Evaluation of US EPA Environmental Monitoring and Assessment Program's (EMAP)-Wetlands Sampling Design and Classification

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ABSTRACT / The United States Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) will monitor the nation's resources by evaluating the status and trends of selected indicators of condition using a probability-based sampling design. The EMAP-Wetlands program will monitor the condition of the nation's wetlands. The EMAP classification system is an aggregation of the many subclasses of the US Fish and Wildlife Service's National Wetlands Inventory (NWI) classification system. This aggregation results in fewer wetland classes with more wetlands per class than the NWI system. Aggregation of the NWI classification was based primarily on dominant vegetation cover, flooding regimes, dominant water source, and adjacency to rivers and lakes. We evaluated the EMAP classification system and sampling design using NWI digital wetlands data for portions of Illinois, Washington, North Dakota, and South Dakota. Relative numbers of wetlands, total areas, average areas, and common versus rare classes were compared between the EMAP and NWI classification systems. As expected, the EMAP classification provided fewer wetland polygons, each with larger areas, without altering total wetland area. Summary statistics comparing sample estimates to true population parameters (represented by the NWI data) demonstrated the effectiveness of the EMAP sampling design with the exception of rare EMAP classes in the selected regions. Although simple random sampling is inadequate for both large and small wetlands, the EMAP sampling design is readily adapted to provide better estimates for these categories. Aggregating the NWI classification to the EMAP classification provides fewer wetland classes, with more wetlands per class, for EMAP's annual reports and statistical summaries.

The United States Environmental Protection Agency (EPA) initiated the Environmental Monitoring and Assessment Program (EMAP)-Wetlands program (Leibowitz and others 1991) to provide quantitative assessments of the condition of the nation's wetlands with the following objectives: estimate the current status, trends, and changes in selected indicators of the condition of the nation's ecological resources on a regional basis with known confidence; estimate the geographic coverage and extent of the nation's ecological resources with known confidence; seek associations among selected indicators of natural and anthropogenic stresses and indicators of the condition of ecological resources; and provide annual sta-

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Table 1. EMAP wetland classification system[a]

EMAP class[b]	Cowardin class
Palustrine lake edge	
Vegetation	Palustrine emergent, forested or scrub-shrub wetland adjacent to lacustrine system (limnetic or littoral subsystem)
Palustrine Basin	
Shallows	Palustrine unconsolidated bottom, aquatic bed, unconsolidated shore
Emergent	Palustrine emergent wetlands
Forested/scrub-shrub	Palustrine forest and scrub-shrub wetlands
Palustrine river edge	
Emergent	Palustrine emergent wetlands adjacent to all riverine subsystems (except intermittent)
Forested/scrub-shrub	Palustrine forest and scrub-shrub wetlands adjacent to all riverine subsystems (except intermittent)
Estuarine	
Emergent	Estuarine emergent wetlands
Forested/scrub-shrub	Estuarine forested and scrub-shrub wetlands

[a]Proposed EMAP classification system for reporting wetland condition for the continental United States and corresponding classes in the *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin and others 1979)

[b]Most classes will be monitored for temporary flooded, saturated, and seasonal-permanent flooded water regimes as defined in the *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin and others 1979).

tistical summaries and periodic assessments of the nation's ecological resources. EMAP-Wetlands will meet these objectives by developing and evaluating the following elements: a sampling strategy providing unbiased probability estimates of wetland condition with known precision and accuracy for national and regional scales of resolution; indicators that describe and quantify wetland condition; and a conceptual framework and techniques to analyze the data collected so that results accurately represent the condition of wetlands on a regional scale. A wetlands classification system is required that balances a sufficient number of wetland classes to describe the various wetland types with a small enough number of classes to provide adequate sample sizes. The wetlands classification must also establish boundaries between other EMAP resource groups.

A wetlands sampling frame, built upon the EMAP design, provides a list of functionally distinct wetlands that could be selected for field visits. Development of a wetlands sampling frame depends on several criteria: the availability of spatial data including the distribution and extent of wetlands; complete coverage for the region of interest; an accurate representation of the wetlands resource; and a wetland classification system that allows conversion to the EMAP classification scheme. The most appropriate data source for developing the EMAP-Wetlands frame is the US Fish and Wildlife Service's National Wetlands Inventory (NWI) wetland maps, which cover 73% of the nation's wetland resources, 14% of which have been digitized (Wilen 1990).

NWI employs aerial photographs to classify wetlands based on vegetation types, geomorphic settings, and flooding regimes. The NWI classification incorporates five system names, eight subsystem names, 11 class names, 28 subclass names, and an unspecified number of dominance types (Cowardin and others 1979). The NWI classification provides for more wetland classes than EMAP could adequately report on. Therefore, Leibowitz and others (1991) proposed aggregating the NWI classes into fewer wetland classes characterized by dominant vegetation cover, dominant water sources, (e.g., lake, river, basin, estuary, or marine) and flooding regime (Table 1).

The purpose of this study was to quantitatively assess the EMAP classification system and statistical sampling design using regionally representative NWI digital data sets. The specific objectives of the project were to: compare the EMAP classification to the NWI classification, evaluate the EMAP systematic sampling design at the base EMAP grid density of 27 km between sampling points; compare the design and classification across three regions—the Upper Mississippi drainage area represented by Illinois, the Pacific Northwest represented by Washington, and the Upper Midwest Prairie Pothole region represented by North and South Dakota; and discuss the feasibility of using NWI digital map data for generating an EMAP-Wetlands sampling frame. When considering the EMAP design performance, we recognized that estimates of number and areas of rare wetland classes (defined as comprising less than 1% of the total wetlands area or less than 1% of the total number of wetlands) would be poor. This is typical of any sampling program—characteristics of rare classes are usually estimated with poor precision unless special design provisions are invoked specifically for improving estimates of rare classes. A more in-depth discussion of this study can be found in Leibowitz and others (1993).

METHODS

To evaluate the EMAP classification and statistical sampling design, three areas of the country were chosen to achieve a representative sample geographically distributed across several ecoregions (Omernik 1987). The data include portions of Illinois, Washington, North Dakota, and South Dakota. The Illinois data represent inland wetlands with a broad range of flooded water regimes, primarily situated in floodplains with a smaller population of wetlands associated with isolated basins. The Washington data represent the West Coast environment with extreme diversity in water regimes and habitats, including desert, wet and dry floodplains, isolated wetland basins, and estuarine resources. All EMAP classes were represented. The North and South Dakota data represent the Prairie Pothole region containing a dense population of very small (<1.0 ha) wetlands set in an agricultural landscape.

