OGC-biomass

Primary Analyses

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Contents

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.

```r
## 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)
```

```r
## 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")
```

```r
## 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

```r
## 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 η_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	0.207
Season	winter - summer	0	-0.796	0.414	41	-1.922	0.062
Season	winter - fall	0	-0.818	0.429	41	-1.907	0.064
Season	spring - summer	0	-0.246	0.404	41	-0.609	0.546
Season	spring - fall	0	-0.268	0.419	41	-0.640	0.526
Season	summer - fall	0	-0.022	0.404	41	-0.055	0.957

Table 7: Effect sizes for the constrasts 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 constrasts 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

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

```r
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	0.114
Season	winter - summer	0	-0.919	0.400	41	-2.296	0.027
Season	winter - fall	0	-1.096	0.415	41	-2.642	0.012
Season	spring - summer	0	-0.249	0.391	41	-0.637	0.528
Season	spring - fall	0	-0.425	0.406	41	-1.049	0.300
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	0.776
Period*Season	Period1980 winter - Period1980 spring	0	-0.318	0.574	41	-0.554	0.582
Period*Season	Period1980 winter - Period2010 spring	0	-1.179	0.574	41	-2.056	0.046
Period*Season	Period1980 winter - Period1980 summer	0	-1.084	0.553	41	-1.962	0.057
Period*Season	Period1980 winter - Period2010 summer	0	-0.910	0.553	41	-1.647	0.107
Period*Season	Period1980 winter - Period1980 fall	0	-1.842	0.574	41	-3.212	0.003
Period*Season	Period1980 winter - Period2010 fall	0	-0.505	0.574	41	-0.881	0.383
Period*Season	Period2010 winter - Period1980 spring	0	-0.146	0.602	41	-0.242	0.810
Period*Season	Period2010 winter - Period2010 spring	0	-1.007	0.602	41	-1.674	0.102
Period*Season	Period2010 winter - Period1980 summer	0	-0.912	0.582	41	-1.568	0.125
Period*Season	Period2010 winter - Period2010 summer	0	-0.738	0.582	41	-1.269	0.212
Period*Season	Period2010 winter - Period1980 fall	0	-1.670	0.602	41	-2.777	0.008
Period*Season	Period2010 winter - Period2010 fall	0	-0.333	0.602	41	-0.554	0.583
