RESEARCH SECTION

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Regional patterns of total nitrogen concentrations in the National Rivers and Streams Assessment

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Abstract: Patterns of nitrogen (N) concentrations in streams sampled by the National Rivers and Streams Assessment (NRSA) were examined semiquantitatively to identify regional differences in stream N levels. The data were categorized and analyzed by watershed size classes to reveal patterns of the concentrations that are consistent with the spatial homogeneity in natural and anthropogenic characteristics associated with regional differences in N levels. Ecoregions and mapped information on human activities including agricultural practices were used to determine the resultant regions. Marked differences in N levels were found among the nine aggregations of ecoregions used to report the results of the NRSA. We identified distinct regional patterns of stream N concentrations within the reporting regions that are associated with the characteristics of specific Level III ecoregions, groups of Level III ecoregions, groups of Level IV ecoregions, certain geographic characteristics within ecoregions, and/or particular watershed size classes. We described each of these regions and illustrated their areal extent and median and range in N concentrations. Understanding the spatial variability of nutrient concentrations in flowing waters and the apparent contributions that human and nonhuman factors have on different sizes of streams and rivers is critical to the development of effective water quality assessment and management plans. This semiquantitative analysis is also intended to identify areas within which more detailed quantitative work can be conducted to determine specific regional factors associated with variations in stream N concentrations.

Key words: ecoregions—environmental sampling—nitrogen—nutrients—water quality—watersheds

Nutrient pollution of streams has been an important target of pollution control policies in many countries for several decades (Melillo and Cowling 2002). In the United States, addressing nutrient "enrichment" has been a key element of the Clean Water Act of 1972. Strategies to reduce human-caused contributions to increased nitrogen (N) concentrations in streams have often focused on developing an understanding of "natural background" conditions (i.e., N concentrations that would exist in the absence of human activity). Determining these conditions is difficult, of course, and has many limitations because of the omnipresent anthropogenic contributions from atmospheric sources and the expansiveness of agricultural activities and urbanization (Smith et al. 2003; Sobota et al. 2015). An understanding of these "natural background" conditions is facilitated by appropriate approaches to regionalization and a thorough description of the range of concentrations occurring and their relationship to land use patterns and human activity (Hughes 1995; Bailey et al. 2004; Stoddard et al. 2006).

The National Rivers and Streams Assessment (NRSA) and its predecessor the Wadeable Streams Assessment (WSA) were conducted by the US Environmental Protection Agency (USEPA) in collaboration with states and tribes to determine the condition of the nation's streams and rivers (USEPA 2006, 2016). Among the questions these assessments were designed to answer are the following: (1) is there a water quality problem; (2) if so, how extensive is the problem; and (3) does the problem occur in "hotspots" or is it widespread? To address these questions the NRSA and WSA divided the conterminous United States into nine reporting regions similar to, but fewer in number than, Level II ecoregions (http://www.epa.gov/eco-research/ecoregions) (figure 1). The relative quality of the physical, biological, and chemical characteristics at each stream site was determined and classified by USEPA for each of the nine reporting regions (USEPA 2016).

The advantage of using NRSA data to assess regional patterns of stream nutrient concentration over other attempts lies in the number of stream sites sampled, the consistency by which the data were collected, the different stream size classes that were included, and that the collection of sites sampled is a statistically representative set of locations for the conterminous United States. The NRSA included sampling from 1,924 unique sites selected using a stratified random survey design. Of these 1,924 sites, 7 did not have data on N and an additional 18 did not have useable watershed area information. This left 1,899 sites for our analysis in this manuscript (figure 2). Each NRSA probability site is "weighted" for the length of stream and river represented by that site (USEPA 2016).

Because streams reflect the aggregate of characteristics of the watersheds they drain and ecological regions identify areas within which there are particular patterns in this aggregate, ecoregions, including NRSA reporting regions, are effective in illustrating broad differences in central tendencies and ranges of river and stream characteristics (Omernik and Bailey 1997; Griffith et al. 1999; Omernik and Griffith 2014). However, due largely to their size, there is considerable variability within NRSA reporting regions, much of which can be explained by differences among the more detailed Level III ecoregions, or particular aggregations of Level III regions, nested within the NRSA regions (figure 1). In some cases, differences among smaller Level IV ecoregions help explain variability within each Level III region.

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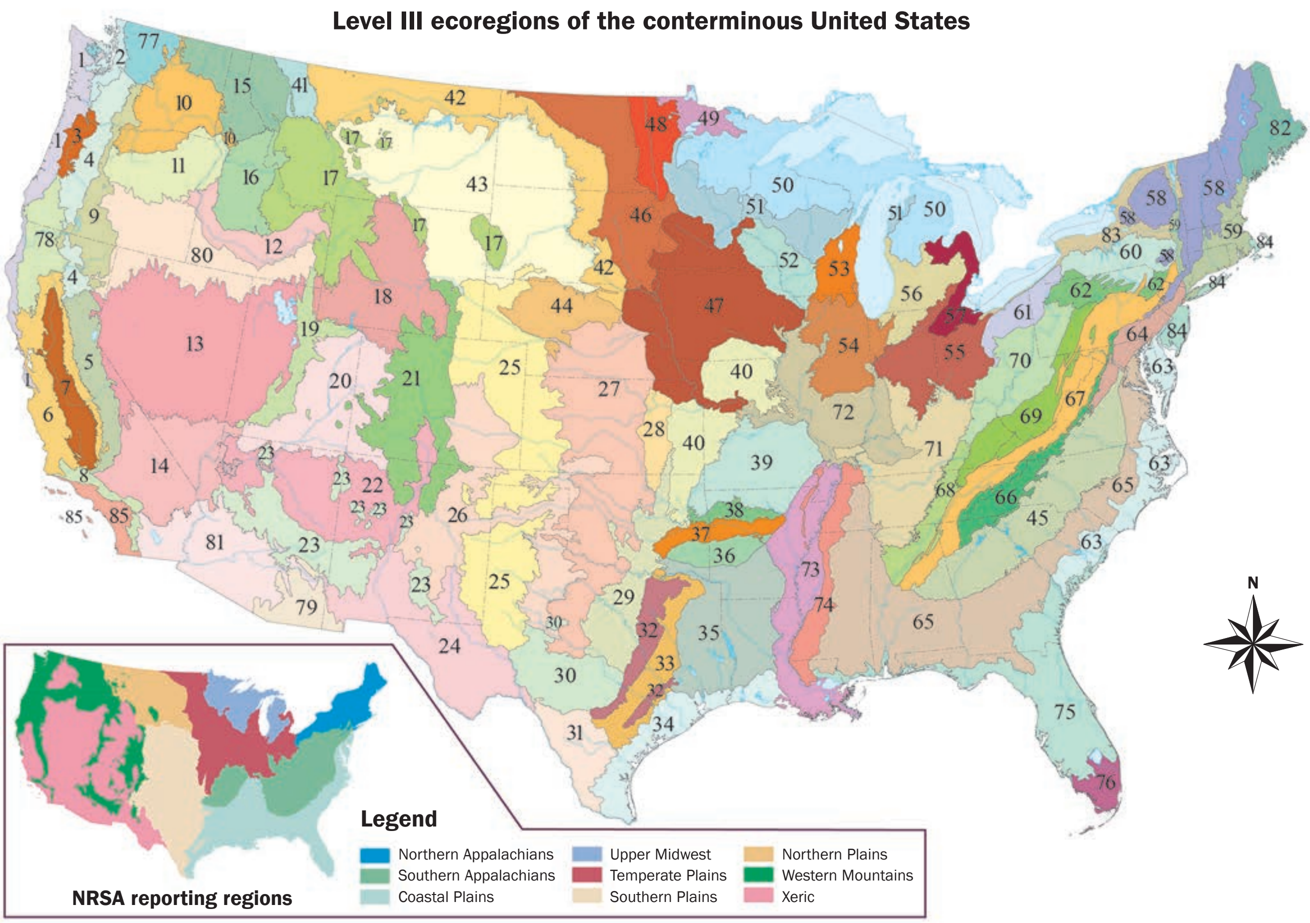
Figure 1

The National Rivers and Streams Assessment (NRSA) reporting regions and Level III ecoregions. Maps, names, and descriptions of Level I, II, III, and IV ecoregions can be found at www.epa.gov/eco-research/ecoregions.



