

Field Verification of Original and Updated National Wetlands Inventory Maps in three Metropolitan Areas in Illinois, USA

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Abstract National Wetland Inventory (NWI) maps are the most comprehensive wetland maps in the U.S., but NWI maps are now outdated in many regions. A consortium led by Ducks Unlimited is updating the NWI for the Great Lakes/Atlantic Region. Updates are complete for several states but have not been verified extensively with field data. We used wetland maps from 129 on-site wetland delineation projects in three Illinois regions to assess accuracy of original and updated NWI maps. We used ancillary spatial data to characterize areas that were incorrectly classified and identify potential sources of error. Across the three regions, the original NWI omitted 49 % of total wetland area for wetlands greater than 0.2 ha, and 57 % of the area mapped by the NWI was non-wetland. The updated NWI omitted less wetland area (40 % omitted for wetlands larger than 0.2 ha), but only slightly improved errors of commission (55 % of mapped area was non-wetland). Polygons mapped as forested wetlands were less likely to be truly wetlands. Small (<0.06 ha) wetlands were often omitted. Errors reflect ambiguity in the definition of wetlands and technical limitations of the NWI methodology. Due to the high error rates, we recommend further refinement of regional wetland inventories.

Keywords Classification and regression trees · Forested wetlands · Mapping accuracy · Small wetlands · Wetland mapping

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Introduction

Accurate accounting of remaining wetland acreage is an essential component of wetland and watershed management. National Wetland Inventory (NWI) maps, produced by the U.S. Fish and Wildlife Service, are the most widely available wetland maps in the United States. The objective of the original NWI was to locate and classify all wetlands and deepwater habitats in the U.S. based on visual interpretation of high altitude aerial photography. In most regions of the U.S., these maps are the only data available at a scale large enough for regional and basin-wide inventories and applications. Direct management uses of NWI data include restoration planning, environmental impact assessment, land use planning, species management, wetland permitting, land acquisition, and stormwater management (Tiner 2009; Stelk 2013). Researchers have used NWI data to evaluate wetland loss (Kentula et al. 2004; Oslund et al. 2010; Johnston 2013), predict changes in wetland extent under future climatic conditions (Garris et al. 2015), model habitat suitability for wildlife (Newbold and Eadie 2004), and evaluate wetland functions and the monetary value of ecosystem services (Tiner 2005; Troy and Wilson 2006; Patton et al. 2015). The management and science of wetlands at large spatial scales, therefore, hinges on accurate wetland inventories.

Researchers have assessed the accuracy of NWI maps in several regions of the U.S. One approach is to overlay NWI data onto other geographic data to assess the agreement between data sources. For example, Kuzila et al. (1991) found 94 % congruence between the NWI and hydric soils mapped by the U.S. Department of Agriculture (USDA) Soil Conservation Service in a study area in Nebraska. Others have verified NWI maps using field surveys (e.g., Nichols 1994; Stolt and Baker 1995; Wu et al. 2014). Stolt and Baker (1995), for example, reported that 91 % of NWI-mapped polygons in

a study region in Virginia were jurisdictional wetlands, but they also found that a large proportion of the total wetland acreage identified in the field had been omitted by the NWI. The omitted wetlands were often small, forested wetlands which are difficult to detect using photointerpretation. The scale of the imagery used to prepare NWI maps limits the detectability of small wetlands, and in addition to forested wetlands, other types of wetlands such as farmed wetlands, partly drained wetlands, and wetlands in narrow valleys, can be difficult to photointerpret (Tiner 1999). Inaccuracy in the NWI precludes certain local, on-site applications. For example, due to discrepancies between NWI maps and actual wetland occurrences, NWI data may be inappropriate for applications such as reserve planning or wetland delineation. Managers and researchers often assume that NWI data are reasonably accurate for large-scale applications. However, because certain types of wetlands are likely to be omitted from inventories (e.g., Stolt and Baker 1995), biases in NWI data may propagate to confound even large-scale applications.

Furthermore, NWI maps for many regions of the U.S. are outdated, especially in regions that have undergone extensive land use change during the past few decades. The original NWI maps for the Great Lakes region were prepared using aerial imagery taken primarily in the 1980s. However, lack of funding for NWI has slowed the creation of updated maps, prompting states to produce wetland inventories (Tiner 2009). Currently, a consortium of public and private entities led by the non-profit organization Ducks Unlimited (DU) is updating NWI maps for states in the Great Lakes/Atlantic Region. The goal is to provide an updated wetlands data layer with corrections for previous mapping errors and changes in land use since the original NWI (DU 2010).

The updated NWI maps for the Great Lakes/Atlantic Region have undergone only minimal field verification, and the accuracy of the updated maps has not been compared to that of the original NWI maps. Precise, on-the-ground mapping of wetland boundaries is routine, however, for wetland delineations that are conducted for the purpose of permitting wetland impacts under Section 404 of the U.S. Clean Water Act (Environmental Laboratory 1987). Therefore, wetland delineations provide a large number of field verification sites against which NWI maps might be verified. Our objectives for this study were to: 1) Use wetland delineation data to assess errors of commission and omission for original and updated NWI maps in urbanizing areas in the state of Illinois, and 2) expand on previous evaluations of NWI maps by using ancillary spatial data from a variety of sources to identify potential sources of errors of omission and commission for the updated NWI.

