QRULE

A COMPUTER PROGRAM FOR LANDSCAPE HYPOTHESIS TESTING

developed by

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QRULE is an extension of RULE (Gardner 1999), a program for scale-dependent analysis of landscape patterns. The extensions provided in QRULE are designed to assist the user in the development and testing of alternative hypotheses relating the process of landscape change to the patterns observed. These differences may be statistically compared with a simple random pattern (i.e., the classical neutral model of Gardner et al. 1987), against an new model within QRULE, or by alternative models developed by the user.

This document provides a brief overview, focusing on the new features in QRULE. It is assumed that the reader has experience using RULE and is familiar with the concepts of neutral landscape models (Turner et al. 2001).

Program documentation, example input and output files, and the source code for QRULE may be obtained from www.al.umces.edu/QRULE. The Open Software License (http://www.opensource.org/licenses/index.php) applies to the distribution, use, and possible alteration of QRULE.

OVERVIEW OF IMPROVEMENTS AND ADDITIONS

1. The output files generated by QRULE have been extensively revised and reformatted to assist in data display and statistical comparisons (see Table 1). Two new files, *assmat.dat* and *arcgrid.map* have been added. The association matrix among map cover types is statistically evaluated in *assmat.dat*, while *arcgrid.map* formats the first map iteration for display in ArcInfo.
2. The pattern metrics produced from map analysis are now expressed in metric units (i.e., in meters, hectares, etc.).
3. It is now possible, using the *patch_cfd.dat* data file to directly display the cumulative frequency distribution of patch sizes for each land-cover class. A program written in PERL is provided (cfdsum.pl) to illustrate how these plots may be performed.
4. The addition of alternative neutral models to QRULE is illustrated with the "mask" <X> option. This model is designed to test the hypothesis that landscape pattern is largely determined by dominant features (e.g., rivers, lakes, urban development) that constrain the patterns of other cover types. Adding additional options to QRULE is not difficult, but requires familiarity with Fortran 95 and the availability of a suitable compiler.

RUNNING QRULE

Input to QRULE may be either interactive or via file redirection. Each execution of QRULE requires the specification of: 1) the type of map to be generated and/or analyzed; 2) map characteristics; and 3) the output desired. Two types of input requests are illustrated below. The first is to analyze an existing map, while the second is to use the "masked" model for hypothesis testing. Blue text indicates output from QRULE while black text indicates user response.

First example: Analyze an input map

```
         Qrule (v 4.1) Landscape Pattern Analysis          08/01/05
         Enter map type to be analyzed:
               <I>  Input existing map file
               <R>  Generate a random map (with replacement)
               <S>  Generate a simple random map
               <M>  Generate a multifractal random map
               <G>  Generate a multifractal random map with a gradient
               <X>  Use input map as mask, random map for neutral model

i
         Map choice: I
         Enter name of input map file

rocr_reclass.map
         Input map name: rocr_reclass.map

         Enter number of map rows and columns (max =  2048 ea.)
512 512
         Rows x Columns =    512 x    512
         Enter the number of map classes

4
         Map classes =     4
         Enter the neighborhood rule
               1 - nearest neighbor (N_nb = 4)
               2 - next nearest neighbor (N_nb = 8)
               3 - 3rd nearest neighbor (N_nb = 12)
               4 - user defined

1
         Rule choice is: 1

         Enter the number of replications

1
         N_Reps =       1
         Create an output maps?
            N = None
            G = generated map
            S = cluster Size map
            C = cluster ID map

n
         Map output choice = N
```

```
          Perform map analysis?
               <N>o analysis
               <L>acunarity analysis
               <R>ule analysis
               <A>ll (both Rule and Lacunarity)

r
          Analysis method: RULE

          What is the resolution of each grid element?
             (length of the side of a grid element, in meters)

30

      . . . . . .
```

Appendix A gives the results of this example in the 'rulerun.log' file.

