Contents

Competition and Selection

Accounting for behavioral measurement uncertainty

```r
library(MASS) # MASS clashes with dplyr... so always load first
library(pander) # pander clashes with dplyr... so always load first
library(ggplot2)
library(grid)
library(dplyr)
set.alignment('right', row.names = 'left')
```

```r
load("data/analyses_data/sel_grads_mcmc.RData")
fitness <- read.table(file = "data/fitness+competition.csv", sep = ',',
  header = TRUE, stringsAsFactors = FALSE)
load("data/analyses_data/fit_raneff_data.RData")
```

We will examine the effect of competition on selection in two general steps.

1. Is there an interaction between competition and behavior on fitness?
2. Are there nonlinear effects of behavior on fitness?

Correlations between selection gradients and competition

First a plot of the relationship between selection gradients and competition. The two study areas were pooled to calculate selection gradients for each year. Therefore we need to calculate competition for the combined study areas. Competition is the number of offspring produced during the year divided by the number of offspring that survived to spring (i.e. recruited into the population).

```r
competition_year <- fitness %>%
  filter(grid_year != "SU2008") %>%
  select(Year, competition) %>%
  unique() %>%
  group_by(Year, add = FALSE) %>%
  summarise(mean_competition = mean(competition))

n_year <- filter(fit_raneff_data, type == "blup") %>%
  group_by(Year, add = FALSE) %>% summarise(n = n())
competition_year <- left_join(competition_year, n_year, by = "Year")
competition_year$Year <- as.character(competition_year$Year)

load("data/analyses_data/sel_grads_mcmc.RData")
sel_grads_mcmc_comp <- left_join(
  filter(sel_grads_mcmc, standardization == "SD"), competition_year,
  by = "Year")
save(sel_grads_mcmc_comp, competition_year,
  file = "data/analyses_data/sel_grads_mcmc_comp.RData")

load("data/analyses_data/sel_grads_mcmc_comp.RData")

cor_sgrad_comp <- function(x){
  v <- x$variable[1]
  ct <- cor.test(x$post_mode, x$mean_competition)
  data.frame(variable = v, est = ct$estimate, lower = ct$conf.int[1],
    upper = ct$conf.int[2], stringsAsFactors = FALSE)
}

mcmc_cor <- sel_grads_mcmc_comp %>%
  group_by(variable, add = FALSE) %>%
  do(cor_sgrad_comp(.))
mcmc_cor[ ,2:4] <- round(mcmc_cor[ ,2:4], digits = 2)
mcmc_cor$print <- paste(mcmc_cor$est,
  " (", mcmc_cor$lower, ", ", mcmc_cor$upper, ")", sep = "")
```

Aggression and Competition

```r
p <- ggplot(data = filter(sel_grads_mcmc_comp, variable == "Aggression"),
  aes(x = mean_competition, y = post_mode))
p <- p + geom_errorbar(aes(ymin = lower, ymax = upper), width = 0.2, size = 0.2)
p <- p + geom_point()
p <- p + theme_bw(base_size = 10)
p <- p + scale_x_continuous(breaks = c(3,4,5,6,7,8,9))
p <- p + ylab("Selection Gradient")
p <- p + ggtitle("Aggression")
p <- p + xlab("Juvenile Competition")
p <- p + theme(panel.grid.major = element_blank(),
  panel.grid.minor = element_blank(), panel.background = element_blank(),
  strip.background = element_blank(), strip.text = element_text(size = 10),
  panel.border = element_rect(linetype = "solid", colour = "black"),
  plot.title = element_text(size = 10))
p <- p + geom_text(data = filter(mcmc_cor, variable == "Aggression"),
  aes(x = 6.5, y = 1.1, label = paste("Correlation = ", print, sep = '')),
  size = 2.5)
p + theme(plot.margin = unit(c(0.1, 0.1, 0.1, 0.1), "cm"))
```


Activity and Competition

```r
p <- ggplot(data = filter(sel_grads_mcmc_comp, variable == "Activity"),
  aes(x = mean_competition, y = post_mode))
p <- p + geom_errorbar(aes(ymin = lower, ymax = upper), width = 0.2, size = 0.2)
p <- p + geom_point()
p <- p + theme_bw(base_size = 10)
p <- p + scale_x_continuous(breaks = c(3,4,5,6,7,8,9))
p <- p + ylab("Selection Gradient")
p <- p + ggtitle("Activity")
p <- p + xlab("Juvenile Competition")
p <- p + theme(panel.grid.major = element_blank(),
  panel.grid.minor = element_blank(), panel.background = element_blank(),
  strip.background = element_blank(), strip.text = element_text(size = 10),
```

```
  panel.border = element_rect(linetype = "solid", colour = "black"),
  plot.title = element_text(size = 10))
p <- p + ylim(c(-1, 1.5))
p <- p + geom_text(data = filter(mcmc_cor, variable == "Activity"),
  aes(x = 6.1, y = 1.5, label = paste("Correlation = ", print, sep = '')),
  size = 2.5)
p + theme(plot.margin = unit(c(0.1, 0.1, 0.1, 0.1), "cm"))
```
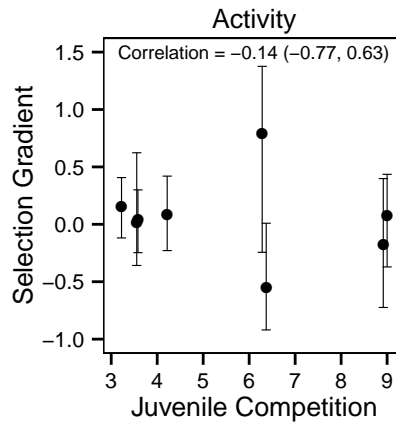

