NATIONAL WETLANDS INVENTORY (NWI) ACCURACY IN NORTH CAROLINA

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Executive Summary

Development of the National Wetland Inventory (NWI) was begun by the US Fish and Wildlife Service in the 1970's using the data sources, technologies, and wetland classification system available at that time. Mapping in North Carolina (NC) was primarily completed using 1980's-era aerial imagery collected and since then, there have been very few updates. Limitations of the data set, in addition to the age of the data, include a relatively large (0.5 ac.) minimum mapping size, relatively coarse resolution of the source imagery, and inclusion of many features that do not meet the current common definition of "wetland". However, it is the only widely available map of wetland locations and extent within NC and for much of the US, and so is widely used for purposes for which it was not designed.

The accuracy of NWI for NC has not been independently assessed for much of the state, which adds uncertainty to projects and management decisions that rely on NWI to support decision-making. This study was intended to fill that knowledge gap by comparing the current NWI spatial data to field delineations of wetland and non-wetland areas collected in 2001-2019.

Field-delineations were obtained from three NC state agencies and one federal agency and represented groundtruthed conditions (wetland presence or absence) for approximately 103,000 acres statewide. Field-delineations included a total of 4,655 individual wetlands statewide, with sizes ranging from <0.01 – 1,271 ac. Wetland size varied across the state and tended to be much smaller in the Blue Ridge (median = 0.1 ac.; mean = 0.3 ± 0.9 ac.) and Piedmont (median = 0.1 ac.; mean = 0.4 ± 1.3 ac.). In these two ecoregions, >90% of field-verified wetlands were below the NWI minimum mapping size of 0.5 ac. Wetlands tended to be larger in the in the Southeastern Plains (median = 0.6 ac.; mean = 2.5 ± 6.7 ac.) and Mid-Atlantic Coastal Plain (median = 0.7 ac.; mean = 9.0 ± 51 ac.) ecoregions, both of which are located in the eastern part of the state.

The relative frequency of wetlands in the field-delineated data was used to calculate an estimate of total wetland acreage statewide (3.98 million ac.) as well as for each of the four major ecoregions. These estimates were compared to wetland acreage derived from NWI, and results suggest that NWI underestimates wetlands statewide by approximately 60,000 ac. Results by ecoregion were mixed, with NWI drastically underestimating wetland acreage in the Blue Ridge and slightly underestimating acreage in the Mid-Atlantic Coastal Plain. NWI greatly overestimated wetland acreage in the Piedmont and moderately overestimated in the Southeastern Plains.

Multiple accuracy metrics were calculated using the NWI and corresponding field-delineations. The odds ratio was used to represent total accuracy for all classifications (wetland and non-wetland), and was highest in the Blue Ridge; had a moderate value in the Piedmont, Southeastern Plains, and statewide; and was lowest in the Mid-Atlantic Coastal Plain. However, further reviews of the data suggested that the high value in the Blue Ridge was likely due to the NWI correctly identifying the few large wetlands in this area while missing many small wetlands, which was confirmed by very low odds ratios for smaller feature size classes. Since the odds ratio reflects correct identification of non-wetlands as well as wetlands, the odds ratios were also likely inflated due to the high prevalence of large non-wetlands in the Blue Ridge. When examined by feature size, odds ratios ranged from 0.1 – 1.4 for all feature size classes <1.0 ac., which indicates extremely poor accuracy.

Errors of commission and omission for the wetland class were represented by User's Accuracy (UA_{WL}) and Producer's Accuracy (PA_{WL}), respectively. Small wetlands (all size classes ≤1.0 ac.) had extremely high errors of omission statewide, as indicated by very low PA_{WL} (8-29%), though errors of commission were low to moderate, as indicated by higher UA_{WL} (68 – 85%). Wetlands >1.0 ac. had somewhat high levels of omission and commission (PA_{WL} = 52%, UA_{WL} = 62%), and the similarity of these values suggest that NWI over- and under-predicts wetlands at roughly the same rate.

Results suggest that NWI is a largely unreliable data source for identification of smaller wetlands (<1.0 ac.) in NC. This leads to overall poor accuracy (specifically, high rates of omission for wetlands) in the central Piedmont and western Blue Ridge ecoregions, where wetlands are naturally much smaller. However, even in the eastern part of the state (Southeastern Plains and Mid-Atlantic Coastal Plain ecoregions), where wetlands tend to be much larger, NWI accuracy was still problematic in many areas, with almost all of the eastern Level IV ecoregions having UA_{WL} and/or PA_{WL} <75% (i.e., errors of commission and/or omission >25%), and several having UA_{WL} and/or PA_{WL} <50%.

While NWI can be a valuable data set when used for its intended purposes, the accuracy issues found for the NC data suggest it should be used with caution, particularly if smaller wetlands (<1.0 ac.) are of interest, or the area of interest is located in the central or western portion of the state where smaller wetlands are very common. Funding for more updated, accurate wetland mapping for the entire state of NC is sorely needed to provide government and the public with information needed to make sound management decisions.

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Abbreviations

EC_{WL}	Error of commission (wetland classification)
EO_{WL}	Error of omission (wetland classification)
FGDC	Federal Geographic Data Committee
NC	North Carolina
NCDCM	North Carolina Division of Coastal Management
NCDMS	North Carolina Division of Mitigation Services
NCDOT	North Carolina Department of Transportation
NCDWR	North Carolina Division of Water Resources
NLCD	National Land Cover Database
NPSGRSM	National Park Service Great Smoky Mountains National Park
NWCA	National Wetland Condition Assessment
NWI	National Wetlands Inventory
OA	Overall accuracy
PA_{WL}	Producer's Accuracy (wetland classification)
RPD	Relative percent difference
SD	Standard deviation
UA_{WL}	User's accuracy (wetland classification)
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service
USGS	United States Geological Survey
WOTUS	Waters of the United States

Introduction

Background

Maps of the location and extent of wetlands are used for many purposes, including natural resource research and management; environmental impact assessments for transportation planning and other development activities; hydrological and climatological modeling; water quality and watershed assessments; identification of conservation or ecological restoration opportunities (including compensatory mitigation); training and/or verification data for other remote sensing methods for land classification; and outreach/education to the general public. The most commonly used wetlands map in North Carolina (NC) is the National Wetlands Inventory (NWI) spatial data set.

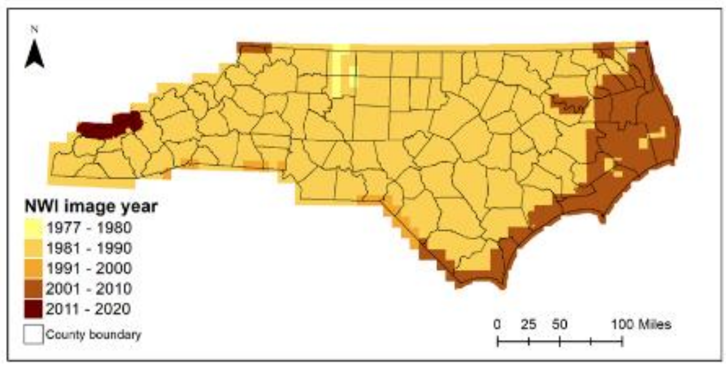


Figure 1. Dates of source imagery used to develop current NWI spatial data set in NC

Today's NWI remains largely unchanged from the original hard copy maps developed from aerial imagery collected in the 1980's and 1990's (Figure 1), and so often reflects conditions from over 30 years ago. The location, extent, and types of wetlands in the US have been changing, and continue to change, as a result of human activities and natural events, but there is no current mandate or responsibility to update the NWI. The US Fish and Wildlife Service (USFWS) was tasked with the original development of the NWI, but they have transitioned to solely managing the existing data set. Since no one is responsible for updating NWI, it will continue to represent 20th century conditions for the foreseeable future in NC.

In addition to concerns over the age of the data, the types of features included in the NWI are not necessarily representative of the types of ecosystems that are commonly considered "wetlands" by many natural resource professionals. Many wetland scientists and regulators currently define "wetlands" as land areas that are subject to saturation or shallow inundation, which results in the presence of additional field indicators such as hydrophytic vegetation and hydric soils. Common examples of these types of wetlands would be forested wetlands, fresh- and saltwater marshes, swamps, seeps, and bogs. The features depicted by the NWI include these types of features, but also include open water (lakes, reservoirs, ponds), lotic systems (streams and rivers), and deepwater fresh, estuarine, and marine habitats. These types of open water, flowing water, and deepwater habitats can certainly be important for wildlife management, which is likely why the USFWS chose to include them in the NWI, since the NWI was developed to meet this particular agency's mandates and responsibilities.

Many of the criticisms of the NWI may, in part, come from a misunderstanding of the purpose and requirements for development of the data set. The USFWS has repeatedly communicated that those criticisms are not valid because the maps are being used for purposes for which they were not designed, and there appears to be a misunderstanding on the part of many end-users about how the NWI was created and for what purpose (Tiner 1997). Federal wetland mapping standards that guide development of the NWI have formalized what is – and isn't – depicted on NWI, and the current standards (FGDC 2009) are fairly consistent with earlier documentation of the mapping procedures. Current standards include requirements for the use of the Cowardin classification system to define types of features depicted (including deepwater and open water habitats) (Cowardin 1979), minimum size of features to be mapped (≥0.5 ac.), the use of aerial imagery as the primary data source for identifying wetland features, and the scale of the source imagery.

