

Comparison of Alternative Approaches for Wetlands Mapping: A Case Study from three U.S. National Parks

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Abstract We performed an assessment of U.S. Geological Survey/National Park Service (USGS/NPS) vegetation mapping versus National Wetland Inventory (NWI) estimates of wetland occurrence and extent for three national parks, each having a different NWI mapping scale (1:40,000, 1:58,000, and 1:80,000). Our prediction was that the USGS/NPS mapping would be significantly more effective than NWI in predicting total wetland area within each park, and would commit fewer errors of omission and commission. For use as a control group, each park had recent wetland field determination data collected in accordance with U.S. Army Corps of Engineers protocols. Contrary to our prediction, mean NWI wetland area estimates were more accurate than USGS/NPS mapping at the 1:40,000 and 58,000 scales. At the 1:80,000 scale, NWI and USGS/NPS estimates were similar. NWI wetland area estimates were not significantly different ($\alpha=0.05$) from the control data at two of the study parks, whereas USGS/NPS estimates were significantly larger than the

control group at two of the three parks. This research highlights the relative strength of NWI mapping for landscape level wetland analysis, and the need to support remote sensing data by allocating field resources for accuracy assessment in specific areas based on management goals.

Keywords Remote sensing · Omission · Commission · National Parks · NWI · Wetlands mapping

Introduction

The intrinsic benefits of wetland ecosystems and the ecological and societal services they provide have been gaining increased global recognition (Tiner et al. 2015). Wetland ecosystem functions ranging from water storage to carbon sequestration can provide substantial economic and ecological value. The global need to understand and conserve wetland resources has resulted in new regulations, scientific investigation, and is part of an ecological restoration economy that employs an estimated 126,000 workers and generates \$9.5 billion in annual sales in the U.S. alone (BenDor et al. 2015).

With an estimated 1.3 billion hectares (ha) of wetlands throughout the world (Tiner et al. 2015), accurate inventories of these ecosystems are vital. Remote sensing (satellite- or airplane-generated imagery) is a practical and cost efficient method of generating spatial data on wetland abundance, distribution, and, in some cases, biochemical and biophysical parameters (Ozesmi and Bauer 2002; Adam et al. 2010). The predominant remote-sensing wetland mapping program used in the U.S. is the National Wetland Inventory (NWI), which is managed by the U.S. Fish and Wildlife Service (USFWS 2016).

The U.S. National Park System encompasses 408 areas totaling 33,993,593 ha of lands managed by the National

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Park Service (NPS); these areas include national parks, monuments, battlefields, military parks, historical parks, historic sites, lakeshores, seashores, recreation areas, scenic rivers and trails, and the White House (NPS 2016). These lands are also home to more than 6 million ha of wetland habitat (Wagner and Noon 2005), ranging from tidal salt marshes along the coasts to non-tidal palustrine and riverine wetlands in the continental interior. These habitats provide valuable ecosystem services that include structural benefits for storm surge protection, stream and river channel stabilization, and water-quality treatment, as well as other services such as carbon sequestration, endangered species habitat, and biodiversity maintenance. In 1977, President Carter issued Executive Order 11990: “Protection of Wetlands” (42 Federal Register 26961), which required avoiding adverse impacts to wetlands on NPS-managed lands to the greatest extent possible. In addition to this executive order, NPS activities that involve the discharge of dredged or fill material into wetlands or other “waters of the United States” must comply with regulations under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act (33 CFR 320–331).

A key mechanism for meeting these executive and legislative mandates is maintaining accurate wetland inventory data and mapping at the individual park level. This information is critical for effective resource management and facility planning (e.g., roadways, visitor centers, parking areas) and for minimizing wetland impacts. However, the vast majority of the 270 park units with significant natural resources are currently operating without a detailed wetland inventory (Wagner and Noon 2005).

Until ca. 2000 there were two options for developing comprehensive wetland inventories on NPS-managed lands: (1) conduct a conventional, on-site field delineation and boundary determination, or (2) utilize NWI mapping data (USFWS 2013). As a remote-sensing approach utilizing high altitude aerial photography and satellite imagery, the NWI offers a less accurate but significantly more cost-effective means of providing a comprehensive, landscape-level wetlands inventory. Consequently, many early NPS estimates of wetland frequency, distribution, and habitat within parks exclusively used NWI maps. NWI mapping has strengths (Tiner 1997) including: (1) time efficiencies for discerning initial wetland type, frequency, and distribution on a landscape, and (2) identification of wetlands regardless of whether they are considered jurisdictional by the Army Corp of Engineers or other agencies. This second strength is of particular importance, as the NPS is required to regulate all wetlands whether or not they meet specific federal regulatory or administrative definitions (NPS Organic Act 16 U.S.C. 1 and Director’s Order 77.1).