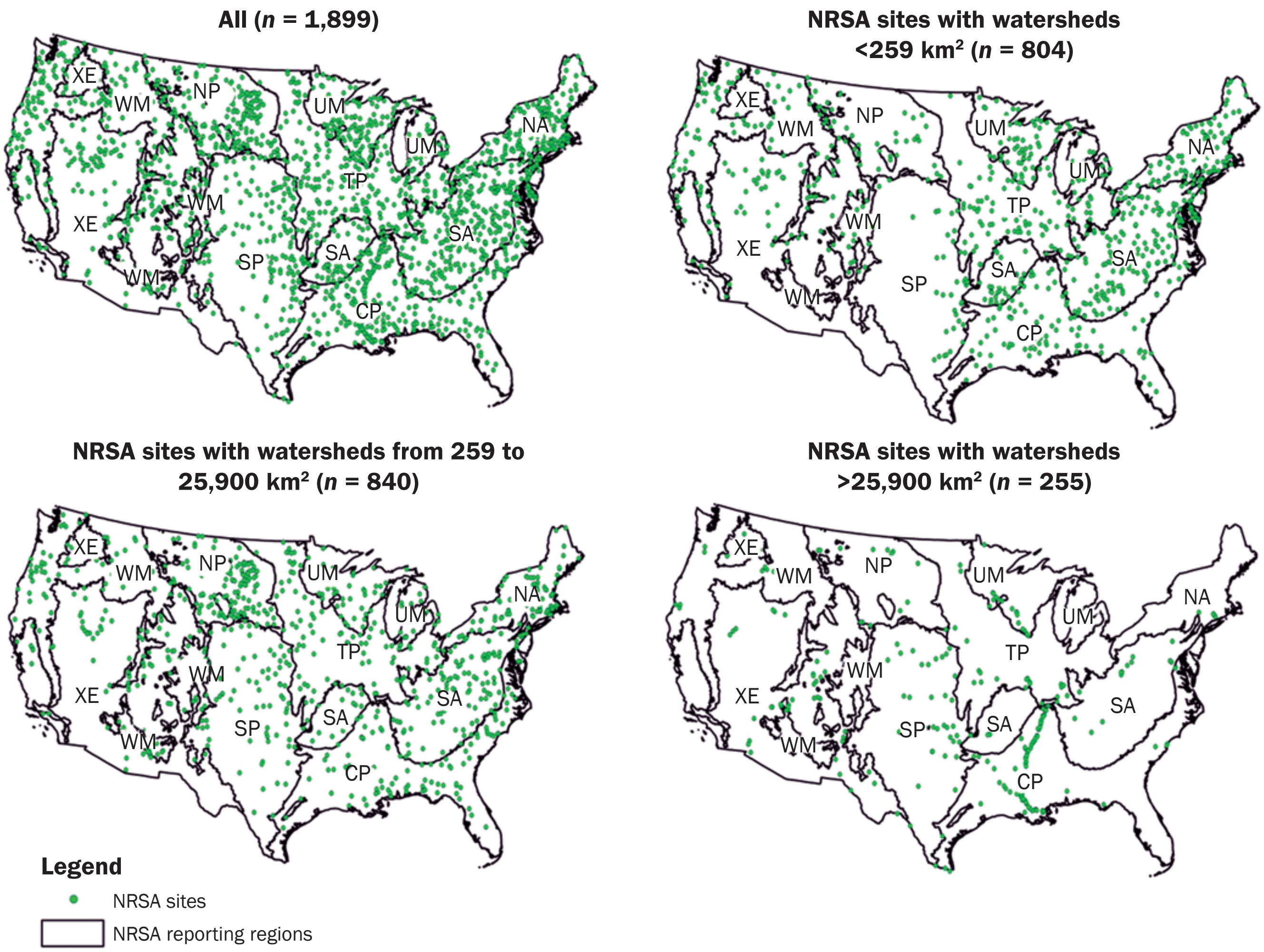
In general, water quality in streams with watersheds completely within an ecoregion at any level will be different than that in streams in other ecoregions of the same level, as will the factors that influence these differences (Omernik 2003). Streams that have watersheds covering more than one ecoregion will reflect the characteristics of all of the ecoregions they drain (Omernik and Bailey 1997). In order to distinguish regions of similar patterns in stream quality, one must select sites with watershed sizes consistent with the regional differences in the combination of geographic phenomena, such as land use, soils, physiography, and geology, that may influence water quality.

The NRSA examined the condition of streams and rivers of all sizes, from those with watersheds less than 26 km^2 (10 mi^2) to those with watersheds of more than 2,589,988 km^2 (1,000,000 mi^2). One goal of the NRSA was to allow a description of spatial differences in water quality in streams of comparable size as well as to determine the differences in conditions of streams of different sizes. This adds another dimension to questions regarding the representativeness of reference conditions.

Much of the complexity of analyzing patterns of stream quality is due to the nature of streams and the geographic phenomena that influence the quality and quantity of streams. Streams are linear characteristics at regional and national scales, while soils, land use, vegetation, land surface forms, and ecoregions can be depicted as spatial units. Stream quality and quantity are measured at points on streams, and there are literally an infinite number of these points. As noted above, the quality and quantity of streams reflect the conditions in the watersheds upgradient from these points, where watersheds can be defined (Hughes and Omernik 1981).

It should be noted that ecoregions are a general purpose framework, as opposed to one designed for a single or special purpose. They identify areas of similarity in combinations of biotic, abiotic, terrestrial, and aquatic ecosystem components with humans considered as part of the biota. As such, ecoregions provide the spatial framework for the research, assessment, and management of ecosystems and facilitate integration of these activities across agencies and programs with different interests in the same geographic areas, as well as an overall interest in ecosystems as a whole (Omernik 2004). Although spatial patterns of different characteristics of water quality and quantity may vary, all of these characteristics are interrelated to one another as they are to the combination of integrating and causal factors that are used to define ecoregions. Hence, ecoregions have proven to be effective for the assessment of water quality at state, regional, and national

Figure 2
Three selected watershed size classes or groupings of classes of National Rivers and Streams Assessment (NRSA) probability-based sample sites.



levels (USEPA 1991; Denton et al. 2001; Arnwine and Denton 2001; IDNR 2001; Heiskary and Wilson 2008). This qualitatively developed hierarchical framework has also been helpful in explaining regional patterns of broad-scale quantitative assessments, such as the US Geological Survey (USGS) land cover trends project (Drummond et al. 2012; Sleeter et al. 2012, 2013) and the USGS spatial analysis of N loads and factors controlling N delivery to streams (Hoos and McMahon 2009).

The primary purpose of this paper is to examine patterns in N concentrations in NRSA sampled streams for significant regional differences within the relatively large Level II-type ecoregions used by the NRSA. A second purpose is to identify significant patterns in N concentrations in streams with different sizes of watersheds. That is, are N concentrations in streams with watersheds completely within a particular ecoregion different than those for streams in the same region but with watersheds that drain other ecoregions containing different factors affecting water quality? Finally, we examine the geographic characteristics that appear to be associated with regional differences in stream N concentrations, as well as differences among streams with different watershed sizes. Our qualitative and semi-quantitative analyses are intended to identify areas within which more quantitative work can be conducted to determine the relative importance of the factors associated with variations in stream N concentrations.

Materials and Methods

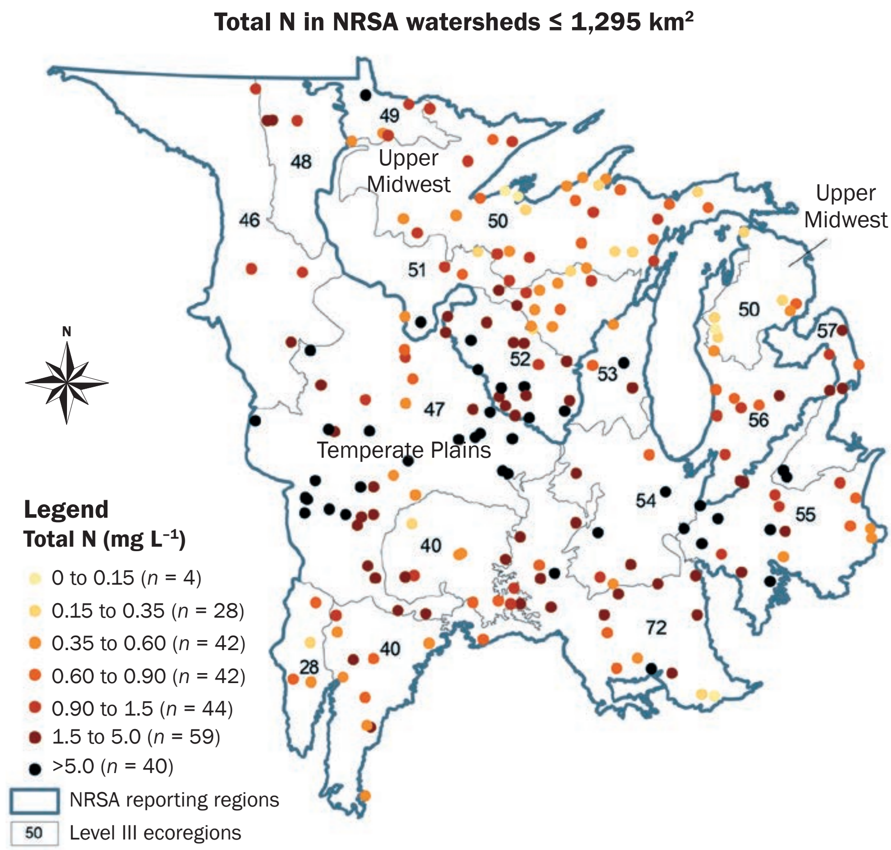
For the NRSA, sites were selected using a probability survey design similar to a stratified random sampling technique (USEPA 2016). In our characterization of the regional patterns of N concentrations in streams, we used results from the probability sample for which watershed areas were available and N concentrations had been sampled, a total of 1,899 sites. All sites were sampled during a single index period constituting base flow that ranged from mid-June through August of 2008 or 2009, depending on the part of the country in which the site existed. Samples were sent on ice via overnight shipping and handled in a central laboratory in Corvallis, Oregon, at the USEPA Western Ecology Division. The NRSA data set, reports, and background information are available at http://water.epa.gov/national-aquatic-resource-surveys/nrsa.

In this analysis, we divided the NRSA sites into six watershed size classes that had some meaning and utility for the analysis of N relative to regional land characteristics and also were relatively equal in number. Of the 1,899 sites, 476 have watersheds smaller than 26 km^2 (10 mi^2), 328 have watersheds between 26 to 259 km^2 (10 to 100 mi^2) in size, 262 have watersheds of between 259 to 1,295 km^2 (100 to 500 mi^2), 155 have watersheds between 1,295 to 2,590 km^2 (500 to 1,000 mi^2) in size, 423 have watersheds of between 2,590 to 25,900 km^2 (1,000 to 10,000 mi^2), and 255 have watersheds larger than 25,900 km^2 (10,000 mi^2). We then subdivided the sites into one of seven N concentration classes that were relatively equal in the number of sites in each class with the exception of the highest class, which contained approximately 25% of the sites of the other classes. The classes were based on the total N concentrations found for 1,899 sites used for this study. The total range for all the sites was 0.001 to 48.020 mg L^{-1}. We developed color-keyed dot maps for each watershed size class, with the lowest N concentration class represented by a light yellow dot, the highest class identified by a black dot, and the classes in between identified by colors ranging from dark yellow to dark brown depending on their concentration class (figure 3). The dot maps of each watershed size class, and some groups of size classes (e.g., ≤1,295 km^2 [500 mi^2]), were then examined for significant regional patterns of N concentrations for streams within the larger NRSA reporting regions, as well as the smaller Level III ecoregions (figure 3). To help in this analysis, we also examined patterns of N concentrations for larger streams of different watershed size classes to see how the values may be affected by multiple Level III ecoregions and/or NRSA reporting regions. Watershed boundaries of the larger size classes, i.e., 2,590 to 25,900 km^2 (1,000 to 10,000 mi^2) and >25,900 km^2 were also shown on these working maps.