The reliance on NWI for identification of wetlands for any other purposes than those for which it was developed can be problematic. The core issue is that the NWI is really the only source of wetland mapping within NC and for much of the US, so natural resource managers, the regulated community, and the general public must rely on NWI simply because there are no other options. This necessarily makes management of wetland resources extremely difficult since the accuracy of estimates of the resource extent is essentially unknown. It also has a direct economic impact on the regulated community, including Federal and State Transportation agencies and private entities whose activities may impact wetlands due to additional costs for project planning and implementation.

The use of NWI in applications for which it was not designed introduces a level of uncertainty to management activities, projects, or applications that employ NWI as a key part of the decision-making process. However, the magnitude of that uncertainty is poorly understood, as few formal assessments of NWI accuracy have been completed for many areas, including the state of NC, particularly against field-verified conditions. There is much anecdotal evidence that suggests that NWI does have issues with accuracy in NC, and that the level of accuracy likely varies across the state. A more formal, quantitative assessment of NWI would provide valuable information for decision-makers to assist with managing that uncertainty and the potential risks to the outcomes of their projects.

Study objectives

The US Fish and Wildlife Service (USFWS) was the original developer and is the current steward of the NWI, and has consistently maintained that perceived inaccuracies of the NWI are due to misuse of these maps beyond their initial intended purpose. Unfortunately, NWI is the only source depicting wetland locations that is available for most of the US, so it is often “misused” by necessity. It is believed that a formal, quantified assessment of the NWI would fill a significant knowledge gap for current users of the NWI beyond the USFWS, and allow more informed use of this data set.

The primary objective of this study was to quantify the accuracy of the NWI against field-delineated wetland and non-wetland areas across NC. The project relied on existing sources of field delineations, which were found to be a fairly robust data set with good coverage across the state. Therefore, a secondary objective was identified, which was to characterize wetland size and relative frequency across the state.

Methods

Project area

The project area consisted of the entire state of NC. A wide variety of natural conditions exist across the state, and differences in geology, landforms, soils, vegetation, climate, and hydrology affect the relative frequency, types, and size of wetlands present. For example, wetlands represent a large proportion of the landscape in coastal areas, but they tend to decrease in size and frequency in the central and the western portions of the state. To control for this diversity, data were further subdivided for most analyses using the US Environmental Protection's (USEPA) Level III ecoregions (Griffith 2002): Blue Ridge, Piedmont, Southeastern Plains, and Mid-Atlantic Coastal Plain (Figure 2). The state was further subdivided using the 27 Level IV ecoregions for some analyses (where field-delineated data were available).

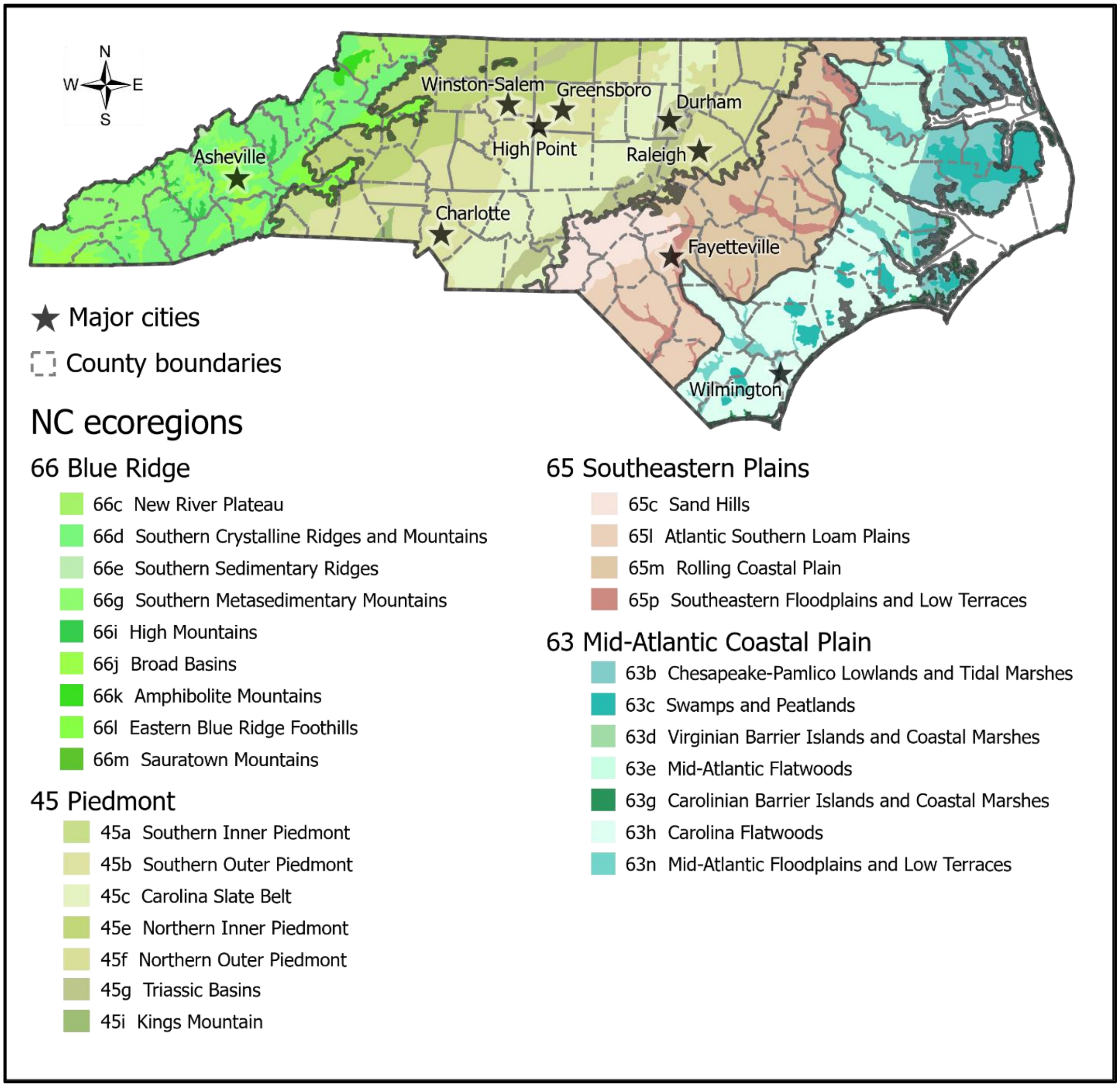


Figure 2. Level III and Level IV ecoregions of NC

General approach

The wetland features addressed by this study are generally considered to be habitats that are neither fully terrestrial ("upland") nor fully aquatic ecosystems. This aligns with the definition of "wetland" as defined the National Academy's Committee on Wetlands Characterization (National Research Council 1995):

> *"A wetland is an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation."*

The inclusion of secondary indicators of saturation/inundation (hydric soils, hydrophytic vegetation) and the specification of "shallow inundation" in this definition represent a subset of the types of features that are included in the NWI data set. For example, NWI also includes deepwater, open water, and lotic systems, which don't meet the definition above due to their deepwater or flowing water characteristics. Therefore, the statewide NWI spatial data were modified to remove features that were outside of this project's scope.

Spatial data representing field-delineated wetland and non-wetland features were obtained from four State and Federal agencies for comparison to NWI. These field-delineated data were also used to calculate descriptive statistics of wetland size and relative frequency in the landscape at several different scales: statewide; for each of the Level III ecoregions present in NC (Blue Ridge, Piedmont, Southeastern Plains, and Mid-Atlantic Coastal Plain); and for 24 of the 27 Level IV ecoregions present in NC.

Preparation of the NWI and field-delineated spatial data sets are described in more detail in the following sections of the report. The prepared vector data sets were then converted to raster format in ESRI ArcGIS Pro software and wetland presence/absence was compared at the level of each individual raster pixel. Multiple accuracy metrics were calculated in order to capture not only overall accuracy of NWI, but also rates of omission and commission for wetlands. Accuracy assessments were completed at multiple scales (statewide, Level III ecoregion, and Level IV ecoregion) and by size class.

Modification of National Wetlands Inventory (NWI) spatial data

The NWI spatial data and supporting documentation were downloaded from the USFWS website (https://www.fws.gov/wetlands/data/mapper.html) in June 2020 as a pre-staged geodatabase for the state of NC that depicted wetland features as a polygon (vector) data type. The original data set included almost 590,000 features that were assigned to one of eight general wetland types: Estuarine and Marine Deepwater; Estuarine and Marine Wetland; Freshwater Emergent Wetland; Freshwater Forested/Shrub Wetland; Freshwater Pond; Lake (including reservoirs); Riverine (streams, rivers, and similar lotic waterbodies); and Other. The NWI further subdivided these into 1,229 unique coded values corresponding to the Cowardin classification system described in the federal wetland mapping standards (FGDC 2013).

Many of the features included in the NWI were not relevant to this project, and had to be removed. Given the large number of features and unique Cowardin codes, it was not feasible to manually review each individual feature. The USEPA also encountered this issue during identification of sites for their National Wetland Condition Assessment (USEPA 2016) and had to complete a similar culling process. The USEPA approach was used as a model for this project, and features with the following Cowardin codes were removed from the NWI data: all Marine and Estuarine Deepwater types (Subsystems M1, M2, and E1); Estuarine Intertidal Aquatic Bed

(Class E2AB); Unconsolidated Shore (Class E2US); Rocky Shore (E2RS); Lacustrine (System L); Riverine (System R); Palustrine Unconsolidated Shore (PUS); and all non-beaver ponds (Classes PUB and PAB without "b" modifier). Farmed wetlands (Pf) were also excluded for this project, though they were included in the NWCA. All features were clipped to the NC boundary. The final modified NWI data set included the following wetland types/codes: Estuarine Intertidal Emergent (Class E2EM); Estuarine Forested (Class E2FO); Estuarine Scrub-Shrub (Class E2SS); Palustrine Emergent (Class PEM); Palustrine Scrub-Shrub (Class PSS); Palustrine Forested (Class PFO); and beaver ponds (Class PAB and PUB with the "b" modifier).