However, NWI mapping also has limitations. For non-tidal wetlands in the Northeast U.S., these limitations include: (1) use of summer leaf-on photography for photo-interpretation, (2) difficulty of identifying and delineating forested wetlands,

linear wetland features, and farmed/mowed wetlands in aerial images, (3) under-detection of wetlands that are at the drier end of the hydrologic spectrum, and (4) use of older aerial photography (mainly from the 1980s) at relatively coarse mapping scales (typically 1:40,000 but also smaller) (Tiner 1990, 1997; Johnston and Meysembourg 2002; Tiner 2005; Munoz et al. 2009; Martin et al. 2012). Of these limitations, map scale may have the greatest relevance to the NPS. Even at the largest scale of commonly available maps (1:40,000), the target mapping unit (i.e., minimum wetland size that the NWI attempts to map consistently) is a wetland that is at least 0.4 ha (1 acre) (Tiner 1997). By overlooking smaller wetlands, the NWI may underestimate as many as 82 % of all wetland habitats on a landscape (Morrissey and Sweeney 2006).

More recently, the NPS has been using remotely sensed vegetation-community mapping developed through a joint USGS/NPS Vegetation Mapping Program protocol (VegMap) produced by The Nature Conservancy and Environmental Systems Research Institute, Inc. (TNC and ESRI 1994; Lea 2011). This large-scale mapping (1:6,000) uses a combination of leaf-on and leaf-off, low-elevation color-infrared aerial photography, coupled with field data collection and accuracy assessment points. The goal is to develop comprehensive vegetation maps with a reported accuracy level of 0.51 ha, similar to the smallest target mapping unit available from the NWI; however, in some cases the USGS/NPS maps may display a minimum accuracy level of 0.20 ha.

VegMap was not developed specifically for wetland community types, but rather for all vegetation classes consistent with the association level of the U.S. National Vegetation Classification (USNVC 2016). Thus, there is some question as to whether the wetland community data contained therein is substantially more accurate than conventional NWI data. Because the VegMap protocol utilizes a combination of NWI maps, soils data, and site-specific hydrologic information as part of the initial classification and mapping review process for wetland habitats, it might be assumed that the wetland estimates are at least equivalent to NWI estimates. To evaluate this assumption, we quantitatively assessed data using both mapping programs for wetland habitats in three national parks that also had recent wetland field delineations. Each park had NWI maps at a different available scale (1:40,000, 1:58,000 and 1:80,000). Our prediction was that the VegMap products would be significantly more accurate than NWI mapping in terms of predicting average and total wetland area within a given park.

Methods

Beginning in May 2011, non-tidal palustrine (e.g., freshwater inland swamp/marsh) wetland habitats were surveyed at three national park units in the Northeast region of the United

States. The three parks were Valley Forge National Historical Park (VAFO), Allegheny Portage Railroad National Historical Park (ALPO), and Fredericksburg and Spotsylvania National Military Park (FRSP) (Fig. 1). These park locations lie within three distinct physiographic provinces: Ridge and Valley (ALPO), Piedmont (VAFO), and Atlantic Coastal Plain (FRSP). Wetland surveys were conducted within a 1,397-ha study area at VAFO, a 95-ha study area at ALPO, and a 502-ha study area at FRSP. Each of the study areas could be broadly categorized as having some combination of open field and broad-leaved eastern deciduous forest. The wetland field survey areas are subsets of the three national parks, corresponding to zones of special interest identified by NPS park staff. The field wetland delineations were conducted to facilitate avoidance and minimization of potential adverse impacts to wetland resources during activities ranging from standard maintenance to proposed infrastructure changes.

Wetland Field Delineation, Classification, and Mapping

Wetland field delineations conducted by professional wetland scientists from May 2011 to November 2012 were used as the means of assessing the accuracy of NWI versus VegMap wetland estimates. Field protocols utilized U.S. Army Corps of Engineers (USACE) wetland delineation methods. A traverse of the entire study area boundary at each park was performed by investigators to ensure that no potential wetlands were excluded from consideration. The boundaries of each wetland were determined by establishing a series of transects from known wetland habitat into known upland locations surrounding the wetland under examination. At random intervals along each transect, investigators looked for evidence of hydric soils, hydrophytic vegetation, and wetland hydrology, according to methods outlined in the appropriate regional supplement manuals (USACE 2012 for ALPO and VAFO; USACE 2010 for FRSP).

