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Wetlands Regulatory Assistance Program (WRAP)

Testing Methods for Challenging the National Wetland Plant List

Using *Tsuga canadensis* (L.) Carr. (Eastern Hemlock) as a Case Study

Robert W. Lichvar and Jennifer J. Goulet

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Abstract

This study explored methods for collecting and analyzing data during challenges to wetland ratings on the National Wetland Plant List (NWPL) to determine if study area size and landscape type affect wetland frequency and ratings. Data were collected in three different-sized study areas with different types of landscapes. Wetland frequency was calculated by using the original and an adjusted formula; and wetland ratings were predicted by using a Bayesian model. The original formula produced fewer hydrophytic ratings than the adjusted formula and the Bayesian model. In the smallest study areas (100 km^2), wetland ratings varied with landscape characteristics. The same wetland frequencies and ratings were produced in moderately large (20,000 km^2) and large (742,800 km^2) study areas provided sample size was adequate.

These results suggest that a wetland determination should be made for each sample unit based on the presence or absence of wetland indicators. Sample size should be large enough to achieve a confidence interval of 95% and a 3%–5% margin of error. When wetland frequency is close to 33%, Bayesian models could provide support for wetland rating determinations. The National Technical Committee for Wetland Vegetation and the National Panel of the NWPL will work with challengers to create a study design appropriate for each species.

Contents

Report Documentation Page

Figures and Tables

Figures

Tables

Preface

This study was conducted for and funded by the U.S. Army Corps of Engineers (USACE) Wetlands Regulatory Assistance Program (WRAP) under Work Item 5H27CJ, “NWPL Challenge Study.” The program manager was Ms. Sally Stroupe, U.S. Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL). The study design was developed in conjunction with the National Technical Committee for Wetland Vegetation (NTCWV).

The work was performed by the LiDAR and Wetlands Group (CEERD-RRC), of the Remote Sensing and Geographic Information Systems Center of Expertise (RS/GIS CX) (CEERD-RZR), ERDC Cold Regions Research and Engineering Laboratory (CRREL). At the time of publication, Dr. Elias Deeb was Chief, CEERD-RRC; Mr. David Finnegan was Director, CEERD-RZR. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Joseph L. Corriveau.

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COL Bryan S. Green was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Acronyms and Abbreviations

BONAP	Biota of North America Program
CRREL	Cold Regions Research and Engineering Laboratory
CX	Center of Expertise
EL	Environmental Laboratory
FAC	Facultative
FACU	Facultative Upland
FACW	Facultative Wetland
ERDC	U.S. Army Engineer Research and Development Center
ESRI	Environmental Systems Research Institute
GIS	Geographic Information Systems
HUC	Hydrologic Unit Code
na	Not Applicable
NC	Nature Conservancy
NCNE	Northcentral and Northeast
NTCWV	National Technical Committee for Wetland Vegetation
NWI	National Wetland Inventory
NWPL	National Wetland Plant List
OBL	Obligate
RS/GIS	Remote Sensing/Geographic Information Systems
SA	Study Areas
UPL	Upland
USACE	U.S. Army Corps of Engineers
WRAP	Wetlands Regulatory Assistance Program

1 Introduction

1.1 Background

In the United States, all federal agencies and many state regulatory programs determine wetland boundaries based on the presence of wetland hydrology, hydric soils, and hydrophytic vegetation. Hydrophytic vegetation determinations are made using percent areal cover estimates, vegetation formulas, the wetland ratings of plant species on the National Wetland Plant List (NWPL). Each species on the list has been assigned to one of five wetland rating categories, based on the frequency with which it is thought to occur in wetlands across its entire range. Plants in three categories, obligate (OBL) (>99%), facultative wetland (FACW) (67%–99%), and facultative (FAC) (34%–66%), are thought to show greater fidelity to wetlands and are considered indicators of hydrophytic vegetation (Reed 1988). Plants in the remaining two categories are thought to show less fidelity to wetlands and are not usually considered hydrophytic vegetation indicators. These nonhydrophytic categories are facultative upland (FACU) (1%–33%) and upland (UPL) (<1%). Botanists and plant ecologists assigned these ratings to plant species based on their field experiences and on the botanical literature. Until recently, no landscape-scale frequency data were available to confirm or refute any prior or current wetland ratings.

Since 2006, the NWPL has been administered by the U.S. Army Corps of Engineers (USACE) at the Cold Regions Research and Engineering Laboratory (CRREL). In 2012, the wetland ratings of 8200 plant species were reevaluated in 10 geographic regions across the U.S. and its territories (Lichvar and Gillrich 2011). This update process included a provision for challenging the wetland rating of a species on the NWPL if it is thought to be incorrect (Office of the Federal Register 2011). The challenge process has several steps, including a review of the literature and reevaluation by Regional and National Panels. If these panels do not change the wetland rating based on the request, then the species' rating can be challenged by collecting data in the field by using appropriate sampling and statistical methods. The original definition of wetland frequency, how often a plant species occurs in wetlands as opposed to uplands across the entire distribution of that species (Reed 1988), is used as the basis for challenges to the NWPL (Trott 2011; Lichvar et al. 2012; NTCWV 2013). This definition suggests that field sampling should not be restricted to wetland boundaries. Instead, it should be conducted in locations where the species is known to occur, at an appropriate sampling scale, given the target species' range. More information on the challenge process is available at the NWPL website.

1.1.1 Factors that may affect wetland frequency

Three factors, including scale, unequal proportions of wetlands and uplands in the landscape, and disproportionate search efforts in different landscape types, may affect the outcome of wetland frequency studies. A study's spatial scale, including the size of the study area (spatial extent) and the size of the sample unit, is very important because it determines the patterns of plant frequency that an investigator detects and where conclusions apply (Wiens 1989). A very large study area, the size of a USACE region, is appealing for NWPL challenges because wetland ratings are applied regionally. But sampling a broad spatial extent is problematic for several reasons. First, the logistics of time, money, and personnel required to sample vegetation across very large areas make it unfeasible. Second, it may be more difficult to discern patterns in the data because environmental variation increases as the size of the study area increases (Wiens 1989). Conversely, less time, money, and personnel are required to sample a smaller area. However, the landscape may be more homogenous in smaller study areas, producing ratings that either conflict with one another or do not reflect plant distribution across the landscape as a whole. Because the best spatial extent for measuring wetland frequency is not known, our team examined differences in wetland frequency produced by data collected across very small, moderately large, and extremely large study areas. Each very small study area was approximately 100 km^2, the average size of a 12-digit Hydrologic Unit Code (HUC). The extremely large study area was about 742,800 km^2, the area of the USACE Northcentral and Northeast (NCNE) region. The size of the moderately large study area, approximately 20,000 km^2, fell between these two extremes.

