert, and J. C. Axmacher. 2017. Buried alive: Aquatic plants survive in ‘ghost ponds’ under agricultural fields. Biological Conservation **212**:105-110.

Berg, M. D., S. C. Popescu, B. P. Wilcox, J. P. Angerer, E. C. Rhodes, J. McAlister, and W. E. Fox. 2016. Small farm ponds: overlooked features with important impacts on watershed sediment transport. Journal of the American Water Resources Association **52**:67-76.

Biggs, J., S. von Fumetti, and M. Kelly-Quinn. 2016. The importance of small waterbodies for biodiversity and ecosystem services: implications for policy makers. Hydrobiologia **793**:1-37.

Boothby, J. 1997. Pond conservation: towards a delineation of pondscape. Aquatic Conservation: Marine and Freshwater Ecosystems **7**:127-132.

Boyd, C. E., C. W. Wood, P. L. Chaney, and J. F. Queiroz. 2010. Role of aquaculture pond sediments in sequestration of annual global carbon emissions. Environmental pollution **158**:2537-2540.

Briggs, A. J., J. S. Pryke, M. J. Samways, and D. E. Conlong. 2019. Complementarity among dragonflies across a pondscape in a rural landscape mosaic. Insect Conservation and Diversity **12**:241-250.

Campbell, B. D., R. J. Haro, and W. B. Richardson. 2009. Effects of agricultural land use on chironomid communities: comparisons among natural wetlands and farm ponds. Wetlands **29**:1070-1080.

Chumchal, M. M., and R. W. Drenner. 2015. An environmental problem hidden in plain sight? Small Human-made ponds, emergent insects, and mercury contamination of biota in the Great Plains. Environmental Toxicology and Chemistry **34**:1197-1205.

Chumchal, M. M., R. W. Drenner, and K. J. Adams. 2016. Abundance and size distribution of permanent and temporary farm ponds in the southeastern Great Plains. Inland Waters **6**:258-264.

Clean Water Act. 1972. Federal Water Pollution Control Act.

Clifford, C., and J. Heffernan. 2018. Artificial aquatic ecosystems. Water **10**:1096.

Compton, L. V. 1952. Farm and ranch ponds. The Journal of Wildlife Management **16**:238-242.

Dahl, T. E. 1990. Wetlands: losses in the United States 1780's to 1980's., U.S. Fish and Wildlife Service, Washington, D.C., USA.

Deal, C., J. L. Edwards, N. Pellmann, R. Tuttle, and D. Woodward. 1997. Ponds: planning, design, construction. Pages 1-85 *in* M. R. Mattinson, L. S. Glasscock, J. D. Massey, and W. R. Pierce, editors. Agriculture Handbook No. 590. USDA Natural Resources Conservation Service, Washington, DC.

Downing, J. A. 2010. Emerging global role of small lakes and ponds: little things mean a lot. Limnetica **29**:0009-0024.

Gallant, A. L., R. W. Klaver, G. S. Casper, and M. J. Lannoo. 2007. Global rates of habitat loss and implications for amphibian conservation. Copeia **2007**:967-979.

Gallant, A. L., W. Sadinski, M. F. Roth, and C. A. Rewa. 2011. Changes in historical Iowa land cover as context for assessing the environmental benefits of current and future conservation efforts on agricultural lands. journal of soil and water conservation **66**:67A-77A.

Giuliano, W. M. 2006. Should I fence the streams, ponds, and wetlands in my pastures? Fencing pasture streams, ponds, and wetlands can improve fish and wildlife habitat and benefit agricultural landowners. Rangelands **28**:29-31.

Greenland-Smith, S., J. Brazner, and K. Sherren. 2016. Farmer perceptions of wetlands and waterbodies: Using social metrics as an alternative to ecosystem service valuation. Ecological Economics **126**:58-69.

Haley, N. V., R. A. Wright, D. R. DeVries, and M. S. Allen. 2012. Privately Owned Small Impoundments in Central Alabama: A Survey and Evaluation of Management Techniques for Largemouth Bass and Bluegill. North American Journal of Fisheries Management **32**:1180-1190.

