

Example 18
Analysis of Variance (ANOVA)
Comparing more than 2 samples
Setup

An ornithologist suspects that roost site influences the body mass of starlings. The ornithologist has collected body mass data from four roost sites. Body masses are in grams. Does roost site influence body mass?

Sample	Mass
A	78
A	88
A	87
A	88
A	83
A	82
A	81
A	80
A	80
A	89
B	78
B	78
B	83
B	81
B	78
B	81
B	81
B	82
B	76
B	76
C	79
C	73
C	79
C	75
C	77
C	78
C	80
C	78
C	83
C	84
D	77
D	69
D	75
D	70
D	74
D	83
D	80
D	75
D	76
D	75

Example 18
Analysis of Variance (ANOVA)
Comparing more than 2 samples
Solution

1. State your question: Do the mean body masses of starlings differ according to roosting site?
 - a. Is it a good scientific question? Definable, measurable, and controllable.
 - b. Identify your population: Body mass of starlings
 - c. Identify your dependent variable: Body Mass
 - d. Identify your independent variable: Roost sites
2. State your hypothesis set
 - a. Verbal hypothesis: Roost site influences starling mass
 - b. Statistical hypothesis (H_0 , H_A):
 H_0 : $\mu_A = \mu_B = \mu_C = \mu_D$ The mean body masses of the starlings do not differ according to roost site.
 H_A : The mean body masses of the starlings are not all equal
 - c. Is your hypothesis set exhaustive? Yes
 - d. Is your hypothesis set exclusive? Yes
3. State your significance level: $\alpha = 0.05$
4. Select the appropriate test.
 - a. Variable scales
 - i. Dependent variable: Ratio
 - Converted or Transformed? No
 - ii. Independent variable: Nominal
 - Converted or Transformed? No
 - b. What information is given or available?
 - Sample data
 - c. Number of samples: 4
 - d. Are the data paired or unpaired? Unpaired
 - e. What aspect of the variable do you want to compare?
 - i. Central tendency -- Means
 - f. State the test to be used: One-way ANOVA
 - i. Are the assumptions met? Yes
 - Random samples – Assumed
 - Independent samples – Assumed
 - Normally distributed populations – Tested using Shapiro-Wilk Test
 - Equal Variances – Tested using Levene's Test

Shapiro-Wilk normality test

data: StarlingsA\$Mass
 W = 0.893, p-value = 0.1835

Shapiro-Wilk normality test

data: StarlingsB\$Mass
 W = 0.8992, p-value = 0.2148

Shapiro-Wilk normality test

data: StarlingsC\$Mass
 W = 0.9658, p-value = 0.8494

Shapiro-Wilk normality test

data: StarlingsD\$Mass
 W = 0.9463, p-value = 0.625

Levene's Test for Homogeneity of Variance (center = median)

group	df	F value	Pr(>F)
	3	0.5947	0.6226
	36		

5. Conduct your sampling

Sample A	Sample B	Sample C	Sample D	Total
78	78	79	77	
88	78	73	69	
87	83	79	75	
88	81	75	70	
83	78	77	74	
82	81	78	83	
81	81	80	80	
80	82	78	75	
80	76	83	76	
89	76	84	75	
n=10	n=10	n=10	n=10	n _T =40
X=83.6 g	x=79.4 g	x=78.6 g	x=75.4 g	x=79.25 g
s ² =16.3 g ²	s ² =6.3 g ²	s ² =10.9 g ²	s ² =17.2 g ²	s ² =20.4 g ²

