OGC-biomass

Environmental Comparisons

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Contents

Load Data

```
## Read in sampling period environmental data
environmental.data <- read_csv(
    "data/OGC_final_biomass_data.csv",
    show_col_types = FALSE
    ) %>%
    select(UID, Year, Season, Period, CaCO, Carbon, Conductivity, DO, pH,
                 Water_Temperature, Air_Temperature, Precipitation, Mean_Discharge)

## Set variables as factors
environmental.data$UID    <- as_factor(environmental.data$UID)
environmental.data$Year   <- as_factor(environmental.data$Year)
environmental.data$Season <- as_factor(environmental.data$Season)
environmental.data$Period <- as_factor(environmental.data$Period)

## Load the final workspace for reproducibility
load("data_analysis/OGC-biomass-environmental_comparisons-workspace.RData")
```

USGS Discharge Data

We obtained average daily discharge (m^3 s^{-1}) and water chemistry metrics from the United States Geological Survey (USGS, gage 02202500) to calculate the average discharge over a two-week period preceding each sampling date. Discharge data were downloaded using the `waterData` package. Water data were collected from the USGS water quality dataset, and air temperature and precipitation data were gathered from the National Weather Service Forecast Office in Louisville, GA.

```
## List of start dates
start.dates <- c("1981-12-02", "1982-01-09", "1982-02-15", "1982-03-09",
                 "1982-04-02", "1982-04-30", "1982-05-25", "1982-06-26",
                 "1982-07-23", "1982-08-19", "1982-09-15", "1982-10-15",
                 "1982-11-18", "1982-12-24", "1983-01-22", "1983-02-18",
                 "1983-03-25", "1983-04-23", "1983-05-20", "1983-06-17",
                 "1983-07-15", "1983-08-13", "1983-09-09", "1983-10-08",
                 "1983-11-04",
                 "2015-06-26", "2015-07-27", "2015-08-29", "2015-10-02",
                 "2015-11-06", "2015-12-03", "2016-01-21", "2016-02-24",
                 "2016-03-30", "2016-04-27", "2016-05-31", "2016-08-03",
                 "2016-09-05", "2016-10-05", "2016-11-02", "2016-11-30",
                 "2017-01-06", "2017-02-10", "2017-03-08", "2017-04-12",
                 "2017-05-03", "2017-05-29", "2017-07-05", "2017-08-08")

## List of end dates
end.dates <- c("1981-12-16", "1982-01-23", "1982-03-01", "1982-03-23",
               "1982-04-16", "1982-05-14", "1982-06-08", "1982-07-10",
               "1982-08-06", "1982-09-02", "1982-09-29", "1982-10-29",
               "1982-12-02", "1983-01-07", "1983-02-05", "1983-03-04",
               "1983-04-08", "1983-05-07", "1983-06-03", "1983-07-01",
               "1983-07-29", "1983-08-27", "1983-09-23", "1983-10-22",
               "1983-11-18",
               "2015-07-10", "2015-08-10", "2015-09-12", "2015-10-16",
               "2015-11-20", "2015-12-17", "2016-02-04", "2016-03-09",
               "2016-04-13", "2016-05-11", "2016-06-14", "2016-08-17",
               "2016-09-19", "2016-10-19", "2016-11-16", "2016-12-14",
               "2017-01-20", "2017-02-24", "2017-03-22", "2017-04-26",
               "2017-05-17", "2017-06-12", "2017-07-19", "2017-08-22")

## Bind start and end dates into a single dataframe
flow.dates <- as.data.frame(cbind(start.dates, end.dates))

## Add UID identifier to flow dates
flow.dates$UID <- environmental.data$UID
```

```r
## Empty dataframe for discharge data
discharge.data <- tibble(data.frame(matrix(0, nrow = 15, ncol = 49)))

## Append data for all dates
for(x in 1:49){
  require(waterData)
  bin.1 <- importDVs(staid = "02202500", code = "00060", stat = "00003",
                     sdate = flow.dates[x, 1],
                     edate = flow.dates[x, 2])
  bin.2 <- cleanUp(bin.1, task = "fix", replace = 0.001)
  bin.3 <- fillMiss(bin.1, block = 2, pmiss = 5, model = "trend",
                    smooth = FALSE, log = "y")
  bin.4 <- bin.3[, c(2, 3)]
  colnames(bin.4) <- c(flow.dates[x, 3])
  discharge.data[, x] <- bin.4[, 1]
}
```

```r
## Calculate two week mean & convert from ft3 to m3
mean.discharge <- sapply(discharge.data, mean)
metric.shift   <- (mean.discharge / 35.315)

## Create mean discharge dataframe
metric.shift            <- tibble(mean.discharge)
metric.shift$UID        <- environmental.data$UID
```

Sampling Period Environmental Comparisons

Environmental Variable ANOVAs

ANOVAs were conducted for discharge, precipitation, water temperature, and air temperature to test the effects of period, season, and the interaction with Type II sums-of-squares. ANOVA assumptions were inspected graphically using `check_model()`. 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.

