7. CLASSIFICATION OF FRESHWATER SYSTEMS[40]

Stratification of a region into a number of relatively homogeneous sub-regions is an important tool for many aspects of environmental research and management. Examples include: allocation of sampling effort, data analysis and hypothesis testing, characterization of environmental resources / ecological conditions, communicating information, conservation planning, and establishing reference conditions. Many stratification frameworks have been developed; most are not watershed-based, but rather define regional boundaries regardless of watershed limits.

This chapter presents a brief review of work carried out during MABP to develop and evaluate stratification frameworks for Maine. It is intended as an introduction to and illustration of this quantitative approach, rather than an exhaustive analysis. Allied to the GIS-based regionalization described in this chapter is a finer-scale GIS-based lake classification that was developed for Maine. This is being used for TNC's ecoregional planning purposes and is described elsewhere (TNC, in prep). A similar lake classification has been developed for New Hampshire (Olivero and Bechtel 2005).

Figure 7.1 illustrates four stratifications developed for Maine (after Krohn et al. 1999). The McMahon (1990) and Keys and Carpenter (1995) biophysical regions are based on climate, topography and terrestrial vegetation. Briggs and Lemin's (1992) are climate-based. The biophysical regions of Krohn et al. (1999) integrate elevation, slope, two measures of species richness (vertebrates and woody plants), and weather variables.

None of the four stratifications shown in Figure 7.1 are watershed-based. However, the regions within each stratification framework are generally contiguous. In contrast, Wolock et al. (2005) recently developed a watershed-based stratification for the entire U.S. in which the country is divided into a series of 20 non-contigous regions, or Hydrologic Landscape Regions. These are based on similarities in landform, geologic texture and climate. The regions for Maine are shown in Figure 7.2.

Because Wolock et al.'s system of hydrologic landscape regions was not available to us at the outset of this work, we developed for MABP an alternative watershed-based stratification framework for Maine. This was done by using TWINSPAN clustering to aggregate HUC-10 watersheds based on their elevation and bedrock and surficial geology[41]. Figure 7.3 illustrates three split levels in the clustering process. For our purposes, we wanted to define a series of contiguous regions because we considered that these would provide a more useful framework for conservation planning than a series of disjointed regions. Based on the TWINSPAN output, we made manual revisions to cluster assignation for some HUC-10 units. We also decided to "impose" the structure of TNC's Ecological Drainage Units (Lammert et al. 1997). This process produced a series of 13 "systems" depicted in Figure 7.3 D. Brief narratives of these systems are provided in Table 7.1.

We also derived a stratification in which watersheds were aggregated based on the McMahon biophysical regions. Each watershed was attributed by the biophysical region which represented the greatest amount of watershed area. These biophysical systems are shown in Figure 7.3 E.

Key to understanding the utility of a stratification framework is the extent to which it represents patterns in resources other than those explicity used to develop the regionalization. We evaluated a series of frameworks to detect which appeared, overall, to be most effective in characterizing a series of biological, physical and chemical elements of the Maine landscape. The following frameworks were used:

[40] Much of the material presented in this chapter was developed through collaboration with Arlene Olivero, TNC, Boston.
[41] Details of this approach are provided in Vaux and Olivero (ms.).

(1) Watersheds clustered by geology and elevation (Figure 7.3 D);
(2) Watersheds clustered by predominant biophysical region (Figure 7.3 E);
(3) Ecological drainage units (Figure 7.3 E);
(4) Counties;
(5) Random aggregation for lake-based data, in which we assigned each lake a random number and then aggregated lakes based on number classes.

We evaluated these frameworks for the series of biophysical attributes shown in Table 7.1. The data are very heterogeneous and clearly do not provide "replicated" units within each geographic region. However, our intent was simply to explore the extent to which the various stratification frameworks are able to capture variability within the lake-based and watershed-based data sets available to us.

For the evaluation, we employed a non-parametric statistical procedure called Multi-Response Permutation Procedure (MRPP), using PC-ORD (McCune and Mefford 1999). MRPP tests the extent to which pre-defined groupings (our stratification frameworks) produce homogeneity in the series of biophysical attributes tested. An effective stratification is one in which the within-group variance is low compared to the among-group variance. MRPP produces a significance value and also a "size effect" value: "A", which quantifies the extent to which the stratification captures underlying variance in the attribute being examined.