Methods

Study Regions

We focused on five counties in three urbanizing regions in Illinois: Lake and McHenry Counties in northeastern Illinois, Madison and St. Clair Counties in southwestern Illinois, and Rock Island County in northwestern Illinois (Fig. 1). Wetlands in these regions have been disproportionately affected by urban and ex-urban development.

Lake and McHenry Counties occur at the northern fringe of the greater Chicago metropolitan area, and are respectively, the third and sixth most populous counties in the state. Lake and eastern McHenry Counties have poorly defined drainages that often terminate in wetlands (Calsyn 2001, 2005). Historically, these counties were 30 to 60 % wetland (Suloway and Hubbell 1994). Despite extensive historic drainage, wetlands still cover 8 % of the land surface and

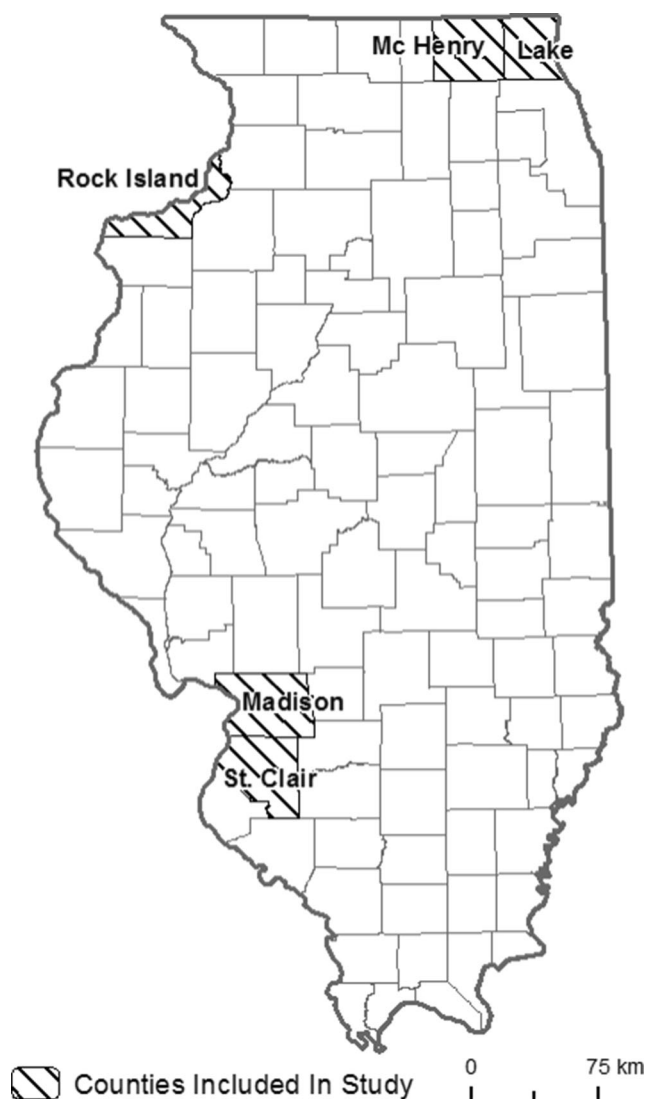


Fig. 1 Study areas within the state of Illinois, USA

include depressional marshes and wet meadows, bogs, riparian wetlands, and marshes fringing Lake Michigan (Suloway and Hubbell 1994; Calsyn 2005). Lake and McHenry Counties have experienced among the highest rates of wetland conversion in the state since the release of the original NWI maps for Illinois (DU 2010).

Madison and St. Clair Counties occur within the “Metro-East” area of the city of St. Louis, Missouri. Physiography varies from upland till plains and dissected bluffs to the broad Mississippi River floodplain, known as the American Bottoms (Indorante and Leeper 2000; Leeper 2004). Madison and St. Clair Counties have experienced 40–69 % loss of historic wetland area (Suloway and Hubbell 1994).

Rock Island County occurs within the metropolitan complex of the “Quad Cities” of Rock Island and Moline, Illinois, and Davenport and Bettendorf, Iowa. Rock Island County is characterized by upland plains, dissected valleys, and floodplains (Elmer 2004). Wetland loss in the county is estimated to be 80–89 % (Suloway and Hubbell 1994). Most remaining wetlands occur within the floodplains of the Mississippi and Rock Rivers.

National Wetlands Inventory Data

Original NWI data for the five focal counties were obtained from the U.S. Fish and Wildlife Service (Table 1). Staff from the NWI program of the U.S. Fish and Wildlife Service hand drew and labeled wetlands and deepwater habitats of Illinois by interpreting 1:58,000 color infrared photographs taken from 1980 to 1987 as part of the National High Altitude Aerial Photography Program (Tiner 2009). Additional data sources, including 7.5-min topographic maps from the U.S. Geological Survey and soil surveys by the USDA Soil Conservation Service, were used to aid mapping and classification. The target mapping unit (the minimum size that NWI attempted to consistently map) was 0.4–1.2 ha for this region of the U.S., but smaller wetlands do appear on the NWI maps (Tiner 2009).

