Article

Abundance and size distribution of permanent and temporary farm ponds in the southeastern Great Plains

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Abstract

Using aerial images from the US Department of Agriculture National Agriculture Imagery Program and the US Geological Survey National Hydrology Dataset, we estimated 577654 farm ponds with surface areas from 0.005 to 1 ha in a 229489 km^2 region of the southeastern Great Plains (2.52 ponds/km^2). Ponds with surface areas from 0.005 to 0.1 ha were the numerically dominant size class in the study region. The distribution of farm pond sizes followed an inverse power law relationship. We estimated 376209 permanent ponds and 201445 temporary ponds were in our study area. The ratio of temporary to permanent ponds within a pond size class was inversely related to pond surface area; 47% of ponds with surface areas of 0.005–0.1 ha were temporary, whereas only 13% of ponds with surface areas of 0.91–1 ha were temporary. Because permanent and temporary farm ponds are abundant and have different physicochemical properties and ecological communities, assessments of regional biogeochemical processes and biodiversity in the Great Plains must consider both types of ecosystems.

Key words: farm ponds, Great Plains, permanent, temporary

Introduction

Understanding the abundance and size distribution of lentic waterbodies is critical to assessing the role of these ecosystems in regional and global biogeochemical processes (Hanson et al. 2007, Downing 2009, 2010, Seekell et al. 2013). Historically, small lentic waterbodies with surface areas <0.1 km^2 have either not been included (Meybeck 2003, Lehner and Döll 2004) or were under-censused (Downing et al. 2006) in surveys of the abundance and surface area of lentic waterbodies. Several investigators recently estimated the abundance of small lentic waterbodies in global and continental-scale inventories and found that small waterbodies can occur at high densities and cover large surface areas (Smith et al. 2002, Downing et al. 2006, McDonald et al. 2012), suggesting they may play an important role in biogeochemical cycling and the maintenance of biodiversity.

Understanding the role of small lentic waterbodies in the environment is complicated because some small waterbodies are not permanent but instead are temporary and periodically dry. Permanent and temporary lentic waterbodies have different ecological communities (Batzer and Wissinger 1996, Wellborn et al. 1996, Williams 1996) and potentially different roles in biogeochemical cycling and the maintenance of biodiversity (Smith et al. 2002, Renwick et al. 2005, 2006, Drenner et al. 2009, Henderson et al. 2012). An important first step in assessing the role of permanent and temporary lentic waterbodies in the environment is to determine their abundance.

Farm ponds in the US Great Plains

The present study focuses on farm ponds in the US Great Plains, an extensive agricultural region where the construction of farm ponds constitutes a fundamental transformation of the hydrologic landscape (Smith et al. 2002, Renwick et al. 2005, 2006, Huggins et al. 2011, McDonald et al. 2012). Prior to settlement by Europeans, the Great Plains was a grassland with natural lotic and lentic waterbodies that included perennial and intermittent

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streams, springs, oxbow lakes, playa lakes (primarily in West Texas and New Mexico), Nebraska Sandhill lakes (primarily in Nebraska), and prairie pothole lakes (primarily in Iowa, Minnesota, South Dakota, North Dakota, and Montana; Dodds et al. 2004, Huggins et al. 2011). Over the past 150 years, most of this ecoregion has been converted to cropland, rangeland, or pastureland (Samson et al. 2004, USEPA 2013). Millions of farm ponds have been constructed in the Great Plains (Smith et al. 2002, Renwick et al. 2005, 2006, McDonald et al. 2012, Chumchal and Drenner 2015) to capture runoff of surface water for a variety of uses, including water supply for livestock, sediment trapping and erosion control, and recreation (Renwick et al. 2005, 2006). The construction of farms ponds has resulted in the Great Plains having one of the highest densities of lentic waterbodies (McDonald et al. 2012) and highest shoreline densities in the contiguous United States (Winslow et al. 2014), and small farm ponds are now the dominant lentic ecosystem in the Great Plains (Huggins et al. 2011). The changes in hydrology have been particularly dramatic in the southeastern Great Plains (Smith et al. 2002, Renwick et al. 2005, 2006), an area historically devoid of natural lentic ecosystems. Here we provide the first estimate of the abundance of farm ponds ≤1 ha and the number of permanent and temporary farm ponds as a function of pond surface area in the southeastern Great Plains.