Wetlands data for this study were mapped and digitized by the NWI Program (Wilen 1990). Dates of aerial photography used for the three regions included 1980–1987 for Illinois, 1980–1984 for Washington, and 1979 for North and South Dakota. Each digital 7.5′ NWI quadrangle map included the coverages of all linear and polygon wetlands coded using the Cowardin system (Cowardin and others 1979). The mapping was executed using primarily color infrared (CIR) photography at a scale of 1:58,000–1:65,000 for Illinois, North Dakota, and South Dakota and 4% black and white photography (1:80,000) and 96% CIR at a scale of 1:58,000 for Washington. Wetlands attribute data analyzed statistically were surface area and number of wetlands for both the regional wetland populations and samples for each NWI and EMAP class. All wetlands, including dot, linear, and polygons, were assigned surface area values according to NWI photointerpretation and cartographic standards (US Fish and Wildlife Service 1990a,b). Linear wetlands were considered the domain of other EMAP resource groups, but were used in this study to assign qualifiers indicating the wetland was associated with a riverine system.

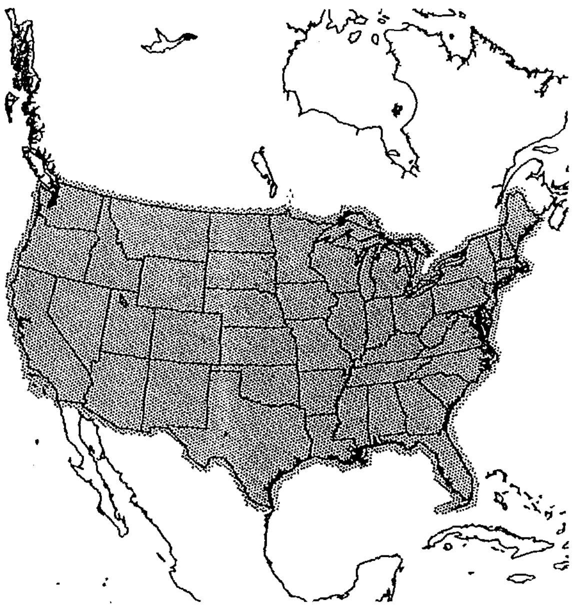

Figure 1. EMAP grid (not randomized) for North America. Spacing between points is approximately 27 km (Overton and others 1991).

Evaluation of both the EMAP classification system and sampling design necessitates bounding of the regional populations, and extracting a representative sample within each region. The initial step in the EMAP sampling design was to place a large hexagon containing a triangular grid of sampling points approximately 27 km apart over North America (Figure 1). The wetland population domain is defined by overlaying adjacent 640-km^2 hexagons, centered on the sampling points, on the available digital information. Sample data are extracted from 40-km^2 hexagons also centered on the same sampling points of each 640-km^2 hexagon in the selected regions. The sample data, therefore, represent 1/16 of the area of the population (Overton and others 1991) (Figure 2).

The distribution of 640-km^2 hexagons in each region (referred to here also as tiles) was selected to intersect with as many ecoregions (Omernik 1987) or subregions (Mann 1974) as possible. Analysis of the Illinois data included 99 tiles distributed across five ecoregions (Figure 3). The Washington data included 97 tiles distributed across five ecoregions (Figure 4). The Prairie Pothole wetlands data included 36 tiles spread across three subregions (Figure 5).

An "expansion factor" is applied to the 640-km^2 hexagons and 40-km^2 hexagons to compensate for hexagons that are only partially represented. Partial hexagons result from boundary lines (extent of NWI

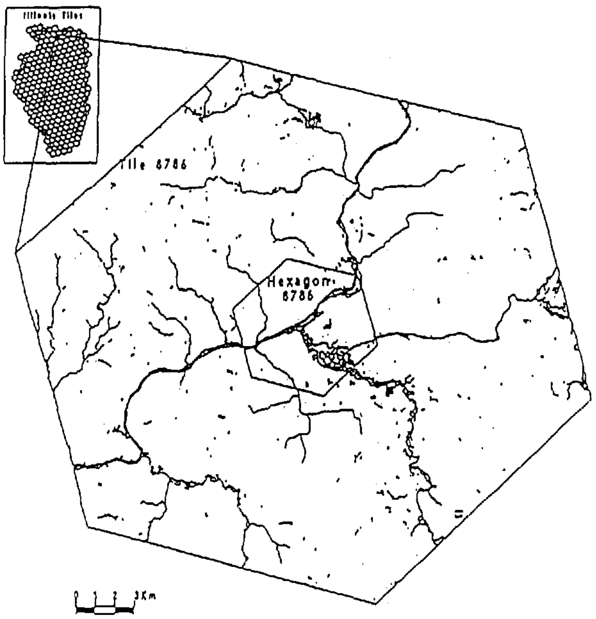

Figure 2. Example demonstrating placement of the 640-km^2 hexagons over a region (in this case Illinois) and the relationship between the 40-km^2 hexagons (hexagon number 8786) and the 640-km^2 hexagon (tile number 8786).

digital data) cutting through the interior of a hexagon rather than following the perimeter. The expansion factor is determined by calculating the inverse of the proportion of the hexagon: expansion factor = (proportion of hexagon)$^{-1}$. The wetland attribute is multiplied by the expansion factor to estimate the attribute value as if the entire hexagon had been included in the study. The 640-km^2 hexagons and 40-km^2 hexagons are treated separately. For example, suppose only 60% of a 640-km^2 hexagon and 10% of a 40-km^2 hexagon were included in the study. Then the number and area of the wetlands in the entire 640-km^2 hexagon would be multiplied by 1.67 = (1/0.60) but by 10 = (1/0.10) for wetlands in the 40-km^2 hexagon.

Specialized geographic information systems (GIS) parograms were developed by the Environmental Photographic Interpretation Center (EPIC in Warrenton, Virginia) to automate the conversion of NWI wetland polygons into EMAP wetland polygons and to generate the sample and population data. GIS algorithms were developed to automate the recoding of the Cowardin (NWI) wetland classes into the EMAP classification (Roose and Stout 1992). The recoding portion of the program performs the following four functions: (1) splits the full Cowardin code into its hierarchical components and recognizes the components germane to the EMAP classes; (2) aggregates functionally similar NWI codes into EMAP codes; (3) identifies wetlands adjacent to riverine and lacustrine systems, which approximates the dominant water source and assigns special hydrologic location codes; and (4) combines the coded results of the two previous steps into an EMAP code. (Descriptions of the EMAP codes for the 16 EMAP classes are listed in Table 2.)

Once the EMAP coding is established, the associated wetland characteristics for the EMAP and NWI polygons, polygon number, and polygon size are determined for both the 640-km^2 hexagons and 40-km^2 hexagons. Surface areas of individual wetlands were generated by ARC/Info version 5.0.1 software (Environmental Systems Research Institute, Redlands, California). To prevent double counting, wetland polygons cut by the tile boundaries are tagged to exclude them from any individual wetland size analyses (e.g., average size), but not from total area calculations. See Roose and Stout (1992) for details on how the associated wetland characteristics were generated.