Hawley, A. J. 1973. Farm ponds in the United States: a new resource for farmers. Pages 746-749 *in* W. C. Ackermann, G. F. White, and E. B. Worthington, editors. Man-Made Lakes: Their Problems and Environmental Effects. American Geophysical Union, Washington, D.C., USA.

Hill, M., C. Hassall, B. Oertli, L. Fahrig, B. Robson, J. Biggs, M. Samways, N. Usio, N. Takamura, and J. Krishnaswamy. 2018. New policy directions for global pond conservation. Conservation Letters **11**:e12447.

Howell, H. J., C. C. Mothes, S. L. Clements, S. V. Catania, B. B. Rothermel, and C. A. Searcy. 2019. Amphibian responses to livestock use of wetlands: new empirical data and a global review. Ecological Applications **0**:e01976.

Huggins, D., J. Kastens, D. Baker, and C. Freeman. 2017. Conversion of existing farm ponds to wetlands in agricultural landscapes for mitigation, land use treatment and conservation with a perspective toward climate change. Kansas Biological Survey Report No. 189, University of Kansas.

Knutson, M. G., W. B. Richardson, D. M. Reineke, B. R. Gray, J. R. Parmelee, and S. E. Weick. 2004. Agricultural ponds support amphibian populations. Ecological Applications **14**:669-684.

Koh, I., E. V. Lonsdorf, N. M. Williams, C. Brittain, R. Isaacs, J. Gibbs, and T. H. Ricketts. 2016. Modeling the status, trends, and impacts of wild bee abundance in the United States. Proceedings of the National Academy of Sciences **113**:140-145.

Kupferberg, S. J., A. Catenazzi, K. Lunde, A. J. Lind, and W. J. Palen. 2009. Parasitic copepod (Lernaea cyprinacea) outbreaks in foothill yellow-legged frogs (Rana boylii) linked to unusually warm summers and amphibian malformations in Northern California. Copeia **2009**:529-537.

Lannoo, M. 1996. A fish fry: the role of exotic species and aquacultural practices in producing amphibian declines in the upper Midwest. Pages 25-27 *in* J. J. Moriarty and D. Jones, editors. Minnesota’s amphibians and reptiles: conservation and status, Proceedings of Symposium. Serpent’s Tale Press, Excelsior, MN, USA.

Lannoo, M. 1998. Amphibian conservation and wetland management in the upper Midwest: a catch-22 for the cricket frog. Pages 330-339 *in* M. J. Lannoo, editor. Status and conservation of midwestern amphibians. University of Iowa, Iowa City, Iowa, USA.

Layden, L. 2014. Confusion fueling Oklahoma outcry over EPA's 'Waters of the United States' rule. StateImpact. Oklahoma Public Media Exchange.

Leja, W. T. 1998. Aquatic habitats in the Midwest: waiting for amphibian conservation initiatives. Pages 345-353 *in* M. J. Lanoo, editor. Status and conservation of midwestern amphibians. University of Iowa Press, Iowa City, Iowa, USA.

Lewis-Phillips, J., S. J. Brooks, C. D. Sayer, I. R. Patmore, G. M. Hilton, A. Harrison, H. Robson, and J. C. Axmacher. 2020. Ponds as insect chimneys: Restoring overgrown farmland ponds benefits birds through elevated productivity of emerging aquatic insects. Biological Conservation **241**:108253.

McLeman, R. A., J. Dupre, L. B. Ford, J. Ford, K. Gajewski, and G. Marchildon. 2014. What we learned from the Dust Bowl: lessons in science, policy, and adaptation. Population and Environment **35**:417-440.

Miracle, R., B. Oertli, R. Céréghino, and A. P. Hull. 2010. Preface: conservation of European ponds-current knowledge and future needs. Limnetica **29**:1-8.

NRCS. 2006. Farm pond ecosystems. Page 12. United States Department of Agriculture, Washington, D.C.

NRCS. 2015. Restoring America's Wetlands: A Private Lands Conservation Success Story.*in* U. S. D. o. Agriculture, editor. Natural Resources Conservation Service, Washington D.C.