Updated NWI data for Illinois were obtained from Ducks Unlimited (Table 1). Ducks Unlimited, in consultation with federal and state partners, updated the original NWI maps by onscreen digitizing of wetlands on digital orthophotographs (DU 2010). Spring aerial photos, best for identifying seasonal and forested wetlands, and summer photos, best for identifying emergent, aquatic and farmed wetlands, were used. Photos included natural color aerial photos from spring 2005 and summer 2007, and color-infrared photos from the USDA National Aerial Imagery Program from summer 2004. Ancillary data, including USGS topographic maps, hydric soils from the Soil Survey Geographic Database (SSURGO) of the Natural Resources Conservation Service (NRCS), and maps of DU wetland restorations, were used to aid photo interpretation (DU 2010). Photointerpreters overlaid the

original NWI onto orthophotographs section by section (~1 mi²) to determine if wetlands had been destroyed or modified, or had changed class. Photointerpreters also digitized any detectable wetlands that had been missed by the original NWI or had been newly created. The minimum mapping unit for the update was 0.04 ha, much smaller than original NWI and smaller than the Federal Geographic Data Committee’s standard of 0.2 ha (FGDC 2009), which should have allowed more inclusive mapping of small wetlands (DU 2010).

Field Verification Sites

The Illinois Natural History Survey (INHS) Wetland Science Program has delineated wetlands throughout Illinois within defined environmental survey corridors associated with Illinois Department of Transportation road improvement projects. All wetlands within these corridors are identified and delineated on-site following U.S. Army Corps of Engineers (ACOE) methodology. To be considered a wetland, positive evidence is required for the presence of hydrophytic vegetation, wetland hydrology, and hydric soils (Environmental Laboratory 1987; ACOE 2010). Beginning in 2003, wetland boundaries were recorded in the field using a Trimble Global Positioning System with a presumed accuracy of +/- 0.5 m under optimal field conditions. The resulting field maps, created by experienced wetland scientists during on-site surveys, are an ideal data source for field verification of NWI data. Within the five focal counties, INHS conducted 129 wetland delineation projects from 2003 to 2012, surveying a total of 7281 ha for wetlands. Survey corridors varied in length and width but were usually wider 60 m and had a median area of 9.3 ha. A total of 1101 wetlands, totaling 397 ha, were mapped within these environmental survey corridors.

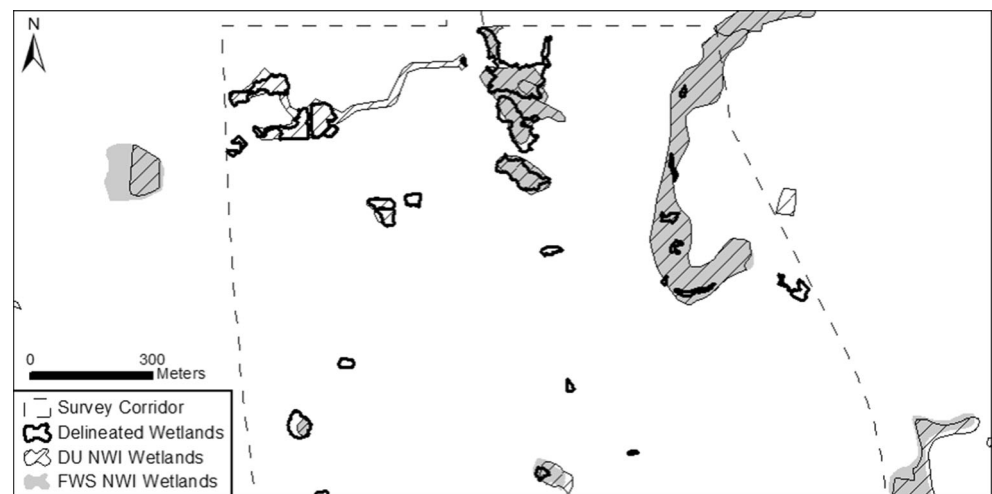
Spatial and Numerical Analyses

We compiled available data from INHS wetland surveys, then overlaid the INHS wetland data layer onto the original and updated NWI maps to determine the accuracy of the NWI maps (Fig. 2). Because on-site wetland determinations were restricted to the area within 129 environmental survey corridors, we limited our assessment of the NWI maps to within these corridors. We evaluated the predictive strength of the original and updated NWI maps based on errors of commission (non-wetlands incorrectly mapped as wetlands by the NWI) and errors of omission (true wetlands omitted by the NWI). We defined commission error rate as: 1) the percentage of NWI polygons that did not overlap a field-delineated wetland (minimum overlap required =10 % of a polygon’s area), and 2) the percentage of the total area of NWI polygons that did not overlap field-delineated wetlands. We similarly defined omission error rate as: 1) the percentage of field-delineated wetlands that did not overlap an NWI polygon

Table 1 Sources of spatial data used in the evaluation of the Ducks Unlimited updated NWI

