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GENERAL WETLAND SCIENCE

Comparison of USACE Three-Factor Wetland Delineations to National Wetland Inventory Maps

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Abstract
Wetlands are mapped across the USA for compliance with §404 of the Clean Water Act using field-collected data and protocols in the 1987 Federal Wetlands Delineation Manual (3-factor method). The National Wetlands Inventory (NWI) maps wetlands and deepwater habitats for management and policy-making using aerial image analysis with limited field verification. There have been few comparisons of maps other than for limited geographic areas or wetland types. We compared 3-factor wetland delineations to NWI maps for 1751 assessment areas (AA) in different regions. We did not assess the accuracy of either product, but instead compared mapped area and polygon count for existing data at sites, then aggregated results to broader scales and compared with ancillary data to identify factors correlated with map differences. In a subset of NWI polygons eliminating non-wetland Cowardin types, 74% of NWI polygons were mapped in common with 3-factor polygons. NWI identified greater area in 33% of AA and greater total area across all sites. Approximately 27% of AA had 3-factor but no NWI polygons, while 6.7% of AA had features mapped only by NWI. Multiple factors likely contributed to differences including polygon size and temporal mismatches between maps, suggesting caution be used when comparing products.

Keywords Wetland regulation · Wetland mapping · Wetland delineation

Introduction

Section 404 of the Clean Water Act (CWA), administered by the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (EPA), provides the framework for regulating wetlands in the U.S. at the federal level. Regulations and guidance documents define wetlands and provide procedures for their identification and delineation (Environmental Laboratory 1987). The U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI) has created maps of wetlands and deepwater habitats for the entire U.S. that are widely used by managers, policy makers, and the public (Wilen and Bates 1995; Tiner 1997a; Dahl 2011; Dahl and Stedman 2013). While sharing a common focus on wetlands, these programs use different definitions and protocols and have distinct program histories and goals.

The USACE Wetland Delineation Manual (Environmental Laboratory 1987) and subsequent regional supplements (USACE 2007, 2008, 2010) use diagnostic field indicators of hydrophytic vegetation, hydric soils, and hydrology to establish the presence of a wetland and identify its boundaries. This method, referred to here as the 3-factor approach, requires that under normal circumstances, indicators of soils, vegetation, and hydrology be present for positive determination of a wetland (Environmental Laboratory 1987; Tiner 2016). Indicators are assessed in the field and any area meeting these criteria, regardless of size, is a considered a wetland.

The NWI program produces maps of wetlands and deepwater habitats across the U.S. through photo-interpretation of aerial imagery. Maps depict the location, size, and type of wetlands using the Cowardin et al. (1979) classification system, as updated by the NWI program (Wilen and Bates 1995; Tiner 1997a; Federal Geographic Data Committee 2013).

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NWI maps are an important tool for wetland management but are not intended to define wetland boundaries for Clean Water Act regulatory purposes (Wilen and Bates 1995), as clearly indicated by a disclaimer on all NWI maps. However, NWI maps and related Status and Trends Reports (Dahl 2000; Dahl 2006; Dahl and Stedman 2013), also based on aerial image analysis, have been used to make inferences to management goals and some local and state governments (e.g., Vermont) have implemented wetland regulations based in part on NWI data (Morrissey and Sweeney 2006) or have used it in zoning regulations (Kusler 2006).

The NWI program has been innovative in making their data accessible to the public. Their 'Wetlands Mapper' provides an intuitive, web-based interface for accessing data, while raw geospatial data are available for analysis by users of GIS software. However, although distributed as a single, seamless dataset, NWI is a heterogeneous mosaic of maps produced from imagery collected at different times, varying spatial scales, and several emulsion types (FGDC Wetlands Subcommittee 2009; Tiner 2016). The age of NWI maps varies widely, and in many areas, data underlying maps are decades old. This may affect map accuracy for contemporary landscapes, since wetlands may have been lost or created since a particular NWI map was produced (Matthews et al. 2016).

General procedures for mapping wetlands using the 3-factor approach are identical across the U.S. (Environmental Laboratory 1987), but wetland types and the specific soil, vegetation, and hydrology indicators useful for their identification and boundary delineation vary, prompting the development of region-specific indicators (USACE 2008, 2010). Wetland delineations using the 3-factor approach are typically completed by private companies, with oversight from USACE regulators and other federal and state agencies. Because of variation in project setting, scope, and complexity, and the large number of individuals involved in preparing delineations nationally, there is considerable heterogeneity in the characteristics of 3-factor wetlands maps, which may also contribute to differences in mapping outcomes with the NWI.

Past Comparisons of NWI and 3-Factor Maps

Despite the long history of both the USACE and NWI programs, there have been few quantitative comparisons of maps produced by the two approaches, and most have been for small geographic areas or specific wetland types (Nichols 1994; McMullen and Meacham 1996; Kudray and Gale 2000). Several authors have used NWI maps to test new mapping techniques using remote sensing or to compare wetland maps produced using methods other than the 3-factor approach (Johnston and Meysembourg 2002; Wardlow and Egbert 2003; Brooks et al. 2004; Wardrop et al. 2007b; Wright and Gallant 2007; Martin et al. 2012; Rampi et al. 2014; Kloiber et al. 2015; Xie et al. 2015).

Where 3-factor delineations and NWI maps have been compared, outcomes have varied widely (Morrissey and Sweeney 2006; Wu et al. 2014; Matthews et al. 2016; Sharpe et al. 2016). In three northeastern US National Parks, Sharpe et al. (2016) found good agreement between NWI and 3-factor wetland polygons, and in the heavily forested Upper Peninsula of Michigan, NWI maps were "91% accurate" in identifying 3-factor wetlands, although how different types of errors influenced accuracy wasn't reported (Kudray and Gale 2000). In New York, 90% of sample locations within NWI wetland boundaries were 3-factor wetlands (Wu et al. 2014), but other research from the same region found NWI maps did not capture ~40% of the wetland area mapped using the 3-factor approach (McMullen and Meacham 1996). A Virginia study found that 91% of palustrine wetlands identified by NWI had all 3-factors present, but the total wetland area mapped by NWI was only 9.9% of that mapped using the 3-factor approach (Stolt and Baker 1995). In the Northeast US, 79% of forested vernal pools were mapped by NWI (Calhoun et al. 2003), but another study in the region found that half of small forested wetlands were missed (Baldwin et al. 2009). A comparison of original and updated NWI maps to 3-factor delineations found that the original NWI missed 49% of wetland area for polygons greater than 0.2 ha with differences concentrated in forested areas (Matthews et al. 2016).