Study area

Our study area was located in the southeastern portion of the Great Plains US Environmental Protection Agency (USEPA) level I ecoregion (http://www.epa.gov/wed/pages/ecoregions/na_eco.htm), selected after examining the geographic distribution of ponds in the southern portion of the Great Plains (Fig. 1a). Using the United States Geological Survey (USGS) High-Resolution National Hydrology Dataset (NHD) sub-database "NHDWaterbody" (http://nhd.usgs.gov/), we determined that the number of waterbodies in the southern Great Plains varied from west to east and were greatest near the eastern border of the ecoregion (Fig. 1a). For our study area, we selected a 229 489 km^2 region between 31–37°N and 96–100°W (Fig. 1b) where farm ponds are abundant lentic ecosystems (Fig. 1c).

Methods

Overview

We used the NHD, the largest database of waterbodies in the United States, to estimate farm pond abundance. The NHD was developed from USGS topographic maps, and in some areas of Texas and Oklahoma the NHD source data were last updated in 1978 and therefore may not

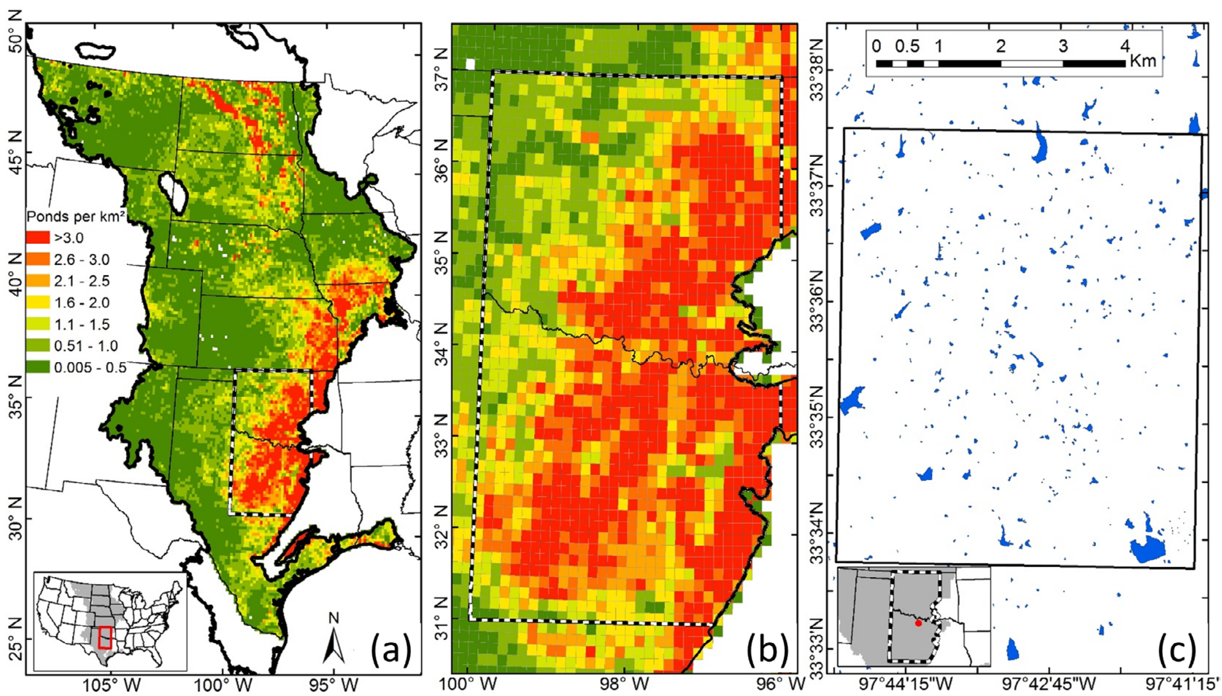

Fig. 1. (a) Density of lentic waterbodies ≤10 ha in the US Great Plains, (b) density of lentic waterbodies ≤10 ha in our study area, and (c) ponds in one-quarter quadrangle in Throckmorton County, TX. The boundaries of our study area within the Great Plains are indicated by a checkered black border. Lentic waterbody data are from the National Hydrology Dataset.

represent present-day conditions. Ponds are dynamic features of agricultural areas, both added and removed from the landscape over time (Renwick et al. 2006), which could lead to errors in the NHD. For example, some ponds may not be included in the NHD because they were recently constructed or were initially missed due to human error, whereas other ponds included in the NHD dataset may no longer be present on the landscape. Therefore, in our analysis we checked and corrected the NHD using visual inspection of individual ponds in aerial images from the USDA National Agriculture Imagery Program (NAIP) database. Specifically, we randomly subsampled 18 sites within our study area and visually analyzed aerial images of ponds during drought-free conditions to assess the completeness of the NHD and correct the dataset for ponds added and removed from the landscape. To identify permanent and temporary ponds, we analyzed aerial images of ponds from the same 18 subsampling sites during drought-free and drought conditions. We used the proportion of permanent and temporary ponds in our 18 subsampling sites along with the corrected NHD to estimate the abundance of permanent and temporary ponds across our study area. This study focused on ponds with surface areas ranging from 0.005 to 1 ha. Ponds >1 ha occurred at relatively low densities and were not abundant enough to be included in our analyses.

Identification of subsampling sites