The final edited NWI vector (polygon) data set was then converted to a statewide raster with a resolution of 20 feet, with each pixel assigned a classification of NWI wetland or NWI non-wetland.

Field-delineated features

Sources of spatial data depicting field-delineated wetland and non-wetland features were obtained directly from several state agencies and one federal agency: NC Division of Water Resources (NCDWR) wetland monitoring program; NC Department of Transportation (NCDOT) project corridors field surveys; NC Division of Mitigation Services (NCDMS) wetland preservation sites; and the National Park Service Great Smoky Mountains National Park wetland field census (NPSGRSM). Features included in these data sets should not be considered jurisdictional determinations, as they were delineated only for research or preliminary environmental planning purposes, but can be assumed to have field indicators of wetland hydrology, hydrophytic vegetation, and hydric soils. All data sets included wetland features, but only the NCDOT and NPSGRSM data included non-wetland features.

Spatial data underwent manual and automated quality checks to identify and correct potential issues, such as bad topology (for example, overlapping features), duplicated features, or missing attributes. The year of last field verification was not provided with the spatial data in some cases, so original documentation for each project was reviewed to assign a year of field verification to those features that were missing this information. Unfortunately, wetland type was not provided for most features. Even when assigned, different projects used different classification systems, including NC Wetlands Assessment Method (NCWFAT 2016), NC Natural Heritage Program (Schafele 1990), and NC compensatory mitigation type. Therefore, differences based on wetland type could not be addressed during this study.

The final set of field-delineated vector data was converted to a raster with identical resolution and statewide extent as the one created from the modified NWI data. The raster of field-delineated features was joined to the attribute table from the original vector data in order to retain the characteristics of the original features, such as size (in acres), data source (i.e., agency that collected the data), and ecoregion (Level III and Level IV). An additional field was created to contain the classification (wetland or non-wetland) assigned for those raster pixels located within field-delineated features. All other pixels were assigned no classification (i.e., left as null) so that these pixels would be excluded from analyses. Finally, wetland and non-wetland pixels were screened to determine if they had stable land use throughout the time period of interest. This was done by comparing the land use category (e.g., Wetlands, Developed, Forest) assigned by the National Land Cover Database (NLCD) in 2001 and 2016 for each raster pixel. A change in land use suggested that the original wetland or non-wetland classification assigned during field delineation may no longer be valid, so any pixels showing a change in their land use category were excluded from further analyses.

Accuracy assessments

The NWI and field-delineated rasters were overlaid in ESRI ArcGIS Pro. The classifications for individual pixels from both data sets (along with ancillary characteristics from the field-delineated data) were exported to a text file for analysis. Any pixel that had a null value in one or both data sources was excluded from analysis.

The first step in the analysis process was to create a contingency table, also referred to as a confusion matrix (Table 1). For each data record (i.e., raster pixel), the NWI classification was compared to the field-delineated classification and assigned a wetland classification accuracy of true positive (*A* in Table 1), false positive (*B*), false negative (*C*), or true negative (*D*). The total number of records in each category was used to build a contingency table, which is the basis for calculating many common accuracy measures (Congalton 1991), (Fielding 1997).

Table 1. Contingency table example

		Field-delineated classification		
		Wetland	Non-wetland	TOTAL
NWI classification	Wetland	A	B	A + B
	Non-wetland	C	D	C + D
	TOTAL	A + C	B + D	A + B + C + D

For this project, accuracy metrics included overall accuracy (OA), error of commission (EC), error of omission (EO), Producer's Accuracy (PA), and User's Accuracy (UA), and were calculated using the following equations:

$$Overall\ accuracy\ (OA)\ (\%) = \frac{A + D}{A + B + C + D} \times 100$$

$$Error\ of\ omission_{wetland}\ (EO_{WL})\ (\%) = \frac{C}{A + C} \times 100$$

$$Error\ of\ commission_{wetland}\ (EC_{WL})\ (\%) = \frac{B}{A + B} \times 100$$

$$Producer's\ accuracy_{wetland} (PA_{WL})\ (\%) = \frac{A}{A + C} \times 100 = (1 - EO_{WL}) \times 100$$

$$User's\ accuracy_{wetland}\ (UA_{WL})\ (\%) = \frac{A}{A + B} \times 100 = (1 - EC_{WL}) \times 100$$

Overall accuracy (in this case, the percentage of pixels that were correctly classified by NWI) is one of the more commonly reported metrics in land classification accuracy assessments. It reflects the accuracy of all categories (in this case, wetland and non-wetland) but can be somewhat misleading if one class is much more prevalent than the other, as is the case with non-wetlands and wetlands in NC. A better understanding of NWI accuracy can be gained by examining the additional accuracy metrics described above that focus on a single classification, such as wetlands. For example, EO_{WL} quantifies the frequency of predicting a non-wetland on the ground when a wetland does exist and EC_{WL} indicates the frequency of a wetland being predicted on the ground when one does not exist. These measures are captured by PA_{WL} and UA_{WL}, which historically have been the measures most commonly reported for land classification mapping. PA_{WL} is often described as accuracy from the mapper's perspective and describes the frequency at which a particular classification that exists on the ground is correctly identified by the map (NWI, in this case). A high PA_{WL} implies a low EO_{WL}. Conversely, UA_{WL} represents the perspective of the map user, and is the frequency that a specific classification will be found on the ground when it is indicated on the map. A high UA_{WL} implies a low EC_{WL}.

The odds-ratio statistic, like overall accuracy, provides a single number to represent the accuracy of the all classifications. However, it is not sensitive to relative differences in prevalence between classes (Fielding 1997), making it useful for comparisons across data groupings or categories (such as size class or ecoregions), so the odds ratio (as opposed to overall accuracy) is used in this report. It is calculated as:

$$Odds\ ratio = \frac{A * D}{B * C}$$

The odds ratio has a lower limit of 0, and the upper limit is dependent on the sample size. It is undefined when *B* and/or *C* is equal to 0. Larger values of the odds ratio indicate higher accuracy.

An additional metric – the relative percent difference (RPD) – was used to compare absolute values from two different data sets (for example, total wetland acres from NWI and from field-delineated data). RPD is not calculated using a contingency table, instead it is a calculated using the individual results (X and Y) from the two different sources that are being compared:

$$Relative\ percent\ difference\ (RPD)(\%) = \frac{|X - Y|}{(X + Y)/2} \times 100$$

The value of the RPD is that it takes the magnitude of a particular pair of measurements/results into account in the calculation. In other words, an absolute difference of 2 between X and Y would likely be considered negligible if $X = 998$ and $Y = 1000$, but would be of concern if $X = 5$ and $Y = 7$.

Results

Characteristics of NC wetlands

The field-delineated wetland and non-wetland features in the final edited data set were last field-verified between 2002-2019 and represented just over 103,000 acres of field-verified conditions (Table 2). Data were available for all Level III ecoregions and for 24 of 27 Level IV ecoregions, though several of these had very small sample sizes. While this data set was not collected using stringent statistical sampling methods, it does represent a substantial statewide snapshot of wetlands across the state of NC (Figure 3). Relative density of available data varied and was more strongly clustered around the larger metropolitan areas (Figure 4).

Table 2. Summary of wetland and non-wetland area and wetland frequency by ecoregion for field-delineated features

Ecoregion (Level III) Ecoregion (Level IV)	**Non-wetland acres**	**Wetland acres**	**Wetland frequency by area**
Blue Ridge	***14,370***	***177***	***1%***
66c New River Plateau	988	23	2%
66d Southern Crystalline Ridges and Mountains	980	6	1%
66g Southern Metasedimentary Mountains	5,690	59	1%
66i High Mountains	1,847	22	1%
66j Broad Basins	4,846	63	1%
66k Amphibolite Mountains	19	3	14%
66l Eastern Blue Ridge Foothills	0	< 1	100%
66m Sauratown Mountains	0	1	100%
Piedmont	***39,759***	***592***	***1%***
45a Southern Inner Piedmont	523	0	0%
45b Southern Outer Piedmont	19,308	181	1%
45c Carolina Slate Belt	9,857	236	2%
45e Northern Inner Piedmont	4,141	54	1%
45f Northern Outer Piedmont	2,433	63	3%
45g Triassic Basins	3,498	58	2%
Southeastern Plains	***19,153***	***2,399***	***11%***
65c Sand Hills	3,090	414	12%
65l Atlantic Southern Loam Plains	4,496	796	15%
65m Rolling Coastal Plain	10,990	1,041	9%
65p Southeastern Floodplains and Low Terraces	577	148	20%
Middle Atlantic Coastal Plain	***16,894***	***10,172***	***38%***
63b Chesapeake-Pamlico Lowlands and Tidal Marshes	3,872	1,571	29%
63c Swamps and Peatlands	39	716	95%
63e Mid-Atlantic Flatwoods	2,647	1,745	40%
63g Carolinian Barrier Islands and Coastal Marshes	397	763	66%
63h Carolina Flatwoods	9,730	5,139	35%
63n Mid-Atlantic Floodplains and Low Terraces	209	239	53%
Statewide	***90,176***	***13,340***	***13%***

The relative frequency of wetlands on the landscape was calculated as total area of wetlands as a percentage of total surveyed area. Frequency was 1% in the Blue Ridge and Piedmont, 11% in the Southeastern Plains, and 38% in the Mid-Atlantic Coastal Plain. The NCDOT data, which was the largest single source of field-delineated data, may represent a slight underestimation of wetland frequency since project corridors are often selected based on their relatively lower impacts to cultural and natural resources (such as wetlands), among other factors. Conversely, since no non-wetland areas were surveyed by NCDWR or NCDMS, those data sources may be leading to a slight overestimation of wetland frequency. For example, two Blue Ridge Level IV ecoregions (66l Eastern Blue Ridge Foothills and 66m Sauratown Mountains) had wetland frequency of 100%, but this was due to a lack of field-delineated non-wetlands in these ecoregions.

