

# GRTS Survey Designs for a Linear Resource

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This document presents example GRTS survey designs for a linear resource. The linear resource used in the designs is streams that comprise the Luckiamute watershed in Oregon. Four survey designs will be presented: (1) an unstratified, equal probability design; (2) a stratified, equal probability design with an oversample; (3) a stratified, unequal probability design with an oversample; and (4) a stratified, unequal probability design with an oversample and a panel structure for survey over time. The sampling frame used for the survey designs is contained in either an ESRI shapefile or an `sp` package object. The frame contains the coordinates for a set of line segments that define the linear resource in addition to attribute data associated with the line segments. The coordinate system for the set of points in the sampling frame is an equal area projection rather than latitude and longitude. An equal area projection is used so that calculation of distance between points is valid.

## 1 Preliminaries

The initial step is to use the library function to load the `spsurvey` package. After the package is loaded, a message is printed to the R console indicating that the `spsurvey` package was loaded successfully.

Load the `spsurvey` package

```
> # Load the spsurvey package
> library(spsurvey)
>
```

Version 2.1 of the `spsurvey` package was loaded successfully.

## 2 Shapefile attribute data

The next step is to read the attribute data from the shapefile. The `read.dbf` function in the `spsurvey` package is used to read the attribute (dbf) file in the shapefile and assign it to a data frame named `att`. The initial six lines in the `att` data frame are printed using the `head` function

Next, two attributes, stream type and Strahler stream order, that will be used to define, respectively, stratum codes and unequal selection probability (multidensity) categories for the survey designs are examined. Stream type is contained in a variable named `"perint"`, and Strahler stream order is contained in a variable named `"strahcat"`. For stream type, streams are classified as either perennial or intermittent. For Strahler stream order, streams are classified as either first order (`"1st"`), second order (`"2nd"`), or third order and higher (`"3rd+"`). The `table` and `addmargin` functions are used to produce a table displaying number of stream segments for each combination of values for the strata and multidensity category variables.

Finally, frame stream length is summarized for the strata and multidensity category attributes. Note that stream length measured in kilometers is contained in the variable named "length\_km". The tapply function is used to calculate total stream length for each combination of stream type and Strahler stream order. The addmargins function is applied to the output from tapply to calculate stream length for each category of stream type and Strahler stream order, and the round function is used to round value to two decimal places. Finally, the resulting cross-tabulation of sum of stream length in kilometers for Strahler stream order and stream type is displayed.

Read the attribute table from the shapefile

```
> # Read the attribute table from the shapefile
> att <- read.dbf("luck_ash")
>
```

Display the initial six lines in the attribute data frame

```
> # Display the initial six lines in the attribute data frame
> head(att)
```

	perint	strahcat	length_km	length_mdm
1	Perennial	2nd	2.3261097	2326.1097
2	Intermittent	1st	0.5785829	578.5829
3	Intermittent	1st	0.7796058	779.6058
4	Perennial	1st	1.8757176	1875.7176
5	Intermittent	1st	1.0012245	1001.2245
6	Perennial	1st	1.6464196	1646.4196

```
>
```

Display number of stream segments cross-classified by the strata and multidensity category variables

```
> # Display number of stream segments cross-classified by the strata and
> # multidensity category variables
>
> addmargins(table("Stream Type"=att$perint, "Strahler Order"=att$strahcat))
```

Stream Type	Strahler Order			Sum
	1st	2nd	3rd+	
Intermittent	137	20	2	159
Perennial	104	78	88	270
Sum	241	98	90	429

```
>
```

Summarize frame stream length by stratum and multidensity category

```
> # Summarize frame stream length by stratum and multidensity category
> temp <- tapply(att$length_km, list(att$perint, att$strahcat), sum)
> temp <- round(addmargins(temp), 2)
> names(dimnames(temp)) <- list("Stream Type", "Strahler Order")
> temp
```

Stream Type	Strahler Order			Sum
	1st	2nd	3rd+	
Intermittent	305.53	20.51	3.03	329.07
Perennial	200.53	133.10	159.79	493.42
Sum	506.06	153.61	162.82	822.49

>

Streams in the Luckiamute watershed are displayed in Figure 1 classified by stream type and in Figure 2 classified by Strahler stream order category. To produce the figure, first the `read.shape` function in the `spsurvey` package is used to read the shapefile and assign it to an object named `shp`. The `shp` object takes the form of a spatial data object defined in the `sp` package. Specifically, `shp` belongs to class "SpatialLinesDataFrame". For further information about spatial data objects, see documentation for the `sp` package. The `spplot` function in the `sp` package is used to create the figures.