Perry, K., D. Jayne, M. Smith, and A. Branson. 2015. Missouri Pond Handbook. Page 72 *in* M. D. o. Conservation, editor. Missouri Department of Conservation, Jefferson City, Missouri, USA.

Peters, D. P., O. E. Sala, C. D. Allen, A. Covich, and M. Brunson. 2007. Cascading events in linked ecological and socioeconomic systems. **5**:221-224.

Porej, D., and T. E. Hetherington. 2005. Designing wetlands for amphibians: the importance of predatory fish and shallow littoral zones in structuring of amphibian communities. Wetlands Ecology and Management **13**:445-455.

Renwick, W. H., R. O. Sleezer, R. W. Buddemeier, and S. V. Smith. 2006. Small artificial ponds in the United States: impacts on sedimentation and carbon budget. Pages 738-744 *in* Proceedings of the Eighth Federal Interagency Sedimentation Conference.

Ruggiero, A., R. Céréghino, J. Figuerola, P. Marty, and S. Angélibert. 2008. Farm ponds make a contribution to the biodiversity of aquatic insects in a French agricultural landscape. Comptes Rendus Biologies **331**:298-308.

Sauer, J. R., K. L. Pardieck, D. J. Ziolkowski Jr, A. C. Smith, M.-A. R. Hudson, V. Rodriguez, H. Berlanga, D. K. Niven, and W. A. J. T. C. O. A. Link. 2017. The first 50 years of the North American Breeding Bird Survey. **119**:576-593.

Sayer, C., K. Andrews, E. Shilland, N. Edmonds, R. Edmonds-Brown, I. Patmore, D. Emson, and J. Axmacher. 2012. The role of pond management for biodiversity conservation in an agricultural landscape. Aquatic Conservation: Marine and Freshwater Ecosystems **22**:626-638.

Sayer, C. D., and H. Greaves. In Press. Making an impact on UK farmland pond conservation. Aquatic Conservation: Marine and Freshwater Ecosystems.

Schmutzer, A. C., M. J. Gray, E. C. Burton, and D. L. Miller. 2008. Impacts of cattle on amphibian larvae and the aquatic environment. Freshwater Biology **53**:2613-2625.

Schonrock, A. E. 2005. An internet survey of private pond owners and managers in texas. Texas A&M, College Station, TX.

Semlitsch, R. D., and J. R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology **17**:1219-1228.

Smith, S., W. Renwick, J. Bartley, and R. Buddemeier. 2002. Distribution and significance of small, artificial water bodies across the United States landscape. Science of the Total Environment **299**:21-36.

Swartz, T. M., J. J. Coon, J. R. Mattes, and J. R. Miller. 2019a. Identifying Opportunities to Conserve Farm Ponds on Private Lands: Integration of Social, Ecological, and Historical Data. Land **8**:127.

Swartz, T. M., and J. R. Miller. 2019. Managing farm ponds as breeding sites for amphibians: key trade-offs in agricultural function and habitat conservation. Ecological Applications **29**:e01964.

Swartz, T. M., E. K. Wilson, and J. R. Miller. 2019b. Natural History Note: *Lithobates blairi* (Plains leopard frog): Ectoparasites. Herpetological Review **50**:114.

Tiner, R. W. 2003. Geographically isolated wetlands of the United States. Wetlands **23**:494-516.

Trimble, S. W., and A. C. Mendel. 1995. The cow as a geomorphic agent—a critical review. Geomorphology **13**:233-253.

U.S. Department of Agriculture. 1985. Food Security Act of 1985.*in* 99th Congress of the United States, editor. P.L. 99-198, Washington, D.C.

USFWS. 1956. Farm ponds get increasing attention from fish and wildlife service. Page 1. Department of the Interior, Information Service, Washington, D.C.

Wait, K. R., and A. A. Ahlers. 2020. Virginia opossum distributions are influenced by human-modified landscapes and water availability in tallgrass prairies. Journal of Mammalogy **101**:216-225.

Winter, T. C. 1989. Hydrologic studies of wetlands in the northern prairie. Pages 16-54 *in* A. G. Van der Valk, editor. Northern Prairie Wetlands. Iowa State University, Ames, Iowa, USA.