The size of the sample units (plots, transects, or relevés) used to collect data may also affect wetland frequency. The size must be consistent because frequency increases as plot size increases (Barbour et al. 1999). Large sample units are preferred for sampling broad spatial extents. When sampling large plants, such as trees, this approach is particularly advantageous because the study is conducted at a spatial scale relevant to the organism. In addition, a larger percentage of the landscape is sampled when large, as opposed to smaller, sample units are used. Large sample units also moderate the variance (Wiens 1989), making it easier to separate the signal in the data from noise. Drawbacks include overestimating percent cover in large sample units and overlooking small seedlings (McCune and Grace 2002). However, accuracy increases as sampling intensity increases. For instance, large sample units may be subsampled using point-intercept methods (Gignac and Vitt 1990). A second concern is that large sample units randomly located across a landscape are more likely than smaller ones to encompass both wetland and upland and therefore more likely to produce a wetland frequency near 50% and a FAC wetland rating (Olsen 2013). One solution to this problem is to stratify the landscape into two habitat types: uplands and wetlands. This method ensures that each large sample unit is located entirely in wetland or entirely in upland and that a FAC wetland rating is not an artifact of the sampling design.

The third factor that may affect wetland frequency results is the unequal proportion of wetlands and uplands in some landscapes. Wetlands represent an estimated 5%–8% of the global land cover, and their distribution is non-random (Mitsch and Gosslink 2007). At a continental scale, wetlands may be either abundant, as in the boreal zone, or sparse, as some in arid areas of the warm temperate zone. The same may also be true of smaller spatial scales. In the cool, temperate northeastern United States, wetlands may represent larger proportions of gradually sloped, U-shaped watersheds when compared to the steeply sloped, V-shaped watersheds common in the mountains. It is possible that some plant species may occur in wetlands more frequently when wetlands are more abundant in the landscape, while other species are unaffected. To test this hypothesis, equal numbers of wetlands and uplands should be sampled so that an equal opportunity is provided for the plant to occur in both landscape types. However, in landscapes where wetlands are sparse, obtaining an equal number of samples from each landscape type may not be possible, given the need for a large number of samples.

1.1.2 Calculating wetland frequency

Wetland frequency is a percentage, calculated as the number of times a species occurs in wetlands divided by the total number of occurrences across the landscape (Reed 1988). Because it is based on a species' presence and absence, frequency may need to be adjusted to account for differences in sample effort when wetlands and uplands are sampled disproportionately. For instance, other studies have adjusted wetland frequency by weighting the proportions of a species' wetland and upland occurrences by the reciprocal of these landscape proportions (Klein and Lichvar 2008). This method gives extra weight to the under-represented landscape type when calculating wetland frequency. Weighting has no effect on wetland frequency when proportions of wetlands and uplands are equal. However, this type of weighting would obscure differences in wetland frequency driven by the proportion of wetlands in the landscape. Weighting by sampling or search effort is another method used to normalize wetland frequency when the proportions of wetlands and uplands in the landscape are highly skewed and equal numbers of samples from each landscape type cannot be obtained. Several methods have been used. Wetland frequency has been weighted by the reciprocal of the proportion of wetlands and uplands sampled (Gillrich and Lichvar 2012). Similarly, wetland occurrences may be multiplied by the proportion of uplands searched relative to wetlands searched across the landscape (Buff and Leopold 2013). Both methods of weighting give extra weight to the under-represented landscape type but have little effect when wetlands and uplands receive equal search effort.

1.2 Objectives

The goal of this pilot study was to use *Tsuga canadensis* L. Carr. (Eastern Hemlock) as a case study to field test a sampling methodology for challenges to the NWPL and to explore methods for analyzing frequency data and assigning wetland ratings during NWPL challenges. On the 2016 NWPL, *T. canadensis* is rated FACU in all Corps regions in which it occurs as this species usually grows in uplands. However, it is considered problematic in the NCNE region because it can dominate wetlands and may cause a plant community to fail to meet hydrophytic vegetation indicators (USACE 2012). To examine the effect of insufficient sampling on frequency, this pilot study collected data on four co-occurring species though they were not the focus of the investigation. Specific objectives included

1. comparing the wetland frequency and rating of *T. canadensis* as the study area was increased from very small to moderately large to extremely large by using three metrics—(a) the original frequency formula, (b) an adjusted frequency formula, and (c) a Bayesian model—to calculate wetland frequency and ratings;
2. exploring the effect of small sample size on wetland frequency calculations and Bayesian model probabilities by using frequency data from four non-target plant species;

3. comparing how often *T. canadensis* occurs in wetlands in two small study areas, one with a steeply sloped and V-shaped landscape and the other with a gradually sloped and U-shaped landscape; and
4. determining if *T. canadensis* occurs in wetlands more often in watersheds where wetlands compose a larger percentage of the landscape.

1.3 Approach

Data for *T. canadensis* and for four nontarget species were collected in three different-sized study areas. Two small study areas with different landscape characteristics were sampled: one gradually sloped, U-shaped HUC and one steeply sloped, V-shaped HUC. In the moderately large study area, data were collected in a total of ten HUCs, five U-shaped and five V-shaped. In the extremely large study area, data collected across the landscape were obtained from an existing database. To meet the first objective, wetland frequency was calculated by using data from each study area and the original frequency formula and an adjusted frequency formula. Wetland ratings were also predicted by using a Bayesian model although they could not be modeled in the extremely large study area because data were summarized. To meet the second objective, these procedures were repeated using the nontarget species' data. The raw data collected in the two very small study areas were compared to meet the third objective. One null hypothesis was tested: there is no significant difference in the number of times *T. canadensis* occurs in wetlands in a gradually sloped, U-shaped HUC and a steeply sloped, V-shaped HUC. To examine relationships between wetland frequency and the proportion of wetlands in the landscape, the last objective, the raw data from the moderately large study area (10 HUCs) were used. Two null hypotheses were tested. First, there is no significant difference in the proportion of wetlands in the U-shaped vs. the V-shaped HUCs. Second, there is no significant difference in the number of times *T. canadensis* occurs in wetlands in the U-shaped vs. the V-shaped HUCs.