To help determine the factors associated with the central tendencies and extremes in N concentrations within and among NRSA reporting regions, as well as significant Level III ecoregions, we also examined the field notes from the sampling crews and other information, such as land use/land cover data (Homer et al. 2007; Fry et al. 2011) and aerial imagery (Google Earth, www.google.com/earth/index/html) of watersheds of selected sites with very high, very low, or average values. This analysis was done to examine the watershed characteristics that sites with high values had in common as compared to those with unusually low and average values.

Figure 3

A portion of a color keyed dot map of total nitrogen (N) concentrations at National Rivers and Streams Assessment (NRSA) stream sampling sites. This example is for two watershed size classes, <259 km^2 and 259 to 1,295 km^2, in two NRSA reporting regions, the Upper Midwest and Temperate Plains.



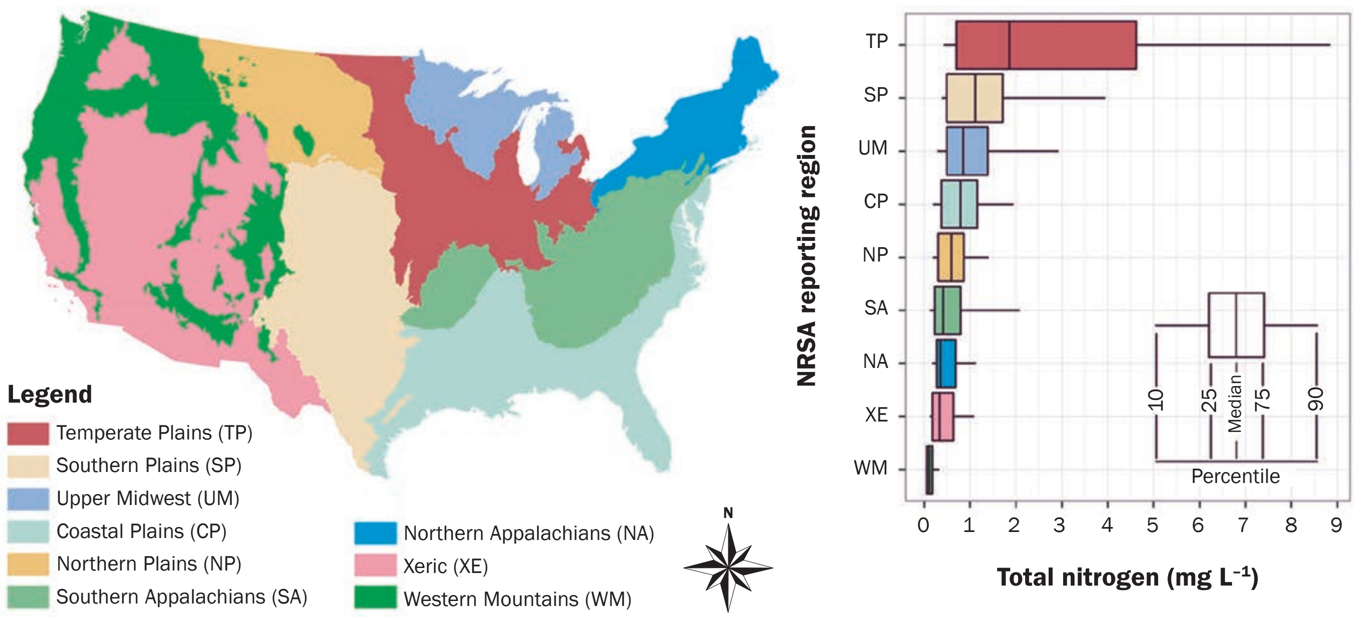
Results and Discussion

Regional Analysis. As shown in figure 4, the central tendencies of N concentrations in streams are significantly different among the nine NRSA reporting regions. The frequency distributions of concentrations for all of these regions are heavily skewed to the left (low values) with a few higher outliers having values 20 to 60 times higher than the medians. Thus, the median value is a better representation of central tendency for each ecoregion than the mean. When compared to a national map of land cover (Homer et al. 2012), figure 4 illustrates a fairly obvious association between N concentration in streams and land use, particularly agricultural activity, although a more accurate picture of this or any other association is partially masked by the misrepresentation of the stream sites that drain additional areas beyond the reporting region where they are located. Of the 1,899 NRSA probability-based sites, 255 (about 13%) have watersheds greater than 25,900 km^2 (10,000 mi^2). Most of these watersheds drain more than one of the nine reporting regions, some drain multiple reporting regions, and all drain more than one Level III ecoregion (figure 1). It is apparent from the patterns of the NRSA sites with watersheds greater than 25,900 km^2 that many of these sites are on the same river (e.g., the Missouri, Mississippi, Platte, Red, Ohio, and Arkansas) as one or more of the other sites (figure 2). On the other hand, nearly all of the 804 sites with watersheds less than 259 km^2 (100 mi^2) drain areas that are completely within one Level III ecoregions as well as one reporting region.

Northern Appalachians. This reporting region comprises the northeastern part of the United States largely north of the southern extent of continental glaciation (figure 5). The region includes the mostly forested highlands of New York, New England, and Pennsylvania, as well as surrounding plains

Figure 4

Medians and ranges of stream nitrogen (N) concentrations in National Rivers and Streams Assessment (NRSA) reporting regions.



and hills that are characterized by a land cover mosaic of forest, agriculture, wetlands, and glacial lakes.

The median value of total N concentrations represented by the 219 sites in the region is 0.36 mg L^{-1} (figure 5). In general, the streams and rivers in the Northeastern Highlands (Level III Ecoregion 58) had slightly lower concentrations (median = 0.32 mg L^{-1}), and the streams in the regions with mixed land use surrounding the higher forested highlands (Ecoregion 58) had higher concentrations (median = 0.48 mg L^{-1}). Except for a few scattered anomalies, the highest N concentrations were in streams in the densely populated region of southeastern New England (Level IV Ecoregions 59c and 59e), the eastern part of which is on the edge of one of the highest concentrations of cranberry (*Vaccinium oxycoccos* L.) production in the country (Griffith et al. 2009). Two of the sites with the highest N concentrations (1.94 and 2.05 mg L^{-1}) have watersheds with dense concentrations of cranberry bogs (USDA 2012) as well as the dense patterns of exurbanization typical of southeastern New England (Theobald 2005; Berube et al. 2006). The median value represented by the 19 sites in Ecoregions 59c and 59e was 0.92 mg L^{-1}, which is more than two and a half times higher than the median N concentration of the larger Northern Appalachians reporting unit.

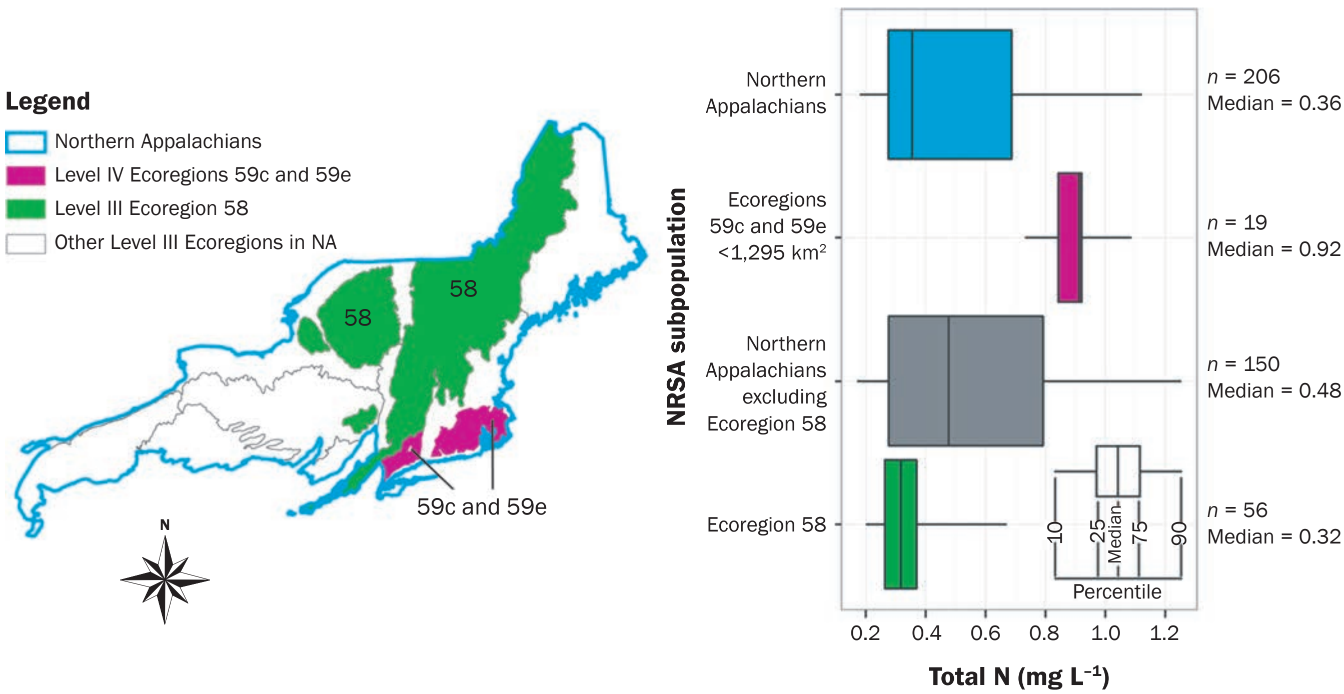
Southern Appalachians. This reporting region contains the mostly forested and nonglaciated Appalachians of the east, the Ozark Plateau, Boston Mountains, Ouachita Mountains, and Arkansas River Valley of the south-central United States, as well as the Piedmont regions and Interior Plateau that flank the Appalachians to the east and west, respectively. The Piedmont and Interior Plateau contain a mix of forest, pasture, cropland, and urban and suburban land. Livestock grazing occurs on many of the pasture and woodland areas.