Study Objectives

In this study we provide a quantitative comparison of maps produced by the NWI and 3-factor wetland delineations from a range of sites across the USA and describe factors potentially contributing to observed differences. We sought to compare the correspondence between the number, area, and boundary characteristics of areas mapped by NWI and 3-factor approaches to address the following questions:

- How does the total number and area of wetlands and deepwater polygons mapped by NWI compare with delineations performed using the 3-factor approach?
- How does the age of available NWI data relate to differences in mapping outcomes with 3-factor delineations?
- Does regional context correlate with differences in mapping outcomes between NWI and 3-factor approaches?

Clarifying the nature of differences between maps produced using these two programs can help minimize confusion for wetland managers and the public and ensure appropriate use of information in management and policy making.

Methods

Overview

There were three main steps in the analysis: 1) data acquisition and preprocessing; 2) GIS-based site-level geographic comparisons between 3-factor and NWI wetland polygons; and 3) statistical aggregation and analysis to identify patterns and important correlates of differences in mapping outcomes (Fig. 1). The goal was to evaluate the correspondence between the occurrence, area, and boundaries of wetlands mapped using the two approaches. In this study, we explicitly did not evaluate the accuracy of either product, since field validation was not possible due to lack of site access, land use changes, and the logistics of the large number of sites analyzed. Rather, we compared the similarity of wetland maps produced by the two approaches using several quantitative metrics.

Data Sources and Processing Procedures

The 3-factor wetland data used in this study came from several sources. The USACE administers the regulatory §404 program, but most delineations are done by consulting companies on behalf of private landowners. Obtaining 3-factor delineations was difficult because USACE districts do not generally archive geospatial layers such as shapefiles or CAD drawings and most private wetland delineators were unwilling to share data due to client confidentiality. Where available, we obtained data from USACE districts, USACE scientists, states, non-governmental organizations, and other agencies such as the National Park Service. Publicly-available delineation data from baseline assessments of mitigation banks included in RIBITS (Regulatory In-lieu Fee Bank Information Tracking System) were used (Martin and Brumbaugh 2011) as well as limited data provided by private consulting firms. All delineations, including those done at the larger military installations, were field-based assessments. As is standard practice when conducting 3-factor delineations, aerial imagery was used to aid in landscape interpretation, but all boundary lines were determined in the field using indicators in the 1987 Wetland Delineation Manual and relevant supplements (Environmental Laboratory 1987; USACE 2010) and boundaries captured using USACE guidelines.

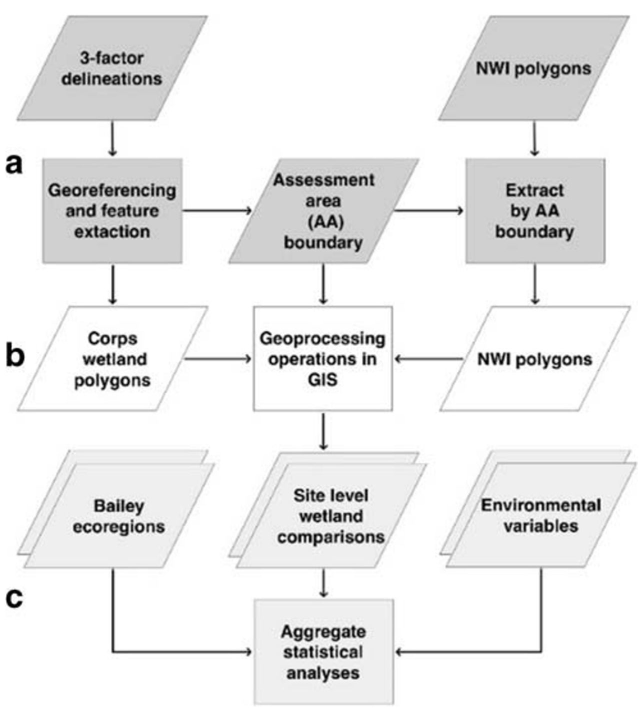


Fig. 1 Flowchart illustrating main steps in analysis: data preparation (**a**), site level analysis (**b**), and aggregate modeling and analysis (**c**)

A primary source of 3-factor data was scanned hardcopy maps in permit applications. These were transformed into GIS-analyzable data through a process of scanning, georeferencing and rectifying hard copy maps, then digitizing features for GIS analysis (Figs. 1 and 2). Using ArcGIS (ESRI, Inc., version 10.4), we digitized assessment area (AA) boundaries, defined as individual, contiguous polygons where wetlands, if present, were mapped. This was commonly a parcel boundary, but for some sites (e.g., a pipeline corridor), AA were polygons using a fixed offset from a centerline. Delineated 3-factor wetlands were then digitized and the AA boundary, acting as a common reference frame, was used to extract NWI polygons. The area encompassed by the AA boundary was used in calculations of response metrics such as the proportional area mapped by each map product.

AA boundaries were used to extract NWI data obtained as separate state-level downloads from the USFWS NWI website. Data represented the current distribution of the NWI product in October 2016, but included data created over 40+ years. The scale of imagery for mapping has varied over time, influencing the target mapping unit (TMU) size represented by each NWI map (Dahl et al. 2015). High altitude imagery collected at scales of either 1:80,000 or 1:58,000 was used to develop maps in the 1970's and 1980's, while more recent maps have used higher resolution imagery, allowing for a smaller TMU. NWI polygons are classified using the Cowardin et al. (1979) at the time of mapping, but not all Cowardin classes are considered wetlands using the USACE methodology. For example, some sites classified as Lacustrine, Marine deepwater, and Riverine do not meet the USACE criteria (Matthews et al. 2016). Therefore, our analyses were done using two versions of the NWI: the first (full NWI) included all NWI polygons for a given AA, while the second (reduced NWI), excluded polygons in the Lacustrine, Riverine, and Marine deepwater systems as well as polygons with the following NWI Cowardin modifiers: RB – Rock Bottom, UB – Unconsolidated Bottom, AB – Aquatic Bed, RF – Reef, SB – Streambed, and US – Unconsolidated Shore (beaches, bars, and flats). These often do not meet one or more