Docility and Competition

```
p <- ggplot(data = filter(sel_grads_mcmc_comp, variable == "Docility"),
  aes(x = mean_competition, y = post_mode))
p <- p + geom_errorbar(aes(ymin = lower, ymax = upper), width = 0.2, size = 0.2)
p <- p + geom_point()
p <- p + theme_bw(base_size = 10)
p <- p + scale_x_continuous(breaks = c(3,4,5,6,7,8,9))
p <- p + ylab("Selection Gradient")
p <- p + ggtitle("Docility")
p <- p + xlab("Juvenile Competition")
p <- p + theme(panel.grid.major = element_blank(),
  panel.grid.minor = element_blank(), panel.background = element_blank(),
  strip.background = element_blank(), strip.text = element_text(size = 10),
  panel.border = element_rect(linetype = "solid", colour = "black"),
  plot.title = element_text(size = 10))
p <- p + geom_text(data = filter(mcmc_cor, variable == "Docility"),
  aes(x = 6.1, y = 0.65, label = paste("Correlation = ", print, sep = '')),
  size = 2.5)
p + theme(plot.margin = unit(c(0.1, 0.1, 0.1, 0.1), "cm"))
```
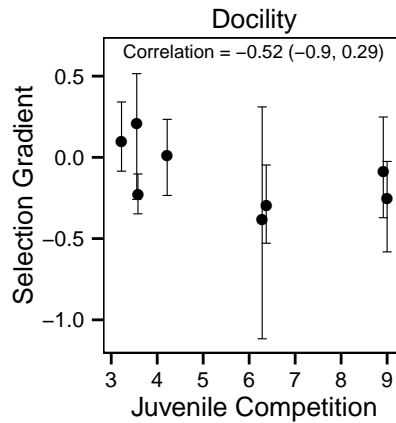
Effect of competition on linear selection (glmms)

```
load("data/analyses_data/fit_raneff_data.RData")
library(dplyr)
fit_raneff_data <- tbl_df(fit_raneff_data)
```

4

Docility

Correlation = −0.52 (−0.9, 0.29)

```r
library(lme4)

# Model with interactions between competition and the behavioral traits.
# grid_year and ID are random effects.
arsLinearCompetition <- function(dat){
  ars_linear_comp <- glmer(
    ars_all ~
    competition_s +
    aggression_s +
    competition_s:aggression_s +
    activity_s +
    competition_s:activity_s +
    docility_s +
    competition_s:docility_s +
    (1|Grid) + (1|ID),
    data = dat, family = poisson, control=glmerControl(optimizer="bobyqa")
    )
  random_effect_variances <- VarCorr(ars_linear_comp)
  data.frame(t(summary(ars_linear_comp)$coefficients[ ,"Estimate"]),
  ID = random_effect_variances$ID[1], Grid = random_effect_variances$Grid[1])
}

library(foreach)


## foreach: simple, scalable parallel programming from Revolution Analytics
## Use Revolution R for scalability, fault tolerance and more.
## http://www.revolutionanalytics.com


library(doMC)


## Loading required package: iterators
## Loading required package: parallel


ncores = 12
registerDoMC(cores = ncores)
```

```r
batches <- data.frame(start = seq(1, 1000, round(1000/ncores))[1:ncores])
batches$stop <- c(batches$start[2:length(batches$start)] - 1, 1000)

start_time <- Sys.time()
ars_linear_comp_posterior <- foreach(i = 1:ncores, .combine = rbind) %dopar% {
  results <- fit_raneff_data %>%
    filter(type == "raneff", itt %in% batches$start[i]:batches$stop[i]) %>%
    group_by(itt, add = FALSE) %>%
    do(arsLinearCompetition(.))
}
run_time <- Sys.time() - start_time
print(run_time)


## Time difference of 2.539 mins


save(ars_linear_comp_posterior,
  file = "data/analyses_data/ars_linear_comp_posterior.RData")


load("data/analyses_data/ars_linear_comp_posterior.RData")
library(MCMCglmm)
library(lme4)
library(data.table)


## data.table 1.9.2  For help type: help("data.table")
##
## Attaching package: 'data.table'
##
## The following objects are masked from 'package:dplyr':
##
##     between, last


getPosteriorParams <- function(x){
  require(MCMCglmm)
  dat_mcmc <- mcmc(x)
  pm <- posterior.mode(dat_mcmc)
  hpd <- HPDinterval(dat_mcmc, prob = 0.9)
  pm_table <-  format(round(pm , digits = 2), digits = 1, nsmall = 2,
    scientific = FALSE)
  hpd_table <- format(round(hpd, digits = 2), digits = 1, nsmall = 2,
    scientific = FALSE)
  pm_hpd_table <- data.frame(cbind(pm_table, hpd_table))
  pm_hpd_table$pm_hpd <- paste(
    pm_table, " (", hpd_table[ ,1], ", ", hpd_table[ ,2], ")", sep = ''
    )
  pm_hpd_table$sig[sign(hpd[ ,1]) == sign(hpd[ ,2])] <- "*"
  pm_hpd_table$sig[sign(hpd[ ,1]) != sign(hpd[ ,2])] <- " "
  pm_hpd_table$space[sign(hpd[ ,1]) == sign(hpd[ ,2])] <- "*"
  pm_hpd_table$space[sign(hpd[ ,1]) != sign(hpd[ ,2])] <- " "
  pm_hpd_table$pm_hpd <- paste(pm_hpd_table$pm_hpd, pm_hpd_table$sig, sep = "")
```

```
    return(pm_hpd_table)
}

linear_hpd_ars <- getPosteriorParams(ars_linear_comp_posterior %>%
  ungroup() %>%
  select(Intercept = X.Intercept., Competition = competition_s,
    Aggression = aggression_s, Activity = activity_s, docility = docility_s,
    "Competition x Aggression" = competition_s.aggression_s,
    "Competition x Activity" = competition_s.activity_s,
    "Competition x Docility" = competition_s.docility_s)
    )
```