Patterns of stream N concentrations in the region vary considerably, with low values in the more forested regions and higher values in the more agricultural and urbanized regions. The median value for the streams and rivers in the reporting region is 0.41 mg L^{-1} (figure 6). Not surprisingly, values in the sparsely populated, nearly completely forested Boston Mountains (Level III Ecoregion 38) of Arkansas and Oklahoma are much lower (median = 0.08 mg L^{-1}) than the median for the reporting region. Most streams with watersheds less than 259 km^2 (100 mi^2) that are completely within another forested Level III ecoregion, the Western Allegheny Plateau (Ecoregion 70), have lower concentrations (median = 0.27 mg L^{-1}) than those of the larger reporting region, but not as low as in the Boston Mountains. The watersheds of the two streams in the Western Allegheny Plateau that had extremely high N concentrations (10.5 and 19.4 mg L^{-1}) contained a disproportionately high amount of agricultural activity, including meat and poultry processing facilities.

Some of the highest N concentrations in streams in the Southern Appalachians are found in the Northern Piedmont (Level III Ecoregion 64). Here, the median value of the streams with watersheds less than 25,900 km^2 (10,000 mi^2) is 2.32 mg L^{-1}. These high values may be associated with the region's relatively high population density, a high concentration of layer, broiler, and dairy operations (USDA 1999, 2012), as well as the region's high percentage of urban and exurban land. By contrast, N concentrations in streams of the Piedmont (Level III Ecoregion 45) to the southwest are lower. Curiously, the median value represented by the 46 streams in this region that have watersheds less than 1,295 km^2 (500 mi^2) is 0.47 mg L^{-1}, whereas the median of the 16 streams in the region with watersheds between 1,295 km^2 (500 mi^2) and 25,900 km^2 (10,000 mi^2) is 0.60 mg L^{-1}. Apparently, the small portion of some of the watersheds of larger streams that overlap the Blue Ridge (Level III Ecoregion 66) to the northwest do not result in lower median N concentrations, although the box plot for the smaller streams is skewed to the right, probably due to the relatively large number of small streams affected by point sources.

Figure 5

Boxplots of stream nitrogen (N) concentrations in the Northern Appalachians (NA) National Rivers and Streams Assessment (NRSA) reporting region and specific ecoregions and watershed size classes.



Stream N concentrations in the Ozark Plateau (Level III Ecoregion 39), a region of mixed land use/land cover with a similar percentage of forest land as the Piedmont (45) and more cropland than the mountainous Appalachians and Interior Plateau (70), fall between those two Southern Appalachian regions. The median concentration for streams with watersheds less than 1,295 km^2 (500 mi^2) was 0.36 mg L^{-1}.

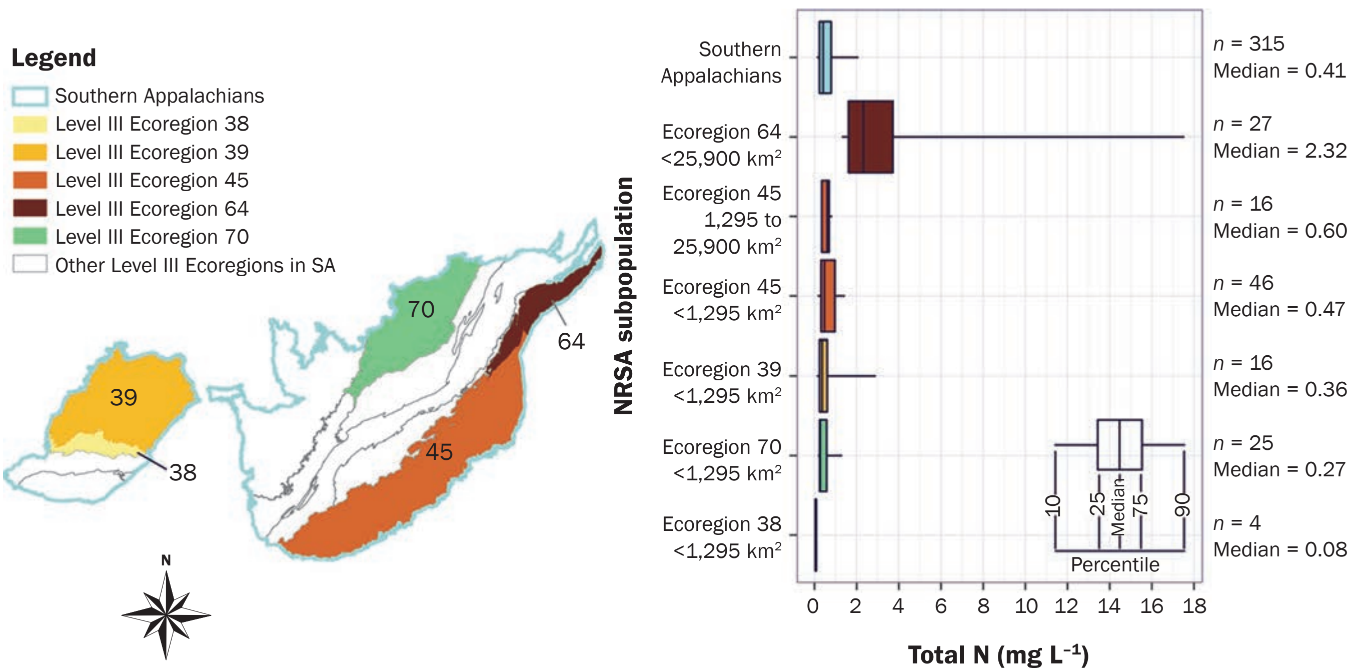
Coastal Plains. Over half of this reporting region consists of flat coastal or alluvial plains. The remainder of this reporting region comprises mostly irregular plains and low hills that lie adjacent to the hillier and forested Southern Appalachians to the north and to the drier Southern Great Plains to the west (figure 4). Although most of this area was originally forested, it now consists of a mix of forest, pasture, cropland, and urban areas, but contains less cropland than most of the Southern Plains reporting region.

Total N concentrations in streams in the region are generally about two times higher than in the Southern Appalachians. The median value for the entire region is 0.79 mg L^{-1}, but streams in the parts of the region with high population densities, high concentrations of poultry operations, and heavy fertilizer use on croplands have considerably higher values (figure 7). The median value represented by the 22 sites in the Middle Atlantic Coastal Plains (Level III Ecoregion 63) that drain watersheds less than 259 km^2 (100 mi^2) is 1.04 mg L^{-1}. The Delmarva Peninsula in the northern part of Ecoregion 63 contains a high density of poultry operations, and fertilizer use on cropland in the region as a whole is relatively high (USDA 1999, 2012). Confined hog operations are common in parts of the Coastal Plain Ecoregion 63, especially in North Carolina; the Southern Coastal Plain (Level III Ecoregion 75) of southeast Georgia and most of Florida also has some areas of high fertilizer use on croplands (USDA 1999, 2012). For the streams in this region with watersheds less than 2,590 km^2 (1,000 mi^2), the median concentration is 1.08 mg L^{-1}. Streams in the Mississippi Alluvial Plain (Level III Ecoregion 73) that have watersheds less than 259 km^2 contain the highest N concentrations in the Coastal Plains (median = 1.61 mg L^{-1}). Most of the central and northern parts of the Mississippi Alluvial Plain (Ecoregion 73) are in relatively heavily fertilized cropland of rice (*Oryza sativa* L.), cotton (*Gossypium* L.), and soybeans (*Glycine max* [L.] Merr.). It was necessary to use only values from the nine streams in the Mississippi Alluvial Plain that drain less than 259 km^2 because most of the remaining sites have very large watersheds that drain multiple ecoregions, some covering as much as a third of the United States.

Some of the reporting region's lowest N concentrations in streams are in the South Central Plains (Level III Ecoregion 35) of northwest Louisiana, east Texas, and southwest Arkansas. The median value for the streams with watersheds less than 259 km^2 (100 mi^2) that are completely within Ecoregion 35 as well as within the larger Coastal Plains is 0.56 mg L^{-1}. The median value for the streams and rivers in the region with watersheds between 259 and 25,900 km^2 (100 and 10,000 mi^2) is slightly lower at 0.53 mg L^{-1}. However, this median concentration is not representative of Ecoregion 35, nor the larger Coastal Plains, because many of these sites are nested (have watersheds within that of another site) on the Red River and drain regions outside the reporting region. A large portion of the South Central Plains ecoregion (Ecoregion 35) is forested or in pastureland, but poultry production and processing is also an important economic activity. Discharges from processing facilities, as well as poultry litter for pasture fertilization and as a soil amendment

Figure 6

Boxplots of stream nitrogen (N) concentrations in the Southern Appalachians (SA) National Rivers and Streams Assessment (NRSA) reporting region and specific ecoregions and watershed size classes.



in pine plantations, may be elevating stream nutrient concentrations, especially phosphorus (P), in some areas (Gaston et al. 2003; LSU AgCenter 2010). Examination of other stream and reference site N concentrations suggests this region has some higher N concentrations than indicated by the NRSA probability-sampling data set.

Upper Midwest. The Upper Midwest reporting region contains large areas of forest, some cropland and arable land, and numerous glacial lakes and wetlands. The northern part of the region has a land cover dominated by forests, lakes, and wetlands, and is bordered to the south by an area of cropland, pasture, woodland, and forest. With the exception of the Driftless Area (Level III Ecoregion 52) in southwestern Wisconsin, southeastern Minnesota, and northeastern Iowa, the entire Upper Midwest reporting region was heavily impacted by continental glaciation.

