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ARTICLE

Discrepancies in Hydrophytic Determinations Produced by Three Vegetation Formulas Used for Wetland Delineations

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Abstract We examined disagreement among three methods used in the USA to make hydrophytic vegetation determinations during wetland delineations: the Dominance Ratio (DR), the Prevalence Index (PI), and the FAC-neutral Dominance Ratio (FN-DR). We had two objectives: to determine whether the number of dominant species in a plot affects the percentage of hydrophytic vegetation determinations made by each of the three methods and, if so, to explain the mathematical origin of disagreements among the methods. We compared the percentage of hydrophytic vegetation determinations produced when each method was applied to 200,000 simulations. The PI was the most consistent method for making hydrophytic vegetation determinations. We found that the DR is biased toward nonhydrophytic vegetation when there is an even number of dominant plant species in a plot; it is biased toward hydrophytic vegetation when there is an odd number of dominants. As the number of dominant species and strata increased, there were >20% more hydrophytic determinations made when we used DR than when we used PI. The FN-DR was also biased; it consistently produced fewer hydrophytic determinations than the other methods. When the DR disagrees with hydric soil and hydrology indicators, delineators should re-examine vegetation using the plot-based PI approach.

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Introduction

For wetland delineation purposes in the USA, a plot is determined to be in a wetland if it meets the criteria for each of three factors: hydric soils, wetland hydrology, and hydrophytic vegetation (Environmental Laboratory 1987). For vegetation to be determined to be hydrophytic, >50% of the dominant vegetation must consist of wetland species. That determination is made using abundance measurements in combination with the wetland indicator status ratings of the species present. Wetland delineators obtain the wetland ratings for species from a national list of wetland plant species developed at regional levels (Reed 1988). The five categories of wetland ratings are obligate (OBL), facultative wetland (FACW), facultative (FAC), facultative upland (FACU), and upland (UPL) (Table 1). Species considered to be hydrophytes are in the OBL, FACW, and FAC categories. The abundance measurements and wetland ratings are then evaluated mathematically to determine if more than 50% are hydrophytic (Environmental Laboratory 1987; U.S. Army Corps of Engineers 2010).

The two primary methods used for determining if vegetation is hydrophytic are the Prevalence Index (PI) and the Dominance Ratio (DR). A third method, the FAC-neutral version of the DR (FN-DR), was originally developed as a vegetation indicator (Environmental Laboratory 1987) but is currently used as an indicator of wetland hydrology when direct observation of surface or ground water is not possible (U.S. Army Corps of Engineers 2010).

The PI is a weighted average that was originally calculated using frequency data from line-intercept sam-

Table 1 Wetland Indicator Status Ratings (Reed 1988) and Indicator Values used to calculate the Prevalence Index (U.S. Army Corps of Engineers 2010)

Species Designation	Indicator Status (abbreviation)	Indicator Value	% Occurrence in Wetlands
Hydrophyte	Obligate (OBL)	1	99
Hydrophyte	Facultative Wetland (FACW)	2	67–99
Hydrophyte	Facultative (FAC)	3	34–66
Nonhydrophyte	Facultative Upland (FACU)	4	1–33
Nonhydrophyte	Upland (UPL)	5	1

pling (Wentworth et al. 1988). Weighted average formulas are used for various purposes in many disciplines, from biology to business to engineering. For wetland delineation purposes, Wakeley and Lichvar (1997) presented a modified "plot-based PI method" in which the total cover of all species in each wetland indicator category (OBL-UPL) are summed across strata, multiplied by their indicator value (Table 1), and divided by the total abundance of all plant species. A worksheet is used to calculate PI using percent cover (Online Resource 1) (See Methods for the PI formula). The weighted average method has been tested for use in locating consistent wetland boundaries nationally (Carter et al. 1988). They found that the PI approach confirmed the presence of hydrophytic vegetation but could not objectively locate the wetland boundary using vegetation as a single indicator alone.