To select our subsampling sites, we first identified candidate USGS quarter quadrangles suitable for visual inspection of individual ponds. Quarter quadrangles are derived from USGS 7.5 minute quadrangle maps (USGS 2002) divided into quarters. We used data from the US Drought Monitor (http://droughtmonitor.unl.edu/MapsAndData/GISData.aspx) to identify all USGS quarter quadrangles in the study area that experienced both drought-free and "D3 Extreme Drought" conditions during 2003–2013 (hereafter referred to as drought-free and drought conditions, respectively). We then searched the NAIP Imagery Database (http://datagateway.nrcs.usda.gov/) for 1–2 m resolution aerial images of the previously identified quarter quadrangles taken during drought-free and drought conditions (open pink rectangles in Fig. 2). When multiple NAIP images were available, we randomly selected a single year for analysis. Because the region varies in temperature and precipitation, we randomly selected 4–5 quarter quadrangles from the NW, NE, SW, and SE subareas of our study area for further study (18 quarter quadrangles total, solid black rectangles in Fig. 2).

Correction of NHD dataset and estimation of total number of ponds in the study area

We began by visually identifying all ponds in the aerial images of the 18 selected quarter quadrangles during drought-free conditions. We then compared these ponds to ponds in the NHD to assess 2 types of errors in the NHD: (1) ponds not included in the NHD that were observed in the aerial image (e.g., ponds added to the landscape) or (2) ponds included in the NHD that were not observed in the aerial images (e.g., ponds removed from the landscape). If a pond observed in the aerial image was not present in the NHD, we incorporated it into our database (Table 1, column B). If a pond was present in the NHD but was not observed in the aerial image, we removed it from the database (Table 1, column C). Finally, for the 18 quarter quadrangles, we corrected the number of ponds in the NHD (Table 1, column D) by adding the number of ponds observed in aerial images that were not included in the NHD (Table 1, column B) and subtracting the number of ponds in the NHD that were not observed in the aerial images (Table 1, column C). The corrected number of ponds in the 18 quarter quadrangles for each size category were documented (Table 1, column E). The ratio of the corrected number of ponds in the NHD to the number of ponds in the NHD for the 18 quarter quadrangles is a measure of net error (Table 1, column F). In each size category, some ponds observed in the aerial images were missing from the NHD, and some ponds in the NHD were not observed in the aerial images. The net error (estimated as a ratio) was relatively small for the smallest size categories of ponds but increased with pond size (Table 1, column F). To estimate the total number of ponds in the study area (Table 1, column H), we multiplied the total number of ponds in the NHD for the study area (Table 1, column G) by the ratio of the corrected number of ponds to the number of ponds in the NHD (Table 1, column F).