Summary results from the MRPP analyses are shown in Table 7.1. The "A" values have been multiplied by 100 to make comparisons easier. Because of data sample size, not all attributes could be tested for all stratifications. The larger the "A" value, the more effectively the stratification captures regional variance in the attribute being considered. Overall, the GIS-based Systems were as effective as biophysical regions in defining homogeneous groupings for both landscape-level (landform, geology), water quality and biological attributes. Both of these stratifications were generally more effective than EDU's. This is not surprising because there are only four EDUs represented in Maine, while there are 13 GIS-systems and a similar number of biophysical regions. Consequently, each EDU covers a broader geographic area and is therefore likely to include a greater range of ecological conditions. Counties are also relatively effective in capturing spatial variability in Maine (at least with the parameters tested in this analysis). Again, this is not surprising because the number and spatial arrangement of counties is quite similar to that of GIS-systems and biophysical regions.

The stratifications were generally effective in capturing variation in: landform, geology, lake alkalinity and conductivity, watershed population density, odonates, mussels and fish. Effectiveness of the GIS-Systems for representing geology is expected because geology was used in system definition. The stratifications were relative ineffective in capturing variation in other water quality parameters, such as transparency and pH, and in several biological parameters including macrophyte and stream invertebrate assemblages.

Data in Table 7.1 are overall summaries from the MRPP analyses. Of perhaps greater interest is an examination of how different various regional pairs are from each other in terms of their biology, water quality, landscape features, etc. For these pair-wise comparisons, we also used MRPP and focused on the GIS-systems. Results for each pair-wise combination are shown in Table 7.2. All significant comparisons are shown with the corresponding "A" values. Again, the larger the "A" value, the greater the difference between each of the pair members. For each of the attributes, the system pairs with the highest "A" values are shown in red.

An over-arching conclusion from these pair-wise comparisons is that the extent to which regions differ from each other depends on what attributes are being examined. For example, Systems 1 and 4 (upper and lower eastern Aroostook County, respectively) appear to differ significantly in terms of their odonate assemblages, but much less so in terms of their fish assemblages and water quality. Systems 1 and 8 (Downeast region) differ substantially in terms of landform, geology, water quality, mussels and fish. With fish assemblages, the greatest regional differences were generally seen between higher elevation areas (Systems 6 and 3) and lower elevation areas (Systems 7-10). At the same time, very few major differences were seen between eastern (System 1) and western (System 2) regions of Aroostook County.

The results from these MRPP analyses presented in Tables 7.1 and 7.2 should be viewed only as an illustration of this quantitative approach. The effectiveness of the comparisons is dependent on the amount, coverage and uniformity of the available biological data. As additional data become available in the future, it will be possible to refine these analyses and produce a finer-scale resolution between the different regions of Maine.

Table 7.1: Overview of major watershed groupings.
Systems are mapped in Figure 7.3 D. "EDU" = Ecological Drainage Unit.

UPPER ST. JOHN / AROOSTOOK

System 1: Low elevation watersheds with some small patchy hill areas of moderate elevation. Geology dominated by calcareous and moderately calcareous in the east along the Maine/NB border with the western half of the EDU a mixture of acidic sedimentary and small areas of intermediate granitic

System 2: Moderate elevation watersheds with mainstem of St. John in low elevation. Acidic sedimentary geology except for the southeast corner which contains an intermediate to acidic granitic patch

NORTH COASTAL MAINE - ST CROIX

System 8: Watersheds in low-elevation zone. Geology dominated by acidic granitic, some large moderately calcareous swaths high, some small areas of acidic sedimentary and large areas of fine grained maine clay sediment along the coast.

System 13: Watersheds in low-elevation zone. Geology dominated by acidic granitic and large areas of fine grained marine clay sediment along the coast.

PENOBSCOT, KENNEBEC, ANDROSCROGGIN

System 3: Moderate elevation watersheds. Geology dominated by acidic sedimentary with only very small patches of intermediate granitic.