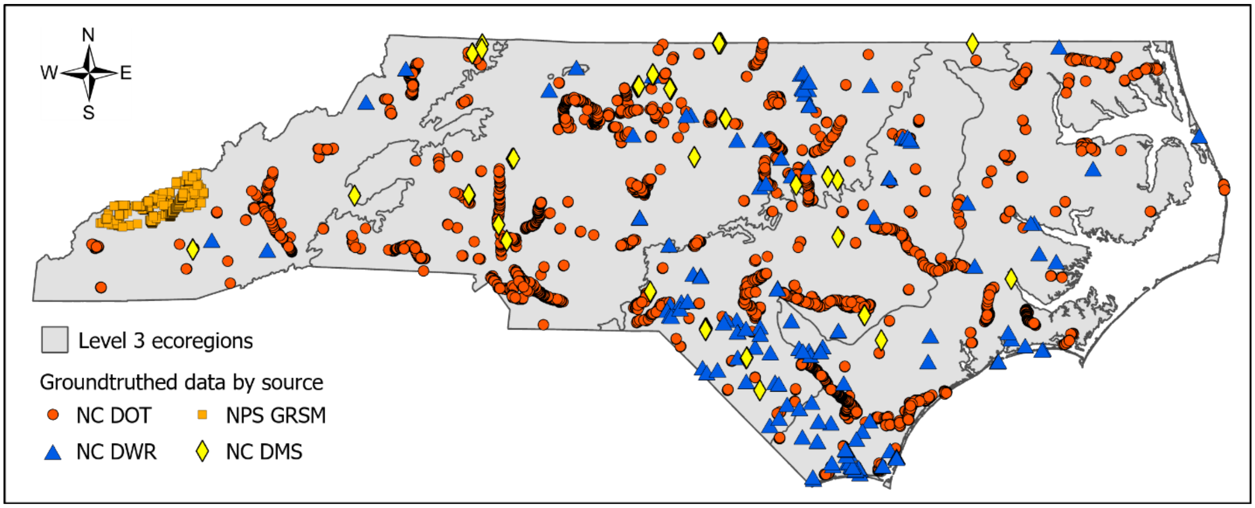


Figure 3. Location of field-delineated data by source agency

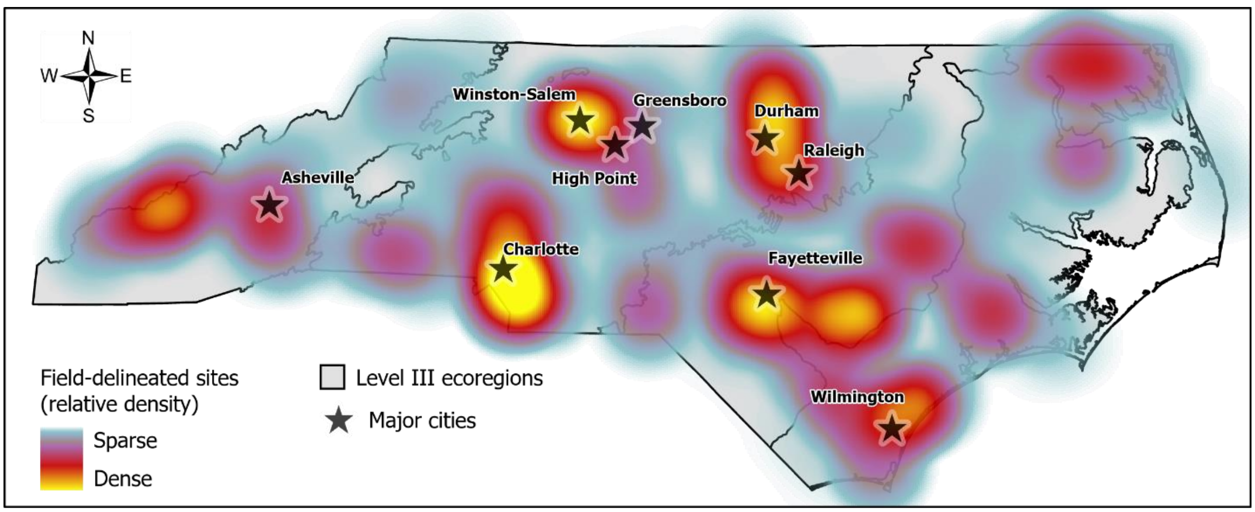


Figure 4. Relative density of field-delineated features

Total wetland acreage by Level III ecoregion and statewide were estimated using these frequencies and the total land area for each ecoregion derived from the USEPA ecoregion spatial data (Table 3). The total estimated wetland acreage for the state was 3.98 million ac., but the great majority (3.1 million ac.) came from the Mid-Atlantic Coastal Plain ecoregion. While wetland frequency was roughly equal (1%) in the Blue Ridge and Piedmont, the total estimated acreages for these ecoregions were vastly different: ~53,000 ac. in the Blue Ridge and ~117,000 ac. in the Piedmont. Estimated acreage in the Southeastern Plains ecoregion (~706,000 ac.) was intermediate between the Piedmont and Mid-Atlantic Coastal Plain.

Table 3. Estimated wetland acreage by Level III ecoregion and statewide

Ecoregion (Level III)	Region area (ac.)	Estimated wetland frequency	Estimated wetland area (ac.)
Blue Ridge	5,302,820	1%	53,028
Piedmont	11,718,586	1%	117,186
Southeastern Plains	6,416,176	11%	705,779
Mid-Atlantic Coastal Plain	8,159,745	38%	3,100,703
STATEWIDE	31,597,326	13%	3,976,696

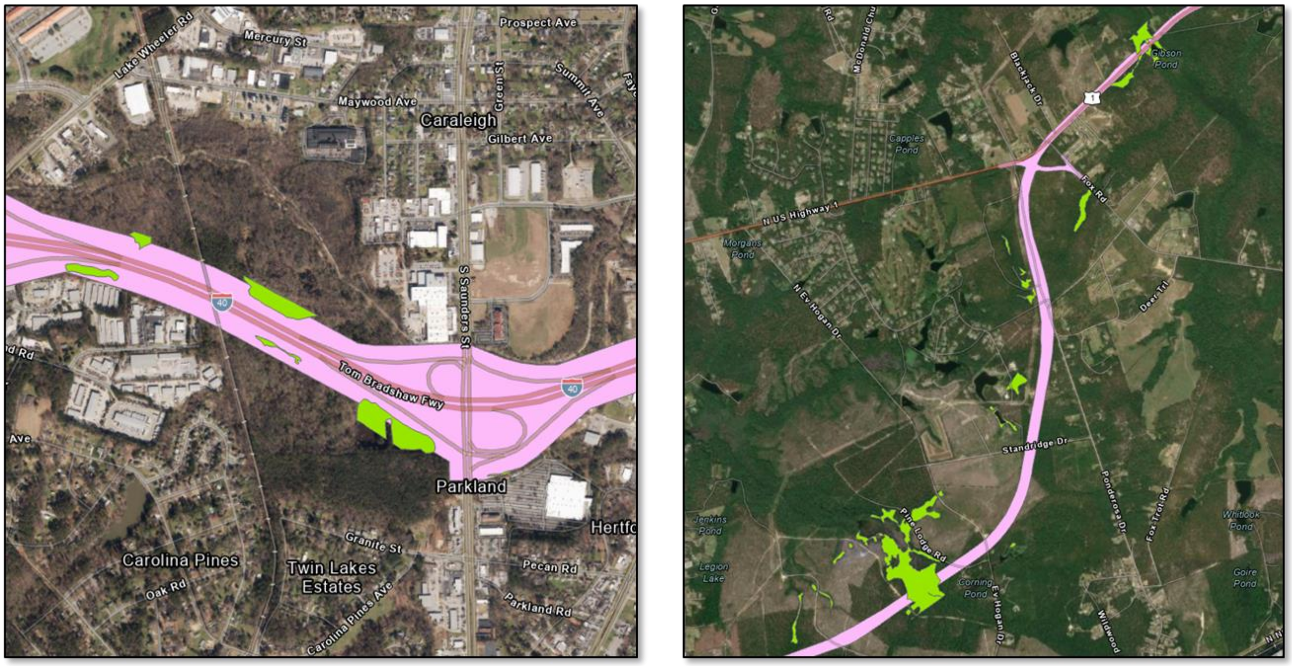
The size of individual wetlands varied greatly across ecoregions (Table 4). Size distributions were fairly similar for the Piedmont and Blue Ridge, as was seen for relative wetland frequency. Median values were very similar between the Southeastern Plains and Mid-Atlantic Coastal Plain but the mean and standard deviation (SD) was much higher in the Mid-Atlantic Coastal Plain.