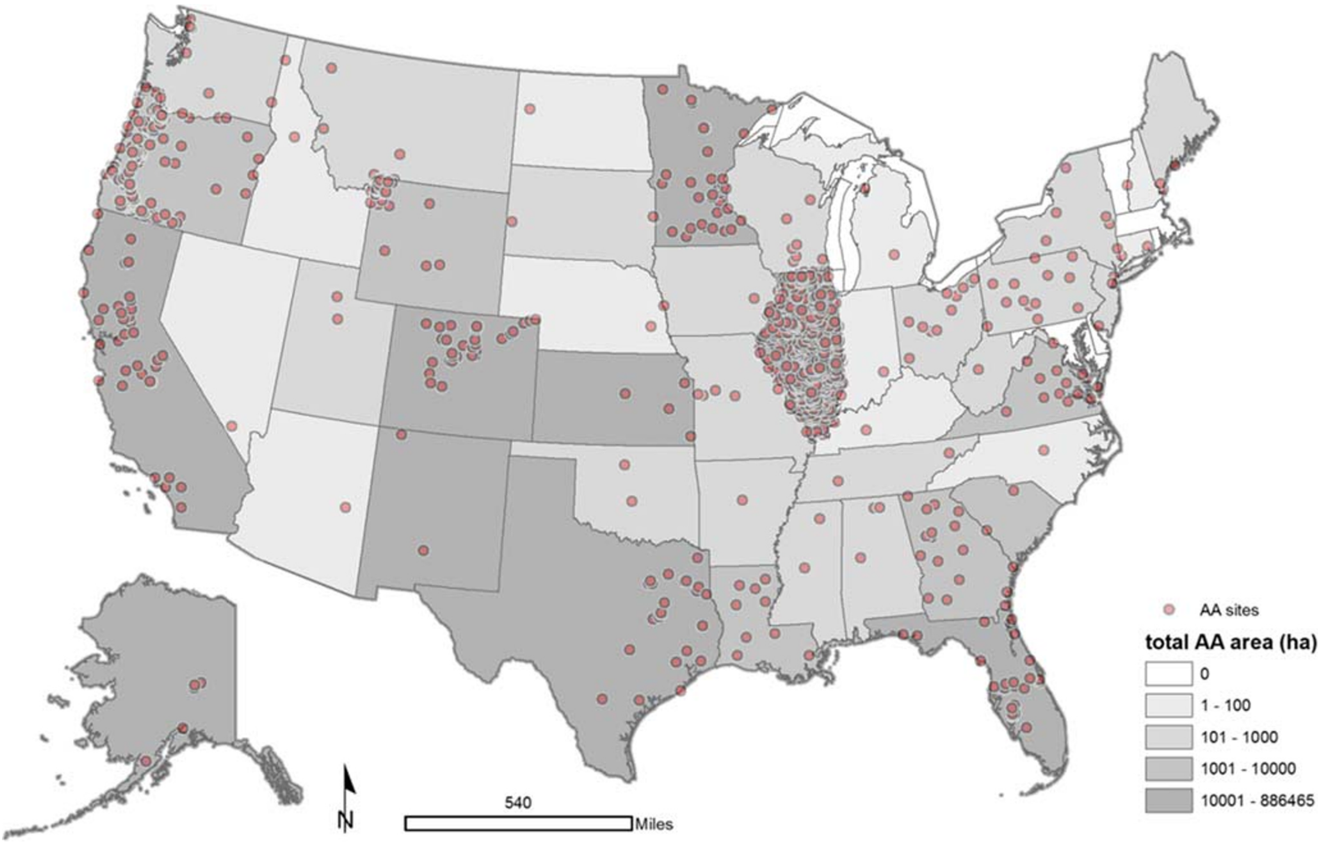


Fig. 2 Assessment areas (AA, red points) where 3-factor and NWI polygons were compared. Shading indicates total AA area summed for each state

of the 3-factor criteria. See electronic supplement for list of NWI attribute codes and wetland types. The location of each AA was used to extract contextual information from ancillary GIS data layers such as temperature (Daly et al. 2008; PRISM Climate Group 2014), administrative areas (e.g., USACE Divisions), ecoregions, and ecological land units (Bailey 1980; Omernik 1987; Metzger et al. 2013).

GIS and Statistical Analyses

For each AA, the count and total area of wetland polygons for each dataset was summed and the percentage of each AA mapped calculated by summing wetland area and dividing it by total AA area. Area data were used to calculate the normalized index of area difference (NDAI, eq. 1), a metric meant to allow comparisons between AA of different sizes. NDAI values range from −1, for areas with only NWI polygons mapped, to 1, for sites with only 3-factor polygons mapped, and is undefined when no features are mapped by either product.

$$NDAI = \frac{\left(A_{3f} - A_{NWI}\right)}{\left(A_{3f} + A_{NWI}\right)} \quad (1)$$

Aggregate analyses comparing mapping outcomes between larger units like USACE Divisions and ecoregions were done using R, version 3.53 (R Core Team 2017).

Results

We evaluated 1751 separate assessment area (AA) polygons covering more than 1,529,950 ha (Fig. 2). Individual AA varied from less than 0.5 ha to over 809,371 ha on the White Sands Missile Base in New Mexico. The largest AA were military installations in the southwestern states and Alaska, Pacific Northwest, Midwest, and Southeastern US. Total AA area was greatest in the South Pacific USACE Division, followed by the Pacific Ocean and South Atlantic Divisions. The Pacific Ocean Division included several large DoD installations in Alaska and had the largest median AA polygon size, followed by the South Atlantic USACE Division. Within any Division, there was wide variation in AA area. Total AA area was greatest in New Mexico and Alaska, due to the large DoD installations. In contrast, more numerous but smaller AA were analyzed in Florida and Illinois. Our sample AA occurred in over 30 different Bailey eco-regional provinces. The Chihuahuan semi-desert province had the greatest total AA area, followed by the Yukon inter-montane plateaus taiga province in Alaska. The age distribution of NWI maps across all AA was similar to that of the NWI product nationally. In our dataset, 1979 was the image year with the greatest NWI mapped area, while 1981 had the highest polygon count (Fig. 3). In contrast, the peak year for 3-factor delineations was 2015. For all COE divisions except the North Atlantic, peak area and AA count were greatest in the early 1980s.

