R Vignette

Variable responses of lentil (*Lens culinaris* Medik.) germplasm to changes in photoperiod and temperature

Derek Michael Wright derek.wright@usask.ca

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Contents

Data Preparation **3**

Materials & Methods **6**

Supplemental table 1 . . . 6

Supplemental table 2 . . . 6

Figure 1 Field Trial Info . . . 7

Additional Figure 1 LDP Origin Map . . . 8

Supplemental Figure 1 Scaling . . . 9

Phenology **10**

Figure 2 Data Overview . . . 10

Additional Figures - Entry Phenology . . . 13

Additional Figure 2 DTF DTS DTM . . . 14

Additional Figure 3 MacroEnv Phenology . . . 15

Additional Figure 4 ggridges . . . 16

Supplemental Figure 2 Missing Data . . . 17

Supplemental Figure 3 Correlation Plots . . . 18

Additional Figures - Correlations . . . 20

PCA **23**

Figure 3 PCA . . . 23

Additional Figure 5 Interactive PCA Plot . . . 26

Additional Figure 6 PCA . . . 26

Additional Figure 7 DTF By Cluster . . . 28

Additional Figure 8 Cluster Origins . . . 29

Additional Figure 9 LDP Origins By Cluster . . . 30

Modeling DTF **31**

Additional Figures - Entry Regressions . . . 31
PhotoThermal Plane . . . 32
Supplemental Figure 4 Regressions . . . 35
Modeling DTF - functions . . . 37
Modeling DTF (T + P) - All Site-years . . . 39
Modeling DTF (T x P) - All Site-years . . . 42
Supplemental Table 3 Model Constants . . . 45
Additional Figure 10 significant T x P interactions . . . 46
Supplemental Figure 5 Model T + P vs T x P . . . 47
Additional Figure 11 Constants . . . 48
Additional Figure 12 Coefficient p-values . . . 49
Additional Figure 13 p-values b c . . . 50
Modeling DTF (T + P) - Location Out . . . 51
Figure 4 Test Model . . . 52
Supplemental Table 4 Test Model . . . 54
Modeling DTF (T + P) - 3 Best . . . 56
Modeling DTF (T + P) - 3 Worst . . . 59
DTF Model correlation coefficients . . . 62
Supplemental Figure 6 Compare Constants Entry . . . 63
Supplemental Figure 7 3 best 3 worst . . . 65
Supplemental Figure 8 Compare Constants All . . . 66
Base Temperature & Critical Photoperiod . . . 67
Figure 5 Tb and Pc . . . 68
Figure 6 Origin Constants . . . 70
Supplemental Figure 9 Pc Tf PTT . . . 73
Additional Figure 14 PTT . . . 75
Supplemental Figure 10 Thermal Sums . . . 77
Supplemental Figure 11 Photoperiodic Sums . . . 79
Figure 7 Temperature Increase By MacroEnv . . . 80

APPLICATION OF GENOMICS
TO INNOVATION IN THE LENTIL ECONOMY

This vignette contains the R code and analysis done for the paper: **Variable responses of lentil (*Lens culinaris* Medik.) germplasm to changes in photoperiod and temperature"**

Data Preparation

Load the nessesary R packages, Prepare the data for analysis.

```
#install.packages(c("tidyverse","scales","rworldmap","ggrepel","magick","GGally",
#                   "ggbeeswarm","FactoMineR","plot3D","stringr"))
# Load libraries
library(tidyverse)  # data wrangling
library(scales)     # rescale()
library(rworldmap)  # mapBubbles()
library(ggrepel)    # geom_text_repel() + geom_label_repel()
library(magick)     # image editing
library(GGally)     # ggpairs() + ggmatrix()
library(ggpubr)     # ggarrange()
library(ggbeeswarm) # geom_quasirandom()
library(FactoMineR) # PCA() & HCPC()
library(plot3D)     # 3D plots
library(stringr)    # str_pad()
# General color palettes
colors <- c("darkred",   "darkorange3", "darkgoldenrod2", "deeppink3",
            "steelblue", "darkorchid4", "cornsilk4",      "darkgreen")
# Expts color palette
colors_Expt <- c("lightgreen",      "palegreen4",       "darkgreen",   "darkolivegreen3",
                 "darkolivegreen4", "springgreen4",     "orangered2",  "orangered4",
                 "palevioletred",    "mediumvioletred", "orange2",     "orange4",
                 "slateblue1",       "slateblue4",      "aquamarine3", "aquamarine4",
                 "deepskyblue3",     "deepskyblue4" )
# Locations
names_Location <- c("Rosthern, Canada", "Sutherland, Canada",  "Central Ferry, USA",
                    "Bhopal, India",    "Jessore, Bangladesh", "Bardiya, Nepal",
```

```
                    "Cordoba, Spain",   "Marchouch, Morocco",  "Metaponto, Italy" )
# Experiments
names_Expt <- c("Rosthern, Canada 2016",    "Rosthern, Canada 2017",
                "Sutherland, Canada 2016",  "Sutherland, Canada 2017",
                "Sutherland, Canada 2018",  "Central Ferry, USA 2018",
                "Bhopal, India 2016",       "Bhopal, India 2017",
                "Jessore, Bangladesh 2016", "Jessore, Bangladesh 2017",
                "Bardiya, Nepal 2016",      "Bardiya, Nepal 2017",
                "Cordoba, Spain 2016",      "Cordoba, Spain 2017",
                "Marchouch, Morocco 2016",  "Marchouch, Morocco 2017",
                "Metaponto, Italy 2016",    "Metaponto, Italy 2017" )
# Experiment short names
names_ExptShort <- c("Ro16", "Ro17", "Su16", "Su17", "Su18", "Us18",
                     "In16", "In17", "Ba16", "Ba17", "Ne16", "Ne17",
                     "Sp16", "Sp17", "Mo16", "Mo17", "It16", "It17" )
# Macro-Environments
macroEnvs <- c("Temperate", "South Asia", "Mediterranean")
# ggplot theme
theme_AGL <- theme_bw() +
  theme(strip.background = element_rect(colour = "black", fill = NA, size = 0.5),
        panel.background = element_rect(colour = "black", fill = NA, size = 0.5),
        panel.border     = element_rect(colour = "black", size = 0.5),
        panel.grid       = element_line(color  = alpha("black", 0.1), size = 0.5),
        panel.grid.minor.x = element_blank(),
        panel.grid.minor.y = element_blank())
# Create scaling function
traitScale <- function(x, trait) {
  xout <- rep(NA, nrow(x))
  for(i in unique(x$Expt)) {
    mn <- x %>% filter(Expt == i) %>% pull(trait) %>% min(na.rm = T)
    mx <- x %>% filter(Expt == i) %>% pull(trait) %>% max(na.rm = T)
    xout <- ifelse(x$Expt == i, rescale(x %>% pull(trait), c(1,5), c(mn,mx)), xout)
  }
  xout
}
# Prep data
# Note: DTF2 = non-flowering genotypes <- group_by(Expt) %>% max(DTF)
rr <- read.csv("data/data_raw.csv") %>%
  mutate(Rep          = factor(Rep),
         Year         = factor(Year),
         PlantingDate = as.Date(PlantingDate),
         Location     = factor(Location, levels = names_Location),
         Expt         = factor(Expt,     levels = names_Expt),
         ExptShort    = plyr::mapvalues(Expt, names_Expt, names_ExptShort),
         ExptShort    = factor(ExptShort, levels = names_ExptShort),
         DTF2_scaled = traitScale(., "DTF2"),
         RDTF         = round(1 / DTF2, 6),
         VEG          = DTF - DTE,
         REP          = DTM - DTF)
# Average raw data
dd <- rr %>% group_by(Entry, Name, Expt, ExptShort, Location, Year) %>%
  summarise_at(vars(DTE, DTF, DTS, DTM, VEG, REP, RDTF, DTF2),
               funs(mean), na.rm = T) %>% ungroup() %>%
```

```
  mutate(DTF2_scaled = traitScale(., "DTF2"))
# Prep environmental data
ee <- read.csv("data/data_env.csv") %>%
  mutate(Date      = as.Date(Date),
         ExptShort = plyr::mapvalues(Expt, names_Expt, names_ExptShort),
         ExptShort = factor(ExptShort, levels = names_ExptShort),
         Expt      = factor(Expt,      levels = names_Expt),
         Location  = factor(Location,  levels = names_Location),
         DayLength_rescaled = rescale(DayLength, to = c(0, 40)) )
# Prep field trial info
xx <- dd %>% group_by(Expt) %>%
  summarise_at(vars(DTE, DTF, DTS, DTM), funs(min, mean, max), na.rm = T) %>%
  ungroup()
ff <- read.csv("data/data_info.csv") %>%
  mutate(Start = as.Date(Start) ) %>%
  left_join(xx, by = "Expt")
for(i in unique(ee$Expt)) {
  ee <- ee %>%
    filter(Expt != i | (Expt == i & DaysAfterPlanting <= ff$DTM_max[ff$Expt == i]))
}
xx <- ee
for(i in unique(ee$Expt)) {
  xx <- xx %>%
    filter(Expt != i | (Expt == i & DaysAfterPlanting <= ff$DTF_max[ff$Expt == i]))
}
xx <- xx %>% group_by(Location, Year) %>%
  summarise(T_mean = mean(Temp_mean, na.rm = T), T_sd = sd(Temp_mean, na.rm = T),
            P_mean = mean(DayLength, na.rm = T), P_sd = sd(DayLength, na.rm = T) ) %>%
  ungroup() %>%
  mutate(Expt = paste(Location, Year)) %>%
  select(-Location, -Year)
ff <- ff %>% left_join(xx, by = "Expt") %>%
  mutate(ExptShort = plyr::mapvalues(Expt, names_Expt, names_ExptShort),
         ExptShort = factor(ExptShort, levels = names_ExptShort),
         Expt      = factor(Expt,      levels = names_Expt),
         MacroEnv  = factor(MacroEnv,  levels = macroEnvs),
         T_mean    = round(T_mean, 1),
         P_mean    = round(P_mean, 1))
# Lentil Diversity Panel metadata
ldp <- read.csv("data/data_ldp.csv")
# Country info
ct <- read.csv("data/data_countries.csv") %>% filter(Country %in% ldp$Origin)
```

- `ldp` = Lentil Diversity Panel Metadata
- `rr` = Raw Phenotype Data
- `dd` = Averaged Phenotype Data
- `ee` = Environmental Data
- `ff` = Field Trial Info
- `ct` = Country Info

Materials & Methods

Supplemental table 1

```
s1 <- select(ldp, Entry, Name, Origin, Source, Synonyms)
write.csv(s1, "Supplemental_Table_01.csv", row.names = F)
```