Interaction between competition and linear selection results The effect of competition on linear selection on female behavioral traits for annual reproductive success. Posterior modes are given with highest posterior density intervals in parentheses.

```
pandoc.table(linear_hpd_ars %>% select(pm_hpd), justify="right")
```

	pm_hpd
Intercept	-1.01 (-1.11, -0.93)*
Competition	-3.27 (-3.65, -3.09)*
Aggression	0.36 (0.13, 0.63)*
Activity	-0.12 (-0.37, 0.15)
docility	-0.18 (-0.38, -0.06)*
Competition x Aggression	1.30 (0.50, 1.99)*
Competition x Activity	-0.45 (-1.26, 0.32)
Competition x Docility	-0.54 (-1.13, -0.09)*

Competition and nonlinear selection (glmms)

```
load("data/analyses_data/fit_raneff_data.RData")
library(lme4)

arsNonlinearResults <- function(dat){
  ars_model  <- glmer(ars_all ~ aggression_s*competition_s +
    activity_s*competition_s + docility_s*competition_s +
    aggression_s*activity_s*competition_s + I(aggression_s^2)*competition_s +
    I(activity_s^2)*competition_s + I(docility_s^2)*competition_s +
    (1 | grid_year) + (1|ID), data = dat, family = poisson,
    control=glmerControl(optimizer="bobyqa"))
  kpd_model  <- glmer(kprod   ~ aggression_s*competition_s +
    activity_s*competition_s + docility_s*competition_s +
    aggression_s*activity_s*competition_s + I(aggression_s^2)*competition_s +
    I(activity_s^2)*competition_s + I(docility_s^2)*competition_s +
```

```r
      (1 | grid_year) + (1|ID), data = dat, family = poisson,
      control=glmerControl(optimizer="bobyqa"))
  ows_model  <- glmer(prop    ~ aggression_s*competition_s +
      activity_s*competition_s + docility_s*competition_s +
      aggression_s*activity_s*competition_s + I(aggression_s^2)*competition_s +
      I(activity_s^2)*competition_s + I(docility_s^2)*competition_s +
      (1 | grid_year) + (1|ID), data = dat, weights = kprod, family = binomial,
      control=glmerControl(optimizer="bobyqa"))

  ars_vc <- VarCorr(ars_model)
  ars_t <- data.table(fitness = "ars",
      t(summary(ars_model)$coefficients[ ,"Estimate"]), ID = ars_vc$ID[1],
      grid_year = ars_vc$grid_year[1])
  kpd_vc <- VarCorr(kpd_model)
  kpd_t <- data.table(fitness = "kpd",
      t(summary(kpd_model)$coefficients[ ,"Estimate"]), ID = kpd_vc$ID[1],
      grid_year = kpd_vc$grid_year[1])
  ows_vc <- VarCorr(ows_model)
  ows_t <- data.table(fitness = "ows",
      t(summary(ows_model)$coefficients[ ,"Estimate"]), ID = ows_vc$ID[1],
      grid_year = ows_vc$grid_year[1])
  rbind(rbind(ars_t, kpd_t), ows_t)
}


library(foreach)
library(doMC)
ncores = 12
registerDoMC(cores = ncores)

batches <- data.frame(start = seq(1, 1000, round(1000/ncores)))[1:ncores])
batches$stop <- c(batches$start[2:length(batches$start)] - 1, 1000)

start_time <- Sys.time()
nonlinear_mcmc <- foreach(i = 1:ncores, .combine = rbind) %dopar% {
  results <- fit_raneff_data %>%
      filter(type == "raneff", itt %in% batches$start[i]:batches$stop[i]) %>%
      group_by(itt, add = FALSE) %>%
      do(arsNonlinearResults(.))
}
run_time <- Sys.time() - start_time
print(run_time)

## Time difference of 20.4 mins


save(nonlinear_mcmc, file = "data/analyses_data/nonlinear_mcmc_models.RData")

load("data/analyses_data/nonlinear_mcmc_models.RData")

pm_hpd_ars <- getPosteriorParams(
  nonlinear_mcmc[nonlinear_mcmc$fitness =="ars", 3:18])
```

8

```r
pm_hpd_ows <- getPosteriorParams(
  nonlinear_mcmc[nonlinear_mcmc$fitness =="ows", 3:18])
pm_hpd_kpd <- getPosteriorParams(
  nonlinear_mcmc[nonlinear_mcmc$fitness =="kpd", 3:18])

nonlinear_results_mcmc <- data.frame(ARS = pm_hpd_ars$pm_hpd,
  OWS = pm_hpd_ows$pm_hpd, Fecundity = pm_hpd_kpd$pm_hpd)

row.names(nonlinear_results_mcmc) <- c("Intercept", "Aggression",
 "Competition", "Activity", "Docility", "Aggression^2", "Activity^2",
 "Docility^2", "Aggression x Competition", "Activity x Competition",
 "Docility x Competition", "Aggression x Activity",
 "Aggression^2 x Competition", "Activity^2 x Competition",
 "Docility^2 x Competition", "Agg. x Act. x Competition"
 )
```