Period*Season	Period1980 spring - Period2010 spring	0	-0.861	0.574	41	-1.502	0.141
Period*Season	Period1980 spring - Period1980 summer	0	-0.767	0.553	41	-1.387	0.173
Period*Season	Period1980 spring - Period2010 summer	0	-0.592	0.553	41	-1.072	0.290
Period*Season	Period1980 spring - Period1980 fall	0	-1.525	0.574	41	-2.658	0.011
Period*Season	Period1980 spring - Period2010 fall	0	-0.187	0.574	41	-0.327	0.745
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	0.629
Period*Season	Period2010 spring - Period1980 fall	0	-0.663	0.574	41	-1.157	0.254
Period*Season	Period2010 spring - Period2010 fall	0	0.674	0.574	41	1.175	0.247
Period*Season	Period1980 summer - Period2010 summer	0	0.174	0.531	41	0.328	0.745
Period*Season	Period1980 summer - Period1980 fall	0	-0.758	0.553	41	-1.372	0.178
Period*Season	Period1980 summer - Period2010 fall	0	0.579	0.553	41	1.048	0.301
Period*Season	Period2010 summer - Period1980 fall	0	-0.932	0.553	41	-1.687	0.099
Period*Season	Period2010 summer - Period2010 fall	0	0.405	0.553	41	0.733	0.468
Period*Season	Period1980 fall - Period2010 fall	0	1.337	0.574	41	2.331	0.025

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 η_P^2 using `eta_squared()`. Pairwise contrasts between influential factors were performed using `emmeans()`, with effect sizes for contrasts calculated as Cohen's d.

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

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

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

# Density
predator.density <- invertebrate.density.matrix[, 47:72] %>%
  rowSums()
predator.density.data <- tibble(sampling.info, predator.density) %>%
  rename(Summed_Density = 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	0.569
Period*Season	Period1980 winter - Period1980 spring	0	353.366	2675.934	41	0.132	0.896
Period*Season	Period1980 winter - Period2010 spring	0	92.877	2675.934	41	0.035	0.972
Period*Season	Period1980 winter - Period1980 summer	0	-4658.950	2578.594	41	-1.807	0.078
Period*Season	Period1980 winter - Period2010 summer	0	1165.428	2578.594	41	0.452	0.654
Period*Season	Period1980 winter - Period1980 fall	0	-7531.450	2675.934	41	-2.815	0.007
Period*Season	Period1980 winter - Period2010 fall	0	1555.815	2675.934	41	0.581	0.564