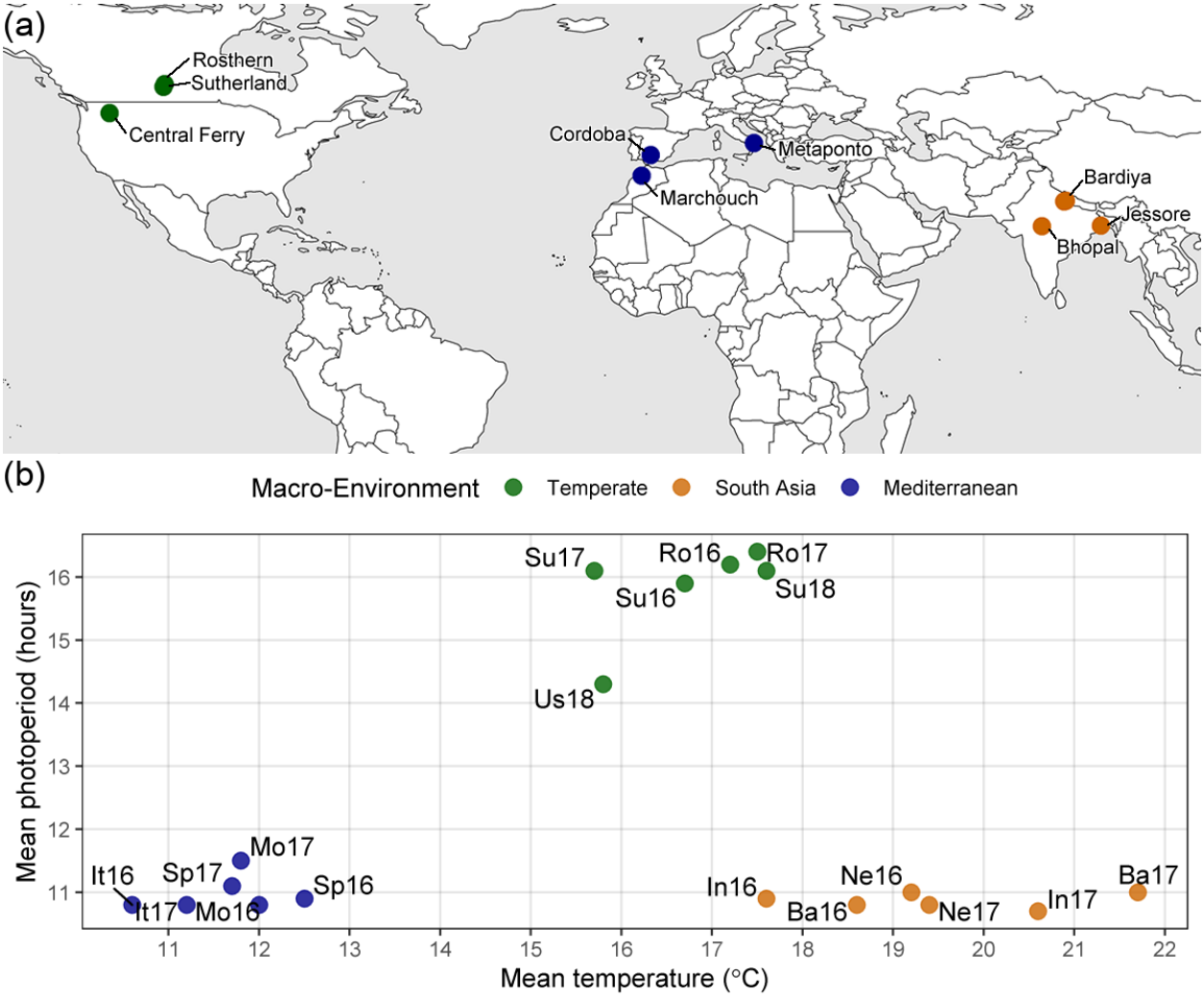
	Entry	Name	Origin	Source	Synonyms
1	1	CDC Asterix AGL	Canada	USASK	
2	2	CDC Rosie AGL	Canada	USASK	
3	3	3156-11 AGL	Canada	USASK	
4	4	CDC Greenstar AGL	Canada	USASK	
5	5	CDC Cherie AGL	Canada	USASK	
320	320	W6 27754 LSP AGL	USDA	USDA	
321	321	W6 27760 LSP AGL	USDA	USDA	
322	322	W6 27763 LSP AGL	USDA	USDA	
323	323	W6 27766 LSP AGL	USDA	USDA	
324	324	W6 27767 LSP AGL	USDA	USDA	*Not Barimasur-4*

Supplemental table 2

```
s2 <- select(ff, Location, Year, `Short Name`=ExptShort, Latitude=Lat, Longitude=Lon,
  `Planting Date`=Start, `Temperature (mean)`=T_mean, `Photoperiod (mean)`=P_mean,
  `Number of Seeds Sown`=Number_of_Seeds_Sown, `Plot Type`=Plot_Type)
write.csv(s2, "Supplemental_Table_02.csv", row.names = F)
```

```
'data.frame':   18 obs. of  10 variables:
 $ Location            : Factor w/ 9 levels "Bardiya, Nepal",..: 9 8 6 4 7 2 1 5 9 8 ...
 $ Year                : int  2016 2016 2016 2016 2016 2016 2016 2016 2017 2017 ...
 $ Short Name          : Factor w/ 18 levels "Ro16","Ro17",..: 3 1 15 13 17 7 11 9 4 2 ...
 $ Latitude            : num  52.2 52.7 33.6 37.9 40.4 ...
 $ Longitude           : num  -106.51 -106.29 -6.72 -4.8 16.78 ...
 $ Planting Date       : Date, format: "2016-04-27" "2016-05-06" ...
 $ Temperature (mean)  : num  16.7 17.2 12 12.5 10.6 17.6 19.2 18.6 15.7 17.5 ...
 $ Photoperiod (mean)  : num  15.9 16.2 10.8 10.9 10.8 10.9 11 10.8 16.1 16.4 ...
 $ Number of Seeds Sown: int  60 60 25 25 25 25 25 25 70 70 ...
 $ Plot Type           : Factor w/ 3 levels "one, 1 meter row",..: 2 2 1 1 1 1 1 1 2 2 ...
```

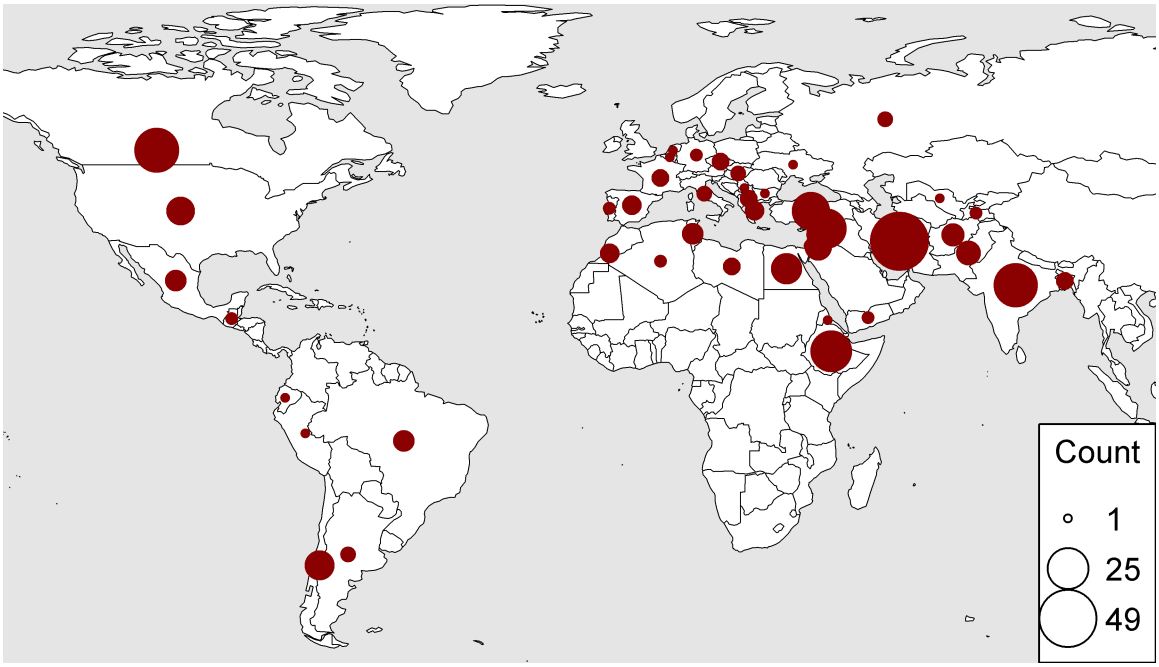
Figure 1 Field Trial Info




```
# Prep data
xx <- ff %>% mutate(Size = 1)
# Plot (a) Map
invisible(png("Additional/Temp/Temp_F01_1.png", width = 4200, height = 1575, res = 600))
par(mai = c(0,0,0,0), xaxs = "i", yaxs = "i")
mapBubbles(dF = xx, nameX = "Lon", nameY = "Lat", nameZColour = "MacroEnv",
           nameZSize = "Size", symbolSize = 0.5, pch = 20, fill = F, addLegend = F,
           colourPalette = c("darkgreen", "darkorange3", "darkblue"), addColourLegend = F,
           xlim = c(-140,110), ylim = c(10,35),
           oceanCol = "grey90", landCol = "white", borderCol = "black")
invisible(dev.off())
# Plot (b) mean T and P
mp <- ggplot(ff, aes(x = T_mean, y = P_mean)) +
  geom_point(aes(color = MacroEnv), size = 3, alpha = 0.8) +
  geom_text_repel(aes(label = ExptShort)) +
  scale_x_continuous(breaks = 11:22) +
  scale_y_continuous(breaks = 11:16) +
  scale_color_manual(name = "Macro-Environment",
```

```
                      values = c("darkgreen","darkorange3","darkblue")) +
  theme_AGL +
  theme(legend.position = "top", legend.margin = unit(c(0,0,0,0), "cm")) +
  labs(x = expression(paste("Mean temperature (", degree, "C)", sep = "")),
       y = "Mean photoperiod (hours)")
ggsave("Additional/Temp/Temp_F01_2.png", mp, width = 7, height = 3.25, dpi = 600)
# Labels were added to "Additional/Temp/Temp_F1_1.png" in image editing software
# Append (a) and (b)
im1 <- image_read("Additional/Temp/Temp_F01_1_1.png") %>%
  image_annotate("(a)", size = 35)
im2 <- image_read("Additional/Temp/Temp_F01_2.png") %>% image_scale("1200x") %>%
  image_annotate("(b)", size = 35)
im <- image_append(c(im1,im2), stack = T)
image_write(im, "Figure_01.png")
```

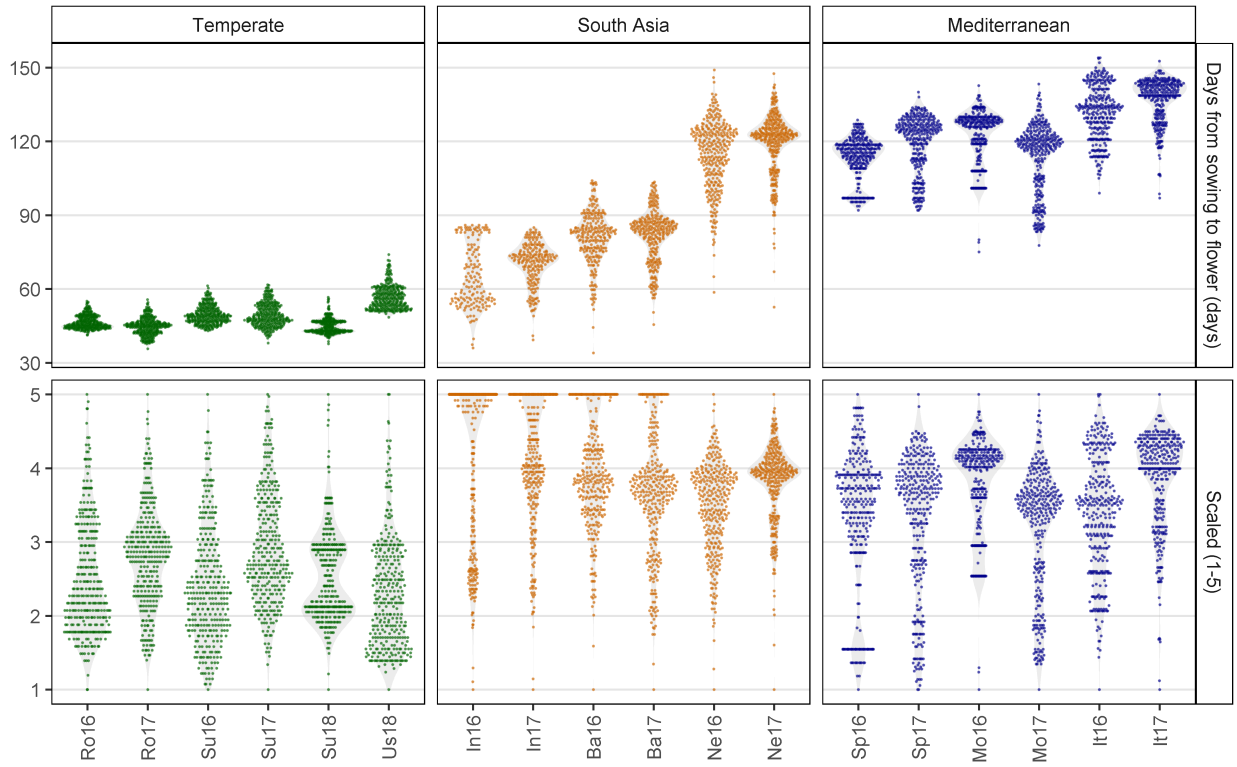
Additional Figure 1 LDP Origin Map




```
# Prep data
x1 <- ldp %>% filter(Origin != "Unknown") %>%
  mutate(Origin = recode(Origin, "ICARDA"="Syria", "USDA"="USA")) %>%
  group_by(Origin) %>% summarise(Count = n()) %>%
  left_join(select(ct, Origin = Country, Lat, Lon), by = "Origin") %>%
  ungroup() %>% as.data.frame()
x1[is.na(x1)] <- 0
# Plot
invisible(png("Additional/Additional_Figure_01.png",
              width = 3600, height = 2055, res = 600)) #res = 150
par(mai = c(0,0,0,0), xaxs = "i",yaxs = "i")
mapBubbles(dF = x1, nameX = "Lon", nameY = "Lat",
        nameZSize = "Count", nameZColour = "darkred",
```

```
        xlim = c(-140,110), ylim = c(5,20),
        oceanCol = "grey90", landCol = "white", borderCol = "black")
invisible(dev.off())
```