Although the DR method is described in the Corps of Engineers Wetland Delineation Manual and regional supplements (Environmental Laboratory 1987; U.S. Army Corps of Engineers 2010), a specific formula has never been published. Instead, a worksheet is used to determine whether vegetation is hydrophytic (Online Resource 1). In the column on the left side of the worksheet, the plant species in each stratum, their absolute cover values, and their indicator status (Table 1) are listed. Three values are calculated for each stratum: total cover, 50% of total cover, and 20% of total cover. These values are used to determine the dominant species in each stratum (See Methods for a detailed description of the dominant selection process). In the top right column, the numbers of hydrophytic dominants and total dominants are tallied. The DR is the total number of dominant hydrophytes divided by the total number of dominant species. There are two possible outcomes: hydrophytic (DR >50%) and nonhydrophytic (DR ≤50%).

The FN-DR method is also described in delineation manuals (Environmental Laboratory 1987; U.S. Army Corps of Engineers 2010), but, as with the DR, a formula has never been published. The FN-DR is calculated like the DR, using the dominant species listed on the left side of the worksheet in Online Resource 1. However, FAC species are omitted before tallying the total number of dominants and hydrophytic dominants. The FN-DR is the total number of OBL and FACW dominants divided by the total number of UPL, FACU, OBL, and FACW dominants. Initial determinations have three possible outcomes: hydrophytic (FN-DR >50%), nonhydrophytic (FN-DR ≤49%), or tie (FN-DR = 50%). Ties occur when there are equal numbers of hydrophytic and nonhydrophytic dominants or when a plot is entirely dominated by FAC species. To break a tie, the indicator status of nondominant species listed on the left side of the worksheet in Online Resource 1 is evaluated. The total number of OBL and FACW nondominants is divided by the total number of UPL, FACU, OBL, and FACW nondominants. There are two outcomes: hydrophytic (FN-DR values >50%) and nonhydrophytic (FN-DR values ≤50%).

The basis of the DR and the FN-DR methods is the concept of dominant species. This concept has long been used to describe patterns of species dominance and diversity and to develop corresponding hypotheses regarding species' ecological responses (Preston 1948, MacArthur 1957, Whittaker 1965). Using this basic premise, the DR was specifically designed for hydrophytic vegetation determinations during the wetland delineation process described in the 1987 manual (Environmental Laboratory 1987; James Wakeley 2010, personal communication), and the calculation method was later presented in the Federal Manual for Identifying and Delineating Jurisdictional Wetlands (Federal Interagency Committee for Wetland Delineation 1989). The FN-DR method was developed as an alternative hydrophytic vegetation indicator in response to criticism of the DR from some Corps of Engineers districts (James Wakeley 2010, personal communication). However, other districts have complained that the FN-DR yields very different results than the DR method. Unlike the PI, the DR and the FN-DR methods are not used in other disciplines and lack published test results. To explore the magnitude of the disagreement and to determine whether these disagreements are statistically significant, we included the FN-DR in this analysis.

Disagreement Between the PI and the DR

Results of the PI and DR methods have been reported to differ from 16.0% (Wakeley and Lichvar 1997) to 54.3% (Dewey et al. 2006) of the time. Wakeley and Lichvar (1997) suggested two reasons for the 16.0% difference they found between the methods: the use of strata and species richness. The PI and the DR methods use vegetative strata in different ways. In the plot-based PI method, species with low cover values have less influence on the final determination but are still used in the calculation. In the DR method, species with low cover can either be excluded (when the vegetative stratum has a high cover value and they do not meet the requirements of being considered a dominant) or considered dominant (when the vegetative stratum has a low cover value). In this way, the strata approach to ranking dominant species sets up an artificial treatment of species abundance beyond cover value.

Species richness may also cause disagreement because the two methods differ in how they handle high or low numbers of species and total cover values. Wakeley and Lichvar (1997) and Dewey et al. (2006) both concluded that the PI and the DR can yield different hydrophytic determinations because many nondominants are discarded in the DR but used in the PI calculation, particularly in species-rich plots characterized by low cover values. In addition, Wakeley and Lichvar (1997) reported an interesting pattern of disagreement. When species richness was high in single-stratum plots, the DR determined that the vegetation was hydrophytic, while the PI determined that it was nonhydrophytic. The pattern was reversed when species richness was low. We believe that the mathematical characteristics of the number of dominant species might better explain this pattern.

