

# OGC-biomass

## Primary Analyses

Kelly Murray Stoker, David Murray-Stoker

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## Raw Data Management

Raw data were imported and compiled for each of the two sampling periods, 1980s and 2010s. Subsets were merged or cast as needed for later analyses. Raw data were initially managed in the R environment, but final data management tasks were performed in Microsoft Excel after exporting the data; final data files are imported from csv files.

```
## Read in raw data files
raw.biomass.1982 <- read_csv("data/OGC_biomass_data-1982.csv", show_col_types = FALSE)
raw.biomass.1983 <- read_csv("data/OGC_biomass_data-1983.csv", show_col_types = FALSE)
raw.biomass.2010s <- read_csv("data/OGC_biomass_data-2010s.csv", show_col_types = FALSE)

## Set column structure for the raw data
raw.biomass.1982$Date <- as_factor(raw.biomass.1982$Date)
raw.biomass.1982$Snag <- as_factor(raw.biomass.1982$Snag)
raw.biomass.1983$Date <- as_factor(raw.biomass.1983$Date)
raw.biomass.1983$Snag <- as_factor(raw.biomass.1983$Snag)
raw.biomass.2010s$Date <- as_factor(raw.biomass.2010s$Date)
raw.biomass.2010s$Snag <- as_factor(raw.biomass.2010s$Snag)
```

```

## Biomass data management

## Create date-by-taxa matrices for biomass values
# 1982 raw biomass by taxa matrix
OGC.biomass.1982 <- dcast(
  raw.biomass.1982, Date ~ Genus, sum, value.var = "Biomass_Estimate"
)
# 1983 raw biomass by taxa matrix
OGC.biomass.1983 <- dcast(
  raw.biomass.1983, Date ~ Genus, sum, value.var = "Biomass_Estimate"
)
# 2010s raw biomass by taxa matrix
OGC.biomass.2010s <- dcast(
  raw.biomass.2010s, Date ~ Genus, sum, value.var = "Biomass_Estimate"
)

## Create dataframe of biomass values for each dataset
OGC.biomass.1982.values <- tibble(OGC.biomass.1982[, 2:59])
OGC.biomass.1983.values <- tibble(OGC.biomass.1983[, 2:48])
OGC.biomass.2010s.values <- tibble(OGC.biomass.2010s[, 2:64])

## Average by number of snags
OGC.biomass.1982.snag.correction <- OGC.biomass.1982.values/20
# Correct for 19 snags instead of 20 in first sample
OGC.biomass.1982.snag.correction[1, ] <- ((OGC.biomass.1982.snag.correction[1, ] * 20)/19)
OGC.biomass.1983.snag.correction <- OGC.biomass.1983.values/10
OGC.biomass.2010s.snag.correction <- OGC.biomass.2010s.values/10

## Add Date to the biomass data
OGC.biomass.1982.final <- OGC.biomass.1982.snag.correction %>%
  add_column(OGC.biomass.1982$Date) %>%
  rename(UID = "OGC.biomass.1982$Date")
OGC.biomass.1983.final <- OGC.biomass.1983.snag.correction %>%
  add_column(OGC.biomass.1983$Date) %>%
  rename(UID = "OGC.biomass.1983$Date")
OGC.biomass.2010s.final <- OGC.biomass.2010s.snag.correction %>%
  add_column(OGC.biomass.2010s$Date) %>%
  rename(UID = "OGC.biomass.2010s$Date")

## Export biomass data files
write_csv(OGC.biomass.1982.final, file = "data/OGC_1982_biomass_by_taxa.csv")
write_csv(OGC.biomass.1983.final, file = "data/OGC_1983_biomass_by_taxa.csv")
write_csv(OGC.biomass.2010s.final, file = "data/OGC_2010s_biomass_by_taxa.csv")

```

```

## Density data management

## Create date-by-taxa matrices for density values
# 1982 density by taxa matrix
OGC.density.1982 <- dcast(
  raw.biomass.1982, Date ~ Genus, sum, value.var = "Density"
)
# 1983 density by taxa matrix
OGC.density.1983 <- dcast(
  raw.biomass.1983, Date ~ Genus, sum, value.var = "Density"
)
# 2010s density by taxa matrix
OGC.density.2010s <- dcast(
  raw.biomass.2010s, Date ~ Genus, sum, value.var = "Density"
)

## Create dataframe of density values for each dataset
OGC.density.1982.values <- OGC.density.1982[, 2:59]
OGC.density.1983.values <- OGC.density.1983[, 2:48]
OGC.density.2010s.values <- OGC.density.2010s[, 2:64]

## Average by number of snags
OGC.density.1982.snag.correction <- OGC.density.1982.values/20
# Correct for 19 snags instead of 20 in first sample
OGC.density.1982.snag.correction[1, ] <- ((OGC.density.1982.snag.correction[1, ] * 20)/19)
OGC.density.1983.snag.correction <- OGC.density.1983.values/10
OGC.density.2010s.snag.correction <- OGC.density.2010s.values/10

## Add UID to density values
OGC.density.1982.final <- OGC.density.1982.snag.correction %>%
  add_column(OGC.density.1982$Date) %>%
  rename(UID = "OGC.density.1982$Date")
OGC.density.1983.final <- OGC.density.1983.snag.correction %>%
  add_column(OGC.density.1983$Date) %>%
  rename(UID = "OGC.density.1983$Date")
OGC.density.2010s.final <- OGC.density.2010s.snag.correction %>%
  add_column(OGC.density.2010s$Date) %>%
  rename(UID = "OGC.density.2010s$Date")

## Export density data files
write_csv(OGC.density.1982.final, file = "data/OGC_1982_density_by_taxa.csv")
write_csv(OGC.density.1983.final, file = "data/OGC_1983_density_by_taxa.csv")
write_csv(OGC.density.2010s.final, file = "data/OGC_2010s_density_by_taxa.csv")

```

## Load Processed Data

```
## Read in data
biomass.data <- read_csv("data/OGC_final_biomass_data.csv", show_col_types = FALSE)
density.data <- read_csv("data/OGC_final_density_data.csv", show_col_types = FALSE)

## Set variables as factors
# Biomass data
biomass.data$UID <- as_factor(biomass.data$UID)
biomass.data$Year <- as_factor(biomass.data$Year)
biomass.data$Year_Recoded <- as_factor(biomass.data$Year_Recoded)
biomass.data$Season <- as_factor(biomass.data$Season)
biomass.data$Season_Recoded <- as_factor(biomass.data$Season_Recoded)
biomass.data$Period <- as_factor(biomass.data$Period)

# Density data
density.data$UID <- as_factor(density.data$UID)
density.data$Year <- as_factor(density.data$Year)
density.data$Year_Recoded <- as_factor(density.data$Year_Recoded)
density.data$Season <- as_factor(density.data$Season)
density.data$Season_Recoded <- as_factor(density.data$Season_Recoded)
density.data$Period <- as_factor(density.data$Period)

## Dataframe of sampling info
sampling.info <- biomass.data[, 1:6]

## Matrices of invertebrate biomass and density
invertebrate.biomass.matrix <- biomass.data[, 16:87]
invertebrate.density.matrix <- density.data[, 16:87]

## Filter biomass and density data by sampling period; no further subsetting
# Biomass data
biomass.1980s <- invertebrate.biomass.matrix[1:25, ]
biomass.2010s <- invertebrate.biomass.matrix[26:49, ]

# Density data
density.1980s <- invertebrate.density.matrix[1:25, ]
density.2010s <- invertebrate.density.matrix[26:49, ]
```

## Biomass & Density ANOVAs

Biomass and density were compared by sampling period, season, and the interaction using an ANOVA with Type II sums-of-squares. ANOVA assumptions were inspected graphically using `check_model()`, and effect sizes for the ANOVAs were calculated as  $\eta_p^2$  using `eta_squared()`. Pairwise contrasts between influential factors were performed using `emmeans()`, with effect sizes for contrasts calculated as Cohen's  $d$ .

### Biomass ANOVA

```
biomass.anova <- lm(  
  log(Summed_Biomass) ~ Period * Season, data = biomass.data  
)
```

```
check_model(biomass.anova)
```

Table 1: ANOVA results for biomass by period, season, and the interaction.

|               | Sums-of-Squares | df | F     | P-value |
|---------------|-----------------|----|-------|---------|
| Period        | 6.348           | 1  | 6.014 | 0.019   |
| Season        | 5.432           | 3  | 1.716 | 0.179   |
| Period:Season | 4.199           | 3  | 1.326 | 0.279   |
| Residuals     | 43.275          | 41 | NA    | NA      |

Table 2: Table of the effect sizes in the biomass ANOVA.

| Term          | Eta-squared | CI   | CI Low | CI High |
|---------------|-------------|------|--------|---------|
| Period        | 0.128       | 0.95 | 0.013  | 1       |
| Season        | 0.112       | 0.95 | 0.000  | 1       |
| Period:Season | 0.088       | 0.95 | 0.000  | 1       |

Table 3: Estimated marginal means by period in the biomass ANOVA.

| Period | Estimate | SE    | df | t      | P-value |
|--------|----------|-------|----|--------|---------|
| 1980   | 8.854    | 0.205 | 41 | 43.092 | 0       |
| 2010   | 8.158    | 0.210 | 41 | 38.900 | 0       |

Table 4: Estimated marginal means by season in the biomass ANOVA.

| Season | Estimate | SE    | df | t      | P-value |
|--------|----------|-------|----|--------|---------|
| winter | 7.951    | 0.310 | 41 | 25.668 | 0       |
| spring | 8.501    | 0.297 | 41 | 28.662 | 0       |
| summer | 8.747    | 0.275 | 41 | 31.855 | 0       |
| fall   | 8.769    | 0.297 | 41 | 29.567 | 0       |

Table 5: Contrasts by period in the biomass ANOVA.

| Term   | Contrast                | Null Value | Estimate | SE    | df | t     | P-value |
|--------|-------------------------|------------|----------|-------|----|-------|---------|
| Period | Period1980 - Period2010 | 0          | 0.697    | 0.294 | 41 | 2.372 | 0.022   |

Table 6: Contrasts by season in the biomass ANOVA.

| Term   | Contrast        | Null Value | Estimate | SE    | df | t      | P-value |
|--------|-----------------|------------|----------|-------|----|--------|---------|
| Season | winter - spring | 0          | -0.549   | 0.429 | 41 | -1.281 | 0.415   |
| Season | winter - summer | 0          | -0.796   | 0.414 | 41 | -1.922 | 0.191   |
| Season | winter - fall   | 0          | -0.818   | 0.429 | 41 | -1.907 | 0.191   |
| Season | spring - summer | 0          | -0.246   | 0.404 | 41 | -0.609 | 0.655   |
| Season | spring - fall   | 0          | -0.268   | 0.419 | 41 | -0.640 | 0.655   |
| Season | summer - fall   | 0          | -0.022   | 0.404 | 41 | -0.055 | 0.957   |

Table 7: Effect sizes for the contrasts by period in the biomass ANOVA.

| Contrast                  | Cohen's d | SE    | df | CI Lower | CI Upper |
|---------------------------|-----------|-------|----|----------|----------|
| (Period1980 - Period2010) | 0.678     | 0.295 | 41 | 0.081    | 1.275    |



Table 8: Effect sizes for the contrasts by season in the biomass ANOVA.

| Contrast          | Cohen's d | SE    | df | CI Lower | CI Upper |
|-------------------|-----------|-------|----|----------|----------|
| (winter - spring) | -0.535    | 0.422 | 41 | -1.386   | 0.317    |
| (winter - summer) | -0.774    | 0.412 | 41 | -1.606   | 0.057    |
| (winter - fall)   | -0.796    | 0.427 | 41 | -1.657   | 0.066    |
| (spring - summer) | -0.240    | 0.394 | 41 | -1.036   | 0.557    |
| (spring - fall)   | -0.261    | 0.409 | 41 | -1.088   | 0.565    |
| (summer - fall)   | -0.022    | 0.393 | 41 | -0.816   | 0.773    |

## Density ANOVA

```
density.anova <- lm(  
  log(Summed_Density) ~ Period * Season, data = density.data  
)
```

```
check_model(density.anova)
```

Table 9: ANOVA result for density by period, season, and the interaction.

|               | Sums-of-Squares | df | F     | P-value |
|---------------|-----------------|----|-------|---------|
| Period        | 0.201           | 1  | 0.204 | 0.654   |
| Season        | 8.029           | 3  | 2.712 | 0.057   |
| Period:Season | 7.575           | 3  | 2.558 | 0.068   |
| Residuals     | 40.465          | 41 | NA    | NA      |

Table 10: Table of the effect sizes in the density ANOVA.

| Term          | Eta-squared | CI   | CI Low | CI High |
|---------------|-------------|------|--------|---------|
| Period        | 0.005       | 0.95 | 0      | 1       |
| Season        | 0.166       | 0.95 | 0      | 1       |
| Period:Season | 0.158       | 0.95 | 0      | 1       |

Table 11: Estimated marginal means of season in the density ANOVA.

| Season | Estimate | SE    | df | t      | P-value |
|--------|----------|-------|----|--------|---------|
| winter | 10.363   | 0.300 | 41 | 34.597 | 0       |
| spring | 11.033   | 0.287 | 41 | 38.473 | 0       |
| summer | 11.282   | 0.266 | 41 | 42.492 | 0       |
| fall   | 11.459   | 0.287 | 41 | 39.956 | 0       |

Table 12: Estimated marginal means of period and season in the density ANOVA.

| Period | Season | Estimate | SE    | df | t      | P-value |
|--------|--------|----------|-------|----|--------|---------|
| 1980   | winter | 10.285   | 0.406 | 41 | 25.359 | 0       |
| 2010   | winter | 10.457   | 0.444 | 41 | 23.537 | 0       |
| 1980   | spring | 10.603   | 0.406 | 41 | 26.142 | 0       |
| 2010   | spring | 11.464   | 0.406 | 41 | 28.266 | 0       |
| 1980   | summer | 11.369   | 0.375 | 41 | 30.278 | 0       |
| 2010   | summer | 11.195   | 0.375 | 41 | 29.815 | 0       |
| 1980   | fall   | 12.127   | 0.406 | 41 | 29.902 | 0       |
| 2010   | fall   | 10.790   | 0.406 | 41 | 26.605 | 0       |

Table 13: Pairwise contrasts between season in the density ANOVA.

| Term   | Contrast        | Null Value | Estimate | SE    | df | t      | P-value |
|--------|-----------------|------------|----------|-------|----|--------|---------|
| Season | winter - spring | 0          | -0.670   | 0.415 | 41 | -1.616 | 0.227   |
| Season | winter - summer | 0          | -0.919   | 0.400 | 41 | -2.296 | 0.081   |
| Season | winter - fall   | 0          | -1.096   | 0.415 | 41 | -2.642 | 0.070   |
| Season | spring - summer | 0          | -0.249   | 0.391 | 41 | -0.637 | 0.633   |
| Season | spring - fall   | 0          | -0.425   | 0.406 | 41 | -1.049 | 0.451   |
| Season | summer - fall   | 0          | -0.177   | 0.391 | 41 | -0.452 | 0.654   |

Table 14: Pairwise contrasts between period and season in the density ANOVA.