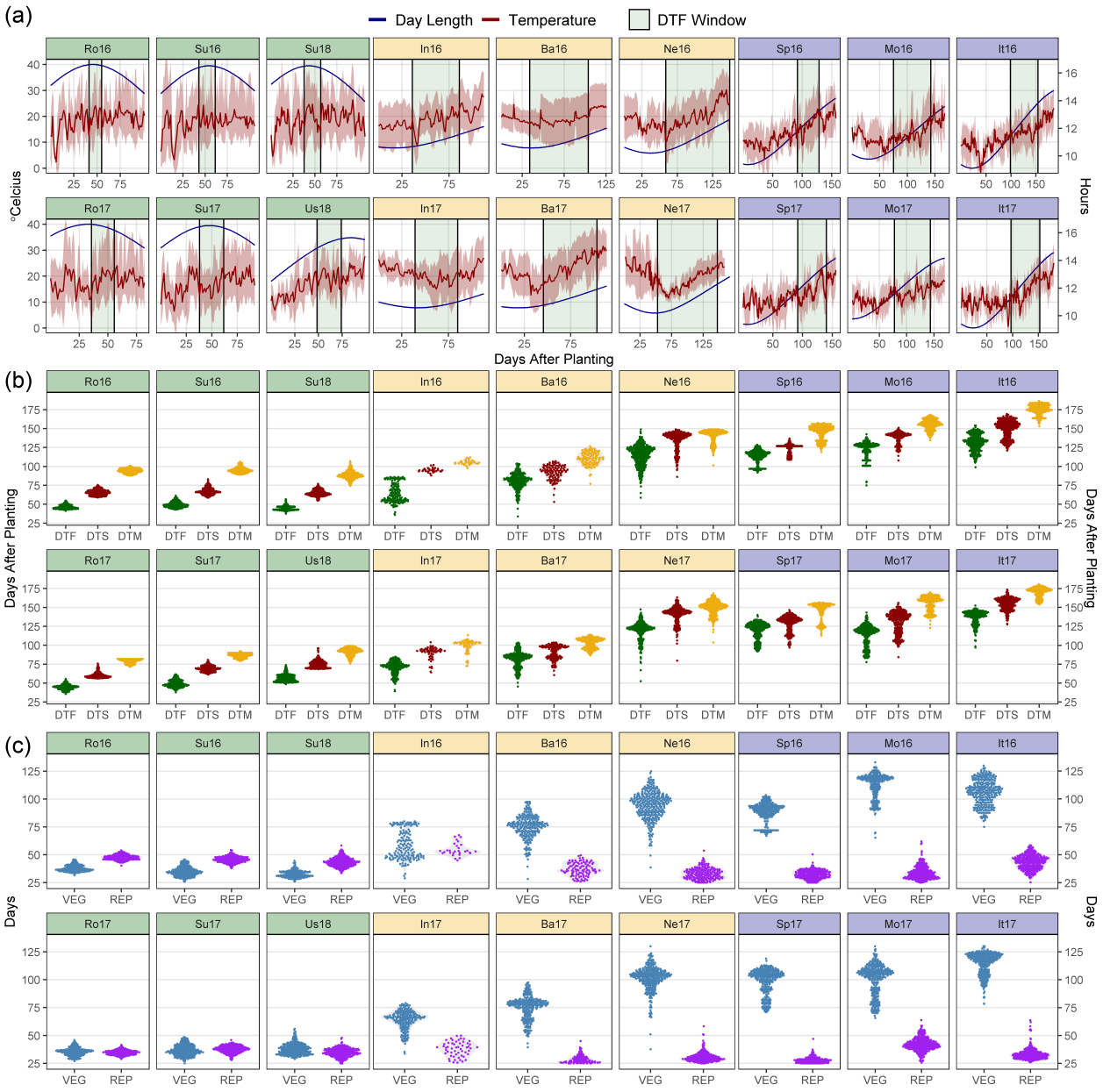
Supplemental Figure 1 Scaling




```
# Prep data
levs <- c("Days from sowing to flower (days)", "Scaled (1-5)")
xx <- dd %>% select(Entry, Expt, ExptShort, DTF, DTF2_scaled) %>%
  left_join(select(ff, Expt, MacroEnv), by = "Expt") %>%
  gather(Trait, Value, DTF, DTF2_scaled) %>%
  mutate(Trait = plyr::mapvalues(Trait, c("DTF", "DTF2_scaled"), levs),
         Trait = factor(Trait, levels = levs) )
# Plot
mp <- ggplot(xx, aes(x = ExptShort, y = Value)) +
  geom_violin(fill = "grey", alpha = 0.3, color = NA) +
  geom_quasirandom(aes(color = MacroEnv), size = 0.1, alpha = 0.5) +
  scale_color_manual(values = c("darkgreen","darkorange3","darkblue")) +
  facet_grid(Trait ~ MacroEnv, scales = "free") +
  theme_AGL +
  theme(legend.position = "none",
        panel.grid.major.x = element_blank(),
        axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1)) +
  labs(x = NULL, y = NULL)
ggsave("Supplemental_Figure_01.png", mp, width = 8, height = 5, dpi = 600)
```

Phenology

Figure 2 Data Overview




```
# Create plot function
ggEnvPlot <- function(x, nr = 2, nc = 3, mybreaks) {
  yy <- ff %>% filter(Expt %in% unique(x$Expt)) %>%
    select(ExptShort, Location, Year, min=DTF_min, max=DTF_max) %>%
    mutate(Trait = "DTF Window")
  ggplot(x) +
    geom_rect(data = yy, aes(xmin = min, xmax = max, fill = Trait),
              ymin = -Inf, ymax = Inf, alpha = 0.1, color = "black") +
    geom_line(aes(x = DaysAfterPlanting, y = DayLength_rescaled, color = "Day Length")) +
```

```
    geom_line(aes(x = DaysAfterPlanting, y = Temp_mean, color = "Temperature") ) +
    geom_ribbon(aes(x = DaysAfterPlanting, ymin = Temp_min, ymax = Temp_max),
                fill = "darkred", alpha = 0.3) +
    facet_wrap(ExptShort ~ ., scales = "free_x", dir = "v", nrow = 2, ncol = 3) +
    scale_x_continuous(breaks = mybreaks) +
    scale_color_manual(name = NULL, values = c("darkblue", "darkred")) +
    scale_fill_manual(name = NULL, values = "darkgreen") +
    coord_cartesian(ylim=c(0, 40)) +
    theme_AGL +
    theme(plot.margin = unit(c(0,0,0,0), "cm"),
          legend.text = element_text(size = 12)) +
    labs(y = NULL, x = NULL) +
    guides(colour = guide_legend(order = 1, override.aes = list(size = 1.25)),
           fill = guide_legend(order = 2))
}
# Plot (a) T and P
mp1.1 <- ggEnvPlot(ee %>% filter(MacroEnv == "Temperate"), mybreaks = c(25,50,75)) +
  labs(y = expression(paste(degree, "Celcius"))) +
  theme(strip.background = element_rect(alpha("darkgreen", 0.3)),
        plot.margin = unit(c(0,0,0,0.155), "cm"),
        plot.title = element_text(hjust = -0.12, vjust = -10))
mp1.2 <- ggEnvPlot(ee %>% filter(MacroEnv == "South Asia"), mybreaks = c(25,75,125)) +
  labs(x = "Days After Planting") +
  theme(strip.background = element_rect(fill = alpha("darkgoldenrod2", 0.3)),
        axis.text.y = element_blank(),
        axis.ticks.y = element_blank())
mp1.3 <- ggEnvPlot(ee %>% filter(MacroEnv == "Mediterranean"), mybreaks = c(50,100,150)) +
  scale_y_continuous(sec.axis = sec_axis(~ (16.62 - 9.11) * . / (40 - 0) + 9.11,
                       name = "Hours", breaks = c(10, 12, 14, 16))) +
  theme(strip.background = element_rect(fill = alpha("darkblue", 0.3)),
        plot.margin = unit(c(0,0.17,0,0), "cm"),
        axis.text.y.left = element_blank(),
        axis.ticks.y.left = element_blank())
mp1 <- ggarrange(mp1.1, mp1.2, mp1.3, nrow = 1, ncol = 3, align = "h",
                 legend = "top", common.legend = T)
# Prep data
xx <- dd %>% select(Entry, Year, Expt, ExptShort, Location, DTF, DTS, DTM) %>%
  left_join(select(ff, Expt, MacroEnv), by = "Expt") %>%
  gather(Trait, Value, DTF, DTS, DTM) %>%
  mutate(Trait = factor(Trait, levels = c("DTF", "DTS", "DTM")))
# Create plot function
ggDistroDTF <- function(x) {
  ggplot(x, aes(x = Trait, y = Value) ) +
    geom_violin(color = NA, fill = "grey", alpha = 0.3) +
    geom_quasirandom(size = 0.3, aes(color = Trait)) +
    facet_wrap(ExptShort ~ ., scales = "free_x", dir = "v", ncol = 3, nrow = 2) +
    scale_color_manual(values = c("darkgreen", "darkred", "darkgoldenrod2")) +
    scale_y_continuous(limits = c(30,190), breaks = c(25,50,75,100,125,150,175)) +
    theme_AGL + labs(y = NULL, x = NULL) +
    theme(plot.margin = unit(c(0.1,0,0.3,0), "cm"))
}
# Plot (b) DTF, DTS and DTM
mp2.1 <- ggDistroDTF(xx %>% filter(MacroEnv == "Temperate")) +
```

```
  labs(y = "Days After Planting") +
  theme(strip.background = element_rect(fill = alpha("darkgreen", 0.3)),
        panel.grid.major.x = element_blank(),
        plot.title = element_text(hjust = -0.12, vjust = -10))
mp2.2 <- ggDistroDTF(xx %>% filter(MacroEnv == "South Asia")) +
  theme(strip.background = element_rect(fill = alpha("darkgoldenrod2", 0.3)),
        panel.grid.major.x = element_blank(),
        axis.text.y = element_blank(),
        axis.ticks.y = element_blank())
mp2.3 <- ggDistroDTF(xx %>% filter(MacroEnv == "Mediterranean")) +
  scale_y_continuous(limits = c(30,190), breaks = c(25,50,75,100,125,150,175),
                     sec.axis = sec_axis(~ ., name = "Days After Planting",
                       breaks = c(25,50,75,100,125,150,175))) +
  theme(strip.background = element_rect(fill = alpha("darkblue", 0.3)),
        panel.grid.major.x = element_blank(),
        panel.grid.minor.x = element_line(),
        axis.text.y.left = element_blank(),
        axis.ticks.y.left = element_blank())
# Append
mp2 <- ggarrange(mp2.1, mp2.2, mp2.3, nrow = 1, ncol = 3, align = "h", legend = "none")
# Prep data
xx <- dd %>% select(Entry, Name, Expt, ExptShort, Location, Year, VEG, REP) %>%
  left_join(select(ff, Expt, MacroEnv), by = "Expt") %>%
  gather(Trait, Value, VEG, REP) %>%
  mutate(Trait = factor(Trait, levels = c("VEG", "REP")))
# Create plot function
ggDistroREP <- function(x) {
  ggplot(x, aes(x = Trait, y = Value)) +
    geom_violin(color = NA, fill = "grey", alpha = 0.3) +
    geom_quasirandom(size = 0.3, aes(color = Trait)) +
    facet_wrap(ExptShort ~ ., scales = "free_x", dir = "v", ncol = 3, nrow = 2) +
    scale_color_manual(values = c("steelblue", "purple")) +
    scale_y_continuous(limits = c(25,135), breaks = c(25,50,75,100,125)) +
    theme_AGL + labs(x = NULL, y = NULL) +
    theme(plot.margin = unit(c(0,0,0.3,0), "cm"))
}
# Plot (c) REP and VEG
mp3.1 <- ggDistroREP(xx %>% filter(MacroEnv == "Temperate")) +
  labs(y = "Days") +
  theme(strip.background = element_rect(fill = alpha("darkgreen", 0.3)),
        panel.grid.major.x = element_blank(),
        plot.title = element_text(hjust = -0.12, vjust = -10))
mp3.2 <- ggDistroREP(xx %>% filter(MacroEnv == "South Asia")) +
  theme(strip.background = element_rect(fill = alpha("darkgoldenrod2", 0.3)),
        panel.grid.major.x = element_blank(),
        axis.text.y = element_blank(),
        axis.ticks.y = element_blank())
mp3.3 <- ggDistroREP(xx %>% filter(MacroEnv == "Mediterranean")) +
  scale_y_continuous(limits = c(25,135), breaks = c(25,50,75,100,125),
                     sec.axis = sec_axis(~ ., name = "Days",
                       breaks = c(25,50,75,100,125))) +
  theme(strip.background = element_rect(fill = alpha("darkblue", 0.3)),
        panel.grid.major.x = element_blank(),
```