2 Methods

2.1 Small study areas (100 km^2)

2.1.1 Constructing a sampling frame

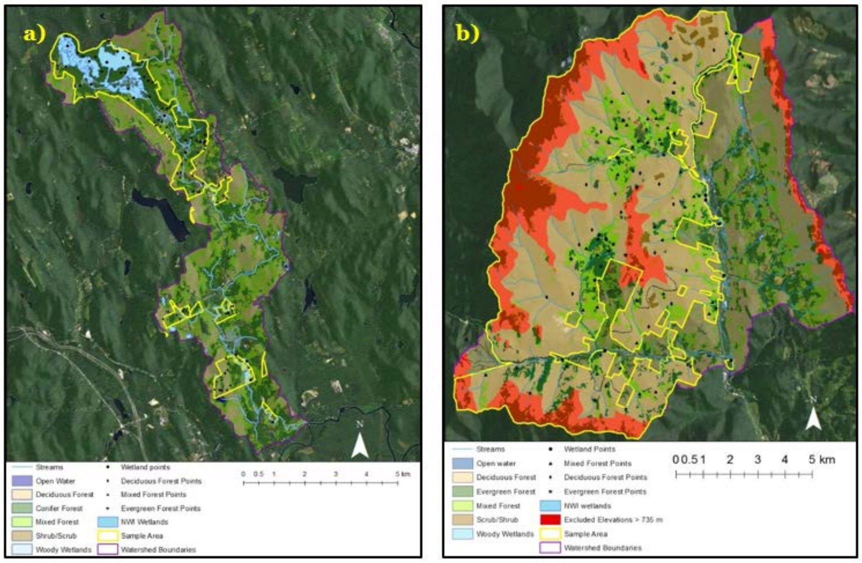
To compare the wetland frequency of *T. canadensis* in two small study areas with different landscape characteristics, two small watersheds, 12-digit HUCs, were selected by using ARCMap 10.1 (ESRI 2011) and Geographic Information Systems (GIS) data from public databases (Table 1). HUCs consisting mainly of cropland, pasture, developed land, or open water were excluded from consideration as *T. canadensis* was unlikely to occur in these landscapes. HUCs with little or no public land or insufficient access to public land were also removed from consideration as vegetation sampling was to be conducted on public land. Two HUCs characterized by conifer-dominated, deciduous, or mixed forests on public land were selected for sampling *T. canadensis*. The Lower Blackwater River HUC (hereafter Blackwater River) is a gradually sloped, U-shaped watershed in New Hampshire. The White River–Headwaters to Howe Brook (hereafter White River) is a steeply sloped, V-shaped HUC in Vermont.

Table 1. Geospatial data used to identify upland and wetland areas for sampling *Tsuga canadensis* (L.) Carr. in 10 forested 12-digit Hydrologic Unit Code (HUCs).

Name	Date	Source	Website
National Elevation Dataset	2009	U.S. Geological Survey	http://datagateway.nrcs.usda.gov
National Hydrography Dataset	2012	U.S. Geological Survey	http://datagateway.nrcs.usda.gov
National Land Cover Dataset	2006	Multi-Resolution Land Characteristics Consortium	http://www.mrlc.gov
National Wetland Inventory	2009	U.S. Fish & Wildlife Service	http://www.fws.gov/wetlands/Data/Data-Download.html
New Hampshire Public/Conserved Lands	2009	University of New Hampshire Statewide GIS Clearinghouse	http://granit.sr.unh.edu
USA Topographic Basemap	2009	Environmental Systems Research Institute (ESRI)	http://www.esri.com
Vermont Public/Conserved Lands	2009	Vermont Center for Geographic Information	http://vcgi.vermont.gov

In each HUC, a wetland and an upland sampling frame were constructed based on GIS data (Table 1) and habitat descriptions of areas where *T. canadensis* was likely to occur, such as wooded swamps, moist rocky woodlands, or on hillsides (Gleason and Cronquist 1991, 34; Hardin et al. 2001, 183–85; McGee and Ahles 2007, 103). The upland sampling frame was defined as public forests less than 735 m in elevation that were not mapped as wetlands by the National Wetland Inventory (NWI). In each HUC, 85 sets of coordinates were randomly generated in these upland areas. The wetland sampling frame consisted of public wooded wetlands below 735 m in elevation. In each HUC, 15 sets of coordinates were randomly generated in these wetland areas. Each set of coordinates represented a potential sampling location for *T. canadensis*. Figure 1 shows the potential sampling locations in wetland and upland for each HUC.

Figure 1. Spatial extent of the small study areas (≈100 km^2). Points represent potential locations for vegetation sampling in the (*a*) gradually sloped, U-shaped, Blackwater River HUC and (*b*) steeply sloped, V-shaped, White River HUC. HUC locations are shown in Fig. 2a.



2.1.2 Field methods

Field methods were developed with guidance and input from National Technical Committee for Wetland Vegetation (NTCWV). To collect frequency data, our team navigated to each randomly generated sample location and determined if it met two criteria: *T. canadensis* was present, and extreme disturbance was absent. If the target species was not spotted immediately, the area surrounding the point was searched using a 15-minute reconnaissance. If *T. canadensis* was not located, the point was discarded.

In each study area, 22–25 sample locations were discarded. If a sampling location met the study criteria, soil and hydrology indicators from the USACE NCNE Regional Supplement (USACE 2012) were used to determine if a three-factor wetland or a FACU-dominated wetland was present.

Transects were laid out in randomly chosen directions. Each 100 m transect was restricted to the plant community in which *T. canadensis* occurred. For example, if a sample location was in a Maple-Beech-Birch forest, then the entire transect remained in that community. Likewise, each transect was located entirely within an upland or a wetland. Transects never crossed upland–wetland boundaries. Transects did cross minor inclusions, such as hummocks in wetland areas or the headwaters of small ephemeral streams in upland areas. To ensure that each transect remained either in wetland or in upland, the presence and absence of soil and hydrology indicators described in the NCNE Regional Supplement (USACE 2012) were recorded in five representative locations, about once every 25 m. When necessary, transects were bent at randomly chosen angles to avoid crossing a wetland boundary or to remain in the same plant community.

To increase the accuracy of frequency calculations and gain insights on wetland fidelity, point-line-intercept sampling methods were used to collect presence and absence data every meter along 100 m transects. When *T. canadensis* intercepted a meter mark, it was counted once as an “occurrence.” The canopy of trees growing on wetland boundaries were included in wetland transects only if they were rooted in the same soil type or were lower than a topographic break. In each small study area, 60 transects were sampled, 12 in wetland and 48 in upland (Table 2). A maximum of 6000 occurrences of *T. canadensis* were possible in each study area, 12oo in wetland and 4800 in upland.