Table 4. Descriptive statistics of field-delineated wetland size by Level III ecoregion

			Percentiles of wetland feature area (ac)						
Ecoregion	**# wetland features**	**Mean area (ac) ± SD**	**Min**	**10th**	**25th**	**50th**	**75th**	**90th**	**Max**
Blue Ridge	690	0.3 ± 0.9	0.002	0.01	0.03	0.1	0.2	0.5	15.8
Piedmont	1,666	0.4 ± 1.3	0.002	0.01	0.04	0.1	0.3	0.8	30.7
Southeastern Plains	1,009	2.5 ± 6.7	0.002	0.05	0.2	0.6	1.9	6.4	79.0
Mid-Atlantic Coastal Plain	1,290	9.0 ± 51	0.001	0.05	0.2	0.7	2.9	13.8	1,271
STATEWIDE	4,655	3.2 ± 27	0.001	0.02	0.06	0.22	0.89	3.6	1,271

Statewide, 68% of field-delineated wetlands were below the NWI minimum mapping size of 0.5 ac. In both the Piedmont and Blue Ridge, the median (50th percentile) for field-delineated wetland size was 0.1 ac., and more than 90% of wetlands were smaller than 1.0 ac. Only the Mid-Atlantic Coastal Plain and Southeastern Plains Level III ecoregions had median wetland areas that were above the NWI mapping threshold.

However, field-delineated data were likely biased towards smaller wetlands. For example, certain NCDWR wetland monitoring projects targeted wetland types that naturally tend to be smaller in size (e.g., headwater wetlands) (K. Gianopulos, 2021, personal communication). In the case of NCDOT projects, project corridors were generally only 500-1000 ft. wide, which is sufficient to capture potential impacts due to a linear transportation project but not necessarily able to capture the full extent of larger wetlands. NCDOT surveys sometimes included only the portion of large wetlands that intersected the project corridor (Figure 5A), but in other cases, delineations were conducted outside of the corridors to fully capture the full extent of larger wetlands (Figure 5B). Visual reviews of the spatial data suggested that small wetlands tended to be fully delineated in most cases, but full delineation of larger wetlands was inconsistent.



5A. Wetland delineations contained within corridor

5B. Wetland delineations outside of corridor

Figure 5. Examples of NCDOT field delineations (non-wetlands in pink and wetlands in green).
Figure 5A is an example of wetland delineations restricted to within project corridor. Figure 5B is an example of wetlands delineated outside of the project corridor.

Comparison of field-delineated and NWI wetlands

Summary statistics of wetland size were also calculated for the final edited version of the NWI and compared to the field-delineated data (Table 5). The NWI was anticipated to be biased towards larger wetlands due to its minimum mapping size of 0.5 ac., and would also be much more likely than the field-delineated datasets to fully capture some of the very large wetlands that exist within the state. The NWI did contain some smaller features, though: approximately 25,500 statewide were <0.5 ac., and of those, 2,700 were <0.1 ac. However, the field-delineated data contained just over 2,000 wetlands that were ≤0.1 ac., but the total area of field-delineated features represented approximately 0.3% of the total land area of the state. Overall the NWI wetlands were much larger than the field-delineated wetlands, generally by at least one order of magnitude.

Even though both data sources (NWI and field-delineated wetlands) had their own sources of bias, the field-delineated data do suggest that there are many small (<0.5 ac.) wetlands in the state that NWI is not capturing well. This is actually an expected limitation of NWI, based on the federal wetland mapping standards used to develop the NWI (FGDC 2009).

Table 5. Comparison of statewide wetland size distributions in field-delineated data and modified NWI

			Percentiles of wetland feature area (ac)						
Data source	**# wetland features**	**Mean area (ac) ± SD**	**Min**	**10th**	**25th**	**50th**	**75th**	**90th**	**Max**
NWI	211,020	19 ± 125	<0.01	0.44	1.1	3.4	11	33	17,405
Field-delineated data	4,655	3.2 ± 27	<0.01	0.02	0.06	0.22	0.89	3.6	1,271

Comparisons of estimates of total wetland acreage

Total wetland acreage in the modified NWI spatial data set was calculated in ESRI ArcGIS Pro for all Level III ecoregions. Estimates of wetland acreage were also calculated using the relative frequency of wetlands from the field-delineated data and total area of each ecoregion. Differences between the estimated wetland acreages from NWI and from the field-delineated data were reported as net raw acres and the relative percent difference (RPD). Results are shown in Table 6.

Table 6 Estimated wetland acreage based on NWI and field-delineated data by ecoregion and statewide

		Estimated wetland area (ac.)		Difference (NWI - Field)	
Ecoregion (Level III)	**Region area (ac.)**	**NWI**	**Field-delineated**	**Net difference (ac.)**	**Relative percent difference (RPD)**
Blue Ridge	5,302,820	8,128	53,028	- 44,900	147%
Piedmont	11,718,586	221,741	117,186	104,555	62%
Southeastern Plains	6,416,176	904,592	705,779	198,813	25%
Mid-Atlantic Coastal Plain	8,159,745	2,782,054	3,100,703	- 318,649	11%
STATEWIDE	31,597,326	3,916,515	3,976,696	- 60,181	2%

Total statewide wetland acreage from NWI was slightly less than the estimate from the field-delineated data by 60,181 acres (2% RPD). However, differences between the two estimates did not show a consistent pattern when examined by Level III ecoregion. For example, the NWI estimate of total wetland acres in the Blue Ridge was almost 45,000 acres less than the field-delineated estimate, with a very large RPD of 147%. Given the small size of wetlands in this area of the state, this suggests that NWI could be omitting a very large number of individual, small wetlands. In the Piedmont, the NWI estimate was quite a bit higher than the field-delineated estimate, by almost 105,000 acres, with an RPD of 62%. A similar inconsistency was seen in the eastern portion of the state, with NWI estimates being higher than the field-delineated estimates in the Southeastern Plains (net difference of 198,813 ac., 25% RPD) and lower in the Mid-Atlantic Coastal Plain (net difference of -318,649 ac., 11% RPD). Even though the differences in net acreage were much larger for these two ecoregions, they represented a much smaller proportion because of the overall higher prevalence of wetlands in these areas, which is reflected by the RPDs.

NWI Accuracy

During exploratory data analyses it was found that the accuracy between NWI and the NCDWR and NCDMS field-delineated wetland data was much greater than when compared to the NCDOT data, as indicated by higher rates of true positives for those agencies' data (NCDWR 81%, NCDMS 83%, NCDOT 49%). A review of documentation from the programs that collected the field data indicated that NCDWR and NCDMS often used NWI for initial identification of wetlands for many of their projects. Due to this site selection process, it would be expected that there would be significant overlap between the field delineations from NCDWR and NCDMS and the NWI data sets, and this could artificially increase accuracy metrics for NWI.

NPSGRSM sites also showed higher true positive rates when compared to NCDOT (NPSGRSM 61%, NCDOT 49%). A more detailed examination of the metadata provided with the NPSGRSM and NWI spatial data indicated that NWI had been updated in 2015 by NPSGRSM using their field delineations. This brought into question the original assumption that the GRSM data represented an "independent" verification data set, since significant portions of the field delineations had been incorporated into NWI already.

The NCDOT data were the only source of field-delineated data collected that used a census-type field survey approach, and therefore had a significantly greater level of independence from NWI than the data collected by other agencies. Therefore, only the NCDOT data were used for calculation of the NWI accuracy metrics described in this section. The full set of raw values from contingency tables and associated accuracy metrics are provided in the *Appendix: Contingency table values and accuracy metric summaries*.

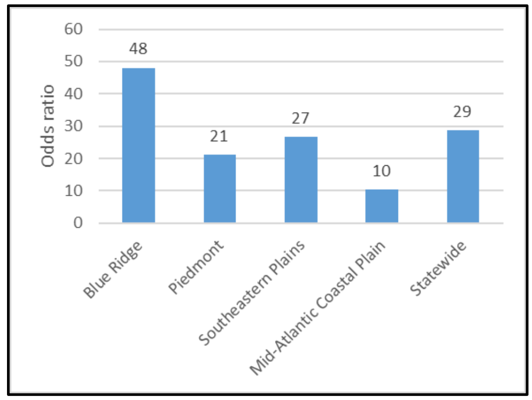


Figure 6. Odds ratios for NWI accuracy by Level III ecoregion and statewide

NWI accuracy was first examined statewide and by Level III ecoregions. Odds ratios (Figure 6) indicated that combined accuracy for wetland and non-wetland categories was highest in the Blue Ridge and lowest in the Mid-Atlantic Coastal Plain. The high value in the Blue Ridge was somewhat unexpected, given that field-delineated wetlands in this area tended to be small and were not anticipated to be captured well by NWI. A manual review of spatial data indicated that NWI is likely capturing the largest wetland features in this area while missing the great majority of the smaller wetlands (see

Figure 7 for examples). Since the accuracy assessment was done at the scale of individual pixels in the raster spatial data, the large wetland features would contribute more pixels, and therefore could mask the poor accuracy of NWI in regards to very small wetlands. Also, since the odds ratio reflects the accuracy of correctly identifying non-wetlands as well as wetlands, these unexpected results could be due to a high rate of correctly identifying non-wetlands, which are much more prevalent than wetlands in the Blue Ridge. Conversely, wetlands were much more prevalent in the Mid-Atlantic Coastal Plain, so high rates of errors in correctly identifying non-wetlands could lead to a lowering of odds ratio in this area of the state.