As with the other broad reporting regions, differences in N concentrations in streams are strongly associated with regional patterns in soil nutrient richness and agricultural practices, such as fertilizer use and animal unit densities (Omernik 1977). Whereas the median concentration of total N for the 161 streams in the Upper Midwest is 0.85 mg L^{-1}, the median value for streams in the forested Northern Lakes and Forests (Level III Ecoregion 50) is much lower; the median for the 22 streams with watersheds from 259 to 25,900 km^2 (100 to 10,000 mi^2) is 0.20 mg L^{-1} (figure 8). On the other hand, the streams in the Southern Michigan/Northern Indiana Drift Plains (Level III Ecoregion 56) with watersheds less than 25,900 km^2 have a median value of 1.32 mg L^{-1}. Although glaciated and containing many lakes (similar to Ecoregion 50), much of Ecoregion 56 has highly agriculturally managed soil, which may help explain the higher N concentrations in this ecoregion. Streams in the Driftless Area (Ecoregion 52) have high N concentrations, with a median value of 2.67 mg L^{-1} for the streams with watersheds less than 1,295 km^2 (500 mi^2). Unlike the glaciated parts of the Upper Midwest where stream drainage is poorly defined, drainage in Ecoregion 52 is well defined. Similar to adjacent regions in Wisconsin to the north and east, Ecoregion 52 contains a high density of dairy cattle, with most of the animals in close proximity to streams (Weigel et al. 2000; Omernik et al. 1982; John Lyons, Wisconsin Department of Natural Resources [DNR], personal communication, August 12, 2013). High cattle density coupled with the geomorphology of the region may contribute to the high N values found in Ecoregion 52 (Omernik et al. 2000; John Lyons, Wisconsin DNR, personal communication August 12, 2013). Illustrating the problem of including sites with watershed sizes inconsistent with spatial characteristics associated with differences in stream nutrient concentrations, the median N concentration for the larger streams and rivers located in the Driftless Area (Ecoregion 52) that have watersheds greater than 25,900 km^2 is 1.50 mg L^{-1} (figure 8). This value does not represent conditions of the relatively homogeneous Driftless Area, but instead reflects additional influences from the much larger multiecoregion area upgradient from the Driftless Area.

Temperate Plains. Perhaps more appropriately called the Agricultural Midwest, much of this reporting region is coincident with the area of major nonirrigated corn (*Zea mays* L.) and soybean production in the country (USDA 1999, 2012). Now mostly cropland and pasture, the western drier part of the region was once in tallgrass prairie, the central part in a mosaic of bluestem prairie and oak-hickory forest, and the eastern part covered mostly by beech (*Fagus* L.)-maple (*Acer* L.) and elm (*Ulmus* L.)-ash (*Fraxinus* L.) forests. The central part of this reporting region also contains the broadest area

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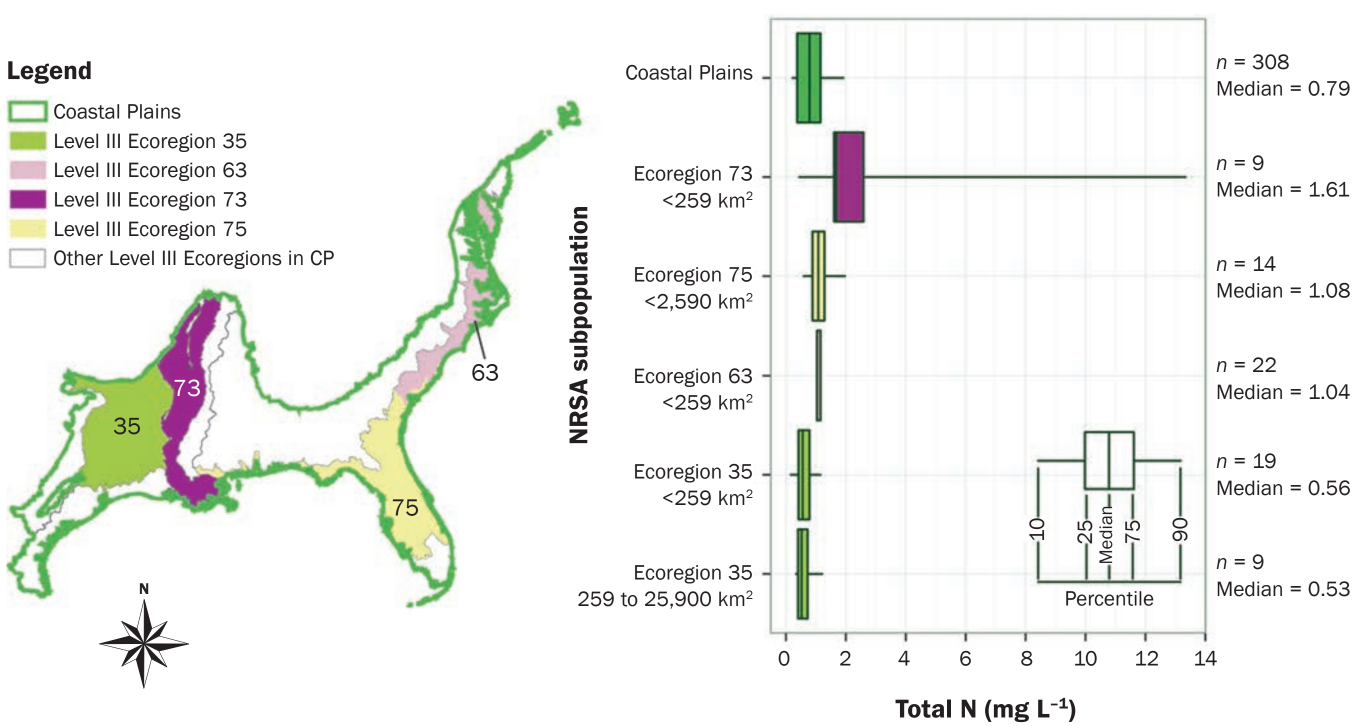
Figure 7

Boxplots of stream nitrogen (N) concentrations in the Coastal Plains (CP) National Rivers and Streams Assessment (NRSA) reporting region and specific ecoregions and watershed size classes.



of industrialized agriculture in the nation (Hoban et al. 1997). The densest concentrations of hog and turkey production are found in the western part of the region with hog farming centered in southern Minnesota and northern Iowa and turkey farms located in west-central Minnesota (USDA 2012). Concentrations of confined feeding operations for poultry layer production are lumped in several specific counties in Iowa, Indiana, and Ohio (USDA 1999, 2012).

Associated with this region's nutrient rich soils, intensive cropland agriculture, tiled drainage, and numerous confined feeding operations, N concentrations represented by the 193 sites in the region are high with a median value of 1.85 mg L^{-1} (figure 9). The highest values (median = 3.54 mg L^{-1}) are found in the 61 streams in the Western, Central, and Eastern Corn Belt Plains (Level III Ecoregions 47, 54, and 55, respectively), which have watersheds of less than 1,295 km^2 (500 mi^2). Streams in the Central Irregular Plains (Level III Ecoregion 40), a region with less intensive cropland agriculture and fewer hectares of cropland fertilized as a percentage of all cropland, have low nutrient concentrations. The median concentration in streams of Ecoregion 40 is 0.59 mg L^{-1}. Nitrogen concentrations are even lower (median = 0.26 mg L^{-1}) in the five streams with watersheds within the Flint Hills (Level III Ecoregion 28), a region of shale, cherty limestone, and rocky soils, which supports little cropland agriculture.

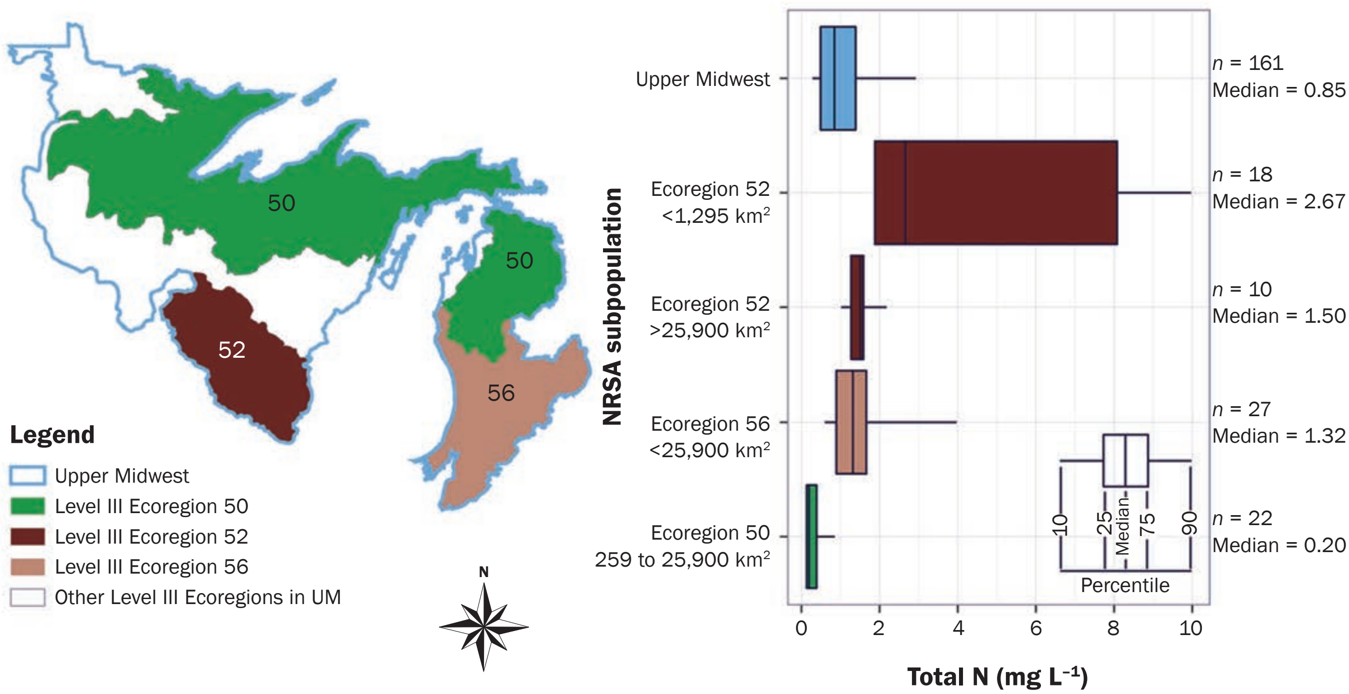
Southern Plains. Comprising the southern part of the Great Plains of the United States, this once mostly grassland region consists of smooth to irregular plains, with some areas of hills and tablelands. Like other parts of the Great Plains, the western part of the region is drier than the eastern parts. Perennial streams that originate in the region are few and flow can vary greatly seasonally and from year to year due to the region's erratic precipitation. Since the early 1960s when wide-scale irrigation began in the western part of the region resulting in a lowering of the water table, many streams that were perennial became intermittent or ephemeral (Falke et al. 2011; Angelo et al. 2003).