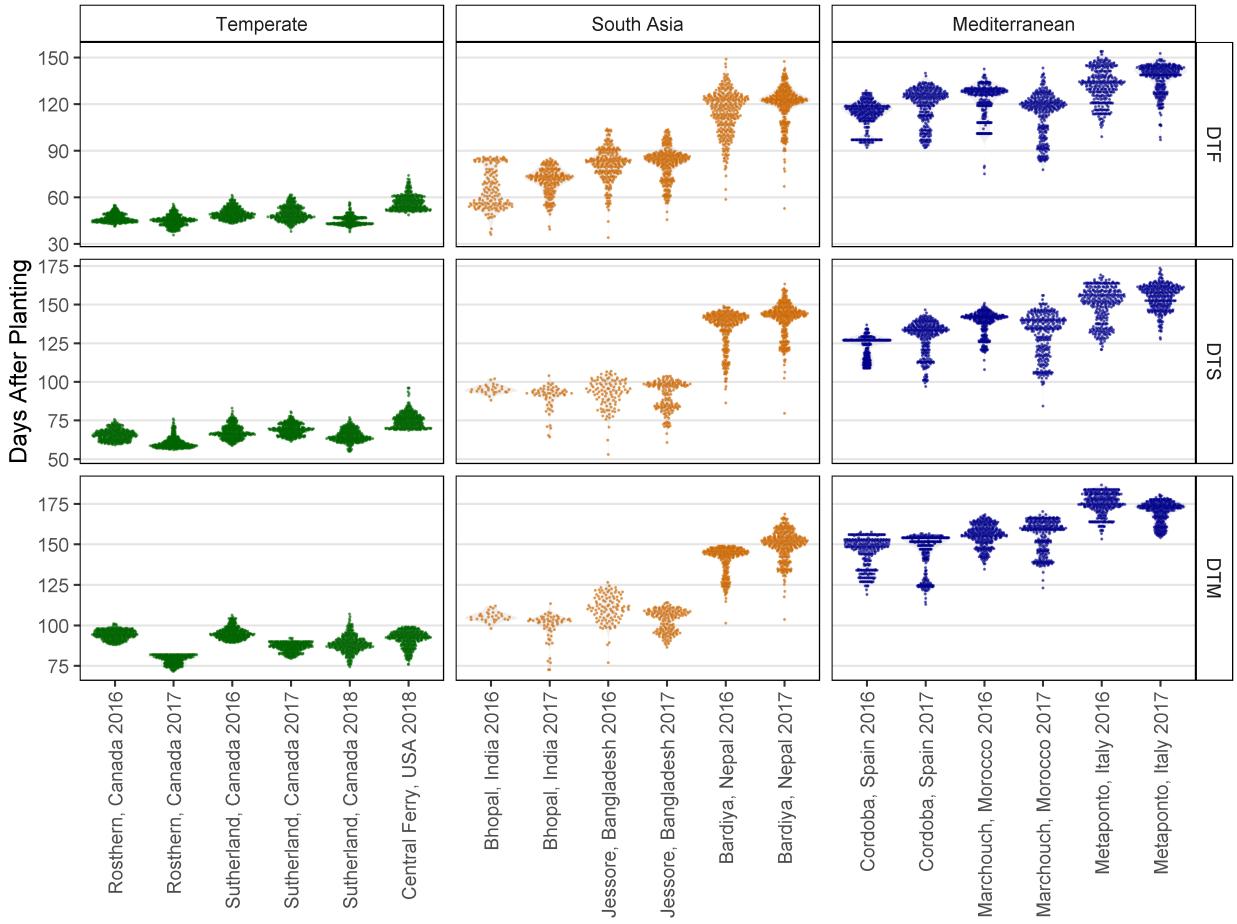
```
        axis.text.y.left = element_blank(),
        axis.ticks.y.left = element_blank())
# Append
mp3 <- ggarrange(mp3.1, mp3.2, mp3.3, nrow = 1, ncol = 3, align = "h", legend = "none")
# Save
ggsave("Additional/Temp/Temp_F02_1.png", mp1, width = 12, height = 4, dpi = 600)
ggsave("Additional/Temp/Temp_F02_2.png", mp2, width = 12, height = 4, dpi = 600)
ggsave("Additional/Temp/Temp_F02_3.png", mp3, width = 12, height = 4, dpi = 600)
# Append (a), (b) and (c)
mp1 <- image_read("Additional/Temp/Temp_F02_1.png")  %>%
  image_annotate("(a)", size = 150)
mp2 <- image_read("Additional/Temp/Temp_F02_2.png") %>%
  image_annotate("(b)", size = 150)
mp3 <- image_read("Additional/Temp/Temp_F02_3.png") %>%
  image_annotate("(c)", size = 150)
mp <- image_append(c(mp1, mp2, mp3), stack = T)
image_write(mp, "Figure_02.png")
```

Additional Figures - Entry Phenology

```
# Create plotting function
gg_phenol <- function(x, xE, colnums) {
  mycols <- c("darkgreen", "darkorange3", "darkblue")
  ggplot(xE, aes(x = Trait, y = Value, group = Entry, color = MacroEnv)) +
    geom_line(data = x, color = "grey", alpha = 0.5) +
    geom_line() + geom_point() +
    facet_grid(MacroEnv ~ ExptShort) +
    scale_color_manual(values = mycols[colnums]) +
    theme_AGL +
    theme(legend.position = "none", panel.grid.major.x = element_blank()) +
    ylim(c(min(x$Value, na.rm = T), max(x$Value, na.rm = T))) +
    labs(x = NULL, y = "Days")
}
# Prep data
xx <- dd %>% select(Entry, Name, ExptShort, DTF, DTS, DTM) %>%
  left_join(select(ff, ExptShort, MacroEnv), by = "ExptShort") %>%
  gather(Trait, Value, DTF, DTS, DTM) %>%
  mutate(Trait = factor(Trait, levels = c("DTF","DTS","DTM")))
x1 <- xx %>% filter(MacroEnv == "Temperate")
x2 <- xx %>% filter(MacroEnv == "South Asia")
x3 <- xx %>% filter(MacroEnv == "Mediterranean")
# Create PDF
pdf("Additional/pdf_Phenology.pdf", width = 8, height = 6)
for(i in 1:324) {
  xE1 <- xx %>% filter(Entry == i, !is.na(Value), MacroEnv == "Temperate")
  xE2 <- xx %>% filter(Entry == i, !is.na(Value), MacroEnv == "South Asia")
  xE3 <- xx %>% filter(Entry == i, !is.na(Value), MacroEnv == "Mediterranean")
  mp1 <-  gg_phenol(x1, xE1, 1)
  mp2 <-  gg_phenol(x2, xE2, 2)
  mp3 <-  gg_phenol(x3, xE3, 3)
  figlab <- paste("Entry", str_pad(i, 3, "left", "0"), "|", unique(xE1$Name))
```

```
  mp <- ggarrange(mp1, mp2, mp3, nrow = 3, ncol = 1) %>%
    annotate_figure(top = figlab)
  print(mp)
  ggsave(paste0("Additional/Entry_Phenology/Phenology_Entry_",
                str_pad(i, 3, "left", "0"), ".png"),
         mp, width = 8, height = 6, dpi = 600)
}
dev.off()#dev.set(dev.next())
```

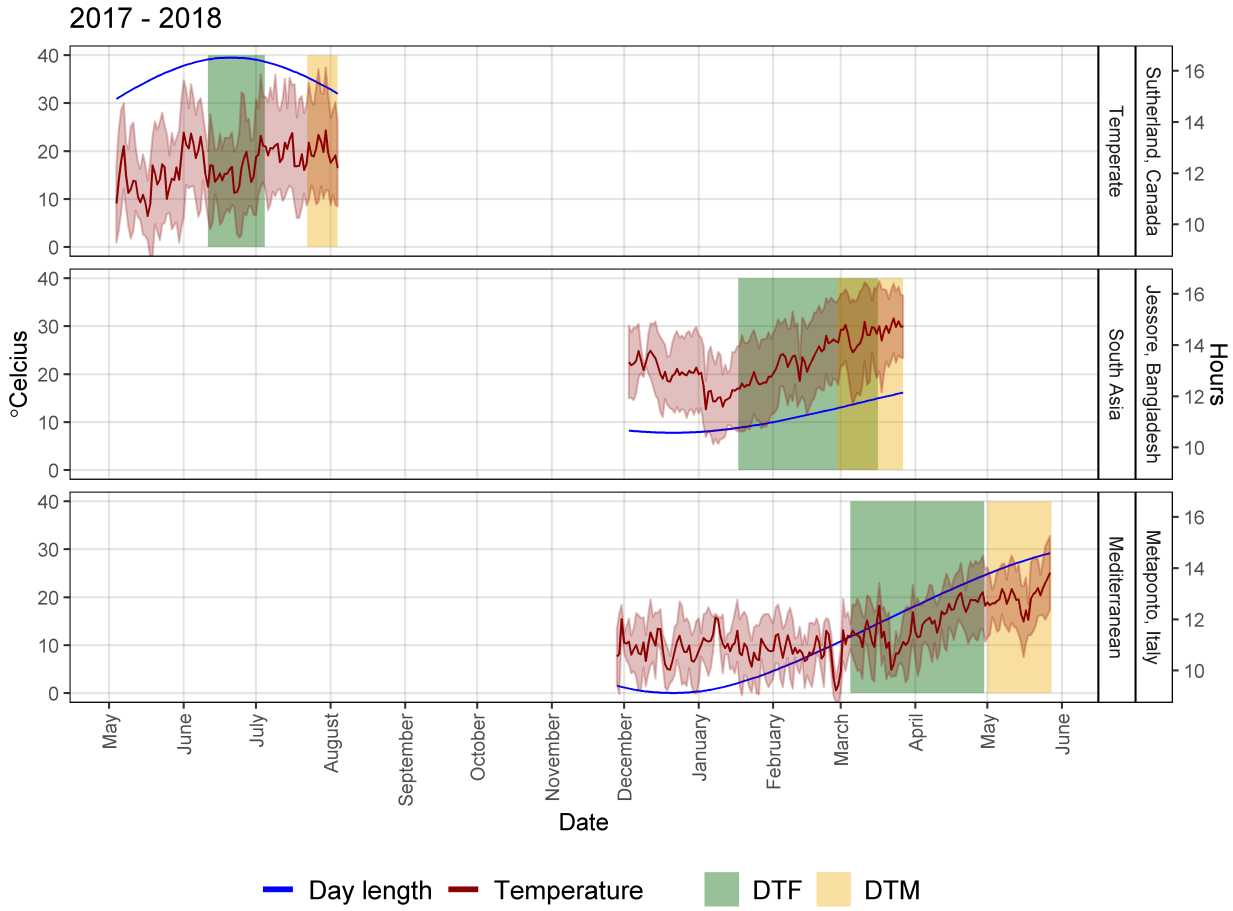
Additional Figure 2 DTF DTS DTM




```
# Prep data
xx <- dd %>% select(Entry, Expt, ExptShort, DTF, DTS, DTM) %>%
  left_join(select(ff, Expt, MacroEnv), by = "Expt") %>%
  gather(Trait, Value, DTF, DTS, DTM) %>%
  mutate(Trait = factor(Trait, levels = c("DTF", "DTS", "DTM")) )
# Plot
mp <- ggplot(xx, aes(x = Expt, y = Value)) +
  geom_violin(fill = "grey", alpha = 0.25, color = NA) +
  geom_quasirandom(size = 0.1, alpha = 0.5, aes(color = MacroEnv)) +
  facet_grid(Trait ~ MacroEnv, scales = "free") +
  scale_color_manual(values = c("darkgreen", "darkorange3", "darkblue")) +
```

```
  theme_AGL +
  theme(legend.position = "none",
        panel.grid.major.x = element_blank(),
        axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1)) +
  labs(x = NULL, y = "Days After Planting")
ggsave("Additional/Additional_Figure_02.png", mp, width = 8, height = 6, dpi = 600)
```