Area Mapped by NWI and 3-Factor Datasets

Approximately 304,900 ha was mapped across all AA using the full NWI data set (inclusive of all Cowardin types including non-wetland deepwater features), covering 19.9% of the area. Approximately 71% of these NWI polygons intersected 3-factor wetland polygons. Approximately 89,435 ha, 29% of the full NWI dataset, were areas mapped only by NWI. Some of these are likely not wetlands per 3-factor definition. The reduced NWI data set, created by excluding polygons classified in the Cowardin classification as riverine,

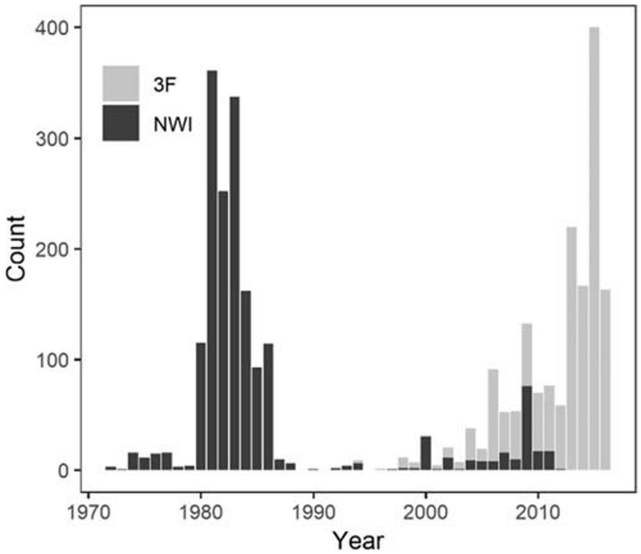


Fig. 3 Count of study AA by image year used to map wetlands (NWI approach) or delineation year (for the COE 3-factor approach, 3F). Note that the NWI image year is not generally the same as the year the map was produced or published

lacustrine, freshwater pond, or marine deepwater (electronic appendix, Table 1) included 285,256 ha, a reduction of ~7% from the full NWI data set. Of this total, 74% was mapped in common with the 3-factor data set, and 26% mapped exclusively by NWI. Areas mapped exclusively as 3-factor wetlands comprised 12% of total 3-factor wetland area under the reduced NWI data set. Polygon size was highly variable, in part because 'sliver' polygons created when NWI and 3-factor polygons partly overlap with AA.

In 14% of AA, no wetlands were mapped, while ~27% of AA mapped some 3-factor wetlands but no NWI wetland area. These were primarily in arid climate regions with small wetlands occurring in low densities. In contrast, only 7% of AA had wetlands mapped only by NWI. For those AA with wetlands mapped by both NWI and 3-factor approaches, there was general congruence in the locations of wetlands, but often differences in polygon shape or mapped area. The relationship between the proportional area mapped by NWI and 3-factor datasets varied depending on the abundance of wetlands in an AA. Where a large proportion of an AA was mapped as wetland, on average the NWI approach mapped a greater area than the 3-factor approach. However, where the average proportional mapped wetland area was less than ~12%, the reverse was true (Fig. 4).

Normalized difference area index (NDAI) values showed a similar trend across AA of different sizes. Where the proportion of AA mapped as wetland by NWI was low, the values were positive, indicating greater 3-factor wetland area. As the percent of area mapped as wetland by NWI increased, average NDAI dropped below zero, indicating greater NWI wetland area relative to 3-factor area. This pattern was relatively consistent whether the AA were small or large, or whether the full or reduced NWI data were considered (Fig. 5).

The fraction of AA mapped by the two protocols varied among Bailey ecoregions. The Yukon Inter-Montane Plateaus Bailey Province had the greatest fraction of mapped wetlands in common between 3-factor and NWI approaches, while the Great Plains Steppe and Chihuahuan Semi-Desert Provinces had the lowest common mapped area. NDAI values, which normalize area differences into the same scale for small to large AA, were variable within and among USACE Divisions. The Northwest USACE Division had the highest median NDAI, followed by the South Pacific Division (Fig. 6). Across all AA, the Mississippi Valley Division had the widest variation in NDAI. Comparisons of mapping outcomes in relation to imagery age used to produce NWI maps revealed no consistent effect of image date nor a strong relation to annual climate means. The 3-factor approach mapped slightly greater % AA in areas with lower mean annual temperatures, but no consistent trend was observed for the effect of PRISM-modelled precipitation.

Discussion

While there was general congruence in wetland area mapped, there were important differences in outcomes for the NWI and 3-factor approaches that limit their comparability. The difference in total area mapped by 3-factor and NWI datasets was greatest when comparing NWI maps that included all Cowardin types, unsurprising since these are known to include some classes not meeting the 3-factor criteria (e.g., deepwater habitats). In excluding riverine, marine deepwater, pond, and lacustrine types (the reduced NWI dataset), we still mapped greater total NWI area than 3-factor polygons in almost a third of AA. However, fewer sites mapped some NWI and no 3-factor polygons than the reverse scenario, highlighting how differences in definitions, goals, and issues like TMU can influence mapping results.

Past comparisons of wetland area mapped by NWI and 3-factor approaches have shown variable results. Analyses of specific wetland types like forested vernal pools have emphasized the difficulty of capturing small forested wetlands on aerial imagery, leading to their omission on maps (Baldwin and deMaynadier 2009). Many AA we analyzed were part of linear transportation corridors with small features mapped by the 3-factor approach but not identified by the NWI. These differences are to be expected given TMU size limits published by NWI. Transportation corridors are typical of areas affected by COE wetland regulation but are not representative of all the wetland types mapped by NWI.

The magnitude of differences between maps produced using each approach depends on the metric being evaluated. Focusing on area differences and ignoring the relative abundance of wetland polygons on the landscape makes differences appear larger than if differences are framed as the proportion of landscape mapped as wetland. Overall differences may be relatively small where wetlands are a small portion of the landscape, such as in the southwestern U.S. For example, doubling the area mapped as wetland in an AA where wetlands are 1–2% of the landscape will not produce a large change in the percent of AA that is wetland.