Period*Season	Period2010 winter - Period1980 spring	0	-1259.646	2806.543	41	-0.449	0.656
Period*Season	Period2010 winter - Period2010 spring	0	-1520.136	2806.543	41	-0.542	0.591
Period*Season	Period2010 winter - Period1980 summer	0	-6271.963	2713.892	41	-2.311	0.026
Period*Season	Period2010 winter - Period2010 summer	0	-447.585	2713.892	41	-0.165	0.870
Period*Season	Period2010 winter - Period1980 fall	0	-9144.462	2806.543	41	-3.258	0.002
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	0.923
Period*Season	Period1980 spring - Period1980 summer	0	-5012.316	2578.594	41	-1.944	0.059
Period*Season	Period1980 spring - Period2010 summer	0	812.061	2578.594	41	0.315	0.754
Period*Season	Period1980 spring - Period1980 fall	0	-7884.816	2675.934	41	-2.947	0.005
Period*Season	Period1980 spring - Period2010 fall	0	1202.449	2675.934	41	0.449	0.656
Period*Season	Period2010 spring - Period1980 summer	0	-4751.827	2578.594	41	-1.843	0.073
Period*Season	Period2010 spring - Period2010 summer	0	1072.551	2578.594	41	0.416	0.680
Period*Season	Period2010 spring - Period1980 fall	0	-7624.327	2675.934	41	-2.849	0.007
Period*Season	Period2010 spring - Period2010 fall	0	1462.938	2675.934	41	0.547	0.588
Period*Season	Period1980 summer - Period2010 summer	0	5824.378	2477.433	41	2.351	0.024
Period*Season	Period1980 summer - Period1980 fall	0	-2872.500	2578.594	41	-1.114	0.272
Period*Season	Period1980 summer - Period2010 fall	0	6214.765	2578.594	41	2.410	0.021
Period*Season	Period2010 summer - Period1980 fall	0	-8696.877	2578.594	41	-3.373	0.002
Period*Season	Period2010 summer - Period2010 fall	0	390.387	2578.594	41	0.151	0.880
Period*Season	Period1980 fall - Period2010 fall	0	9087.265	2675.934	41	3.396	0.002

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 seasonin 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	0.104
Season	winter - summer	0	-0.944	0.401	41	-2.353	0.023
Season	winter - fall	0	-1.100	0.416	41	-2.646	0.012
Season	spring - summer	0	-0.253	0.392	41	-0.646	0.522
Season	spring - fall	0	-0.409	0.407	41	-1.005	0.321
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	0.792
Period*Season	Period1980 winter - Period1980 spring	0	-0.336	0.575	41	-0.584	0.563
Period*Season	Period1980 winter - Period2010 spring	0	-1.193	0.575	41	-2.074	0.044