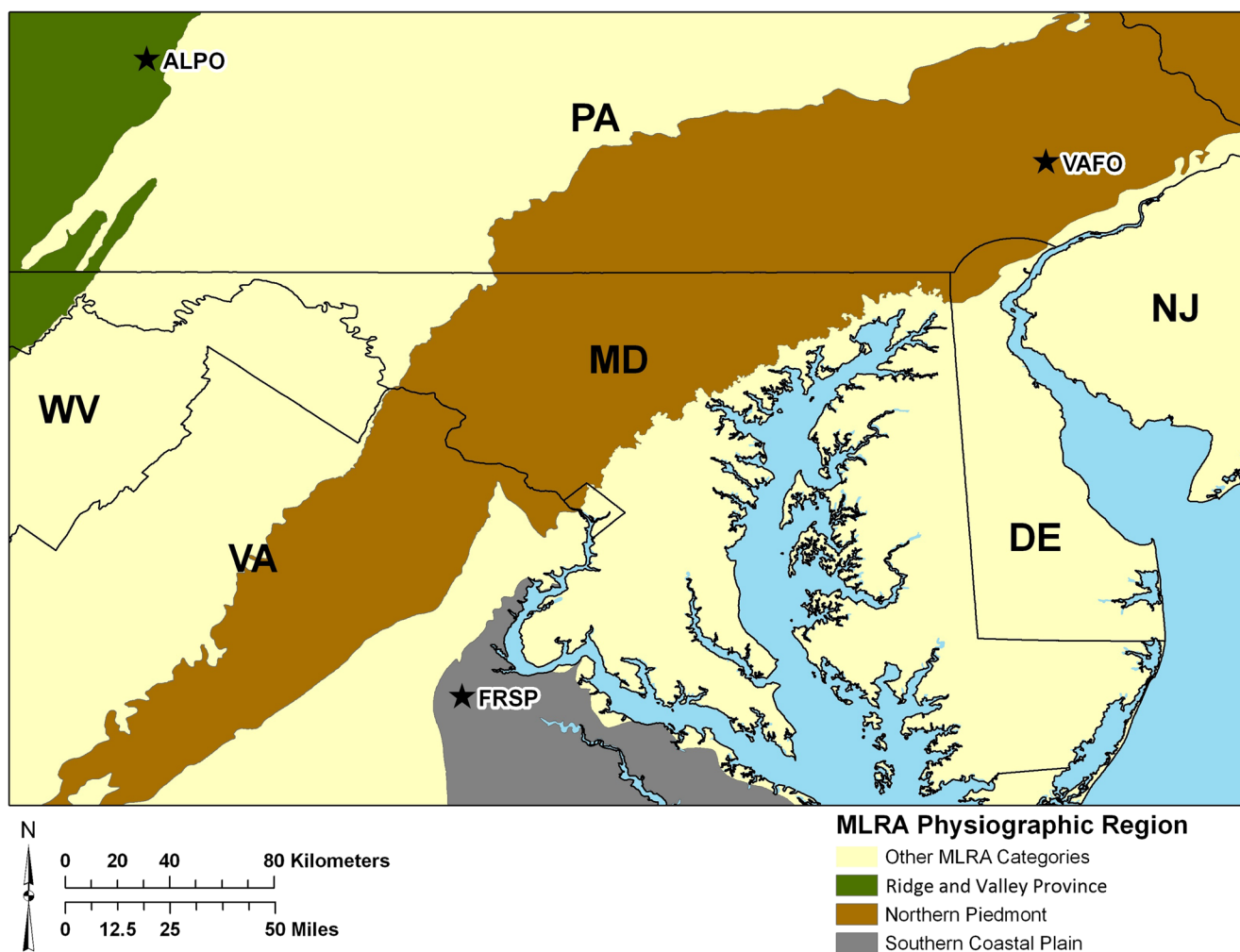


Fig. 1 Study site map showing the three study parks. Park locations lie within three distinct physiographic provinces (Major Land Resource Areas): Ridge and Valley - Allegheny Portage Railroad National

Historical Park (ALPO), Piedmont - Valley Forge National Historical Park (VAFO), and Atlantic Coastal Plain - Fredericksburg and Spotsylvania National Military Park (FRSP)

Identified and delineated wetlands were assigned to a wetland type under the Cowardin classification system (Cowardin et al. 1979). Cowardin wetland classes observed in the field were exclusively palustrine systems that fell within the emergent, scrub-shrub, or forested non-tidal wetland classes. Cowardin classes encountered at FRSP tended to be forested, broad-leaved deciduous systems, with some special modifiers associated with draining, ditching, and farming. VAFO generally possessed an even mixture of forested and emergent Cowardin classes with the latter class often associated with a farmed, managed, or diked/impounded special modifiers. ALPO had the most anthropogenically disturbed systems (historically). The bulk of these wetlands were emergent with special modifiers ranging from partly drained/ditched to artificial substrate. Boundaries of the study wetlands were not independently verified via an official USACE Jurisdictional Determination; therefore, while we are confident that the field-determined boundary data are accurate, they should be considered provisional.