Read the shapefile

```
> shp <- read.shape("luck_ash")
```

Plot streams in the Luckiamute watershed classified by stream type

```
> spplot(shp, zcol="perint", col.regions=c("red", "blue"))
```

Plot streams in the Luckiamute watershed classified by Strahler stream order

```
> spplot(shp, zcol="strahcat", col.regions=c("red", "green", "blue"))
```

### 3 Unstratified, equal probability, GRTS survey design

The first survey design is an unstratified, equal probability design. The `set.seed` function is called so that, if necessary, the designs can be replicated.

The initial step is to create a list named `Equaldsgn` that contains information for specifying the survey design. Since the survey design is unstratified, the list contains a single item named "None" that also is a list. The "None" list includes two items: `panel`, which is used to specify the sample size for each panel, and `seltype`, which is used to input the type of random selection for the design. For this example, `panel` is assigned a single value named "PanelOne" that is set equal to 50, and `seltype` is assigned the value "Equal", which indicates equal probability selection.

The `grts` function in the `spsurvey` package is called to select the survey design. The following arguments are included in the call to `grts`: (1) `design`: the named list of stratum design specifications, which is assigned the `Equaldsgn` list; (2) `DesignID`: name for the design, which is used to create a site ID for each site and is assigned the value "EQUAL"; (3) `type.frame`: the type of frame, which is assigned the value "linear" to indicate a linear resource; (4) `src.frame`: source of the frame, which is assigned the value "shapefile" to indicate a shapefile frame; (5) `in.shape`: name of the input shapefile, which is assigned the value "luck\_ash"; (6) `att.frame`: the data frame of attributes associated with elements in the frame, which is assigned the `att` data frame; and (7) `shapefile`: option to create a shapefile containing the survey design information, which is assigned `FALSE`.

During execution of the `grts` function, messages are printed that indicate the initial number of hierarchical levels used for the GRTS grid, the current number of levels, and the final number of levels. The set of messages is printed for each stratum, and is labeled with the stratum name. For