These data manipulations yielded wetland data with wetland polygon numbers and surface areas identified by EMAP class. Wetlands attributes were extracted from a single GIS layer of wetlands data with both NWI and EMAP codes. This extraction occasionally resulted in contiguous wetlands with identical EMAP codes. Therefore, a new GIS layer was created to merge all contiguous wetlands having identical EMAP codes, resulting in fewer total wetlands without altering the total surface area. Wetland attributes were then recalculated.

Data analysis consists of two major components. The first component describes and compares population characteristics between EMAP and NWI in the three regions. These data represent complete populations and thus permit assessing differences among the regional data sets without considering sampling variability. Complete population data are rarely available. The surface area and number of polygons for each wetland class and the surface area and number for several size classes for each region were compared between the EMAP and NWI data.

The second component compares estimates of surface area and number of wetland polygons obtained from the EMAP 40-km^2 hexagon sample data to the known population parameters. The EMAP sampling design is evaluated by comparing the number and area of wetland polygons in the 40-km^2 hexagon sample data to the population parameters (number and area in the 640-km^2 hexagon). Relative differences (the ratio of the difference between the estimated value and the population value divided by the popula-

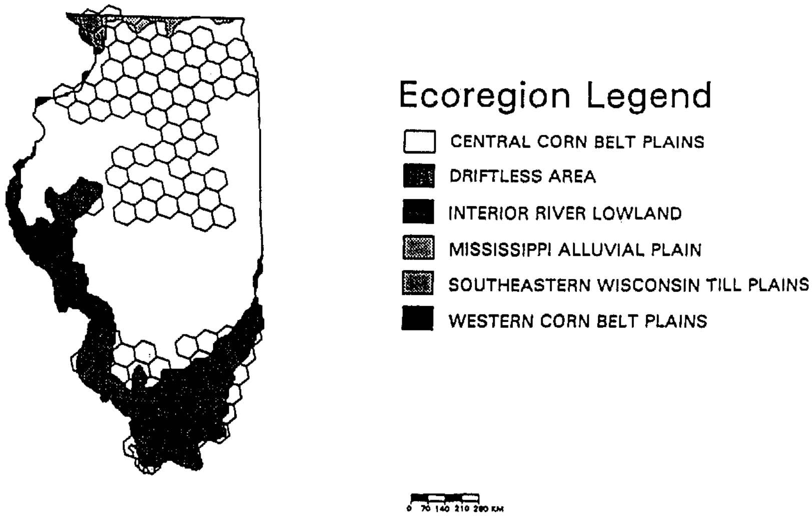

Figure 3. Illnois project area showing the location of the hexagons and ecoregions (Omernik 1987).

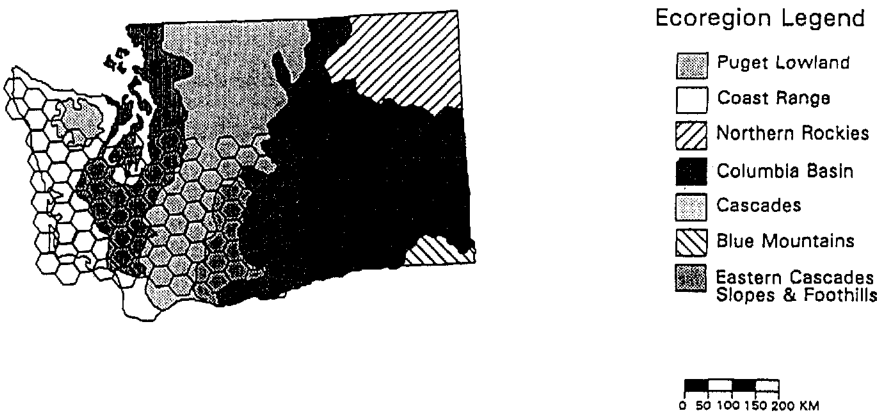

Figure 4. Washington project area showing the location of the hexagons and ecoregions (Omernik 1987).

tion value) and coefficients of variation (CV; ratio of the standard error and the estimated value) are employed to assess the performance of the statistical design in each region.

The hexagon sample data represent a single application of the EMAP design. Although the statistical properties of the design, which are based on repeated applications of the sampling strategy, cannot be evaluated from this single sample, a comparison of the sample estimates to the population parameters provides a quantitative demonstration of the performance of an EMAP sample for wetlands. Additionally, this comparison provides information about the numbers and surface areas of wetlands likely to be obtained from the EMAP sampling design. Results from this analysis will help when assessing whether there are sufficient numbers of wetlands, sampled by the EMAP grid density of one sampling point per 27 km, to satisfy the precision standards of the design.

Estimates of surface area and number within each wetland class or size class are theoretically unbiased. Deviations of the sample estimates from the known population parameters reflect the inherent sampling error of any sampling design. We determined deviations, both absolute and relative to the true surface area or number, for the EMAP sample.

Population estimates of both surface area and number of wetlands in any wetland or size class are attainable from the EMAP sample data. Estimates were obtained by multiplying the total number or total surface area of wetlands in the 40-km^2 sample within any EMAP classification (wetland, size, or combination of wetland and size class) by 16 (the EMAP 40-km^2 hexagon represents 1/16 of the total surface area of the 640-km^2 hexagon). From standard sam-

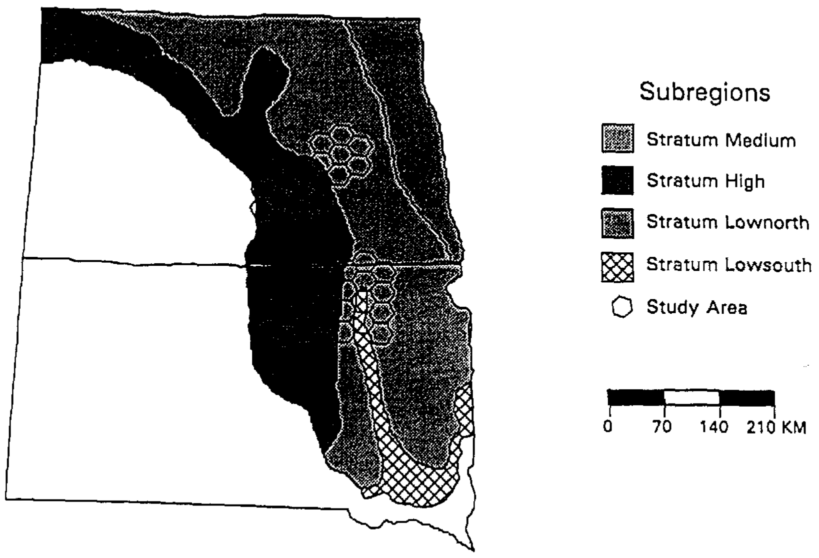

Figure 5. Prairie Pothole region project area of North and South Dakota showing the location of the hexagons and ecoregions (Mann 1974).

pling theory, these estimates of numbers and surface areas are unbiased (Cochran 1977).