To develop mapped polygons for wetland area, delineation flags were marked with a unique alphanumeric code and hung at regular intervals around the perimeter of each identified wetland habitat. Locations of upland and wetland soil test pits were also flagged. GPS-based coordinates were collected for all boundary and test pit flags within a week of field work completion, using a Trimble GeoXT receiver with an external Hurricane antenna in datum NAD83 (UTM zone 17 N for ALPO and zone 18 N for FRSP and VAFO), meter coordinates and TerraSync software. A minimum of four satellite vehicles were tracked. Where possible, a maximum Position Dilution of Precision (PDOP) of six was maintained for each set and a minimum of 50 positions were taken at each point feature. The data were post-processed and differentially corrected using Pathfinder Office 5.30 and base data from the GPS base station nearest to each park. The data were then exported to shapefile format. Following this procedure, we estimated wetland boundary accuracies in the X and Y direction of 0 to 2 meters, using the aforementioned standards while setting selective availability (SA) to zero. No tests were

done to confirm the X/Y direction accuracy during this investigation.

NWI and VegMap Data Sources

Table 1 summarizes the available spatial wetland data sets, by park, that were used in this analysis. Digital NWI maps at each of the mapping scales were downloaded and clipped to each of the three park study area boundaries in ArcMap version 10.1 and projected into UTM 18 N for overlay with the VegMap mapping and the field-verified wetland polygons. VegMap data for each study unit at 1:6,000 scale were modified such that only the vegetation polygons defined as representative of wetland formations (i.e., habitats with hydrologic modifiers of temporarily flooded, seasonally flooded, saturated, semi-permanently flooded, etc.) were visible. Digital versions of the VegMap data coupled with the NWI information, and field-verified wetland polygons at each park location were combined and converted to shapefiles for analysis in ArcMap.

Unique area values (in ha) representing areas of NWI and VegMap errors of commission were generated by looking at regions of overlap between the datasets (Actual wetlands, NWI wetlands, VegMap wetlands) and subsequently erasing them. The input polygon features in each case were either the VegMap or NWI wetland polygon layers for a given park, and the erase coverage feature was the Actual wetland polygon layer for a given park. The output following this exercise was a series of unique area values representing upland locations in the parks which were erroneously mapped as wetlands by either VegMap or NWI.

The same technique was utilized in reverse to generate a series of unique area values for each study park (ha) representing NWI/VegMap errors of omission. In this instance, the input polygon feature was the Actual wetland data layer for a given park and the erase coverage feature was either the VegMap or NWI wetland layers. The resulting output provided a series of quantitative area values representing wetland areas within the parks that were not mapped by VegMap and/or NWI (but should have been). This technique allowed us to

Table 1 Summary description of NWI and VegMap mapping data characteristics assessed by park for Valley Forge National Historical Park (VAFO), Allegheny Portage Railroad National Historical Park (ALPO), and Fredericksburg and Spotsylvania National Military Park (FRSP)

	FRSP		VAFO		ALPO	
	NWI	VegMap	NWI	VegMap	NWI	VegMap
Imagery dates	1980, 1989, 1990	Oct 2001, Feb 2002	1981	Sept 1999	1977	Apr 2003
Mapping scale	1:40,000	1:6,000	1:58,000	1:6,000	1:80,000	1:6,000
Minimum mapping unit (ha)	0.40	0.20-0.51	0.40-1.21	0.20-0.51	1.21-2.02	0.20-0.51
Leaf-on imagery	Yes	Yes	Yes	Yes	Yes	No
Leaf-off imagery	No	Yes	No	No	No	Yes
Study area size (ha)	502		1397		95	

generate a series of error polygons for each park by which statistical comparisons and summations of wetland errors of commission and omission could be performed.

Data Analysis

ANOVA analysis comparing mean wetland areas mapped between the field-verified wetlands (hereafter “Actual wetlands”), NWI, and VegMap wetlands for FRSP and VAFO was performed using SAS version 9.1 (SAS 2002). The alpha level for all statistical analysis in this study was set at 0.05, and differences of least squares means using a post-hoc Tukey-Kramer HSD adjusted p-value were used as a conservative measure of determining significant differences between the three mapping techniques. Normality and variance heterogeneity of the data were also examined prior to analysis to assess whether or not ANOVA assumptions were met. However, ANOVA is robust with regards to departures from normality, and the post-hoc Tukey-Kramer HSD test for unequal group sizes is conservative if the normality assumption is not met.

No statistical analysis was performed for the ALPO wetlands data as both the NWI and VegMap techniques found only a single wetland polygon within the park study area. Due to a lack of replication at the park scale, the analysis and results reporting was done strictly on a park-by-park basis to avoid the potential confounding effects of varying study area sizes, time, and available NWI mapping scales. Statistical differences reported between the various wetland mapping techniques are provided simply to quantify differences between observations within each study park.

For FRSP and VAFO, Mann–Whitney U-tests were performed on the unique area polygons generated in ArcMap to assess the extent of errors of omission and commission generated from the NWI and VegMap wetland data layers. This non-parametric test was used because the omission and commission data was unbalanced and assumed non-normal. The Mann–Whitney U-tests were run using Sigma Plot 12.0 (SigmaPlot 2012) along with a Shapiro-Wilk normality test to provide verification of our assumption regarding the omission and commission data.