Figure 7. Examples of NWI wetlands and field-delineated wetlands in two corridors in the Blue Ridge ecoregion (Level IV ecoregion 66j Broad Basins)

When odds ratios were reviewed by size classes (<0.1 ac., 0.1-0.25 ac., 0.25-0.5 ac., 0.5-1.0 ac., and >1.0ac), stark differences were found between smaller (≤1.0 ac.) and larger (>1.0 ac.) features (Figure 8). Since the odds ratio takes into consideration the accuracy of all classes (wetlands and non-wetlands) and non-wetland areas tended to be larger, this relatively high odds ratio for features >1.0 ac. may be due, in part, to NWI accurately identifying non-wetlands in addition to large wetlands. However, the more notable result was that the odds ratios for the smaller size classes were extremely low, suggesting that NWI does very poorly at correctly identifying small features, which is particularly problematic, given that the vast majority of the wetlands in the field-delineated data had areas ≤1.0 ac.

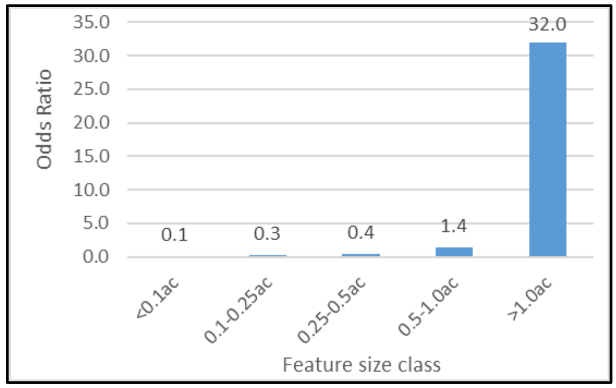


Figure 8. Odds ratios for NWI accuracy by size class

Odds ratios were also examined by Level IV ecoregion to determine if NWI's accuracy varied spatially (Figure 9, Figure 10), but there was no obvious overall pattern. The Mid-Atlantic Coastal Plain had some of the lowest odds ratios, with the exception of 63n Mid-Atlantic Floodplains and Low Terraces. Very low values were also seen in 66c New River Plateau and 45c Carolina Slate Belt. Areas with the highest odds ratios included 65c Sandhills, 45f Northern Outer Piedmont, and 66j Broad Basins. This last ecoregion was the source of the previous examples comparing NWI and field-delineated wetlands of variable sizes (Figure 7), so this relatively high accuracy may reflect accurate capture of the few large wetlands in this area. The 66j Broad Basins also had the largest total acreage of field-delineated data in the Blue Ridge ecoregion, and so the correct identification of non-wetlands may have contributed to this higher odds ratio.

Two ecoregions (66d Southern Crystalline Ridges and Mountains and 45a Southern Inner Piedmont) had no correctly identified wetland pixels, which resulted in odds ratios of 0. Two others (66g Metasedimentary Mountains and 66k Amphibolite Mountains) had undefined odds ratios due to a lack of false positives and true positives for wetlands. These Level IV ecoregions had very small sample sizes with very few field-delineated wetland pixels (ranging from 12 to 697), so results for these four Level IV ecoregions should be interpreted with caution.

Accuracy of NWI with regards to only the wetland classification is better captured by the PA_{WL} and UA_{WL}. Overall, PA_{WL} increased with increasing wetland size. UA_{WL} also increased with size, but only for wetland size classes ≤1.0 ac. The combination of very low PA_{WL} and relatively high UA_{WL} values for all but the largest wetland size class (Figure 11), implies that NWI had large errors of omission for wetlands ≤1.0 ac., but those smaller wetlands that are depicted by NWI are likely to exist on the ground. Large wetlands (>1.0 ac.) exhibited a different pattern – PA_{WL} was higher than the PA_{WL} results for smaller wetlands, and therefore NWI had a

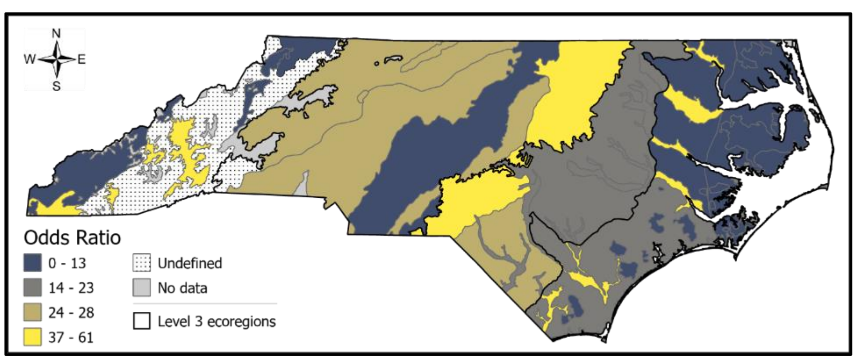


Figure 9. Map of odds ratio by Level IV ecoregion for NWI. Ranges for symbology correspond to quantiles of all odds ratios.

lower error of omission for large wetlands. However, there was also a higher level of commission errors for large wetlands as compared to wetlands ≤1.0 ac.

Since wetland size varies across the state, these results based on size class suggest that NWI is more likely to underestimate wetlands in the Piedmont and Blue Ridge ecoregions than in eastern portions of the state. This was confirmed using PA_{WL} results by Level III ecoregion (Figure 12). Notably, UA_{WL} values were also very low for the Blue Ridge and Piedmont. The combination of low PA_{WL} and low UA_{WL} in these two ecoregions implies that NWI has high rates of both omission and commission and would be expected to be highly unreliable for identifying wetlands in these areas. PA_{WL} and UA_{WL} were higher in the Southeastern Plains and Mid-Atlantic Coastal Plain, but still suggest moderate to high levels of omission and commission.

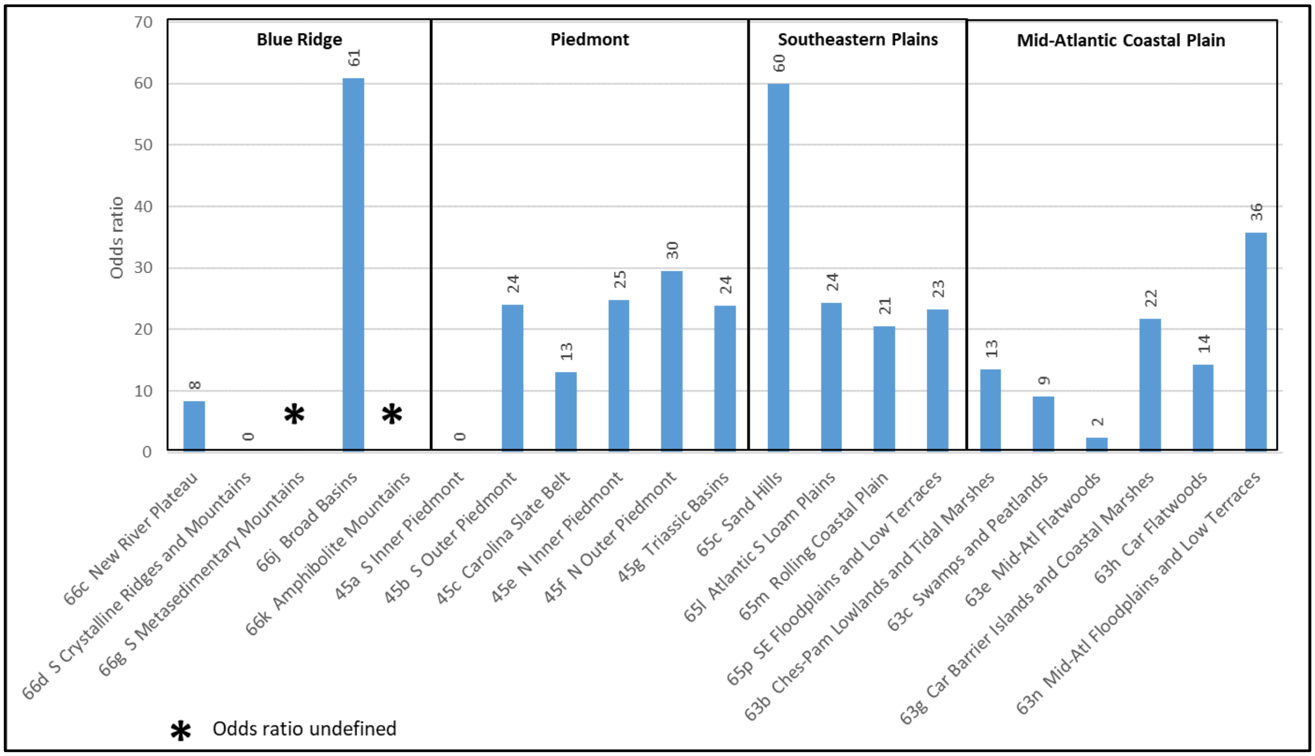


Figure 10. Odds ratios by Level IV ecoregion for NWI

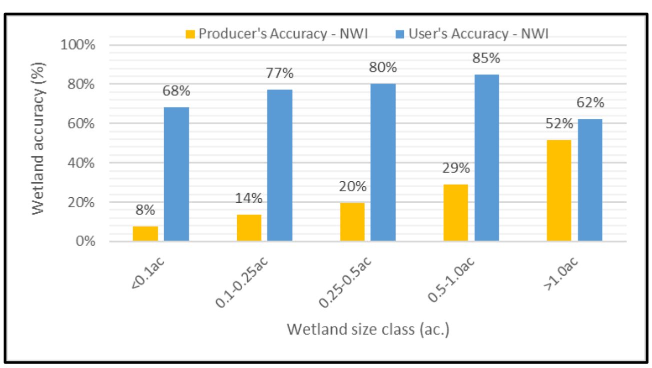


Figure 11. Producer's Accuracy and User's Accuracy for NWI wetlands by size class