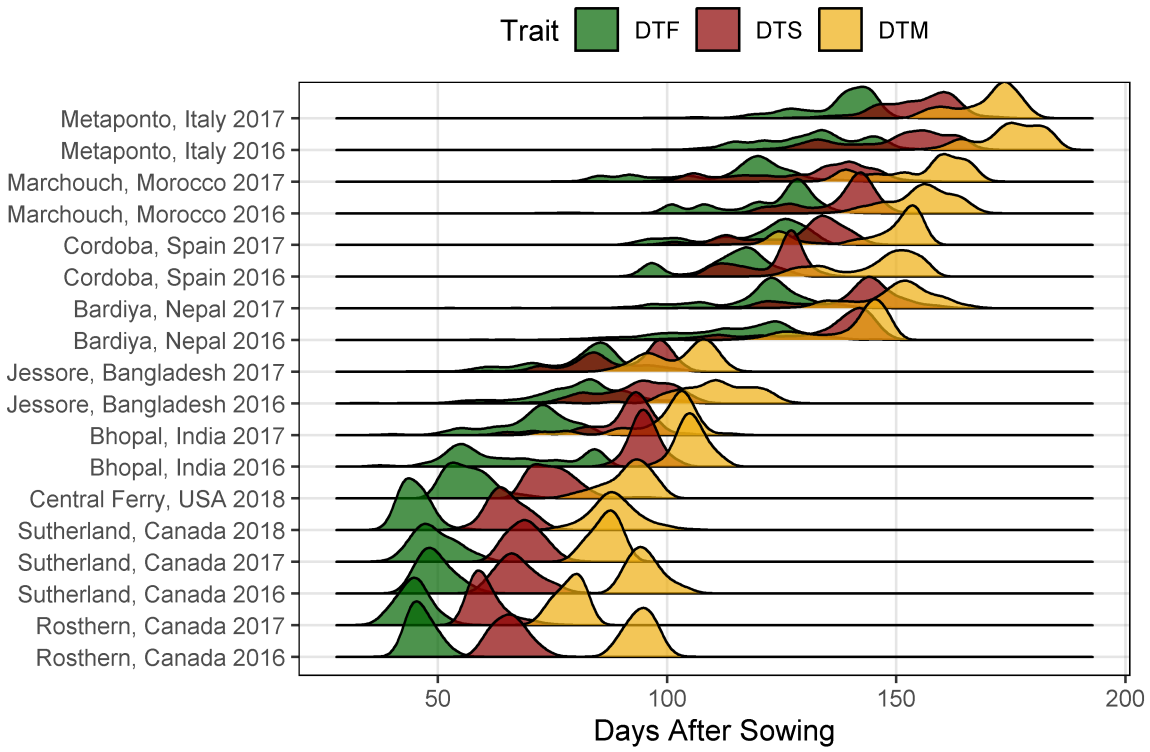
Additional Figure 3 MacroEnv Phenology




```
# Prep data
xx <- ee %>% filter(ExptShort %in% c("Su17", "Ba17", "It17"))
yy <- ff %>% filter(Expt %in% unique(xx$Expt)) %>%
  mutate(DTF_min = Start + DTF_min, DTF_max = Start + DTF_max,
         DTM_min = Start + DTM_min, DTM_max = Start + DTM_max)
y1 <- select(yy, Expt, Location, Year, MacroEnv, min = DTF_min, max = DTF_max) %>%
  mutate(Trait = "DTF")
y2 <- select(yy, Expt, Location, Year, MacroEnv, min = DTM_min, max = DTM_max) %>%
  mutate(Trait = "DTM")
yy <- bind_rows(y1, y2)
# Plot
mp <- ggplot(xx) +
  geom_rect(data = yy, aes(xmin = min, xmax = max, fill = Trait),
```

```
            ymin = 0, ymax = 40, alpha = 0.4) +
  geom_line(aes(x = Date, y = DayLength_rescaled, color = "Blue")) +
  geom_line(aes(x = Date, y = Temp_mean, color = "darkred") ) +
  geom_ribbon(aes(x = Date, ymin = Temp_min, ymax = Temp_max),
              fill = alpha("darkred", 0.25), color = alpha("darkred", 0.25)) +
  facet_grid(Location +MacroEnv  ~ ., scales = "free_x", space = "free_x") +
  scale_color_manual(name = NULL, values = c("Blue", "darkred"),
                     labels = c("Day length", "Temperature") ) +
  scale_fill_manual(name = NULL, values = c("darkgreen", "darkgoldenrod2")) +
  coord_cartesian(ylim = c(0,40)) +
  theme_AGL +
  theme(legend.position = "bottom",
        legend.text = element_text(size = 12),
        axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5)) +
  scale_x_date(breaks = "1 month", labels = date_format("%B")) +
  scale_y_continuous(sec.axis = sec_axis(~ (16.62 - 9.11) * . / (40 - 0) + 9.11,
                     breaks = c(10, 12, 14, 16), name = "Hours")) +
  labs(title = "2017 - 2018", y = expression(paste(degree, "Celcius"), x = NULL)) +
  guides(colour = guide_legend(order = 1, override.aes = list(size = 1.25)),
         fill   = guide_legend(order = 2))
ggsave("Additional/Additional_Figure_03.png", mp, width = 8, height = 6, dpi = 600)
```

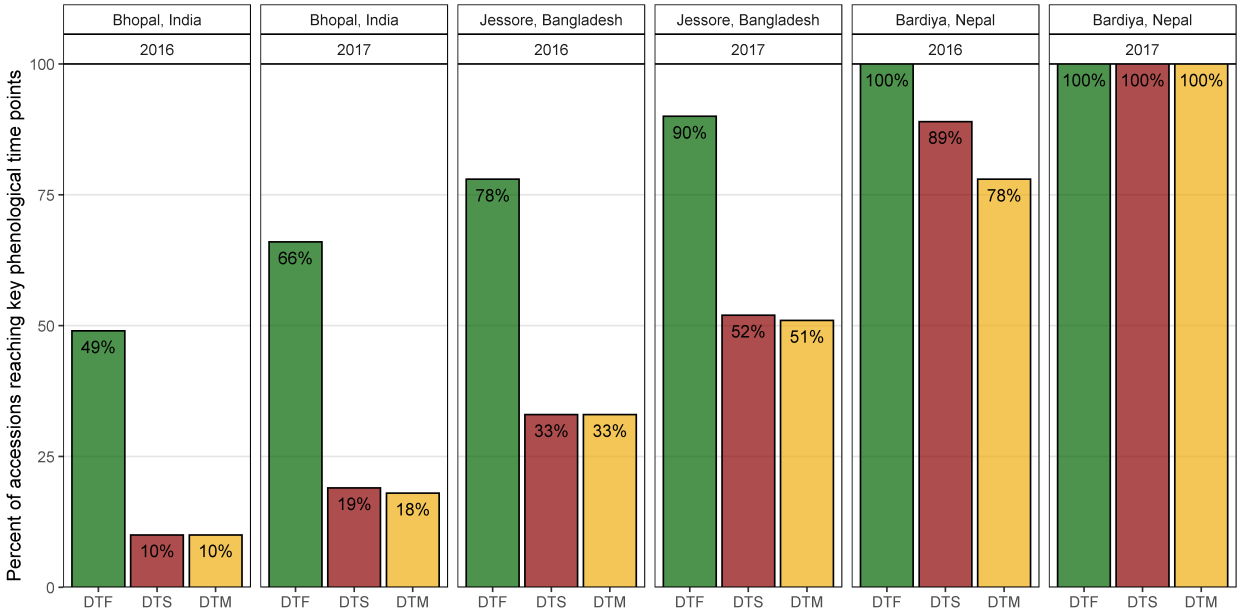
Additional Figure 4 ggridges




```
# Prep data
xx <- dd %>% select(Expt, DTF, DTS, DTM) %>%
  gather(Trait, Value, DTF, DTS, DTM) %>%
```

```
  mutate(Trait = factor(Trait, levels = c("DTF", "DTS", "DTM")))
# Plot
mp <- ggplot(xx, aes(x = Value, y = Expt, fill = Trait)) +
  ggridges::geom_density_ridges(alpha = 0.7) +
  scale_fill_manual(values = c("darkgreen", "darkred", "darkgoldenrod2")) +
  theme_AGL +
  theme(legend.position = "top", legend.margin = unit(c(0,0,0,0), "cm")) +
  labs(y = NULL, x = "Days After Sowing")
ggsave("Additional/Additional_Figure_04.png", mp, width = 6, height = 4, dpi = 600)
```

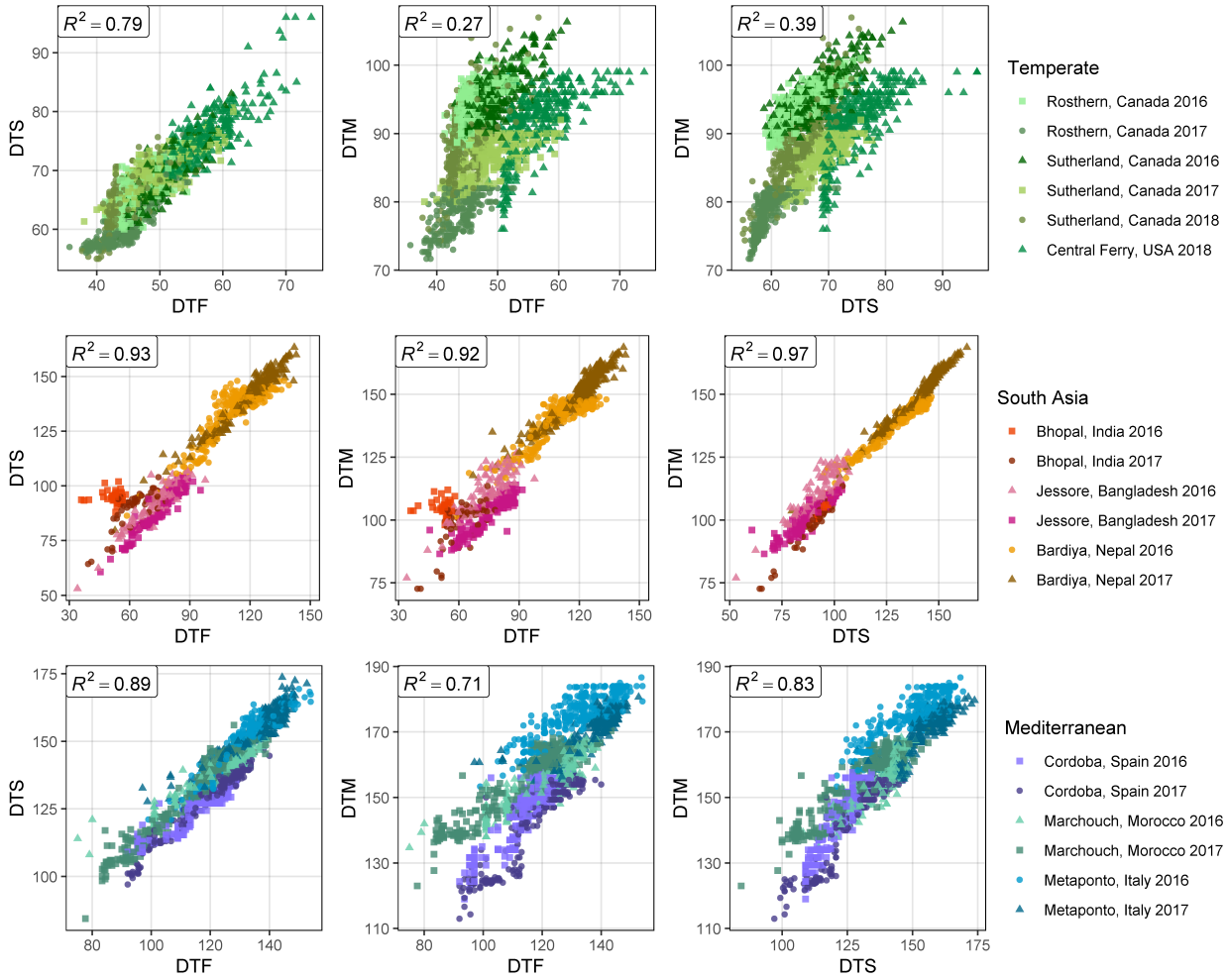
Supplemental Figure 2 Missing Data




```
# Prep data
xx <- dd %>%
  filter(Location %in% c("Bhopal, India", "Jessore, Bangladesh", "Bardiya, Nepal")) %>%
  mutate(DTF = ifelse(is.na(DTF), 0, 1),
         DTS = ifelse(is.na(DTS), 0, 1),
         DTM = ifelse(is.na(DTM), 0, 1) ) %>%
  group_by(Expt, Location, Year) %>%
  summarise_at(vars(DTF, DTS, DTM), funs(sum), na.rm = T) %>%
  ungroup() %>%
  gather(Trait, Flowered, DTF, DTS, DTM) %>%
  mutate(Total = ifelse(Expt == "Bardiya, Nepal 2016", 323, 324),
         # One accession was not planted in Bardiya, Nepal 2016
         DidNotFlower = Total - Flowered,
         Percent = round(100 * Flowered / Total),
         Label = paste0(Percent, "%"),
         Trait = factor(Trait, levels = c("DTF", "DTS", "DTM")))
# Plot
mp <- ggplot(xx, aes(x = Trait, y = Percent, fill = Trait)) +
  geom_bar(stat = "identity", color = "black", alpha = 0.7) +
  geom_text(aes(label = Label), nudge_y = -3, size = 3.5) +
```

```
  facet_grid(. ~ Location + Year) +
  scale_fill_manual(values = c("darkgreen", "darkred", "darkgoldenrod2")) +
  scale_y_continuous(limits = c(0,100), expand = c(0,0)) +
  theme_AGL +
  theme(legend.position = "none",
        panel.grid.major.x = element_blank() ) +
  labs(x = NULL, y = "Percent of accessions reaching key phenological time points")
ggsave("Supplemental_Figure_02.png", width = 10, height = 5, dpi = 600)
```