Factors beyond definitional differences may contribute to discrepancies between maps. Identification of wetlands for NWI maps relies on tonal variations in photographic images that may not align with field indictors used in the 3-factor approach. While evidence of all three indicators (vegetation, soils, and hydrology) is required for wetland determination using the 3-factor approach under normal circumstances, indicators of one or two classes can be used for mapping a wetland under the NWI protocol (Federal Geographic Data Committee 2013; Tiner 2016). Differences in factors such as the prevailing climate at the time of image acquisition or site visitation can also lead to different outcomes (Dahl et al. 2015). Features smaller than the TMU may not be included in NWI maps, while the 3-factor approach has no minimum mapping unit size.

Our results are consistent with past studies that found varying differences between wetland maps. In the mid-Atlantic region, a nearly twofold increase in wetland area was observed when updated maps were compared to older NWI maps created in the 1980s from high altitude B&W and CIR imagery (Wardrop et al. 2007a, b), with differences attributed to small wetlands missed due to forest canopy cover. Morrissey and Sweeney (2006) found that NWI missed nearly 80% of wetland polygons in their study area by not mapping wetlands smaller than the TMU. Aerial signatures may not always track hydrologic patterns that are best assessed in the field or with other remote sensing data. Research from Maryland (Lang and McCarty 2009) found that 82% of areas mapped as wetland by NWI were not identified as being inundated using LiDAR data, although many past studies found differences due to omission rather than commission were more common for NWI maps in forested areas (Tiner 1990; Stolt et al. 1995; Kudray and Gale 2000).

Each region of the U.S. has wetland types that are problematic to identify and map. For instance, forested pinewood flats wetlands in the southeast coastal plain are difficult to identify and delineate using air photos (Ozesmi and Bauer 2002), while ponds and lacustrine wetlands are comparatively easy to identify and map (Tiner 1997b). The variable size of AA could affect metrics, since relatively small differences in interpretation by different mappers and registration may average out over large areas but be more significant for small AA. Basic geometric properties of AA were also highly variable, ranging from compact and regular parcel boundaries to irregularly shaped areas along roads. Differences in AA size and shape may be drivers of differences in map outcomes distinct from those due to definitional or methodological reasons.

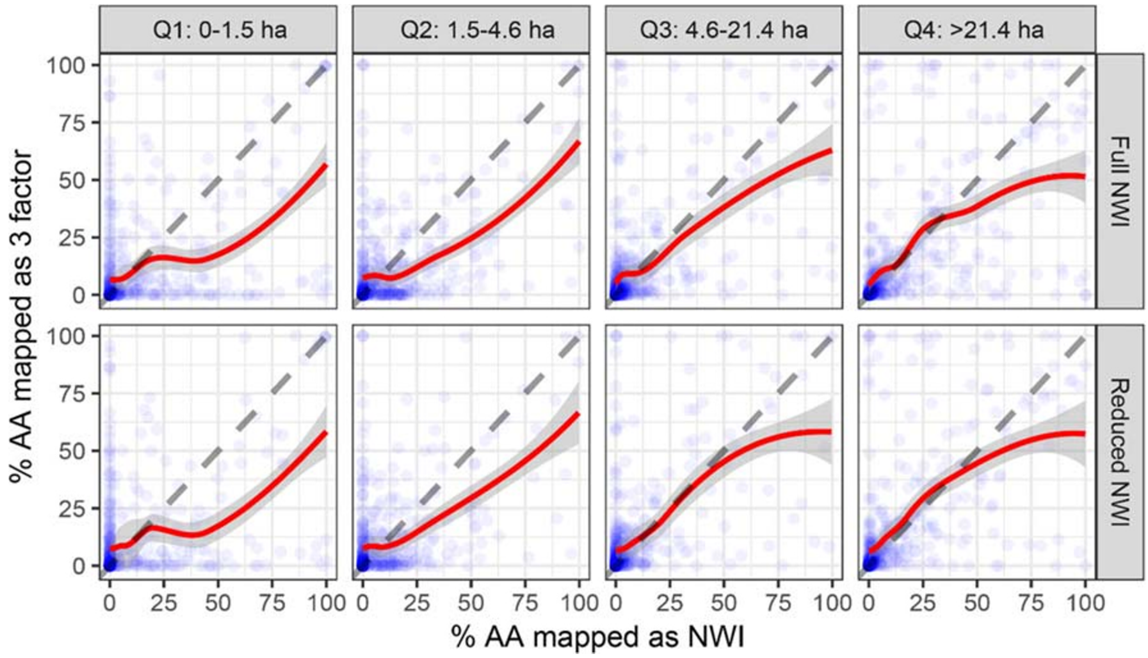
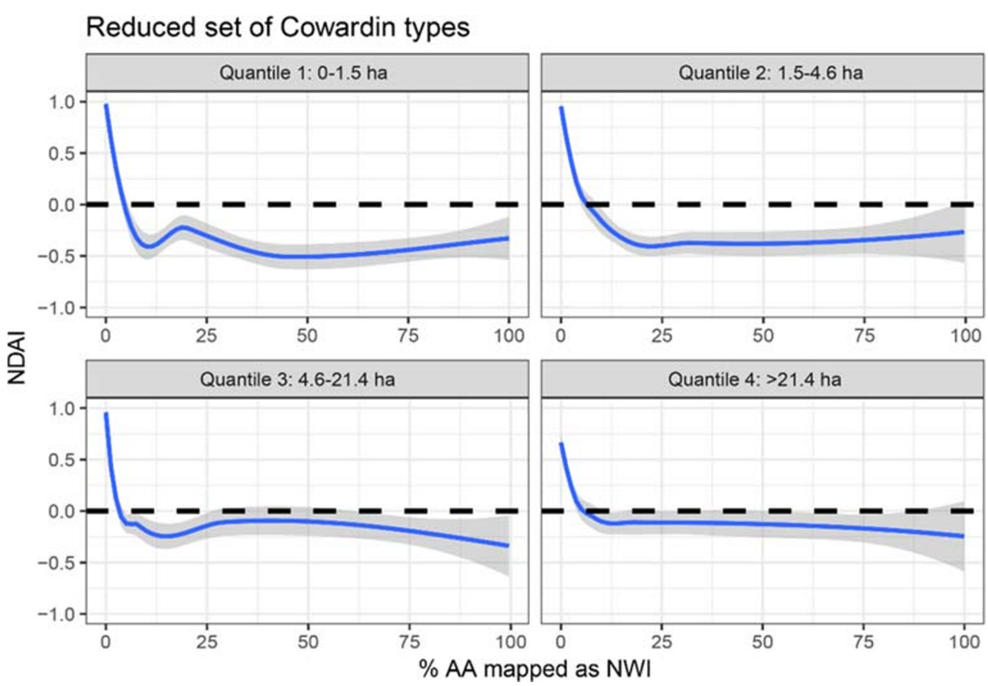