Period*Season	Period1980 winter - Period1980 summer	0	-1.113	0.554	41	-2.009	0.051
Period*Season	Period1980 winter - Period2010 summer	0	-0.921	0.554	41	-1.662	0.104
Period*Season	Period1980 winter - Period1980 fall	0	-1.864	0.575	41	-3.241	0.002
Period*Season	Period1980 winter - Period2010 fall	0	-0.481	0.575	41	-0.837	0.407
Period*Season	Period2010 winter - Period1980 spring	0	-0.175	0.603	41	-0.291	0.773
Period*Season	Period2010 winter - Period2010 spring	0	-1.032	0.603	41	-1.712	0.094
Period*Season	Period2010 winter - Period1980 summer	0	-0.953	0.583	41	-1.634	0.110
Period*Season	Period2010 winter - Period2010 summer	0	-0.761	0.583	41	-1.304	0.199
Period*Season	Period2010 winter - Period1980 fall	0	-1.704	0.603	41	-2.825	0.007
Period*Season	Period2010 winter - Period2010 fall	0	-0.321	0.603	41	-0.533	0.597
Period*Season	Period1980 spring - Period2010 spring	0	-0.857	0.575	41	-1.490	0.144
Period*Season	Period1980 spring - Period1980 summer	0	-0.778	0.554	41	-1.404	0.168
Period*Season	Period1980 spring - Period2010 summer	0	-0.585	0.554	41	-1.056	0.297
Period*Season	Period1980 spring - Period1980 fall	0	-1.528	0.575	41	-2.658	0.011
Period*Season	Period1980 spring - Period2010 fall	0	-0.146	0.575	41	-0.254	0.801
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	0.626
Period*Season	Period2010 spring - Period1980 fall	0	-0.671	0.575	41	-1.167	0.250
Period*Season	Period2010 spring - Period2010 fall	0	0.711	0.575	41	1.237	0.223
Period*Season	Period1980 summer - Period2010 summer	0	0.193	0.532	41	0.362	0.719
Period*Season	Period1980 summer - Period1980 fall	0	-0.750	0.554	41	-1.354	0.183
Period*Season	Period1980 summer - Period2010 fall	0	0.632	0.554	41	1.140	0.261
Period*Season	Period2010 summer - Period1980 fall	0	-0.943	0.554	41	-1.702	0.096
Period*Season	Period2010 summer - Period2010 fall	0	0.439	0.554	41	0.793	0.432
Period*Season	Period1980 fall - Period2010 fall	0	1.382	0.575	41	2.404	0.021

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	0.075
Season	winter - summer	0	-0.962	0.556	41	-1.731	0.091
Season	winter - fall	0	-1.400	0.576	41	-2.433	0.019
Season	spring - summer	0	0.089	0.543	41	0.164	0.870
Season	spring - fall	0	-0.349	0.563	41	-0.621	0.538
Season	summer - fall	0	-0.439	0.543	41	-0.808	0.424