Category	Data Layer	County	Data Source Name	Data Source Web Site	Publication Date	Originator
National Wetlands Inventory	NWI	All	NWI Data Download	http://www.fws.gov/wetlands/Data/Data-Download.html		U.S. Fish and Wildlife Service
National Wetlands Inventory	Ducks Unlimited Updated NWI	All	Ducks Unlimited	http://www.ducks.org/conservation/glaro/glaro-gis-nwi-update-data	7/6/2011	Ducks Unlimited, Great Lakes/Atlantic Regional Office
Flood zones	National Flood Hazard Layer	Lake, McHenry, Rock Island	FEMA Map Service Center	https://msc.fema.gov	12/18/2012	Federal Emergency Management Agency
Streams	One-Hundred and Five-Hundred Year Floodzones for Unincorporated Areas in Illinois	Madison, St. Clair	Illinois Geospatial Data Clearinghouse	http://www.isgs.uiuc.edu/nsd/home/	1996	Illinois State Water Survey
	National Hydrography Dataset (NHD) Plus, Version2	All	Horizon Systems	http://www.horizon-systems.com/nhdplus/	1/15/2013	U.S. Environmental Protection Agency, U.S. Geological Survey, Horizon Systems
Soils	Soil Survey Geographic (SSURGO) database for Lake County, Illinois	Lake	NRCS Soil Data Mart	http://soildatamart.nrcs.usda.gov	1/20/2012	USDA, Natural Resources Conservation Service
	Soil Survey Geographic (SSURGO) database for Madison County, Illinois	Madison	NRCS Soil Data Mart	http://soildatamart.nrcs.usda.gov	1/20/2012	USDA, Natural Resources Conservation Service
	Soil Survey Geographic (SSURGO) database for McHenry County, Illinois	McHenry	NRCS Soil Data Mart	http://soildatamart.nrcs.usda.gov	2/12/2010	USDA, Natural Resources Conservation Service
	Soil Survey Geographic (SSURGO) database for Rock Island County, Illinois	Rock Island	NRCS Soil Data Mart	http://soildatamart.nrcs.usda.gov	1/20/2012	USDA, Natural Resources Conservation Service
	Soil Survey Geographic (SSURGO) database for St. Clair County, Illinois	St. Clair	NRCS Soil Data Mart	http://soildatamart.nrcs.usda.gov	1/20/2012	USDA, Natural Resources Conservation Service
Land Cover	National Land Cover Dataset	All	NRCS Geospatial Data Gateway	http://datagateway.nrcs.usda.gov/	2006	USDA/NRCS - National Geospatial Management Center

Fig. 2 A comparison of field-delineated and NWI boundaries within a small study area in Lake County, Illinois



(minimum overlap required = 10 % of a wetland's area), and 2) the percentage of the total area of field-delineated wetlands that did not overlap NWI polygons.

The Federal Geographic Data Committee (FGDC) has established standards for federally funded wetland mapping in the U.S. with the objectives of supporting accurate, consistent mapping and ensuring updates and revisions (FGDC 2009). FGDC has set a standard target mapping unit of 0.2 ha (FGDC 2009). Therefore, we evaluated omission rates separately for wetlands that were larger and smaller than 0.2 ha.

Certain types of sites, or sites in certain locations, are more likely to be misclassified. Therefore, we compiled variables from existing, widely available spatial data sources (Table 1), and used these variables to construct a statistical model to predict the types of sites correctly or incorrectly classified as wetlands. This analysis was conducted for the updated NWI only. Unlike previous studies that have used similar ancillary spatial data to verify the accuracy of NWI maps (e.g., Kuzila et al. 1991), our accounting of updated NWI errors was based only on the on-site wetland determinations. The ancillary spatial data were used instead to define variables that may point to the causes of mapping errors.

Some of these additional variables were obtained from the NWI itself, which includes information on the type and water regime of mapped wetlands. The NWI classified wetlands and deepwater habitats hierarchically into systems, classes and subclasses (Cowardin et al. 1979). Systems, in Illinois, include Palustrine, Lacustrine and Riverine and differentiate sites based on fundamental characteristics of their hydrology, geomorphology, chemistry, and biology (Cowardin and Golet 1995). Because Lacustrine and Riverine sites are often deepwater habitats that are not considered to be wetlands under the ACOE methodology, we included only Palustrine sites in our analysis. Classes and subclasses are akin to habitat type, and are assigned based on the physiognomy of the dominant vegetation or, in the case of non-vegetated wetlands, on

characteristics of the substrate. In addition to the hierarchical classification, wetlands are described using “water regime modifiers” and, in some cases, “special modifiers”. Water regime modifiers characterize the hydrology of a wetland based on the frequency and duration of inundation or saturation, and special modifiers describe alterations to wetlands by humans or beavers, and include categories for excavated, impounded, diked, partly drained, farmed, and artificial wetlands. The NWI includes all ponded habitats, including farm ponds, sewage lagoons, and stormwater retention basins. Many of these sites are non-vegetated, deepwater habitats, and therefore are not considered “wetlands” using ACOE field determination methods (Environmental Laboratory 1987). Therefore, we excluded from our analysis all NWI polygons with a water regime modifier of K (artificially impounded) or special modifiers *h* (diked/impounded) or *x* (excavated).

In addition to NWI classifications, we described field-delineated wetlands and NWI polygons based on geographic location (region and county), area, and other geographic data (Tables 1 and 2). We determined whether wetlands and NWI polygons occurred within the 100-year floodplain using state or federal flood hazard data. We determined the distance to, and order of, the nearest stream based on data from the National Hydrography Dataset. We determined the area and percentage of each wetland or NWI polygon with poorly drained or somewhat poorly drained soil according to the Soil Survey Geographic (SSURGO) database. We also determined the area of each wetland or NWI polygon classified as water, developed land, grassland, agricultural land, and wetland according to the National Land Cover Dataset.