Second Example: Use the "mask" neutral model

This example requires two maps. The first map will be used to extract the land-cover adjacency matrix used in the neutral model. Bracketed text (in italics) has been inserted to clarify the purpose of some of the responses.

```
          Qrule (v 4.1) Landscape Pattern Analysis          08/01/05
          Enter map type to be analyzed:
                <I>  Input existing map file
                <R>  Generate a random map (with replacement)
                <S>  Generate a simple random map
                <M>  Generate a multifractal random map
                <G>  Generate a multifractal random map with a gradient
                <X>  Use input map as mask, random map for neutral model

x
          Map choice: X
          Enter number of map rows and columns (max =  2048 ea.)
512 512
          Rows x Columns =    512 x    512
          Enter name of file to be used as a mask
rocr_reclass.map
          Input map name: rocr_reclass.map
          Enter number of cover types of the mask map
4
          Enter number of cover types for random generated maps
3            {reclassification will be necessary}

          Cover types: mask =    4 random =    3
               Reclassify masked map
               Cover type   0 becomes ...
0            {the '0' class is a non-cover type - e.g., roads, etc.}
               Cover type   1 becomes ...
1
               Cover type   2 becomes ...
2
               Cover type   3 becomes ...
```

```
3
              Cover type    4 becomes ...
0           {class '4' has been set to class '0'}
         from --> to
             0    0
             1    1
             2    2
             3    3
             4    0
         Type in the habitat type for the matrix
           set to zero to automatically select
1           {'1' is agriculture}
         Background (matrix) =   1
         Now we need the parameters for the
          random map cover types

         Enter a negative random number seed

-1918171
         Random number seed:   -1918171
         Enter the neighborhood rule
               1 - nearest neighbor (N_nb = 4)
               2 - next nearest neighbor (N_nb = 8)
               3 - 3rd nearest neighbor (N_nb = 12)
               4 - user defined

1
         Rule choice is: 1
         Map classes =     3
         Enter the   4 probabilities, starting with p(0)

0
0.79955
0.19029
0.01015
         The normalized probabilities are:
                 P          CumP
           0    0.0000     0.0000
           1    0.7996     0.7996
           2    0.1903     0.9898
           3    0.0102     1.0000

         Enter the number of replications

12
         N_Reps =     12
         Create an output maps?
            N = None
            G = generated map
            S = cluster Size map
            C = cluster ID map

g
         Map output choice = G
         Name of output file?

scratch.map
```

```
          Output file for generated map: scratch.map

          Perform map analysis?
               <N>o analysis
               <L>acunarity analysis
               <R>ule analysis
               <A>ll (both Rule and Lacunarity)

r
          Analysis method: RULE
          What is the resolution of each grid element?
             (length of the side of a grid element, in meters)

30
```

....

See Appendix B for a listing of the entire input-output stream for this example.

File redirection for batch-mode execution

Analysis projects often require multiple executions of QRULE. In these cases it will be convenient to use file redirection for input and output. In addition, the files produced by QRULE (Table X) will need to be renamed in order to prevent them from being overwritten (and thus destroyed) by subsequent program execution. If all the input responses are prepackaged in an input file (i.e., *name.scriptfile*) then QRULE can be run with a single line typed at the command prompt:

Qrule < *name.scriptfile* > *output.save*

Where ‘QRULE’ executes the program, the ‘<’ causes QRULE to read input from *name.scriptfile* and the ‘>’ causes screen output to be redirected to a file called *output.save.* Of course *name.scriptfile* and *output.save* are optional names for the files of your choice. Subsequent to execution, *rulerun.log* should be renamed to save the results and *patch_cfd.dat* renamed if summary statistics of patch sizes are desired.

Of course, multiple runs can be packaged into a batch file allowing unattended execution of multiple maps. This is most useful when the size maps and number of iterations are large.

Table 1. ASCII files that are used (I) or generated (G) by QRULE

File name[1]	Unit	Type	General description of contents
rulerun.log	10	G	log file of program input and simulation results
patch_cfd.dat	11	G	patch size frequency distribution for each map and habitat type. Output includes mean patch size, edge, radius mean square, and fractal for each patch size.
'Idfile'	12	G	output map with each patch uniquely identified
'sizefile'	13	G	name of output map with the patch sizes uniquely labeled
'outfile'	14	G	name of output map with habitat types uniquely labeled
'mapfile'	15	I	name of input map file for analysis by RULE
assmat.dat	16	G	matrix of neighbor association frequencies for each map
arcgrid.map	19	G	single map with header for input to ArcGrid for visualization and display
lacun.dat	20	G	output of lacunarity results

[1] Single quoted names are specified by the user at runtime. Non-quoted names are invariant, being produced by each use of QRULE. The non-quoted file names should be renamed following each execution of QRULE to preserve program results.