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.

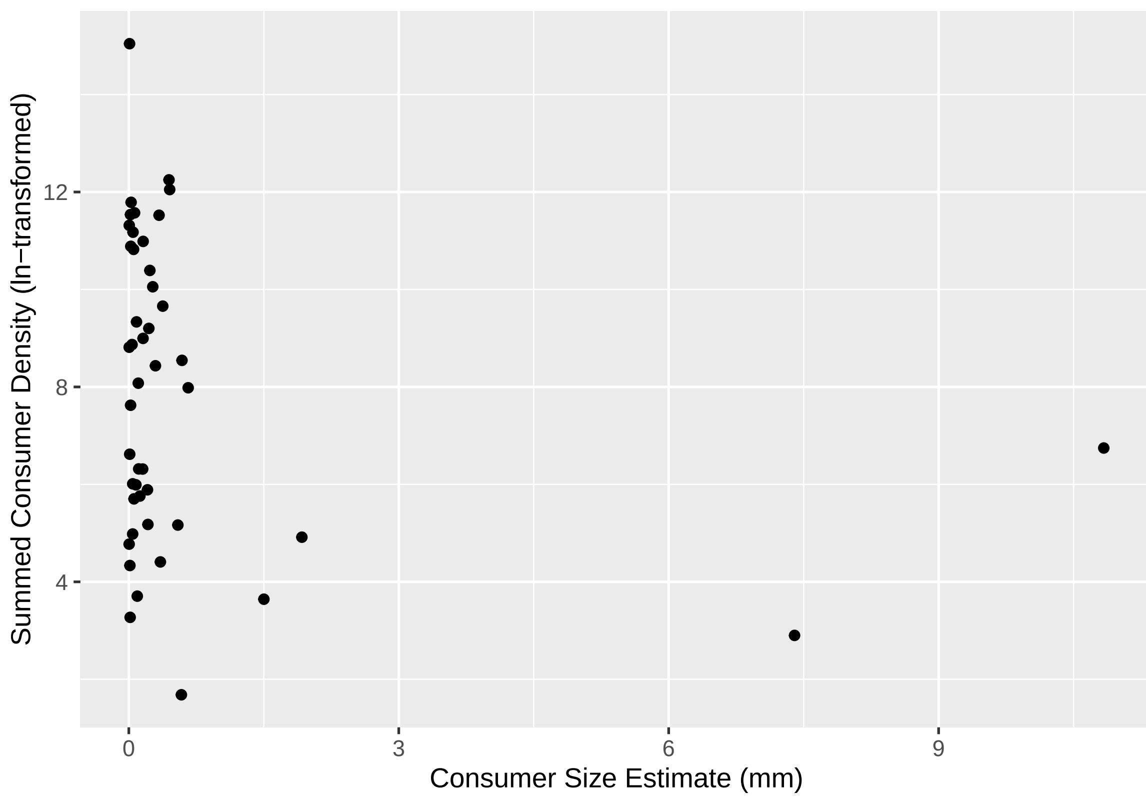
Contrast	Cohen's d	SE	df	CI Lower	CI Upper
(Period1980 - Period2010)	-0.685	0.296	41	-1.282	-0.088

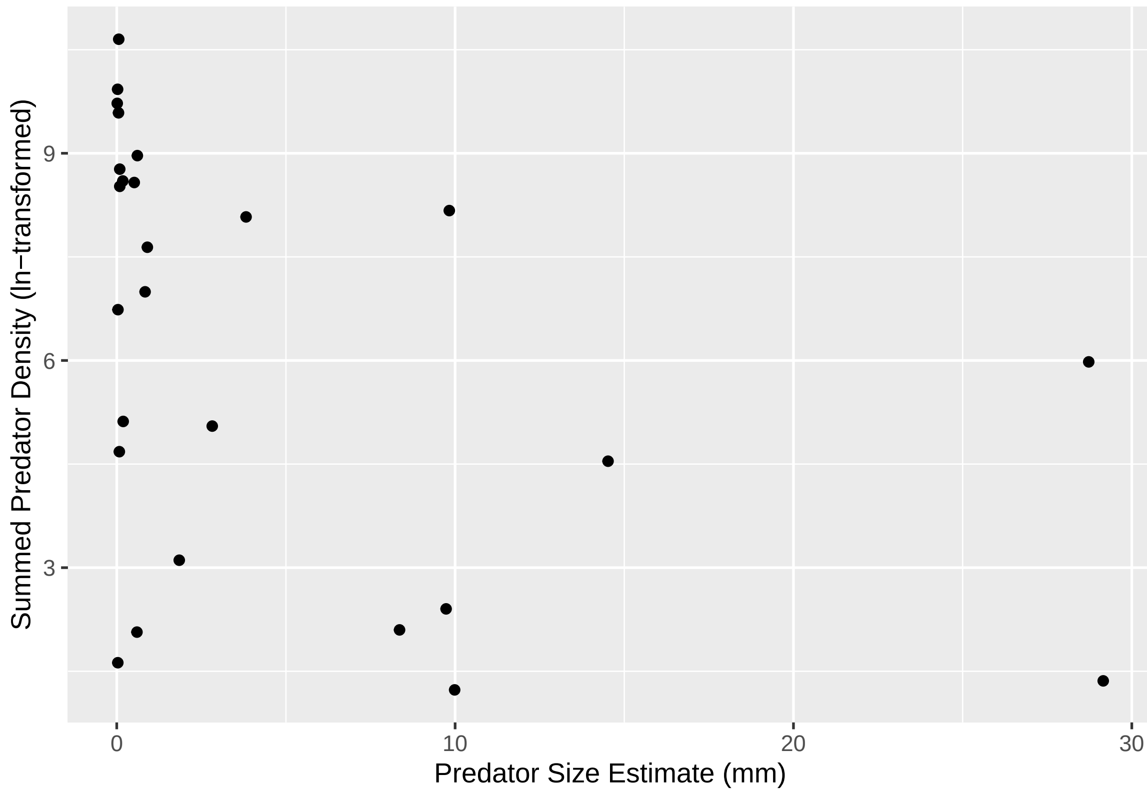
Size Groupings

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
)
```






```r
## 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, Cyrnellus, 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, Shipsa
- 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
```

```r
## 1980s consumers group 1 taxa
group.1.consumer.biomass.1980s <- consumer.biomass.1980s %>%
  select(
    Amphinemura, Ancyronyx, Baetidae, Baetisca, Brachycentrus, Caenidae,
    Cheumatopsyche, Chironomidae, Crambidae, Cyrnellus, 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
```

```r
## 1980s consumers group 2 taxa
group.2.consumer.biomass.1980s <- consumer.biomass.1980s %>%
  select(Chimarra, Ectopria, Hydropsyche, Macrostemum, Paraponyx, Shipsa) %>%
  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
```

```r
## 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
```

```r
## 2010s consumers group 1 taxa
group.1.consumer.biomass.2010s <- consumer.biomass.2010s %>%
  select(
    Amphinemura, Ancyronyx, Baetidae, Baetisca, Brachycentrus, Caenidae,
    Cheumatopsyche, Chironomidae, Crambidae, Cyrnellus, 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
```

```r
## 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
```

```r
## 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
```

```r
## 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, Cernotina, 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
```

```r
## 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
```

```r
## 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
```

```r
## 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
```

```r
## 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
```

```r
## 2010s predators group 2 taxa
group.2.predator.biomass.2010s <- predator.biomass.2010s %>%
  select(Aeshna, Boyeria, Corydalus, 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
```

```r
## 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
```

```r
## 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