Fig. 4 Percent of AA mapped as wetland by NWI (top row: inclusive of all Cowardin types, bottom row: reduced Cowardin types) vs. 3-factor datasets. Blue dots represent individual AA polygons, the dashed 1–1 line, and the best-fit LOESS (i.e., local polynomial regression) trend line (red) fit through the data and 95% confidence interval. Columns plot data for AA are separated by quantiles of AA size

While the age of imagery used to produce NWI data was not correlated with differences in mapping outcomes in our analysis, we attribute this primarily to the nature of our sample. Newer NWI wetland maps likely provide a better representation of contemporary wetland distribution because polygons based on older imagery have a greater likelihood to have been modified by changes in land use or hydrologic regime. Improvements in image resolution and GIS technology can significantly improve mapping accuracy (Wardrop et al. 2007b; Lang and McCarty 2009; Kloiber et al. 2015; Matthews et al. 2016), especially for small wetlands. Approaches for mapping wetlands have improved since the origins of the NWI program in the 1970s. Higher quality imagery, the use of LiDAR, and advances in data processing techniques such as object-oriented analysis and machine learning algorithms have improved both the accuracy and efficiency of mapping (Maxa and Bolstad 2009; Kloiber et al. 2015; O'Neil et al. 2019). However, due to fundamental difference in the two approaches, mapping outcomes will likely always differ.

A variety of factors can influence the accuracy and precision of 3-factor delineations. Correctly identifying wetland plants is difficult outside of the growing season. Hydrology indicators can be unreliable in dry seasons for wetland types with intermittent or ephemeral hydrologic regimes like vernal pools, playas, or wet meadows (Brostoff et al. 2001; Lichvar et al. 2004;

Fig. 5 Best-fit LOESS (i.e., local polynomial regression) trend line and 95% confidence interval fit to NDAI values for the reduced set of NWI polygons. Separate panels plot data separated by quantiles of AA size. When total wetland area was small, NDAI values were positive, indicating greater 3-factor area, but the reverse was true at higher wetland percentages, regardless of AA size (different panels in figure)



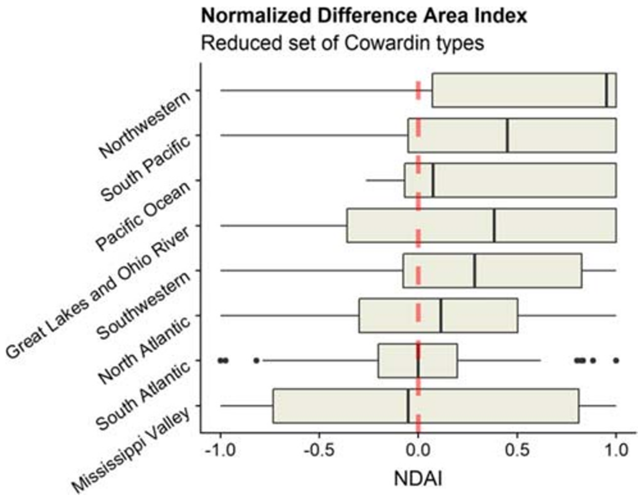


Fig. 6 Box plots depicting Normalized Difference Area Index (NDAI) aggregated by USACE Division. Values were calculated using the reduced subset of NWI polygons. NDAI values range from 1 (area dominated by 3-factor wetlands) to −1 (area dominated by NWI polygons); NDAI of zero indicates parity in mapped area. Boxplots are constructed from individual AA NDAI values across each region

Lichvar et al. 2008; Korfel et al. 2010). Precisely delineating boundaries can be difficult in many ecological contexts, especially if the wetland practitioner is inexperienced. These factors need to be recognized as potentially affecting comparisons. Another caveat to our analysis is that small spatial shifts can more easily result in non-congruence between tested dataset pairs when polygons are small.

NWI maps are available for most of the U.S., but 3-factor delineations are typically only done for USACE permitting. Thus, they represent a small fraction of all the habitats mapped by NWI. Inferences should be restricted to the domain represented by our sample. Even if we had access to all 3-factor delineations done across the U.S., it would still poorly represent wetlands where few USACE permit actions are taken. Wetland delineations for regulatory compliance are not systematically archived. This limited the data available for our analyses. Wetland delineations are a potentially valuable source of field-based wetland mapping, and if these data could be made available, they could be useful for a wide variety of analyses.

NWI maps are not produced for regulatory use, as is clearly stated on the maps and accompanying digital data downloads. But as the only national-scale wetlands dataset, there is the potential for people to use NWI data to evaluate the effects of regulatory programs. However, results from this study suggest that the NWI geospatial dataset, as made available through the online NWI Wetlands Mapper, should not be used for quantifying wetland change attributable to the USACE regulatory program on wetlands, and as a static dataset, it should not be used to monitor change. Despite issues like spatial or temporal misalignment of the 3-factor and NWI datasets, we found general congruence between wetlands mapped by 3-factor and NWI approaches, suggesting that NWI data can be used as a landscape scale indicator of where Corps regulatory wetlands are likely to occur. However, the differences we observed highlight the necessity of field verification for boundary identification using the 3-factor approach for regulatory purposes.

NWI mapping is primarily based on image analysis with limited field verification. Field verification could be provided for more areas if 3-factor wetland delineation data were more widely available. However, multiple barriers limit the utility of 3-factor wetland data. The infrastructure for managing and distributing delineation data, especially the spatial component, is poorly developed. Importantly, most 3-factor delineations are done for regulatory purposes and so are not an unbiased sample of wetlands in any region.

The NWI program continues to update maps, but in many regions the maps are decades old. Improved data and analysis techniques offer the promise of more accurate and efficient mapping in the future, which could support other types of analyses (Wright and Gallant 2007; Lang and McCarty 2009; Lang et al. 2013; DeLancey et al. 2019). For example, assessments of ecological condition such as the Floristic Quality Assessment Index (FQAI) can utilize NWI to calibrate landscape assessments, identify areas for restoration, or inform management (Fennessy et al. 2007; Wardrop et al. 2007b). Because they are field-based, 3-factor delineation data could provide useful information that is hard to obtain from imagery alone such as HGM subclass (Wardrop et al. 2007a).