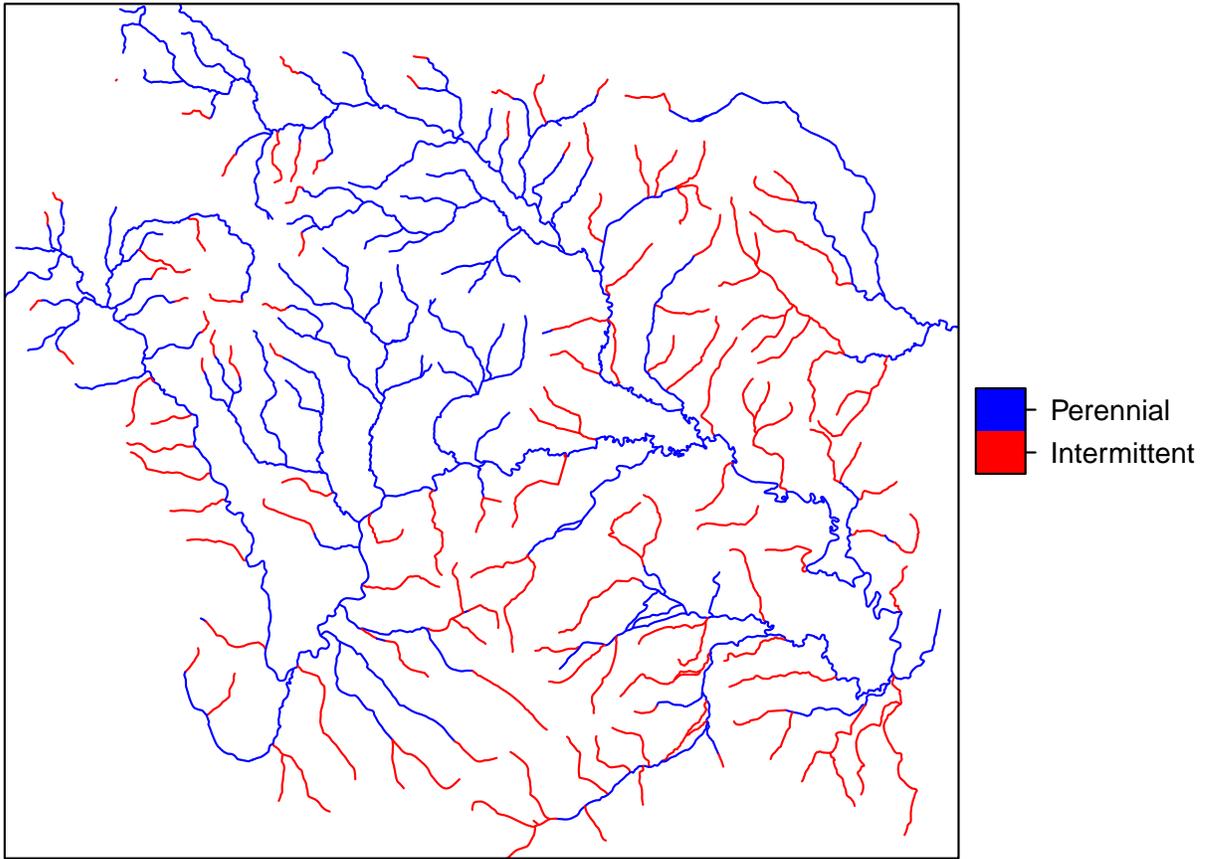


Figure 1: Streams in the Luckiamute Watershed Classified by Stream Type.