| Term          | Contrast                              | Null Value | Estimate | SE    | df | t      | P-value |
|---------------|---------------------------------------|------------|----------|-------|----|--------|---------|
| Period*Season | Period1980 winter - Period2010 winter | 0          | -0.172   | 0.602 | 41 | -0.286 | 0.836   |
| Period*Season | Period1980 winter - Period1980 spring | 0          | -0.318   | 0.574 | 41 | -0.554 | 0.742   |
| Period*Season | Period1980 winter - Period2010 spring | 0          | -1.179   | 0.574 | 41 | -2.056 | 0.259   |
| Period*Season | Period1980 winter - Period1980 summer | 0          | -1.084   | 0.553 | 41 | -1.962 | 0.264   |
| Period*Season | Period1980 winter - Period2010 summer | 0          | -0.910   | 0.553 | 41 | -1.647 | 0.334   |
| Period*Season | Period1980 winter - Period1980 fall   | 0          | -1.842   | 0.574 | 41 | -3.212 | 0.072   |
| Period*Season | Period1980 winter - Period2010 fall   | 0          | -0.505   | 0.574 | 41 | -0.881 | 0.565   |
| Period*Season | Period2010 winter - Period1980 spring | 0          | -0.146   | 0.602 | 41 | -0.242 | 0.840   |
| Period*Season | Period2010 winter - Period2010 spring | 0          | -1.007   | 0.602 | 41 | -1.674 | 0.334   |
| Period*Season | Period2010 winter - Period1980 summer | 0          | -0.912   | 0.582 | 41 | -1.568 | 0.349   |
| Period*Season | Period2010 winter - Period2010 summer | 0          | -0.738   | 0.582 | 41 | -1.269 | 0.423   |
| Period*Season | Period2010 winter - Period1980 fall   | 0          | -1.670   | 0.602 | 41 | -2.777 | 0.104   |
| Period*Season | Period2010 winter - Period2010 fall   | 0          | -0.333   | 0.602 | 41 | -0.554 | 0.742   |
| Period*Season | Period1980 spring - Period2010 spring | 0          | -0.861   | 0.574 | 41 | -1.502 | 0.359   |
| Period*Season | Period1980 spring - Period1980 summer | 0          | -0.767   | 0.553 | 41 | -1.387 | 0.383   |
| Period*Season | Period1980 spring - Period2010 summer | 0          | -0.592   | 0.553 | 41 | -1.072 | 0.468   |
| Period*Season | Period1980 spring - Period1980 fall   | 0          | -1.525   | 0.574 | 41 | -2.658 | 0.104   |
| Period*Season | Period1980 spring - Period2010 fall   | 0          | -0.187   | 0.574 | 41 | -0.327 | 0.835   |
| Period*Season | Period2010 spring - Period1980 summer | 0          | 0.095    | 0.553 | 41 | 0.171  | 0.865   |
| Period*Season | Period2010 spring - Period2010 summer | 0          | 0.269    | 0.553 | 41 | 0.487  | 0.766   |
| Period*Season | Period2010 spring - Period1980 fall   | 0          | -0.663   | 0.574 | 41 | -1.157 | 0.445   |
| Period*Season | Period2010 spring - Period2010 fall   | 0          | 0.674    | 0.574 | 41 | 1.175  | 0.445   |
| Period*Season | Period1980 summer - Period2010 summer | 0          | 0.174    | 0.531 | 41 | 0.328  | 0.835   |
| Period*Season | Period1980 summer - Period1980 fall   | 0          | -0.758   | 0.553 | 41 | -1.372 | 0.383   |
| Period*Season | Period1980 summer - Period2010 fall   | 0          | 0.579    | 0.553 | 41 | 1.048  | 0.468   |
| Period*Season | Period2010 summer - Period1980 fall   | 0          | -0.932   | 0.553 | 41 | -1.687 | 0.334   |
| Period*Season | Period2010 summer - Period2010 fall   | 0          | 0.405    | 0.553 | 41 | 0.733  | 0.655   |
| Period*Season | Period1980 fall - Period2010 fall     | 0          | 1.337    | 0.574 | 41 | 2.331  | 0.173   |

Table 15: Effect sizes for the pairwise contrasts by season in the density ANOVA.

| Contrast          | Cohen's d | SE    | df | CI Lower | CI Upper |
|-------------------|-----------|-------|----|----------|----------|
| (winter - spring) | -0.675    | 0.424 | 41 | -1.531   | 0.182    |
| (winter - summer) | -0.925    | 0.416 | 41 | -1.765   | -0.086   |
| (winter - fall)   | -1.103    | 0.435 | 41 | -1.981   | -0.225   |
| (spring - summer) | -0.250    | 0.394 | 41 | -1.047   | 0.546    |
| (spring - fall)   | -0.428    | 0.411 | 41 | -1.258   | 0.402    |
| (summer - fall)   | -0.178    | 0.394 | 41 | -0.973   | 0.618    |

Table 16: Effect sizes for the pairwise contrasts by period and season in the density ANOVA.

| Contrast                                | Cohen's d | SE    | df | CI Lower | CI Upper |
|---|-----------|-------|----|----------|----------|
| (Period1980 winter - Period2010 winter) | -0.173    | 0.606 | 41 | -1.397   | 1.050    |
| (Period1980 winter - Period1980 spring) | -0.320    | 0.578 | 41 | -1.488   | 0.848    |
| (Period1980 winter - Period2010 spring) | -1.187    | 0.592 | 41 | -2.383   | 0.009    |
| (Period1980 winter - Period1980 summer) | -1.091    | 0.569 | 41 | -2.241   | 0.058    |
| (Period1980 winter - Period2010 summer) | -0.916    | 0.565 | 41 | -2.058   | 0.226    |
| (Period1980 winter - Period1980 fall)   | -1.855    | 0.613 | 41 | -3.092   | -0.617   |
| (Period1980 winter - Period2010 fall)   | -0.509    | 0.580 | 41 | -1.680   | 0.663    |
| (Period2010 winter - Period1980 spring) | -0.147    | 0.606 | 41 | -1.370   | 1.077    |
| (Period2010 winter - Period2010 spring) | -1.014    | 0.616 | 41 | -2.257   | 0.230    |
| (Period2010 winter - Period1980 summer) | -0.918    | 0.594 | 41 | -2.118   | 0.282    |
| (Period2010 winter - Period2010 summer) | -0.743    | 0.591 | 41 | -1.937   | 0.451    |
| (Period2010 winter - Period1980 fall)   | -1.681    | 0.633 | 41 | -2.960   | -0.402   |
| (Period2010 winter - Period2010 fall)   | -0.335    | 0.607 | 41 | -1.561   | 0.890    |
| (Period1980 spring - Period2010 spring) | -0.867    | 0.585 | 41 | -2.049   | 0.315    |
| (Period1980 spring - Period1980 summer) | -0.772    | 0.563 | 41 | -1.908   | 0.365    |
| (Period1980 spring - Period2010 summer) | -0.596    | 0.560 | 41 | -1.728   | 0.535    |
| (Period1980 spring - Period1980 fall)   | -1.535    | 0.602 | 41 | -2.750   | -0.319   |
| (Period1980 spring - Period2010 fall)   | -0.189    | 0.578 | 41 | -1.355   | 0.978    |
| (Period2010 spring - Period1980 summer) | 0.095     | 0.556 | 41 | -1.028   | 1.219    |
| (Period2010 spring - Period2010 summer) | 0.271     | 0.557 | 41 | -0.855   | 1.396    |
| (Period2010 spring - Period1980 fall)   | -0.668    | 0.582 | 41 | -1.843   | 0.508    |
| (Period2010 spring - Period2010 fall)   | 0.678     | 0.582 | 41 | -0.498   | 1.854    |
| (Period1980 summer - Period2010 summer) | 0.175     | 0.535 | 41 | -0.905   | 1.255    |
| (Period1980 summer - Period1980 fall)   | -0.763    | 0.563 | 41 | -1.899   | 0.373    |
| (Period1980 summer - Period2010 fall)   | 0.583     | 0.560 | 41 | -0.548   | 1.714    |
| (Period2010 summer - Period1980 fall)   | -0.938    | 0.566 | 41 | -2.081   | 0.205    |
| (Period2010 summer - Period2010 fall)   | 0.408     | 0.558 | 41 | -0.720   | 1.535    |
| (Period1980 fall - Period2010 fall)     | 1.346     | 0.596 | 41 | 0.142    | 2.550    |

## Consumer & Predators ANOVAs

Biomass and density values were subset and summed for consumer and predator taxa. Biomass and density were then compared by sampling period, season, and the interaction using an ANOVA with Type II sums-of-squares. ANOVA assumptions were inspected graphically using `check_model()`, and effect sizes for the ANOVAs were calculated as  $\eta_P^2$  using `eta_squared()`. Pairwise contrasts between influential factors were performed using `emmeans()`, with effect sizes for contrasts calculated as Cohen's d.

```
## Subset data to only include consumer taxa
# Biomass
consumer.biomass <- invertibrate.biomass.matrix[, 1:46] %>%
  rowSums()
consumer.biomass.data <- tibble(sampling.info, consumer.biomass)

# Density
consumer.density <- invertibrate.density.matrix[, 1:46] %>%
  rowSums()
consumer.density.data <- tibble(sampling.info, consumer.density)

## Subset data to only include predator taxa
# Biomass
predator.biomass <- invertibrate.biomass.matrix[, 47:72] %>%
  rowSums()
predator.biomass.data <- tibble(sampling.info, predator.biomass)

# Density
predator.density <- invertibrate.density.matrix[, 47:72] %>%
  rowSums()
predator.density.data <- tibble(sampling.info, predator.density)
```

## Consumer ANOVAs

### Biomass ANOVA

```
consumer.biomass.anova <- lm(  
  consumer.biomass ~ Period * Season, data = consumer.biomass.data  
)
```

```
check_model(consumer.biomass.anova)
```

Table 17: ANOVA results for consumer biomass by period, season, and the interaction.

|               | Sums-of-Squares | df | F      | P-value |
|---------------|-----------------|----|--------|---------|
| Period        | 214935664       | 1  | 10.005 | 0.003   |
| Season        | 113765041       | 3  | 1.765  | 0.169   |
| Period:Season | 158830701       | 3  | 2.465  | 0.076   |
| Residuals     | 880756410       | 41 | NA     | NA      |

Table 18: Table of the effect sizes in the consumer biomass ANOVA.

| Term          | Eta-squared | CI   | CI Low | CI High |
|---------------|-------------|------|--------|---------|
| Period        | 0.196       | 0.95 | 0.046  | 1       |
| Season        | 0.114       | 0.95 | 0.000  | 1       |
| Period:Season | 0.153       | 0.95 | 0.000  | 1       |

Table 19: Estimated marginal means by period in the consumer biomass ANOVA.

| Period | Estimate | SE      | df | t     | P-value |
|--------|----------|---------|----|-------|---------|
| 1980   | 8195.969 | 926.971 | 41 | 8.842 | 0       |
| 2010   | 4080.589 | 946.085 | 41 | 4.313 | 0       |

Table 20: Estimated marginal means by period and season in the consumer biomass ANOVA.

| Period | Season | Estimate  | SE       | df | t     | P-value |
|--------|--------|-----------|----------|----|-------|---------|
| 1980   | winter | 5168.723  | 1892.171 | 41 | 2.732 | 0.009   |
| 2010   | winter | 3555.710  | 2072.769 | 41 | 1.715 | 0.094   |
| 1980   | spring | 4815.356  | 1892.171 | 41 | 2.545 | 0.015   |
| 2010   | spring | 5075.846  | 1892.171 | 41 | 2.683 | 0.010   |
| 1980   | summer | 9827.673  | 1751.810 | 41 | 5.610 | 0.000   |
| 2010   | summer | 4003.295  | 1751.810 | 41 | 2.285 | 0.028   |
| 1980   | fall   | 12700.172 | 1892.171 | 41 | 6.712 | 0.000   |
| 2010   | fall   | 3612.908  | 1892.171 | 41 | 1.909 | 0.063   |

Table 21: Pairwise contrasts by period in the consumer biomass ANOVA.

| Term   | Contrast                | Null Value | Estimate | SE      | df | t     | P-value |
|--------|-------------------------|------------|----------|---------|----|-------|---------|
| Period | Period1980 - Period2010 | 0          | 4115.38  | 1324.52 | 41 | 3.107 | 0.003   |

Table 22: Pairwise contrasts by period and season in the consumer biomass ANOVA.

| Term          | Contrast                              | Null Value | Estimate  | SE       | df | t      | P-value |
|---------------|---------------------------------------|------------|-----------|----------|----|--------|---------|
| Period*Season | Period1980 winter - Period2010 winter | 0          | 1613.012  | 2806.543 | 41 | 0.575  | 0.906   |
| Period*Season | Period1980 winter - Period1980 spring | 0          | 353.366   | 2675.934 | 41 | 0.132  | 0.984   |
| Period*Season | Period1980 winter - Period2010 spring | 0          | 92.877    | 2675.934 | 41 | 0.035  | 0.984   |
| Period*Season | Period1980 winter - Period1980 summer | 0          | -4658.950 | 2578.594 | 41 | -1.807 | 0.182   |
| Period*Season | Period1980 winter - Period2010 summer | 0          | 1165.428  | 2578.594 | 41 | 0.452  | 0.906   |
| Period*Season | Period1980 winter - Period1980 fall   | 0          | -7531.450 | 2675.934 | 41 | -2.815 | 0.035   |
| Period*Season | Period1980 winter - Period2010 fall   | 0          | 1555.815  | 2675.934 | 41 | 0.581  | 0.906   |
| Period*Season | Period2010 winter - Period1980 spring | 0          | -1259.646 | 2806.543 | 41 | -0.449 | 0.906   |
| Period*Season | Period2010 winter - Period2010 spring | 0          | -1520.136 | 2806.543 | 41 | -0.542 | 0.906   |
| Period*Season | Period2010 winter - Period1980 summer | 0          | -6271.963 | 2713.892 | 41 | -2.311 | 0.081   |
| Period*Season | Period2010 winter - Period2010 summer | 0          | -447.585  | 2713.892 | 41 | -0.165 | 0.984   |
| Period*Season | Period2010 winter - Period1980 fall   | 0          | -9144.462 | 2806.543 | 41 | -3.258 | 0.021   |
| Period*Season | Period2010 winter - Period2010 fall   | 0          | -57.198   | 2806.543 | 41 | -0.020 | 0.984   |
| Period*Season | Period1980 spring - Period2010 spring | 0          | -260.489  | 2675.934 | 41 | -0.097 | 0.984   |
| Period*Season | Period1980 spring - Period1980 summer | 0          | -5012.316 | 2578.594 | 41 | -1.944 | 0.165   |
| Period*Season | Period1980 spring - Period2010 summer | 0          | 812.061   | 2578.594 | 41 | 0.315  | 0.960   |
| Period*Season | Period1980 spring - Period1980 fall   | 0          | -7884.816 | 2675.934 | 41 | -2.947 | 0.035   |
| Period*Season | Period1980 spring - Period2010 fall   | 0          | 1202.449  | 2675.934 | 41 | 0.449  | 0.906   |
| Period*Season | Period2010 spring - Period1980 summer | 0          | -4751.827 | 2578.594 | 41 | -1.843 | 0.182   |
| Period*Season | Period2010 spring - Period2010 summer | 0          | 1072.551  | 2578.594 | 41 | 0.416  | 0.906   |
| Period*Season | Period2010 spring - Period1980 fall   | 0          | -7624.327 | 2675.934 | 41 | -2.849 | 0.035   |
| Period*Season | Period2010 spring - Period2010 fall   | 0          | 1462.938  | 2675.934 | 41 | 0.547  | 0.906   |
| Period*Season | Period1980 summer - Period2010 summer | 0          | 5824.378  | 2477.433 | 41 | 2.351  | 0.081   |
| Period*Season | Period1980 summer - Period1980 fall   | 0          | -2872.500 | 2578.594 | 41 | -1.114 | 0.585   |
| Period*Season | Period1980 summer - Period2010 fall   | 0          | 6214.765  | 2578.594 | 41 | 2.410  | 0.081   |
| Period*Season | Period2010 summer - Period1980 fall   | 0          | -8696.877 | 2578.594 | 41 | -3.373 | 0.021   |
| Period*Season | Period2010 summer - Period2010 fall   | 0          | 390.387   | 2578.594 | 41 | 0.151  | 0.984   |
| Period*Season | Period1980 fall - Period2010 fall     | 0          | 9087.265  | 2675.934 | 41 | 3.396  | 0.021   |