Nonlinear results

The effect of competition on linear and nonlinear selection on female behavioral traits for annual reproductive success. Posterior modes are given with highest posterior density intervals in parentheses.

```r
pandoc.table(nonlinear_results_mcmc[c(1,3,2,4:16), ],
  split.tables = 160)
```

	ARS	OWS	Fecundity
Intercept	-0.76 (-1.18, -0.42)*	-1.84 (-2.35, -1.42)*	1.34 (1.28, 1.41)*
Competition	-2.58 (-3.98, -1.72)*	-2.41 (-4.21, -1.27)*	-0.06 (-0.19, 0.09)
Aggression	0.45 (0.08, 0.82)*	0.59 (0.17, 1.13)*	-0.04 (-0.09, 0.02)
Activity	-0.17 (-0.53, 0.17)	-0.06 (-0.68, 0.24)	0.03 (-0.05, 0.06)
Docility	-0.29 (-0.55, -0.13)*	-0.29 (-0.54, -0.03)*	0.04 (0.00, 0.07)*
Aggression^2	-0.12 (-0.51, 0.15)	-0.28 (-0.70, 0.16)	0.02 (-0.05, 0.05)
Activity^2	0.00 (-0.36, 0.23)	-0.07 (-0.42, 0.31)	-0.02 (-0.07, 0.02)
Docility^2	-0.15 (-0.33, 0.04)	-0.20 (-0.41, 0.05)	0.01 (-0.03, 0.04)
Aggression x Competition	1.71 (0.48, 2.66)*	2.16 (0.55, 3.53)*	-0.03 (-0.16, 0.09)
Activity x Competition	-0.72 (-1.77, 0.35)	-0.24 (-1.70, 1.10)	-0.03 (-0.15, 0.08)
Docility x Competition	-0.70 (-1.55, -0.26)*	-0.45 (-1.13, 0.49)	-0.04 (-0.14, 0.02)
Aggression x Activity	0.14 (-0.22, 0.67)	0.21 (-0.29, 0.84)	0.02 (-0.06, 0.08)
Aggression^2 x Competition	-0.27 (-1.36, 0.56)	-0.35 (-1.98, 0.70)	0.03 (-0.11, 0.14)
Activity^2 x Competition	-0.06 (-1.07, 0.68)	-0.11 (-1.32, 1.00)	0.00 (-0.11, 0.11)
Docility^2 x Competition	-0.51 (-1.05, 0.15)	-0.34 (-1.29, 0.19)	-0.02 (-0.11, 0.05)
Agg. x Act. x Competition	0.44 (-0.75, 1.92)	0.52 (-1.08, 2.57)	0.01 (-0.20, 0.16)

Ignoring behavioural uncertainty

```r
load("data/analyses_data/sel_grads_blup.RData")
load("data/analyses_data/fit_raneff_data.RData")
```

Correlations between selection gradients and competition

```r
competition_year <- fitness %>%
  filter(grid_year != "SU2008") %>%
  select(Year, competition) %>%
  unique() %>%
  group_by(Year, add = FALSE) %>%
  summarise(mean_competition = mean(competition))

n_year <- filter(fit_raneff_data, type == "blup") %>%
  group_by(Year, add = FALSE) %>%
  summarise(n = n())
competition_year <- left_join(competition_year, n_year, by = "Year")
competition_year$Year <- as.character(competition_year$Year)

load("data/analyses_data/sel_grads_blup.RData")
sel_grads_blup_competition <- left_join(
  filter(sel_grads_blup, standardization == "SD"), competition_year,
  by = "Year")
save(sel_grads_blup_competition, competition_year,
  file = "data/analyses_data/sel_grads_blup_competition.RData")

load("data/analyses_data/sel_grads_blup_competition.RData")

cor_sgrad_comp <- function(x){
  v <- x$variable[1]
  ct <- cor.test(x$coefficients, x$mean_competition)
  data.frame(variable = v, est = ct$estimate, lower = ct$conf.int[1],
    upper = ct$conf.int[2], stringsAsFactors = FALSE)
}

sg.comp <- sel_grads_blup_competition %>%
  group_by(variable, add = FALSE) %>%
  do(cor_sgrad_comp(x=.))
sg.comp[ ,2:4] <- round(sg.comp[ ,2:4], digits = 2)
sg.comp$print <- paste(sg.comp$est, " (", sg.comp$lower, ", ",
  sg.comp$upper, ")", sep = "")
```
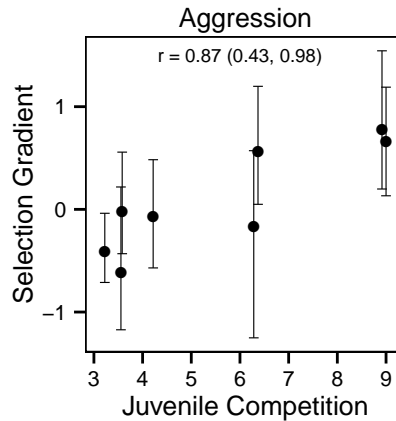
Aggression and Competition

```r
p <- ggplot(data = filter(sel_grads_blup_competition,
  variable == "Aggression"), aes(x = mean_competition, y = coefficients))
p <- p + geom_errorbar(aes(ymin = lower, ymax = upper), width = 0.2, size = 0.2)
p <- p + geom_point()
p <- p + theme_bw(base_size = 10)
```

```
p <- p + scale_x_continuous(breaks = c(3,4,5,6,7,8,9))
p <- p + ylab("Selection Gradient")
p <- p + ggtitle("Aggression")
p <- p + xlab("Juvenile Competition")
p <- p + theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(), panel.backgro
p <- p + geom_text(data = filter(sg.comp, variable == "Aggression"),
  aes(x = 6, y = 1.5, label = paste("r = ", print, sep = '')), size = 2.5)
p + theme(plot.margin = unit(c(0.1, 0.1, 0.1, 0.1), "cm"))
```