In addition to the statistical analysis, descriptive summaries of the total wetland areas mapped across each park for Actual, NWI, and VegMap techniques, along with total wetland areas not mapped (errors of omission) and erroneously mapped (errors of commission) were developed. The total number and size class distribution of Actual, NWI, and VegMap wetlands were also calculated for each park and reported for comparison. Size classes were based on the minimum mapping criteria for NWI and VegMap and were assigned values of 1–5 (smallest to largest) as follows: Class 1 (0.004–0.04 ha), Class 2 (0.04–0.20 ha), Class 3 (0.20–0.40 ha), Class 4 (0.40–2.02 ha), Class 5 (>2.02 ha). These descriptive

summaries were produced to illuminate potential effects of map scale and technique in relation to wetland sizes.

Results

Fredericksburg and Spotsylvania National Military Park (FRSP)

At the largest NWI scale (1:40,000), the ANOVA analyses of FRSP revealed significant overall differences in the average wetland area mapped ($F_{2,86}=4.63$, $P<0.05$). Specifically, the mean wetland area mapped by VegMap ($\bar{X}=9.10$ ha ± 2.38 SE) were significantly higher on average than either NWI ($\bar{X}=1.08$ ha ± 1.37 SE) ($t=-2.92$, $p=0.01$) or the Actual wetlands found ($\bar{X}=1.50$ ha ± 1.41 SE) ($t=-2.75$, $p=0.02$) (Fig. 2a). This high average wetland area for VegMap was in contrast to the much lower number of unique wetlands

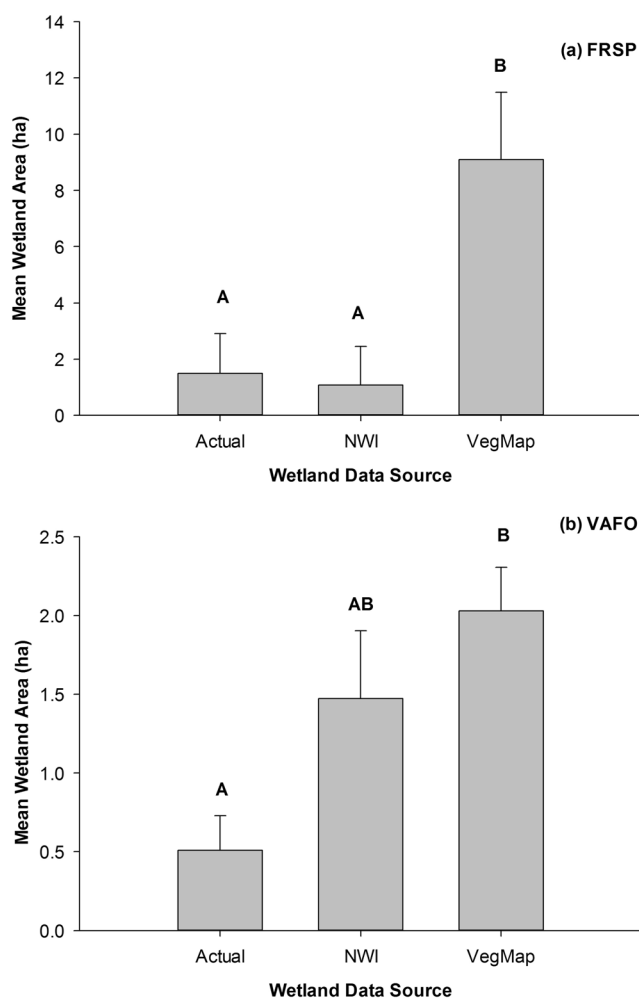


Fig. 2 Mean wetland area (+ SE) estimated by three mapping techniques (Actual, NWI, VegMap) for (a) FRSP and (b) VAFO parks. See Fig. 1 legend for park names. Different letters denote significant differences (Tukey's HSD, $p<0.05$)

mapped ($n=13$) in comparison to either NWI ($n=39$) or the Actual wetlands found ($n=37$) (Table 2). The majority of the VegMap wetland area mapped at FRSP came from a small number of Size Class 5 wetlands (Fig. 3).

Despite the low number of uniquely mapped wetlands at FRSP, VegMap also displayed the highest total amount of estimated wetland area (118.33 ha) compared to NWI (42.05 ha) and the Actual wetlands (55.33 ha), overestimating by 114 % compared to Actual wetlands found (Table 3). The majority of the mapping errors associated with VegMap occurred as errors of commission (i.e., mapping non-wetland habitats as wetlands). As shown in Table 3, these errors totaled 69.96 ha, compared to 11.71 ha for NWI. Median errors of commission were significantly less for NWI (0.19, $n=38$) compared to VegMap (1.62, $n=13$) (Mann–Whitney $U=120$, $p<0.01$) (Table 3, Fig. 4). No significant differences were observed between NWI and VegMap in errors of omission, though NWI underestimated the actual wetland acreage within FRSP by 24 %.