York, B. 2019. Oklahoma department of wildlife conservation 2019 oklahoma angler survey. Oklahoma department of wildlife conservation.

FIGURES

Figure 1. Farm ponds serve two primary agricultural functions. (a) This farm pond in Ringgold County, Iowa, provides water for a small herd of cattle. The cattle have direct access to all parts of the pond and spend a great deal of time along the embankment, as evidenced by the extensive bare ground along the top of the dam. (b) This pond captures sediments and runoff from the surrounding cropland. Small gullies are visible across the hillside upstream from the pond, but the formation of more extensive erosion has been prevented by the pond.

Figure 2. The Pond Belt (a), located in the central United States, comprises more than 2 million farm ponds (outlined in dark gray). Ponds are concentrated in the eastern portion of the Great Plains ecoregion, where cattle grazing is widespread. The Pond Belt does not correspond to any of the known naturally formed complexes of geographically isolated wetlands (b, blue polygons). While other clusters of constructed water bodies are visible in urban and rural areas throughout the country, they are most dense in the Pond Belt. The pond density layer in (a) includes all waterbodies ≤ 1 ha from the National Hydrography Dataset mapped by USGS 24k Quadrangle,

after Chumchal et al. (2016). Geographically isolated wetlands layer in (b) adapted from Tiner (2003).

Figure 3. Conceptual diagram depicting the drivers of farm pond construction (a) and succession (b) and their impacts on agricultural function and conservation. Farm pond construction is initially driven by agricultural concerns but yields aquatic habitat with conservation value. This habitat undergoes considerable changes due to succession, affecting both its quality as an agricultural and conservation asset.

Figure 4. Illustration of key biophysical differences that characterize many new and old farm ponds of the eastern Great Plains, USA. (a) New ponds tend to support diverse communities of predatory vertebrates, like turtles, fish, and wading birds. Amphibians and macroinvertebrates that reproduce in permanent wetlands can also be abundant. Emergent vegetation is typically limited in these newer ponds. (b) Older ponds may be characterized by predatory invertebrates like dragonflies and predaceous diving beetles as well as fish-sensitive amphibians that favor temporary or vegetated wetlands like Blanchard's cricket frog, gray treefrogs and chorus frogs. Emergent vegetation can be abundant in older ponds and some trees, especially willows (*Salix* spp.), can become established along their banks. This vegetation may provide habitat for marsh-breeding birds, like red-winged blackbirds. It should be noted that the precise composition of the communities of both new and old ponds will be influenced substantially by both pond management practices, like species introductions, and ecological processes, like natural colonization. Illustrations by L.F. Heller

Figure 5. Examples of ponds at a range of successional stages. (a) Ponds are usually built by using heavy machinery to enlarge a natural valley and build an embankment at the downstream end. (b) New ponds have steep sides and a deep basin and aquatic vegetation is usually absent at this stage. (c) As successional processes take hold, the basin fills with sediment and shallow edges develop. These provide habitat for a growing number of plants and animals. (d) As succession progresses, open water areas become more scarce and macrophytes dominate the pond surface. (e) Without tree and shrub removal, encroachment by woody plants can become extensive, shading out aquatic macrophytes as ponds age. (f) At the end of its life, ponds may hold little water and become completely overtaken by cattails. From here, further sedimentation leads to terrestrialization and the pond disappears.

Figure 6. A small wetland plant community has become established in the area below the dam of a pond built in 2005. The outlet pools of large ponds like this one may provide an opportunity for creating and conserving small wetlands.

Figure 7. Aerial image depicting a pondscape consisting of ponds in a range of successional states and with differing functions. Farmers may own many ponds that each play different roles in their agricultural enterprise depending on pond age, size, and location. Furthermore, pondscapes are dynamic and each pond will likely undergo substantial changes over time. If succession is left unchecked, an aging pond may fully terrestrialize and disappear. Newer reservoir and cattle ponds may gradually transition to habitats with decreased agricultural function but increased shallow water habitats for organisms of conservation concern. Managing pondscapes to ensure the availability of older ponds with well-developed wetland habitat should be a key priority for conservation.