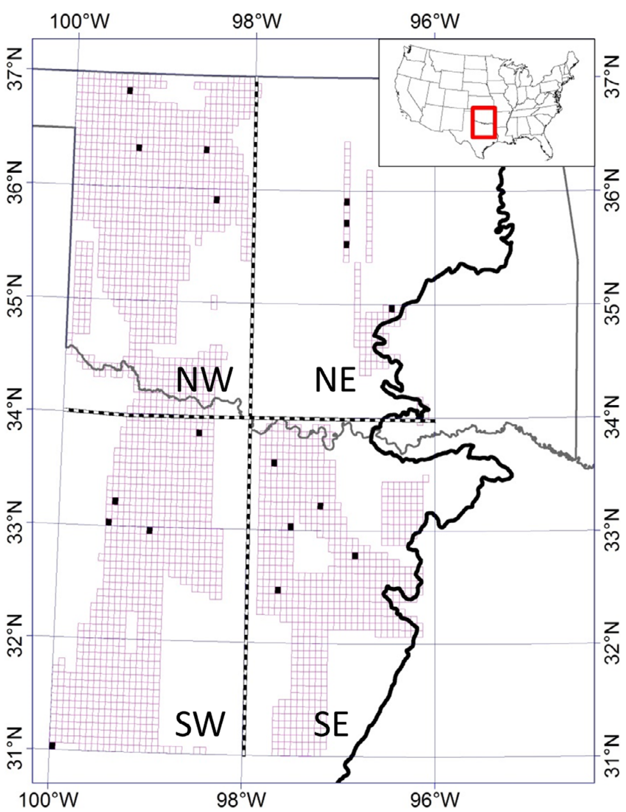

Fig. 2. Open pink rectangles represent USGS quarter quadrangles that experienced both drought-free and "D3 Extreme Drought" conditions during 2003–2013 and for which USDA National Agriculture Imagery Program 1–2 m resolution aerial images were available. Solid black rectangles represent quarter quadrangles selected for visual analysis in the NW, NE, SW, and SE subareas of our study area (demarcated by dashed lines).

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Table 1. Correction of the National Hydrology Dataset (NHD) and estimation of total number of ponds in the study area.

	Quarter Quadrangle Analysis (B through F)					Study Area Analysis (G and H)	
A. Size category (ha)	B. Number of ponds observed in aerial images not in NHD	C. Number of ponds in NHD not observed in aerial images	D. Number of ponds in NHD	E. Corrected number of Ponds	F. Ratio of the corrected number of ponds to the number of ponds in NHD	G. Number of ponds in NHD	H. Estimated total number of ponds
0.005–0.1	234	222	886	898	1.01	247 476	249 951
0.11–0.2	119	107	502	514	1.02	155 368	158 475
0.21–0.3	65	38	189	216	1.14	61 245	69 819
0.31–0.4	34	15	86	105	1.22	30 406	37 095
0.41–0.5	24	11	72	85	1.18	17 890	21 110
0.51–0.6	13	5	43	51	1.19	11 685	13 905
0.61–0.7	8	5	29	32	1.10	8079	8887
0.71–0.8	12	5	24	31	1.29	5926	7645
0.81–0.9	5	2	11	14	1.27	4548	5776
0.91–1.0	6	1	10	15	1.50	3327	4991
Total						545 950	577 654