Table 23: Effect sizes for the pairwise contrasts by period in the consumer biomass ANOVA.

| Contrast                  | Cohen's d | SE    | df | CI Lower | CI Upper |
|---------------------------|-----------|-------|----|----------|----------|
| (Period1980 - Period2010) | 0.888     | 0.302 | 41 | 0.278    | 1.498    |

Table 24: Effect sizes for the pairwise contrasts by period and season in the consumer biomass ANOVA.

| Contrast                                | Cohen's d | SE    | df | CI Lower | CI Upper |
|---|-----------|-------|----|----------|----------|
| (Period1980 winter - Period2010 winter) | 0.348     | 0.607 | 41 | -0.877   | 1.573    |
| (Period1980 winter - Period1980 spring) | 0.076     | 0.577 | 41 | -1.090   | 1.242    |
| (Period1980 winter - Period2010 spring) | 0.020     | 0.577 | 41 | -1.146   | 1.186    |
| (Period1980 winter - Period1980 summer) | -1.005    | 0.567 | 41 | -2.151   | 0.141    |
| (Period1980 winter - Period2010 summer) | 0.251     | 0.557 | 41 | -0.874   | 1.376    |
| (Period1980 winter - Period1980 fall)   | -1.625    | 0.605 | 41 | -2.846   | -0.404   |
| (Period1980 winter - Period2010 fall)   | 0.336     | 0.579 | 41 | -0.833   | 1.504    |
| (Period2010 winter - Period1980 spring) | -0.272    | 0.606 | 41 | -1.496   | 0.953    |
| (Period2010 winter - Period2010 spring) | -0.328    | 0.607 | 41 | -1.553   | 0.897    |
| (Period2010 winter - Period1980 summer) | -1.353    | 0.604 | 41 | -2.574   | -0.133   |
| (Period2010 winter - Period2010 summer) | -0.097    | 0.586 | 41 | -1.279   | 1.086    |
| (Period2010 winter - Period1980 fall)   | -1.973    | 0.644 | 41 | -3.273   | -0.673   |
| (Period2010 winter - Period2010 fall)   | -0.012    | 0.606 | 41 | -1.235   | 1.211    |
| (Period1980 spring - Period2010 spring) | -0.056    | 0.577 | 41 | -1.222   | 1.110    |
| (Period1980 spring - Period1980 summer) | -1.081    | 0.569 | 41 | -2.231   | 0.068    |
| (Period1980 spring - Period2010 summer) | 0.175     | 0.557 | 41 | -0.949   | 1.299    |
| (Period1980 spring - Period1980 fall)   | -1.701    | 0.607 | 41 | -2.927   | -0.475   |
| (Period1980 spring - Period2010 fall)   | 0.259     | 0.578 | 41 | -0.908   | 1.427    |
| (Period2010 spring - Period1980 summer) | -1.025    | 0.568 | 41 | -2.172   | 0.121    |
| (Period2010 spring - Period2010 summer) | 0.231     | 0.557 | 41 | -0.893   | 1.356    |
| (Period2010 spring - Period1980 fall)   | -1.645    | 0.605 | 41 | -2.867   | -0.423   |
| (Period2010 spring - Period2010 fall)   | 0.316     | 0.578 | 41 | -0.852   | 1.484    |
| (Period1980 summer - Period2010 summer) | 1.257     | 0.552 | 41 | 0.141    | 2.372    |
| (Period1980 summer - Period1980 fall)   | -0.620    | 0.561 | 41 | -1.752   | 0.512    |
| (Period1980 summer - Period2010 fall)   | 1.341     | 0.576 | 41 | 0.178    | 2.504    |
| (Period2010 summer - Period1980 fall)   | -1.876    | 0.594 | 41 | -3.075   | -0.677   |
| (Period2010 summer - Period2010 fall)   | 0.084     | 0.556 | 41 | -1.039   | 1.208    |
| (Period1980 fall - Period2010 fall)     | 1.961     | 0.617 | 41 | 0.715    | 3.206    |

## Density ANOVA

```
consumer.density.anova <- lm(
  log(consumer.density) ~ Period * Season, data = consumer.density.data
)
```

```
check_model(consumer.density.anova)
```

Table 25: ANOVA results for consumer density by period, season, and the interaction.

|               | Sums-of-Squares | df | F     | P-value |
|---------------|-----------------|----|-------|---------|
| Period        | 0.269           | 1  | 0.271 | 0.605   |
| Season        | 8.236           | 3  | 2.768 | 0.054   |
| Period:Season | 7.867           | 3  | 2.644 | 0.062   |
| Residuals     | 40.666          | 41 | NA    | NA      |

Table 26: Table of the effect sizes in the consumer density ANOVA.

| Term          | Eta-squared | CI   | CI Low | CI High |
|---------------|-------------|------|--------|---------|
| Period        | 0.007       | 0.95 | 0      | 1       |
| Season        | 0.168       | 0.95 | 0      | 1       |
| Period:Season | 0.162       | 0.95 | 0      | 1       |

Table 27: Estimated marginal means by season in the consumer density ANOVA.

| Season | Estimate | SE    | df | t      | P-value |
|--------|----------|-------|----|--------|---------|
| winter | 10.317   | 0.300 | 41 | 34.358 | 0       |
| spring | 11.008   | 0.287 | 41 | 38.290 | 0       |
| summer | 11.261   | 0.266 | 41 | 42.308 | 0       |
| fall   | 11.417   | 0.287 | 41 | 39.711 | 0       |

Table 28: Estimated marginal means by period and season in the consumer density ANOVA.

| Period | Season | Estimate | SE    | df | t      | P-value |
|--------|--------|----------|-------|----|--------|---------|
| 1980   | winter | 10.244   | 0.407 | 41 | 25.196 | 0       |
| 2010   | winter | 10.404   | 0.445 | 41 | 23.360 | 0       |
| 1980   | spring | 10.580   | 0.407 | 41 | 26.021 | 0       |
| 2010   | spring | 11.437   | 0.407 | 41 | 28.129 | 0       |
| 1980   | summer | 11.357   | 0.376 | 41 | 30.172 | 0       |
| 2010   | summer | 11.165   | 0.376 | 41 | 29.661 | 0       |
| 1980   | fall   | 12.108   | 0.407 | 41 | 29.780 | 0       |
| 2010   | fall   | 10.726   | 0.407 | 41 | 26.380 | 0       |

Table 29: Pairwise contrasts by season in the consumer density ANOVA.

| Term   | Contrast        | Null Value | Estimate | SE    | df | t      | P-value |
|--------|-----------------|------------|----------|-------|----|--------|---------|
| Season | winter - spring | 0          | -0.691   | 0.416 | 41 | -1.663 | 0.208   |
| Season | winter - summer | 0          | -0.944   | 0.401 | 41 | -2.353 | 0.070   |
| Season | winter - fall   | 0          | -1.100   | 0.416 | 41 | -2.646 | 0.069   |
| Season | spring - summer | 0          | -0.253   | 0.392 | 41 | -0.646 | 0.626   |
| Season | spring - fall   | 0          | -0.409   | 0.407 | 41 | -1.005 | 0.481   |
| Season | summer - fall   | 0          | -0.156   | 0.392 | 41 | -0.397 | 0.693   |

Table 30: Pairwise contrasts by period and season in the consumer density ANOVA.

| Term          | Contrast                              | Null Value | Estimate | SE    | df | t      | P-value |
|---------------|---------------------------------------|------------|----------|-------|----|--------|---------|
| Period*Season | Period1980 winter - Period2010 winter | 0          | -0.160   | 0.603 | 41 | -0.266 | 0.831   |
| Period*Season | Period1980 winter - Period1980 spring | 0          | -0.336   | 0.575 | 41 | -0.584 | 0.750   |
| Period*Season | Period1980 winter - Period2010 spring | 0          | -1.193   | 0.575 | 41 | -2.074 | 0.239   |
| Period*Season | Period1980 winter - Period1980 summer | 0          | -1.113   | 0.554 | 41 | -2.009 | 0.239   |
| Period*Season | Period1980 winter - Period2010 summer | 0          | -0.921   | 0.554 | 41 | -1.662 | 0.308   |
| Period*Season | Period1980 winter - Period1980 fall   | 0          | -1.864   | 0.575 | 41 | -3.241 | 0.066   |
| Period*Season | Period1980 winter - Period2010 fall   | 0          | -0.481   | 0.575 | 41 | -0.837 | 0.600   |
| Period*Season | Period2010 winter - Period1980 spring | 0          | -0.175   | 0.603 | 41 | -0.291 | 0.831   |
| Period*Season | Period2010 winter - Period2010 spring | 0          | -1.032   | 0.603 | 41 | -1.712 | 0.308   |
| Period*Season | Period2010 winter - Period1980 summer | 0          | -0.953   | 0.583 | 41 | -1.634 | 0.308   |
| Period*Season | Period2010 winter - Period2010 summer | 0          | -0.761   | 0.583 | 41 | -1.304 | 0.399   |
| Period*Season | Period2010 winter - Period1980 fall   | 0          | -1.704   | 0.603 | 41 | -2.825 | 0.102   |
| Period*Season | Period2010 winter - Period2010 fall   | 0          | -0.321   | 0.603 | 41 | -0.533 | 0.760   |
| Period*Season | Period1980 spring - Period2010 spring | 0          | -0.857   | 0.575 | 41 | -1.490 | 0.366   |
| Period*Season | Period1980 spring - Period1980 summer | 0          | -0.778   | 0.554 | 41 | -1.404 | 0.392   |
| Period*Season | Period1980 spring - Period2010 summer | 0          | -0.585   | 0.554 | 41 | -1.056 | 0.462   |
| Period*Season | Period1980 spring - Period1980 fall   | 0          | -1.528   | 0.575 | 41 | -2.658 | 0.104   |
| Period*Season | Period1980 spring - Period2010 fall   | 0          | -0.146   | 0.575 | 41 | -0.254 | 0.831   |
| Period*Season | Period2010 spring - Period1980 summer | 0          | 0.079    | 0.554 | 41 | 0.143  | 0.887   |
| Period*Season | Period2010 spring - Period2010 summer | 0          | 0.272    | 0.554 | 41 | 0.490  | 0.763   |
| Period*Season | Period2010 spring - Period1980 fall   | 0          | -0.671   | 0.575 | 41 | -1.167 | 0.429   |
| Period*Season | Period2010 spring - Period2010 fall   | 0          | 0.711    | 0.575 | 41 | 1.237  | 0.417   |
| Period*Season | Period1980 summer - Period2010 summer | 0          | 0.193    | 0.532 | 41 | 0.362  | 0.831   |
| Period*Season | Period1980 summer - Period1980 fall   | 0          | -0.750   | 0.554 | 41 | -1.354 | 0.394   |
| Period*Season | Period1980 summer - Period2010 fall   | 0          | 0.632    | 0.554 | 41 | 1.140  | 0.429   |
| Period*Season | Period2010 summer - Period1980 fall   | 0          | -0.943   | 0.554 | 41 | -1.702 | 0.308   |
| Period*Season | Period2010 summer - Period2010 fall   | 0          | 0.439    | 0.554 | 41 | 0.793  | 0.605   |
| Period*Season | Period1980 fall - Period2010 fall     | 0          | 1.382    | 0.575 | 41 | 2.404  | 0.146   |

Table 31: Effect sizes for the pairwise contrasts by season in the consumer density ANOVA.

| Contrast          | Cohen's d | SE    | df | CI Lower | CI Upper |
|-------------------|-----------|-------|----|----------|----------|
| (winter - spring) | -0.694    | 0.424 | 41 | -1.551   | 0.163    |
| (winter - summer) | -0.948    | 0.416 | 41 | -1.789   | -0.107   |
| (winter - fall)   | -1.104    | 0.435 | 41 | -1.983   | -0.226   |
| (spring - summer) | -0.254    | 0.394 | 41 | -1.051   | 0.542    |
| (spring - fall)   | -0.410    | 0.411 | 41 | -1.240   | 0.419    |
| (summer - fall)   | -0.156    | 0.394 | 41 | -0.951   | 0.639    |

Table 32: Effect sizes for the pairwise contrasts by period and season in the consumer density ANOVA.

| Contrast                                | Cohen's d | SE    | df | CI Lower | CI Upper |
|---|-----------|-------|----|----------|----------|
| (Period1980 winter - Period2010 winter) | -0.161    | 0.606 | 41 | -1.384   | 1.063    |
| (Period1980 winter - Period1980 spring) | -0.337    | 0.579 | 41 | -1.505   | 0.831    |
| (Period1980 winter - Period2010 spring) | -1.197    | 0.592 | 41 | -2.394   | -0.001   |
| (Period1980 winter - Period1980 summer) | -1.118    | 0.570 | 41 | -2.269   | 0.033    |
| (Period1980 winter - Period2010 summer) | -0.925    | 0.566 | 41 | -2.067   | 0.218    |
| (Period1980 winter - Period1980 fall)   | -1.871    | 0.613 | 41 | -3.110   | -0.633   |
| (Period1980 winter - Period2010 fall)   | -0.483    | 0.580 | 41 | -1.654   | 0.688    |
| (Period2010 winter - Period1980 spring) | -0.176    | 0.606 | 41 | -1.400   | 1.047    |
| (Period2010 winter - Period2010 spring) | -1.037    | 0.616 | 41 | -2.281   | 0.208    |
| (Period2010 winter - Period1980 summer) | -0.957    | 0.595 | 41 | -2.159   | 0.245    |
| (Period2010 winter - Period2010 summer) | -0.764    | 0.592 | 41 | -1.958   | 0.431    |
| (Period2010 winter - Period1980 fall)   | -1.711    | 0.634 | 41 | -2.992   | -0.430   |
| (Period2010 winter - Period2010 fall)   | -0.323    | 0.607 | 41 | -1.548   | 0.902    |
| (Period1980 spring - Period2010 spring) | -0.860    | 0.585 | 41 | -2.042   | 0.321    |
| (Period1980 spring - Period1980 summer) | -0.781    | 0.563 | 41 | -1.918   | 0.356    |
| (Period1980 spring - Period2010 summer) | -0.588    | 0.560 | 41 | -1.719   | 0.544    |
| (Period1980 spring - Period1980 fall)   | -1.535    | 0.602 | 41 | -2.750   | -0.319   |
| (Period1980 spring - Period2010 fall)   | -0.146    | 0.578 | 41 | -1.313   | 1.020    |
| (Period2010 spring - Period1980 summer) | 0.080     | 0.556 | 41 | -1.044   | 1.203    |
| (Period2010 spring - Period2010 summer) | 0.273     | 0.557 | 41 | -0.852   | 1.398    |
| (Period2010 spring - Period1980 fall)   | -0.674    | 0.582 | 41 | -1.850   | 0.502    |
| (Period2010 spring - Period2010 fall)   | 0.714     | 0.583 | 41 | -0.463   | 1.891    |
| (Period1980 summer - Period2010 summer) | 0.193     | 0.535 | 41 | -0.887   | 1.274    |
| (Period1980 summer - Period1980 fall)   | -0.754    | 0.563 | 41 | -1.890   | 0.383    |
| (Period1980 summer - Period2010 fall)   | 0.634     | 0.561 | 41 | -0.498   | 1.767    |
| (Period2010 summer - Period1980 fall)   | -0.947    | 0.566 | 41 | -2.090   | 0.196    |
| (Period2010 summer - Period2010 fall)   | 0.441     | 0.558 | 41 | -0.687   | 1.569    |
| (Period1980 fall - Period2010 fall)     | 1.388     | 0.597 | 41 | 0.182    | 2.594    |