Figure 1.

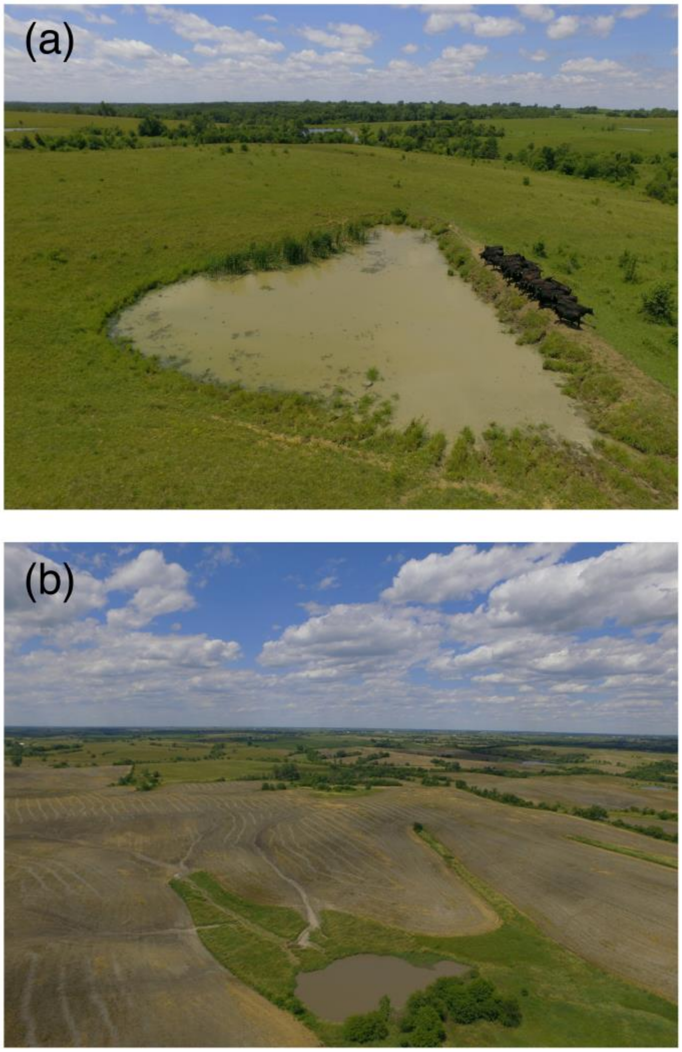


Figure 2.

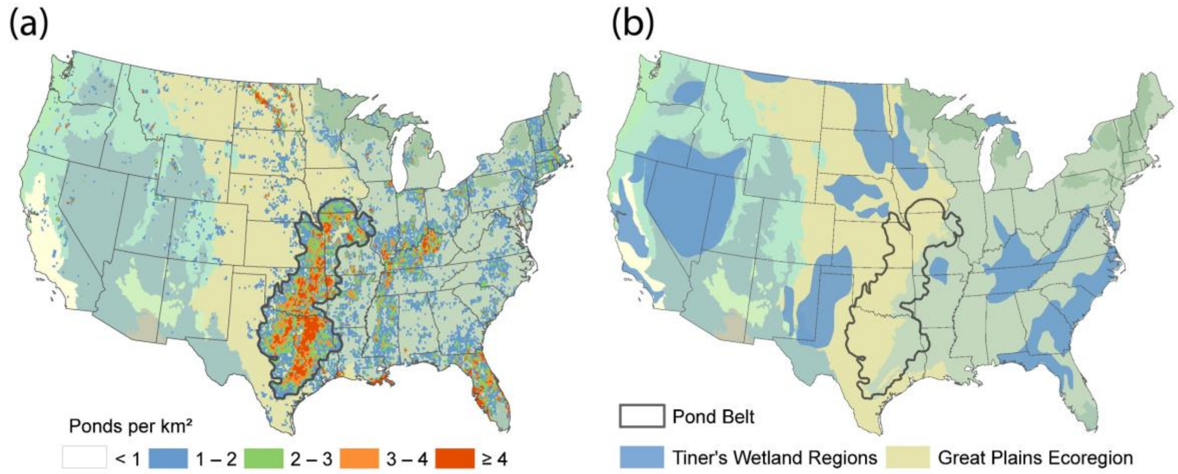

(a)
(b)
Ponds per km²
< 1
1 – 2
2 – 3
3 – 4
≥ 4
Pond Belt
Tiner's Wetland Regions
Great Plains Ecoregion

Figure 3.