For the purpose of this report we use the distinction between precision and accuracy presented in Cochran (1977). Accuracy refers to the magnitude of deviations from a population mean. Precision is reserved for describing the magnitude of deviations from a sampling mean. For example, the relative difference is a measure of accuracy. Relative difference measures the proportional difference between the known population value and an estimate of that value obtained by sampling. The coefficient of variation, on the other hand, is the ratio between the standard error of an estimate and the estimate and is therefore considered a measure of precision.

Because the EMAP sample is a systematic sample, unbiased estimates of precision are not available from a single systematic sample (Snedecor and Cochran 1980), so variances are approximated. The approximation assumes the EMAP sample performs as if the 40-km^2 hexagons were selected completely at random, rather than by the systematic spatial pattern used. Thus, this approximation performs well when wetlands are randomly distributed throughout the region. The more likely scenario, though, is a clustered spatial distribution of wetlands. The variance approximation is inaccurate to the degree that the random distribution assumption is violated. While certain spatial distribution patterns (e.g., wetlands clustered in the landscape) create problems with variance estimation, such patterns often favor the true precision of the EMAP systematic design (Overton and others 1991). The estimated variance overestimates the true variance if wetlands display a clustered spatial distribution. Thus, a trade-off characteristic of systematic sampling is likely present—the actual precision of the design is better than a completely random design, but the estimates of precision do not reflect the gain in precision actually achieved.

Results and Discussion

Characterization of Area, Size, and Wetland Classes of the Three Regions

The three regions are distinct with respect to wetland composition (Table 3) as expected because the regions were selected to obtain characteristic geographic representations. Illinois wetlands are dominated by palustrine shallows (PS; 51.4% of total wetland polygons), and seasonally flooded emergents (PEMC; 13.8% of total wetland polygons). While the PS class in Illinois comprises 51.4% of the wetland population in terms of numbers, only 10.5% of the total wetland area is PS. Washington wetlands are more diverse and biologically variable, with common classes including seasonally flooded emergents (PEMC), seasonally flooded forest/scrub–shrub along rivers (PFO/SSCR), seasonally flooded forest/scrub-shrub (PFO/SSC), and palustrine shallows (PS). The Prairie Pothole region wetlands were dominated by emergents, primarily temporarily flooded emergents (PEMA) and seasonally flooded emergents (PEMC). The following EMAP classes were relatively rare throughout the three regions: saturated emergents (PEMB), saturated emergents along rivers (PEMBR), saturated forest/scrub-shrub along rivers (PFO/SSBR), and saturated forest/scrub-shrub (PFO/SSB).

Table 2. EMAP wetland code description

EMAP code	Description
E2EM	Estuarine emergent
E2FO/SS	Estuarine forest and scrub-shrub
PEMAR	Palustrine emergent—temporarily flooded adjacent to a perennial riverine system
PEMA	Palustrine emergent—temporarily flooded
PEMBR	Palustrine emergent—saturated adjacent to a perennial riverine system
PEMB	Palustrine emergent—saturated
PEMCR	Palustrine emergent—seasonally flooded adjacent to a perennial riverine system
PEMC	Palustrine emergent—seasonally flooded
PFO/SSAR	Palustrine forested and scrub-shrub—temporarily flooded
PFO/SSA	Palustrine forested and scrub-shrub—temporarily flooded
PFO/SSBR	Palustrine forested and scrub-shrub—saturated adjacent to a perennial riverine system
PFO/SSB	Palustrine forested and scrub-shrub—saturated
PFO/SSCR	Palustrine forested and scrub-shrub—seasonally flooded adjacent to a perennial riverine system
PFO/SSC	Palustrine forested and scrub-shrub—seasonally flooded
PL	Palustrine vegetation adjacent to lacustrine system
PS	Palustrine shallows

Analysis of Size Classes of the Three Regions

Small wetland polygons dominate across all three regions; 73% of Illinois, 62% of Washington, and 82% of the Prairie Pothole region are less than 1.0 ha (Figure 6), but it is important to note that these small polygons comprise only 10%–20% of the wetland area in a region. In Illinois, 60% of the wetland polygons are less than 0.5 ha (Figure 6), and these comprise 6% of the total wetland area (Figure 7). Similarly, in Washington, 44% of the EMAP wetland polygons are less than 0.5 ha in size, comprising 4% of the wetland area. Prairie Pothole wetland polygons are also predominantly small, 69% are less than 0.5 ha, but comprise only 11% of the total wetland area in the region. As expected, the EMAP aggregations of the NWI data results in a slight shift in the distribution of wetland areas to the larger size classes. Figures 6 and 7 also provide information for assessing the effects of establishing minimum mapping unit standards for the detection of wetlands from aerial photography, satellite imagery, or other types of remote sensing technology. Caution is recommended when evaluating map resolutions (e.g., minimum mapping units). Most wetlands in these regions are less than 1.0 ha and samples based on minimum mapping units of greater than 1.0 ha may result in erroneous conclusions by failing to detect the majority of wetlands in a region.

Comparison of EMAP and NWI Population Data

Aggregations resulted in a decrease of 4.0% of the number of wetland polygons for all the regions combined. Aggregations in Illinois showed a 6.0% decrease in total number of wetland polygons (Table 4), the Washington wetland polygon number decreases by 11% (Table 5), whereas the Prairie Pothole aggregation decreases the total number of wetland polygons by only 2.0% (Table 6). The smaller decrease in total wetland polygons reflects the existence of the Prairie Pothole wetlands as single units with fewer being subdivided than Illinois and Washington wetlands. Decreases in the number of wetland polygons following aggregation measures how often adjacent wetland polygons labeled with different NWI codes were relabeled with identical EMAP codes.For example, if, following aggregation, two adjacent polygons had identical EMAP codes, the boundary between them would be dissolved, the areas combined, and the polygon counted as a single wetland. Therefore, the actual number of wetland polygons based in the NWI classification would decrease by one but the total wetland surface area would remain unchanged (Table 4).

In Illinois, the largest relative difference (approximately 50%) in wetland numbers resulted from aggregation of adjacent emergents, forests, and scrub-shrub around lakes (PL). Relative differences for number of wetland polygons for PFO/SSAR and PFO/SSCR coded wetlands in Illinois are approximately 27% and 16%, respectively. Relative differences from EMAP aggregations of NWI polygons for the remaining Illinois wetland classes are comparatively small, with changes in polygon numbers of less than 12%. Relative differences resulting from aggregations of adjacent polygons in the Prairie Pothole region are smaller because the individual, functionally distinct, wetland classes are isolated in the landscape.