Although the FN-DR relies mainly, and the DR relies solely, on dominant species to make hydrophytic vegetation determinations, no one has investigated the effect that the number of dominant plant species might have on the percentage of hydrophytic determinations that each formula produces. In this study we had two objectives: to determine whether the percentage of hydrophytic vegetation determinations made by the PI, the DR, and the FN-DR is significantly affected by the number of dominant species in a plot and, if so, to explain the mathematical origin of disagreements among the methods. We compared the percentage of hydrophytic vegetation determinations produced by the three methods in single-stratum vegetation simulations, when the number of dominant plant species was small, large, even, and odd. We also compared the percentage of hydrophytic vegetation determinations produced by each method in more complex simulations with up to four strata.

We made the following hypotheses:

1. In simple simulations with a single vegetative stratum, there will be no significant difference in the percentages of hydrophytic vegetation determinations produced by the PI, the DR, and the FN-DR when the number of dominant plant species:
   a. ranges from one to twelve
   b. is small and odd (one or three)
   c. is small and even (two or four)
   d. is large and odd (five, seven, nine, or eleven)
   e. is large and even (six, eight, ten, or twelve).
2. In more complex vegetation simulations with multiple strata, there will be no significant difference in the percentages of hydrophytic vegetation determinations produced by the three methods as the number of vegetative strata increases from one to four.

Methods

Approach for Evaluating Differences Among the Methods

We tested these hypotheses using data from 200,000 simulations. Pearson Chi-square tests and Minitab 14.0 statistical software (Minitab 2004) were used to determine whether the percentages of hydrophytic vegetation determinations produced by the three equations were significantly different from one another. We used simple binomial probability statistics to predict the likelihood that the DR would produce a hydrophytic vegetation determination, given the binomial setting and three hydrophytic indicator statuses out of a total of five, all of which had an equal likelihood of occurring (Online Resource 2).

Probability statistics were also used to calculate the likelihood that the FN-DR would produce a hydrophytic vegetation determination, given that initially there are three possible outcomes, two out of four indicator statuses are hydrophytic, FAC species are null, and ties are broken in a binomial setting (Online Resource 3). These predictions were compared to simulation results and used to explain the mathematical origins of the patterns of disagreement among the formulas.

Simulation of Simple Vegetation Plots with One Stratum

To test agreement among the PI, the DR, and the FN-DR, we simulated 200,000 sample plots by random generation using MATLAB® (2007) software. Each simulated plot contained between two and 21 plant species, with up to 12 dominant species. Within each plot, every plant species was randomly assigned an absolute cover value, represented by a number between 1% and 100%, and a wetland indicator status of OBL, FACW, FAC, FACU, or UPL, represented by a number between one and five (Table 1). Species assigned an indicator status of OBL, FACW, or FAC were considered hydrophytes.

To calculate the PI, we used MATLAB (2007) software and the following equation:

$$\mathrm{PI} = \left(S_{obl} + 2S_{facw} + 3S_{fac} + 4S_{facu} + 5S_{upl}\right) / \left(S_{obl} + S_{facw} + S_{fac} + S_{facu} + S_{upl}\right)$$

where S = summed percent aerial cover. For each plot, the software produced an identification number, the number of total species, the total percent cover, and a PI value between 1.0 and 5.0. Plots that contained vegetation with PI values less than or equal to 3.0 were determined to be hydrophytic. Plots that contained vegetation with PI values greater than 3.0 were determined to be nonhydrophytic (U.S. Army Corps of Engineers 2010).

MATLAB software was also used to apply the DR method (Online Resource 1) to simulation data. Dominant species were selected based on cover values, according to the 50/20 rule (Environmental Laboratory 1987; Federal Interagency Committee for Wetland Delineation 1989). The software calculated the total cover for each plot by summing the absolute cover values for each species. Plant species were ranked in descending order by absolute cover values, and the 50% and 20% thresholds were determined by multiplying the total cover by 50% and 20%, respectively. The dominant species were those selected from the top of this list until the cumulative cover exceeded 50%. If multiple species on the list had the same cover value, they were all selected. In addition, any species with an absolute cover value greater than or equal to 20% was also considered dominant. For each plot, the software produced two values: the number of hydrophytic dominants (with an indicator status of OBL, FACW, or FAC) and the total number of dominant species. Hydrophytic vegetation determinations were made using an Excel spreadsheet. The number of hydrophytic dominants was divided by the total number of dominants and multiplied by 100 to yield the DR. Plots with DR values greater than 50.0% were determined to be hydrophytic. Plots with DR values less than or equal to 50.0% were determined to be nonhydrophytic (Environmental Laboratory 1987; U.S. Army Corps of Engineers 2010).