```r
## 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
```

```r
## 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, Cyrnellus, 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, Shipsa
- Group 3: Ironoquia, Neargyractis, Pteronarcys, Pycnopsyche

```r
## 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
```

```r
## 1980s consumers group 1 taxa
group.1.consumer.density.1980s <- consumer.density.1980s %>%
  select(
    Amphinemura, Ancyronyx, Baetidae, Baetisca, Brachycentrus, Caenidae,
    Cheumatopsyche, Chironomidae, Crambidae, Cyrnellus, 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
```

```r
## 1980s consumers group 2 taxa
group.2.consumer.density.1980s <- consumer.density.1980s %>%
  select(Chimarra, Ectopria, Hydropsyche, Macrostemum, Paraponyx, Shipsa) %>%
  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
```

```r
## 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
```

```r
## 2010s consumers group 1 taxa
group.1.consumer.density.2010s <- consumer.density.2010s %>%
  select(
    Amphinemura, Ancyronyx, Baetidae, Baetisca, Brachycentrus, Caenidae,
    Cheumatopsyche, Chironomidae, Crambidae, Cyrnellus, 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
```

```r
## 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
```

```r
## 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
```

```r
## 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
```

```r
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, Cernotina, 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
```

```r
## 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
```

```r
## 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
```

```r
## 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
```

```r
## 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
```

```r
## 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
```

```r
## 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
```

```r
## 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

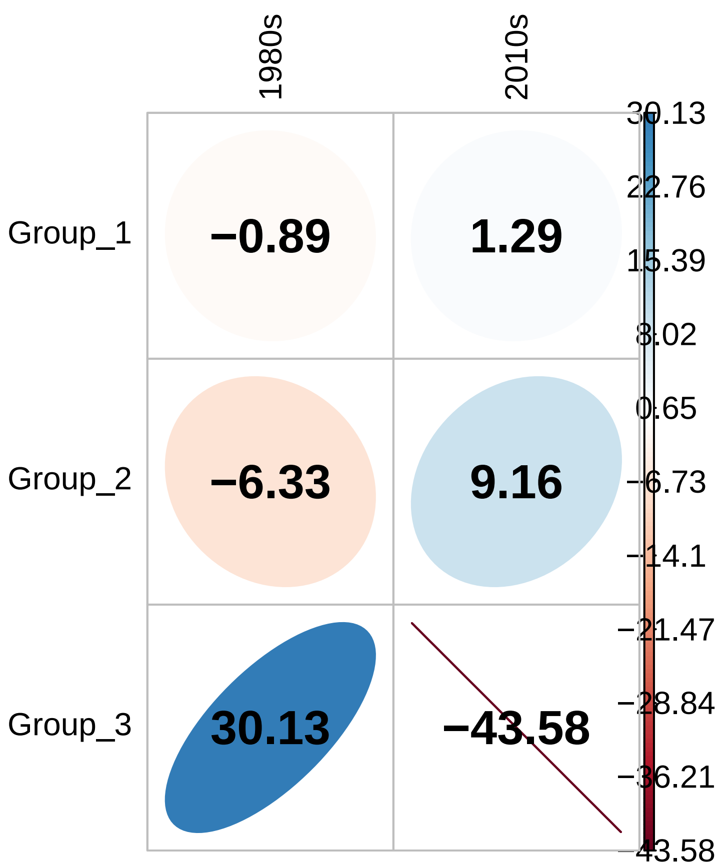


Figure 1: Plot of residuals from the consumer chi-squared test.

Consumer Density

```r
## 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
)
```

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

```r
## 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

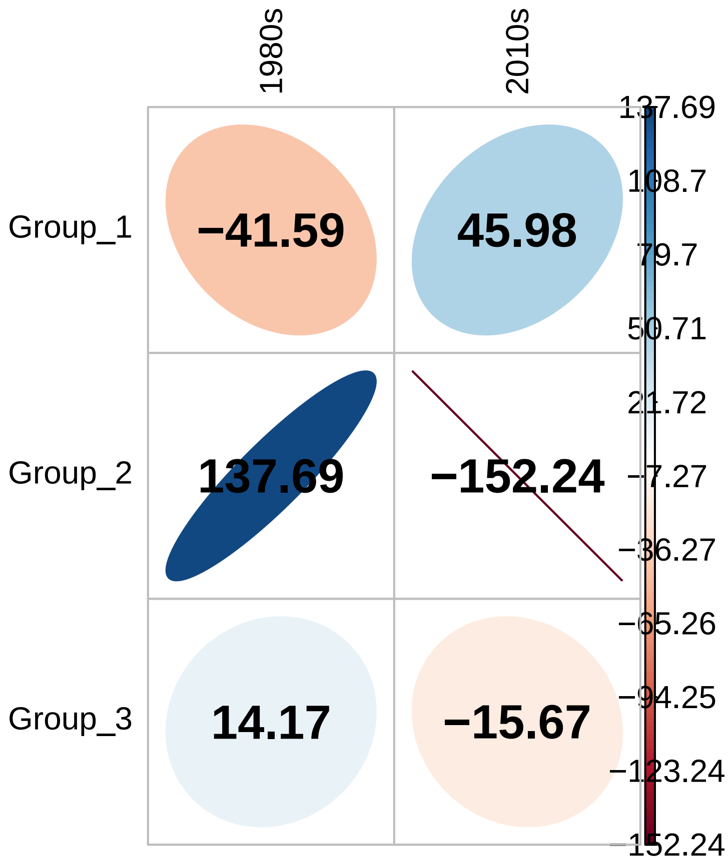


Figure 2: Plot of residuals from the consumer chi-squared test.