Discharge

```
discharge.anova <- lm(
    log(Mean_Discharge) ~ Period * Season, data = environmental.data
    )
```

```
check_model(discharge.anova)
```

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

	Sums-of-Squares	df	F	P-value
Period	0.412	1	0.637	0.429
Season	20.681	3	10.657	0.000
Period:Season	4.478	3	2.308	0.091
Residuals	26.522	41	NA	NA

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

Term	Eta-squared	CI	CI Low	CI High
Period	0.015	0.95	0.000	1
Season	0.438	0.95	0.225	1
Period:Season	0.144	0.95	0.000	1

Table 3: Estimated marginal means by season in the discharge ANOVA.

Season	Estimate	SE	df	t	P-value
winter	4.177	0.243	41	17.223	0
spring	4.307	0.232	41	18.550	0
summer	3.027	0.215	41	14.082	0
fall	2.856	0.232	41	12.300	0

Table 4: Estimated marginal means by period and season in the discharge ANOVA.

Period	Season	Estimate	SE	df	t	P-value
1980	winter	4.051	0.328	41	12.338	0
2010	winter	4.327	0.360	41	12.030	0
1980	spring	4.818	0.328	41	14.674	0
2010	spring	3.795	0.328	41	11.559	0
1980	summer	3.247	0.304	41	10.682	0
2010	summer	2.807	0.304	41	9.233	0
1980	fall	2.587	0.328	41	7.880	0
2010	fall	3.124	0.328	41	9.516	0

Table 5: Pairwise contrasts by season in the discharge ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	t	P-value
Season	winter - spring	0	-0.130	0.336	41	-0.388	0.700
Season	winter - summer	0	1.150	0.324	41	3.547	0.001
Season	winter - fall	0	1.321	0.336	41	3.934	0.000
Season	spring - summer	0	1.280	0.316	41	4.045	0.000
Season	spring - fall	0	1.451	0.328	41	4.419	0.000
Season	summer - fall	0	0.171	0.316	41	0.541	0.591

Table 6: Pairwise contrasts by period and season in the discharge ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	t	P-value
Period*Season	Period1980 winter - Period2010 winter	0	-0.276	0.487	41	-0.567	0.574
Period*Season	Period1980 winter - Period1980 spring	0	-0.767	0.464	41	-1.652	0.106
Period*Season	Period1980 winter - Period2010 spring	0	0.256	0.464	41	0.551	0.585
Period*Season	Period1980 winter - Period1980 summer	0	0.804	0.447	41	1.797	0.080
Period*Season	Period1980 winter - Period2010 summer	0	1.244	0.447	41	2.781	0.008
Period*Season	Period1980 winter - Period1980 fall	0	1.464	0.464	41	3.153	0.003
Period*Season	Period1980 winter - Period2010 fall	0	0.927	0.464	41	1.996	0.053
Period*Season	Period2010 winter - Period1980 spring	0	-0.491	0.487	41	-1.008	0.319
Period*Season	Period2010 winter - Period2010 spring	0	0.532	0.487	41	1.092	0.281
Period*Season	Period2010 winter - Period1980 summer	0	1.080	0.471	41	2.293	0.027
Period*Season	Period2010 winter - Period2010 summer	0	1.520	0.471	41	3.228	0.002
Period*Season	Period2010 winter - Period1980 fall	0	1.740	0.487	41	3.573	0.001
Period*Season	Period2010 winter - Period2010 fall	0	1.203	0.487	41	2.469	0.018
Period*Season	Period1980 spring - Period2010 spring	0	1.023	0.464	41	2.203	0.033
Period*Season	Period1980 spring - Period1980 summer	0	1.571	0.447	41	3.511	0.001
Period*Season	Period1980 spring - Period2010 summer	0	2.011	0.447	41	4.495	0.000
Period*Season	Period1980 spring - Period1980 fall	0	2.231	0.464	41	4.805	0.000
Period*Season	Period1980 spring - Period2010 fall	0	1.694	0.464	41	3.648	0.001
Period*Season	Period2010 spring - Period1980 summer	0	0.548	0.447	41	1.225	0.228
Period*Season	Period2010 spring - Period2010 summer	0	0.989	0.447	41	2.209	0.033
Period*Season	Period2010 spring - Period1980 fall	0	1.208	0.464	41	2.602	0.013
Period*Season	Period2010 spring - Period2010 fall	0	0.671	0.464	41	1.445	0.156
Period*Season	Period1980 summer - Period2010 summer	0	0.440	0.430	41	1.024	0.312
Period*Season	Period1980 summer - Period1980 fall	0	0.660	0.447	41	1.475	0.148
Period*Season	Period1980 summer - Period2010 fall	0	0.123	0.447	41	0.274	0.785
Period*Season	Period2010 summer - Period1980 fall	0	0.220	0.447	41	0.491	0.626
Period*Season	Period2010 summer - Period2010 fall	0	-0.318	0.447	41	-0.710	0.482
Period*Season	Period1980 fall - Period2010 fall	0	-0.537	0.464	41	-1.157	0.254