Estimation of the abundance of permanent and temporary ponds

We determined whether ponds were permanent or temporary by visually inspecting aerial imagery from the 18 selected quarter quadrangles during drought-free conditions and comparing them to aerial images taken during drought conditions. We classified ponds that contained water during both drought-free and drought conditions as permanent (Table 2, column B). Ponds containing water during drought-free conditions but dry during drought conditions were classified as temporary (Table 2, column C). To estimate the abundance of permanent and temporary ponds in the study area (Table 2, columns F and G, respectively), we multiplied the proportion of permanent (Table 2, column D) and temporary ponds (Table 2, column E) in 18 quarter quadrangles by our estimate of the number of ponds within the study area (Table 1, column H). All data were processed using Esri ArcMap 10.1 (Build 3035).

Results and discussion

After correcting the NHD dataset, we estimated 577 654 ponds ≤1 ha were in our study area, 6% more than the 545 950 ponds included in the NHD. We estimated that the density of ponds in our study area was 2.52 ponds/km^2, considerably higher than the 0.64 lentic waterbodies per km^2 estimated for the South-Central Prairies and Southern Texas Plains subareas of the Great Plains (McDonald et al. 2012) but less than the maximum estimate of >5 ponds/km^2 for the conterminous United States (Renwick et al. 2006).

Ponds with surface areas from 0.005 to 0.1 ha were the numerically dominant size class of pond in the study area, and the number of ponds declined with increasing size (Fig. 3). The distribution of farm pond sizes followed a power law, as found in previous studies of lakes, ponds, and impoundments (reviewed in Downing et al. 2006; Fig. 3).

Table 2. Estimation of the abundance of permanent and temporary ponds.

	Quarter Quadrangle Analysis (B–E)				Study Area Analysis (F and G)	
A. Size category (ha)	B. Number of permanent ponds	C. Number of temporary ponds	D. Proportion of permanent ponds	E. Proportion of temporary ponds	F. Number of permanent ponds	G. Number of temporary ponds
0.005–0.1	474	424	0.53	0.47	132 474	117 477
0.11–0.2	353	161	0.69	0.31	109 348	49 127
0.21–0.3	171	45	0.79	0.21	55 157	14 662
0.31–0.4	81	24	0.77	0.23	28 563	8532
0.41–0.5	70	15	0.82	0.18	17 310	3800
0.51–0.6	42	9	0.82	0.18	11 402	2503
0.61–0.7	23	9	0.72	0.28	6399	2488
0.71–0.8	27	4	0.87	0.13	6651	994
0.81–0.9	11	3	0.79	0.21	4563	1213
0.91–1.0	13	2	0.87	0.13	4342	649
Total					376 209	201 445

To our knowledge, this is the first study to demonstrate that the distribution of farm pond sizes follows a power law.

We estimated 376 209 permanent ponds and 201 445 temporary ponds were in our study area. The proportion of temporary ponds within a pond size class was inversely related to pond surface area; 47% of ponds with surface areas of 0.005–0.1 ha were temporary, whereas only 13% of ponds with surface areas of 0.91–1.0 ha were temporary (Fig. 4). Ponds with small surface areas are more susceptible to drying and becoming temporary because they likely have shallow depths and less ability to maintain water during periods of low rainfall.

Construction of farm ponds has been so extensive that these systems have transformed the hydrology of the Great Plains (Smith et al. 2002, Renwick et al. 2005, 2006, Huggins et al. 2011), yet the importance of farm ponds is frequently not acknowledged in descriptions of aquatic ecosystems in the southern Great Plains (Covich et al. 1997, Laubhan and Fredrickson 1997, Wiken et al. 2011, Batzer and Baldwin 2012). In our study, we demonstrated that both permanent and temporary farm ponds are abundant. Because permanent and temporary ponds have different physicochemical properties and ecological communities (Williams 1997, Drenner et al. 2009, Henderson et al. 2012), assessments of regional biogeochemical processes and biodiversity in the Great Plains must consider both types of ecosystems. Many studies have shown that constructed systems may be important contributors to regional biodiversity (Knutson et al. 2004, Abellán et al. 2006, Brainwood and Burgin 2006, Failey et al. 2007, Bilton et al. 2009, Campbell et al. 2009, Drenner et al. 2009, Sebastián-González et al. 2010, Casas et al. 2012).