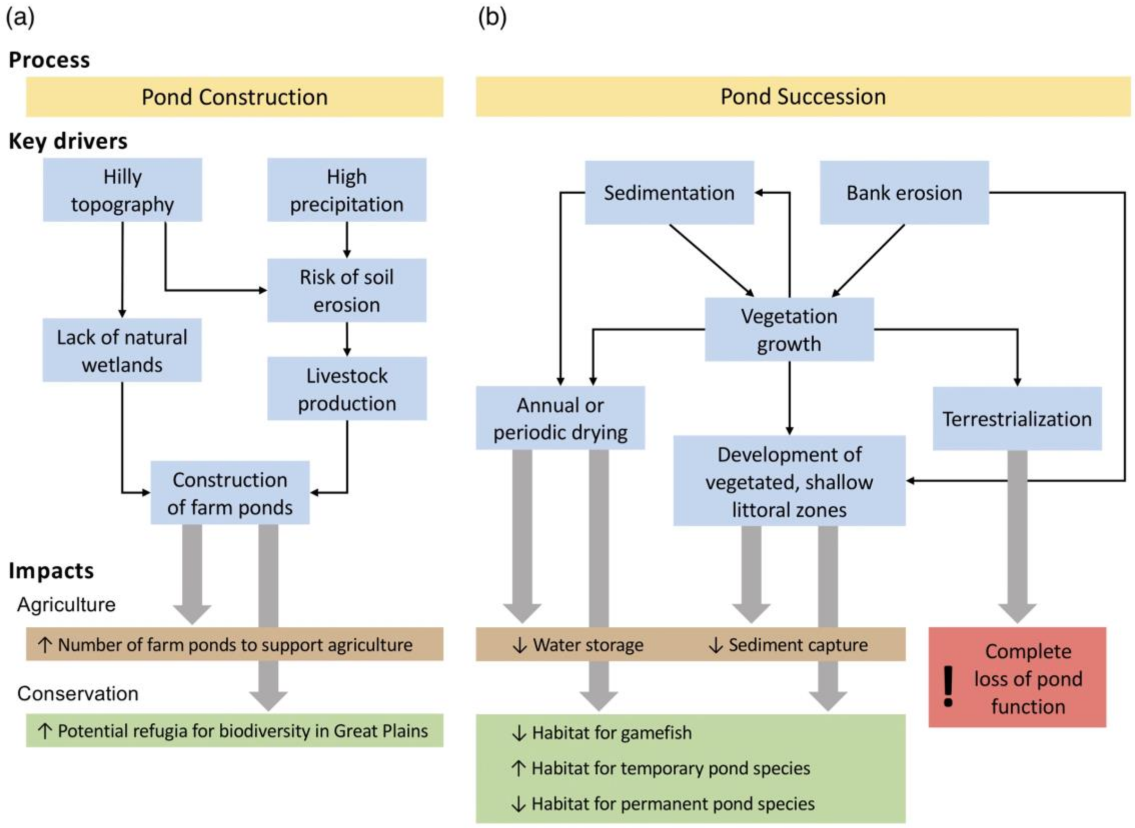

(a)
Process
Pond Construction
Key drivers
Hilly topography
High precipitation
Risk of soil erosion
Lack of natural wetlands
Livestock production
Construction of farm ponds
Impacts
Agriculture
↑ Number of farm ponds to support agriculture
Conservation
↑ Potential refugia for biodiversity in Great Plains
(b)
Pond Succession
Sedimentation
Bank erosion
Vegetation growth
Annual or periodic drying
Terrestrialization
Development of vegetated, shallow littoral zones
↓ Water storage
↓ Sediment capture
Complete loss of pond function
↓ Habitat for gamefish
↑ Habitat for temporary pond species
↓ Habitat for permanent pond species

Figure 4.