Activity and Competition

```
p <- ggplot(data = filter(sel_grads_blup_competition, variable == "Activity"),
  aes(x = mean_competition, y = coefficients))
p <- p + geom_errorbar(aes(ymin = lower, ymax = upper), width = 0.2, size = 0.2)
p <- p + geom_point()
p <- p + theme_bw(base_size = 10)
p <- p + scale_x_continuous(breaks = c(3,4,5,6,7,8,9))
p <- p + ylab("Selection Gradient")
p <- p + ggtitle("Activity")
p <- p + xlab("Juvenile Competition")
p <- p + theme(panel.grid.major = element_blank(),
  panel.grid.minor = element_blank(), panel.background = element_blank(),
  strip.background = element_blank(), strip.text = element_text(size = 10),
  panel.border = element_rect(linetype = "solid", colour = "black"),
  plot.title = element_text(size = 10))
p <- p + geom_text(data = filter(sg.comp, variable == "Activity"),
  aes(x = 6, y = 2.2, label = paste("r = ", print, sep = '')), size = 2.5)
  pdf(file = "test.pdf", width = 2.17, height = 2.03)
p + theme(plot.margin = unit(c(0.1, 0.1, 0.1, 0.1), "cm"))
```

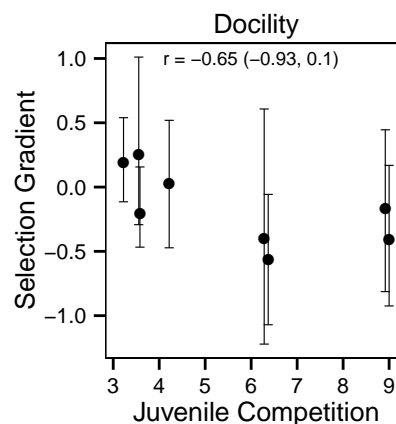**Docility and Competition**

```
p <- ggplot(data = filter(sel_grads_blup_competition, variable == "Docility"),
  aes(x = mean_competition, y = coefficients))
```

```
p <- p + geom_errorbar(aes(ymin = lower, ymax = upper), width = 0.2, size = 0.2)
p <- p + geom_point()
p <- p + theme_bw(base_size = 10)
p <- p + scale_x_continuous(breaks = c(3,4,5,6,7,8,9))
p <- p + ylab("Selection Gradient")
p <- p + ggtitle("Docility")
p <- p + xlab("Juvenile Competition")
p <- p + theme(panel.grid.major = element_blank(),
  panel.grid.minor = element_blank(), panel.background = element_blank(),
  strip.background = element_blank(), strip.text = element_text(size = 10),
  panel.border = element_rect(linetype = "solid", colour = "black"),
  plot.title = element_text(size = 10))
p <- p + geom_text(data = filter(sg.comp, variable == "Docility"),
  aes(x = 6, y = 1, label = paste("r = ", print, sep = '')), size = 2.5)
p + theme(plot.margin = unit(c(0.1, 0.1, 0.1, 0.1), "cm"))
```


Effect of competition on linear selection

```
load("data/analyses_data/fit_raneff_data.RData")
library(dplyr)
fit_raneff_data <- tbl_df(fit_raneff_data)
library(lme4)
fit_raneff_data$oID <- 1:nrow(fit_raneff_data)

ars_linear_model  <- glmer(ars_all ~ aggression_s*competition_s +
  activity_s*competition_s + docility_s*competition_s + (1 | grid_year) +
  (1|ID) + (1|oID), data = filter(fit_raneff_data, type == "blup"),
  family = poisson, control=glmerControl(optimizer="bobyqa"))
kpd_linear_model  <- glmer(kprod ~ aggression_s*competition_s +
  activity_s*competition_s + docility_s*competition_s + (1 | grid_year) +
  (1|ID) + (1|oID), data = filter(fit_raneff_data, type == "blup"),
  family = poisson, control=glmerControl(optimizer="bobyqa"))
ows_linear_model  <- glmer(prop ~ aggression_s*competition_s +
  activity_s*competition_s + docility_s*competition_s + (1 | grid_year) +
  (1|ID) + (1|oID), data = filter(fit_raneff_data, type == "blup"),
```

```r
  weights = kprod, family = binomial, control=glmerControl(optimizer="bobyqa"))

save(ars_linear_model, kpd_linear_model, ows_linear_model,
  file = "data/analyses_data/ars_linear_blup_models.RData")
```