## Predator ANOVAs

### Biomass ANOVA

```
predator.biomass.anova <- lm(  
  log(predator.biomass) ~ Period * Season, data = predator.biomass.data  
)
```

```
check_model(predator.biomass.anova)
```

Table 33: ANOVA results for predator biomass by period, season, and the interaction.

|               | Sums-of-Squares | df | F     | P-value |
|---------------|-----------------|----|-------|---------|
| Period        | 0.145           | 1  | 0.076 | 0.784   |
| Season        | 12.100          | 3  | 2.121 | 0.112   |
| Period:Season | 2.442           | 3  | 0.428 | 0.734   |
| Residuals     | 77.975          | 41 | NA    | NA      |

Table 34: Table of the effect sizes in the predator biomass ANOVA.

| Term          | Eta-squared | CI   | CI Low | CI High |
|---------------|-------------|------|--------|---------|
| Period        | 0.002       | 0.95 | 0      | 1       |
| Season        | 0.134       | 0.95 | 0      | 1       |
| Period:Season | 0.030       | 0.95 | 0      | 1       |

Table 35: Estimated marginal means of season in the predator biomass ANOVA.

| Season | Estimate | SE    | df | t      | P-value |
|--------|----------|-------|----|--------|---------|
| winter | 5.819    | 0.416 | 41 | 13.995 | 0       |
| spring | 6.870    | 0.398 | 41 | 17.258 | 0       |
| summer | 6.781    | 0.369 | 41 | 18.398 | 0       |
| fall   | 7.220    | 0.398 | 41 | 18.135 | 0       |

Table 36: Pairwise contrasts by season in the predator biomass ANOVA.

| Term   | Contrast        | Null Value | Estimate | SE    | df | t      | P-value |
|--------|-----------------|------------|----------|-------|----|--------|---------|
| Season | winter - spring | 0          | -1.051   | 0.576 | 41 | -1.826 | 0.182   |
| Season | winter - summer | 0          | -0.962   | 0.556 | 41 | -1.731 | 0.182   |
| Season | winter - fall   | 0          | -1.400   | 0.576 | 41 | -2.433 | 0.117   |
| Season | spring - summer | 0          | 0.089    | 0.543 | 41 | 0.164  | 0.870   |
| Season | spring - fall   | 0          | -0.349   | 0.563 | 41 | -0.621 | 0.646   |
| Season | summer - fall   | 0          | -0.439   | 0.543 | 41 | -0.808 | 0.635   |

Table 37: Effect sizes for the pairwise contrasts by season in the predator biomass ANOVA.

| Contrast          | Cohen's d | SE    | df | CI Lower | CI Upper |
|-------------------|-----------|-------|----|----------|----------|
| (winter - spring) | -0.762    | 0.426 | 41 | -1.622   | 0.098    |
| (winter - summer) | -0.697    | 0.410 | 41 | -1.526   | 0.131    |
| (winter - fall)   | -1.015    | 0.432 | 41 | -1.888   | -0.143   |
| (spring - summer) | 0.065     | 0.393 | 41 | -0.730   | 0.859    |
| (spring - fall)   | -0.253    | 0.409 | 41 | -1.080   | 0.573    |
| (summer - fall)   | -0.318    | 0.395 | 41 | -1.116   | 0.480    |

## Density ANOVA

```
predator.density.anova <- lm(
  log(predator.density) ~ Period * Season, data = predator.density.data
)
```

```
check_model(predator.density.anova)
```

Table 38: ANOVA results for predator density by period, season, and the interaction.

|               | Sums-of-Squares | df | F     | P-value |
|---------------|-----------------|----|-------|---------|
| Period        | 7.688           | 1  | 5.651 | 0.022   |
| Season        | 3.138           | 3  | 0.769 | 0.518   |
| Period:Season | 1.308           | 3  | 0.320 | 0.811   |
| Residuals     | 55.780          | 41 | NA    | NA      |

Table 39: Table of the effect sizes in the predator density ANOVA.

| Term          | Eta-squared | CI   | CI Low | CI High |
|---------------|-------------|------|--------|---------|
| Period        | 0.121       | 0.95 | 0.01   | 1       |
| Season        | 0.053       | 0.95 | 0.00   | 1       |
| Period:Season | 0.023       | 0.95 | 0.00   | 1       |

Table 40: Estimated marginal means of period in the predator density ANOVA.

| Period | Estimate | SE    | df | t      | P-value |
|--------|----------|-------|----|--------|---------|
| 1980   | 6.889    | 0.233 | 41 | 29.531 | 0       |
| 2010   | 7.689    | 0.238 | 41 | 32.293 | 0       |

Table 41: Pairwise contrasts between period in the predator density ANOVA.

| Term   | Contrast                | Null Value | Estimate | SE    | df | t      | P-value |
|--------|-------------------------|------------|----------|-------|----|--------|---------|
| Period | Period1980 - Period2010 | 0          | -0.799   | 0.333 | 41 | -2.398 | 0.021   |



Table 42: Effect sizes for the pairwise contrasts by period in the predator density ANOVA.

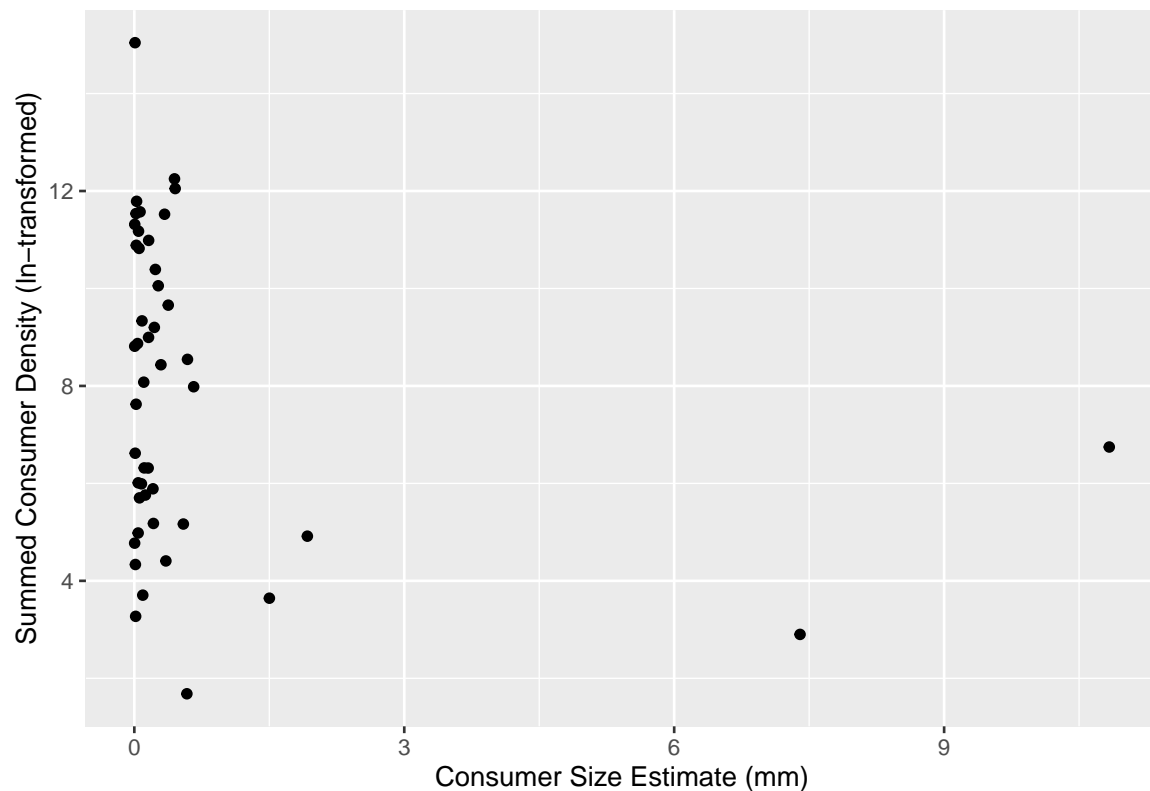
| Contrast                  | Cohen's d | SE    | df | CI Lower | CI Upper |
|---------------------------|-----------|-------|----|----------|----------|
| (Period1980 - Period2010) | -0.685    | 0.296 | 41 | -1.282   | -0.088   |

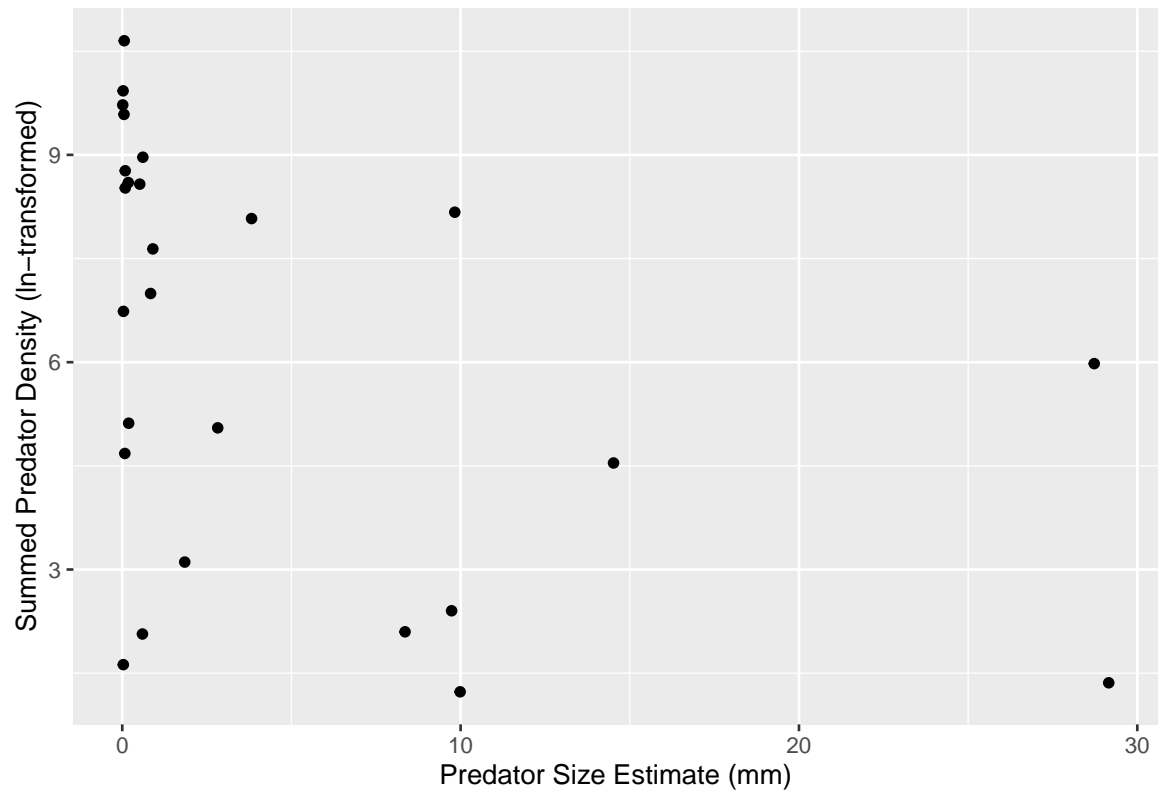
## Size Groupings

Body sizes were plotted to estimate size groupings. For each taxon, we calculated mean body mass across time periods by dividing total biomass by total abundance. Primary consumers were classified as Small: 0 – 0.4 mg, Medium: 0.41 – 1.0 mg, and Large: 1.1 – 12.0 mg. Predators were classified as Small: 0 – 5.0 mg, Medium: 5.1 – 15.0 mg, and Large: 15.1 – 30.0 mg.

```
## Define size classes
# Consumers
consumer.summed.biomass <- colSums(invertebrate.biomass.matrix[, 1:46])
consumer.summed.density <- colSums(invertebrate.density.matrix[, 1:46])
consumer.size.estimates <- consumer.summed.biomass/consumer.summed.density
consumer.size.data <- tibble(
  consumer.summed.biomass, consumer.summed.density, consumer.size.estimates
)

# Predators
predator.summed.biomass <- colSums(invertebrate.biomass.matrix[, 47:72])
predator.summed.density <- colSums(invertebrate.density.matrix[, 47:72])
predator.size.estimates <- predator.summed.biomass/predator.summed.density
predator.size.data <- tibble(
  predator.summed.biomass, predator.summed.density, predator.size.estimates
)
```





```
## Divide groups up by size as per plot groupings
# Consumers
consumer.size.groups <- cut(
  consumer.size.data$consumer.size.estimates, c(0, 0.4, 1.0, 12.0, Inf),
  right = FALSE
)
consumer.size.data$size.group <- as.numeric(consumer.size.groups)

# Predators
predator.size.groups <- cut(
  predator.size.data$predator.size.estimates, c(0, 5, 15, 30, Inf),
  right = FALSE
)
predator.size.data$size.group <- as.numeric(predator.size.groups)
```

## Biomass Change

We numerically evaluated changes in biomass by size groupings for consumers and predators.