Tree-based models are used to explain the variation in a single categorical (classification trees) or numeric (regression trees) response variable using one or more categorical or numeric predictor variables (Breiman et al. 1984; De'ath and Fabricius 2000). A tree is constructed by repeatedly partitioning subjects in a data set into two exclusive groups. Tree-based algorithms begin by selecting the single variable

Table 2 Independent variables used as potential predictors of misclassification errors in the updated NWI

Independent Variable	Data Source	Variable Type	Levels for Categorical Variables
region		categorical	Chicago, St. Louis or Rock Island regions
County		categorical	Lake, McHenry, St. Clair, Madison or Rock Island
NWI class*	Ducks Unlimited NWI Update	categorical	aquatic bed (AB), emergent (EM), forested (FO), unconsolidated bottom (UB) or scrub-shrub (SS)
NWI water regime modifier*	Ducks Unlimited NWI Update	categorical	temporarily flooded (A), saturated (B), seasonally flooded (C), semipermanently flooded (F), intermittently exposed (G) or permanently flooded (H)
NWI special modifier <i>f</i> (farmed)*	Ducks Unlimited NWI Update	categorical	yes or no
NWI special modifier <i>d</i> (partially drained/ditched)*	Ducks Unlimited NWI Update	categorical	yes or no
area of wetland polygon	Ducks Unlimited NWI Update or INHS wetland layers	numeric	
presence in 100-year flood zone	flood zone and hazard layers	categorical	yes or no
distance to nearest stream	National Hydrologic Dataset	numeric	
order of nearest stream	National Hydrologic Dataset	ordinal	
area within polygon of poorly drained and somewhat poorly drained soil	SSURGO	numeric	
percent of polygon with poorly drained and somewhat poorly drained soil	SSURGO	numeric	
percent of polygon with water land cover	National Land Cover Dataset	numeric	
percent of polygon with developed land cover	National Land Cover Dataset	numeric	
percent of polygon with grassland land cover	National Land Cover Dataset	numeric	
percent of polygon with agricultural land cover	National Land Cover Dataset	numeric	
percent of polygon with wetland land cover	National Land Cover Dataset	numeric	

*Used in models for errors of commission only

from a set of candidate predictor variables that best partitions the full data set into two homogeneous subgroups with respect to the response variable. Each subgroup is then split again, and this recursive partitioning continues until further splitting yields no significant decrease in misclassification rates. The objective is to create a tree with a minimal number of splits, to avoid overfitting the data, and a small number of terminal nodes that are as homogeneous as possible with respect to the response variable.

We evaluated potential sources of errors of commission by classifying updated NWI wetlands as true wetlands or non-wetlands based on predictor variables (Table 2) derived from spatial data layers (Table 1). Similarly, we evaluated potential sources of errors of omission by classifying field-delineated wetlands as detected or undetected by the updated NWI based on predictor variables (Table 2). For these analyses, we considered field-delineated wetlands and NWI-mapped wetlands to be in agreement if they overlapped in area by at least 10 %. We used the package ‘rpart’ (Therneau and Atkinson 1997), developed for R software (R Development Core Team 2013), to construct classification trees, and pruned trees to an optimal size using a 10-fold cross-validation procedure (Breiman et al. 1984). Trees were pruned by selecting the complexity parameter which produced the smallest tree with a

cross-validated error within one standard error of the minimum cross-validated error.

Results

Commission Errors in Original and Updated NWI

Errors of commission, wetlands mapped by the original NWI that were identified as non-wetlands in the field, were frequent. Across the three study regions, 37 % of the 529 NWI polygons did not overlap wetlands within the field survey areas, and 57 % of the total area (381 ha) of NWI polygons was mapped as non-wetland in the field (Table 3). Commission errors were greater for the St. Louis metropolitan region than for the Chicago or Rock Island regions (Table 3).

Compared to the original NWI, the updated NWI included 114 additional polygons and 54 additional ha of wetland in our study areas. Almost all of this increase was concentrated in the Chicago region (Table 3). Errors of commission were frequent for the updated NWI. Across the three regions, 36 % of updated NWI polygons were non-wetlands—a commission error similar to the original NWI. Across the three regions, 55 % of the total area identified by the updated NWI was

Table 3 Errors of commission and omission for original NWI and updated NWI in three study regions in Illinois

Region	Inventory	Commission errors				Omission errors			
		Number of polygons mapped by NWI	Error rate for number of polygons	Area of polygons mapped by NWI (ha)	Error rate for area	Number of field-delineated wetlands	Error rate for number of wetlands	Area of field-delineated wetlands (ha)	Error rate for area
Chicago	Original NWI	346	32 %	234	51 %	856	69 %	287	55 %
	Updated NWI	465	31 %	291	50 %	856	55 %	287	42 %
Rock Island	Original NWI	21	5 %	8	17 %	44	45 %	23	64 %
	Updated NWI	23	9 %	8	17 %	44	41 %	23	63 %
St. Louis	Original NWI	162	54 %	139	69 %	201	47 %	87	43 %
	Updated NWI	155	53 %	136	68 %	201	45 %	87	45 %
All regions	Original NWI	529	37 %	381	57 %	1101	63 %	397	53 %
	Updated NWI	643	36 %	435	55 %	1101	52 %	397	44 %

actually non-wetland (Table 3). Similar to the original NWI, commission errors were greater in the St. Louis metropolitan region than in the Chicago or Rock Island regions (Table 3).