Presence and absence data for four nontarget species were also collected. They were *Acer rubrum* L. (Red Maple), *Pinus strobus* L. (Eastern White Pine), *Maianthemum canadense* Desf. (Canada Mayflower), and *Onoclea sensibilis* L. (Sensitive Fern). Frequency data for these nontarget species were recorded along transects used to sample *T. canadensis*. To examine the effect of insufficient sampling on frequency, no effort was made to ensure that data were collected from large numbers of transects throughout each species’ range.

Table 2. Number of sample units used to calculate wetland frequency and determine wetland ratings of five plant species in large, moderately large, and small study areas. Each small (≈100 km^2) study area was a 12-digit HUC characterized by a different type of landscape, either gradually sloped and U-shaped or steeply sloped and V-shaped (Fig. 1). The large (742,800 km^2) and moderately large (20,000 km^2) study areas consisted of both U-shaped and V-shaped 12-digit HUCs (Fig. 2).

	Wetland			Upland		
Study Area (Landscape Type)	# of Transects	# Times Occurred	% of Sample	# of Transects	# Times Occurred	% of Sample
a) *Tsuga canadensis* (L.) Carr. (Eastern Hemlock)						
Small, gradual slope (U-shaped)	12	422	20	48	2,275	80
Small, steep slope (V-shaped)	12	102	20	48	1,482	80
Moderately large (U- and V-shaped)	12	193	33	24	902	67
Large (U- and V-shaped)	na	26	29	na	143	71
b) *Pinus strobus* L. (Eastern White Pine)						
Small, gradual slope (U-shaped)	6	49	13	40	1,358	87
Small, steep slope (V-shaped)	1	4	20	4	45	80
Moderately large (U- and V-shaped)	2	15	18	9	197	82
Large (U- and V-shaped)	na	56	29	na	254	71
c) *Acer rubrum* L. (Red Maple)						
Small, gradual slope (U-shaped)	12	645	21	46	1,687	79
Small, steep slope (V-shaped)	8	189	22	29	613	78
Moderately large (U- and V-shaped)	10	333	33	20	612	67
Large (U- and V-shaped)	na	159	29	na	443	71
d) *Maianthemum canadense* Desf. (Canada Mayflower)						
Small, gradual slope (U-shaped)	8	57	22	28	294	78
Small, steep slope (V-shaped)	4	12	17	19	76	83
Moderately large (U- and V-shaped)	5	68	25	15	102	75
Large (U- and V-shaped)	na	89	29	na	492	71
e) *Onoclea sensibilis* L. (Sensitive Fern)						
Small, gradual slope (U-shaped)	8	133	89	1	1	11
Small, steep slope (V-shaped)	9	152	64	5	12	36
Moderately large (U- and V-shaped)	9	88	69	4	8	31
Large (U- and V-shaped)	na	120	29	na	49	71

na = not applicable

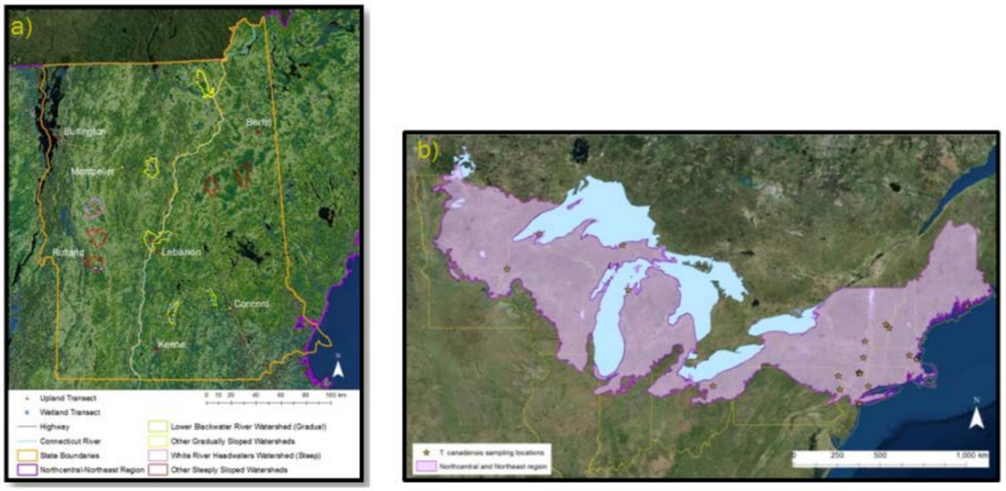
2.2 Moderately large study area (20,000 km^2)

The moderately large study area was composed of ten HUCs, the two previously described HUCs and eight additional HUCs, which were randomly selected by using ARCMap 10.1 (ESRI 2011), the GIS data from public databases (Table 1), and the previously mentioned *T. canadensis* habitat descriptions. Four of the eight HUCs were U-shaped with gradually sloped terrain, and four were V-shaped with steeply sloped terrain (Table 3). Within each of the eight HUCs, a sampling frame was constructed. It consisted of areas where *T. canadensis* was likely to occur based on the same resources used at the small scale and knowledge gained from sampling the small study areas. The upland sampling frame consisted of conifer or mixed conifer-deciduous forests less than 735 m in elevation with a flat, northern, or eastern aspect. Deciduous forests with southern and western aspects were excluded because the literature and our field experience suggested that *T. canadensis* does not occur in these habitats. In each HUC, 13 sets of coordinates were randomly generated in this upland habitat. The wetland sampling frame consisted of public, wooded wetlands below 735 m in elevation as described for the small study areas. Seven sets of coordinates were randomly generated in the wetland habitat. Each set of coordinates represented a potential sampling location. In each HUC, up to 19 of the 20 sample points were discarded because *T. canadensis* was absent or the landscape was disturbed. Figure 2a shows the locations sampled at the moderately large scale.

Table 3. Number of transects used to sample *Tsuga canadensis* (L.) Carr. in the small (marked with an *asterisk*) and moderately large study areas. Study areas (SA) were composed of 12-digit Hydrologic Unit Codes (HUCs). The letters U and V represent gradually sloped and steeply sloped landscapes, respectively. Fig. 2a shows HUC locations.