Compared to the other ecoregions in the Southern Plains, patterns in stream N concentrations are considerably higher in the Central Great Plains (Level III Ecoregion 27), where cropland agriculture is more intensive and the amount of cropland fertilized is the greatest (USDA 1999, 2012). While the median value represented by the 163 stream sites in the overall Southern Plains is 1.11 mg L^{-1}, the median represented by the 35 sites in the Central Great Plains (Ecoregion 27) that have watersheds less than 2,590 km^2 (1,000 mi^2) is 1.64 mg L^{-1} (figure 10). Conversely, the Southwestern Tablelands (Level III Ecoregion 26) in the western part of the Southern Plains has a small percentage of land in cropland and corresponding low N concentrations in streams. The median for the streams in Ecoregion 26 that have watersheds of between 259 and 25,900 km^2 (100 and 10,000 mi^2) is 0.40 mg L^{-1}, which is less than 40% of the central tendency for the larger Southern Plains reporting region and only 24% of the median for the intensively farmed Central Great Plains (Ecoregion 27) to the east. Nitrogen concentrations are even less (median = 0.21 mg L^{-1}) in four streams with watersheds in the Edwards Plateau (Level III Ecoregion 30) of Texas, another area of little cropland agriculture. Karst topography and the resulting underground drainage in this ecoregion produce perennial streams that are relatively clear and cool compared to those of surrounding regions.

Whereas the values for most of the stream sites in the Southern Plains reflect the mix

Figure 8

Boxplots of stream nitrogen (N) concentrations in the Upper Midwest (UM) National Rivers and Streams Assessment (NRSA) reporting region and specific ecoregions and watershed size classes.



of natural (e.g., soils and geology) and nonpoint agricultural characteristics of the region, a few N concentrations far higher than the rest may be attributable to point sources. For example, a site on Village Creek in the Cross Timbers (Level III Ecoregion 29) of east-central Texas, a region bordering and to the east of the Central Great Plains, had a concentration of 10.41 mg L^{-1}, which the sampling crew noted was likely due to sewage plant effluent. Also, in the western part of the Southern Plains reporting region where most of the N concentrations in NRSA streams were in the 0.2 to 0.7 mg L^{-1} range, a few sites downstream from large confined animal feeding operations and/or other point sources had values that were an order of magnitude higher. One site on the South Platte River between Denver and Greeley, Colorado, in the High Plains (Level III Ecoregion 25) had an N concentration of 9.57 mg L^{-1}.

Northern Plains. Once a mostly grass-covered prairie, the Northern Plains region contains less cropland and is drier than the Temperate Plains to the east; yet it is cooler and has a different mosaic of natural vegetation than the Southern Plains reporting region. Reflecting this difference in phenology, the combination of major crops in the region includes spring wheat (*Triticum aestivum* L.), barley (*Hordeum* L.), corn, and soybeans and is different than the present combination of winter wheat, sorghum (*Sorghum bicolor* [L.] Moench), corn, and locally, cotton of the Southern Great Plains. The northern and eastern parts of the region were sculpted by continental glaciation and contain hummocky moraines that are pocked with wetlands, locally called prairie potholes. This part of the region contains considerably more agricultural cropland than the unglaciated predominantly rangeland portion that is characterized by flat to irregular plains, tablelands, stabilized sand dunes, and badlands. Most of the region's streams are intermittent and ephemeral. The few perennial streams that are present largely originate in the mountainous ecoregion to the west.

Like the Southern Plains, streams in the eastern, more intensively farmed part of this reporting region have higher N concentrations than those in the western portion. The median concentration for all streams and rivers in the region is 0.6 mg L^{-1}. The median for the streams with watersheds less than 1,295 km^2 (500 mi^2), more than half of which are in the eastern part of the region, is 0.61 mg L^{-1} (figure 11). Nitrogen concentrations represented by the 15 sites on rivers with watersheds greater than 25,900 km^2 (10,000 mi^2) were much lower (median = 0.30 mg L^{-1}) than streams with watersheds less than 1,295 km^2. Most of these 15 sites are on the Missouri, Little Missouri, Yellowstone, and Cheyenne Rivers and have headwaters in the Western Mountains reporting unit.

Western Mountains. This region of high, rugged, mostly forested mountains and scattered wide open valleys is characterized by elevational banding. The highest elevations are alpine or above timberline and ice and snow covered for most of the year. Mid-elevations are mostly forested and lower elevations are typically in grass and/or shrub vegetation. Due to the orographic effect of the mountains and prevailing west-to-east pattern of weather systems, the region receives considerably greater amounts of precipitation than the adjacent Northern Plains, Southern Plains, and Xeric reporting regions and results in drier, "rain shadow" conditions on eastern lee sides. Much of the water in streams in these adjacent regions originates via surface or subsurface pathways from the Western Mountains. Anthropogenic activities that have an impact on the region's stream quality are predominately timber harvest in the heavily forested lower and mid-elevations and grazing, which is common in the lower elevations and valleys.

Figure 9

Boxplots of stream nitrogen (N) concentrations in the Temperate Plains (TP) National Rivers and Streams Assessment (NRSA) reporting region and specific ecoregions, groups of ecoregions, and watershed size classes.

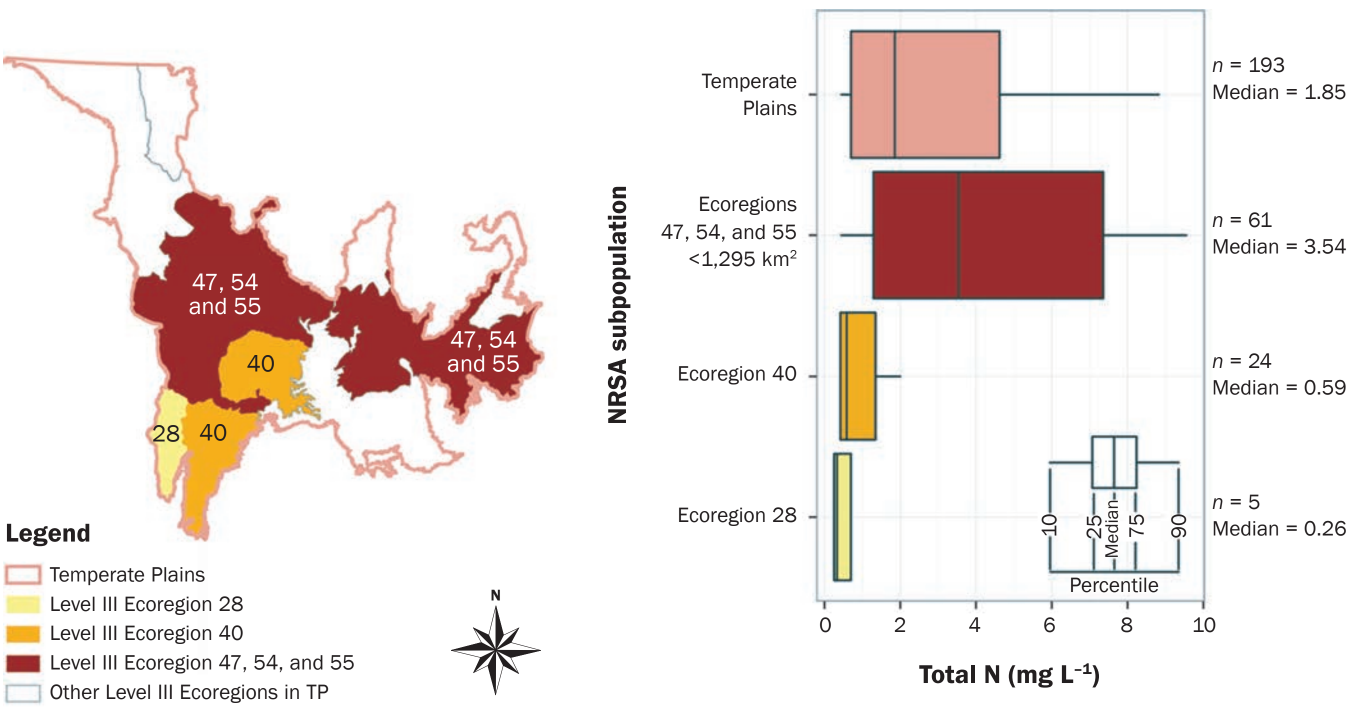


Figure 10

Boxplots of stream nitrogen (N) concentrations in the Southern Plains National Rivers and Streams Assessment (NRSA) reporting region and specific ecoregions and watershed size classes.