Models with observation level random effect.

```r
load("data/analyses_data/fit_raneff_data.RData")
library(dplyr)
fit_raneff_data <- tbl_df(fit_raneff_data)
library(lme4)

fit_raneff_data$oID <- 1:nrow(fit_raneff_data)

ars_linear_model_  <- glmer(ars_all ~ aggression_s*competition_s +
  activity_s*competition_s + docility_s*competition_s + (1 | oID) +
  (1 | grid_year) + (1|ID), data = filter(fit_raneff_data, type == "blup"),
  family = poisson, control=glmerControl(optimizer="bobyqa"))
kpd_linear_model_  <- glmer(kprod   ~ aggression_s*competition_s +
  activity_s*competition_s + docility_s*competition_s + (1 | oID) +
  (1 | grid_year) + (1|ID), data = filter(fit_raneff_data, type == "blup"),
  family = poisson, control=glmerControl(optimizer="bobyqa"))
ows_linear_model_  <- glmer(prop    ~ aggression_s*competition_s +
  activity_s*competition_s + docility_s*competition_s + (1 | oID) +
  (1 | grid_year) + (1|ID), data = filter(fit_raneff_data, type == "blup"),
  weights = kprod, family = binomial, control=glmerControl(optimizer="bobyqa"))

save(ars_linear_model, kpd_linear_model, ows_linear_model,
  file = "data/analyses_data/ars_linear_blup_models.RData")


load("data/analyses_data/ars_linear_blup_models.RData")
library(lme4)

getLmerParams <- function(x){
  coefs <- summary(x)$coefficients
  coef.table <- data.frame(format(coefs[ ,1:3], digits = 1, nsmall = 2,
    scientific = FALSE))
  coef.table$pval[coefs[ ,4] > 0.001] <- format(coefs[coefs[ ,4] > 0.001, 4],
    digits = 1, nsmall = 2)
  coef.table$pval[coefs[ ,4] < 0.001] <- "< 0.001"
  coef.table$coefs <- paste(coef.table$Estimate, " ±", coef.table$Std..Error,
    sep = '')
  return(coef.table)
}

ars_linear_blup_results <- getLmerParams(ars_linear_model)
row.names(ars_linear_blup_results) <- c("Intercept", "Aggression",
  "Competition", "Activity", "Docility", "Aggression x Competition",
  "Activity x Competition", "Docility x Competition")
names(ars_linear_blup_results) <- c("Estimate", "SE", "Z", "P", "Est ± se")
```

Interaction between competition and linear selection results

```
pandoc.table(ars_linear_blup_results[c(1,3,2,4:8), c(5,4,3)],
  justify = "right", split.tables = 160)
```

	Est $\pm$ se	P	Z
Intercept	-1.10 $\pm$ 0.22	< 0.001	-5.09
Competition	-3.62 $\pm$ 0.64	< 0.001	-5.64
Aggression	0.74 $\pm$ 0.21	< 0.001	3.49
Activity	-0.32 $\pm$ 0.20	0.11	-1.61
Docility	-0.27 $\pm$ 0.16	0.10	-1.67
Aggression x Competition	2.62 $\pm$ 0.64	< 0.001	4.07
Activity x Competition	-1.36 $\pm$ 0.61	0.03	-2.21
Docility x Competition	-0.77 $\pm$ 0.49	0.11	-1.58

Competition and nonlinear selection

```
load("data/analyses_data/fit_raneff_data.RData")
library(lme4)
fit_blups_data <- filter(fit_raneff_data, type == "blup")
fit_blups_data$oID <- 1:nrow(fit_blups_data)

ars_nl_model <- glmer(ars_all ~ aggression_s*competition_s +
  activity_s*competition_s + docility_s*competition_s +
  aggression_s*activity_s*competition_s + I(aggression_s^2)*competition_s +
  I(activity_s^2)*competition_s + I(docility_s^2)*competition_s +
  (1 | grid_year) + (1|ID) + (1|oID),
  data = fit_blups_data, family = poisson,
  control=glmerControl(optimizer="bobyqa"))

ars_nl_model <- glmer(ars_all ~ aggression_s*competition_s +
  activity_s*competition_s + docility_s*competition_s +
  aggression_s*activity_s*competition_s + I(aggression_s^2)*competition_s +
  I(activity_s^2)*competition_s + I(docility_s^2)*competition_s +
  (1 | grid_year) + (1|ID),
  data = fit_blups_data, family = poisson,
  control=glmerControl(optimizer="bobyqa"))

kpd_nl_model <- glmer(kprod ~ aggression_s*competition_s +
  activity_s*competition_s + docility_s*competition_s +
  aggression_s*activity_s*competition_s + I(aggression_s^2)*competition_s +
  I(activity_s^2)*competition_s + I(docility_s^2)*competition_s +
  (1 | grid_year) + (1|ID) + (1|oID),
  data = fit_blups_data, family = poisson,
  control=glmerControl(optimizer="bobyqa"))
```

```r
ows_nl_model <- glmer(prop ~ aggression_s*competition_s +
  activity_s*competition_s + docility_s*competition_s +
  aggression_s*activity_s*competition_s + I(aggression_s^2)*competition_s +
  I(activity_s^2)*competition_s + I(docility_s^2)*competition_s +
  (1 | grid_year) + (1|ID) + (1|oID),
  data = fit_blups_data, weights = kprod,
  family = binomial,
  control=glmerControl(optimizer="bobyqa"))

save(ars_nl_model,kpd_nl_model, ows_nl_model,
  file = "data/analyses_data/nl.blup_models.RData")

fit_raneff_data %>%
  ungroup() %>%
  summarise(
    mean_ars = mean(ars_all, na.rm = TRUE),
    var_ars = var(ars_all, na.rm = TRUE),
    mean_kpd = mean(kprod, na.rm = TRUE),
    var_kpd = var(kprod, na.rm = TRUE)
    )

## Source: local data frame [1 x 4]
##
##   mean_ars var_ars mean_kpd var_kpd
## 1   0.8784   1.255    3.902   4.372
```