Assessment of EMAP Sampling Design

The EMAP sampling design generally provided accurate and precise estimates of wetland numbers and areas with relative differences of less than 0.20 for most EMAP classes (Tables 7–9). Generally, the rare EMAP classes (PEMB, PEMBR, PFO/SSBR, and PFO/SSB) and most riverine classes were estimated with less accuracy than common classes. For example, in Illinois, the relative difference for numbers of PEMA (<0.01), PEMC (−0.01), PL (−0.03), and PS (−0.01) were good (Table 7). In the Prairie Pothole region

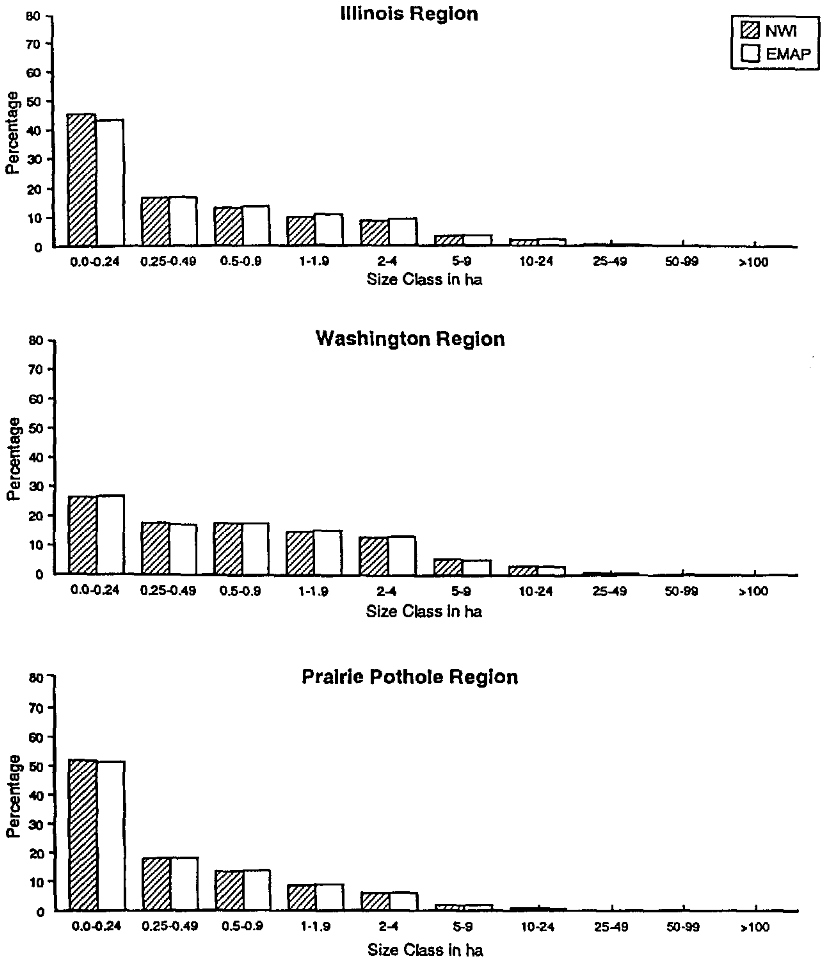

Figure 6. Population summary based on percentage of the number of wetlands in each region.

(Table 9) the results are based on a smaller number of hexagons and, therefore, less satisfactory estimates are expected. Furthermore, the existence of a few large wetland areas among the smaller sized wetlands would result in larger variances and thus less accurate estimates (see PL, Table 8). Nonrare wetland classes with relative differences greater than 0.20 probably reflect nonrandom distributional patterns. The estimation procedure employed assumes a random distribution across the landscape. Wetlands clustered in a restricted region or distributed linearly (i.e., riverine wetlands) would produce poorer estimates.

Recall that the estimated CVs are probably high because of the variance approximation used. The estimated variance overestimates the true variance if wetlands display a clustered spatial distribution.

Generally, EMAP classes with fewer that 500 wetland polygons were estimated with less precision (CV range: 0.50–0.97) and accuracy (relative difference range: 0.38–2.20). In only one class, seasonally flooded palustrine forested/scrub-shrub (PFO/SSC) wetlands of the Prairie Pothole region (Table 9), was this not the case. There were 366 PFO/SSC wetland polygons with a relative difference of −0.04 and CV of 0.25.

Estimates of the true population values for wetland numbers and surface areas were, in most instances, contained within the 90% confidence bounds (Tables 7–9). Exceptions to this trend were usually, but not exclusively, rare classes. In the Washington region (Table 8), PEMA, PEMC, and PS wetlands were underestimated with respect to wetland surface area. The existence of a few large wetlands in an EMAP class would increase the mean surface area. When a random sample is applied, these relatively rare large wetlands may not be sampled. Therefore, the true surface area would be underestimated. In the Prairie Pothole region, PL was underestimated with respect to both numbers of wetland polygons and surface area and PEMA, PEMC, and PL with respect to sur-

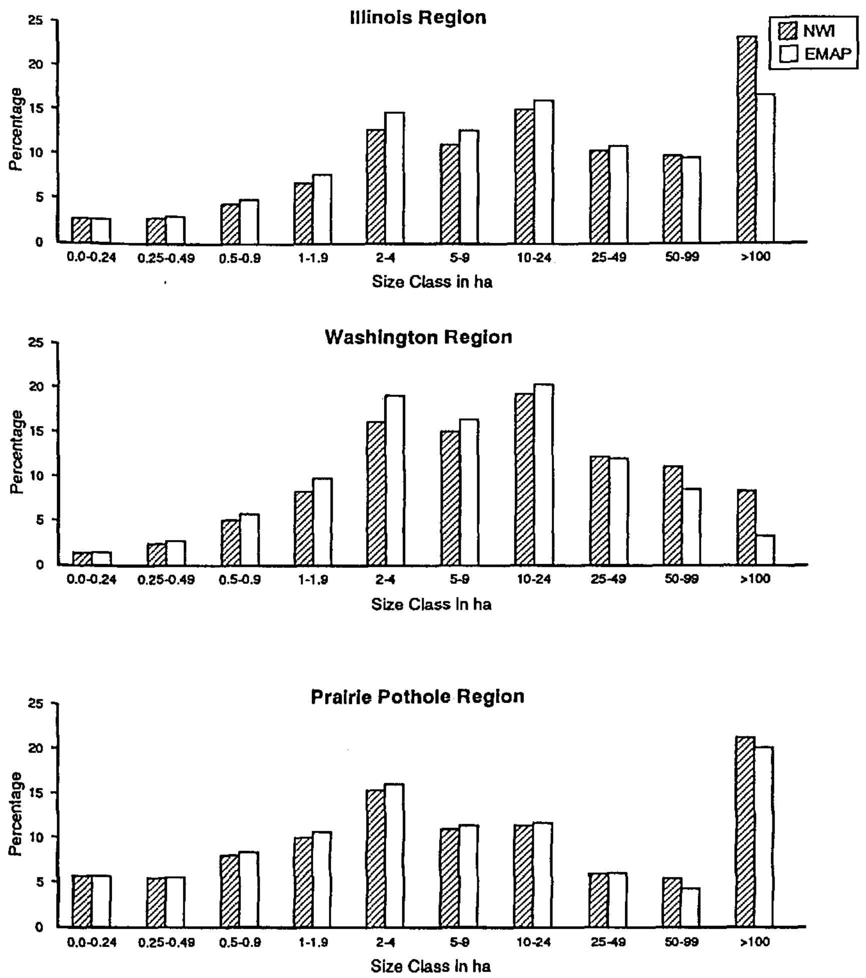

Figure 7. Population summary based on percentage of wetlands surface area in each region.

face area. Sample size in conjunction with the existence of a few large wetlands contributed to the relatively poorer estimations. The EMAP sampling design provides for intensification of the sampling grid density to increase the sampling intensity when rare classes are of interest.