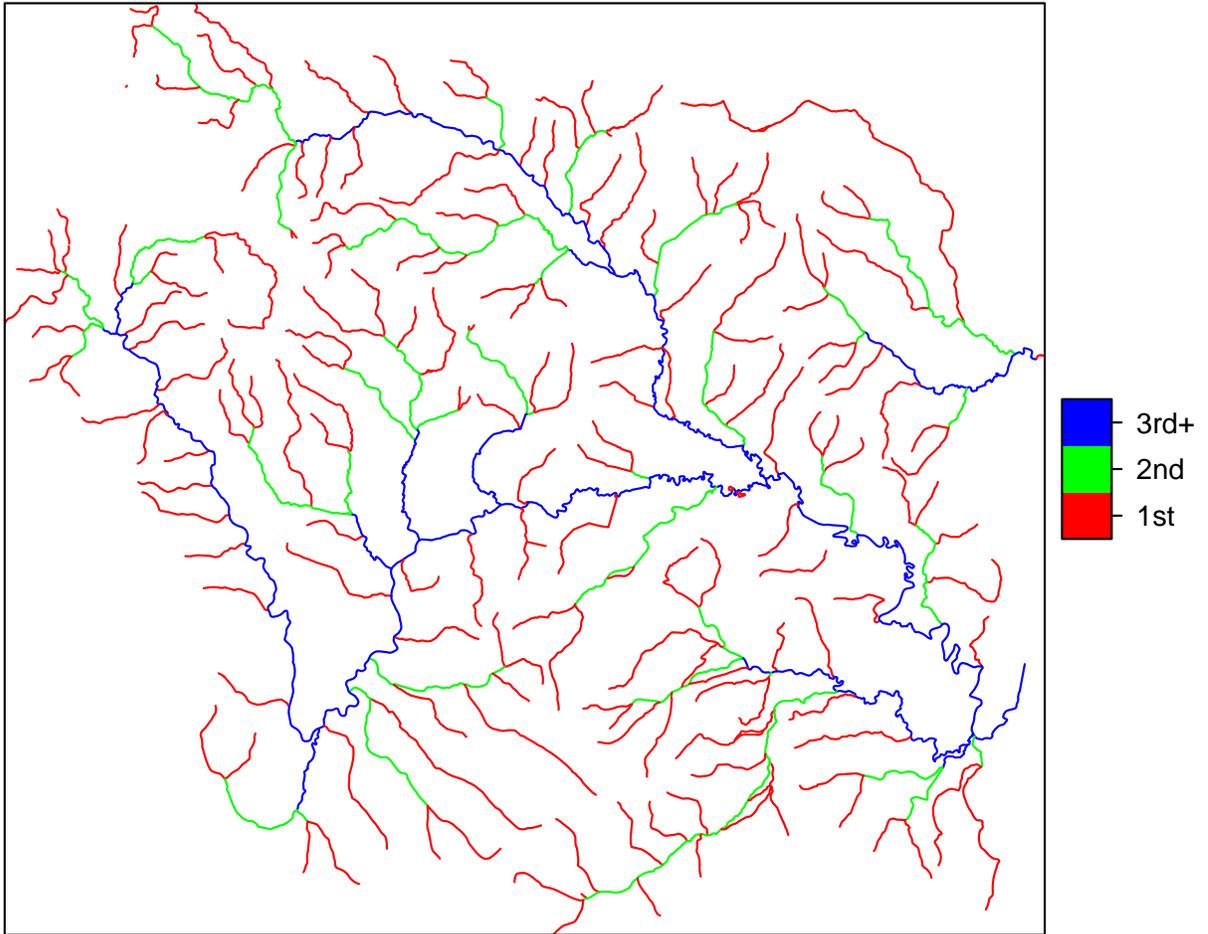


Figure 2: Streams in the Luckiamute Watershed Classified by Strahler Stream Order Category.

this example, the set of messages is labeled "None", i.e., the name used in the Equaldsgn list. Upon completion of the call to grts, the initial six sites for the survey design and a design summary are printed.

Call the set.seed function so that the design can be replicated

```
> # Call the set.seed function so that the survey designs can be replicate
> set.seed(19742003)
>
```

Create the design list

```
> # Create the design list
> Equaldsgn <- list(None=list(panel=c(PanelOne=50), seltype="Equal"))
>
```

Select the sample

```
> Equalsites <- grts(design=Equaldsgn,
+                    DesignID="EQUAL",
+                    type.frame="linear",
+                    src.frame="shapefile",
+                    in.shape="luck_ash",
+                    att.frame=att,
+                    shapefile=FALSE)
```

Stratum: None

```
Initial number of levels: 3
Current number of levels: 3
Current number of levels: 4
Final number of levels: 4
```

Print the initial six lines of the survey design

```
> # Print the initial six lines of the survey design
> head(Equalsites@data)
```

	siteID	xcoord	ycoord	mdcaty	wgt	stratum	panel	EvalStatus
1	EQUAL-01	-2150812	2735224	Equal	16449.76	None	PanelOne	NotEval
2	EQUAL-02	-2144418	2735266	Equal	16449.76	None	PanelOne	NotEval
3	EQUAL-03	-2141716	2742115	Equal	16449.76	None	PanelOne	NotEval
4	EQUAL-04	-2124993	2721669	Equal	16449.76	None	PanelOne	NotEval
5	EQUAL-05	-2129214	2731968	Equal	16449.76	None	PanelOne	NotEval
6	EQUAL-06	-2141493	2721389	Equal	16449.76	None	PanelOne	NotEval

	EvalReason	perint	strahcat	length_km
1	Perennial		1st	1.5970450
2	Intermittent		1st	1.4952739
3	Perennial		1st	0.6707707
4	Perennial		2nd	2.7419852
5	Perennial		3rd+	3.6578044
6	Perennial		3rd+	2.7692863

>

Print the survey design summary

```
> # Print the survey design summary
> dsgnsum(Equalsites)
```

Design Summary: Number of Sites

```
stratum
None   Sum
   50   50
```

>

## 4 Stratified, equal probability, GRTS survey design with an oversample

The second survey design is a stratified, equal probability design with an oversample. The stream type attribute is used to identify strata. List `Stratdsgn` is assigned design specifications. Since the survey design is stratified, `Stratdsgn` includes two lists named "Perennial" and "Intermittent" that contains three items: `panel`, `seltype`, and `over`. Note that the names for the two lists match the levels of the `stratum` variable. For both lists, the values for `panel` and `seltype` are the same as the ones used for the equal probability design. The third item, `over`, assigns the value 50 for size of the oversample. An oversample provides additional sample sites to replace sites that cannot be used, e.g., to replace sites in the sample that are not accessible.

For this survey design, a shapefile will be used as the sampling frame. The following arguments are included in the call to `grts`: (1) `design`: assigned the `Stratdsgn` list; (2) `DesignID`: assigned the value "STRATIFIED"; (3) `type.frame`: assigned the value "linear"; (4) `src.frame`: assigned the value "shapefile"; (5) `in.shape`: assigned the value "luck\_ash"; (6) `att.frame`: assigned the att data frame; (7) `stratum`: name of the column in the attributes data frame that identifies the `stratum` code for each element in the frame, which is assigned the value "perint"; and (8) `shapefile`: assigned the value FALSE. Upon completion of the call to `grts`, the initial six sites for the survey design and a design summary are printed.