Format results of nonlinear selection for table

```r
load("data/analyses_data/nl.blup_models.RData")

coef_p_ars <- getLmerParams(ars_nl_model)
coef_p_ows <- getLmerParams(ows_nl_model)
coef_p_kpd <- getLmerParams(kpd_nl_model)

term_names <- c("Intercept", "Aggression",
 "Competition", "Activity", "Docility", "Aggression^2", "Activity^2",
 "Docility^2", "Aggression x Competition", "Activity x Competition",
 "Docility x Competition", "Aggression x Activity",
 "Aggression^2 x Competition", "Activity^2 x Competition",
 "Docility^2 x Competition", "Agg. x Act. x Competition"
 )

row.names(coef_p_ars) <- term_names
row.names(coef_p_ows) <- term_names
row.names(coef_p_kpd) <- term_names

names(coef_p_ars) <- c("Estimate", "SE", "Z", "P", "Est ± se")
names(coef_p_ows) <- c("Estimate", "SE", "Z", "P", "Est ± se")
names(coef_p_kpd) <- c("Estimate", "SE", "Z", "P", "Est ± se")
```

Nonlinear results

The effect of competition on linear and nonlinear selection on female behavioral traits for annual reproductive success. Posterior modes are given with highest posterior density intervals in parentheses.

ARS

```
pandoc.table(coef_p_ars[c(1,3,2,4:16), c(5,3,4)],
 split.tables = 160)
```

	Est ± se	Z	P
Intercept	-0.68 ± 0.31	-2.23	0.025
Competition	-2.24 ± 0.91	-2.46	0.014
Aggression	0.96 ± 0.31	3.06	0.002
Activity	-0.66 ± 0.28	-2.35	0.019
Docility	-0.51 ± 0.23	-2.18	0.029
Aggression^2	-0.65 ± 0.32	-2.07	0.039
Activity^2	-0.30 ± 0.26	-1.16	0.247
Docility^2	-0.18 ± 0.12	-1.48	0.139
Aggression x Competition	3.40 ± 0.92	3.68	< 0.001
Activity x Competition	-2.45 ± 0.84	-2.90	0.004
Docility x Competition	-1.41 ± 0.69	-2.04	0.041
Aggression x Activity	1.01 ± 0.43	2.35	0.019
Aggression^2 x Competition	-1.86 ± 0.96	-1.93	0.053
Activity^2 x Competition	-0.81 ± 0.77	-1.05	0.295
Docility^2 x Competition	-0.63 ± 0.39	-1.61	0.107
Agg. x Act. x Competition	2.62 ± 1.32	1.99	0.046

OWS

```
pandoc.table(coef_p_ows[c(1,3,2,4:16), c(5,3,4)],
 split.tables = 160)
```

	Est ± se	Z	P
Intercept	-1.92 ± 0.39	-4.87	< 0.001
Competition	-2.48 ± 1.18	-2.11	0.035
Aggression	1.33 ± 0.42	3.17	0.001
Activity	-0.82 ± 0.38	-2.14	0.032

	Est ± se	Z	P
Docility	-0.49 ± 0.29	-1.70	0.088
Aggression^2	-1.02 ± 0.43	-2.36	0.018
Activity^2	-0.37 ± 0.36	-1.03	0.304
Docility^2	-0.18 ± 0.15	-1.17	0.242
Aggression x Competition	4.75 ± 1.28	3.70	< 0.001
Activity x Competition	-2.89 ± 1.20	-2.40	0.016
Docility x Competition	-0.78 ± 0.90	-0.86	0.388
Aggression x Activity	1.40 ± 0.60	2.35	0.019
Aggression^2 x Competition	-3.11 ± 1.36	-2.29	0.022
Activity^2 x Competition	-1.17 ± 1.10	-1.06	0.291
Docility^2 x Competition	-0.50 ± 0.50	-0.98	0.325
Agg. x Act. x Competition	3.95 ± 1.86	2.13	0.034

Fecundity

```
pandoc.table(coef_p_kpd[c(1,3,2,4:16), c(5,3,4)],
 split.tables = 160)
```

	Est ± se	Z	P
Intercept	1.362 ± 0.091	14.937	< 0.001
Competition	-0.017 ± 0.161	-0.106	0.92
Aggression	-0.058 ± 0.049	-1.176	0.24
Activity	0.030 ± 0.050	0.594	0.55
Docility	0.030 ± 0.041	0.724	0.47
Aggression^2	0.036 ± 0.053	0.672	0.50
Activity^2	-0.064 ± 0.051	-1.248	0.21
Docility^2	0.005 ± 0.026	0.209	0.83
Aggression x Competition	-0.067 ± 0.117	-0.579	0.56
Activity x Competition	0.008 ± 0.088	0.086	0.93
Docility x Competition	-0.116 ± 0.087	-1.325	0.19
Aggression x Activity	0.024 ± 0.075	0.319	0.75
Aggression^2 x Competition	0.153 ± 0.149	1.029	0.30
Activity^2 x Competition	0.079 ± 0.145	0.545	0.59
Docility^2 x Competition	-0.067 ± 0.055	-1.218	0.22
Agg. x Act. x Competition	-0.252 ± 0.240	-1.051	0.29