Valley Forge National Historical Park (VAFO)

At the second-largest NWI scale (1:58,000), the ANOVA analyses of VAFO also revealed a significant overall difference in the average wetland area mapped ($F_{2,92}=9.63$, $P<0.05$). The mean wetland area delineated by VegMap ($\bar{X}=2.03$ ha ± 0.28 SE) were significantly higher on average than the Actual wetlands ($n=50$, $\bar{X}=0.51$ ha ± 0.22 SE) ($t=-4.32$, $p<0.01$) found but not the NWI estimates ($\bar{X}=1.47$ ha ± 0.43 SE) ($t=-1.09$, $p=0.52$) (Fig. 2b). VegMap total wetland area

Table 2 Total number of wetlands by size class for Actual, NWI, and VegMap wetland groups in each study park (FRSP, VAFO, ALPO). See Table 1 for park names. Size classes are: Class 1 (0.004–0.04 ha), Class 2 (0.04–0.20 ha), Class 3 (0.20–0.40 ha), Class 4 (0.40–2.02 ha), Class 5 (>2.02 ha)

	Number of wetlands per size class					Total
	Class 1	Class 2	Class 3	Class 4	Class 5	
FRSP						
Actual wetlands	7	12	8	6	4	37
NWI wetlands	0	10	5	19	5	39
VegMap wetlands	0	0	4	2	7	13
VAFO						
Actual wetlands	14	13	9	11	3	50
NWI wetlands	0	2	1	6	4	13
VegMap wetlands	0	4	4	13	11	32
ALPO						
Actual wetlands	2	1	3	1	0	7
NWI wetlands	0	0	1	0	0	1
VegMap wetlands	0	0	0	1	0	1

estimates for VAFO were 156 % higher than the Actual wetlands found, and, as at FRSP, the bulk of the wetland area was comprised of large wetlands (Table 2, Fig. 3).

Unlike at FRSP, VegMap delineated more than twice as many unique features at VAFO ($n=32$) compared to NWI ($n=13$), including slightly more small (Size Class 2) wetlands (Table 2). However, of the 64.98 total ha delineated by VegMap, 79 % were errors of commission compared to just 15.14 ha of committed error by NWI. While NWI consistently avoided errors of commission at VAFO and FRSP, the program's propensity for omission errors was evident at VAFO, where NWI failed to map 21.43 ha of Actual wetlands (Table 3, Fig. 4). There were no significant differences found between VegMap or NWI in Mann–Whitney rank sum tests on either the errors of omission or commission.

Allegheny Portage Railroad National Historical Park (ALPO)

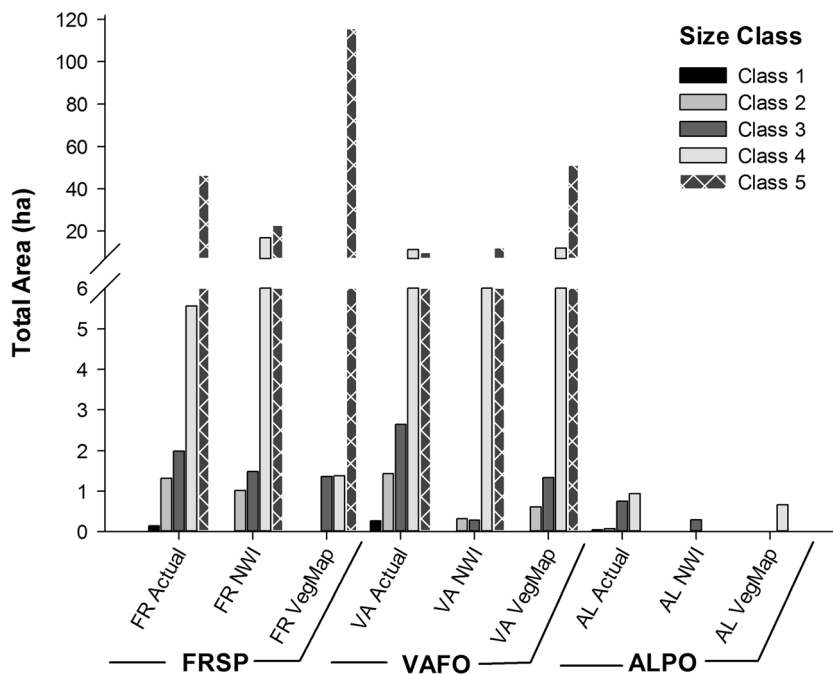
At the smallest NWI scale (1:80,000), both VegMap and NWI found only 1 of the 7 total wetland habitats observed at ALPO (Table 2). The mapping programs also underestimated the total wetland area by 84 % (NWI) and 63 % (VegMap) respectively (Table 3). The underestimation of total wetland area by both NWI and VegMap occurred within the smaller size class ranges. The majority of the Actual wetlands ($n=6$) fell within size classes 1–3 (Table 2, Fig. 3). These six small wetlands were below the reported minimum mapping unit for NWI, but three of the six were within the reported minimum mapping unit range for VegMap. Neither VegMap nor NWI generated large errors of commission (NWI=0.17 and VegMap=0.18 ha). Both programs omitted a considerable amount of total wetland area (NWI=1.68 and VegMap=1.32 ha) compared to the 1.8 ha of Actual wetlands (Table 3, Fig. 4).