Omission Errors in Original and Updated NWI

Omissions, true wetlands missed by the original NWI, were also frequent. Across the three regions, 63 % of the wetlands, and 53 % of the total area of wetlands, delineated within the field survey areas was omitted by the NWI (Table 3). A greater number of wetlands were omitted in the Chicago region than in the other two regions (Table 3).

Omission rates were smaller for the updated NWI than the original NWI. Across the three regions, 52 % of the wetlands, and 44 % of the total area of wetlands, was omitted by the updated NWI (Table 3). Almost all of the improvement in the updated NWI was the result of decreased omission rates for

the Chicago region (Table 3). Nevertheless, 55 % of wetlands and 42 % of the total wetland area in the Chicago study region was omitted by the updated NWI (Table 3).

Omission rates were much greater for wetlands with less than 0.2 ha occurring within our study corridors (Table 4). Across all three regions the original NWI omitted 75 % of wetlands and 81 % of the total area for wetlands smaller than 0.2 ha, but omitted only 38 % of wetlands and 49 % of the total area for wetlands larger than 0.2 ha (Table 4). The updated NWI, which had a smaller target mapping unit than the original NWI, was better at capturing small wetlands than the original NWI. However, despite the fact that the stated target mapping unit was 0.04 ha, the updated NWI omitted 63 % of wetlands and 68 % of the wetland area for wetlands smaller than the FGDC threshold of 0.2 ha (Table 4). The updated NWI omitted 29 % of larger wetlands and 40 % of the total area for these larger wetlands.

Table 4 Errors of omission for original NWI and updated NWI in three study regions in Illinois, separated by wetlands larger or smaller than 0.2 ha, the Federal Geographic Data Committee's target mapping unit for wetlands

Region	Inventory	Omission errors for wetlands <0.2 ha				Omission errors for wetlands >0.2 ha			
		Number of wetlands delineated by INHS	Error rate for number of wetlands	Area of wetlands delineated by INHS (ha)	Error rate for area	Number of field-delineated wetlands	Error rate for number of wetlands	Area of field-delineated wetlands (ha)	Error rate for area
Chicago	Original NWI	620	79 %	39	85 %	236	42 %	248	51 %
	Updated NWI	620	64 %	39	68 %	236	29 %	248	38 %
Rock Island	Original NWI	15	73 %	1	73 %	29	31 %	22	64 %
	Updated NWI	15	67 %	1	72 %	29	28 %	22	62 %
St. Louis	Original NWI	127	58 %	9	68 %	74	28 %	78	40 %
	Updated NWI	127	54 %	9	67 %	74	30 %	78	42 %
All regions	Original NWI	762	75 %	49	81 %	339	38 %	348	49 %
	Updated NWI	762	63 %	49	68 %	339	29 %	348	40 %

Classification Tree Analyses

We constructed a classification tree with a binary response variable for errors of commission: ‘< or >10% of the updated NWI polygon is truly wetland’. The final pruned classification model first separated updated NWI polygons based on wetland class (Fig. 3). Forested (FO) wetlands in the updated NWI were less likely to have been delineated as actual wetlands in the field compared to aquatic bed (AB), emergent (EM), scrub-shrub (SS) or unconsolidated bottom (UB) wetlands. Only 44 % of NWI polygons with class FO were actually wetlands (compared to 64 % for SS, 72 % for EM, 84 % for UB, and 100 % for AB). Within the FO class, updated NWI polygons located near streams of order 4 or greater were more likely to be wetlands than areas mapped near smaller streams. Within the other wetland classes, NWI polygons that included greater than 0.15 ha of poorly drained soils were almost always wetlands. There was also evidence of a spatial component to misclassification rates. Although DU used consistent mapping methods statewide, updated NWI sites in the Chicago and Rock Island regions were more likely to have been identified as true wetlands (see also Table 3). Overall, the classification tree model was able to distinguish between correctly and incorrectly mapped updated NWI polygons in 481 (75 %) of 643 cases.