HUC name	Total Transects		Percent Wetlands	Landscape Shape	Location
	Small SA	Moderately Large SA			
Lower Blackwater River*	60	5	9.1	U	Northwest of Concord, NH
White River–Headwaters to Howes Brook*	60	5	3.0	V	Southwest of Montpelier, VT
Nulhegan River–Yellow Branch to mouth		2	7.3	U	Northwest of Berlin, NH
Ashuelot Pond		4	3.9	U	Northeast of Keene, NH
Upper Wells River		3	2.9	U	East of Montpelier, VT
Cold River		5	2.0	V	East of Rutland, VT
Connecticut mainstem–Ompompanoosuc River to White River		4	0.9	U	North of Lebanon, NH
Upper Pemigewasset Headwaters		1	0.8	V	South of Berlin, NH
Tweed River		5	0.4	V	Northeast of Rutland, VT
Headwaters-Saco River		2	0.2	V	Southwest of Berlin, NH

Figure 2. Spatial extent of the (*a*) moderately large (20,000 km^2) study area, where data collected in five steeply and five gradually sloped Hydrologic Unit Codes (HUCs) were used to calculate wetland frequency, and (*b*) the large (742,800 km^2) study area, where data were collected across 19 National Park (https://irma.nps.gov) landscapes in the Corps' Northcentral and Northeast region.



Frequency data were collected using the same field methods described for the small study area although fewer transects were sampled in each HUC (Table 3). A total of 26 transects were sampled in the 8 randomly selected HUCs. In addition, 10 transects were randomly selected for inclusion in the moderately large dataset from data collected in the small study areas. Three upland and two wetland transects were selected from the Blackwater River and White River HUCs. In total, there were thirty-six 100 m transects in the moderately large dataset: twelve from wetlands and twenty-four from uplands (Table 2). A maximum of 3600 occurrences of *T. canadensis* were possible at the moderately large scale, 1200 from wetlands and 2400 from uplands.

2.3 Largest study area (742,800 km^2)

In the largest study area (Figure 2b), data were obtained by Buff and Leopold (2013). They developed a database of plant species occurrences in wetlands and uplands in 10 USACE regions by using data from the United States Geological Survey and National Park Service Vegetation Characterization Program database (https://irma.nps.gov). The National Parks data were collected over a period of 20 years to characterize the structure and species composition of plant communities across National Park landscapes. The data were collected as part of a vegetation survey designed to characterize as many vegetation patterns as possible, so a randomized sampling design was not used (NC and ESRI 1994). Plot size and shape varied with vegetation type. Abundance estimates for trees were collected in plots that varied from 20 × 50 m to 5 × 5 m in size. Abundance estimates for shrubs and herbs were collected in plots that varied from 20 × 20 m to 5 × 5 m in size (NC and ESRI 1994). The entire dataset includes 400,000 species records for more than 8000 taxa collected in 16,000 plots. Cowardin wetland classification codes (Cowardin et al. 1979) and the designation “upland” were used to characterize plots as wetland or upland. Buff and Leopold (2013) standardized differences in scientific names to follow Kartesz (2013). Abundance data were transformed to presence and absence data. The geographic coordinates of each plot were used to separate records by USACE regions. Data used in our report are the most recent for parks in the NCNE region (Figure 2b). The data represent search efforts in 131,962 wetland plots (29%) and 326,574 upland plots (71%).

For the purposes of this study, *T. canadensis* was counted as present, regardless of its size (e.g., tree or seedling) or percent cover value, in every plot in which it occurred. When *T. canadensis* occurred several times in the same plot, it was counted as one occurrence. The number of times that *T. canadensis* was present in upland and in wetland plots in the Corps’ NCNE region was tallied and used to calculate wetland frequency.

3 Data Analysis

3.1 Calculating wetland frequency

This study used two formulas to meet the first objective of comparing wetland frequency among study areas. The first was the original (traditional) frequency formula based on the definition of wetland frequency (Reed 1988). Original wetland frequency for each species was calculated by using the raw occurrence data from each study area and the formula

$$F_{\text{original}} = \left(\frac{W}{W + U}\right) \times 100$$

where

F = wetland frequency,
W = the number of wetland occurrences, and
U = the number of upland occurrences.

The second formula was an adjusted wetland frequency formula that weights a species' wetland frequency based on the proportion of wetlands and uplands searched (Buff and Leopold 2013). Adjusted wetland frequency was calculated by using occurrence data from each sampling scale and the formula

$$F_{\text{adjusted}} = \frac{1}{1 + \frac{(\text{nu} * \text{NW})}{(\text{nw} * \text{NU})}}$$

where

F = wetland frequency,
NU = the number of upland occurrences,
NW = the number of wetland occurrences,
nu = the proportion of uplands searched, and
nw = the proportion of wetlands searched.

For the transect sampling at the small and moderately large scales, the margin of error for a 95% confidence interval was calculated as

$$\text{ME} = \pm\, \text{Z}_{0.95}\left(\frac{s}{\sqrt{n}}\right).$$

Because the National Parks data were not collected using a sampling design, statistical inference is somewhat limited. Therefore, the maximum possible error in the wetland frequency was estimated based on sample size by using the formula

$$\text{MPE} = \text{Z}_{0.95}\left(\sqrt{\frac{0.5(1-0.5)}{n}}\right)$$

where

MPE = the maximum possible error,
Z = the test statistic for a 95% confidence level, and
n = the number of plots.

This formula represents the 95% confidence level for a proportion of 0.5.

3.2 Modeling wetland ratings

The wetland rating of each species was predicted by using the frequency observations and a simple Bayesian model. Bayes' Theorem describes the posterior probability (Pr), or likelihood, of parameter *B* occurring, given that *A* is observed:

$$\Pr(B_k \mid A) = \frac{\Pr(B_k)\Pr(A \mid B_k)}{\sum_{i=1}^{m} \Pr(B_i)\Pr(A \mid B_i)}$$

where $k = 1, 2, \ldots m$. Bayesian analysis combines observational data with two types of additional information: prior distribution information and a likelihood function. An uninformed prior was used because there was no prior data available documenting the wetland frequency of *T. canadensis* at a landscape scale. An uninformed prior assumes that the wetland rating of *T. canadensis* is equally likely to be OBL, FACW, FAC, FACU, and UPL. The likelihood function in the Bayesian model compared patterns of wetland frequency in the data our team collected with patterns of wetland frequency produced by plants in each wetland rating category. Patterns of wetland frequency for plants in the FACW, FAC, and FACU rating categories were modeled by using data collected by Clark and Duffy (2006). Descriptions from the literature were used to set the likelihood function for the OBL and the UPL wetland rating categories (Environmental Laboratory 1987) because large numbers of these species did not occur in both uplands and wetlands in the Clark and Duffy data.