Table 7: Effect sizes for the pairwise contrasts by season in the discharge ANOVA.

Contrast	Cohen's d	SE	df	CI Lower	CI Upper
(winter - spring)	-0.162	0.418	41	-1.006	0.682
(winter - summer)	1.429	0.433	41	0.555	2.303
(winter - fall)	1.642	0.455	41	0.723	2.561
(spring - summer)	1.591	0.431	41	0.721	2.461
(spring - fall)	1.804	0.454	41	0.887	2.721
(summer - fall)	0.213	0.394	41	-0.583	1.009

Table 8: Effect sizes for the pairwise contrasts by period and season in the discharge ANOVA.

Contrast	Cohen's d	SE	df	CI Lower	CI Upper
(Period1980 winter - Period2010 winter)	-0.343	0.607	41	-1.568	0.882
(Period1980 winter - Period1980 spring)	-0.954	0.587	41	-2.139	0.231
(Period1980 winter - Period2010 spring)	0.318	0.578	41	-0.850	1.486
(Period1980 winter - Period1980 summer)	1.000	0.567	41	-0.146	2.145
(Period1980 winter - Period2010 summer)	1.547	0.582	41	0.372	2.722
(Period1980 winter - Period1980 fall)	1.820	0.611	41	0.586	3.055
(Period1980 winter - Period2010 fall)	1.152	0.591	41	-0.042	2.346
(Period2010 winter - Period1980 spring)	-0.611	0.609	41	-1.841	0.620
(Period2010 winter - Period2010 spring)	0.661	0.610	41	-0.571	1.893
(Period2010 winter - Period1980 summer)	1.343	0.604	41	0.123	2.563
(Period2010 winter - Period2010 summer)	1.890	0.622	41	0.635	3.146
(Period2010 winter - Period1980 fall)	2.163	0.651	41	0.849	3.478
(Period2010 winter - Period2010 fall)	1.495	0.628	41	0.228	2.763
(Period1980 spring - Period2010 spring)	1.272	0.594	41	0.072	2.472
(Period1980 spring - Period1980 summer)	1.953	0.597	41	0.748	3.158
(Period1980 spring - Period2010 summer)	2.501	0.621	41	1.246	3.755
(Period1980 spring - Period1980 fall)	2.774	0.654	41	1.454	4.094
(Period1980 spring - Period2010 fall)	2.106	0.622	41	0.849	3.363
(Period2010 spring - Period1980 summer)	0.682	0.561	41	-0.452	1.815
(Period2010 spring - Period2010 summer)	1.229	0.573	41	0.073	2.386
(Period2010 spring - Period1980 fall)	1.502	0.601	41	0.289	2.715
(Period2010 spring - Period2010 fall)	0.834	0.585	41	-0.346	2.015
(Period1980 summer - Period2010 summer)	0.547	0.538	41	-0.539	1.634
(Period1980 summer - Period1980 fall)	0.821	0.564	41	-0.318	1.959
(Period1980 summer - Period2010 fall)	0.153	0.557	41	-0.971	1.277
(Period2010 summer - Period1980 fall)	0.273	0.557	41	-0.852	1.398
(Period2010 summer - Period2010 fall)	-0.395	0.558	41	-1.522	0.732
(Period1980 fall - Period2010 fall)	-0.668	0.582	41	-1.843	0.508

Precipitation

```r
precipitation.anova <- lm(
    Precipitation ~ Period * Season, data = environmental.data
    )
```

```r
check_model(precipitation.anova)
```

Table 9: ANOVA results for precipitation by period, season, and the interaction.