Plot of quadratic interaction

```r
library(effects)
```

```
## Loading required package: colorspace
##
## Attaching package: 'effects'
##
## The following object is masked from 'package:car':
##
##     Prestige
```

```r
library(ggplot2)

g.ows <- glm(prop ~ aggression_s * competition_s + activity_s *
    competition_s + docility_s * competition_s + aggression_s:activity_s *
    competition_s + I(aggression_s^2) * competition_s, data = filter(fit_raneff_data,
    type == "blup"), weights = kprod, family = binomial)
```

```
## Warning: glm.fit: fitted probabilities numerically 0 or 1 occurred
```

```r
e.ows <- effect(term = "aggression_s:competition_s:activity_s",
    mod = g.ows)

e <- Effect(c("aggression_s", "activity_s", "competition_s"),
    g.ows, xlevels = list(aggression_s = 100, activity_s = 2,
        competition_s = 2))

s <- summary(e, type = "link")
se <- s$effect
su <- s$upper
sl <- s$lower
d <- as.data.frame(se)
du <- as.data.frame(su)
dl <- as.data.frame(sl)
names(d) <- c("la.lc", "ha.lc", "la.hc", "ha.hc")
names(du) <- c("la.lc", "ha.lc", "la.hc", "ha.hc")
names(dl) <- c("la.lc", "ha.lc", "la.hc", "ha.hc")

plot_d <- data.frame(Aggression = as.numeric(rep(row.names(s$effect),
    12)), OWS = c(d$la.lc, d$ha.lc, d$la.hc, d$ha.hc, du$la.lc,
    du$ha.lc, du$la.hc, du$ha.hc, dl$la.lc, dl$ha.lc, dl$la.hc,
    dl$ha.hc), Competition = rep(rep(c("Low\nCompetition", "High\nCompetition"),
    each = 200), 3), Activity = rep(rep(c("Low", "High"), each = 100),
    6), type = rep(c("main", "upper", "lower"), each = 400))
plot_d$env <- paste(plot_d$Competition, plot_d$Activity, sep = ".")

quad_plot <- ggplot(plot_d, aes(x = Aggression, y = OWS)) + geom_line(aes(alpha = Activity,
    linetype = type, size = type)) + facet_wrap(~Competition) +
    scale_alpha_discrete(range = c(1, 0.3)) + scale_linetype_manual(values = c(2,
```

```
    1, 2)) + scale_size_manual(values = c(0.3, 1, 0.3)) + ylab("Offspring\nOverwinter Survival") +
    xlab("Aggression") + theme_bw(base_size = 10) + theme(panel.grid.major = element_blank(),
    panel.grid.minor = element_blank(), panel.background = element_blank(),
    panel.border = element_rect(linetype = "solid", colour = "black"),
    axis.ticks = element_blank(), axis.text = element_text(size = 10),
    legend.key = element_blank(), strip.background = element_blank()) +
    guides(linetype = FALSE, size = FALSE, alpha = guide_legend(override.aes = list(size = 1))) +
    theme(legend.position = c(0.75, 0.25), legend.background = element_blank(),
        legend.key.size = unit(0.4, "cm")) + theme(plot.margin = unit(c(0.1,
    0.1, 0.1, 0.1), "cm")) + theme(axis.text.x = element_blank(),
    axis.text.y = element_blank())

pdf("figure/05_quad_print.pdf", width = 3.14, height = 2)
quad_plot
dev.off()

## pdf
##   2

quad_plot
```
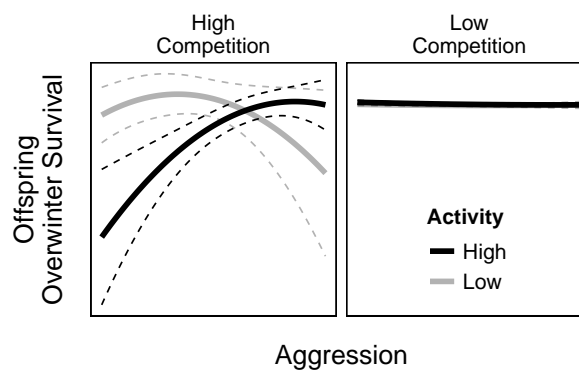

Tile plot of interaction

```
n = 12
e <- Effect(c("aggression_s", "activity_s", "competition_s"),
    g.ows, xlevels = list(aggression_s = n, activity_s = n, competition_s = 2))
s <- summary(e, type = "response")
de <- as.data.frame(s$effect)
de_lc <- de[, 1:n]
de_hc <- de[, (n + 1):(2 * n)]

fix.names <- function(x) {
    a <- unlist(lapply(strsplit(names(x), split = "\\."), "[[",
        1))
    b <- unlist(lapply(strsplit(names(x), split = "\\."), "[[",
        2))
```

19

```
    out <- paste(a, b, sep = ".")
    return(out)
}


d_hc <- data.frame(Aggression = rep(row.names(de_hc), n), Activity = rep(fix.names(de_hc),
    each = n), OWS = as.vector(as.matrix(de_hc)))
d_hc$Aggression <- as.numeric(as.character(d_hc$Aggression))
d_hc$Activity <- as.numeric(as.character(d_hc$Activity))

d_lc <- data.frame(Aggression = rep(row.names(de_lc), n), Activity = rep(fix.names(de_lc),
    each = n), OWS = as.vector(as.matrix(de_lc)))
d_lc$Aggression <- as.numeric(as.character(d_lc$Aggression))
d_lc$Activity <- as.numeric(as.character(d_lc$Activity))

tile_plot <- ggplot(d_lc, aes(x = Aggression, y = Activity, z = OWS)) +
    geom_tile(aes(alpha = OWS), fill = "black", size = 0) + scale_alpha_continuous(range = c(1,
    0)) + ylab("Activity") + xlab("Aggression") + theme_bw(base_size = 10) +
    theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(),
        panel.background = element_blank(), panel.border = element_rect(linetype = "solid",
            colour = "black"), axis.ticks = element_blank(),
        legend.key = element_blank(), strip.background = element_blank()) +
    guides(linetype = FALSE, size = FALSE, alpha = FALSE) + theme(plot.margin = unit(c(0.1,
    0.1, 0.1, 0.1), "cm"))

pdf("figure/05_tile_print.pdf", width = 3.14, height = 3.14)
tile_plot
dev.off()


## pdf
##   2

tile_plot
```