General Patterns

A total of 94 wetlands were delineated at the three parks. As shown in Fig. 3, NWI performed best in identifying the total Actual wetland area for the two largest size classes (habitats above 0.40 ha) at each park. Because the total wetland area was dominated by the two largest size classes, on a percentage basis, NWI adequately captured the overall wetland presence.

VegMap tended to overestimate wetland acreage via errors of commission while NWI displayed the opposite tendency (errors of omission). Both VegMap and NWI tended to miss or, at best, inconsistently capture the smallest wetlands (Table 2). The greater propensity of NWI to err on the side of omission has been well documented (Stolt and Baker 1995; Tiner 1997; Kudray and Gale 2000), and arguably is by design to provide a conservative estimate of wetland habitats within the landscape. However, since 73 % of the three parks'

Fig. 3 Total wetland area (ha) by size class, mapping technique, and park (FRSP, VAFO, ALPO). See Fig. 1 legend for park names



wetlands fell within the three smallest size classes (Table 2). Our findings demonstrate that small wetlands, often ecologically important within a landscape, were not easily captured using either remote sensing technique.

Discussion

The results of this study do not support our initial prediction that the VegMap program would have an improved ability over the NWI program to detect wetlands at the landscape scale. At FRSP and VAFO, the NWI estimates of total and average wetland area were not significantly different from the Actual wetland coverage. In contrast, VegMap data consistently overestimated total and average wetland area for both parks. NWI and VegMap performed equally poorly at ALPO, but statistical analysis of any differences was not possible given that both remote sensing techniques failed to map 6 out of the 7 wetlands present.

Since VegMap wetland estimates at the three parks were derived from more recent aerial imagery at a consistently larger mapping scale than NWI, we must consider what mapping program characteristics or field conditions might have contributed to the weakness in wetland area predictions. This question has implications for understanding how wetland ecosystems can be best captured via remote sensing techniques, as well as how detectability is influenced by natural and anthropogenic landscape features. We suggest at least three possible sources of the mapping discrepancies.

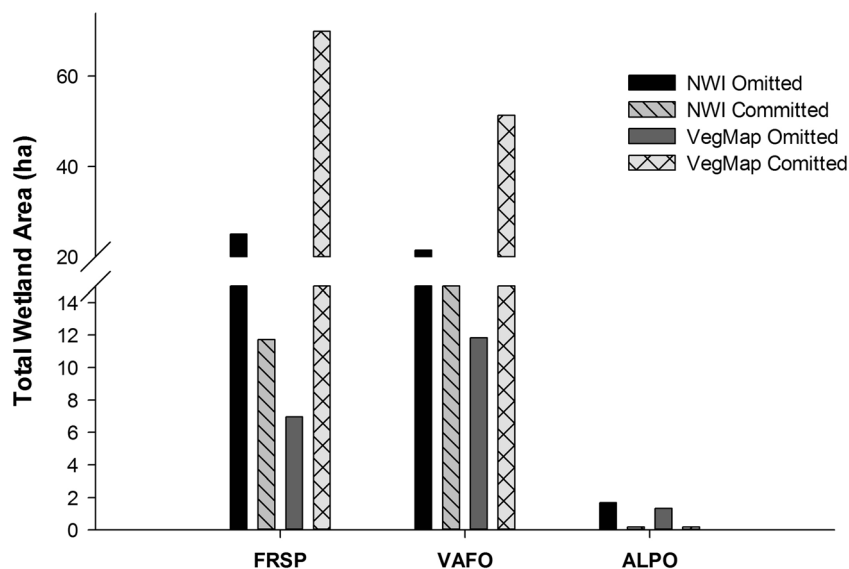
Natural and Anthropogenic Landscape Effects

The USGS/NPS VegMap data possessed several potential advantages compared to NWI, most notably: (1) low-elevation base mapping and large-scale photo-interpretation (1:6,000) that could provide a consistently small minimum mapping unit; (2) use of more recent aerial photography; (3) field assessments of generated polygons to verify the accuracy of habitat mapping; and (4) use of hydric soil and NWI

Table 3 Descriptive summary of the NWI, VegMap, and Actual wetland areas within the three study parks (FRSP, VAFO, ALPO). See Table 1 for park names. Area omitted is wetland habitat not mapped; area committed is non-wetland habitat mapped as wetland