The FN-DR calculations were based on the list of dominants described for the DR calculations, after omitting species with FAC indicator status. For each plot, the software produced four values: the number of dominant species with an UPL or FACU indicator status, the number of dominant species with an OBL or FACW indicator status, the number of nondominant species with an UPL or FACU indicator status, and the number of nondominant species with an OBL or FACW indicator status. Hydrophytic vegetation determinations were made using an Excel spreadsheet. The number of hydrophytic dominants was divided by the total number of dominants and multiplied by 100. If more than 50% of the dominant vegetation consisted of FACW or OBL species, the plot was determined to be hydrophytic. When a plot was entirely dominated by FAC species or when it was necessary to break ties because there were equal numbers of hydrophytic and nonhydrophytic dominants, the indicator status of nondominant species was considered. The tiebreaking process compared the number of hydrophytic nondominants with the total nondominants to determine if the vegetation was hydrophytic or nonhydrophytic (Environmental Laboratory 1987; U.S. Army Corps of Engineers 2010).

Simulation of Complex Vegetation Plots with Multiple Strata

To test agreement among the methods as vegetation becomes more complex, we simulated 40,000 vegetative strata conformations using random generation and MATLAB® software (2007). Each simulated stratum contained between two and five plant species, with up to four dominant species. Within each stratum, every plant species was assigned an absolute cover value and a wetland indicator status as described for the previous dataset. A random number generator shuffled and combined the 40,000 strata to create a new dataset of 10,000 plots, each with four vegetative strata and four to twelve dominant species. This process was repeated to create three additional datasets of 10,000 plots each, with three, two, and one strata. Plots with three strata contained three to eleven dominant species. Plots with two strata contained two to eight dominant species. Within each plot, the software determined the dominant species in each stratum, as described previously. Seven values were produced for each stratum: a PI value between 1.0 and 5.0, the number of dominant species, the number of dominant hydrophytes, the number of dominant species with an UPL or FACU indicator status, the number of dominant species with an OBL or FACW indicator status, the number of nondominant species with an UPL or FACU indicator status, and the number of nondominant species with an OBL or FACW indicator status.

To calculate PI in plots with multiple strata, we chose a method that mimicked the effect of the 50/20 rule (Dewey et al. 2006). The PI values for the individual strata were averaged to obtain a PI value for the plot. Because the index values of all strata were averaged, a stratum with low cover exerted much greater influence on the final value.

In plots with multiple strata, the DR was calculated by tallying the dominant hydrophytes and all dominant species in each stratum, and then summing each group across strata to obtain a total for each group for the plot. The total number of hydrophytes from all strata was divided by the total number of species from all strata and multiplied by 100 to obtain a DR for the plot.

The FN-DR was calculated by tallying the dominant species with an OBL or FACW indicator status across strata, and tallying the dominant species with a FACU, UPL, FACW, or OBL indicator status across strata, to obtain a total for each group for the plot. The first total was divided by the second total and multiplied by 100. If more than 50% of the dominant vegetation consisted of FACW or OBL species, the plot was determined to be hydrophytic. If the only dominants were FAC species or if the plot had an equal number of hydrophytes and nonhydrophytes as dominants, nondominant species were used to break ties, as described for the previous dataset.

Results

Simple Vegetation Simulations with a Single Stratum

When plots containing one to 12 dominants were tested (n=200,000), the DR produced a significantly larger percentage of hydrophytic determinations (56.8%; p<0.001), and the FN-DR produced a significantly smaller percentage of hydrophytic determinations (47.2%; p<0.001), when compared to the PI (53.2%) (Table 2).

In plots containing one or three dominant species (n=51,748), the DR produced a significantly larger percentage of hydrophytic determinations (64.3%; p<0.001), and the FN-DR produced a significantly smaller percentage of hydrophytic determinations (47.3%; p<0.001), when compared to the PI (52.4%) (Table 2). In single-stratum plots containing two or four dominant plant species (n=64,512), the percentage of hydrophytic determinations made by the DR and the FN-DR were significantly smaller (42.1%; p<0.001 and 45.3%; p<0.001, respectively) than those made by the PI (52.8%).