Conclusions

The goal of this study was to assess quantitatively the EMAP classification and statistical sampling design with the following objectives in mind: (1) compare wetland polygon numbers, surface areas, common versus rare wetland classes, and the effect of imposing a minimum mapping unit; (2) evaluate the EMAP base grid density of 27 km between sampling points and compare sample values to known population values; (3) compare the sampling design and EMAP classification across the three regions; and (4) discuss procedures for generating a sampling frame using the NWI digital data.

The large majority of wetlands in the three regions were less than 1.0 ha. The types of wetlands in each of the regions were distinct. In the Illinois region the most common wetlands were seasonally flooded palustrine emergents (PEMC) and palustrine shallows (PS). All wetlands classes were present in the Washington region, which was dominated by seasonally flooded palustrine emergents (PEMC), seasonally flooded forest/shrub-scrub wetlands (PFO/SSC), and palustrine shallows (PS). Palustrine emergents, both temporarily (PEMA) and seasonally flooded (PEMC), dominated the Prairie Pothole region. This information provides professionals interested in wetland monitoring and assessment with the means to evaluate the effect of different sized mapping units. For example, if a minimum mapping unit of 0.5 ha was chosen as the resolution level for identifying wetlands

Table 3. Percentages for EMAP wetlands classes in each region[a]

	Illinois		Washington		Prairie Pothole	
EMAP class	% No.	% Area	% No.	% Area	% No.	% Area
E2EM	NP	NP	1.8	6.6	NP	NP
E2FO/SS	NP	NP	<0.1	<0.1	NP	NP
PEMAR	0.8	1.1	1.1	3.0	<0.1	0.3
PEMA	9.6	4.0	5.3	5.5	45.1	34.0
PEMBR	<0.1	<0.1	0.1	<0.1	NP	NP
PEMB	0.1	0.2	0.6	0.3	<0.1	<0.1
PEMCR	1.0	1.9	4.8	8.1	0.1	1.2
PEMC	13.8	8.4	26.6	17.3	46.6	53.0
PFO/SSAR	6.3	32.3	4.6	7.9	<0.1	0.1
PFO/SSA	7.9	15.0	4.7	5.2	0.5	0.2
PFO/SSBR	<0.1	<0.1	<0.1	<0.1	NP	NP
PFO/SSB	<0.1	<0.1	0.4	0.1	NP	NP
PFO/SSCR	2.2	9.9	9.9	16.1	<0.1	0.1
PFO/SSC	5.5	8.7	20.4	22.4	0.2	0.1
PL	1.6	8.0	1.6	2.4	1.2	8.2
PS	51.4	10.5	18.1	5.0	6.2	2.9

[a]Percentages of the number and areas of wetlands for each EMAP class for each of the three regions. NP denotes that the class was not present in the region.

Table 4. Relative differences resulting from aggregation of NWI classification to EMAP classification and dissolving boundaries between contiguous identically labeled wetlands for the Illinois region

	Illinois region					
	Total number of wetlands			Total surface area (ha)		
EMAP class	NWI	EMAP	Rel. Diff.	NWI	EMAP	Rel. Diff.
E2EM	0	0	0.00	0.0	0.0	0.00
E2FO/SS	0	0	0.00	0.0	0.0	0.00
PEMAR	1,094	968	−0.12	2,741.6	2,741.6	0.00
PEMA	11,605	11,518	−0.01	9,929.2	9,929.2	0.00
PEMBR	5	5	0.00	90.0	90.0	0.00
PEMB	106	104	−0.02	400.9	400.9	0.00
PEMCR	1,297	1,169	−0.10	4,689.7	4,689.7	0.00
PEMC	17,189	16,483	−0.04	20,806.2	20,806.2	0.00
PFO/SSAR	10,333	7,515	−0.27	79,920.3	79,920.3	0.00
PFO/SSA	10,252	9,438	−0.08	37,011.7	37,011.7	0.00
PFO/SSBR	1	1	0.00	0.4	0.4	0.00
PFO/SSB	9	9	0.00	27.1	27.1	0.00
PFO/SSCR	3,076	2,587	−0.16	24,427.0	24,427.0	0.00
PFO/SSC	7,225	6,568	−0.09	21,583.5	21,583.5	0.00
PL	3,680	1,861	−0.49	19,750.5	19,750.5	0.00
PS	61,841	61,519	−0.01	26,042.0	26,042.0	0.00
Overall	127,713	119,745	−0.06	247,420.1	247,420.1	0.00

using remote sensing technology, approximately 70% of the wetlands in the Prairie Pothole region would be excluded. This would severely bias the results and underestimate the number of wetlands.

The comparison of the EMAP and NWI population data for the Illinois, Washington, and Prairie Pothole regions assesses the effect of aggregating classification on total number of wetland polygons, total and average areas of wetlands, and rare and common wetland classes. Evaluation of the sample data by comparison to the known population values provided generally accurate and precise estimates of wetland polygon numbers and surface areas with the exception of rare EMAP classes. The availability of the population permitted identification of rare EMAP classes; however, precision estimates for rare classes were lower than

Table 5. Relative differences resulting from aggregation of NWI classification to EMAP classification and dissolving boundaries between contiguous identically labeled wetlands for the Washington region

	Washington region					
	Total number of wetlands			Total surface area (ha)		
EMAP class	NWI	EMAP	Rel. Diff.	NWI	EMAP	Rel. Diff.
E2EM	1,057	839	−0.21	7,512.2	7,512.2	0.00
E2FO/SS	16	15	−0.06	36.7	36.7	0.00
PEMAR	614	507	−0.17	3,422.2	3,422.2	0.00
PEMA	2,541	2,443	−0.04	6,266.9	6,266.9	0.00
PEMBR	45	43	−0.04	35.7	35.7	0.00
PEMB	281	278	−0.01	303.4	303.4	0.00
PEMCR	2,650	2,219	−0.16	9,264.9	9,264.9	0.00
PEMC	12,900	12,318	−0.05	19,661.1	19,661.1	0.00
PFO/SSAR	2,853	2,129	−0.25	8,979.3	8,979.3	0.00
PFO/SSA	2,283	2,188	−0.04	5,947.0	5,947.0	0.00
PFO/SSBR	20	19	−0.05	16.3	16.3	0.00
PFO/SSB	182	173	−0.05	157.7	157.7	0.00
PFO/SSCR	6,264	4,585	−0.27	18,335.5	18,335.5	0.00
PFO/SSC	10,927	9,454	−0.13	25,476.5	25,476.5	0.00
PL	903	746	−0.17	2,758.8	2,758.8	0.00
PS	8,527	8,390	−0.02	5,676.4	5,676.4	0.00
Overall	52,063	46,346	−0.11	113,850.6	113,850.6	0.00