Example input and output files are available at www.al.umces.edu/Qrule

ADDITIONAL FILES FOR PROCESSING DATA

The philosophy of the UNIX and LINUX operating systems is to increase programming efficiencies by linking programs with existing utilities via input-output files. Many of the statistical analyses that we have performed were accomplished by using existing plotting and statistical analysis software. Three PERL scripts, cfdsum.pl, compare.pl, and Qrule.pl, and a single fortran program, Kstest.f90, are provided (see otherstuff.zip) to aid the user in analyzing the output from QRULE. These files and programs are not documented here, but are offered to those with sufficient expertise to use and adapt to individual needs.

SOURCE CODE OVERVIEW

The list of files required to compile QRULE, and the Makefile used to do so, are given in Table 2. Because QRULE uses advance features of Fortran 95, the Lahey compiler was used for both the DOS and LINUX versions (Lahey Computer Systems 1999). Most of the files listed in Table 2 contain multiple subroutines that are closely related to the functions listed.

Table 2 Program files for compilation and execution of QRULE

File Name	File Type	Purpose
Makefile	make	recompile and update Fortran executable
	Rule Executable	
Qrule	Fortran executable	Available for DOS (Qrule.exe) and LINUX operating systems
	Fortran 95 Source Code	
genmap.f90	Subroutines for map generation	
hfract.f90	Multifractal map routine	
input.f90	Program input and control	
lacun.f90	Subroutine for optional output of lacunarity analysis (Plotnick et al. 1993).	
main.f90	Routine governing program execution	
mapanal.f90	Routines for map analysis	
module.f90	Defines variables and sets their dimensions	
patchid.f90	Routines for identification of landscape patches	
ran1.f90	Random number generation routine from Numerical Receipes (Press et al. 1992)	
sizeit.f90	Subroutines controlling the dynamic dimension of map variables	
stats.f90	Calculation and output of map statistics and indices	

Additional neutral models may be added to QRULE by:

1. Revising the input routine to accept the option of executing a different (additional) neutral model. The variable 'maptype' is used to identify the type of neutral model to generate. Code similar to that for the other map types will need to be added to this input file to recognize this new options and the parameters it may require.
2. The subroutine for the new neutral model should be added to the genmap.f90 file. In addition a call must be added to the GenMap routine (under 'select case (maptype)') in order for this new model to be linked with the QRULE code.
3. Recompile using Makefile

Obviously, the above is only an outline of the changes which may be required. Familiarity with fortran – or the ability to link programs written in other languages with this fortran code – are a prerequisite for making changes to QRULE.

METRICS AND STATISTICS PRODUCED BY QRULE

QRULE provides a set of landscape metrics that have proven to be helpful in understanding the effect of landscape fragmentation on pattern generation (Gardner 1999). Additional analyses may be achieved by exporting maps to ArcView or other programs such as Fragstats (McGarigal et al. 2002).

One new statistic has been added to QRULE: a chi-square test of the matrix of association of land-cover types. 'Chisquare', the subroutine performing this analysis, may be found in the file 'mapanalysis.f90.' There were 4 cover types in the examples listed in the appendices, with an association matrix that formed a 4 x 4 chisquare contingency table with 9 degrees of freedom (Zar 1996). The association matrix is listed in the examples in Appendix A and B includes the '0' cover class –regarded by QRULE as a "no data" class. Although these frequencies are listed, they were not a part of the chisquare test.