Park	Total wetland area mapped (ha)			Total wetland area omitted (ha)		Total wetland area committed (ha)	
	Actual	NWI	VegMap	NWI	VegMap	NWI	VegMap
FRSP	55.33	42.05	118.33	24.99	6.96	11.71	69.96
VAFO	25.43	19.14	64.98	21.43	11.82	15.14	51.37
ALPO	1.80	0.29	0.66	1.68	1.32	0.17	0.18

Fig. 4 Total wetland area (ha) for NWI and VegMap errors of omission and commission, by park (FRSP, VAFO, ALPO). See Fig. 1 legend for park names



mapping as a component of the wetland mapping. Conversely, Tiner (1997) summarized 14 examples of “major NWI map limitations”, of which six were relevant to our study parks: (1) variability in the size of minimum mapping units; (2) use of summer leaf-on photography only; (3) presence of high densities of forested wetlands; (4) presence of linear wetland features; (5) presence of farmed wetlands; and (6) use of much older aerial imagery.

The three study parks possessed both legacy and current landscape level anthropogenic disturbances in the form of extensive Civil War era earth works and ditches at FRSP, and actively maintained battlefields, maintained meadow areas and utility/transportation corridors at VAFO and ALPO. Additionally, nearly the entire FRSP study area and significant portions of the VAFO and ALPO study areas possessed dense forested stands, where many of the Actual wetlands were located. The landscape at ALPO has also been impacted by historic surface and sub-surface mining activity, as well as electrical and gas pipeline construction and right-of-way maintenance. All of these current and legacy impacts have altered the surface and (in some cases), groundwater hydrology, thus altering the distribution of Actual wetlands. The combination of natural (i.e., extensive tree cover) and anthropogenic landscape features potentially confounded the high resolution aerial imagery, and thereby negated many of the VegMap program advantages over NWI.

Different Overall Program Goals

The USGS/NPS VegMap program was not designed to specifically map only wetland habitats, in contrast to NWI. The VegMap data represent mapping of all terrestrial habitats, and the field assessment points used to verify the remote-sensing data are randomly located and not specifically stratified by

habitat type. While this approach provides the greatest objectivity and statistical power, this type of sampling is more likely to overlook wetland mapping errors and thus result in either the omission of small wetlands or over-estimation of wetland size. This is what we observed at FRSP and VAFO. In contrast, the NWI program is focused solely on wetlands and deepwater habitats and has been mapping these specific ecosystems in the U.S. since the 1970s.

The NWI program employs wetland specialists for mapping and (limited) field verification, while the VegMap program does not necessarily rely on wetland specialists. At the three parks, the VegMap field accuracy assessments were conducted by expert botanists, who provided the parks with detailed plant species lists and other products. Some basic hydrologic information and soils data was also assessed; however, our results indicate that this information was not sufficient to verify the presence or absence of wetland features, or to adequately define wetland boundaries. The USGS/NPS methodology is not intentionally plant-centric, but in practice, this limitation appears at the three parks. We contend that a primarily plant-centric approach to verifying wetland habitat presence/absence is likely to overestimate wetland areas, particularly in lowland forested habitat. For example, forested areas can give the false impression of a wetland ecosystem by having a canopy, understory, and herbaceous community dominated by hydrophytic plant species, even if the appropriate soil and hydrologic conditions are lacking.

Deviations from the Standard Protocol

A third possible explanation for our findings is variation within the VegMap survey data itself. As with any national or regional scientific initiative, VegMap has a standard protocol governing the type of aerial photography, scale, and use of leaf

on/off imagery (see Table 1). Ideally, VegMap uses a combination of leaf-on and leaf-off images, but these standards were not fully met at VAFO or ALPO. At VAFO, the only aerial photography used was during leaf-on (September) conditions. Considering that most Actual wetlands within the study parks were forested or had forested habitat components (Sharpe et al. 2012 and 2013), leaf-on photography would make remote sensing of these habitats more difficult, thus contributing to the lower accuracy compared to NWI imagery (1:58,000).

Implications

This research suggests that NWI mapping (specifically the 1:40,000 and 58,000 scales) can be robust in terms of estimating total wetland area and subsets of wetland area in size classes above 0.40 ha. The NWI program is currently updating some spatial products using imagery from the National Agriculture Imagery Program (NAIP) and ESRI World Imagery. See Tiner et al. (2015) for a review of current and emerging wetland remote sensing technology and application.

Our results stress the need to support remote sensing data by allocating limited field resources for accuracy assessment in areas with substantial anthropogenic disturbance and within vegetation communities prone to mapping errors (i.e. lowland forests). If management goals are focused on small semi-aquatic systems (e.g., vernal pool conservation - see Ciccotelli et al. 2011) field specialists may want to use NWI data for large wetlands while field surveying and delineating <0.40 ha systems as a trade-off between accuracy and efficiency. Our results also highlight a continued research need for field verification and data validation efforts at other National Parks to improve the data confidence and generality of these initial observations.

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