6. Graph the data

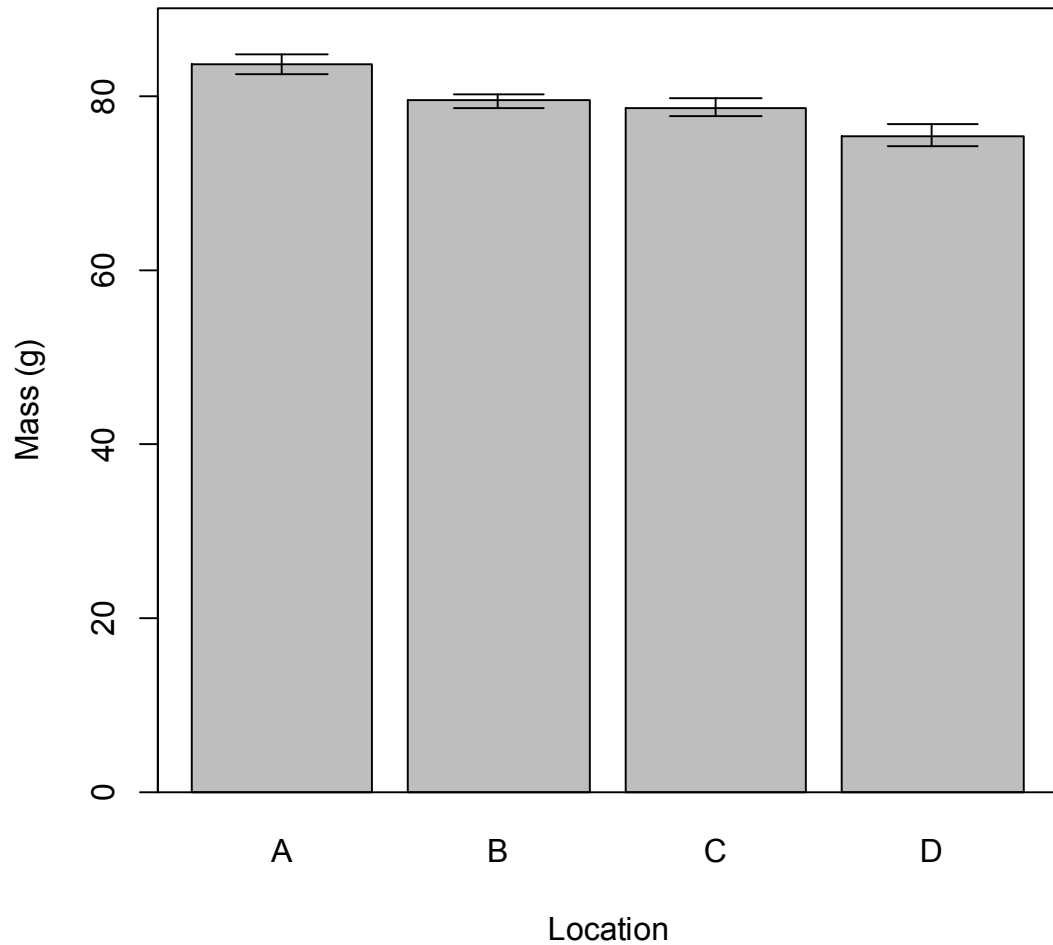


Figure 1. Body of starlings (g) sampled at four locations (A-D).

7. Summarize the data
(Table above)

8. Calculate your test statistic.
(ANOVAs are presented as tables)

	df	Sum Sq	Mean Sq	F value	Pr(>F)
Starlings\$Sample	3	341.9	113.97	9.005	0.000139 ***
Residuals	36	455.6	12.66		

9. Retain or reject your null hypothesis based on your test statistic.
The calculated p-value (0.000139) is less than the significance level (0.05), therefore we would reject our null hypothesis and retain our alternate hypothesis.
10. Interpret the results in biological terms.
The mean body masses of the starlings at the different roost sites are not the same ($F=9.002$, $df= 3, 36$, $p<0.001$).

Example 18b
Analysis of Variance (ANOVA)
with Tukey's Test
Comparing more than 2 samples

8. Calculate your test statistic.
 (ANOVAs are presented as tables)

	df	Sum Sq	Mean Sq	F value	Pr(>F)
Starlings\$Sample	3	341.9	113.97	9.005	0.000139 ***
Residuals	36	455.6	12.66		

Tukey multiple comparisons of means
 95% family-wise confidence level

Fit: aov(formula = Starlings\$Mass ~ Starlings\$Sample)

```
$`Starlings$Sample`
      diff      lwr      upr      p adj
B-A  -4.2  -8.484781  0.08478062  0.0564459
C-A  -5.0  -9.284781 -0.71521938  0.0168364
D-A  -8.2 -12.484781 -3.91521938  0.0000537
C-B  -0.8  -5.084781  3.48478062  0.9578779
D-B  -4.0  -8.284781  0.28478062  0.0745923
D-C  -3.2  -7.484781  1.08478062  0.2027531
```

9. Retain or reject your null hypothesis based on your test statistic.
 The calculated p-value (0.000139) is less than the significance level (0.05),
 therefore we would reject our null hypothesis and retain our alternate
 hypothesis.

Comparison	Difference	p
D vs. A	8.20	<0.001
D vs. B	4.00	0.075
D vs. C	3.20	0.202
C vs. A	5.00	0.017
C vs. B	0.80	0.958
B vs. A	4.20	0.056

10. Interpret the results in biological terms.

The mean body masses of the starlings at the different roost sites are not the same (F=9.002, df= 3, 36, p<0.001).

The body masses of starlings at sites D and C differ from those at site A ($p < 0.05$).

The body masses of starlings at site B do not differ significantly from those at site A ($p = 0.056$).

The body masses of starlings at sites B, C, and D do not differ significantly ($p > 0.05$).