In plots containing a large, odd number of dominant species (five, seven, nine, or eleven) (n=33,623), the DR produced a significantly larger percentage of hydrophytic determinations (69.2%; p<0.001), and the FN-DR produced a significantly smaller percentage of hydrophytic determinations (48.8%; p<0.001), when compared to the PI (53.7%) (Table 2). In plots containing a large, even number of dominant species (six, eight, ten, or twelve) (n=50,117), there were no significant differences between the percentage of hydrophytic vegetation determinations made using the PI (54.3%) and the DR (54.8%). In contrast, the FN-DR produced a significantly smaller percentage of hydrophytic determinations (48.5%; p<0.001) when compared to the other methods.

Complex Vegetation Simulations with Multiple Strata

As vegetation in the plots became more complex and strata increased from one to four (n=40,000), the percentage of hydrophytic vegetation determinations made by the PI increased from 52.3% to 53.6% (Fig. 1), but the increase was not significant (Table 2). In contrast, the percentage of hydrophytic vegetation determinations made by the DR

Table 2 Results from Pearson Chi-Square tests, comparing the proportions of hydrophytic and nonhydrophytic vegetation determinations produced by the Prevalence Index (PI), the Dominance Ratio (DR), and the FAC-Neutral Dominance Ratio (FN-DR)

Hypotheses	n	χ^2	df	p-value
1) Simple vegetation-plots with one stratum				
a) 1 to 12 dominants (all plots)				
PI = DR	200,000	521.7	1	<0.001
PI = FN-DR	200,000	1412.3	1	<0.001
b) small, odd number of dominant species (1 or 3)				
PI = DR	51,748	1493.5	1	<0.001
PI = FN-DR	51,748	269.0	1	<0.001
c) small, even number dominant species (2 or 4)				
PI = DR	64,512	1482.0	1	<0.001
PI = FN-DR	64,512	727.9	1	<0.001
d) large, odd number of dominant species (5, 7, 9, or 11)				
PI = DR	33,623	2550.2	1	<0.001
PI = FN-DR	33,623	238.3	1	<0.001
e) large, even number of dominant species (6, 8, 10, or 12)				
PI = DR	50,117	2.0	1	0.16
PI = FN-DR	50,117	222.2	1	<0.001
2) Complex vegetation-plots with multiple strata				
$Strata_1$ - $Strata_4$				
$PI_1 = PI_2 = PI_3 = PI_4$	40,000	3.5	3	0.33
$DR_1 = DR_2 = DR_3 = DR_4$	40,000	963.2	3	<0.001
$FN\text{-}DR_1 = FN\text{-}DR_2 = FN\text{-}DR_3 = FN\text{-}DR_4$	40,000	87.6	3	<0.001
$FN\text{-}DR_2 = FN\text{-}DR_3 = FN\text{-}DR_4$	30,000	5.3	2	0.07

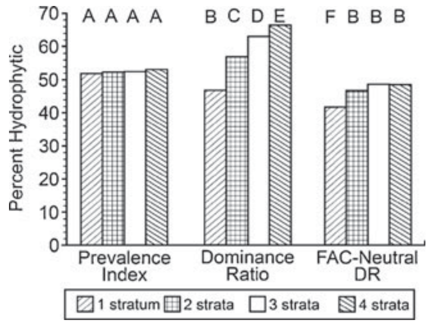

Fig. 1 Comparison of the percentages of plots determined as hydrophytic using the Prevalence Index, the Dominance Ratio, and the FAC-Neutral Dominance Ratio. The vegetative structure within the plots varied in complexity, ranging from simple (one stratum with up to four dominant species) to complex (four strata with up to twelve dominant species). By combining the hydrophytic and nonhydrophytic determinations (not shown), the results equal 100%. Values indexed with the same letter are not significantly different from one another

increased significantly as the number of strata increased, from 47.4% in single-stratum plots to 67.5% in plots with four vegetative strata ($p<0.001$). The FN-DR produced a significantly lower percentage of hydrophytic determinations in single-stratum plots (42.8%) compared to multi-strata plots (47.1%–48.8%; $p<0.001$); however, as strata increased from two to four, the increase in hydrophytic determinations was not significant.