Table 6. Relative differences resulting from aggregation of NWI classification to EMAP classification and dissolving boundaries between contiguous identically labeled wetlands for the Prairie Pothole region

	Prairie Pothole region					
	Total number of wetlands			Total surface area (ha)		
EMAP class	NWI	EMAP	Rel. Diff.	NWI	EMAP	Rel. Diff.
E2EM	0	0	0.00	0.0	0.0	0.00
E2FO/SS	0	0	0.00	0.0	0.0	0.00
PEMAR	117	103	−0.12	858.9	858.9	0.00
PEMA	100,300	99,067	−0.01	85,644.4	85,644.4	0.00
PEMBR	0	0	0.00	0.0	0.0	0.00
PEMB	2	2	0.00	48.0	48.0	0.00
PEMCR	125	112	−0.10	2,999.1	2,999.1	0.00
PEMC	104,224	102,252	−0.02	133,690.8	133,690.8	0.00
PFO/SSAR	93	93	0.00	186.3	186.3	0.00
PFO/SSA	1,187	1,163	−0.02	487.8	487.8	0.00
PFO/SSBR	0	0	0.00	0.0	0.0	0.00
PFO/SSB	0	0	0.00	0.0	0.0	0.00
PFO/SSCR	88	88	0.00	230.9	230.9	0.00
PFO/SSC	370	366	−0.01	303.8	303.8	0.00
PL	3,537	2,739	−0.23	20,586.4	20,586.4	0.00
PS	13,744	13,554	−0.01	7,227.9	7,227.9	0.00
Overall	223,787	219,539	−0.02	252,264.3	252,264.3	0.00

precision estimates for the more common classes. This loss of precision is characteristic of any design not specifically tailored for estimating rare classes. Population information pertaining to rare classes will prove valuable when intensifying the base grid density to sample a rare class.

The EMAP sampling design with a base grid density of 27 km performs well, with the possible exception of rare classes and classes with restricted spatial distributions (e.g., estuarine emergent and riverine wetlands). The 90% confidence intervals for the estimates usually contained the population values for the

Table 7. Sample estimates for number and areas of wetlands by EMAP class for the Illinois region[a]

A. Number of wetlands

EMAP class	Number	Est. number	Rel. Diff.	SE	CV	90% CI Lower bound	90% CI Upper bound
E2EM	NP	—	—	—	—	—	—
E2FO/SS	NP	—	—	—	—	—	—
PEMAR	968	1,079	0.11	208	0.19	737	1,422*
PEMA	11,518	11,531	<0.01	1,398	0.12	9,231	13,831*
PEMBR	5	0	−1.00	—	—	—	—
PEMB	104	64	−0.38	44	0.68	−8	136*
PEMCR	1,169	1,287	0.10	215	0.17	934	1,640*
PEMC	16,483	16,331	−0.01	2,509	0.15	12,203	20,459*
PFO/SSAR	7,515	8,276	0.10	1,196	0.14	6,310	10,243*
PFO/SSA	9,438	10,267	0.09	1,193	0.12	8,303	12,230*
PFO/SSBR	1	0	−1.00	—	—	—	—
PFO/SSB	9	0	−1.00	—	—	—	—
PFO/SSCR	2,587	3,116	0.20	941	0.30	1,567	4,664*
PFO/SSC	6,568	7,882	0.20	1,239	0.16	5,845	9,920*
PL	1,861	1,776	−0.03	533	0.30	900	2,652*
PS	61,519	60,600	−0.01	7,302	0.12	48,588	72,611*
Total	119,745	122,209	−0.02				

B. Area of wetlands (ha)

	Area (ha)	Est. area	Rel. Diff.	SE	CV	90% CI Lower bound	90% CI Upper bound
E2EM	NP	—	—	—	—	—	—
E2FO/SS	NP	—	—	—	—	—	—
PEMAR	2,742	4,089	0.49	1,288	0.32	1,969	6,208*
PEMA	9,929	9,855	−0.01	1,528	0.16	7,341	12,369*
PEMBR	90	0	−1.00	—	—	—	—
PEMB	401	93	−0.77	84	0.90	−45	232
PEMCR	4,690	4,395	−0.06	1,661	0.38	1,663	7,128*
PEMC	20,806	18,279	−0.12	4,398	0.24	11,044	25,513*
PFO/SSAR	79,920	81,169	0.02	25,290	0.31	39,566	122,771*
PFO/SSA	37,012	42,018	0.14	9,661	0.23	26,125	57,910*
PFO/SSBR	0	0	1.00	—	—	—	—
PFO/SSB	27	0	−1.00	—	—	—	—
PFO/SSCR	24,427	22,457	−0.09	7,110	0.32	10,762	34,153*
PFO/SSC	21,584	20,028	−0.07	4,050	0.20	13,365	26,691*
PL	19,751	14,816	−0.25	6,497	0.44	4,129	25,503*
PS	26,042	26,169	<0.01	2,936	0.11	21,339	30,999*
Total	247,421	243,368	0.02				

[a]Asterisks indicate that the true population value is contained within the estimate's confidence interval. NP identifies EMAP classes not present in the region. A dash denotes that estimates were not obtainable for that EMAP class in the region.

EMAP classes. The base grid density may require intensification to ensure adequate sample sizes for rare and spatially restricted wetland types. Results from our study suggest that intensification of the base sampling grid may be necessary when fewer than 500 wetlands occur in an EMAP class over a given region. Furthermore, wetlands with surface areas greater than 50 ha may also require intensification of the base grid density or prestratification based on wetland size for adequate sampling. Rare wetland classes in the regions sampled include saturated palustrine emergents (PEMB), saturated emergents along rivers (PEMBR), and saturated forest/scrub-shrub wetlands along rivers (PFO/SSBR).

As expected, the aggregation of wetlands from the NWI classification to the EMAP classification results in fewer wetlands with larger areas. Total wetland surface area in a region, however, was not affected.