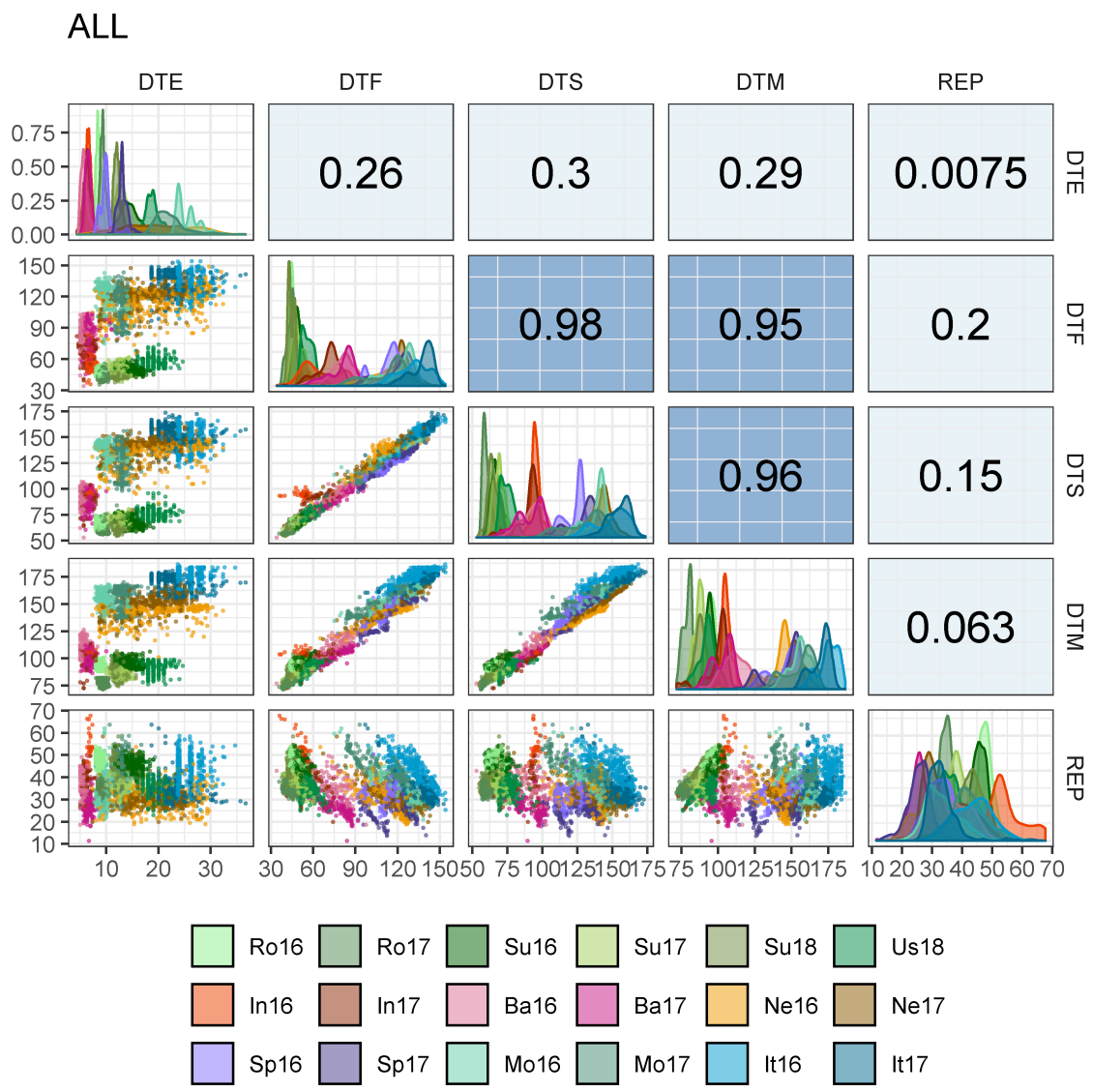
Supplemental Figure 3 Correlation Plots




```
# Prep data
xx <- dd %>% left_join(select(ff, Expt, MacroEnv), by = "Expt") %>%
  select(Entry, Expt, MacroEnv, DTF, DTS, DTM)
# Create plotting function
ggCorPlot <- function(x, legend.title, colNums) {
  # Plot (a)
  r2 <- round(cor(x$DTF, x$DTS, use ="complete", method = "pearson")^2, 2)
  tp1 <- ggplot(x) + theme_AGL +
    geom_point(aes(x = DTF, y = DTS, color = Expt, shape = Expt), alpha = 0.8) +
```

```
    geom_label(x = -Inf, y = Inf, hjust = 0, vjust = 1, parse = T,
               label = paste("italic(R)^2 == ", r2) ) +
    scale_color_manual(name = legend.title, values = colors_Expt[colNums]) +
    scale_shape_manual(name = legend.title, values = c(15,16,17,15,16,17))
  # Plot (b)
  r2 <- round(cor(x$DTF, x$DTM, use ="complete.obs", method = "pearson")^2, 2)
  tp2 <- ggplot(x) + theme_AGL +
    geom_point(aes(x = DTF, y = DTM, color = Expt, shape = Expt), alpha = 0.8) +
    geom_label(x = -Inf, y = Inf, hjust = 0, vjust = 1, parse = T,
               label = paste("italic(R)^2 == ", r2) ) +
    scale_color_manual(name = legend.title, values = colors_Expt[colNums]) +
    scale_shape_manual(name = legend.title, values = c(15,16,17,15,16,17))
  # Plot (c)
  r2 <- round(cor(x$DTS, x$DTM, use = "complete", method = "pearson")^2, 2)
  tp3 <- ggplot(x) + theme_AGL +
    geom_point(aes(x = DTS, y = DTM, color = Expt, shape = Expt), alpha = 0.8) +
    geom_label(x = -Inf, y = Inf, hjust = 0, vjust = 1, parse = T,
               label = paste("italic(R)^2 == ", r2) ) +
    scale_color_manual(name = legend.title, values = colors_Expt[colNums]) +
    scale_shape_manual(name = legend.title, values = c(15,16,17,15,16,17))
  # Append (a), (b) and (c)
  mp <- ggarrange(tp1, tp2, tp3, nrow = 1, ncol = 3,
                  common.legend = T, legend = "right")
  mp
}
# Plot
mp1 <- ggCorPlot(xx %>% filter(MacroEnv == "Temperate"),     "Temperate",      1:6 )
mp2 <- ggCorPlot(xx %>% filter(MacroEnv == "South Asia"),    "South Asia",     7:12)
mp3 <- ggCorPlot(xx %>% filter(MacroEnv == "Mediterranean"), "Mediterranean", 13:18)
mp <- ggarrange(mp1, mp2, mp3, nrow = 3, ncol = 1, common.legend = T, legend = "right")
ggsave("Supplemental_Figure_03.png", mp, width = 10, height = 8, dpi = 600)
```