Discussion

Patterns of Disagreement Among the Methods

The simulations showed two patterns of disagreement among the three methods. The PI produced the most consistent vegetation determinations in all plot types, regularly determining that slightly over 50.0% of the plots contained hydrophytic vegetation, regardless of increases in dominant species or strata (Fig. 1). As in previous studies by Wakeley and Lichvar (1997) and Dewey et al. (2006), the DR disagreed with the PI, producing vegetation determinations ranging from 42.1% to 69.2% hydrophytic. The percentage of hydrophytic vegetation determinations increased significantly with increases in the number of dominant species and strata (Table 2), but the variability was greatest in single-stratum plots with a small number of dominants. Plots dominated by an odd number of species produced significantly greater percentages of hydrophytic vegetation determinations (64.3%), and plots dominated by an even number of species produced significantly fewer hydrophytic vegetation determinations (42.1%), when compared to the PI. Like the DR, the FN-DR was most variable in plots containing four or fewer dominants. The FN-DR consistently exhibited a nonhydrophytic bias when compared to the other methods, determining that approximately 47.0% of plots were hydrophytic.

Odd-even Bias in the Simple Vegetation Simulations

Probability statistics predicted that the percentage of hydrophytic vegetation determinations made by the DR would take on a staggered odd–even bias as the number of dominant species increased (Fig. 2a). Because the DR treats FAC species the same as OBL and FACW species, plants in three of the five categories are considered hydrophytes, and the likelihood of a plant species being hydrophytic, 0.60, is greater than the likelihood of it being nonhydrophytic, 0.40. For example, if there are two dominants in a plot and all indicator categories have an even chance of occurrence, there is a 36.0% probability that the determination will be hydrophytic (Online Resource 2a, Fig. 2a). With three dominants in a plot, the probability of a hydrophytic determination increases to 64.8%. The simulated data showed that this bias of odd and even numbers of dominants created the largest discrepancies in plots dominated by four or fewer species (Fig. 2b). The DR

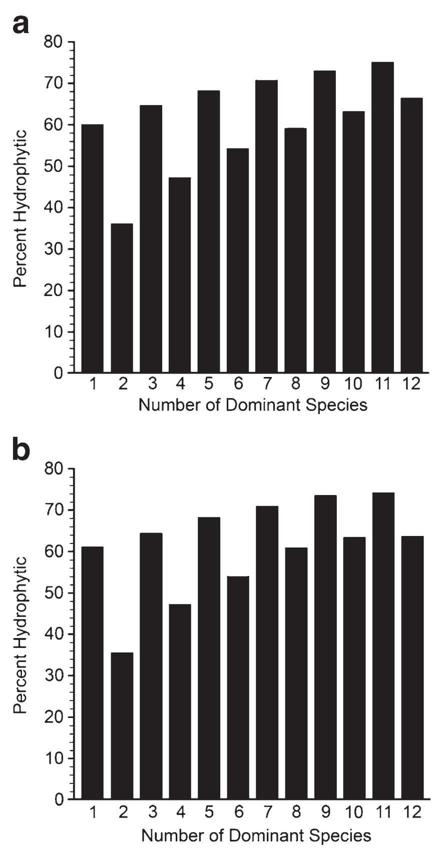

Fig. 2 Comparison of a) the predicted variation in hydrophytic vegetation determinations using the Dominance Ratio and the wetland plant list's five categories of indicator status in a binomial setting, and b) the observed variation in hydrophytic vegetation under the same conditions in 200,000 simulations

determined that hydrophytic vegetation was present in 64.3% of the plots with one or three dominants and in 42.1% of the plots with two or four dominants. This odd–even bias does not occur in PI determinations made in a binomial setting. The PI determined that hydrophytic vegetation was present in 52.4% of the plots with one or three dominants and 52.8% of the plots with two or four dominants. PI is calculated using all species, not just dominants, so there is an immense number of possible combinations of indicator statuses and abundances that could create either a hydrophytic or a nonhydrophytic determination. PI and DR disagreements reported by Wakeley and Lichvar (1997) and Dewey et al. (2006) can be explained by the DR's odd–even bias, particularly in plots with a small number of dominants.