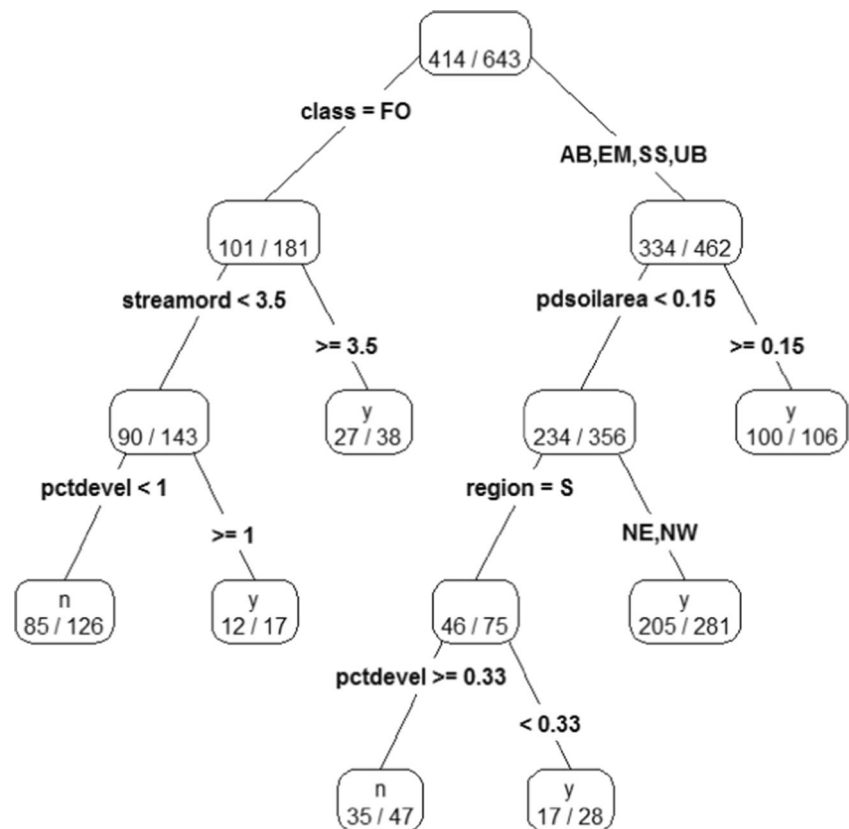
We constructed a separate classification tree to predict the binary response variable for errors of omission: ‘< or >10% of

the INHS field-mapped wetland had been identified as a wetland by the updated NWI’. The pruned classification model identified wetland area as the only important predictor (Fig. 4). Wetlands with total area less than 0.057 ha within the environmental survey corridors were more likely to have been omitted from the updated NWI. Of the field-delineated wetlands with areas within the corridors greater than 0.057 ha, 60 % had been identified by the updated NWI, whereas of the wetlands smaller than 0.057 ha, only 27 % had been identified by the updated NWI. The classification tree, with this single predictor variable, distinguished between true wetlands included and omitted by the updated NWI in 720 (65 %) of 1101 cases.

Discussion

This study is the most extensive evaluation to date of updated NWI maps for the Great Lakes/Atlantic Region. Across the three study areas, 55 % of the updated NWI wetland acreage was actually non-wetland, and the updated NWI omitted 44 % of the total wetland acreage identified during field surveys. Although the updated NWI omitted fewer wetlands than the original NWI, particularly in the Chicago region, errors of commission were not much improved for the updated NWI. There was a 24 % increase in total wetland area mapped, and a 63 % increase in the number of polygons mapped, within the

Fig. 3 Classification tree diagram for analysis of updated NWI polygons. The modeled dependent variable was a binary response ‘< or >10% of the updated NWI polygon is truly wetland’. Independent variables included in the final model were wetland class, area (ha) of poorly drained and somewhat poorly drained soil (pdsoilarea), order of the nearest stream (streamord), region (NE = Chicago, NW = Rock Island, S = St. Louis), and proportion developed land within the polygon (pctdevel). At each node the classification rate is displayed as the number of correct classifications and the number of observations in the node, and each terminal node is assigned to a response category (y = yes, wetland; n = no, non-wetland)



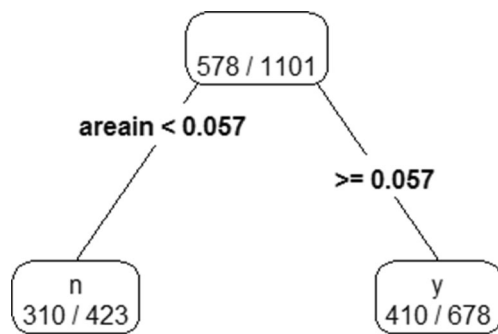


Fig. 4 Classification tree diagram for analysis of field-delineated wetlands. The modeled dependent variable was the binary response ‘< or >10% of the field-delineated wetland had been identified as a wetland by the updated NWI’. The single independent variable included in the final model was area (ha) of the wetland within the survey corridor (areain). At each node the classification rate is displayed as the number of correct classifications and the number of observations in the node, and each terminal node is assigned to a response category (y = yes, NWI; n = no, non-NWI)

Chicago region study areas in the updated NWI compared to the original NWI. Thus, the decrease in errors of omission and increase in errors of commission is likely the result of this more liberal mapping of wetlands in the updated NWI.

Observed commission error rates for both the original and updated NWI were greater than previous field assessments of NWI maps, which have reported <10 % error rates (Nichols 1994; Stolt and Baker 1995; Kudray and Gale 2000; Wu et al. 2014). Omission error rates, however, have varied widely among studies from 3 % (Kudray and Gale 2000) to 97 % (Stolt and Baker 1995), depending on the region, the assessment methodology, and the preponderance of small wetlands. One reason for the relatively high error rates in our study may be that verification was limited to areas within bounded environmental survey corridors. If the updated NWI polygons overlapped actual wetlands outside of these project corridors, we would not have detected the overlap. For example, portions of the same wetlands missed by the NWI within survey corridors may have been captured by the NWI outside of the corridors. This lack of overlap could be exacerbated by positional inaccuracies in the NWI data. Nevertheless, the lack of overlap within the survey corridors suggests that even the updated NWI data suffer from positional errors and/or underestimation of wetland size.