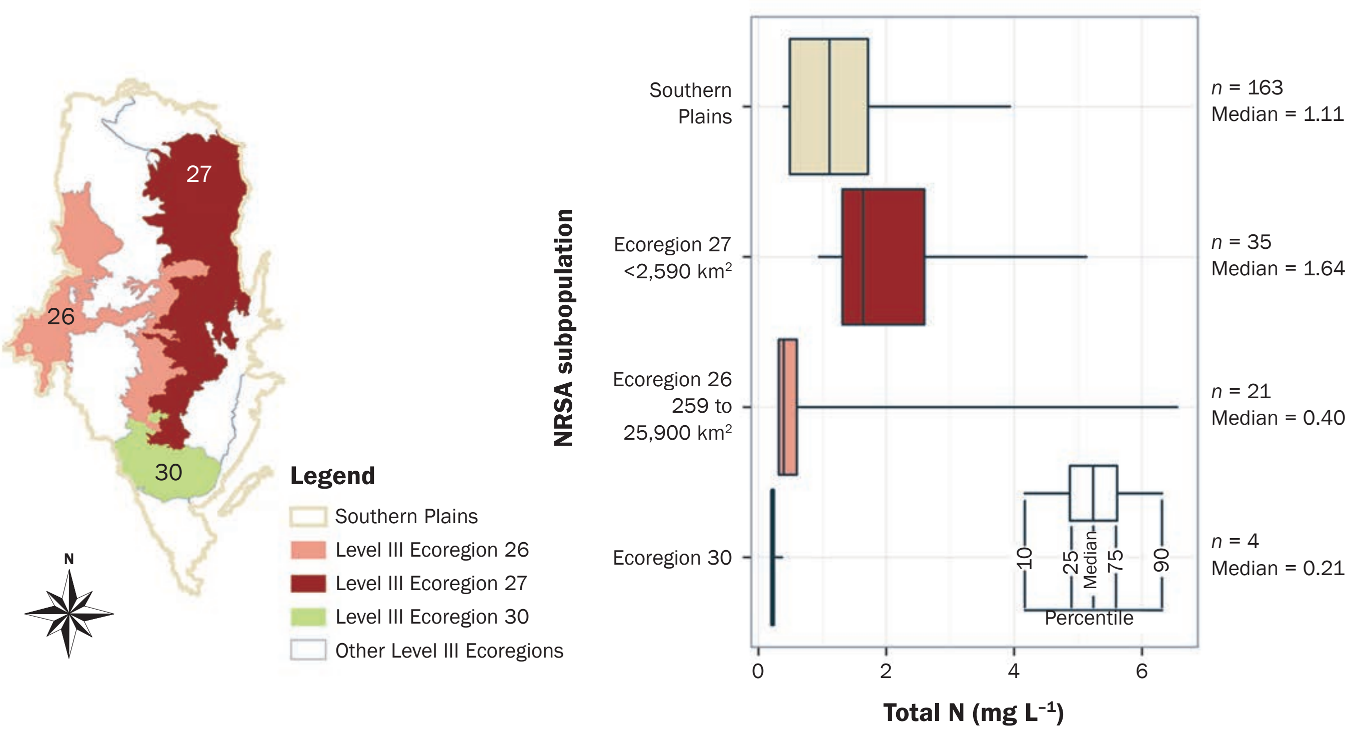
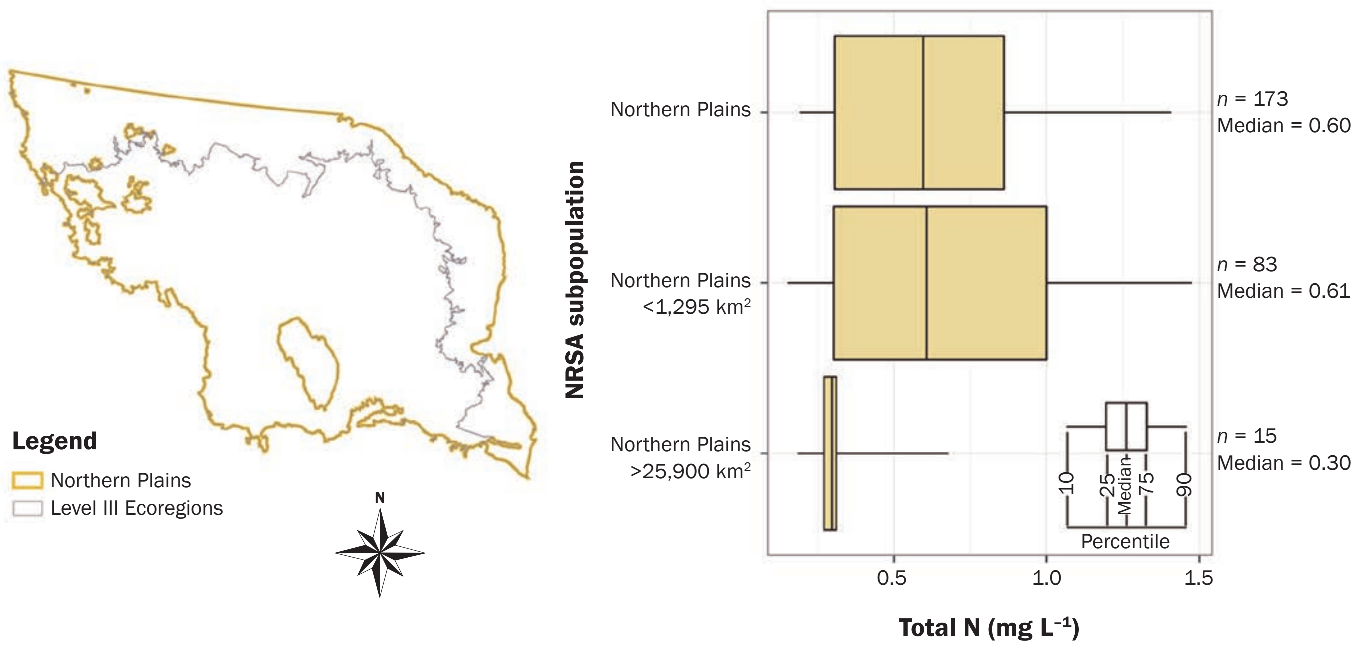


Figure 11
Boxplots of stream nitrogen (N) concentrations in the Northern Plains National Rivers and Streams Assessment (NRSA) reporting region and specific watershed size classes.



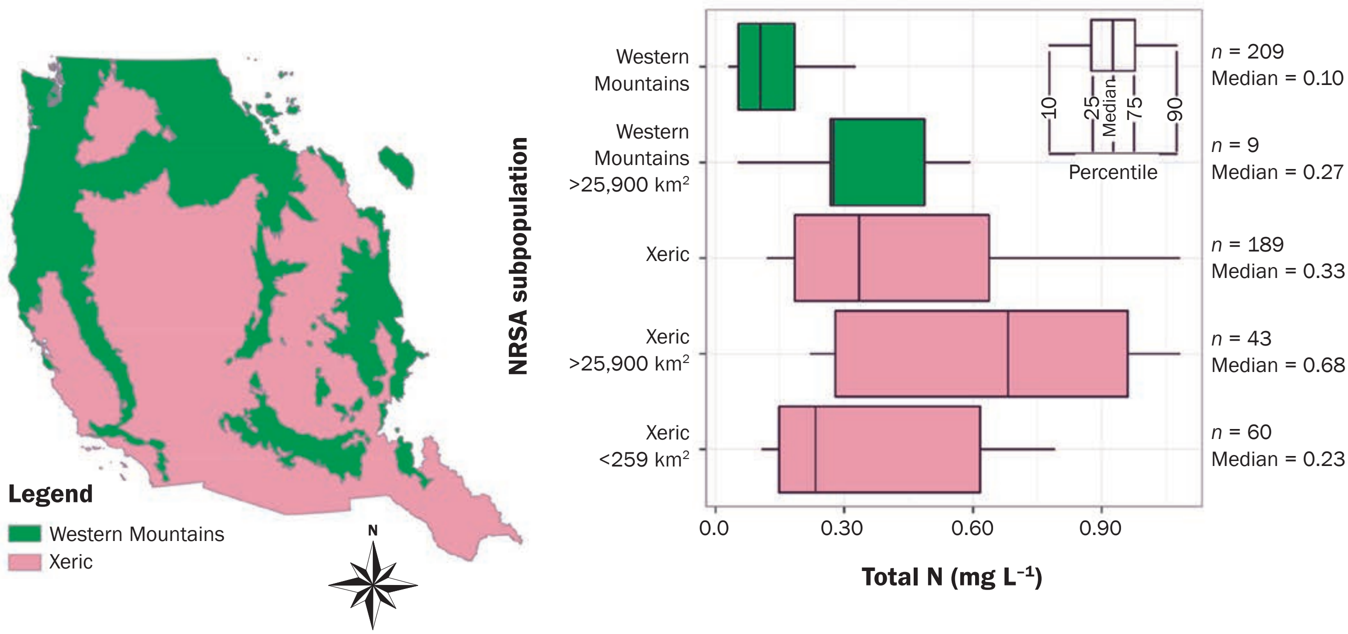
Concentrations of total N in streams are on average much lower in the Western Mountains than any of the other reporting regions (median = 0.10 mg L^{-1}; figures 4 and 12). The few sites having concentrations considerably higher than the median (between 0.8 to 1.5 mg L^{-1}) are at lower elevations and may be associated with grazing activity, urbanization, or natural soil fertility. The site with the highest concentration (6.44 mg L^{-1}) was on Medicine Creek between Olympia and Tacoma, Washington, in the northwest part of the reporting region. This area, located in the Puget Lowland (Level III Ecoregion 2) between the Olympic Mountains and Cascade Range, was once mostly forested or in wetlands but now contains large urban and industrial areas and patches of cropland and grazing land. Sampling field notes for this particular site indicated that water in the stream had been consistently removed for irrigation, riparian buffers were small or nonexistent, cows had access to the stream, and "locals apparently dump vegetative waste here." Only nine sites in this reporting region had watershed sizes greater than 25,900 km^2 (10,000 mi^2). The median value represented by these sites is 0.27 mg L^{-1}, over two and a half times greater than that represented by the 209 sites in the reporting region. These higher values probably reflect the greater likelihood that these sites are at lower elevations compared to those sites with smaller watersheds, are influenced by deeper soils and different hydrology, and may be impacted by grazing or other human disturbances.