### Consumers

Consumer taxa within each size grouping:

- Group 1: Amphinemura, Ancyronyx, Baetidae, Baetisca, Brachycentrus, Caenidae, Cheumatopsyche, Chironomidae, Crambidae, Cynellus, Dubiraphia, Elmidae, Ephemerellidae, Ephemeroptera, Heptageniidae, Hydropsychidae, Isonychia, Isopoda, Lepidoptera, Leptoceridae, Leptophlebiidae, Limnephilidae, Macronychus, Microcylloepus, Nectopsyche, Nemouridae, Neureclipsis, Polycentropodidae, Psephenus, Simuliidae, Stenelmis, Taeniopteryx, Tipulidae, Triaenodes, Trichoptera, Tricorythodes
- Group 2: Chimarra, Ectopria, Hydropsyche, Macrostemum, Paraponyx, Shpsa
- Group 3: Ironoquia, Neargyractis, Pteronarcys, Pycnopsyche

```
## Consumer data management
# 1980s
consumer.biomass.1980s <- biomass.data %>%
  filter(Period == "1980") %>%
  select(Amphinemura:Tricorythodes) %>%
  mutate(summed_biomass = rowSums(.))

# Sum all biomass for the 1980s consumers
consumer.biomass.1980s.total.biomass <- sum(consumer.biomass.1980s$summed_biomass)
# Summed biomass = 204899.2

# 2010s
consumer.biomass.2010s <- biomass.data %>%
  filter(Period == "2010") %>%
  select(Amphinemura:Tricorythodes) %>%
  mutate(summed_biomass = rowSums(.))

# Sum all biomass for the 2010s consumers
consumer.biomass.2010s.total.biomass <- sum(consumer.biomass.2010s$summed_biomass)
# Summed biomass = 97934.14
```

```

## 1980s consumers group 1 taxa
group.1.consumer.biomass.1980s <- consumer.biomass.1980s %>%
  select(Amphinemura, Ancyronyx, Baetidae, Baetisca, Brachycentrus, Caenidae,
         Cheumatopsyche, Chironomidae, Crambidae, Cynellus, Dubiraphia, Elmidae,
         Ephemerellidae, Ephemeroptera, Heptageniidae, Hydropsychidae, Isonychia,
         Isopoda, Lepidoptera, Leptoceridae, Leptophlebiidae, Limnephilidae,
         Macronychus, Microcylloepus, Nectopsyche, Nemouridae, Neureclipsis,
         Polycentropodidae, Psephenus, Simuliidae, Stenelmis, Taeniopteryx,
         Tipulidae, Triaenodes, Trichoptera, Tricorythodes) %>%
  mutate(summed_biomass = rowSums(.))

## 1980s consumers group 1 total biomass
group.1.consumer.biomass.1980s.total.biomass <- sum(group.1.consumer.biomass.1980s$summed_biomass)
# Summed biomass = 78968.09

## 1980s consumers group 2 taxa
group.2.consumer.biomass.1980s <- consumer.biomass.1980s %>%
  select(Chimarra, Ectopria, Hydropsyche, Macrostemum, Paraponyx, Shippa) %>%
  mutate(summed_biomass = rowSums(.))

## 1980s consumers group 2 total biomass
group.2.consumer.biomass.1980s.total.biomass <- sum(group.2.consumer.biomass.1980s$summed_biomass)
# Summed biomass = 116946.4

## 1980s consumers group 3 taxa
group.3.consumer.biomass.1980s <- consumer.biomass.1980s %>%
  select(Ironoquia, Neargyractis, Pteronarcys, Pycnopsyche) %>%
  mutate(summed_biomass = rowSums(.))

## 1980s consumers group 3 total biomass
group.3.consumer.biomass.1980s.total.biomass <- sum(group.3.consumer.biomass.1980s$summed_biomass)
# Summed biomass = 8984.69

```

```

## 2010s consumers group 1 taxa
group.1.consumer.biomass.2010s <- consumer.biomass.2010s %>%
  select(Amphinemura, Ancyronyx, Baetidae, Baetisca, Brachycentrus, Caenidae,
         Cheumatopsyche, Chironomidae, Crambidae, Cynellus, Dubiraphia, Elmidae,
         Ephemerellidae, Ephemeroptera, Heptageniidae, Hydropsychidae, Isonychia,
         Isopoda, Lepidoptera, Leptoceridae, Leptophlebiidae, Limnephilidae,
         Macronychus, Microcylloepus, Nectopsyche, Nemouridae, Neureclipsis,
         Polycentropodidae, Psephenus, Simuliidae, Stenelmis, Taeniopteryx,
         Tipulidae, Triaenodes, Trichoptera, Tricorythodes) %>%
  mutate(summed_biomass = rowSums(.))

## 2010s consumers group 1 total biomass
group.1.consumer.biomass.2010s.total.biomass <- sum(group.1.consumer.biomass.2010s$summed_biomass)
# Summed biomass = 38115.6

## 2010s consumers group 2 taxa
group.2.consumer.biomass.2010s <- consumer.biomass.2010s %>%
  select(Chimarra, Ectopria, Hydropsyche, Macrostemum, Paraponyx, Shipsa) %>%
  mutate(summed_biomass = rowSums(.))

## 2010s consumers group 2 total biomass
group.2.consumer.biomass.2010s.total.biomass <- sum(group.2.consumer.biomass.2010s$summed_biomass)
# Summed biomass = 59127.29

## 2010s consumers group 3 taxa
group.3.consumer.biomass.2010s <- consumer.biomass.2010s %>%
  select(Ironoquia, Neargyractis, Pteronarcys, Pycnopsyche) %>%
  mutate(summed_biomass = rowSums(.))

## 2010s consumers group 3 total biomass
group.3.consumer.biomass.2010s.total.biomass <- sum(group.3.consumer.biomass.2010s$summed_biomass)
# Summed biomass = 691.2489

## 1980s Consumers (% of total biomass within sampling period)
(group.1.consumer.biomass.1980s.total.biomass/consumer.biomass.1980s.total.biomass)*100
# Group 1 = 38.54%
(group.2.consumer.biomass.1980s.total.biomass/consumer.biomass.1980s.total.biomass)*100
# Group 2 = 57.08%
(group.3.consumer.biomass.1980s.total.biomass/consumer.biomass.1980s.total.biomass)*100
# Group 3 = 4.38%

## 2010s Consumers
(group.1.consumer.biomass.2010s.total.biomass/consumer.biomass.2010s.total.biomass)*100
# Group 1 = 38.92%
(group.2.consumer.biomass.2010s.total.biomass/consumer.biomass.2010s.total.biomass)*100
# Group 2 = 60.37%
(group.3.consumer.biomass.2010s.total.biomass/consumer.biomass.2010s.total.biomass)*100
# Group 3 = 0.71%

```

## Predators

Predator taxa within each size grouping:

- Group 1: Acroneuria, Aeshnidae, Amphipoda, Anisoptera, Argia, Ceraclea, Ceratopogoninae, Ceratopogoninae, Coenagrionidae, Enallagma, Hemerodromia, Isoperla, Neoperla, Oecetis, Paragnetina, Perlesta, Perlidae, Perlodidae, Plecoptera
- Group 2: Aeshna, Boyeria, Corydalus, Hydroperla, Nasiaeschna
- Group 3: Helopicus, Neurocordulia

```
## Predator data management
# 1980s
predator.biomass.1980s <- biomass.data %>%
  filter(Period == "1980") %>%
  select(Acroneuria:Plecoptera) %>%
  mutate(summed_biomass = rowSums())

# Sum all biomass for the 1980s predators
predator.biomass.1980s.total.biomass <- sum(predator.biomass.1980s$summed_biomass)
# Summed biomass = 35683.48

# 2010s
predator.biomass.2010s <- biomass.data %>%
  filter(Period == "2010") %>%
  select(Acroneuria:Plecoptera) %>%
  mutate(summed_biomass = rowSums())

# Sum all biomass for the 2010s predators
predator.biomass.2010s.total.biomass <- sum(predator.biomass.2010s$summed_biomass)
# Summed biomass = 41286.46
```

```

## 1980s predators group 1 taxa
group.1.predator.biomass.1980s <- predator.biomass.1980s %>%
  select(Acroneuria, Aeshnidae, Amphipoda, Anisoptera, Argia, Ceraclea,
         Ceratopogoninae, Cernotina, Coenagrionidae, Enallagma, Hemerodromia,
         Isoperla, Neoperla, Oecetis, Paragnetina, Perlesta, Perlidae, Perlodidae, Plecoptera) %>%
  mutate(summed_biomass = rowSums(.))

## 1980s predators group 1 total biomass
group.1.predator.biomass.1980s.total.biomass <- sum(group.1.predator.biomass.1980s$summed_biomass)
# Summed biomass = 13214.15

## 1980s predators group 2 taxa
group.2.predator.biomass.1980s <- predator.biomass.1980s %>%
  select(Aeshna, Boyeria, Corydalus, Hydroperla, Nasiaeschna) %>%
  mutate(summed_biomass = rowSums(.))

## 1980s predators group 2 total biomass
group.2.predator.biomass.1980s.total.biomass <- sum(group.2.predator.biomass.1980s$summed_biomass)
# Summed biomass = 17395.72

## 1980s predators group 3 taxa
group.3.predator.biomass.1980s <- predator.biomass.1980s %>%
  select(Helopicus, Neurocordulia) %>%
  mutate(summed_biomass = rowSums(.))

## 1980s predators group 3 total biomass
group.3.predator.biomass.1980s.total.biomass <- sum(group.3.predator.biomass.1980s$summed_biomass)
# Summed biomass = 5073.609

```



```

## 2010s predators group 1 taxa
group.1.predator.biomass.2010s <- predator.biomass.2010s %>%
  select(Acroneuria, Aeshnidae, Amphipoda, Anisoptera, Argia, Ceraclea,
         Ceratopogoninae, Cernotina, Coenagrionidae, Enallagma, Hemerodromia,
         Isoperla, Neoperla, Oecetis, Paragnetina, Perlesta, Perlidae, Perlodidae, Plecoptera) %>%
  mutate(summed_biomass = rowSums(.))

## 2010s predators group 1 total biomass
group.1.predator.biomass.2010s.total.biomass <- sum(group.1.predator.biomass.2010s$summed_biomass)
# Summed biomass = 15968.22

## 2010s predators group 2 taxa
group.2.predator.biomass.2010s <- predator.biomass.2010s %>%
  select(Aeshna, Boyeria, Corydalis, Hydroperla, Nasiaeschna) %>%
  mutate(summed_biomass = rowSums(.))

## 2010s predators group 2 total biomass
group.2.predator.biomass.2010s.total.biomass <- sum(group.2.predator.biomass.2010s$summed_biomass)
# Summed biomass = 18922.44

## 2010s predators group 3 taxa
group.3.predator.biomass.2010s <- predator.biomass.2010s %>%
  select(Helopicus, Neurocordulia) %>%
  mutate(summed_biomass = rowSums(.))

## 2010s predators group 3 total biomass
group.3.predator.biomass.2010s.total.biomass <- sum(group.3.predator.biomass.2010s$summed_biomass)
# Summed biomass = 6395.791

## 1980s Predators (% of total biomass within sampling period)
(group.1.predator.biomass.1980s.total.biomass/predator.biomass.1980s.total.biomass)*100
# Group 1 = 37.03%
(group.2.predator.biomass.1980s.total.biomass/predator.biomass.1980s.total.biomass)*100
# Group 2 = 48.75%
(group.3.predator.biomass.1980s.total.biomass/predator.biomass.1980s.total.biomass)*100
# Group 3 = 14.22%

## 2010s Predators
(group.1.predator.biomass.2010s.total.biomass/predator.biomass.2010s.total.biomass)*100
# Group 1 = 38.68%
(group.2.predator.biomass.2010s.total.biomass/predator.biomass.2010s.total.biomass)*100
# Group 2 = 45.83%
(group.3.predator.biomass.2010s.total.biomass/predator.biomass.2010s.total.biomass)*100
# Group 3 = 15.49%

## Divide mean 2010s biomass by mean 1980s biomass
percent.predator.biomass.change <- (
  mean(predator.biomass.2010s.total.biomass)/mean(predator.biomass.1980s.total.biomass)
)*100
# 2010s biomass = 115.70% of 1980s biomass

```

## Biomass Change & Contribution of Dominant Caddisflies

### ## Hydropsyche

```
Hydropsyche.biomass.1980s <- biomass.1980s$Hydropsyche  
Hydropsyche.biomass.2010s <- biomass.2010s$Hydropsyche
```

### ## Chimarra

```
Chimarra.biomass.1980s <- biomass.1980s$Chimarra  
Chimarra.biomass.2010s <- biomass.2010s$Chimarra
```

### ## Cheumatopsyche

```
Cheumatopsyche.biomass.1980s <- biomass.1980s$Cheumatopsyche  
Cheumatopsyche.biomass.2010s <- biomass.2010s$Cheumatopsyche
```

### ## Hydropsyche

```
(mean(Hydropsyche.biomass.2010s)/mean(Hydropsyche.biomass.1980s))*100  
# 2010 biomass = 34.31% of 1980s
```

### ## Chimarra

```
(mean(Chimarra.biomass.2010s)/mean(Chimarra.biomass.1980s))*100  
# 2010 biomass = 63.02% of 1980s
```

### ## Cheumatopsyche

```
(mean(Cheumatopsyche.biomass.2010s)/mean(Cheumatopsyche.biomass.1980s))*100  
# 2010 biomass = 14.96% of 1980s
```

### ## Percent of total biomass made up by all 3 dominant caddisflies

#### # 1980s

```
((mean(Hydropsyche.biomass.1980s) + mean(Chimarra.biomass.1980s) +  
  mean(Cheumatopsyche.biomass.1980s)) / mean(summed.biomass.1980s))*100  
# 1980s = 60.80% of all biomass
```

#### # 2010s

```
((mean(Hydropsyche.biomass.2010s) + mean(Chimarra.biomass.2010s) +  
  mean(Cheumatopsyche.biomass.2010s)) / mean(summed.biomass.2010s))*100  
# 2010s = 42.15% of all biomass
```

## Density Change

We numerically evaluated changes in density by size groupings for consumers and predators.

### Consumers

Consumer taxa within each size grouping:

- Group 1: Amphinemura, Ancyronyx, Baetidae, Baetisca, Brachycentrus, Caenidae, Cheumatopsyche, Chironomidae, Crambidae, Cynellus, Dubiraphia, Elmidae, Ephemerellidae, Ephemeroptera, Heptageniidae, Hydropsychidae, Isonychia, Isopoda, Lepidoptera, Leptoceridae, Leptophlebiidae, Limnephilidae, Macronychus, Microcylloepus, Nectopsyche, Nemouridae, Neureclipsis, Polycentropodidae, Psephenus, Simuliidae, Stenelmis, Taeniopteryx, Tipulidae, Triaenodes, Trichoptera, Tricorythodes
- Group 2: Chimarra, Ectopria, Hydropsyche, Macrostemum, Paraponyx, Shpsa
- Group 3: Ironoquia, Neargyractis, Pteronarcys, Pycnopsyche

```
## Consumer data management
# 1980s
consumer.density.1980s <- density.data %>%
  filter(Period == "1980") %>%
  select(Amphinemura:Tricorythodes) %>%
  mutate(summed_density = rowSums(.))

# Sum all density for the 1980s consumers
consumer.density.1980s.total.density <- sum(consumer.density.1980s$summed_density)
# Summed density = 2580454

# 2010s
consumer.density.2010s <- density.data %>%
  filter(Period == "2010") %>%
  select(Amphinemura:Tricorythodes) %>%
  mutate(summed_density = rowSums(.))

# Sum all density for the 2010s consumers
consumer.density.2010s.total.density <- sum(consumer.density.2010s$summed_density)
# Summed density = 2110836
```

```

## 1980s consumers group 1 taxa
group.1.consumer.density.1980s <- consumer.density.1980s %>%
  select(Amphinemura, Ancyronyx, Baetidae, Baetisca, Brachycentrus, Caenidae,
         Cheumatopsyche, Chironomidae, Crambidae, Cynellus, Dubiraphia, Elmidae,
         Ephemerellidae, Ephemeroptera, Heptageniidae, Hydropsychidae, Isonychia,
         Isopoda, Lepidoptera, Leptoceridae, Leptophlebiidae, Limnephilidae,
         Macronychus, Microcylloepus, Nectopsyche, Nemouridae, Neureclipsis,
         Polycentropodidae, Psephenus, Simuliidae, Stenelmis, Taeniopteryx,
         Tipulidae, Triaenodes, Trichoptera, Tricorythodes) %>%
  mutate(summed_density = rowSums(.))

## 1980s consumers group 1 total density
group.1.consumer.density.1980s.total.density <- sum(group.1.consumer.density.1980s$summed_density)
# Summed density = 2302319

## 1980s consumers group 2 taxa
group.2.consumer.density.1980s <- consumer.density.1980s %>%
  select(Chimarra, Ectopria, Hydropsyche, Macrostemum, Paraponyx, Shippa) %>%
  mutate(summed_density = rowSums(.))

## 1980s consumers group 2 total density
group.2.consumer.density.1980s.total.density <- sum(group.2.consumer.density.1980s$summed_density)
# Summed density = 277220.8

## 1980s consumers group 3 taxa
group.3.consumer.density.1980s <- consumer.density.1980s %>%
  select(Ironoquia, Neargyractis, Pteronarcys, Pycnopsyche) %>%
  mutate(summed_density = rowSums(.))

## 1980s consumers group 3 total density
group.3.consumer.density.1980s.total.density <- sum(group.3.consumer.density.1980s$summed_density)
# Summed density = 913.8923