Create the design list

```
> Stratdsgn <- list(Perennial=list(panel=c(PanelOne=50),
+                                 seltype="Equal",
+                                 over=50),
+                  Intermittent=list(panel=c(PanelOne=50),
+                                     seltype="Equal",
+                                     over=50))
```

Select the sample

```
> Stratsites <- grts(design=Stratdsgn,
+                   DesignID="STRATIFIED",
+                   type.frame="linear",
+                   src.frame="shapefile",
```

```

+           in.shape="luck_ash",
+           att.frame=att,
+           stratum="perint",
+           shapefile=FALSE)

```

```

Stratum: Perennial
Initial number of levels: 4
Current number of levels: 4
Current number of levels: 5
Final number of levels: 5

```

```

Stratum: Intermittent
Initial number of levels: 4
Current number of levels: 4
Current number of levels: 5
Final number of levels: 5

```

Print the initial six lines of the survey design

```

> # Print the initial six lines of the survey design
> head(Stratsites@data)

```

	siteID	xcoord	ycoord	mdcaty	wgt	stratum	panel	EvalStatus
1	STRATIFIED-001	-2140465	2743111	Equal	9868.441	Perennial	PanelOne	NotEval
2	STRATIFIED-002	-2151407	2737845	Equal	9868.441	Perennial	PanelOne	NotEval
3	STRATIFIED-003	-2137700	2727590	Equal	9868.441	Perennial	PanelOne	NotEval
4	STRATIFIED-004	-2151808	2736499	Equal	9868.441	Perennial	PanelOne	NotEval
5	STRATIFIED-005	-2144328	2737853	Equal	9868.441	Perennial	PanelOne	NotEval
6	STRATIFIED-006	-2139729	2726615	Equal	9868.441	Perennial	PanelOne	NotEval

	EvalReason	strahcat	length_km
1		1st	2.148345
2		1st	1.081804
3		3rd+	2.026988
4		1st	3.711475
5		1st	5.890572
6		3rd+	2.024677

```

>

```

Print the survey design summary

```

> # Print the survey design summary
> dsgnsum(Stratsites)

```

Design Summary: Number of Sites Classified by panel and stratum

panel	stratum		Sum
	Perennial	Intermittent	
OverSamp	50	50	100
PanelOne	50	50	100
Sum	100	100	200

```

>

```

## 5 Stratified, unequal probability, GRTS survey design with an oversample

The third survey design is a stratified, unequal probability design with an oversample. As for the second survey design, the stream type attribute is used to identify strata. Strahler order categories are used to identify multidensity categories. List Unequaldsgn is assigned design specifications. Unequaldsgn includes the same two lists with three items (panel, seltype, and over) as used for the stratified, equal probability design plus a value for caty.n. For both lists, panel specifies a single panel, and seltype is assigned "Unequal" to indicate unequal probability sampling. Note that the value 0 is assigned to over for the "Intermittent" stratum, i.e., no oversample. The over item could have been omitted from the list for "Intermittent". The vector assigned to caty.n specifies sample sizes for each of the three multidensity categories. Note that the sum of values provided in caty.n must equal the value in panel.

For this survey design, an sp package object will be used as the sampling frame. Recall that the read.shape function was used to read the shapefile and assign its output to an sp object named shp. The following arguments are included in the call to grts: (1) design: assigned the Unequaldsgn list; (2) DesignID: assigned the value "UNEQUAL"; (3) type.frame: assigned the value "linear"; (4) src.frame: assigned the value "sp.object" to indicate that the sampling frame is provided by an sp object; (5) sp.object: name of the sp object, which is assigned the shp object; (6) att.frame: assigned the att data frame; (7) stratum: assigned the value "perint"; (8) mdcaty: name of the column in the attributes data frame that identifies the unequal probability category for each element in the frame, which is assigned the value "strahcat"; (9) shapefile: assigned the value FALSE. Upon completion of the call to grts, the initial six sites for the survey design and a design summary are printed.