The NWI was not intended for use in identifying wetlands that are jurisdictional under Section 404 of the U.S. Clean Water Act (Tiner 1997), and differences in definition of wetlands between the NWI and field delineations using ACOE methodology are a potential source of discrepancy between NWI maps and field-delineated wetlands (Wu et al. 2014). In order for an area to be considered a wetland under the ACOE definition, positive evidence is necessary for each of the three wetland parameters (hydrophytic vegetation, hydric soils, and wetland hydrology). In contrast, in order for an area to be considered a wetland under the FWS definition,

positive evidence is not required for all three parameters (Environmental Laboratory 1987). Nevertheless, the observed high error rates indicate that the updated NWI, although it is currently the best available wetland inventory for much of the Great Lakes Region, should not be used for local-scale applications where complete wetland inventories and accurate boundary determinations are required. Users should recognize that NWI data are intended for initial wetland inventories and delineation and that on-the-ground mapping may be necessary to refine boundaries or identify small wetlands (Tiner 1999).

Upland forests were often misclassified as wetlands. Wetland and upland forests are difficult to differentiate using photointerpretation and remote sensing (Johnston and Meysembourg 2002; Augusteijn and Warrender 2010; Dvoretz et al. 2012). In the present study, errors of commission were common among updated NWI polygons coded as forested (class = FO). Both the original and the updated NWI for Illinois tended to include all riparian forests as wetlands regardless of the likelihood that the soils of these forests are actually saturated or flooded for a significant duration. Many Illinois streams have been channelized and down-cut, lowering riparian water tables and dewatering forests that may have been wetlands previously. Of the 101 forested wetland polygons mapped by the NWI in our study area that were non-wetlands, 55 occurred on areas mapped as poorly drained soils by the USDA, suggesting that they may have been wetlands historically. Although these forests may provide some wetland functions and ecosystem services, they typically lack reducing soil conditions and wetland hydrology, characteristics that are impossible to determine without on-site field surveys. These riparian forests are not considered to be wetlands under the definition of the ACOE (Environmental Laboratory 1987; ACOE 2010).

Errors of omission are more problematic than errors of commission. Omission of wetlands from inventories can lead to major underestimates of wetland area at watershed and landscape scales. Across the three regions, the updated NWI omitted approximately half of the wetlands identified during field surveys. Omission rates were much greater for wetlands with less than 0.2 ha occurring within our study corridors, and were particularly high for small wetlands in Lake and McHenry Counties, a region with many depressional wetlands, both large and small. Although omission of wetlands smaller than the target mapping unit should not be considered to be “errors”, the omission of a large number of small wetlands can lead to underestimates of total wetland area in a region. Small wetlands have been found to be problematic for wetland inventories elsewhere as well (Stolt and Baker 1995; Kudray and Gale 2000; Tang et al. 2015).

Small wetlands are disproportionately lost from landscapes because they have received less protection under the U.S. Clean Water Act and due to agricultural and development practices that disproportionately impact small wetlands (Van

Meter and Basu 2015; Christensen et al. 2016). It is often assumed that small wetlands are inherently less important than larger wetlands. However, the loss of small wetlands leads to the loss of species populations and could disrupt dispersal and metapopulation dynamics (Gibbs 1993; Semlitsch and Bodie 1998). Small wetlands are also important for waterfowl that use multiple wetlands in a landscape (Naugle et al. 2001), and small wetlands with short hydroperiods provide predator-free habitat essential for amphibian eggs and larvae (Semlitsch and Bodie 1998; Snodgrass et al. 2000). Therefore, accurate inventory of small wetlands is particularly important for species management.

Wetland alteration, including both the loss and restoration of wetlands, is potentially a source of discrepancy between field-delineated wetlands and NWI polygons. Wetland alteration may have inflated our estimates of error, particularly for the original NWI, which was prepared using imagery two decades older than the updated NWI. An additional source of discrepancy could be error in field-delineations. However, all NWI polygons within survey corridors were visited during ground-truthing, and delineations were conducted by experienced botanists and soil scientists. Field delineation methods also changed during the course of data collection when ACOE issued regional supplements to the 1987 wetland delineation manual (ACOE 2010). Although in rare situations this could have led to some discrepancies between field delineations prior to and after the regional supplements, the basic delineation methodology and the definitions of wetlands did not change.

Based on our evaluation of the updated NWI for Illinois, we recommend the following. First, users of the updated NWI should be aware that many of the mapped “wetlands” are not regulated, jurisdictional wetlands under the U.S. Clean Water Act. Second, users should be aware that the updated NWI omitted many wetlands, particularly small wetlands. Due to frequent errors of omission, field surveys are necessary for any detailed land use planning applications involving wetlands. The updated NWI is the best data available for many large-scale wetland inventory and planning applications, but users should be aware of inaccuracies. The updated NWI should not be used for local-scale applications unless it is combined with on-site field investigations. Future refinement of NWI products should focus on reducing errors of omission by incorporating additional remote sensing technology, such as LiDAR-derived digital elevation models, to improve the detectability of small wetlands (e.g., Wright and Gallant 2007; Maxa and Bolstad 2009; Lang et al. 2013; Kloiber et al. 2015; Tang et al. 2015; Wu and Lane 2016). Errors of commission might be reduced by incorporating additional field verification, particularly for forested wetlands, riparian wetlands along small streams, and in areas where soils maps indicate the absence of poorly drained or somewhat poorly drained soils.

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