```

```

## 2010s consumers group 1 taxa
group.1.consumer.density.2010s <- consumer.density.2010s %>%
  select(Amphinemura, Ancyronyx, Baetidae, Baetisca, Brachycentrus, Caenidae,
         Cheumatopsyche, Chironomidae, Crambidae, Cynellus, Dubiraphia, Elmidae,
         Ephemerellidae, Ephemeroptera, Heptageniidae, Hydropsychidae, Isonychia,
         Isopoda, Lepidoptera, Leptoceridae, Leptophlebiidae, Limnephilidae,
         Macronychus, Microcylloepus, Nectopsyche, Nemouridae, Neureclipsis,
         Polycentropodidae, Psephenus, Simuliidae, Stenelmis, Taeniopteryx,
         Tipulidae, Triaenodes, Trichoptera, Tricorythodes) %>%
  mutate(summed_density = rowSums(.))

## 2010s consumers group 1 total density
group.1.consumer.density.2010s.total.density <- sum(group.1.consumer.density.2010s$summed_density)
# Summed density = 1999623

## 2010s consumers group 2 taxa
group.2.consumer.density.2010s <- consumer.density.2010s %>%
  select(Chimarra, Ectopria, Hydropsyche, Macrostemum, Paraponyx, Shipsa) %>%
  mutate(summed_density = rowSums(.))

## 2010s consumers group 2 total density
group.2.consumer.density.2010s.total.density <- sum(group.2.consumer.density.2010s$summed_density)
# Summed density = 111083.3

## 2010s consumers group 3 taxa
group.3.consumer.density.2010s <- consumer.density.2010s %>%
  select(Ironoquia, Neargyractis, Pteronarcys, Pycnopsyche) %>%
  mutate(summed_density = rowSums(.))

## 2010s consumers group 3 total density
group.3.consumer.density.2010s.total.density <- sum(group.3.consumer.density.2010s$summed_density)
# Summed density = 130.0784

## 1980s Consumers (% of total density within sampling period)
(group.1.consumer.density.1980s.total.density/consumer.density.1980s.total.density)*100
# Group 1 = 89.22%
(group.2.consumer.density.1980s.total.density/consumer.density.1980s.total.density)*100
# Group 2 = 10.74%
(group.3.consumer.density.1980s.total.density/consumer.density.1980s.total.density)*100
# Group 3 = 0.04%

## 2010s Consumers
(group.1.consumer.density.2010s.total.density/consumer.density.2010s.total.density)*100
# Group 1 = 94.73%
(group.2.consumer.density.2010s.total.density/consumer.density.2010s.total.density)*100
# Group 2 = 5.26%
(group.3.consumer.density.2010s.total.density/consumer.density.2010s.total.density)*100
# Group 3 = 0.01%

## Divide mean 2010s density by mean 1980s density
percent.consumer.density.change <- (
  mean(consumer.density.2010s.total.density)/mean(consumer.density.1980s.total.density)

```

```
) * 100  
# 2010s density = 81.80% of 1980s density
```

## Predators

Predator taxa within each size grouping:

- Group 1: Acroneuria, Aeshnidae, Amphipoda, Anisoptera, Argia, Ceraclea, Ceratopogoninae, Ceratopogoninae, Coenagrionidae, Enallagma, Hemerodromia, Isoperla, Neoperla, Oecetis, Paragnetina, Perlesta, Perlidae, Perlodidae, Plecoptera
- Group 2: Aeshna, Boyeria, Corydalus, Hydroperla, Nasiaeschna
- Group 3: Helopicus, Neurocordulia

```
## Predator data management
# 1980s
predator.density.1980s <- density.data %>%
  filter(Period == "1980") %>%
  select(Acroneuria:Plecoptera) %>%
  mutate(summed_density = rowSums(.))

# Sum all biomass for the 1980s predators
predator.density.1980s.total.density <- sum(predator.density.1980s$summed_density)
# Summed density = 47433.32

# 2010s
predator.density.2010s <- density.data %>%
  filter(Period == "2010") %>%
  select(Acroneuria:Plecoptera) %>%
  mutate(summed_density = rowSums(.))

# Sum all biomass for the 2010s predators
predator.density.2010s.total.density <- sum(predator.density.2010s$summed_density)
# Summed density = 88336.69
```

```

## 1980s predators group 1 taxa
group.1.predator.density.1980s <- predator.density.1980s %>%
  select(Acroneuria, Aeshnidae, Amphipoda, Anisoptera, Argia, Ceraclea,
         Ceratopogoninae, Cernotina, Coenagrionidae, Enallagma, Hemerodromia,
         Isoperla, Neoperla, Oecetis, Paragnetina, Perlesta, Perlidae, Perlodidae, Plecoptera) %>%
  mutate(summed_density = rowSums(.))

## 1980s predators group 1 total density
group.1.predator.density.1980s.total.density <- sum(group.1.predator.density.1980s$summed_density)
# Summed density = 46049.37

## 1980s predators group 2 taxa
group.2.predator.density.1980s <- predator.density.1980s %>%
  select(Aeshna, Boyeria, Corydalus, Hydroperla, Nasiaeschna) %>%
  mutate(summed_density = rowSums(.))

## 1980s predators group 2 total density
group.2.predator.density.1980s.total.density <- sum(group.2.predator.density.1980s$summed_density)
# Summed density = 47433.32

## 1980s predators group 3 taxa
group.3.predator.density.1980s <- predator.density.1980s %>%
  select(Helopicus, Neurocordulia) %>%
  mutate(summed_density = rowSums(.))

## 1980s predators group 3 total density
group.3.predator.density.1980s.total.density <- sum(group.3.predator.density.1980s$summed_density)
# Summed density = 158.1566

```



```

## 2010s predators group 1 taxa
group.1.predator.density.2010s <- predator.density.2010s %>%
  select(Acroneuria, Aeshnidae, Amphipoda, Anisoptera, Argia, Ceraclea,
         Ceratopogoninae, Cernotina, Coenagrionidae, Enallagma, Hemerodromia,
         Isoperla, Neoperla, Oecetis, Paragnetina, Perlesta, Perlidae, Perlodidae, Plecoptera) %>%
  mutate(summed_density = rowSums(.))

## 2010s predators group 1 total density
group.1.predator.density.2010s.total.density <- sum(group.1.predator.density.2010s$summed_density)
# Summed density = 85669.75

## 2010s predators group 2 taxa
group.2.predator.density.2010s <- predator.density.2010s %>%
  select(Aeshna, Boyeria, Corydalus, Hydroperla, Nasiaeschna) %>%
  mutate(summed_density = rowSums(.))

## 2010s predators group 2 total density
group.2.predator.density.2010s.total.density <- sum(group.2.predator.density.2010s$summed_density)
# Summed density = 2425.899

## 2010s predators group 3 taxa
group.3.predator.density.2010s <- predator.density.2010s %>%
  select(Helopicus, Neurocordulia) %>%
  mutate(summed_density = rowSums(.))

## 2010s predators group 3 total density
group.3.predator.density.2010s.total.density <- sum(group.3.predator.density.2010s$summed_density)
# Summed density = 241.0455

## 1980s Predators (% of total density within sampling period)
(group.1.predator.density.1980s.total.density/predator.density.1980s.total.density)*100
# Group 1 = 97.08%
(group.2.predator.density.1980s.total.density/predator.density.1980s.total.density)*100
# Group 2 = 2.58%
(group.3.predator.density.1980s.total.density/predator.density.1980s.total.density)*100
# Group 3 = 0.33%

## 2010s Predators
(group.1.predator.density.2010s.total.density/predator.density.2010s.total.density)*100
# Group 1 = 96.98%
(group.2.predator.density.2010s.total.density/predator.density.2010s.total.density)*100
# Group 2 = 2.75%
(group.3.predator.density.2010s.total.density/predator.density.2010s.total.density)*100
# Group 3 = 0.27%

## Divide mean 2010s density by mean 1980s density
percent.predator.density.change <- (
  mean(predator.density.2010s.total.density)/mean(predator.density.1980s.total.density)
)*100
# 2010s density = 186.23% of 1980s density

```

## Biomass & Density Chi-Squared Tests

We performed chi-squared tests to determine whether there were differences in biomass by size groupings between sampling period for consumers and predators. Chi-squared tests were performed using `chisq.test()`, with observed and expected frequencies examined to confirm test assumptions were met. Additionally, we assessed residuals to determine over- and under-represented size groupings by sampling period. Residuals were calculated as:

$$\frac{Observed - Expected}{\sqrt{Expected}}$$

Effect sizes for the chi-squared tests were calculated as Cramer's V using the `cramers_v()` function in the `effectsize` package.

### Consumer Biomass

```
## Set consumer chi-square dataframe
consumer.biomass.chi.square.data <- as.data.frame(data.frame(matrix(0, nrow = 3, ncol = 2)))
colnames(consumer.biomass.chi.square.data) <- c("1980s", "2010s")
rownames(consumer.biomass.chi.square.data) <- c("Group_1", "Group_2", "Group_3")

## Add biomass values by groups for the 1980s and 2010s
# 1980s
consumer.biomass.chi.square.data$`1980s` <- c(
  group.1.consumer.biomass.1980s.total.biomass,
  group.2.consumer.biomass.1980s.total.biomass,
  group.3.consumer.biomass.1980s.total.biomass
)

# 2010s
consumer.biomass.chi.square.data$`2010s` <- c(
  group.1.consumer.biomass.2010s.total.biomass,
  group.2.consumer.biomass.2010s.total.biomass,
  group.3.consumer.biomass.2010s.total.biomass
)

consumer.biomass.chi.square.test <- chisq.test(consumer.biomass.chi.square.data)
# chi-squared = 2933.7, df = 2, P < 0.00001

## Calculate Cramer's V
cramers_v(consumer.biomass.chi.square.data)
# V = 0.10
```

Table 43: Observed biomass by size groupings for the consumer chi-squared test.

|         | 1980s     | 2010s     |
|---------|-----------|-----------|
| Group_1 | 78968.09  | 38115.600 |
| Group_2 | 116946.43 | 59127.287 |
| Group_3 | 8984.69   | 691.249   |

Table 44: Expected biomass by size groupings for the consumer chi-squared test.

|         | 1980s     | 2010s     |
|---------|-----------|-----------|
| Group_1 | 79219.67  | 37864.027 |
| Group_2 | 119132.74 | 56940.979 |
| Group_3 | 6546.81   | 3129.129  |

Table 45: Residual biomass by size groupings for the consumer chi-squared test.

|         | 1980s  | 2010s   |
|---------|--------|---------|
| Group_1 | -0.894 | 1.293   |
| Group_2 | -6.334 | 9.162   |
| Group_3 | 30.130 | -43.581 |

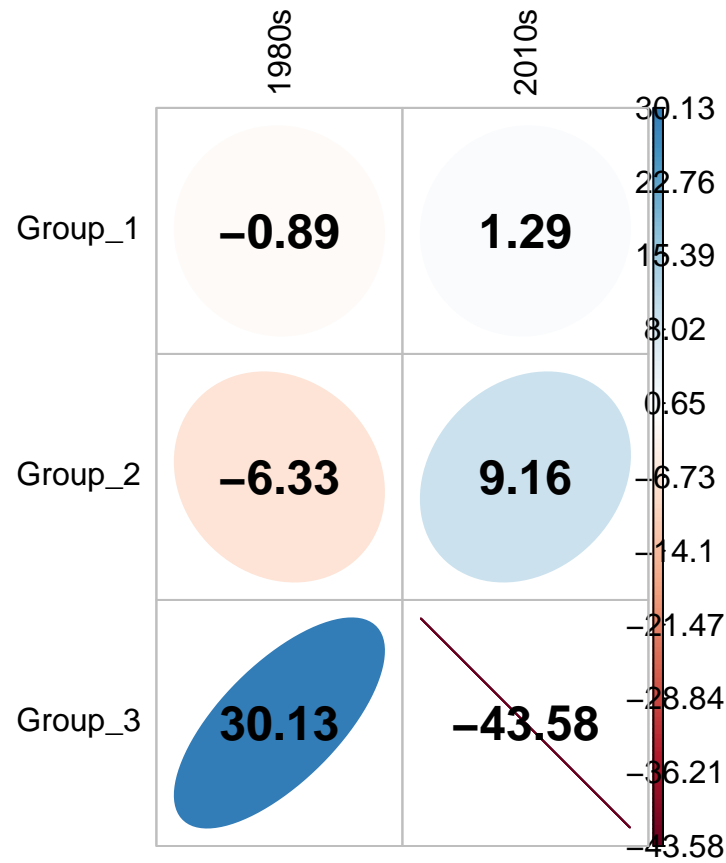


Figure 1: Plot of residuals from the consumer chi-squared test.