The odd–even bias produced by the DR was also predicted and observed in plots dominated by large numbers of species, with one important difference: the likelihood of producing a hydrophytic vegetation determination was greater than 50.0% in all plots with five or more dominants, regardless of whether the plot was dominated by an even or odd number of species (Fig. 2a, b). In the simulated data, plots dominated by an even number of species produced determinations that were not significantly different than those of the PI. However, the percentage of hydrophytic determinations made by the DR in plots dominated by an odd number of species, 69.2%, was significantly greater when compared to the percentage made by the PI, 53.7% (Table 2). These results were statistically significant up to 12 species, where we stopped our testing.

A nonhydrophytic bias was predicted for determinations made by the FN-DR (given equal numbers of dominants and nondominants) (Online Resource 3) and confirmed by the simulations (Table 2). This nonhydrophytic bias was greatest in plots dominated by four or fewer species (Fig. 3). Interestingly, bias decreased as the likelihood of a tie occurring decreased and the number of dominant species increased. For instance, in plots where the bias was greatest (plots dominated by four or fewer species), 19.6%–36.3% of determinations based on dominant species resulted in a tie (Fig. 3a). In plots where the bias was less evident (plots dominated by five or more species), ties occurred just 10.7%–17.9% of the time. This relationship suggests that the omission of FAC species plays a role in creating nonhydrophytic bias in vegetation determinations. By treating FAC species as null, ties are most likely to be created in plots with a small numbers of dominants.

The nonhydrophytic bias increases with the likelihood of a tie between dominants because ties are broken in a binomial setting. When FAC species are null, the binomial setting is more likely to produce a nonhydrophytic determination than a hydrophytic determination, since plots

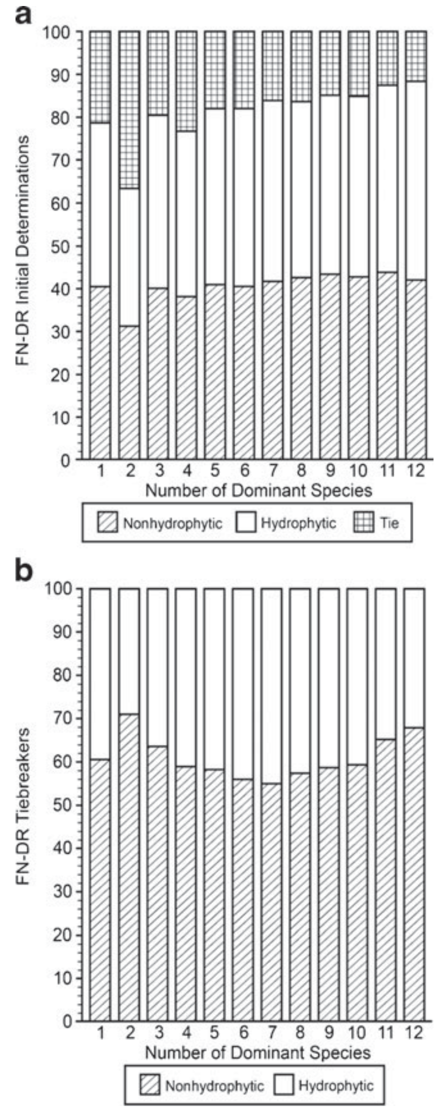

Fig. 3 Comparison of the observed variation in the percentage of hydrophytic and nonhydrophytic determinations produced by the FAC-neutral Dominance Ratio as the number of dominant species increases in a) the initial determination with three possible outcomes and b) the binomial setting used to break ties. Species with FAC indicator status were treated as null in both analyses

containing equal numbers of hydrophytic and nonhydrophytic nondominants are considered nonhydrophytic (Online Resource 3) (U.S. Army Corps of Engineers 2010). The simulations showed that 55.4%–71.3% of FN-DR tiebreaker determinations were nonhydrophytic (Fig. 3b).

The different use of the binomial setting and the different treatment of FAC species explain the patterns of disagreement between the DR and the FN-DR. The binomial setting, combined with three out of five hydrophytic indicator status ratings, produced the highly variable, odd–even bias in the DR simulations. Bias is less pronounced in the FN-DR simulations because the FN-DR uses a binomial setting only to break ties and only two out of four indicator status ratings are hydrophytic. The FN-DR consistently produced significantly smaller percentages of hydrophytic vegetation determinations, but this bias decreased as the number of dominant species increased and the likelihood of ties decreased. However, for both methods, bias was greatest in the type of plots delineators are most likely to encounter in the field: plots with four or fewer dominant species.