Conclusions

We compared maps produced for two national wetland programs, each with different purposes and methods. We found mapping outcomes were variable, within and between different geographic and ecological contexts. Differences were related to wetland definitions, methods (e.g., aerial photo interpretation versus characterization of field indicators), and scale limitations such as image resolution and target mapping sizes for older NWI maps. Wetland delineations developed using the 3-factor approach are an underutilized but potentially valuable source of data for improving wetland mapping efforts and opportunities for synergy should be pursued by the programs.

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References

Bailey, R. G. 1980. Description of the Ecoregions of the United States, Misc. Publication No. 1391. USDA Forest Service, Washington, D.C.

Baldwin RF, deMaynadier PG (2009) Assessing threats to pool-breeding amphibian habitat in an urbanizing landscape. Biol Conserv 142: 1628–1638. https://doi.org/10.1016/j.biocon.2009.02.039

Brooks RP, Wardrop DH, Bishop JA (2004) Assessing wetland condition on a watershed basis in the mid-Atlantic region using synoptic land-cover maps. Environ Monit Assess 94:9–22. https://doi.org/10.1023/B:EMAS.0000016876.63062.3d

Brostoff W, Lichvar R, Sprecher S (2001) Delineating playas in the arid Southwest: a literature review. ERDC TR-01-4. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH

Calhoun AJK, Walls TE, Stockwell SS, McCollough M (2003) Evaluating vernal pools as a basis for conservation strategies: a Maine case study. Wetlands 23:70–81. https://doi.org/10.1672/0277-5212(2003)023[0070:evpaab]2.0.co;2

Cowardin LM, Carter V, Golet FC, LaRoe ET (1979) Classification of wetlands and deepwater habitats of the United States. USDI Fish and Wildlife Service, Washington DC

Dahl TE (2000) Status and trends of wetlands in the conterminous United States 1986 to 1997. USDI Fish and Wildlife Service, Washington DC

Dahl T (2006) Status and trends of wetlands in the conterminous United States 1998 to 2004. USDI Fish and Wildlife Service, Washington DC

Dahl TE (2011) Status and trends of wetlands in the conterminous United States 2004 to 2009. USDI Fish and Wildlife Service, Washington DC

Dahl T, Stedman S (2013) Status and trends of wetlands in the coastal watersheds of the conterminous United States 2004 to 2009. USDI Fish and Wildlife Service and National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington DC

Dahl TE, Dick J, Swords J, Wilen BO (2015) Data collection requirements and procedures for mapping wetland, deepwater, and related habitats of the United States (version 2). USDI Fish and Wildlife Service National Standards and Support Team, Madison

Daly C, Halbleib M, Smith JI, Gibson WP, Doggett MK, Taylor GH, Curtis J, Pasteris PP (2008) Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. International Journal of Climatology 28:2031–2064. https://doi.org/10.1002/joc.1688

DeLancey ER, Kariyeva J, Bried JT, Hird JN (2019) Large-scale probabilistic identification of boreal peatlands using Google earth engine, open-access satellite data, and machine learning. PLoS One 14: e0218165. https://doi.org/10.1371/journal.pone.0218165

Environmental Laboratory (1987) Corps of engineers wetlands delineation manual. U.S. Army Corps of Engineers. Waterways Experiment Station, Vicksburg

Federal Geographic Data Committee (2013) Classification of wetlands and deepwater habitats, 2nd edn. FGDC-STD-004-2013. Wetlands Subcommittee, Federal Geographic Data Committee and USDI Fish and Wildlife Service, Washington DC

Fennessy MS, Jacobs AD, Kentula ME (2007) An evaluation of rapid methods for assessing the ecological condition of wetlands. Wetlands 27:543–560. https://doi.org/10.1672/0277-5212(2007)27[543:AEORMF]2.0.CO;2

FGDC Wetlands Subcommittee (2009) Wetland mapping standard. FGDC-STD-015-2009. US Geological Survey, Reston

Johnston CA, Meysembourg P (2002) Comparison of the Wisconsin and National Wetlands Inventories. Wetlands 22:386–405. https://doi.org/10.1672/0277-5212(2002)022[0386:cotwan]2.0.co;2

Kloiber S, Macleod R, Smith A, Knight J, Huberty B (2015) A semi-automated, multi-source data fusion update of a wetland inventory for East-Central Minnesota. USA Wetlands 35:335–348. https://doi.org/10.1007/s13157-014-0621-3

Korfel CA, Mitsch WJ, Hetherington TE, Mack JJ (2010) Hydrology, physiochemistry, and amphibians in natural and created vernal pool wetlands. Restor Ecol 18:843–854. https://doi.org/10.1111/j.1526-100X.2008.00510.x

Kudray GM, Gale MR (2000) Evaluation of National Wetland Inventory maps in a heavily forested region in the upper Great Lakes. Wetlands 20:581–587. https://doi.org/10.1672/0277-5212(2000)020[0581:EONWIM]2.0.CO;2

Kusler J (2006) Common questions: local government wetland protection programs. association of state wetland managers and the international institute for wetland science and public policy. Berne

Lang M, McCarty G (2009) LIDAR intensity for improved detection of inundation below the forest canopy. Wetlands 29:1166-1178. https://doi.org/10.1672/08-197.1

Lang M, McCarty G, Oesterling R, Yeo I-Y (2013) Topographic metrics for improved mapping of forested wetlands. Wetlands 33:141–155. https://doi.org/10.1007/s13157-012-0359-8

Lichvar R, Gustina G, Bolus R (2004) Ponding duration, ponding frequency, and field indicators: a case study on three California, USA, playas. Wetlands 24:406-413. https://doi.org/10.1672/0277-5212(2004)024[0406:PDPFAF]2.0.CO;2

Lichvar RW, Ochs WR, Gaines SM (2008) Evaluation of surface features for delineating the ordinary high water boundary on playas in the arid western United States. Wetlands 28:68–80. https://doi.org/10.1672/06-107.1