System 5: Moderate elevation with some areas in high or very high elevation. Heterogeneous geology with large swath of moderately calcareous bedrock, large areas of acidic sedimentary bedrock, and a moderately large area of acidic grantic bedrock.

System 4: Low elevation zone with heterogeneous geology including a large swath of moderately calcareous bedrock, large areas of acidic sedimentary bedrock, and small areas of acidic grantic or intermediate bedrock.

System 6: Moderate and high to very high elevation dominated watersheds. Geology a mixture of acidic sedimentary and acidic granitic.

System 7: Watersheds in low-elevation zone.

System 12: Watersheds in low elevation. Very flat landforms with heterogeneous bedrock dominated by large patches of fine-grained marine sediments.

SOUTHERN MAINE:

System 9: Most of the watersheds are in the low elevation zone, but the headwaters of large tributaries start in moderate to high elevation zone where higher slopes lead to higher gradient tributaries. Acidic granitic geology with some coarse grained sediments.

System 10: Watersheds in low-elevation zone. Very flat and gently sloping streams in heterogeneous geology connecting to large rivers or directly to the ocean.

System 11: Watersheds in low-elevation zone. Very flat and gently sloping streams in heterogeneous geology connecting directly to the ocean.

Table 7.2: Evaluation GIS-based classification systems.
Table shows data sets used in the evaluation and the summary results from the MRPP analyses. See text for additional information.

Parameter	Population	"Species"	"A" Values				
			GIS-systems	Biophysical	EDU	County	Random Lake #
ELU *	181 HUCs	214 ELUs	35	35	12		
Geology	181 HUCs	6 geology classes	34	33	17		
%Wetlands:1-10 acre lakes	1980 lakes	Value	2	3	<1	3	NS
%Wetlands:10-99 acre lakes	1575 lakes	Value	2	2	1	2	NS
%Wetlands:100-999 acre lakes	681 lakes	Value	4	3	3	4	NS
Secchi	507 reference lakes	Value	2	3	NS		
pH	366 reference lakes	Value	5	6	5		
TP (log)	411 reference lakes	Value	4	6	2		
Alkal (log)	396 reference lakes	Value	18	15	15		
Cond (log)	391 reference lakes	Value	14	11	7		
Mean chlorophyll	409 reference lakes	Value	2	3	1		
Trophic State Index	147 reference lakes	Value	7	11	6		
Population of DD watershed	516 reference lakes	Value	31	31	11		
Diatoms (surface-sedimented)	85 reference lakes	Assemblage (log Abun)	7	7	4	6	2
Macrophytes (lakes)	27 lakes	Assemblage (p/a)	8	8	6		
Odonates	34 well-sampled HUCs	Assemblage (p/a)	20	21	15		
Mussels	161 HUCs	Assemblage (p/a)	23	20			
Fish:10-99ac	1075 lakes	Assemblage (p/a)	18	18	8	16	NS
Fish:100-999ac	656 lakes	Assemblage (p/a)	20	20	8	16	NS
Stream Inverts	170 Class "A" sites	Assemblage (log Abun)	4	5			
Stream Inverts	170 Class "A" sites	Taxon Richness Value	6	9	2		
Stream Inverts	170 Class "A" sites	Taxon Richness Value (taxa >1%))	7	4	3		

- ELU: Ecological Landscape Units, describing landform.

Table 7.3: Regional pairwise comparisons of landscape-level features, water quality and biology. Systems are shown in Figure 7.3 D. Grand A-Values are from analyses involving all systems. Numbers in red indicate the series of highest A-values for each attribute.