Additional Figures - Correlations



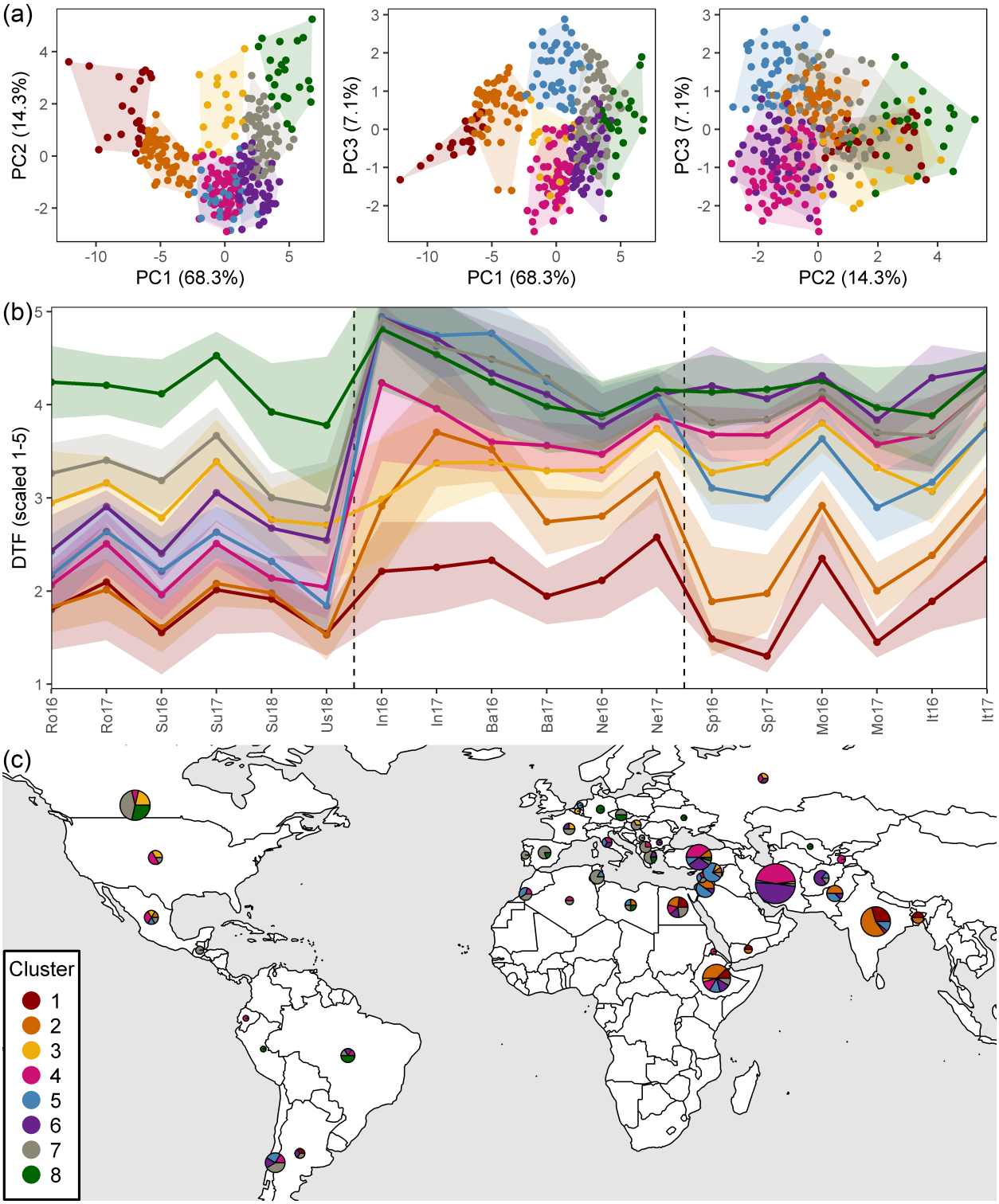

```
# Prep data
xx <- dd %>% left_join(select(ff, Expt, MacroEnv), by = "Expt") %>%
  mutate(DTE = ifelse(Location == "Cordoba, Spain", NA, DTE))
x1 <- xx %>% filter(MacroEnv == "Temperate")
x2 <- xx %>% filter(MacroEnv == "South Asia")
x3 <- xx %>% filter(MacroEnv == "Mediterranean")
# Create plotting functions
my_lower <- function(data, mapping, cols = colors_Expt, ...) {
  ggplot(data = data, mapping = mapping) +
    geom_point(alpha = 0.5, size = 0.3, aes(color = Expt)) +
    theme_bw() +
    scale_color_manual(values = cols)
}
my_middle <- function(data, mapping, cols = colors_Expt, ...) {
  ggplot(data = data, mapping = mapping) +
```

```
    geom_density(alpha = 0.5) + theme_bw() +
    scale_color_manual(name = NULL, values = cols) +
    scale_fill_manual(name = NULL, values = cols) +
    guides(color = F, fill = guide_legend(nrow = 3, byrow = T))
}
# See: https://github.com/ggobi/ggally/issues/139
my_upper <- function(data, mapping, color = I("black"), sizeRange = c(1,5), ...) {
  # Prep data
  x <- eval_data_col(data, mapping$x)
  y <- eval_data_col(data, mapping$y)
  #
  r2 <- cor(x, y, method = "pearson", use = "complete.obs")^2
  rt <- format(r2, digits = 2)[1]
  cex <- max(sizeRange)
  tt <- as.character(rt)
  # plot the cor value
  p <- ggally_text(label = tt, mapping = aes(), color = color,
                   xP = 0.5, yP = 0.5, size = 6,  ... ) + theme_bw()
  # Create color palette
  corColors <- RColorBrewer::brewer.pal(n = 10, name = "RdBu")[2:9]
  if        (r2 <= -0.9)              { corCol <- alpha(corColors[1], 0.5)
  } else if (r2 >= -0.9 & r2 <= -0.6) { corCol <- alpha(corColors[2], 0.5)
  } else if (r2 >= -0.6 & r2 <= -0.3) { corCol <- alpha(corColors[3], 0.5)
  } else if (r2 >= -0.3 & r2 <= 0)    { corCol <- alpha(corColors[4], 0.5)
  } else if (r2 >= 0    & r2 <= 0.3)  { corCol <- alpha(corColors[5], 0.5)
  } else if (r2 >= 0.3  & r2 <= 0.6)  { corCol <- alpha(corColors[6], 0.5)
  } else if (r2 >= 0.6  & r2 <= 0.9)  { corCol <- alpha(corColors[7], 0.5)
  } else                              { corCol <- alpha(corColors[8], 0.5) }
  # Plot
  p <- p +
    theme(panel.background = element_rect(fill = corCol),
          panel.grid.major = element_blank(),
          #panel.grid.minor = element_blank(),
          axis.text = element_text(size = 5))
  p
}
# Plot Correlations for each Expt
for(i in 1:length(names_Expt)) {
  mp <- ggpairs(xx %>% filter(Expt == names_Expt[i]),
                columns = c("DTE", "DTF", "DTS", "DTM", "REP"),
        upper  = list(continuous = my_upper),
        diag   = list(continuous = my_middle),
        lower  = list(continuous = wrap(my_lower, cols = "black")),
        title  = i) +
    theme(strip.background = element_rect(fill = "White"))
  ggsave(paste0("Additional/Corr/Corr_", str_pad(i, 2, "left", "0"),
                "_", names_Expt[i], ".png"),
         mp, width = 6, height = 6, dpi = 600)
}
# Plot (a) Temperate
mp1 <- ggpairs(x1, columns = c("DTE", "DTF", "DTS", "DTM", "REP"),
                aes(color = Expt, fill = Expt),
        upper=list(continuous = my_upper),
```

```
        diag =list(continuous = wrap(my_middle, cols = colors_Expt[1:6])),
        lower=list(continuous = wrap(my_lower,  cols = colors_Expt[1:6])),
        title = "(a) Temperate",
        legend = c(2,2)) +
  theme(strip.background = element_rect(fill = "White"),
        legend.position = "bottom")
ggsave("Additional/Corr/Corr_Temperate.png", mp1, width = 6, height = 6, dpi = 600)
# Plot (b) South Asia
mp2 <- ggpairs(x2, columns = c("DTE", "DTF", "DTS", "DTM", "REP"),
               aes(color = Expt, fill = Expt),
        upper  = list(continuous = my_upper),
        diag   = list(continuous = wrap(my_middle, cols = colors_Expt[7:12])),
        lower  = list(continuous = wrap(my_lower,  cols = colors_Expt[7:12])),
        title  = "(b) South Asia",
        legend = c(2,2)) +
  theme(strip.background = element_rect(fill = "White"),
        legend.position = "bottom")
ggsave("Additional/Corr/Corr_SouthAsia.png", mp2, width = 6, height = 6, dpi = 600)
# Plot (c) Mediterranean
mp3 <- ggpairs(x3, columns = c("DTE", "DTF", "DTS", "DTM", "REP"),
               aes(color = Expt, fill = Expt),
        upper  = list(continuous = my_upper),
        diag   = list(continuous = wrap(my_middle, cols = colors_Expt[13:18])),
        lower  = list(continuous = wrap(my_lower,  cols = colors_Expt[13:18])),
        title  = "(c) Mediterranean",
        legend = c(2,2)) +
  theme(strip.background = element_rect(fill = "White"),
        legend.position = "bottom")
ggsave("Additional/Corr/Corr_Mediterranean.png", mp3, width = 6, height = 6, dpi = 600)
# Plot All
mp4 <- ggpairs(xx, columns = c("DTE", "DTF", "DTS", "DTM", "REP"),
        aes(color = ExptShort, fill = ExptShort),
        upper  = list(continuous = my_upper),
        diag   = list(continuous = my_middle),
        lower  = list(continuous = my_lower),
        title  = "ALL",
        legend = c(2,2)) +
  theme(strip.background = element_rect(fill = "White"),
        legend.position = "bottom")
ggsave("Additional/Corr/Corr_All.png", mp4, width = 6, height = 6, dpi = 600)
```

PCA

Figure 3 PCA



```r
# Prep data
xx <- dd %>% select(Entry, Expt, DTF2_scaled) %>%
  spread(Expt, DTF2_scaled)
xx <- xx %>% column_to_rownames("Entry") %>% as.matrix()
# PCA
mypca <- PCA(xx, ncp = 10, graph = F)
# Heirarcical clustering
mypcaH <- HCPC(mypca, nb.clust = 8, graph = F)
perc <- round(mypca[[1]][,2], 1)
x1.1 <- mypcaH[[1]] %>% rownames_to_column("Entry")
x1.2 <- mypca[[3]]$coord %>% as.data.frame() %>% rownames_to_column("Entry")
x1 <- left_join(x1.1, x1.2, by = "Entry") %>%
  mutate(Entry = as.numeric(Entry)) %>%
  left_join(select(ldp, Entry, Name, Origin), by = "Entry") %>%
  left_join(select(ct, Origin=Country, Region), by = "Origin") %>%
  select(Entry, Name, Origin, Region, Cluster=clust,
         PC1=Dim.1, PC2=Dim.2, PC3=Dim.3, PC4=Dim.4, PC5=Dim.5,
         PC6=Dim.6, PC7=Dim.7, PC8=Dim.8, PC9=Dim.9, PC10=Dim.10)
write.csv(x1, "data/data_pca_results.csv", row.names = F)
# Prep data
x2 <- dd %>% left_join(select(x1, Entry, Cluster), by = "Entry") %>%
  group_by(Expt, ExptShort, Cluster) %>%
  summarise(mean = mean(DTF2_scaled, na.rm = T), sd = sd(DTF2_scaled, na.rm = T)) %>%
  ungroup() %>%
  mutate(ClusterNum = plyr::mapvalues(Cluster, as.character(1:8), summary(x1$Cluster)))
x3 <- x1 %>% count(Cluster) %>%
  mutate(Cluster = factor(Cluster, levels = rev(levels(Cluster))), y = n/2)
for(i in 2:nrow(x3)) { x3$y[i] <- sum(x3$n[1:(i-1)]) + (x3$n[i]/2) }
# Plot (a) PCA 1v2
find_hull <- function(df) df[chull(df[,"PC1"], df[,"PC2"]), ]
polys <- plyr::ddply(x1, "Cluster", find_hull) %>% mutate(Cluster = factor(Cluster))
mp1.1 <- ggplot(x1) +
  geom_polygon(data = polys, alpha = 0.15, aes(x = PC1, y = PC2, fill = Cluster)) +
  geom_point(aes(x = PC1, y = PC2, colour = Cluster)) +
  scale_fill_manual(values = colors) +
  scale_color_manual(values = colors) +
  theme_AGL +
  theme(legend.position = "none", panel.grid = element_blank()) +
  labs(x = paste0("PC1 (", perc[1], "%)"),
       y = paste0("PC2 (", perc[2], "%)"))
# Plot (a) PCA 1v3
find_hull <- function(df) df[chull(df[,"PC1"], df[,"PC3"]), ]
polys <- plyr::ddply(x1, "Cluster", find_hull) %>% mutate(Cluster = factor(Cluster))
mp1.2 <- ggplot(x1) +
  geom_polygon(data = polys, alpha = 0.15, aes(x = PC1, y = PC3, fill = Cluster)) +
  geom_point(aes(x = PC1, y = PC3, colour = Cluster)) +
  scale_fill_manual(values = colors) +
  scale_color_manual(values = colors) +
  theme_AGL +
  theme(legend.position = "none", panel.grid = element_blank()) +
  labs(x = paste0("PC1 (", perc[1], "%)"),
       y = paste0("PC3 (", perc[3], "%)"))
# Plot (a) PCA 2v3
```

```r
find_hull <- function(df) df[chull(df[,"PC2"], df[,"PC3"]), ]
polys <- plyr::ddply(x1, "Cluster", find_hull) %>% mutate(Cluster = factor(Cluster))
mp1.3 <- ggplot(x1) +
  geom_polygon(data = polys, alpha = 0.15, aes(x = PC2, y = PC3, fill = Cluster)) +
  geom_point(aes(x = PC2, y = PC3, colour = Cluster)) +
  scale_fill_manual(values = colors) +
  scale_color_manual(values = colors) +
  theme_AGL +
  theme(legend.position = "none", panel.grid = element_blank()) +
  labs(x = paste0("PC2 (", perc[2], "%)"),
       y = paste0("PC3 (", perc[3], "%)"))
# Append
mp1 <- ggarrange(mp1.1, mp1.2, mp1.3, nrow = 1, ncol = 3, hjust = 0)
# Plot (b) DTF
mp2 <- ggplot(x2, aes(x = ExptShort, y = mean, group = Cluster)) +
  geom_point(aes(color = Cluster)) +
  geom_vline(xintercept = 6.5,  lty = 2) +
  geom_vline(xintercept = 12.5, lty = 2) +
  geom_ribbon(aes(ymin = mean - sd, ymax = mean + sd, fill = Cluster),
              alpha = 0.2, color = NA) +
  geom_line(aes(color = Cluster), size = 1) +
  scale_color_manual(values = colors) +
  scale_fill_manual(values = colors) +
  coord_cartesian(ylim = c(0.95,5.05), expand = F) +
  theme_AGL +
  theme(axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5),
        legend.position = "none", panel.grid = element_blank()) +
  labs(y = "DTF (scaled 1-5)", x = NULL)
#
ggsave("Additional/Temp/Temp_F03_1.png", mp1, width = 8, height =   1*6/2.5, dpi = 600)
ggsave("Additional/Temp/Temp_F03_2.png", mp2, width = 8, height = 1.5*6/2.5, dpi = 600)
# Plot (c)
xx <- ldp %>% left_join(select(x1, Entry, Cluster), by = "Entry") %>%
  mutate(test1 = factor(paste(Origin, Cluster)))
xx <- xx %>% filter(!Origin %in% c("ICARDA","USDA","Unknown")) %>%
  group_by(Origin, Cluster) %>% summarise(Count = n()) %>%
  spread(Cluster, Count) %>%
  left_join(select(ct, Origin=Country, Lat, Lon), by = "Origin") %>%
  ungroup() %>% as.data.frame()
xx[is.na(xx)] <- 0
invisible(png("Additional/Temp/Temp_F03_3.png", width = 4800, height = 2200, res = 600))
par(mai = c(0,0,0,0), xaxs = "i", yaxs = "i")
mapPies(dF = xx, nameX = "Lon", nameY = "Lat", zColours = colors,
        nameZs = c("1","2","3","4","5","6","7","8"), lwd = 1,
        xlim = c(-140,110), ylim = c(0,20), addCatLegend = F,
        oceanCol = "grey90", landCol = "white", borderCol = "black")
```