Xeric. The Xeric reporting region is made up of the drier parts of the western United States, which includes the Columbia Plateau; the Great Basin; the Wyoming Basin; the Colorado Plateaus; the Chihuahuan, Sonoran, and Mojave Deserts; the Madrean Archipelago; and the broad valleys, low coastal ranges, and chaparral foothills of central and southern California that are distinguished by their Mediterranean climate. Most of the perennial streams in the region have their sources in the surrounding higher Western Mountains. In the more desert-like parts of the reporting region, many of these streams become influent and eventually disappear, particularly the streams that have smaller parts of their watersheds in the adjacent mountains. Few parts of the Xeric region have sufficient precipitation to produce perennial streams. Areas with perennial streams are largely in the higher mountains in the basin and range regions, the Madrean Archipelago, and the central California coastal ranges.

Nitrogen concentrations in streams in the Xeric reporting region (median = 0.33 mg L^{-1}) are on average about three times higher than streams of the Western Mountains, but somewhat lower than the more populated and agricultural parts of the country (figures 4 and 12). Nearly 23% of the sites in the Xeric region are on large rivers with watersheds greater than 25,900 km^2 (10,000 mi^2). Many of these rivers, which include the Columbia, Snake, Colorado, and Rio Grande, are impacted by irrigation withdrawal and return, likely contributing to the higher median concentration (0.68 mg L^{-1}). By contrast, only about 4% of the sites in the adjacent Western Mountains are on rivers with watersheds of greater than 25,900 km^2. Compared to 54 % of the stream sites in the Western Mountains that have watersheds of less than 259 km^2 (100 mi^2), only about 32% of the sites in the Xeric region have watersheds this small. The smaller streams in the Xeric region tend to be in the higher, moister areas containing some grazing activity rather than the lower desert-like parts of the region, which have mostly ephemeral streams and more limited grazing potential. However, the median nutrient concentration represented by streams with watersheds of less than 259 km^2 (0.23 mg L^{-1}) is about two thirds of that for the reporting region. This may be due in part to relatively high flows per unit area because of the watersheds' locations, many of which are in close prox-

Figure 12

Boxplots of stream nitrogen (N) concentrations in the Western Mountains and Xeric National Rivers and Streams Assessment (NRSA) reporting regions and specific watershed size classes.



imity to, or are partially within, the adjacent Western Mountains.

Spatial Implications. Analyzing water quality data from the NRSA offers a unique opportunity to increase our understanding of associations among the quality, in this case N concentrations, of streams of different sizes and the spatial factors that may influence this quality. The nine aggregations of ecoregions that were used to report the results of the NRSA were chosen "because the patterns of response to stress, and the stressors themselves, are often best understood in the context of these ecoregions" (USEPA 2016). The USEPA report (2016) illustrates marked differences in N levels among the nine reporting regions. Within all of the reporting regions, there are regional differences in N concentrations that are associated with human- and nonhuman-related characteristics of specific Level III ecoregions, groups of Level III ecoregions, groups of Level IV ecoregions, and/or particular watershed size classes that could not be teased out due to limited sample size within many of the regions. In our analyses, we illustrated that streams with watersheds completely within one Level III ecoregion can have N concentrations that are on average six times higher than streams with watersheds located in another Level III ecoregion that has a highly contrasting natural capacity and anthropogenic activity but is within the same larger NRSA reporting region. Moreover, some of the stream sites have very large watersheds covering parts of other contrasting upstream ecoregions and as a result have different patterns of N concentrations.

Many of the regional patterns of stream N concentrations are associated with differences in land use and characteristics of agricultural activities, including dairy operations and the amount of fertilizer applications to croplands. Although there have been attempts to categorize and estimate the different anthropogenic inputs to land surfaces and ultimately streams and lakes (Sprague and Gronburg 2013; Sobota et al. 2013, 2015), many of these inputs have imprecise definitions with the limits or boundaries of one often bleeding into another. Human contributions to water pollution are commonly termed either point or nonpoint sources. Municipal and industrial waste discharge through pipes directly into streams are point sources and broad-scale cattle grazing is a nonpoint source impact on water quality, but other anthropogenic activities are less well defined. For example, it is unclear when the densities of cattle, whether involving dairy or confined feeding operations, become large enough to become a point-source impact on water quality. In our qualitative analysis, however, many associations with patterns of N concentrations are apparent.

In the eastern part of the country, high N concentrations in streams tend to be associated with large extents of urbanization and suburbanization as well as concentrations of agricultural industry, particularly layer, broiler, and dairy operations, and in some cases specialized cropping. Unlike the eastern and northeastern parts of the United States where cropland developed as a result of where the first Europeans settled, patterns of cropland agriculture in the remainder of the country are more closely correlated with agricultural suitability regarding soil nutrients and climate (Waisanen and Bliss 2002; Hart 1968). These areas of nutrient-rich soils include the Corn Belt that stretches from eastern Nebraska to western Ohio, the Mississippi Alluvial Plain, and the eastern moister parts of the Great Plains. All of these areas also receive relatively high applications of fertilizers (USDA 1999, 2012). Another region with high N concentrations in streams but where less land is in cropland or suitable for cropland is the Driftless Area of southwestern Wisconsin, southeastern Minnesota, and northeastern Iowa. Here, the higher N concentrations appear to be associated with numerous dairy operations along the region's streams, as well as its physiography and history of farming practices.

Streams with low N concentrations tend to be located in sparsely populated, forested, and/or nutrient-poor parts of the country, such as the Northern Lakes and Forests ecoregion, the higher mountainous parts of the West, and regions of limited cropland agricultural potential, such as the Flint Hills of Kansas and Oklahoma and the Edwards Plateau of Texas. As a percentage of total land cover, cultivated cropland in the Flint Hills and Edwards Plateau is relatively low compared to most other Great Plains regions (Fry et al. 2011; Drummond et al. 2012). For some regions with distinct mosaics of natural and human-related geographic characteristics associated with stream quality, it was not possible to determine or verify patterns of higher or lower N concentrations because of the limited number or lack of sample sites.

The Driftless Area provides an excellent case in point of the need to recognize and understand regions that have unique combinations of geographic characteristics and cultural histories that affect water quality, as well as other environmental resources. In the late 1800s, much of this hilly area, once covered with tallgrass prairie and deciduous forest underlain with rich, water-absorbing humus, was converted to dairy operations and subjected to constant plowing, cropping, and livestock grazing, which resulted in massive erosion. The original land parceling using a rectangular surveying system that forced early farmers to cultivate square fields as they had in their European homelands led to row cropping the region's irregular terrain without regard to slope (Wisconsin DNR 2002). This land history, coupled with rapid flow of surface water through underground passages via the region's karst topography, increased N losses to groundwater and surface water (Olmanson 2014).

Although limited in representation by NRSA streams, the High Plains, Southwestern Tablelands, and Edwards Plateau are additional examples of regions with unique natural characteristics and histories of human impact affecting stream quality. Decades of fertilizer application to wheat fields in the High Plains, which coincided with a sharp increase in irrigation, has resulted in greatly increased levels of inorganic N in springs and in the few remaining streams in the adjacent Southwest Tablelands to the east (Angelo et al. 2003). A very different set of natural capacities and human activities have affected stream quantity and quality in the Edwards Plateau. In this region of karst topography, a reduction in the extent of livestock grazing over the past 65 years has contributed to an increase in streamflow (Wilcox and Huang 2010) and possibly a decrease in stream nutrient concentration.

Recognition of these regions that contain particular combinations of natural and human-related characteristics associated with historical, existing, and potential conditions of environmental resources including stream nutrient concentrations is critical to the development of meaningful water quality expectations and management strategies. These regions also provide the spatial framework for further analyses of the factors influencing differences in stream N concentrations, similar to how the ecoregion framework is being used to guide the USGS study of spatial differences in land cover change in the United States (Sleeter et al. 2013). The USGS land cover studies have shown that the trends, as well as the combinations and relative importance of factors associated with land cover change, vary regionally, but within Level III ecoregions are strikingly similar and different than other ecoregions (Sleeter et al. 2013). Our paper illustrates that for particular regions, associations such as Sleeter et al. (2013) have reported are also generally true for N concentrations in streams. Again, it should be noted that the regions we have identified merely reduce the spatial variability and aid in determining the relative importance of characteristics associated with differences in water quality.

The clarification and identification of distinct regional patterns of N concentrations was made possible by analyzing data from streams with different watershed size classes, so that the watershed sizes were kept consistent with the spatial differences in factors that appear to be associated with variations in concentrations. For example, streams with watersheds completely within the Driftless Area had significantly higher N concentrations than larger Driftless Area streams that also drain areas outside the region. Likewise, most streams with watersheds completely within the Great Plains had higher N concentrations than Great Plains streams, which have large portions of their watersheds in the adjacent Western Mountains, except for those streams heavily impacted by point sources. Hence, stream quality, including N concentration, at any point reflects the characteristics of the watershed upgradient from that point. Streams draining more than one region containing different combinations of natural and anthropogenic factors influencing stream quality will be different from those draining only one such region.

Summary and Conclusions

The objectives of this manuscript were threefold. First, we wanted to provide a current documentation of population-weighted N concentrations in rivers and streams across the country. Second, we wanted to demonstrate how this quantitative information on N concentrations in rivers and streams could be complemented and enhanced by the presentation of qualitative information on the nature and characteristics of ecological regions in the conterminous United States. Too often, science views quantitative and qualitative descriptions of the environment as "either/or" options rather than complementary. Third, we wanted to demonstrate how this type of analysis can help account for N variations relative to differences in the mosaic of influencing characteristics of different sizes of watersheds.

The results presented here promote a better understanding of the patterns in stream and river N concentrations across the country and the environmental factors and historical activities associated with those patterns. This paper also provides a method for analyzing the regional aspects of other water quality characteristics. One key objective of environmental monitoring and subsequent analyses is to evaluate when the conditions are the result of human activity and when they are simply a reflection of natural features. Continuing to combine qualitative descriptions with quantitative analyses will be critical to improving our ability to reach such conclusions in the future.

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