Create the design list

```
> Unequaldsgn <- list(Perennial=list(panel=c(PanelOne=75),
+                                   seltype="Unequal",
+                                   caty.n=c("1st"=25, "2nd"=25, "3rd+"=25),
+                                   over=36),
+                    Intermittent=list(panel=c(PanelOne=32),
+                                       seltype="Unequal",
+                                       caty.n=c("1st"=25, "2nd"=5, "3rd+"=2),
+                                       over=0))
```

Select the sample

```
> Unequalsites <- grts(design=Unequaldsgn,
+                      DesignID="UNEQUAL",
+                      type.frame="linear",
+                      src.frame="sp.object",
+                      sp.object=shp,
+                      att.frame=att,
+                      stratum="perint",
+                      mdcaty="strahcat",
+                      shapefile=FALSE)
```

```
Stratum: Perennial
Initial number of levels: 4
Current number of levels: 4
```

Current number of levels: 5  
Final number of levels: 5

Stratum: Intermittent  
Initial number of levels: 3  
Current number of levels: 3  
Current number of levels: 4  
Current number of levels: 5  
Current number of levels: 6  
Final number of levels: 6

Print the initial six lines of the survey design

```
> # Print the initial six lines of the survey design  
> head(Unequalsites@data)
```

	siteID	xcoord	ycoord	mdcaty	wgt	stratum	panel	EvalStatus
1	UNEQUAL-001	-2135601	2731417	3rd+	6391.609	Perennial	PanelOne	NotEval
2	UNEQUAL-002	-2138626	2735785	1st	8021.238	Perennial	PanelOne	NotEval
3	UNEQUAL-003	-2131014	2714764	2nd	5324.034	Perennial	PanelOne	NotEval
4	UNEQUAL-004	-2146969	2738402	2nd	5324.034	Perennial	PanelOne	NotEval
5	UNEQUAL-005	-2129903	2732867	3rd+	6391.609	Perennial	PanelOne	NotEval
6	UNEQUAL-006	-2141733	2721328	3rd+	6391.609	Perennial	PanelOne	NotEval

	EvalReason	length_km
1		4.805305
2		1.772859
3		1.345379
4		4.091204
5		2.963369
6		2.769286

>

Print the survey design summary

```
> # Print the survey design summary  
> dsgnsum(Unequalsites)
```

Design Summary: Number of Sites Classified by mdcaty (Multidensity Category) and stratum

	stratum		
mdcaty	Perennial	Intermittent	Sum
1st	31	26	57
2nd	46	3	49
3rd+	34	3	37
Sum	111	32	143

Design Summary: Number of Sites Classified by panel and stratum

	stratum		
panel	Perennial	Intermittent	Sum
OverSamp	36	0	36
PanelOne	75	32	107
Sum	111	32	143

Design Summary: Number of Sites Classified by mdcaty (Multidensity Category), panel, and stratum

, , stratum = Perennial

	panel		
mdcaty	OverSamp	PanelOne	Sum
1st	13	18	31
2nd	12	34	46
3rd+	11	23	34
Sum	36	75	111

, , stratum = Intermittent

	panel		
mdcaty	OverSamp	PanelOne	Sum
1st	0	26	26
2nd	0	3	3
3rd+	0	3	3
Sum	0	32	32

, , stratum = Sum

	panel		
mdcaty	OverSamp	PanelOne	Sum
1st	13	44	57
2nd	12	37	49
3rd+	11	26	37
Sum	36	107	143

>

## 6 Stratified, unequal probability, GRTS survey design with an oversample and a panel structure for survey over time

The fourth survey design is a stratified, unequal probability design with an oversample and a panel structure for survey over time. List Paneldsgn is assigned design specifications. Analogous to the stratified, unequal probability design, Paneldsgn includes two lists named "Perennial" and

"Intermittent". For the "Perennial" stratum, a vector identifying sample sizes for three panels is assigned to panel. For the "Intermittent" stratum, the sample size for a single panel named "YearOnce" is assigned to panel. The value "Unequal" is assigned to seltype for both lists, which indicates unequal selection probabilities. For both lists, the third item, caty.n, assigns sample sizes for each of the three multidensity categories. Again, note that the sum of sample sizes provided in caty.n must equal the sum of sample sizes in panel. For the "Perennial" stratum, the value 50 is assigned to over, which specifies an oversample of 50 sites. No oversample is specified for the "Intermittent" stratum, and so over is not included in the list. The grts function attempts to distribute the oversample proportionately among sample sizes for the multidensity categories. If the oversample proportion for one or more categories is not a whole number, a warning message is printed and the proportion is rounded to the next higher integer. For the "Perennial" stratum, the oversample is not proportionate to the multidensity category sample sizes, and the warning message is printed by calling the warnings function.