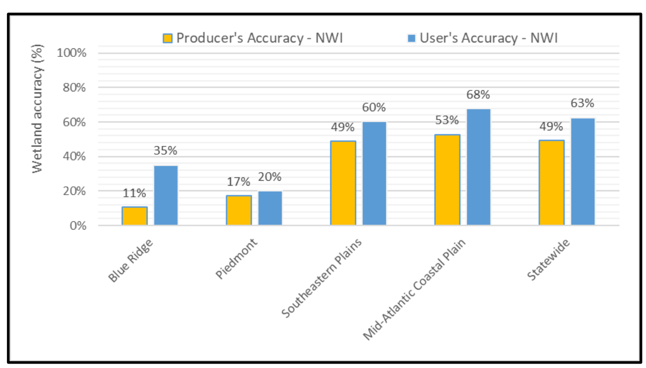


Figure 12. Producer's Accuracy and User's Accuracy for NWI wetlands by Level III ecoregions

When PA_{WL} results were examined by Level IV ecoregion (Figure 13, Figure 14, Figure 15), it was found that NWI misidentified the majority of wetland pixels as non-wetlands for the entirety of the Blue Ridge and Piedmont ecoregions (indicated by PA_{WL} much less than 50% for most Level IV ecoregions in these areas). UA_{WL} was also low (<75%) for the majority of the state. The combination of low PA_{WL} and low UA_{WL} suggests that NWI has high errors of both omission and commission in many areas. This was particularly problematic in the western and central areas of the state, where PA_{WL} and UA_{WL} were <25% for almost all Level IV ecoregions. Four Level IV ecoregions in the Blue Ridge and Piedmont had no wetland pixels correctly identified by NWI, though these had small sample sizes for number of wetland pixels.

While overall, PA_{WL} and UA_{WL} were higher in the eastern part of the state, there were still some Level IV ecoregions where NWI had PA_{WL} and/or UA_{WL} <75% (in some cases, <50%), including all of the Southeastern Plains and three of four Level IV ecoregions in the Mid-Atlantic Coastal Plain. The highest PA_{WL} and UA_{WL} results were seen for three Level IV ecoregions in the Mid-Atlantic Coastal Plain (63c Swamps & Peatlands; 63g Carolina Barrier Islands and Coastal Marshes; and 63n Mid-Atlantic Floodplains and Low Terraces), which were also the Level IV ecoregions that had the highest relative frequency of wetlands in the field-delineated data (53 – 95%).

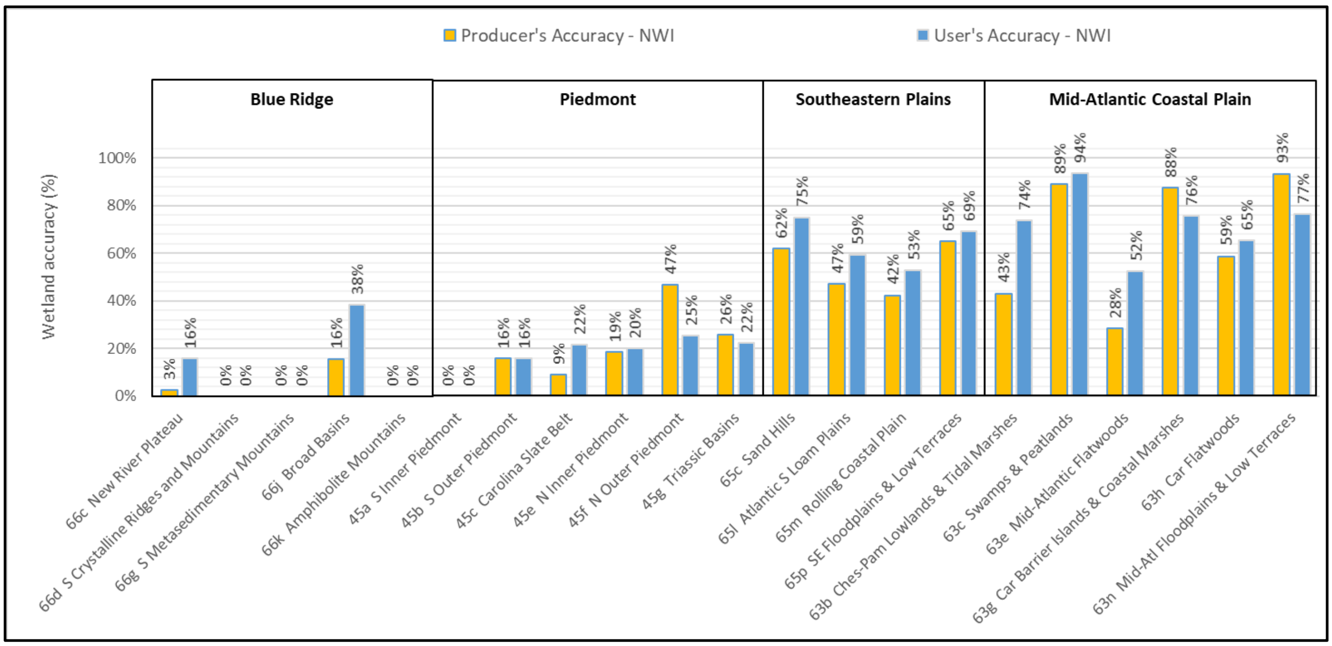


Figure 13. Producer's Accuracy and User's Accuracy for NWI wetlands by Level IV ecoregion

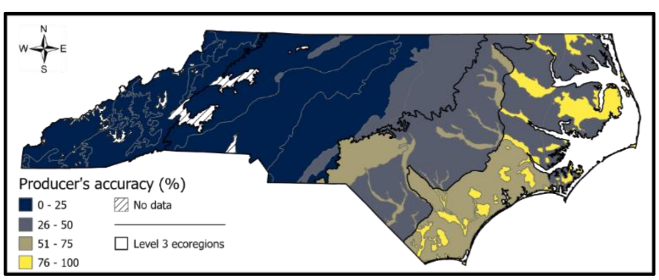


Figure 14. Map of Producer's accuracy of NWI for wetlands by Level IV ecoregion

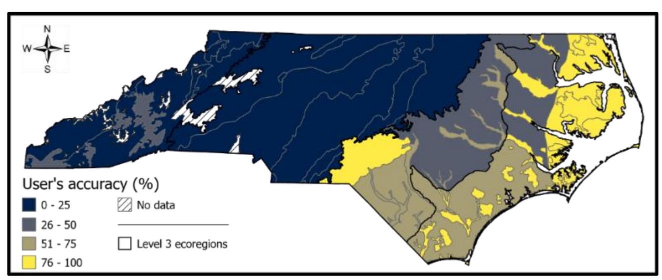


Figure 15. Map of User's accuracy of NWI for wetlands by Level IV ecoregion

It should be noted that a quantitative spatial analysis of results was not completed to determine if the issues with over- and under-prediction by NWI were due to spatial inaccuracies (i.e., NWI wetlands are in close proximity to field-delineated wetlands, or extent of individual wetlands over- or under-represented) or if NWI was missing some features and predicting others incorrectly. Spatial results were visually reviewed in several areas of the Piedmont ecoregion and issues did not appear to be due to spatial inaccuracies, but a more formal analysis would be helpful to further explore this issue.

Discussion

Results from this study strongly suggest that NWI is poorly suited for the identification of wetlands characterized by constant or recurrent, shallow inundation or saturation at or near the surface of the substrate, which are the types of wetlands of most interest to wetland scientists, regulators, and the regulated community. NWI accuracy was found to be generally poor for most areas of the state and was extremely problematic for wetlands ≤1.0 ac. in size. In the central and western portions of NC, the great majority of wetlands were well below this size, and consequently these areas had some of the highest errors of omission for NWI. The omission of smaller wetlands by NWI has been identified in other areas of the US as well (e.g., Gage 2020, Guidugli-Cook 2017, Stolt 1995). As in this study, errors in NWI were often attributed to the minimum mapping size inherent in the NWI mapping methods, and this is an acknowledged limitation of the NWI mapping process (Tiner 1997). However, features below the minimum mapping size were present in the NWI, suggesting that mapping methods had not necessarily been strictly followed; this can certainly lead to confusion on the part of an end-user of NWI in terms of the types of features that NWI intends to represent.

Other studies of NWI accuracy have also reported high errors of omission that grossly underestimate total wetland acreage, and high errors of omission associated with certain wetland types (particularly forested types) due to the reliance on aerial imagery in production of the NWI (Guidugli-Cook 2017, Morrissey 2006, Stolt 1995, Tiner 1997). Our results corroborate the finding that NWI drastically under-represents total wetland acreage in certain parts of the state when compared to estimates derived from our field-delineated data, though there were also areas of the state where NWI overestimated total wetland acreage. These variations in accuracy of NWI extent did not follow any obvious gradient, such as the relative frequency of wetlands for individual ecoregions, suggesting that NWI accuracy varies erratically and unpredictably across NC.

It should be noted, though, that results from other NWI accuracy assessments conducted across the US have been extremely variable (Gage 2020). One difficulty in making comparisons to other studies is that there is no consistency in how accuracy is reported so direct comparisons are somewhat difficult. For example, in many of these studies, an “overall” accuracy may be reported but the method for calculating that value was unclear. In other cases, merely a rate of true positives was reported, though a few studies have provided more detailed information on errors of commission and omission. As was demonstrated in this study, a single measure generally cannot provide a full characterization of accuracy. This variability in NWI accuracy in other studies may reflect differences in the accuracy metrics used, as well as differences in study methods or the data used for verification of NWI (e.g., field-verified vs. interpretation of aerial imagery). Or, as we found in our study, NWI may simply have inconsistent and unpredictable accuracy for different areas.