	Sums-of-Squares	df	F	P-value
Period	6.246	1	0.217	0.644
Season	278.938	3	3.226	0.032
Period:Season	46.817	3	0.541	0.657
Residuals	1181.706	41	NA	NA

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

Term	Eta-squared	CI	CI Low	CI High
Period	0.005	0.95	0.00	1
Season	0.191	0.95	0.01	1
Period:Season	0.038	0.95	0.00	1

Table 11: Estimated marginal means by season in the precipitation ANOVA.

Season	Estimate	SE	df	t	P-value
winter	14.176	1.619	41	8.757	0
spring	8.187	1.550	41	5.283	0
summer	10.278	1.435	41	7.163	0
fall	8.073	1.550	41	5.209	0

Table 12: Pairwise contrasts by season in the precipitation ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	t	P-value
Season	winter - spring	0	5.988	2.241	41	2.672	0.011
Season	winter - summer	0	3.898	2.163	41	1.802	0.079
Season	winter - fall	0	6.103	2.241	41	2.723	0.009
Season	spring - summer	0	-2.091	2.112	41	-0.990	0.328
Season	spring - fall	0	0.114	2.192	41	0.052	0.959
Season	summer - fall	0	2.205	2.112	41	1.044	0.303

Table 13: Effect sizes for the pairwise contrasts by season in the precipitation ANOVA.

Contrast	Cohen's d	SE	df	CI Lower	CI Upper
(winter - spring)	1.115	0.435	41	0.236	1.994
(winter - summer)	0.726	0.411	41	-0.104	1.556
(winter - fall)	1.137	0.436	41	0.256	2.017
(spring - summer)	-0.389	0.396	41	-1.189	0.410
(spring - fall)	0.021	0.408	41	-0.803	0.846
(summer - fall)	0.411	0.396	41	-0.389	1.210

Water Temperature

```
water.temperature.anova <- lm(
    Water_Temperature ~ Period * Season, data = environmental.data
    )
```

```
check_model(water.temperature.anova)
```

Table 14: ANOVA results for water temperature by period, season, and the interaction.

	Sums-of-Squares	df	F	P-value
Period	29.524	1	2.392	0.130
Season	1495.705	3	40.402	0.000
Period:Season	67.991	3	1.837	0.156
Residuals	505.953	41	NA	NA

Table 15: Table of the effect sizes in the water temperature ANOVA.

Term	Eta-squared	CI	CI Low	CI High
Period	0.055	0.95	0.000	1
Season	0.747	0.95	0.625	1
Period:Season	0.118	0.95	0.000	1

Table 16: Estimated marginal means by season in the water temperature ANOVA.

Season	Estimate	SE	df	t	P-value
winter	11.200	1.059	41	10.574	0
spring	18.858	1.014	41	18.596	0
summer	26.807	0.939	41	28.553	0
fall	19.750	1.014	41	19.476	0

Table 17: Pairwise contrasts by season in the water temperature ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	t	P-value
Season	winter - spring	0	-7.658	1.466	41	-5.223	0.000
Season	winter - summer	0	-15.607	1.415	41	-11.027	0.000
Season	winter - fall	0	-8.550	1.466	41	-5.831	0.000
Season	spring - summer	0	-7.949	1.382	41	-5.752	0.000
Season	spring - fall	0	-0.892	1.434	41	-0.622	0.538
Season	summer - fall	0	7.057	1.382	41	5.107	0.000

Table 18: Effect sizes for the pairwise contrasts by season in the water temperature ANOVA.

Contrast	Cohen's d	SE	df	CI Lower	CI Upper
(winter - spring)	-2.180	0.482	41	-3.153	-1.207
(winter - summer)	-4.443	0.635	41	-5.725	-3.161
(winter - fall)	-2.434	0.496	41	-3.437	-1.431
(spring - summer)	-2.263	0.466	41	-3.204	-1.322
(spring - fall)	-0.254	0.409	41	-1.080	0.573
(summer - fall)	2.009	0.452	41	1.097	2.921

Air Temperature

```
air.temperature.anova <- lm(
    Air_Temperature ~ Period * Season, data = environmental.data
    )
```

```
check_model(air.temperature.anova)
```

Table 19: ANOVA results for air temperature by period, season, and the interaction.

	Sums-of-Squares	df	F	P-value
Period	5.835	1	0.610	0.439
Season	1628.691	3	56.783	0.000
Period:Season	11.049	3	0.385	0.764
Residuals	391.994	41	NA	NA

Table 20: Table of the effect sizes in the air temperature ANOVA.

Term	Eta-squared	CI	CI Low	CI High
Period	0.015	0.95	0.00	1
Season	0.806	0.95	0.71	1
Period:Season	0.027	0.95	0.00	1

Table 21: Estimated marginal means by season in the air temperature ANOVA.