Appendix A: Log file for first example

```
        Qrule (v 4.1) Landscape Pattern Analysis          08/01/05
        Map choice: I
        Input map name: rocr_reclass.map
        Rows x Columns =    512 x    512
        Map classes =     4
        Rule choice is: 1
        N_Reps =      1
        Map output choice = N
        Analysis method: RULE

        Resolution:  30.0000     meters

                       Mean Association Matrix
        Avg_ChiX = 890910.     w/    9 df (%Xceed = 100.0000)
              0        1        2        3        4
           0 0.034900 0.001690 0.000614 0.000413 0.001469
           1 0.001690 0.204405 0.008997 0.000947 0.063994
           2 0.000614 0.008997 0.037996 0.000063 0.018968
           3 0.000413 0.000947 0.000063 0.001538 0.000593
           4 0.001469 0.063994 0.018968 0.000593 0.525662


        p's  0.039086 0.280034 0.066639 0.003555 0.610686

        STATISTICAL SUMMARY (N=     1; Resolution= 30.0000 meters)

--Cover Type 0 (non habitat)--    [p =  0.0391   Cum. p =  0.0391]
--Land Cover Type  1--            [p =  0.2800   Cum. p =  0.3191]
Variable  Units  Mean        St.Dev.       C. V.      Minimum      Maximum
 L.C.size  ha  1152.45      0.00000      0.00000      1152.45      1152.45
 L.C.edge  m   238320.      0.00000      0.00000      238320.      238320.
 L.C.fract -   1.69101      0.00000      0.00000      1.69101      1.69101
 L.C._rms  m   2974.93      0.00000      0.00000      2974.93      2974.93
 TTL clstr N   5420.00      0.00000      0.00000      5420.00      5420.00
 TTL edgs  m  0.238968E+07  0.00000      0.00000     0.238968E+07 0.238968E+07
 Sav size  ha  495.711      0.00000      0.00000      495.711      495.711
 S_Freq    N   73393.0      0.00000      0.00000      73393.0      73393.0
 Cor_len   m   2538.97      0.00000      0.00000      2538.97      2538.97
 Perc      %   0.00000      0.00000      0.00000      0.00000      0.00000


--Land Cover Type  2--            [p =  0.0667   Cum. p =  0.3858]
Variable  Units  Mean        St.Dev.       C. V.      Minimum      Maximum
 L.C.size  ha  88.5600      0.00000      0.00000      88.5600      88.5600
 L.C.edge  m   27780.0      0.00000      0.00000      27780.0      27780.0
 L.C.fract -   1.74417      0.00000      0.00000      1.74417      1.74417
 L.C._rms  m   570.210      0.00000      0.00000      570.210      570.210
 TTL clstr N   3349.00      0.00000      0.00000      3349.00      3349.00
 TTL edgs  m   905160.      0.00000      0.00000      905160.      905160.
 Sav size  ha  14.8859      0.00000      0.00000      14.8859      14.8859
 S_Freq    N   17484.0      0.00000      0.00000      17484.0      17484.0
 Cor_len   m   435.873      0.00000      0.00000      435.873      435.873
 Perc      %   0.00000      0.00000      0.00000      0.00000      0.00000


--Land Cover Type  3--            [p =  0.0036   Cum. p =  0.3893]
Variable  Units  Mean        St.Dev.       C. V.      Minimum      Maximum
 L.C.size  ha  6.93000      0.00000      0.00000      6.93000      6.93000
 L.C.edge  m   2400.00      0.00000      0.00000      2400.00      2400.00
 L.C.fract -   1.51765      0.00000      0.00000      1.51765      1.51765
```

L.C._rms	m	204.194	0.00000	0.00000	204.194	204.194
TTL clstr	N	345.000	0.00000	0.00000	345.000	345.000
TTL edgs	m	63780.0	0.00000	0.00000	63780.0	63780.0
Sav size	ha	2.26522	0.00000	0.00000	2.26522	2.26522
S_Freq	N	934.000	0.00000	0.00000	934.000	934.000
Cor_len	m	169.501	0.00000	0.00000	169.501	169.501
Perc	%	0.00000	0.00000	0.00000	0.00000	0.00000

--Land Cover Type 4-- [p = 0.6107 Cum. p = 1.0000]

Variable	Units	Mean	St.Dev.	C. V.	Minimum	Maximum
L.C.size	ha	10208.3	0.00000	0.00000	10208.3	10208.3
L.C.edge	m	0.136008E+07	0.00000	0.00000	0.136008E+07	0.136008E+07
L.C.fract	-	1.87103	0.00000	0.00000	1.87103	1.87103
L.C._rms	m	5419.64	0.00000	0.00000	5419.64	5419.64
TTL clstr	N	2817.00	0.00000	0.00000	2817.00	2817.00
TTL edgs	m	0.270660E+07	0.00000	0.00000	0.270660E+07	0.270660E+07
Sav size	ha	7656.26	0.00000	0.00000	7656.26	7656.26
S_Freq	N	160085.	0.00000	0.00000	160085.	160085.
Cor_len	m	5303.52	0.00000	0.00000	5303.52	5303.52
Perc	%	1.00000	0.00000	0.00000	1.00000	1.00000