## Consumer Density

```
## Set consumer chi-square dataframe
consumer.density.chi.square.data <- as.data.frame(data.frame(matrix(0, nrow = 3, ncol = 2)))
colnames(consumer.density.chi.square.data) <- c("1980s", "2010s")
rownames(consumer.density.chi.square.data) <- c("Group_1", "Group_2", "Group_3")

## Add density values by groups for the 1980s and 2010s
# 1980s
consumer.density.chi.square.data$`1980s` <- c(
  group.1.consumer.density.1980s.total.density,
  group.2.consumer.density.1980s.total.density,
  group.3.consumer.density.1980s.total.density
)

# 2010s
consumer.density.chi.square.data$`2010s` <- c(
  group.1.consumer.density.2010s.total.density,
  group.2.consumer.density.2010s.total.density,
  group.3.consumer.density.2010s.total.density
)

consumer.density.chi.square.test <- chisq.test(consumer.density.chi.square.data)
# chi-squared = 46424, df = 2, P < 0.00001

## Calculate Cramer's V
cramers_v(consumer.density.chi.square.data)
# V = 0.10
```

Table 46: Observed density by size groupings for the consumer chi-squared test.

|         | 1980s       | 2010s       |
|---------|-------------|-------------|
| Group_1 | 2302319.190 | 1999622.789 |
| Group_2 | 277220.761  | 111083.255  |
| Group_3 | 913.892     | 130.078     |

Table 47: Expected density by size groupings for the consumer chi-squared test.

|         | 1980s       | 2010s       |
|---------|-------------|-------------|
| Group_1 | 2366292.170 | 1935649.809 |
| Group_2 | 213587.435  | 174716.581  |
| Group_3 | 574.238     | 469.732     |

Table 48: Residual density by size groupings for the consumer chi-squared test.

|         | 1980s   | 2010s    |
|---------|---------|----------|
| Group_1 | -41.587 | 45.982   |
| Group_2 | 137.688 | -152.236 |
| Group_3 | 14.174  | -15.672  |

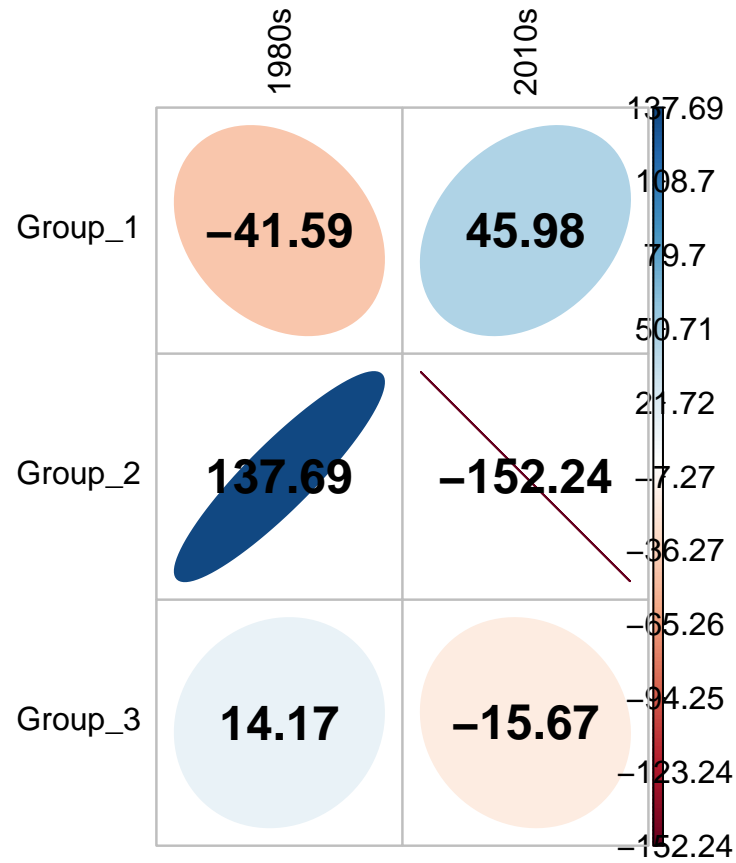


Figure 2: Plot of residuals from the consumer chi-squared test.

## Predator Biomass

```
## Set predator chi-square dataframe
predator.biomass.chi.square.data <- as.data.frame(data.frame(matrix(0, nrow = 3, ncol = 2)))
colnames(predator.biomass.chi.square.data) <- c("1980s", "2010s")
rownames(predator.biomass.chi.square.data) <- c("Group_1", "Group_2", "Group_3")

## Add biomass values by groups for the 1980s and 2010s
# 1980s
predator.biomass.chi.square.data$`1980s` <- c(
  group.1.predator.biomass.1980s.total.biomass,
  group.2.predator.biomass.1980s.total.biomass,
  group.3.predator.biomass.1980s.total.biomass
)

# 2010s
predator.biomass.chi.square.data$`2010s` <- c(
  group.1.predator.biomass.2010s.total.biomass,
  group.2.predator.biomass.2010s.total.biomass,
  group.3.predator.biomass.2010s.total.biomass
)

predator.biomass.chi.square.test <- chisq.test(predator.biomass.chi.square.data)
# chi-squared = 69.014, df = 2, P < 0.00001

## Calculate Cramer's V
cramers_v(predator.biomass.chi.square.data)
# V = 0.03
```

Table 49: Observed biomass by size groupings for the predator chi-squared test.

|         | 1980s     | 2010s     |
|---------|-----------|-----------|
| Group_1 | 13214.148 | 15968.223 |
| Group_2 | 17395.718 | 18922.441 |
| Group_3 | 5073.609  | 6395.791  |

Table 50: Expected biomass by size groupings for the predator chi-squared test.

|         | 1980s     | 2010s     |
|---------|-----------|-----------|
| Group_1 | 13529.029 | 15653.342 |
| Group_2 | 16837.200 | 19480.959 |
| Group_3 | 5317.246  | 6152.154  |

Table 51: Residual biomass by size groupings for the predator chi-squared test.

|         | 1980s  | 2010s  |
|---------|--------|--------|
| Group_1 | -2.707 | 2.517  |
| Group_2 | 4.304  | -4.002 |
| Group_3 | -3.341 | 3.106  |

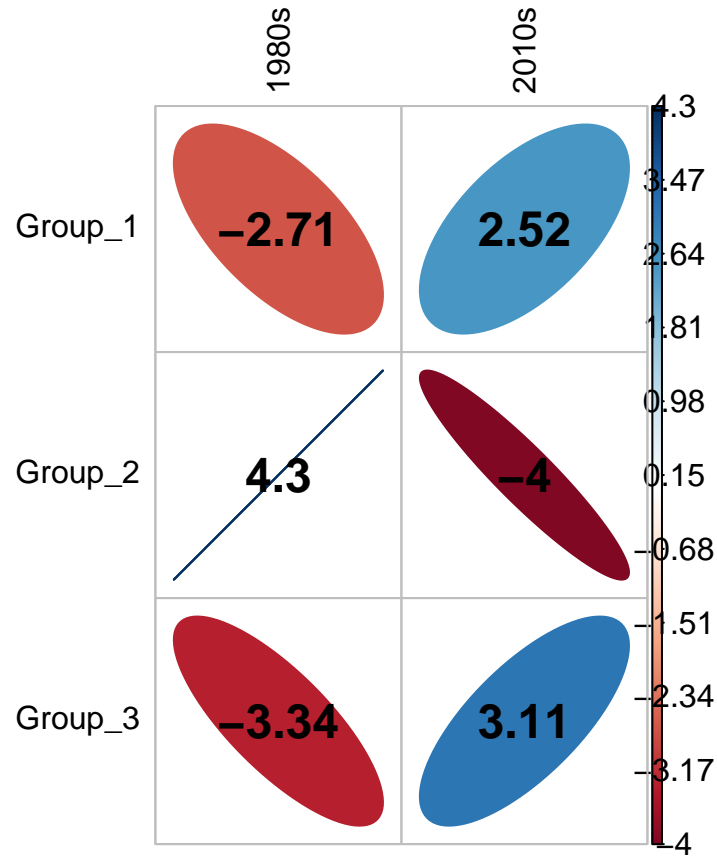


Figure 3: Plot of residuals from the predator chi-squared test.

## Predator Density

```
## Set predator chi-square dataframe
predator.density.chi.square.data <- as.data.frame(data.frame(matrix(0, nrow = 3, ncol = 2)))
colnames(predator.density.chi.square.data) <- c("1980s", "2010s")
rownames(predator.density.chi.square.data) <- c("Group_1", "Group_2", "Group_3")

## Add density values by groups for the 1980s and 2010s
# 1980s
predator.density.chi.square.data$`1980s` <- c(
  group.1.predator.density.1980s.total.density,
  group.2.predator.density.1980s.total.density,
  group.3.predator.density.1980s.total.density
)

# 2010s
predator.density.chi.square.data$`2010s` <- c(
  group.1.predator.density.2010s.total.density,
  group.2.predator.density.2010s.total.density,
  group.3.predator.density.2010s.total.density
)

predator.density.chi.square.test <- chisq.test(predator.density.chi.square.data)
# chi-squared = 6.8918, df = 2, P = 0.03188

## Calculate Cramer's V
cramers_v(predator.density.chi.square.data)
# V < 0.001; essentially no effect or difference
```

Table 52: Observed density by size groupings for the predator chi-squared test.

|         | 1980s     | 2010s     |
|---------|-----------|-----------|
| Group_1 | 46049.372 | 85669.746 |
| Group_2 | 1225.790  | 2425.899  |
| Group_3 | 158.157   | 241.046   |

Table 53: Expected density by size groupings for the predator chi-squared test.

|         | 1980s     | 2010s     |
|---------|-----------|-----------|
| Group_1 | 46018.078 | 85701.040 |
| Group_2 | 1275.773  | 2375.916  |
| Group_3 | 139.467   | 259.735   |



Table 54: Residual density by size groupings for the predator chi-squared test.

|         | 1980s  | 2010s  |
|---------|--------|--------|
| Group_1 | 0.146  | -0.107 |
| Group_2 | -1.399 | 1.025  |
| Group_3 | 1.583  | -1.160 |

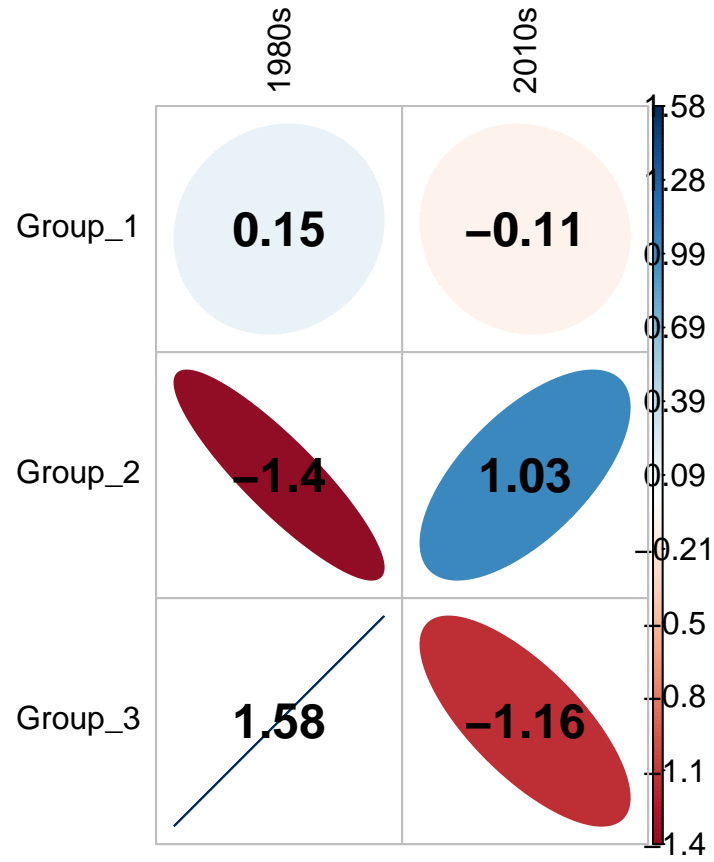


Figure 4: Plot of residuals from the predator chi-squared test.

## Biomass Contributions

Biomass contributions were calculated for consumer and predator groups.

```
## Filter and format total biomass data by sampling period
# 1980s
total.1980s.biomass <- invertebrate.biomass.matrix[1:25, ]
total.1980s.mean.biomass <- t(colMeans(total.1980s.biomass))
total.1980s.percent.biomass.contribution <- (
  (total.1980s.mean.biomass/total.1980s.biomass)*100
)

# 2010s
total.2010s.biomass <- invertebrate.biomass.matrix[1:25, ]
total.2010s.mean.biomass <- t(colMeans(total.2010s.biomass))
total.2010s.percent.biomass.contribution <- (
  (total.2010s.mean.biomass/total.2010s.biomass)*100
)
```

## Consumers

```
## Separate consumer biomass data by sampling period
# 1980s
consumer.1980s.biomass <- invertebrate.biomass.matrix %>%
  select(Amphinemura:Tricorythodes) %>%
  slice(1:25)
consumer.1980s.mean.biomass <- t(colMeans(consumer.1980s.biomass))
consumer.1980s.biomass.contribution <- (
  (consumer.1980s.mean.biomass/consumer.1980s.biomass)*100
)

# 2010s
consumer.2010s.biomass <- invertebrate.biomass.matrix %>%
  select(Amphinemura:Tricorythodes) %>%
  slice(26:49)
consumer.2010s.mean.biomass <- t(colMeans(consumer.2010s.biomass))
consumer.2010s.biomass.contribution <- (
  (consumer.2010s.mean.biomass/consumer.2010s.biomass)*100
)
```

## Predators

```
## Separate predator biomass data by sampling period
# 1980s
predator.1980s.biomass <- invertebrate.biomass.matrix %>%
  select(Acroneuria:Plecoptera) %>%
  slice(1:25)
predator.1980s.mean.biomass <- t(colMeans(predator.1980s.biomass))
predator.1980s.biomass.contribution <- (
  (predator.1980s.mean.biomass/predator.1980s.biomass)*100
)

# 2010s
predator.2010s.biomass <- invertebrate.biomass.matrix %>%
  select(Acroneuria:Plecoptera) %>%
  slice(26:49)
predator.2010s.mean.biomass <- t(colMeans(predator.2010s.biomass))
predator.2010s.biomass.contribution <- (
  (predator.2010s.mean.biomass/predator.2010s.biomass)*100
)
```

## Individual Body Size Change

We tested whether mean body sizes of the most dominant primary consumers and predators were different between sampling periods. We calculated the average percent composition of biomass for each taxon within each sampling period and focused on the five most dominant consumers and the three most dominant predators. We calculated average individual mass for each sampling month by dividing biomass by abundance and performed two-sample Welch t-tests on average mass between the 1980s and the 2010s for each of the dominant taxa.