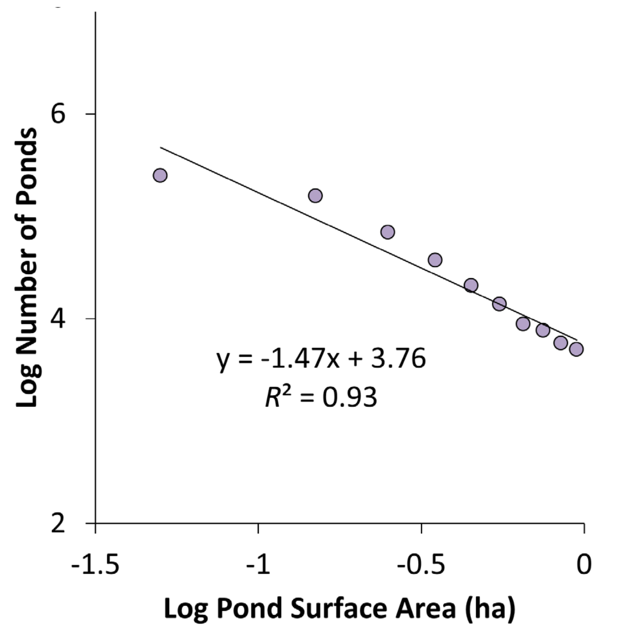

Fig. 3. Log-abundance log-surface area plot for farm ponds in the study area. Points are the total number of ponds in the 10 size classes in Table 1, column H.

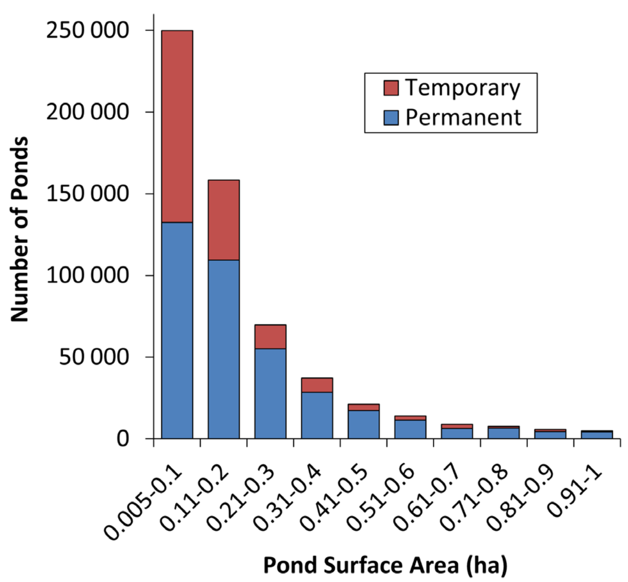

Fig. 4. Estimated number of permanent and temporary ponds in 10 size classes in the study area.

In conclusion, we used a novel method of assessing ponds during drought-free and drought conditions to provide the first estimate of permanent and temporary pond abundance in the southeastern Great Plains. Our analysis represents a snapshot of permanent and temporary ponds in the southeastern Great Plains. The ratio of permanent to temporary ponds will likely change in the future as climate change increases evaporation and reduces precipitation and surface runoff in this area of the Great Plains (Karl et al. 2009, Shafer et al. 2014). Our study provides important baseline data to assess future change in the number of permanent and temporary ponds in the region and their potential roles in biogeochemical cycling and their contribution to biodiversity in the Great Plains.

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