Appendix B: Log file for second example

```
        Qrule (v 4.1) Landscape Pattern Analysis          08/01/05
        Map choice: X
        Rows x Columns =    512 x    512
        File to use as mask: rocr_reclass.map
        Cover types: mask =   4 random =   3
        from --> to
            0    0
            1    1
            2    2
            3    3
            4    0
        Random number seed:   -1918171
        Rule choice is: 1
        Map classes =     3
        The normalized probabilities are:
                P          CumP
          0    0.0000     0.0000
          1    0.7996     0.7996
          2    0.1903     0.9898
          3    0.0102     1.0000
        N_Reps =     12
        Map output choice = G
        Output file for generated map: scratch.map
        Analysis method: RULE

        Resolution:  30.0000     meters

        Using mask with ***** sites [p(0) =  0.64977]
                       Mean Association Matrix
        Avg_ChiX = 875462.     w/    5 df (%Xceed = 100.0000)
               0        1        2        3
           0 0.563500 0.083590 0.002552 0.000131
           1 0.083590 0.174154 0.020895 0.001571
           2 0.002552 0.020895 0.041427 0.001596
           3 0.000131 0.001571 0.001596 0.000249


        p's  0.649772 0.280210 0.066471 0.003547

        STATISTICAL SUMMARY (N=    12; Resolution= 30.0000 meters)

--Cover Type 0 (non habitat)--    [p =  0.6498   Cum. p =  0.6498]
--Land Cover Type  1--            [p =  0.2802   Cum. p =  0.9300]
Variable  Units  Mean        St.Dev.       C. V.      Minimum      Maximum
 L.C.size  ha  584.370      127.073      21.7453      360.810      785.340
 L.C.edge  m   151230.      46130.3      30.5034      95940.0      270300.
 L.C.fract -   1.71680     0.463942E-01  2.70237      1.63812      1.77512
 L.C._rms  m   1716.60      411.685      23.9826      1086.09      2777.87
 TTL clstr N   7315.17      56.0062     0.765618      7232.00      7410.00
 TTL edgs  m  0.334782E+07  13571.6     0.405384    0.331752E+07 0.337638E+07
 Sav size  ha  123.546      28.0879      22.7347      80.3961      184.840
 S_Freq    N   73462.9      7.04477     0.958956E-02  73450.0      73474.0
 Cor_len   m   1439.29      346.311      24.0612      916.164      2255.83
 Perc      %   0.00000      0.00000      0.00000      0.00000      0.00000


--Land Cover Type  2--            [p =  0.0664   Cum. p =  0.9965]
Variable  Units  Mean        St.Dev.       C. V.      Minimum      Maximum
 L.C.size  ha  56.9475      10.4017      18.2654      44.0100      76.6800
 L.C.edge  m   18510.0      3574.78      19.3127      12960.0      24780.0
```

L.C.fract	-	1.68404	0.411394E-01	2.44290	1.63345	1.79039
L.C._rms	m	497.870	52.2798	10.5007	382.026	580.443
TTL clstr	N	2219.58	81.1631	3.65668	2083.00	2403.00
TTL edgs	m	789545.	16484.5	2.08784	758760.	831240.
Sav size	ha	14.8172	1.48497	10.0220	12.3929	17.9630
S_Freq	N	17418.2	5.00227	0.287186E-01	17409.0	17431.0
Cor_len	m	381.128	37.5106	9.84202	312.358	444.973
Perc	%	0.00000	0.00000	0.00000	0.00000	0.00000

--Land Cover Type 3-- [p = 0.0035 Cum. p = 1.0000]

Variable	Units	Mean	St.Dev.	C. V.	Minimum	Maximum
L.C.size	ha	0.562500	0.115925	20.6089	0.450000	0.810000
L.C.edge	m	405.000	81.4081	20.1008	300.000	600.000
L.C.fract	-	1.57308	0.103942	6.60753	1.40368	1.75647
L.C._rms	m	59.4908	5.77370	9.70520	50.9117	71.1996
TTL clstr	N	800.833	11.2802	1.40856	781.000	817.000
TTL edgs	m	103765.	695.943	0.670691	102540.	104880.
Sav size	ha	0.125926	0.512321E-02	4.06842	0.118870	0.135533
S_Freq	N	929.833	1.11464	0.119875	928.000	932.000
Cor_len	m	36.3156	1.57741	4.34362	34.5986	40.1356
Perc	%	0.00000	0.00000	0.00000	0.00000	0.00000

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