- Dominant consumers = Hydropsyche, Cheumatopsyche, Chimarra, Heptageniidae, Chironomidae
- Dominant predators = Corydalus, Paragnetina, Neurocordulia

### Body Size t-Tests

```
## Data management for body size t-tests

## Hydropsyche
Hydropsyche.80.size <- ((biomass.1980s$Hydropsyche)/(density.1980s$Hydropsyche))
Hydropsyche.10.size <- ((biomass.2010s$Hydropsyche)/(density.2010s$Hydropsyche))

## Cheumatopsyche
Cheumatopsyche.80.size <- ((biomass.1980s$Cheumatopsyche)/(density.1980s$Cheumatopsyche))
Cheumatopsyche.10.size <- ((biomass.2010s$Cheumatopsyche)/(density.2010s$Cheumatopsyche))

## Chimarra
Chimarra.80.size <- ((biomass.1980s$Chimarra)/(density.1980s$Chimarra))
Chimarra.10.size <- ((biomass.2010s$Chimarra)/(density.2010s$Chimarra))

## Heptageniidae
Heptageniidae.80.size <- ((biomass.1980s$Heptageniidae)/(density.1980s$Heptageniidae))
Heptageniidae.10.size <- ((biomass.2010s$Heptageniidae)/(density.2010s$Heptageniidae))

## Chironomidae
Chironomidae.80.size <- ((biomass.1980s$Chironomidae)/(density.1980s$Chironomidae))
Chironomidae.10.size <- ((biomass.2010s$Chironomidae)/(density.2010s$Chironomidae))

## Corydalus
Corydalus.80.size <- ((biomass.1980s$Corydalus)/(density.1980s$Corydalus))
Corydalus.10.size <- ((biomass.2010s$Corydalus)/(density.2010s$Corydalus))

## Paragnetina
Paragnetina.80.size <- ((biomass.1980s$Paragnetina)/(density.1980s$Paragnetina))
Paragnetina.10.size <- ((biomass.2010s$Paragnetina)/(density.2010s$Paragnetina))

## Neurocordulia
Neurocordulia.80.size <- ((biomass.1980s$Neurocordulia)/(density.1980s$Neurocordulia))
Neurocordulia.10.size <- ((biomass.2010s$Neurocordulia)/(density.2010s$Neurocordulia))
```

### ## Hydropsycha

```
t.test(log(Hydropsycha.80.size + 0.00001), log(Hydropsycha.10.size + 0.00001),  
       paired = FALSE)  
# t = 1.8613, df = 46.739, P-value = 0.069
```

### ## Cheumatopsyche

```
t.test(log(Cheumatopsyche.80.size + 0.00001), log(Cheumatopsyche.10.size + 0.00001),  
       paired = FALSE)  
# t = 5.1915, df = 46.86, P-value < 0.001
```

### ## Chimarra

```
t.test(log(Chimarra.80.size + 0.00001), log(Chimarra.10.size + 0.00001),  
       paired = FALSE)  
# t = 0.42278, df = 44.042, P-value = 0.675
```

### ## Heptageniidae

```
t.test(log(Heptageniidae.80.size + 0.00001), log(Heptageniidae.10.size + 0.00001),  
       paired = FALSE)  
# t = -0.40634, df = 46.633, P-value = 0.686
```

### ## Chironomidae

```
t.test(log(Chironomidae.80.size + 0.00001), log(Chironomidae.10.size + 0.00001),  
       paired = FALSE)  
# t = -0.17408, df = 46.334, P-value = 0.863
```

### ## Corydalis

```
t.test(log(Corydalis.80.size + 0.00001), log(Corydalis.10.size + 0.00001),  
       paired = FALSE)  
# t = 1.2464, df = 31.152, P-value = 0.222
```

### ## Paragnetina

```
t.test(Paragnetina.80.size + 0.00001, Paragnetina.10.size + 0.00001,  
       paired = FALSE)  
# t = 0.2442, df = 26.9, P-value = 0.809
```

### ## Neurocordulia

```
t.test(Neurocordulia.80.size + 0.00001, Neurocordulia.10.size + 0.00001,  
       paired = FALSE)  
# t = 1.3378, df = 28.187, P-value = 0.192
```

## Community Composition

Community composition was evaluated by calculating a Bray-Curtis distance matrix on a taxon-by-sample biomass matrix. We then conducted a PERMANOVA on this distance matrix to test for effects of sampling period, season, discharge, and water temperature on community structure.

```
## Data management for the PERMANOVA
# Sample information for the distance matrix
distance.matrix.info <- biomass.data %>%
  select(UID, Year, Season, Period, Mean_Discharge, Water_Temperature) %>%
  na.omit()

# Taxa-by-abundance community matrix
community.matrix <- log(invertebrate.biomass.matrix + 1)

## Calculate Bray-Curtis Distance
BC.distance.biomass <- vegdist(community.matrix, method = "bray")

## NMDS Ordination
BC.NMDS.biomass <- monoMDS(BC.distance.biomass, k = 2, model = "global")
# Stress = 0.190

## PERMANOVA by period, season, and the interaction
community.composition.PERMANOVA <- adonis2(
  BC.distance.biomass ~ Period + Season + Period:Season
  + Mean_Discharge + Water_Temperature
  + Mean_Discharge:Water_Temperature
  + Mean_Discharge:Period + Mean_Discharge:Season
  + Mean_Discharge:Period:Season
  + Water_Temperature:Period + Water_Temperature:Season
  + Water_Temperature:Period:Season,
  data = distance.matrix.info,
  permutations = 10000
)
```

Table 55: Summary of the PERMANOVA comparing composition by period, season, mean discharge, and water temperature, with selected two- and three-way interaction terms.

| Term                             | df | Sums-of-Squares | R2    | F      | P-value |
|----------------------------------|----|-----------------|-------|--------|---------|
| Period                           | 1  | 0.985           | 0.196 | 20.552 | 0.000   |
| Season                           | 3  | 1.046           | 0.209 | 7.277  | 0.000   |
| Mean_Discharge                   | 1  | 0.349           | 0.070 | 7.275  | 0.000   |
| Water_Temperature                | 1  | 0.044           | 0.009 | 0.909  | 0.496   |
| Period:Season                    | 3  | 0.242           | 0.048 | 1.682  | 0.034   |
| Mean_Discharge:Water_Temperature | 1  | 0.049           | 0.010 | 1.019  | 0.398   |
| Period:Mean_Discharge            | 1  | 0.094           | 0.019 | 1.964  | 0.059   |
| Season:Mean_Discharge            | 3  | 0.280           | 0.056 | 1.948  | 0.010   |
| Period:Water_Temperature         | 1  | 0.033           | 0.006 | 0.679  | 0.713   |
| Season:Water_Temperature         | 3  | 0.272           | 0.054 | 1.894  | 0.015   |
| Period:Season:Mean_Discharge     | 3  | 0.165           | 0.033 | 1.146  | 0.288   |
| Period:Season:Water_Temperature  | 3  | 0.306           | 0.061 | 2.127  | 0.004   |
| Residual                         | 24 | 1.150           | 0.229 | NA     | NA      |
| Total                            | 48 | 5.013           | 1.000 | NA     | NA      |

## Indicator Taxa Analysis

We conducted an indicator species analysis to determine which taxa characterized specific sampling period and season groups.

```
## Create groups based on season: Group 1 = 1980s, Group 2 = 2010s
period.groups <- c(rep(1, 25), rep(2, 24))
```

```
## Run indicator analysis comparing by period
indicator.analysis <- multipatt(
  community.matrix,
  period.groups,
  control = how(nperm = 10000)
)
```

Table 56: Summary table of the sign of the relationship from the indicator taxa analysis.

|                 | 1980s | 2010s | Index | Test Statistic | P-value |
|-----------------|-------|-------|-------|----------------|---------|
| Amphinemura     | 1     | 0     | 1     | 0.346          | 0.241   |
| Ancyronyx       | 1     | 1     | 3     | 0.857          | NA      |
| Baetidae        | 1     | 1     | 3     | 1.000          | NA      |
| Baetisca        | 0     | 1     | 2     | 0.552          | 0.030   |
| Brachycentrus   | 0     | 1     | 2     | 0.764          | 0.000   |
| Caenidae        | 1     | 1     | 3     | 0.795          | NA      |
| Cheumatopsyche  | 1     | 1     | 3     | 1.000          | NA      |
| Chimarra        | 1     | 1     | 3     | 0.979          | NA      |
| Chironomidae    | 1     | 1     | 3     | 1.000          | NA      |
| Crambidae       | 0     | 1     | 2     | 0.281          | 0.359   |
| Cynellus        | 0     | 1     | 2     | 0.645          | 0.000   |
| Dubiraphia      | 1     | 1     | 3     | 0.319          | NA      |
| Ectopria        | 1     | 0     | 1     | 0.400          | 0.105   |
| Elmidae         | 0     | 1     | 2     | 0.945          | 0.000   |
| Ephemerellidae  | 1     | 1     | 3     | 0.795          | NA      |
| Ephemeroptera   | 0     | 1     | 2     | 0.996          | 0.000   |
| Heptageniidae   | 1     | 1     | 3     | 1.000          | NA      |
| Hydropsyche     | 1     | 1     | 3     | 1.000          | NA      |
| Hydropsychidae  | 1     | 1     | 3     | 0.881          | NA      |
| Ironoquia       | 1     | 1     | 3     | 0.319          | NA      |
| Isonychia       | 1     | 1     | 3     | 0.904          | NA      |
| Isopoda         | 1     | 1     | 3     | 0.728          | NA      |
| Lepidoptera     | 0     | 1     | 2     | 0.568          | 0.006   |
| Leptoceridae    | 0     | 1     | 2     | 0.886          | 0.000   |
| Leptophlebiidae | 0     | 1     | 2     | 0.599          | 0.003   |
| Limnephilidae   | 0     | 1     | 2     | 0.284          | 0.359   |
| Macronychus     | 1     | 1     | 3     | 0.958          | NA      |
| Macrostemum     | 0     | 1     | 2     | 0.839          | 0.000   |
| Microcylloepus  | 0     | 1     | 2     | 0.704          | 0.000   |
| Neargyractis    | 1     | 0     | 1     | 0.400          | 0.110   |
| Nectopsyche     | 0     | 1     | 2     | 0.889          | 0.000   |



Table 56: Summary table of the sign of the relationship from the indicator taxa analysis. (*continued*)

|                   | 1980s | 2010s | Index | Test Statistic | P-value |
|-------------------|-------|-------|-------|----------------|---------|
| Nemouridae        | 1     | 0     | 1     | 0.200          | 1.000   |
| Neureclipsis      | 1     | 1     | 3     | 0.589          | NA      |
| Paraponyx         | 1     | 1     | 3     | 0.429          | NA      |
| Polycentropodidae | 0     | 1     | 2     | 0.661          | 0.001   |
| Psephenus         | 1     | 0     | 1     | 0.200          | 1.000   |
| Pteronarcys       | 1     | 0     | 1     | 0.937          | 0.000   |
| Pycnopsyche       | 1     | 1     | 3     | 0.202          | NA      |
| Shipsa            | 1     | 0     | 1     | 0.200          | 1.000   |
| Simuliidae        | 1     | 1     | 3     | 0.926          | NA      |
| Stenelmis         | 1     | 1     | 3     | 0.990          | NA      |
| Taeniopteryx      | 1     | 1     | 3     | 0.589          | NA      |
| Tipulidae         | 1     | 0     | 1     | 0.529          | 0.012   |
| Triaenodes        | 0     | 1     | 2     | 0.733          | 0.000   |
| Trichoptera       | 0     | 1     | 2     | 0.537          | 0.037   |
| Tricorythodes     | 1     | 1     | 3     | 0.742          | NA      |
| Acroneuria        | 1     | 1     | 3     | 0.833          | NA      |
| Aeshna            | 1     | 0     | 1     | 0.200          | 1.000   |
| Aeshnidae         | 0     | 1     | 2     | 0.289          | 0.236   |
| Amphipoda         | 0     | 1     | 2     | 0.875          | 0.000   |
| Anisoptera        | 0     | 1     | 2     | 0.289          | 0.241   |
| Argia             | 0     | 1     | 2     | 0.745          | 0.000   |
| Boyeria           | 0     | 1     | 2     | 0.507          | 0.039   |
| Ceraclea          | 0     | 1     | 2     | 0.680          | 0.003   |
| Ceratopogoninae   | 1     | 1     | 3     | 0.958          | NA      |
| Cernotina         | 0     | 1     | 2     | 0.577          | 0.002   |
| Coenagrionidae    | 0     | 1     | 2     | 0.524          | 0.065   |
| Corydalus         | 1     | 1     | 3     | 0.881          | NA      |
| Enallagma         | 0     | 1     | 2     | 0.537          | 0.006   |
| Helopicus         | 1     | 0     | 1     | 0.200          | 1.000   |
| Hemerodromia      | 1     | 1     | 3     | 0.881          | NA      |
| Hydroperla        | 0     | 1     | 2     | 0.289          | 0.245   |
| Isoperla          | 0     | 1     | 2     | 0.426          | 0.104   |
| Nasiaeschna       | 0     | 1     | 2     | 0.289          | 0.236   |
| Neoperla          | 1     | 1     | 3     | 0.904          | NA      |
| Neurocordulia     | 1     | 1     | 3     | 0.821          | NA      |
| Oecetis           | 1     | 1     | 3     | 0.904          | NA      |
| Paragnetina       | 1     | 1     | 3     | 0.915          | NA      |
| Perlesta          | 1     | 1     | 3     | 0.795          | NA      |
| Perlidae          | 1     | 1     | 3     | 0.881          | NA      |
| Perlodidae        | 0     | 1     | 2     | 0.354          | 0.111   |
| Plecoptera        | 1     | 1     | 3     | 0.728          | NA      |

## Carbon & Discharge ANCOVA

We evaluated the relationship between dissolved organic carbon and discharge using an ANCOVA. Monthly averages of carbon and discharge during our sampling periods (i.e., 1980s = December 1981–November 1983, 2010s = July 2015–August 2017) were used for this analysis. We structured the ANCOVA as:

$$\text{Carbon} = \alpha + \beta_1(\ln(\text{Discharge})) + \beta_2(\text{Period}) + \beta_3(\ln(\text{Discharge}) \times \text{Period}) + \epsilon$$

with the ANCOVA fitted using `lm()` and model assumptions checked using `check_model()`. Influence of terms within the model was estimated by Type II sums-of-squares using the `Anova()` function.

```
carbon.discharge.ancova <- lm(
  log(Carbon) ~ log(Mean_Discharge) * Period,
  data = biomass.data
)
```

```
check_model(carbon.discharge.ancova)
```

Table 57: Summary of the carbon by discharge ANCOVA.

| Term                       | Sums-of-Squares | df | F      | P-value |
|----------------------------|-----------------|----|--------|---------|
| log(Mean_Discharge)        | 3.098           | 1  | 35.101 | 0.000   |
| Period                     | 0.086           | 1  | 0.976  | 0.329   |
| log(Mean_Discharge):Period | 0.007           | 1  | 0.076  | 0.784   |
| Residuals                  | 3.707           | 42 | NA     | NA      |

Table 58: Table of the effect sizes in the carbon by discharge ANCOVA.

| Term                       | Eta-squared | CI   | CI Low | CI High |
|----------------------------|-------------|------|--------|---------|
| log(Mean_Discharge)        | 0.455       | 0.95 | 0.27   | 1       |
| Period                     | 0.023       | 0.95 | 0.00   | 1       |
| log(Mean_Discharge):Period | 0.002       | 0.95 | 0.00   | 1       |

## R Session Information

Table 59: Packages for data management and analyses.

| Package      | Loaded Version | Date       |
|--------------|----------------|------------|
| bayestestR   | 0.12.1.1       | 2022-07-04 |
| broom        | 1.0.0          | 2022-07-01 |
| car          | 3.1-0          | 2022-06-15 |
| carData      | 3.0-5          | 2022-01-06 |
| correlation  | 0.8.2          | 2022-08-09 |
| datawizard   | 0.5.0          | 2022-08-07 |
| dplyr        | 1.0.9          | 2022-04-28 |
| easystats    | 0.5.1          | 2022-07-18 |
| effectsize   | 0.7.0.5        | 2022-08-10 |
| emmeans      | 1.8.0          | 2022-08-05 |
| forcats      | 0.5.1          | 2021-01-27 |
| ggplot2      | 3.3.6          | 2022-05-03 |
| indicspecies | 1.7.12         | 2022-03-06 |
| insight      | 0.18.2         | 2022-08-10 |
| kableExtra   | 1.3.4          | 2021-02-20 |
| knitr        | 1.39           | 2022-04-26 |
| lattice      | 0.20-45        | 2021-09-22 |
| modelbased   | 0.8.1.1        | 2022-06-25 |
| parameters   | 0.18.2         | 2022-08-10 |
| performance  | 0.9.2          | 2022-08-10 |
| permute      | 0.9-7          | 2022-01-27 |
| purrr        | 0.3.4          | 2020-04-17 |
| readr        | 2.1.2          | 2022-01-30 |
| report       | 0.5.1.2        | 2022-07-08 |
| reshape2     | 1.4.4          | 2020-04-09 |
| see          | 0.7.2          | 2022-08-10 |
| stringr      | 1.4.0          | 2019-02-10 |
| tibble       | 3.1.8          | 2022-07-22 |
| tidyr        | 1.2.0          | 2022-02-01 |
| tidyverse    | 1.3.2          | 2022-07-18 |
| vegan        | 2.6-2          | 2022-04-17 |
| waterData    | 1.0.8          | 2017-04-28 |