For this survey design, a shapefile will be used as the sampling frame. The following arguments are included in the call to grts: (1) design: assigned the Paneldsgn list; (2) DesignID: assigned the value "UNEQUAL"; (3) type.frame: assigned the value "linear"; (4) src.frame: assigned the value "shapefile"; (5) in.shape: assigned the value "luck\_ash"; (6) att.frame: assigned the att data frame; (7) stratum: assigned the value "perint"; (8) mdcaty: assigned the value "strahcat"; (9) shapefile: assigned the value FALSE. Upon completion of the call to grts, the initial six sites for the survey design and a design summary are printed.

Create the design list

```
> Paneldsgn <- list(Perennial=list(panel=c(Year1=17, Year2=17, YearAll=16),
+                               seltype="Unequal",
+                               caty.n=c("1st"=15, "2nd"=15, "3rd+"=20),
+                               over=50),
+                 Intermittent=list(panel=c(YearOnce=27),
+                                   seltype="Unequal",
```

Select the sample

```
> Panelsites <- grts(design=Paneldsgn,
+                   DesignID="UNEQUAL",
+                   type.frame="linear",
+                   src.frame="shapefile",
+                   in.shape="luck_ash",
+                   att.frame=att,
+                   stratum="perint",
+                   mdcaty="strahcat",
+                   shapefile=FALSE)
```

Stratum: Perennial

Initial number of levels: 4

Current number of levels: 4

Current number of levels: 5

Final number of levels: 5

Stratum: Intermittent

Initial number of levels: 3

Current number of levels: 3  
Current number of levels: 4  
Current number of levels: 5  
Final number of levels: 5

Print the warning message

```
> # Print the warning message
> warnings()
>
```

Warning message:

```
In grts(design = Paneldsgn, DesignID = "UNEQUAL", type.frame = "linear", :
```

Oversample size is not proportional to category sample sizes for stratum "Perennial".

Print the initial six lines of the survey design

```
> # Print the initial six lines of the survey design
> head(Panelsites@data)
```

	siteID	xcoord	ycoord	mdcaty	wgt	stratum	panel	EvalStatus
1	UNEQUAL-001	-2121914	2742158	1st	13368.731	Perennial	Year1	NotEval
2	UNEQUAL-002	-2134368	2736824	1st	13368.731	Perennial	Year1	NotEval
3	UNEQUAL-003	-2141032	2729224	2nd	8873.391	Perennial	Year1	NotEval
4	UNEQUAL-004	-2137683	2733743	1st	13368.731	Perennial	Year1	NotEval
5	UNEQUAL-005	-2141244	2742218	3rd+	7989.511	Perennial	Year1	NotEval
6	UNEQUAL-006	-2149405	2737599	1st	13368.731	Perennial	Year1	NotEval
	EvalReason	length_km						
1		11.251478						
2		2.023301						
3		2.670265						
4		3.810946						
5		1.058053						
6		2.735620						

>

Print the survey design summary

```
> # Print the survey design summary
> dsgnsum(Panelsites)
```

Design Summary: Number of Sites Classified by mdcaty (Multidensity Category) and stratum

	stratum		
mdcaty	Perennial	Intermittent	Sum

1st	35	23	58
2nd	28	2	30
3rd+	37	2	39
Sum	100	27	127

Design Summary: Number of Sites Classified by panel and stratum

		stratum		
panel	Perennial	Intermittent	Sum	
OverSamp	50	0	50	
Year1	17	0	17	
Year2	17	0	17	
YearAll	16	0	16	
YearOnce	0	27	27	
Sum	100	27	127	

Design Summary: Number of Sites Classified by mdcaty (Multidensity Category), panel, and stratum

, , stratum = Perennial

		panel					
mdcaty	OverSamp	Year1	Year2	YearAll	YearOnce	Sum	
1st	17	7	4	7	0	35	
2nd	15	5	6	2	0	28	
3rd+	18	5	7	7	0	37	
Sum	50	17	17	16	0	100	

, , stratum = Intermittent

		panel					
mdcaty	OverSamp	Year1	Year2	YearAll	YearOnce	Sum	
1st	0	0	0	0	23	23	
2nd	0	0	0	0	2	2	
3rd+	0	0	0	0	2	2	
Sum	0	0	0	0	27	27	

, , stratum = Sum

		panel					
mdcaty	OverSamp	Year1	Year2	YearAll	YearOnce	Sum	
1st	17	7	4	7	23	58	
2nd	15	5	6	2	2	30	
3rd+	18	5	7	7	2	39	
Sum	50	17	17	16	27	127	

>