The Bayesian model used a matrix of occurrences on $wetland \times upland$ transects from each study area to predict the wetland rating of *T. canadensis* in each study area. In each square of the matrix, wetland frequency was calculated by using the original formula and occurrence data from one wetland and one upland transect. The values from the frequency matrix were sorted into five classes: <1%, 1%–33%, 34%–66%, 67%–99%, and >99%. The number of values in each frequency class was entered into the model:

$$\mathrm{Pr(wetland\ rating|frequency\ values)} = \frac{prior \ \times \ likelihood\ of frequency\ values}{\sum prior \ \times \ likelihood\ of frequency\ values}$$

The model calculated the probabilities that the frequency of *T. canadensis* was consistent with the likelihood function for the OBL, FACW, FAC, FACU, and UPL rating categories, given an uninformed prior of 0.20. Data from the large study area could not be modeled because they were summarized. To meet the second objective, these analyses were repeated using data for the nontarget species.

3.3 Hypothesis testing

The raw data collected in the two very small study areas were compared to meet the third objective. The number of times *T. canadensis* occurred on each wetland transect in each small study area was tested to determine if significant differences existed between the U-shaped (n = 12 transects) and the V-shaped (n = 12 transects) small study areas. Mann-Whitney tests were used to determine if wetland frequency was different in the two small study areas characterized by different types of landscapes. Mann-Whitney tests, nonparametric tests of the median (η), commonly used when sample size is small or data are non-normally distributed, were used to test all three hypotheses (α = 0.05).

To examine relationships between wetland frequency and the proportion of wetlands in the landscape, the last objective, the raw data from the moderately large study area were used. The proportion of wetlands in each of the 10 HUCs was calculated in ArcMap by using the Multi-Resolution Land Characteristics Consortium data. The number of wetland pixels in each HUC was divided by the total number of pixels in that HUC (Table 3).The resulting proportions were used to test for differences between five U-shaped and five V-shaped landscapes in the moderately large study area. The number of times *T. canadensis* occurred on wetland transects was also tested to determine if significant differences existed between U-shaped (n = 6) and V-shaped (n = 6) landscapes in the moderately large study area.

4 Results

The original wetland frequency formula suggested that most species occurred in wetlands less frequently, exhibiting a lower fidelity to wetlands than the adjusted formula and the Bayesian model. Four of the five species were nonhydrophytic according to the original formula, given the constraints of the study design on nontarget species (e.g., small sample size and sampling only a fraction of their actual distribution). The wetland frequencies for *T. canadensis* and *P. strobus* were low (4%–18%), suggesting that a FACU rating is appropriate in both HUC types and at all sampling scales (Table 4a–b). The wetland frequencies of *A. rubrum* (24%–28%, FACU) and *M. canadense* (14%–16%, FACU) were also lower at the smallest and largest scales (Table 4c–d). But, at the moderately large scale, frequencies were higher, 35% and 40% (FAC), respectively. Only *O. sensibilis* was unequivocally hydrophytic (71.0%–99.3%, FACW) (Table 4e).

In contrast, the adjusted wetland frequency formula, which adjusted for unequal sampling efforts in wetlands and uplands, suggested most species had a greater fidelity to wetlands. *T. canadensis* and *P. strobus* were borderline FACU/FAC while the remaining three species were hydrophytic. In the two small study areas, results for *T. canadensis* conflicted: 43% (FAC) in the U-shaped landscape and 22% (FACU) in the V-shaped landscape. In the moderately large and large study areas, *T. canadensis* had similar adjusted wetland frequencies, 30% [±9.5] and 31 [±7.5], respectively, suggesting that its rating is borderline FACU/FAC across heterogeneous (U- and V-shaped) landscapes. Similarly, in the U-shaped small study area, the adjusted frequency of *P. strobus* was 19% (FACU). Yet, frequencies from the steeply sloped V-shaped HUC and the two larger scales ranged from 25.5% [± 10.7] to 35.1 [± 5.6], suggesting a borderline rating of FACU/FAC. The remaining species were hydrophytic given the constraints of the study design. The adjusted frequencies of *Acer rubrum* (46.8%–59.4%) and *O. sensibilis* (83.0%–94.3%) were consistent with the FAC and the FACW rating categories, respectively. Results for *M. canadense* varied with size of the study area and the sample. In the small study areas, this species was best characterized as FAC (40.4%–42.9%). In the moderately large study area, where sample size was lowest (n = 20, Table 2d), a FACW or FAC rating was indicated (66.7 [±4.8]). Yet, in the largest study area, where sample size was largest (n = 581), *M. canadense* was borderline FACU/FAC (30.7% [±4.1]).

Table 4. Wetland frequencies and ratings produced by data collected in study areas of different sizes for five plant species. The two small (100 km^2) study areas were characterized by different landscapes, one gradually sloped and U-shaped and one steeply sloped and V-shaped. The moderately large (20,000 km^2) study area consisted of ten small watersheds (HUCs), five U-shaped and five V-shaped. The large (742,800 km^2) study area consisted of 19 National Park landscapes (https://irma.nps.gov) across the Corps' Northcentral and Northeastern region. Wetland frequency was calculated by using the original frequency formula (Reed 1988) and an adjusted formula (Buff and Leopold 2013). Estimated error for frequency and ratings is shown in brackets. The most likely wetland rating for each species and its probability, as predicted by a Bayesian model, are also shown.