Season	Estimate	SE	df	t	P-value
winter	10.338	0.932	41	11.089	0
spring	17.944	0.893	41	20.104	0
summer	26.540	0.826	41	32.115	0
fall	18.505	0.893	41	20.731	0

Table 22: Pairwise contrasts by season in the air temperature ANOVA.

Term	Contrast	Null Value	Estimate	SE	df	t	P-value
Season	winter - spring	0	-7.606	1.291	41	-5.893	0.00
Season	winter - summer	0	-16.201	1.246	41	-13.004	0.00
Season	winter - fall	0	-8.166	1.291	41	-6.327	0.00
Season	spring - summer	0	-8.595	1.216	41	-7.066	0.00
Season	spring - fall	0	-0.560	1.262	41	-0.444	0.66
Season	summer - fall	0	8.035	1.216	41	6.606	0.00

Table 23: Effect sizes for the pairwise contrasts by season in the air temperature ANOVA.

Contrast	Cohen's d	SE	df	CI Lower	CI Upper
(winter - spring)	-2.460	0.498	41	-3.466	-1.454
(winter - summer)	-5.240	0.705	41	-6.664	-3.816
(winter - fall)	-2.641	0.509	41	-3.669	-1.613
(spring - summer)	-2.780	0.499	41	-3.788	-1.772
(spring - fall)	-0.181	0.409	41	-1.007	0.644
(summer - fall)	2.599	0.487	41	1.615	3.582

Long-Term Environmental Comparisons

Data Management

We obtained historical USGS discharge data from December 1969 to November 2018 to determine average daily discharge for the winter-spring season of each year. Water data collected from 1974 until 2018 were also obtained from the USGS water quality dataset. Precipitation and air temperature data from 1970 until 2018 were obtained from the National Weather Service Forecast Office in Louisville, GA. We then filtered the long-term environmental data to only include the winter-spring season group (winter months = December, January, and February; spring months = March, April, and May), which are important for the flood pulse into the Ogeechee River. Mean values were then aggregated by year to generate a mean winter-spring value per year for use in time series analyses. Trends in the the time series were analyzed with Mann-Kendall tests using `MannKendall()`.

```
## Read in long-term environmental data
long.term.environmental.data <- read_csv(
    "data/OGC_long_term_environmental_data.csv",
    show_col_types = FALSE
    )

## Subset data by season groups
winter.spring.data <- long.term.environmental.data %>%
    filter(Season_Group == "WinterSpring")
```

```
## Aggregate mean values by year for the winter-spring data

## Winter-spring discharge
winter.spring.discharge <- aggregate(
    Mean_Discharge ~ Year,
    data = winter.spring.data,
    FUN = mean
    )

## Winter-spring precipitation
winter.spring.precipitation <- aggregate(
    Precipitation ~ Year,
    data = winter.spring.data,
    FUN = mean
    ) %>%
    na.omit()

## Winter-spring water temperature
winter.spring.water.temperature <- aggregate(
    Water_Temperature ~ Year,
    data = winter.spring.data,
    FUN = mean
    ) %>%
    na.omit()

## Winter-spring air temperature
winter.spring.air.temperature <- aggregate(
    Air_Temperature ~ Year,
    data = winter.spring.data,
```

```
    FUN = mean
    ) %>%
    na.omit()
```

Mann-Kendall Tests on Winter-Spring Trends

We assessed temporal trends in discharge, precipitation, water temperature, and air temperature using Mann-Kendall tests for the winter-spring season group (i.e., flood-prone seasons). We calculated monthly averages for each variable, and then assessed a shift in the time series using `MannKendall()`.

```
MannKendall(winter.spring.discharge$Mean_Discharge)
# tau = -0.248, P = 0.012
```

```
MannKendall(winter.spring.precipitation$Precipitation)
# tau = -0.087, P = 0.384
```

```
MannKendall(winter.spring.air.temperature$Air_Temperature)
# tau = -0.11, P = 0.270
```

```
MannKendall(winter.spring.water.temperature$Water_Temperature)
# tau = 0.442, P < 0.001
```

R Session Information

Table 24: 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
insight	0.18.2	2022-08-10
kableExtra	1.3.4	2021-02-20
Kendall	2.2.1	2022-03-20
knitr	1.39	2022-04-26
modelbased	0.8.1.1	2022-06-25
parameters	0.18.2	2022-08-10
performance	0.9.2	2022-08-10
purrr	0.3.4	2020-04-17
readr	2.1.2	2022-01-30
report	0.5.1.2	2022-07-08
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
waterData	1.0.8	2017-04-28