Predator Biomass

```r
## 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
)
```

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

```r
## 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

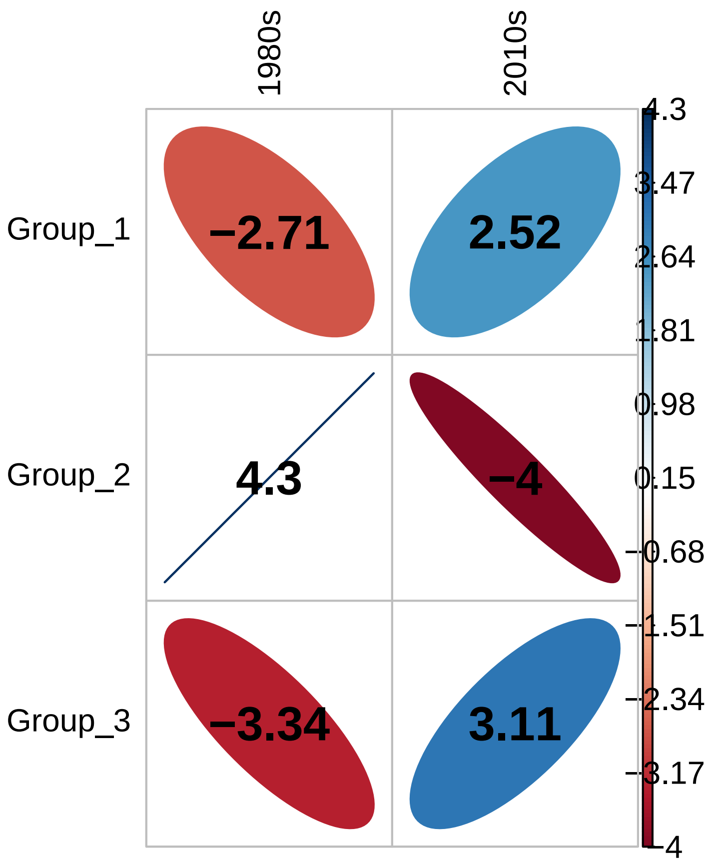


Figure 3: Plot of residuals from the predator chi-squared test.

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

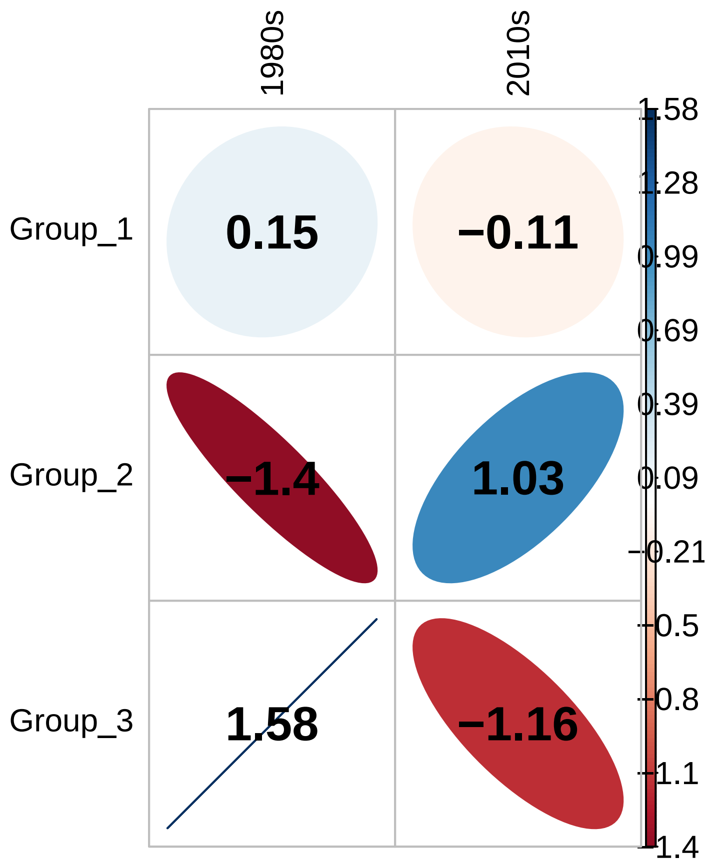


Figure 4: Plot of residuals from the predator chi-squared test.

Biomass Contributions

Biomass contributions were calculated for consumer and predator groups.