PARAMETER:	ELU	Geology	Alkal	Cond	TSI	Diatoms	Odonates	Mussels	Fish:10-99ac	Fish:100-999ac	Stream Inverts
GRAND A-VALUE	**35**	**34**	**18**	**14**	**7**	**7**	**20**	**23**	**18**	**20**	**4**
System Pair											
1--2	6	0	4	**14**	0		10	0	2	3	**4**
1--3	4	4	5	9	6	3	8	14	3	3	1
1--4	11	11	0	10	**21**	0	**22**	10	4	7	0
1--5	14	16	0	12	0	11		0	3	2	**4**
1--6	8	0	0	0	0	**21**	**22**	16	5	6	0
1--7	22	27	19	**21**	**10**	11	**22**	11	8	9	2
1--8	30	31	**34**	**24**	**28**	11		17	11	19	0
1--9	**38**	37	13	0	0	**13**		22	10	14	
1--10	18	12	2	2	4	0	13	16	6	5	0
1--11	30	14	7	0	0	5		13	11	15	2
1--12	15	18	0	6	5	5	11	12	5	4	0
1--13	16	20	7	0	9	0		25	2	3	0
2--3	8	9	5	0	7		3	14	4	5	**3**
2--4	0	0	10	0	**16**		0	0	3	9	0
2--5	6	0	0	0	0			0	7	4	0
2--6	13	15	0	0	0		14	0	8	11	0
2--7	21	26	**37**	12	0		**24**	0	9	14	2
2--8	28	29	**40**	0	**21**			0	13	22	0
2--9	**38**	34	**30**	0	0			13	13	16	
2--10	18	14	9	11	0		0	12	7	6	2
2--11	29	14	18	10	0			0	13	18	0
2--12	15	18	12	0	**10**		12	0	8	10	0
2--13	20	24	21	0	0			26	4	8	**6**
3--4	7	7	0	0	0	0	0	13	1	2	0
3--5	10	13	0	0	0	0		10	1	0	**4**
3--6	5	5	0	0	0	8	7	16	1	1	1
3--7	20	24	6	0	0	0	**21**	21	12	11	2
3--8	31	32	14	3	9	2		**27**	**18**	**24**	0
3--9	32	30	4	0	0	4		15	**18**	18	
3--10	18	18	2	8	0	0	4	0	15	10	0
3--11	29	22	3	5	0	0		14	**19**	20	2
3--12	16	21	4	0	0	0	5	11	2	1	0
3--13	12	15	0	0	0	0		4	5	6	0

PARAMETER:	ELU	Geology	Alkal	Cond	TSI	Diatoms	Odonates	Mussels	Fish:10-99ac	Fish:100-999ac	Stream Inverts
4--5	14	0	0	0	0	8		16	3	5	**3**
4--6	23	25	0	0	**21**	0	12	**38**	4	6	0
4--7	19	21	**47**	**18**	0		**28**	17	15	**32**	0
4--8	25	24	18	0	0	0		13	17	**33**	**6**
4--9	**47**	**42**	11	0	0	0		**30**	17	**27**	
4--10	19	17	0	7	0	0	**16**	19	9	12	0
4--11	30	18	0	8	0	0		17	16	**28**	0
4--12	**39**	**50**	0	0	**10**	0	12	**33**	4	8	0
4--13	23	24	7	0	0			**36**	10	18	0
5--6	21	25	0	0	0	0		0	0	0	0
5--7	29	37	11	0	0	**14**		0	16	18	2
5--8	31	**41**	6	0	0	0		0	16	13	0
5--9	**49**	**56**	6	9	0	0		0	17	10	
5--10	26	32	0	8	0	0		0	8	3	0
5--11	**34**	31	0	10	0	5		0	15	11	2
5--12	32	**41**	5	0	0	0		0	0	0	**3**
5--13	**33**	**41**	0	0	0	0		19	10	6	0
6--7	18	23	**37**	**19**	0	0	**20**	0	**19**	**27**	0
6--8	22	26	18	0	**31**	**17**		0	**21**	**28**	0
6--9	**44**	**50**	11	0	5	**26**		0	**22**	22	
6--10	15	17	0	0	0	**13**	**16**	17	12	9	0
6--11	25	18	0	0	0	**14**		0	**20**	**24**	0
6--12	29	**43**	0	0	0	**13**	5	14	0	2	0
6--13	21	24	0	0	0	0		**43**	12	13	0
7--8	19	5	0	0	0	0		0	2	2	0
7--9	24	0	**25**	**18**	0	**21**		0	6	3	
7--10	12	13	12	**14**	0	0	10	14	5	3	0
7--11	24	17	15	**18**	0	0		0	8	5	1
7--12	23	34	**32**	13	0	6	**16**	0	**18**	**25**	0
7--13	4	0	17	**16**	0			**29**	2	7	0
8--9	0	0	17	9	0	10		8	2	4	
8--10	11	17	**23**	**21**	8	7		18	4	7	0
8--11	19	19	**23**	**18**	**15**	3		**0**	5	5	0
8--12	20	35	**36**	5	**19**	6		0	**21**	**27**	0
8--13	24	9	10	5	**12**			**29**	2	11	0
9--10	17	22	4	4	0	0		12	1	3	
9--11	22	23	0	0	0	5		0	1	3	
9--12	**44**	**66**	14	0	0	7		19	**21**	21	
9--13	**39**	17	0	0	0			**36**	2	9	
10--11	9	0	0	0	0	0		8	1	4	0
10--12	14	25	0	6	0	0	9	14	12	8	0
10--13	15	0	0	2	0	0		0	1	2	0
11--12	20	20	4	3	0	0		0	**20**	21	0