Bias in the Complex Vegetation Simulations: the Effect of Strata

The effect of strata on the DR and the PI adds another level of variability. As the number of strata in a plot increased, the percentage of vegetation determined to be hydrophytic by the DR method increased significantly, from 47.4% to 67.5% (Fig. 1) (Table 2). Since dominants are selected for every stratum with a cover value greater than 5.0%, sparse species may be selected as dominants, inflating the total number of dominants in a plot. When all indicator status categories have an equal chance of occurrence, hydrophytic dominants occur with greater frequency than nonhydrophytic dominants. Probability statistics predicted (Fig. 2a) and the simulations confirmed (Fig. 2b) that the DR produced large percentages (61.2%–74.3%) of hydrophytic vegetation determinations in plots with large numbers of dominants (7–12). As the number of strata increases and dominants are summed across strata, a similar pattern is produced (Fig. 1).

Recall that the way we calculated PI in plots with multiple strata mimicked the effect of the 50/20 rule by overemphasizing the importance of strata with low total cover. Given this method, we expected that the PI would exhibit a similar bias in plots with multiple strata and that there would be fewer differences between the PI and the DR as strata increased. However, this was not the case. As the number of strata increased, increases in the percentage of plots determined to be hydrophytic by the PI were not significant (Fig. 1, Table 2). The overemphasis of low cover strata had less effect on the PI's hydrophytic vegetation determinations because calculations included all species in each strata and each species' influence was based on its abundance rather than its frequency.

Dewey et al. (2006) also observed an increase in hydrophytic determinations as the number of strata increased, and they attributed it to the structure of the vegetation. They noted that the uncut forested areas in their study tended to have more hydrophytic determinations than the cut areas. They speculated that the difference between the overall hydrophytic nature of long-term stands of vegetation versus recently disturbed sites was the probable cause of the difference. The increase of strata bias that we observed in our simulations may well explain part of the disagreement observed by Dewey et al.

Use of the PI, the DR, and the FN-DR in the New Wetland Supplements

The DR method was intended to alleviate intensive vegetation sampling during wetland delineations. It was developed to quickly confirm the presence of hydrophytic vegetation in obvious cases (U.S. Army Corps of Engineers 2010). Clearly, the issues with the DR used in plots with a large number of dominant species are concerning, since the simulations showed significant increases in the percentage hydrophytic determinations as the number of dominants increased (Table 2). However, the odd–even bias was most extreme in the very situations for which the DR was designed—plots with four or fewer dominant species (Fig. 2). Likewise, the FN-DR produces the greatest percentage of biased determinations in plots where it is most likely to be used—plots with a small number of dominant species. Results from the simulations suggested that the use of both methods for the purpose of wetland delineation needs to be re-evaluated.

The PI is the most consistent formula for making hydrophytic vegetation determinations and for wetland research. This formula produced the most constant vegetation determinations in simulations representing a variety of plot types and field conditions. The PI is recommended over the DR and the FN-DR for use in studies or other efforts requiring consistent hydrophytic determinations, particularly research on soil–vegetation correlations. Many studies have evaluated the correspondence of hydrophytic vegetation with hydric soils and found inconsistent correlations between the DR and soil type (Carter et al. 1988, 1994; Wentworth et al. 1988; Scott et al. 1989; Josselyn et al. 1990; Segelquist et al. 1990; Golet et al. 1993; Wakeley et al. 1996). In further hydric soil and hydrophytic vegetation studies, comparisons should be limited to the use of the PI method because of the variability inherent in the DR approach.

In acknowledgment of disagreements between the PI and DR methods, the new Corps regional supplements (e.g., U.S. Army Corps of Engineers 2010) have factored in the probability of disagreements in the hydrophytic vegetation determinations. The first hydrophytic vegetation indicator method listed in the new supplements is the DR approach. This method allows delineators with fewer plant identification skills to focus on the dominant species to determine the hydrophytic nature of the vegetation. If the DR determines the plot to be nonhydrophytic but hydric soils and hydrology indicators are present, the delineator can then use the plot-based PI approach. The vegetation working groups for the new supplements purposely structured the indicators in this fashion to allow users who were trained in the DR approach to take advantage of the method but to ensure that any disagreements between vegetation determinations and indicators of hydric soils and hydrology could be re-examined using the PI method.

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