```r
## 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

```r
## 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

```r
## 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. Effect sizes were calculated using `cohens_d()`.

- 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))
```

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

cohens_d(log(Hydropsyche.80.size + 0.00001), log(Hydropsyche.10.size + 0.00001))
# d = 0.53
```

```r
## 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

cohens_d(log(Cheumatopsyche.80.size + 0.00001), log(Cheumatopsyche.10.size + 0.00001))
# d = 1.48
```

```r
## 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

cohens_d(log(Chimarra.80.size + 0.00001), log(Chimarra.10.size + 0.00001))
# d = 0.12
```

```r
## 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

cohens_d(log(Heptageniidae.80.size + 0.00001), log(Heptageniidae.10.size + 0.00001))
# d = 0.12
```

```r
## 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

cohens_d(log(Chironomidae.80.size + 0.00001), log(Chironomidae.10.size + 0.00001))
# d = 0.05
```

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

```r
cohens_d(log(Corydalus.80.size + 0.00001), log(Corydalus.10.size + 0.00001))
# d = 0.41
```

```r
## 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

cohens_d(log(Paragnetina.80.size + 0.00001), log(Paragnetina.10.size + 0.00001))
# d = 0.45
```

```r
## 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

cohens_d(log(Neurocordulia.80.size + 0.00001), log(Neurocordulia.10.size + 0.00001))
# d = 0.53
```

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.

```r
## 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)
```

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

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

```r
## 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
Cyrnellus	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:

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

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	0.13.0	2022-09-18
broom	1.0.1	2022-08-29
car	3.1-1	2022-10-19
carData	3.0-5	2022-01-06
correlation	0.8.3	2022-10-09
datawizard	0.6.4	2022-11-19
dplyr	1.0.10	2022-09-01
easystats	0.6.0	2022-11-29
effectsize	0.8.2	2022-10-31
emmeans	1.8.3	2022-12-06
forcats	0.5.2	2022-08-19
ggplot2	3.4.0	2022-11-04
indicspecies	1.7.12	2022-03-06
insight	0.18.8	2022-11-24
kableExtra	1.3.4	2021-02-20
knitr	1.41	2022-11-18
lattice	0.20-45	2021-09-22
modelbased	0.8.5	2022-08-19
parameters	0.20.0	2022-11-21
performance	0.10.1	2022-11-25
permute	0.9-7	2022-01-27
purrr	0.3.5	2022-10-06
readr	2.1.3	2022-10-01
report	0.5.5.1	2022-08-22
reshape2	1.4.4	2020-04-09
see	0.7.4	2022-11-26
stringr	1.5.0	2022-12-02
tibble	3.1.8	2022-07-22
tidyr	1.2.1	2022-09-08
tidyverse	1.3.2	2022-07-18
vegan	2.6-4	2022-10-11
waterData	1.0.8	2017-04-28