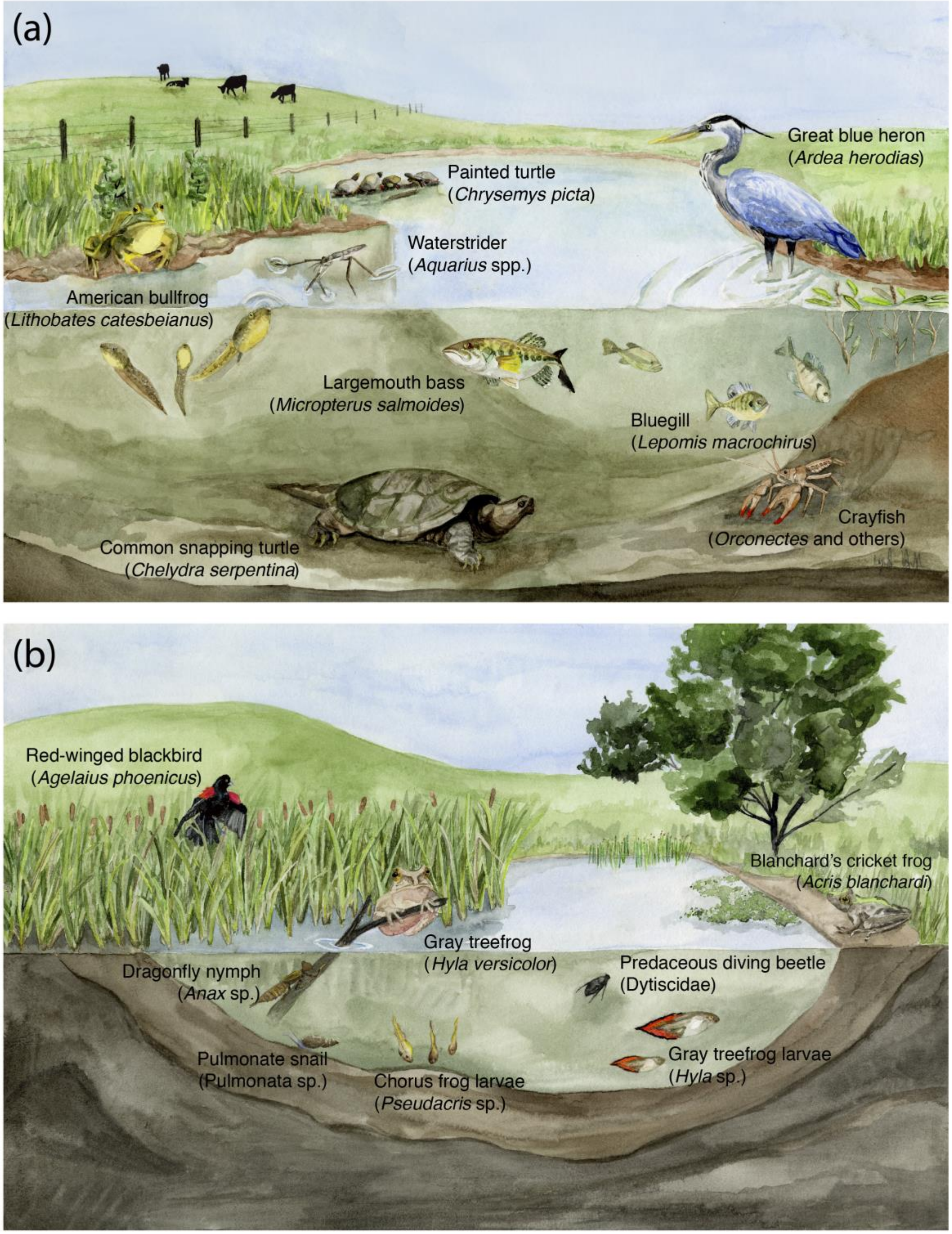
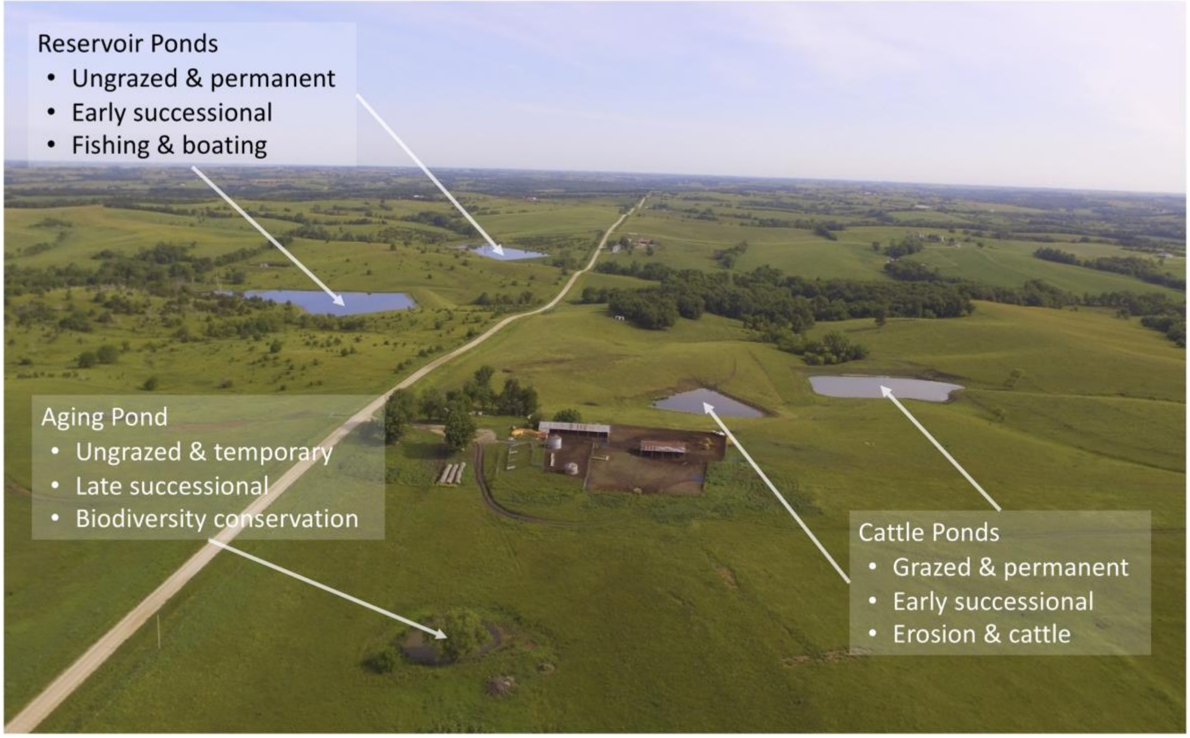

(a)
Great blue heron
(*Ardea herodias*)
Painted turtle
(*Chrysemys picta*)
Waterstrider
(*Aquarius* spp.)
American bullfrog
(*Lithobates catesbeianus*)
Largemouth bass
(*Micropterus salmoides*)
Bluegill
(*Lepomis macrochirus*)
Crayfish
(*Orconectes* and others)
Common snapping turtle
(*Chelydra serpentina*)
(b)
Red-winged blackbird
(*Agelaius phoenicus*)
Blanchard's cricket frog
(*Acris blanchardi*)
Gray treefrog
(*Hyla versicolor*)
Dragonfly nymph
(*Anax* sp.)
Predaceous diving beetle
(Dytiscidae)
Pulmonate snail
(Pulmonata sp.)
Chorus frog larvae
(*Pseudacris* sp.)
Gray treefrog larvae
(*Hyla* sp.)

Figure 5.

Figure 6.

Figure 7.


Reservoir Ponds
• Ungrazed & permanent
• Early successional
• Fishing & boating
Aging Pond
• Ungrazed & temporary
• Late successional
• Biodiversity conservation
Cattle Ponds
• Grazed & permanent
• Early successional
• Erosion & cattle