However, NWI is still the most widely used and referenced wetland map within NC. This reliance on a data set that was not designed for the types of applications for which it is currently used leads to increased uncertainty and costs for resource managers, wetland scientists, regulatory agencies, and the regulated community. In addition, the inaccuracies of NWI are propagated into other data sources as well, since it has been incorporated into other maps and spatial data sources, such as the US Geological Survey (USGS) legacy 1:24,000 scale topographic and current USGS US Topo maps (Davis 2019), the National Land Cover Database (NLCD) (Yang

2018), and NC Division of Coastal Management (NCDCM) spatial data (Sutter 1999). A particularly alarming trend in research is the use of NWI as training and testing data for research focused on spatial modeling for remote identification of wetlands (see Gage 2020 for several recent examples). This approach will proliferate the errors and limitations inherent in the current NWI, even though the use of geospatial modeling to identify wetlands in the landscape is one of the more promising methods for creating new wetland maps.

The use of automated remote modeling methods for remote identification of wetlands is a growing area of research, given the wide variety of sources available now for remote sensing, multispectral imagery, digital elevation models, and other sources of high quality spatial data (Guo 2017). The increases in consumer-level computing power now allow the use of memory- and processing-intensive machine-based learning and similar big data approaches using a desktop PC. This more modern approach has been applied recently within NC using MaxEnt (Pfennigwerth 2019) and in Virginia using Random Forests (O'Neil 2018) and has even been integrated into ESRI ArcGIS Pro's ArcHydro toolbox (ESRI 2020). These types of automated modeling methods have significant advantages over traditional wetland mapping techniques such as being less labor-intensive, potentially resulting in maps of higher resolution that can identify smaller features, can be completed in a more timely manner, and can be easily repeated to update wetland maps as new spatial data are collected.

This repeatability of spatial models for wetland identification would be a key advantage over the manual methods used to create the NWI. The current NWI is no longer being updated by USFWS, so is therefore unusable for tracking changes over time. In fact, the USFWS – the creators and stewards of the NWI – are mandated to perform regular nationwide wetland assessments for their National Status and Trends reports to the US Congress, but the NWI is not used in this process. Instead, the USFWS has developed a completely separate method for identifying wetland survey sites to use for their status and trends assessments (Dahl 2011). The USEPA is also tasked with regular assessment of the "chemical, physical, and biological integrity of wetlands" across the country, which it accomplishes through its National Wetland Condition Assessment (NWCA) monitoring program. They have also found the NWI to be insufficient for this use, so the NWCA uses the sites identified during the USFWS Status and Trends process to identify NWCA study plots (US EPA 2016).

Recently the lack of accurate maps has been noted as a significant issue for understanding and quantifying the potential impacts due to changes to Waters of the US (WOTUS) regulations that were enacted in 2020, even though the NWI has been used for this exact purpose in prior studies due to a complete absence of other available data (e.g., Lane 2012). While the NWI was never intended for regulatory use, it was determined that the NWI was not even suitable for estimating the potential loss of wetland protection due to these proposed rule changes during the rulemaking process. The exact extent of the jurisdictional waters (including wetlands) in the US is essentially unknown and difficult to even estimate due to a lack of high quality data sources. The fact sheet that describes the changes to the WOTUS definition strongly recommended development of more reliable maps of "waters likely subject to federal jurisdiction" to better understand how regulatory changes can impact the ability to effectively implement the protections described in the Clean Water Act (USEPA and USACE 2020).

Results from this study confirm the unsuitability of NWI for management of wetland resources specifically within NC, an issue that has long been acknowledged, but previously only supported by anecdotal evidence. However, it is the only available data source for wetland location and extent for the state, so it will continue to be misused out of necessity, which increases risks of under- or over-protection of this critical resource.

The obvious and most effective solution to the problems with the NWI would be the development of a new spatial dataset representing wetland location and extent for NC that better meets the needs of current users of the NWI. There does seem to be some interest in this at the Federal level, based on comments provided during revisions to WOTUS regulations, though development of new maps remains merely a recommendation and has been neither funded nor mandated. Exploration of a program for implementing such an initiative at the state level would likely better serve local regulators and researchers. The NCDOT has had a pilot project underway for over 10 years to develop models to predict wetlands within NC for application in the planning process for their transportation projects (Wang 2015). It is unclear if models will be developed and applied statewide, and whether results from those applied models would be widely available. However, this is an existing initiative that could likely be expanded with additional support, or used as a model for establishment of a separate initiative.

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Appendix: Contingency table values and accuracy metric summaries

The following table provides the raw values from the contingency tables and accuracy metrics for NWI statewide and by several categories: Level III ecoregions, Level IV ecoregions, and size class. Numbers shown in the true positive (A), false positive (B), false negative (C), and true negative (D) columns are the total number of raster pixels for each category. Each pixel represents a 20ft x 20ft (400 ft^2) area of field-delineated wetland or non-wetland. Refer to the *Methods* section in the main text for more information on how the contingency table values (*A*, *B*, *C*, and *D*) were used to calculate accuracy measures (OA, EO_{WL}, EC_{WL}, PA_{WL}, UA_{WL}, and odds ratio).

	Wetland class only								Wetland and non-wetland classes	
Category	True positive (*A*)	False positive (*B*)	False negative (*C*)	True negative (*D*)	Error of omission (EO_{WL})	Error of commission (EC_{WL})	Producer's accuracy (PA_{WL})	User's accuracy (UA_{WL})	Overall accuracy (OA)	Odds Ratio
ALL DATA	494,475	294,426	508,666	8,772,100	51%	37%	49%	63%	92%	29
BY WETLAND SIZE CLASS										
0.1-0.25 ac.	1,711	504	10,802	998	86%	23%	14%	77%	19%	0.3
0.25-0.5 ac.	4,294	1,064	17,599	1,782	80%	20%	20%	80%	25%	0.4
0.5-1.0 ac.	9,633	1,719	23,770	5,825	71%	15%	29%	85%	38%	1.4
>=1.0 ac.	478,326	290,900	450,385	8,763,071	48%	38%	52%	62%	93%	32
BY ECOREGION										
66 Blue Ridge	1,069	1,980	9,099	809,203	89%	65%	11%	35%	99%	48
66c New River Plateau	65	343	2,450	107,216	97%	84%	3%	16%	97%	8
66d Southern Crystalline Ridges and Mountains	0	25	697	104,860	100%	100%	0%	0%	99%	0
66g Southern Metasedimentary Mountains	0	0	561	68,933	100%	0%	0%	0%	99%	*
66j Broad Basins	1,004	1,612	5,379	526,074	84%	62%	16%	38%	99%	61
66k Amphibolite Mountains	0	0	12	2,120	100%	0%	0%	0%	99%	*
45 Piedmont	10,545	41,678	51,124	4,288,112	83%	80%	17%	20%	98%	21
45a Southern Inner Piedmont	0	56	30	56,898	100%	100%	0%	0%	100%	0
45b Southern Outer Piedmont	3,097	16,317	16,456	2,086,299	84%	84%	16%	16%	98%	24
45c Carolina Slate Belt	2,218	8,033	22,587	1,065,377	91%	78%	9%	22%	97%	13
45e Northern Inner Piedmont	1,051	4,143	4,559	446,772	81%	80%	19%	20%	98%	25
45f Northern Outer Piedmont	2,590	7,621	2,959	257,360	53%	75%	47%	25%	96%	30
45g Triassic Basins	1,589	5,508	4,533	375,406	74%	78%	26%	22%	97%	24

Category	Wetland class only								Wetland and non-wetland classes	
	True positive (*A*)	False positive (*B*)	False negative (*C*)	True negative (*D*)	Error of omission (EO_{WL})	Error of commission (EC_{WL})	Producer's accuracy (PA_{WL})	User's accuracy (UA_{WL})	Overall accuracy (OA)	Odds Ratio
65 Southeastern Plains	109,401	72,278	114,019	2,013,532	51%	40%	49%	60%	92%	27
65c Sand Hills	26,910	8,903	16,535	327,644	38%	25%	62%	75%	93%	60
65l Atlantic Southern Loam Plains	25,338	17,252	28,466	472,405	53%	41%	47%	59%	92%	24
65m Rolling Coastal Plain	46,661	41,479	63,368	1,155,341	58%	47%	42%	53%	92%	21
65p Southeastern Floodplains and Low Terraces	10,492	4,644	5,650	58,142	35%	31%	65%	69%	87%	23
63 Mid-Atlantic Coastal Plain	373,460	178,490	334,424	1,661,253	47%	32%	53%	68%	80%	10
63b Chesapeake-Pamlico Lowlands and Tidal Marshes	63,089	22,513	83,097	399,121	57%	26%	43%	74%	81%	13
63c Swamps and Peatlands	29,719	2,021	3,607	2,238	11%	6%	89%	94%	85%	9
63e Mid-Atlantic Flatwoods	45,238	41,056	114,024	247,181	72%	48%	28%	52%	65%	2
63g Carolinian Barrier Islands and Coastal Marshes	32,595	10,524	4,653	32,756	12%	24%	88%	76%	81%	22
63h Carolina Flatwoods	181,683	95,891	127,559	963,665	41%	35%	59%	65%	84%	14
63n Mid-Atlantic Floodplains and Low Terraces	21,136	6,485	1,484	16,292	7%	23%	93%	77%	82%	36

** Odds ratio undefined due to 0 false positives*