11--13	28	13	0	0	0	0		24	3	10	0
12--13	**33**	**47**	8	0	0	0		**30**	10	11	0

Table 7.3 (end)

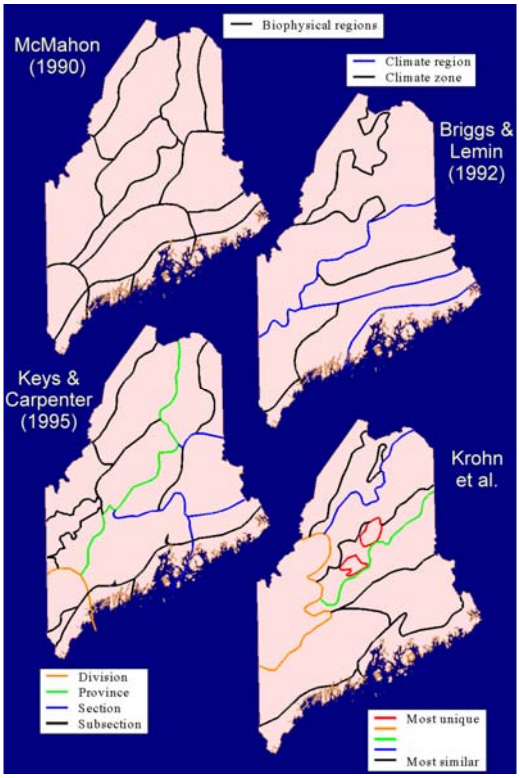

Figure 7.1: Four regionalization frameworks developed for Maine.
Figure from Krohn et al. 1999, courtesy of R. Boone, Colorado State University.

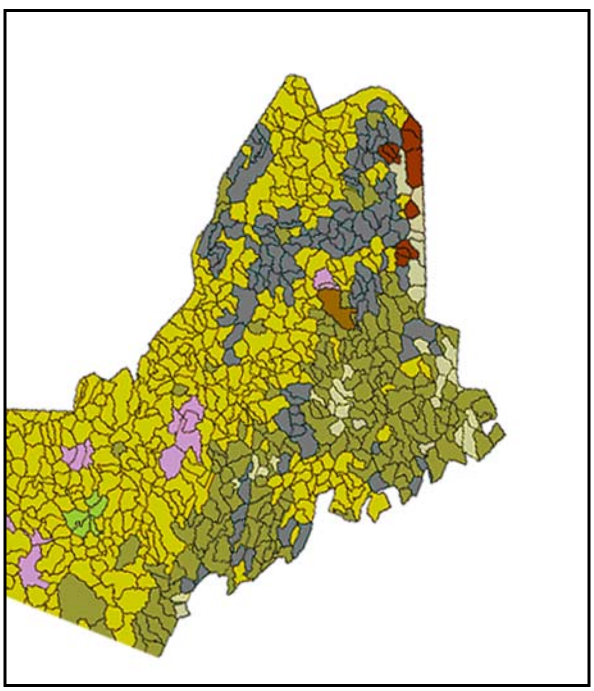

Figure 7.2: Hydrologic landscape regions in Maine (after Wolock et al. 2005).