	Original Formula		Adjusted Formula		Bayesian Model	
Study Area (Landscape type)	Wetland Frequency	Wetland Rating	Wetland Frequency	Wetland Rating	Posterior Probability	Wetland Rating
a) *Tsuga canadensis* (L.) Carr. (Eastern Hemlock)						
Small, gradual slope (U-shaped)	15.6 [±8.3]	FACU	42.6 [±8.3]	FAC	1.00	FAC
Small, steep slope (V-shaped)	6.4 [±6.2]	FACU [UPL]	21.6 [±6.2]	FACU	1.00	FACU
Moderately large (U- and V-shaped)	17.6 [±9.5]	FACU	30.0 [±9.5]	FACU [FAC]	1.00	FACU
Large (U- and V-shaped)	15.4 [±7.5]	FACU	31.1 [±7.5]	FACU [FAC]	na	na
b) *Pinus strobus* L. (Eastern White Pine)						
Small, gradual slope (U-shaped)	3.5 [±6.8]	FACU [UPL]	19.4 [±6.8]	FACU	1.00	FACU
Small, steep slope (V-shaped)	8.2 [±8.9]	FACU [UPL]	26.2 [±8.9]	FACU [FAC]	0.89/0.11	FACU/FAC
Moderately large (U- and V-shaped)	7.1 [±10.7]	FACU [UPL]	25.5 [±10.7]	FACU [FAC]	0.79/0.21	FACU/FAC
Large (U- and V-shaped)	18.1 [±5.6]	FACU	35.1 [±5.6]	FAC [FACU]	na	na
c) *Acer rubrum* L. (Red Maple)						
Small, gradual slope (U-shaped)	27.7 [±5.0]	FACU	59.4 [±5.0]	FAC	1.00	FAC
Small, steep slope (V-shaped)	23.6 [±4.7]	FACU	52.8 [±4.7]	FAC	1.00	FAC
Moderately large (U- and V-shaped)	35.2 [±6.2]	FAC [FACU]	52.1 [±6.2]	FAC	1.00	FAC
Large (U- and V-shaped)	26.4 [±4.0]	FACU	46.8 [±4.0]	FAC	na	na
d) *Maianthemum canadense* Desf. (Canada Mayflower)						
Small, gradual slope (U-shaped)	16.2 [±3.8]	FACU	40.4 [±3.8]	FAC	1.00	FAC
Small, steep slope (V-shaped)	13.6 [±1.4]	FACU	42.9 [±1.4]	FAC	1.00	FAC
Moderately large (U- and V-shaped)	40.0 [±4.8]	FAC	66.7 [±4.8]	FACW [FAC]	1.00	FAC
Large (U- and V-shaped)	15.3 [±4.1]	FACU	30.7 [±4.1]	FACU [FAC]	na	na
e) *Onoclea sensibilis* L. (Sensitive Fern)						
Small, gradual slope (U-shaped)	99.3 [±10.6]	OBL [FACW]	94.3 [±10.6]	FACW [OBL]	1.00	FACW
Small, steep slope (V-shaped)	92.7 [±7.1]	FACW [OBL]	84.9 [±7.1]	FACW	1.00	FACW
Moderately large (U- and V-shaped)	91.7 [±4.0]	FACW	83.0 [±4.0]	FACW	1.00	FACW
Large (U- and V-shaped)	71.0 [±7.5]	FACW	87.5 [±7.5]	FACW	na	na

Like adjusted frequency, the Bayesian model predicted that the wetland ratings for *T. canadensis* and *P. strobus* varied based on study-area size and landscape type. In the small, V-shaped and moderately large study areas, there was a 100% posterior probability that the distribution of *T. canadensis* was consistent with the FACU rating category (Pr =1.00). Yet, its rating was clearly FAC in the small, U-shaped (Pr =1.00) study area. Ratings for *P. strobus* also conflicted. Although clearly FACU in the small, U-shaped study area (Pr =1.00), there was a small probability that *P. strobus* might have a FAC distribution in the small, V-shaped (Pr = 0.11) and the moderately large (Pr = 0.21) study areas where sample size was very small (n = 5, n = 9, Table 2b). The model determined that in all study areas and landscape types, the distributions of *A. rubrum* and *M. canadense* were consistent with the FAC category (Pr = 1.00) and that *O. sensibilis* was consistent with the FACW category (Pr =1.00).

With regard to the hypotheses, the raw occurrence data from the smallest study areas showed that *T. canadensis* occurred in wetlands significantly more often in the U-shaped landscape (median [η] = 30) than in the V-shaped landscape (η = 8) (Mann-Whitney U-Test Statistic [U] = 111.5; p = 0.02). Data from the moderately large scale showed the same pattern. *T. canadensis* occurred in wetlands significantly more often across five U-shaped landscapes (η = 15) than across five V-shaped landscapes (η = 6) (U = 32.5; p = 0.02). In addition, the GIS data from the moderately large scale showed that gradually sloped, U-shaped landscapes contained a significantly larger proportion of wetlands (η = 3.9) than the steeply sloped, V-shaped landscapes (η = 0.8) (U = 22.0; p = 0.05).

5 Discussion

This pilot study provided valuable information regarding the methods of data analysis, study area size, and sample size for NWPL challenges. With regard to analysis methods, the original frequency formula suggested that most species occurred in wetlands less frequently, exhibiting lower wetland fidelity, when compared to the other two methods because it did not adjust for the fact that uplands were sampled more often than wetlands. Of the five species considered, only *Onoclea sensibilis* was determined to be a hydrophyte by the original formula, given the constraints of this study design, such as the small sample size and sampling only a fraction of the nontarget species distribution (Table 4e). In contrast, the adjusted formula and the Bayesian model agreed that three species, *Acer rubrum*, *Maianthemum canadense*, and *O. sensibilis*, were hydrophytes under the constraints of this study design. This discrepancy was present in most of the study areas and in both landscape types. To determine which frequency formula is appropriate for NWPL challenges, investigations focusing on other problematic plant species in different Corps regions are necessary. Studies that use empirical field data (Gage et al. 2016), data from existing databases, and different methods for calculating wetland frequency are currently underway.

These results indicate that a study area of 100 km^2, the average size of a 12-digit HUC, is too small to determine the regional wetland frequency of a problematic plant species during an NWPL challenge. In the two small study areas, the wetland frequency of *T. canadensis* varied between the different landscape types. The adjusted wetland frequency of *T. canadensis* was lower (22%, FACU) in the V-shaped landscape than in the U-shaped one (43%, FAC) (Table 4a). When tested, the raw data suggested that *T. canadensis* occurred in wetlands more often in gradually sloped, U-shaped landscapes where wetlands were more abundant than it did in steeply sloped, V-shaped landscapes where wetlands were sparse ($p = 0.02$, $p = 0.05$). Recent research in the North Parks and Ranges ecoregion (Bailey 1995) of the Rocky Mountains produced similar results (Gage et al. 2016). In the Gage study, *Picea pungens* Engelm. (Blue Spruce) occurred in wetlands more often (FAC–FACU) in northern watersheds and less often (FACU–UPL) in southern watersheds. Both investigations suggest that a small study area, the size of a 12-digit HUC, cannot accurately determine the wetland frequency of problematic plant species for an entire region during NWPL challenges. Although the wetland frequencies and ratings of other species, such as *Acer rubrum*, appear consistent across HUC types, if a problematic species like *T. canadensis* in the NCNE region or *P. pungens* in the Western Mountains, Valleys, and Coast region were challenged, data collected in a small study area would not produce reliable results for the entire USACE region. However, intensively sampling small areas, such as a 12-digit HUC, produces the truest, most accurate frequencies and ratings provided that results are applied only to that HUC. Therefore, in the future, it may be necessary to conduct challenges to the NWPL at small scales, yielding a wetland rating that is specific to only one particular HUC.