Martin S, Brumbaugh R (2011) Entering a new era: What will RIBITS tell us about mitigation banking? National Wetlands Newsletter 33:16–26

Martin GI, Kirkman LK, Hepinstall-Cymerman J (2012) Mapping geographically isolated wetlands in the Dougherty Plain, Georgia, USA. Wetlands 32:149-160. https://doi.org/10.1007/s13157-011-0263-7

Matthews JW, Skultety D, Zercher B, Ward MP, Benson TJ (2016) Field verification of original and updated National Wetlands Inventory maps in three metropolitan areas in Illinois, USA. Wetlands 36: 1155–1165. https://doi.org/10.1007/s13157-016-0836-6

Maxa M, Bolstad P (2009) Mapping northern wetlands with high resolution satellite images and LiDAR Wetlands 29:248–260. https://doi.org/10.1672/08-91.1

McMullen J, Meacham P (1996) A comparison of wetland boundaries delineated in the field to those boundaries on existing state and federal wetland maps in central New York State. In: Wetlands: Environmental Gradients, Boundaries, and Buffers. CRC Press, Lewis Publishers, Boca Raton

Metzger MJ, Bunce RG, Jongman RH, Sayre R, Trabucco A, Zomer R (2013) A high-resolution bioclimate map of the world: a unifying framework for global biodiversity research and monitoring. Glob Ecol Biogeogr 22:630–638. https://doi.org/10.1111/geb.12022

Morrissey LA, Sweeney WR (2006) Assessment of the National Wetlands Inventory: implications for wetland protection. Paper presented at the Geographic Information Systems And Water Resources IV - AWRA Spring Specialty Conference, Houston

Nichols C (1994) Map accuracy of National Wetlands Inventory Maps for areas subject to Maine land use regulation commission jurisdiction. USDI Fish and Wildlife Service, Hadley

Omernik JM (1987) Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77:118–125. https://doi.org/10.1111/j.1467-8306.1987.tb00149.x

O'Neil GL, Saby L, Band LE, Goodall JL (2019) Effects of LiDAR DEM smoothing and conditioning techniques on a topography-based wetland identification model. Water Resour Res 55:4343-4363. https://doi.org/10.1029/2019WR024784

Ozesmi SL, Bauer ME (2002) Satellite remote sensing of wetlands. Wetl Ecol Manag 10:381–402. https://doi.org/10.1023/A:1020908432489

PRISM Climate Group. 2014. Data extracts of 30-year annual temperature and precipitation normals (1981–2010). Oregon State University PRISM Climate Group. http://prism.oregonstate.edu

R Core Team. 2017. R: A language and environment for statistical computing (v3.4.3). R Foundation for Statistical Computing, Vienna, Austria

Rampi LP, Knight JF, Pelletier KC (2014) Wetland mapping in the upper Midwest United States. Photogramm Eng Remote Sens 80:439–448. https://doi.org/10.14358/PERS.80.5.439

Sharpe PJ, Kneipp G, Forget A (2016) Comparison of alternative approaches for wetlands mapping: a case study from three US National Parks. Wetlands 36:547–556. https://doi.org/10.1007/s13157-016-0764-5

Stolt MH, Baker JC (1995) Evaluation of National Wetland Inventory maps to inventory wetlands in the southern Blue Ridge of Virginia. Wetlands 15:346–353. https://doi.org/10.1007/BF03160889

Tiner RW (1990) Use of high-altitude aerial photography for inventorying forested wetlands in the United States. Forest Ecology and Management 33-34:593–604. https://doi.org/10.1016/0378-1127(90)90221-v

Tiner RW (1997a) NWI maps - basic information on the nation's wetlands. Bioscience 47:269. https://doi.org/10.2307/1313186

Tiner RW (1997b) NWI maps: what they tell us. National Wetlands Newsletter 19:7–12

Tiner RW (2016) Wetland indicators: a guide to wetland formation, identification, delineation, classification, and mapping, 2nd edn. CRC Press, Boca Raton

USACE (2007) Regional supplement to the corps of engineers wetland delineation manual: Alaska Region (Version 2.0). US Army Engineer Research and Development Center, Wetlands Regulatory Assistance Program, Vicksburg

USACE (2008) Regional supplement to the Corps of Engineers wetland delineation manual: Arid West Region (Version 2.0). US Army Engineer Research and Development Center, Wetlands Regulatory Assistance Program, Vicksburg

USACE (2010) Regional supplement to the Corps of Engineers wetland delineation manual: Western Mountains, Valleys, and Coast Region (Version 2.0). US Army Engineer Research and Development Center Environmental Laboratory, Vicksburg

Wardlow BD, Egbert SL (2003) A state-level comparative analysis of the GAP and NLCD land-cover data sets. Photogramm Eng Remote Sens 69:1387–1397. https://doi.org/10.14358/PERS.69.12.1387

Wardrop DH, Kentula ME, Jensen SF, Stevens DL, Hychka KC (2007a) Assessment of wetlands in the Upper Juniata Watershed in Pennsylvania, USA using the Hydrogeomorphic Approach. Wetlands 27:432-445. https://doi.org/10.1672/0277-5212(2007)27[432:AOWITU]2.0.CO;2

Wardrop DH, Kentula ME, Stevens DL, Jensen SF, Brooks RP (2007b) Assessment of wetland condition: an example from the upper Juniata watershed in Pennsylvania, USA. Wetlands 27:416–431. https://doi.org/10.1672/0277-5212(2007)27[416:AOWCAE]2.0.CO;2

Wilen BO, Bates MK (1995) The US Fish and Wildlife Service National Wetlands Inventory project. Vegetatio 118:153–169. https://doi.org/10.1007/978-94-011-0427-2_13

Wright C, Gallant A (2007) Improved wetland remote sensing in Yellowstone National Park using classification trees to combine TM imagery and ancillary environmental data. Remote Sensing of Environment 107:582–605. https://doi.org/10.1016/j.rse.2006.10.019

Wu M, Kalma D, Treadwell-Steitz C (2014) Differential assessment of designations of wetland status using two delineation methods. Environ Manag 54:23–29. https://doi.org/10.1007/s00267-014-0273-3

Xie Y, Zhang A, Welsh W (2015) Mapping wetlands and Phragmites using publically available remotely sensed images. Photogramm Eng Remote Sens 81:69–78. https://doi.org/10.14358/PERS.81.1.69