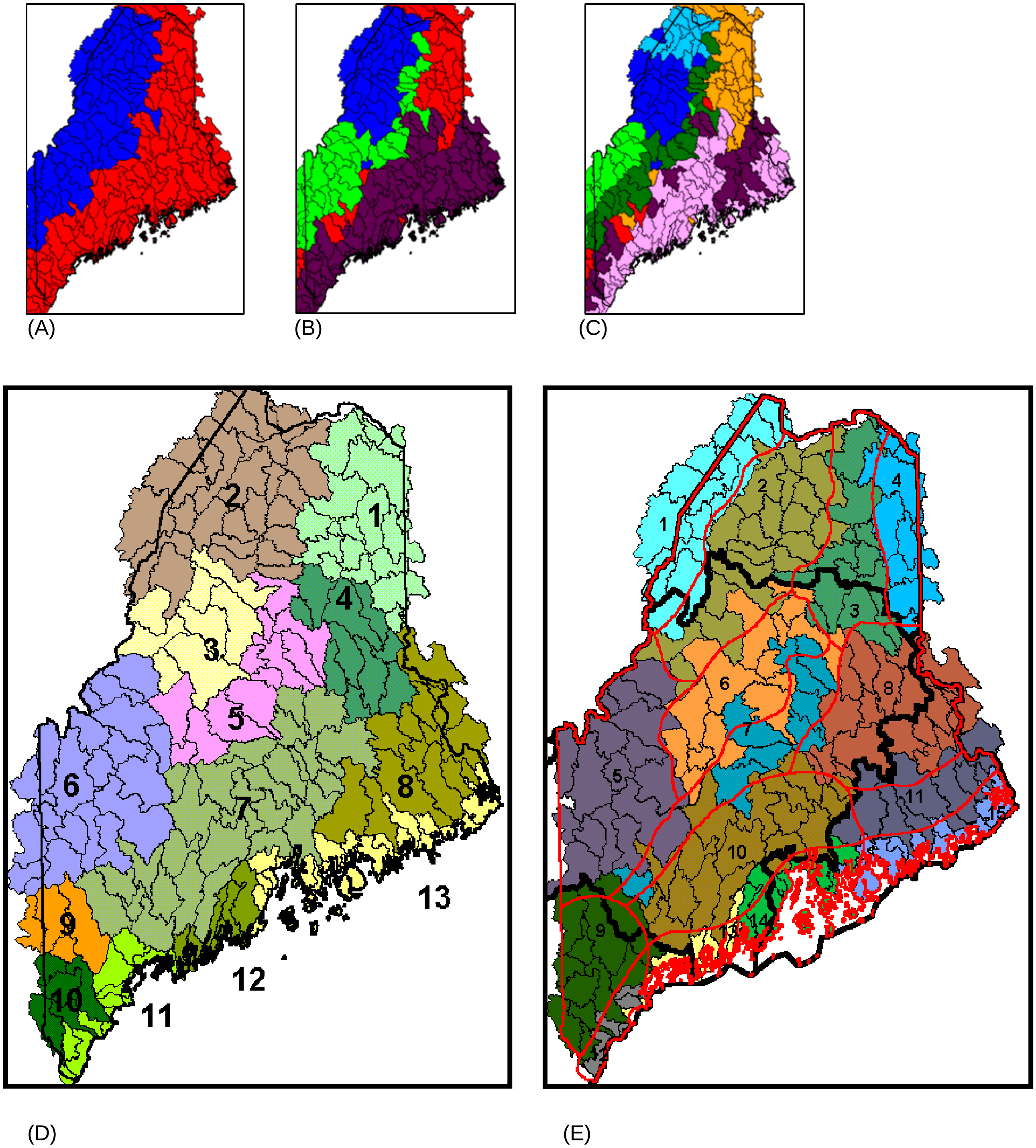

Figure 7.3: Stratification of HUC-10 watersheds in Maine. (A) – (C) Three sequential TWINSPAN splits of watersheds based on geology and elevation. (D) Series of watershed “Systems” developed following manual adjustment of TWINSPAN output. (E) Watershed groupings based on McMahon’s biophysical regions. Also shown in (E) are the biophysical regions (red lines) and TNC’s Ecological Drainage Units (black lines).