In contrast, data collected in the moderately large and large study areas produced the same wetland ratings as each other. For the target species, *T. canadensis*, both scales also produced very similar adjusted wetland frequencies, 30% and 31%, respectively. For most of the nontarget species, the moderately large and large study areas produced the same rating but different wetland frequencies. The study design may explain the discrepancies in the wetland frequencies of nontarget species. In the large study area, nontarget species were sampled across National Park landscapes; and sample size was fairly large (169–602, Table 2b–e). In the moderately large study area, nontarget species were sampled only within the distribution of *T. canadensis*; and sample size was very small (11–30). Although this is an obvious source of error in the wetland frequencies of the nontarget species, both study areas produced the same wetland rating, except in the case of *M. canadense*.

The wetland frequencies for *M. canadense* demonstrate that, when collecting frequency data for NWPL challenges, sample size must be large enough to reduce the influence of extreme observations. For instance, in the large study area where sample size was large (518), the wetland frequency of *M. canadense* was 31%, suggesting a rating of FACU or FAC is appropriate, given the 4% margin of error (Tables 2d and 4d). Yet, in the moderately large study area where sample size was low (20), one extreme observation inflated wetland frequency to 67% and a rating of FACW or possibly FAC, given the 5% margin of error. Sample size for NWPL challenges also depends on the target species. To keep the margin of error low, a larger sample will be necessary for problematic species with a wetland frequency close to borderline values (33% or 66%) or those with highly variable distributions. Fewer samples may be acceptable when wetland frequency falls in the middle of a rating category, as demonstrated by *A.*

rubrum in the moderately large study area (52% ± 6), where 37 transects produced the same results as 602 plots in the large study area.

These results also demonstrate that frequency data cannot always determine wetland ratings. For instance, in the moderately large and the large study areas, the adjusted wetland frequencies of *T. canadensis* (30%–31%) and *P. strobus* (25%–35%) are so close to the borderline between the FAC and FACU rating categories that either rating is possible, given the margins of error (Table 4a–b). Borderline frequencies are problematic for regulatory purposes because FAC species are considered indicators of hydrophytic vegetation; but most often, FACU species are not. Increasing sample size might resolve the discrepancy for *T. canadensis* ($n \leq 169$, Table 2a). However, wetland frequency was borderline for *P. strobus* at the largest sampling scale even though a fairly large number (310) of observations was used to calculate frequency. Under these circumstances, Bayesian models may help resolve wetland ratings if sample size is adequate. For example, the model showed a 100% probability that *T. canadensis* has a FACU distribution at the moderately large scale based on data from 36 transects. The probability that *P. strobus* has a FACU distribution was somewhat lower, 79%, based on data from 11 transects.

Challenges associated with vegetation sampling across large study areas include target-species absence and accessing privately owned land. Although the sampling frame was restricted to areas where *T. canadensis* was likely to occur, it was often absent, particularly in the northern watersheds (Figure 2a). Given the nonrandom occurrence of the target species and the lack of fine-scale vegetation maps, a random sampling design was not the best approach for this study. One alternative that would decrease sampling costs and increase efficiency is a geographically clustered sampling plan (Gage et al. 2016) in which many sample units are randomly placed within a localized area representing a small-scale version of the total population. Likewise, accessing privately owned land can be time consuming and may or may not yield results. However, sampling both public and private lands might increase accuracy because species distributions may vary with land use history. Sampling on only public land was a source of error in this study. Our team observed that in steeply sloped landscapes, *T. canadensis* was often sparse in the state forests and abundant in adjacent residential neighborhoods. Wetland frequency in steeply sloped landscapes might have been lower if these high-frequency upland areas were sampled. But, because conifer-dominated wetlands located on private lands were also omitted, the magnitude and the direction of the error are unknown.

6 Recommendations

These data showed that small study areas with different types of landscapes (gradually vs. steeply sloped) produce different wetland frequencies and ratings for problematic plant species. Given these results, sampling vegetation across a geographic area at least as large as the moderately large study area (20,000 km^2) used here is recommended during challenges to the NWPL because sampling an entire Corps Region is not logistically or economically feasible. When sample size was adequate, the moderately large study area produced wetland ratings that were consistent with the largest study area (742,800 km^2), the size of a Corps region. In most instances, a 6-digit HUC or an 8-digit HUC will provide a sampling scale with an order of magnitude similar to the moderately large sampling scale. However, results from a small study area, such as a 12-digit HUC, could be used to assign a wetland rating specific to that particular HUC.

The NTCWV is still developing recommendations to guide sampling designs for NWPL challenges. However, these results provided some valuable insights. When sampling for challenge purposes, a wetland determination should be made for each sample unit, based on the presence or absence of hydrophytic vegetation, hydric soil indicators, and wetland hydrology indicators. Ideally, vegetation sampling should occur when wetland hydrology indicators are most easily observed. Sample size should be large enough ($n \approx 400$) to achieve a confidence interval of 95% and a 3%–5% margin of error when wetland frequency is close to the borderline between ratings categories (33% or 66%). Confidence intervals may be wider and margin of error may be higher when wetland frequency falls in the middle of a wetland rating category. When wetland frequency is very close to 33%, the threshold value between a FAC and FACU rating, Bayesian models are useful tools that provide further evidence that a particular wetland rating is correct. The NTCWV and the National Panel of the NWPL will work with challengers to refine these recommendations and to create a study design appropriate for each species.

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14. ABSTRACT

This study explored methods for collecting and analyzing data during challenges to wetland ratings on the National Wetland Plant List (NWPL) to determine if study area size and landscape type affect wetland frequency and ratings. Data were collected in three different-sized study areas with different types of landscapes. Wetland frequency was calculated by using the original and an adjusted formula; and wetland ratings were predicted by using a Bayesian model. The original formula produced fewer hydrophytic ratings than the adjusted formula and the Bayesian model. In the smallest study areas (100 km^2), wetland ratings varied with landscape characteristics. The same wetland frequencies and ratings were produced in moderately large (20,000 km^2) and large (742,800 km^2) study areas provided sample size was adequate.

These results suggest that a wetland determination should be made for each sample unit based on the presence or absence of wetland indicators. Sample size should be large enough to achieve a confidence interval of 95% and a 3%–5% margin of error. When wetland frequency is close to 33%, Bayesian models could provide support for wetland rating determinations. The National Technical Committee for Wetland Vegetation and the National Panel of the NWPL will work with challengers to create a study design appropriate for each species.

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Indicator status, National Wetland Plant List, Plants--Classification, Vegetation--Sampling, Vegetation surveys, Wetland ecology, Wetland frequency

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