Table 8. Sample estimates for number and areas of wetlands by EMAP class for the Washington region[a]

A. Number of wetlands

EMAP class	Number	Est. number	Rel. Diff.	SE	CV	90% CI Lower bound	90% CI Upper bound
E2EM	839	800	−0.05	260	0.33	372	1,228*
E2FO/SS	15	48	2.20	34	0.72	−9	105
PEMAR	507	433	−0.15	156	0.36	176	690*
PEMA	2,443	1,905	−0.22	544	0.29	1,010	2,800*
PEMBR	43	16	−0.63	15	0.97	−9	41
PEMB	278	160	−0.42	113	0.71	−26	346*
PEMCR	2,219	1,582	−0.29	351	0.22	1,004	2,160*
PEMC	12,318	9,664	−0.22	1,885	0.20	6,564	12,765*
PFO/SSAR	2,129	2,305	0.08	449	0.19	1,567	3,044*
PFO/SSA	2,188	2,032	−0.07	395	0.19	1,383	2,681*
PFO/SSBR	19	0	−1.00	—	—	—	—
PFO/SSB	173	176	0.02	88	0.50	32	320
PFO/SSCR	4,585	4,558	−0.01	912	0.20	3,058	6,058*
PFO/SSC	9,454	8,753	−0.07	1,398	0.16	6,452	11,053*
PL	746	656	−0.37	238	0.36	264	1,048*
PS	8,390	6,680	−0.22	1,145	0.17	4,797	8,563*
Total	46,346	39,768	−0.14				

B. Area of wetlands (ha)

	Area (ha)	Est. area	Rel. Diff.	SE	CV	90% CI Lower bound	90% CI Upper bound
E2EM	7,512	11,785	0.57	5,244	0.44	3,159	20,411*
E2FO/SS	37	92	1.50	63	0.69	−12	196*
PEMAR	3,422	4,428	0.29	3,544	0.80	−1,403	10,259*
PEMA	6,267	2,968	−0.53	1,271	0.43	878	5,059*
PEMBR	36	1	−0.96	1	0.97	−1	4
PEMB	303	111	−0.64	96	0.87	−48	269
PEMCR	9,265	6,306	−0.32	2,249	0.36	2,606	10,006*
PEMC	19,661	12,970	−0.34	3,594	0.28	7,058	18,881*
PFO/SSAR	8,979	7,161	−0.20	1,884	0.26	4,062	10,259*
PFO/SSA	5,947	5,642	−0.05	1,624	0.29	2,971	8,312*
PFO/SSBR	16	0	−1.00	—	—	—	—
PFO/SSB	158	99	−0.37	78	0.78	−28	227*
PFO/SSCR	18,336	21,396	0.17	8,385	0.39	7,603	35,189*
PFO/SSC	25,477	31,952	0.25	9,055	0.28	17,058	46,848*
PL	2,759	1,851	−0.33	857	0.46	441	3,261*
PS	5,676	3,469	−0.39	608	0.18	2,469	4,468*
Total	113,851	110,231	0.03				

[a]Asterisks indicate that the true population value is contained within the estimate's confidence interval. A dash denotes that estimates were not obtainable for that EMAP class in the region.

The presence of extremely large wetlands also creates a problem for area estimates. A possible solution would be to sample these wetlands using a separate sampling design. Large wetlands are easy to locate, and therefore developing a list frame should not pose a problem. Augmenting the EMAP base grid density will be necessary for rare wetlands and those that are spatially restricted (e.g., estuarine emergent wetlands) to ensure adequate sample sizes. The EMAP sampling design allows for intensification across regions.

The NWI classification and digitized maps can be used for the EMAP sample frame development in the regions investigated. Expanding this procedure for implementation across the entire United States requires further study. The NWI maps effectively match the criteria for EMAP sample frame develop-

Table 9. Sample estimates for number and areas of wetlands by EMAP class for the Prairie Pothole region[a]

A. Number of wetlands

EMAP class	Number	Est. number	Rel. Diff.	SE	CV	90% CI Lower bound	90% CI Upper bound
E2EM	NP	—	—	—	—	—	—
E2FO/SS	NP	—	—	—	—	—	—
PEMAR	103	16	−0.84	15	0.97	−9	41
PEMA	99,067	102,704	0.04	13,144	0.13	81,082	124,326*
PEMBR	NP	—	—	—	—	—	—
PEMB	2	0	−1.00	—	—	—	—
PEMCR	112	0	−1.00	—	—	—	—
PEMC	102,252	84,640	−0.17	10,836	0.13	66,815	102,465*
PFO/SSAR	93	0	−1.00	—	—	—	—
PFO/SSA	1,163	1,232	0.06	261	0.21	802	1662*
PFO/SSBR	NP	—	—	—	—	—	—
PFO/SSB	NP	—	—	—	—	—	—
PFO/SSCR	88	0	−1.00	—	—	—	—
PFO/SSC	366	352	−0.04	87	0.25	209	495*
PL	2,739	944	−0.66	469	0.50	173	1,715
PS	13,554	12,032	−0.11	1,360	0.11	9,794	14,270*
Total	219,539	210,920	0.08				

B. Area of wetlands (ha)

	Area (ha)	Est. area	Rel. Diff.	SE	CV	90% CI Lower bound	90% CI Upper bound
E2EM	NP	—	—	—	—	—	—
E2FO/SS	NP	—	—	—	—	—	—
PEMAR	859	46	−0.95	44	0.97	−27	118
PEMA	85,644	65,046	−0.24	6,826	0.10	53,817	76,275
PEMBR	NP	—	—	—	—	—	—
PEMB	48	0	−1.00	—	—	—	—
PEMCR	2,999	0	−1.00	—	—	—	—
PEMC	133,691	104,001	−0.22	10,933	0.11	86,015	121,986
PFO/SSAR	186	0	−1.00	—	—	—	—
PFO/SSA	488	539	0.10	159	0.30	277	801*
PFO/SSBR	NP	—	—	—	—	—	—
PFO/SSB	NP	—	—	—	—	—	—
PFO/SSCR	231	0	−1.00	—	—	—	—
PFO/SSC	304	278	−0.09	106	0.38	104	452*
PL	20,586	6,206	−0.70	3,670	0.59	168	1,244
PS	7,228	6,960	−0.04	1,625	0.23	4,287	9,632*
Total	252,264	183,076	0.27				

[a]Asterisks indicate that the true population value is contained within the estimate's confidence interval. NP identifies EMAP classes not present in the region. A dash denotes that estimates were not obtainable for that EMAP class in the region.

ment presented in the introduction. The NWI maps contain spatial data, include information about the distribution and extent of wetlands, include all wetlands of interest to EMAP-Wetlands and, when completed, will cover the entire United States. The NWI program was designed to estimate total acreage and change in total acreage for each wetland type within 10% of the true values with a 90% probability (Frayer and others, 1983). Our study demonstrates that the NWI classification based on Cowardin and others (1979) can successfully be aggregated into the EMAP classification. This successful aggregation demonstrates that EMAP-Wetlands can develop sampling frames from the available NWI digital data sets.

It is expected that the EMAP sampling design and EMAP classification system will be useful for wetlands resource managers implementing regional monitoring and research programs. The NWI maps are currently the most appropriate maps available for EMAP-Wetlands sampling frame development. Wedding the NWI maps and classification system with the EMAP-Wetlands sample frame development provides a common basis and efficient mechanism for continuity between these two important and complementary programs.

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