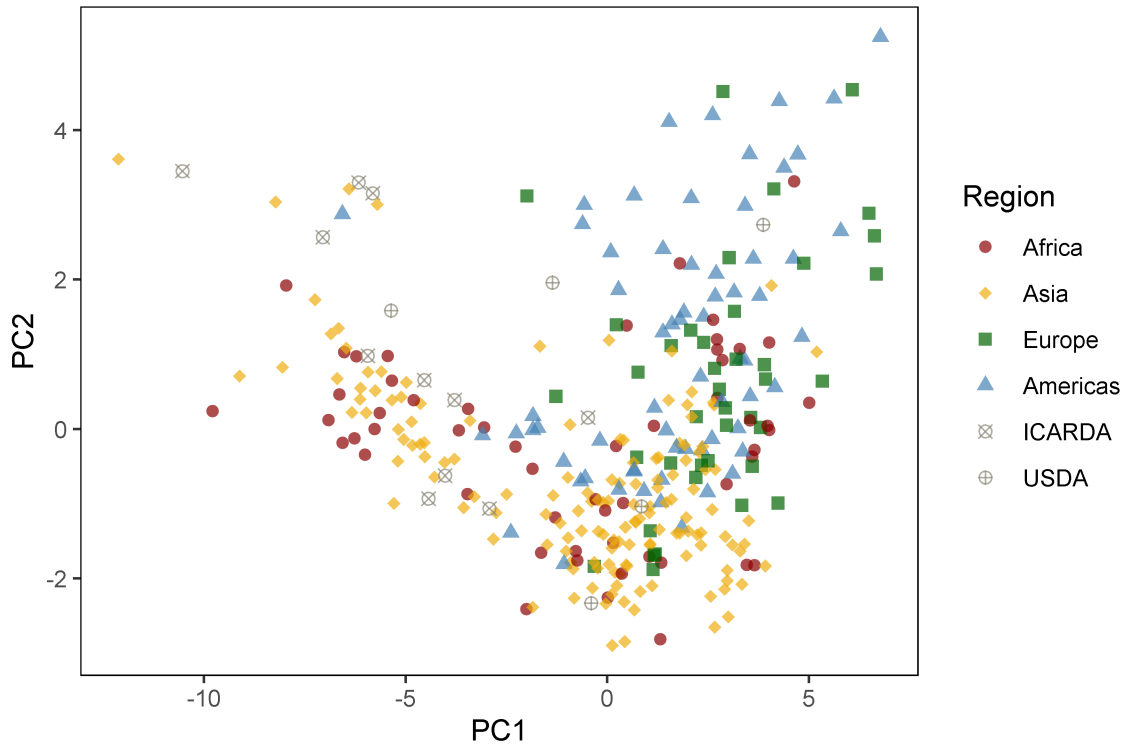
```
symbolMaxSize= 5  maxSumValues= 49  symbolScale= 0.7142857
List of 2
 $ x: num [1:100] -125 -125 -125 -125 -125 ...
 $ y: num [1:100] 57.3 57.6 57.9 58.2 58.5 ...
```

```
legend(-139.5, 15.5, title = "Cluster", legend = 1:8, col = colors,
       pch = 16, cex = 1, pt.cex = 2, box.lwd = 2)
invisible(dev.off())
# Append (a), (b) and (c)
im1 <- image_read("Additional/Temp/Temp_F03_1.png") %>%
  image_annotate("(a)", size = 120, location = "+0+0")
im2 <- image_read("Additional/Temp/Temp_F03_2.png") %>%
  image_annotate("(b)", size = 120, location = "+0+0")
im3 <- image_read("Additional/Temp/Temp_F03_3.png") %>%
  image_annotate("(c)", size = 120, location = "+0+0")
im <- image_append(c(im1, im2, im3), stack = T)
image_write(im, "Figure_03.png")
```

Additional Figure 5 Interactive PCA Plot

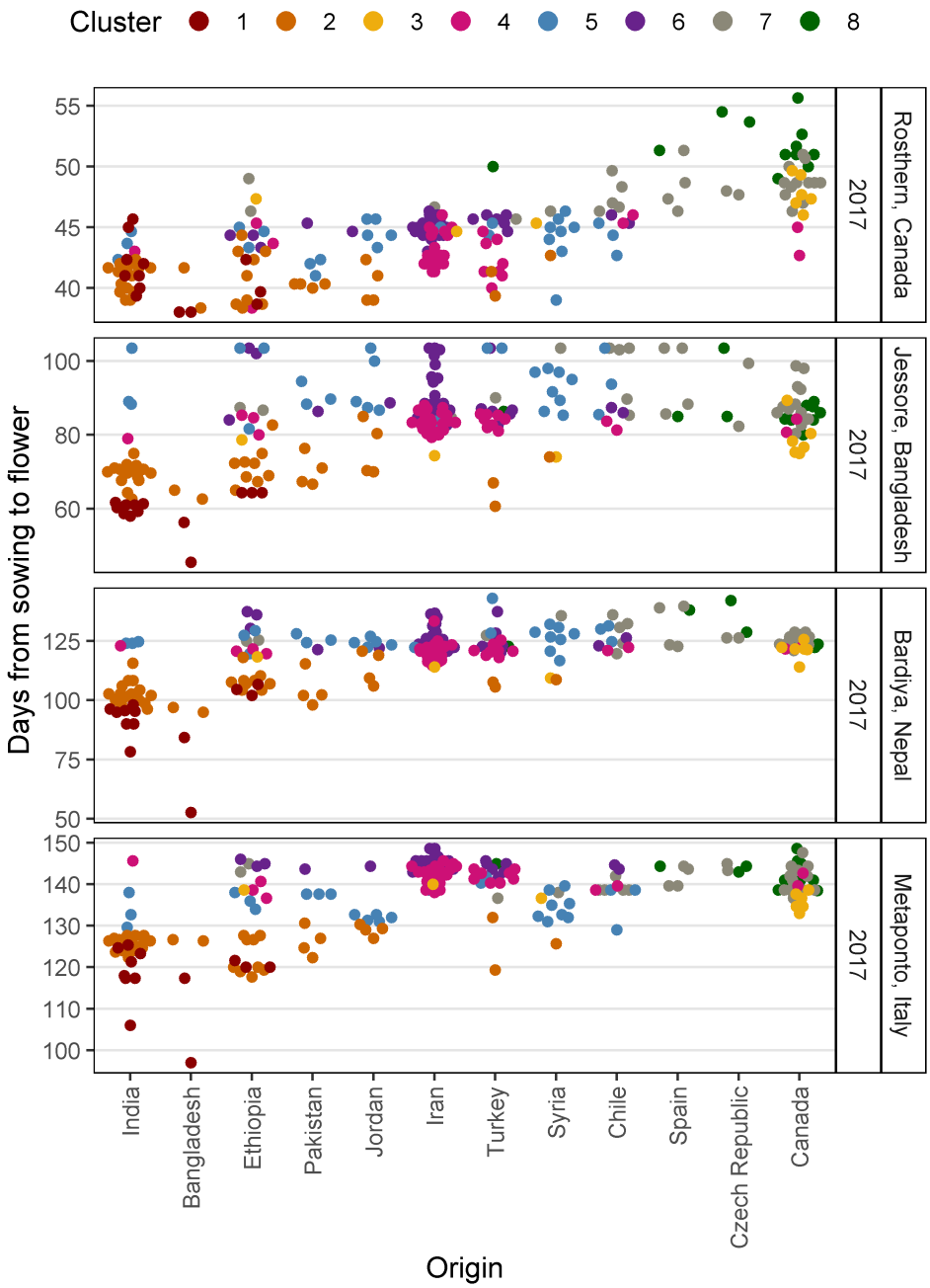
```
pca <- read.csv("data/data_pca_results.csv") %>%
  mutate(Cluster = factor(Cluster),
         myColors = plyr::mapvalues(Cluster, 1:8, colors))
rgl::plot3d(pca[,5:7], col = pca$myColors, size = 15)
rgl::writeWebGL(filename = "Additional/Additional_Figure_05.html",
                width = 650, height = 650)
```

Additional Figure 6 PCA



```r
# Prep data
levs <- c("Africa", "Asia", "Europe", "Americas", "ICARDA", "USDA")
xx <- read.csv("data/data_pca_results.csv") %>%
  filter(Origin != "Unknown") %>%
  mutate(Region = as.character(Region), Origin = as.character(Origin),
         Region = ifelse(Origin %in% levs[5:6], Origin, Region),
         Region = factor(Region, levels = levs))
# Plot
mp <- ggplot(xx, aes(x = PC1, y = PC2, color = Region, shape = Region)) +
  geom_point(alpha = 0.7, size = 2) +
  scale_color_manual(values = colors[c(1,3,8,5,7,7)]) +
  scale_shape_manual(values = c(16,18,15,17,13,10)) +
  theme_AGL +
  theme(panel.grid.major.x = element_blank(),
        panel.grid.major.y = element_blank())
ggsave("Additional/Additional_Figure_06.png", mp, width = 6, height = 4, dpi = 600)
```

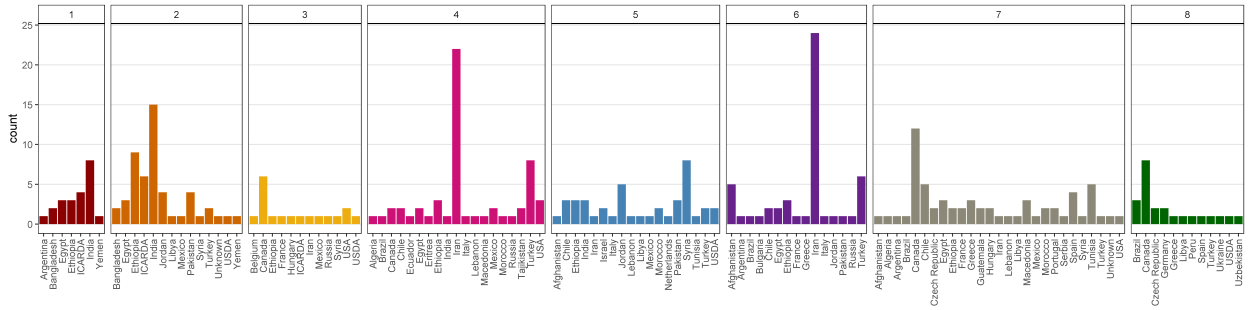
Additional Figure 7 DTF By Cluster




```
# Prep data
x1 <- read.csv("data/data_pca_results.csv") %>% mutate(Cluster = factor(Cluster))
yy <- c("India", "Bangladesh", "Ethiopia", "Pakistan", "Jordan",
        "Iran", "Turkey", "Syria", "Chile", "Spain", "Czech Republic", "Canada" )
xx <- dd %>% left_join(ldp, by = "Entry") %>%
  filter(ExptShort %in% c("Ro17", "Ba17", "Ne17", "It17"), Origin != "Unknown") %>%
  left_join(select(x1, Entry, Cluster), by = "Entry") %>%
  mutate(Origin = factor(Origin, levels = unique(Origin)[rev(order(unique(Origin)))])) %>%
  filter(Origin %in% yy) %>%
```

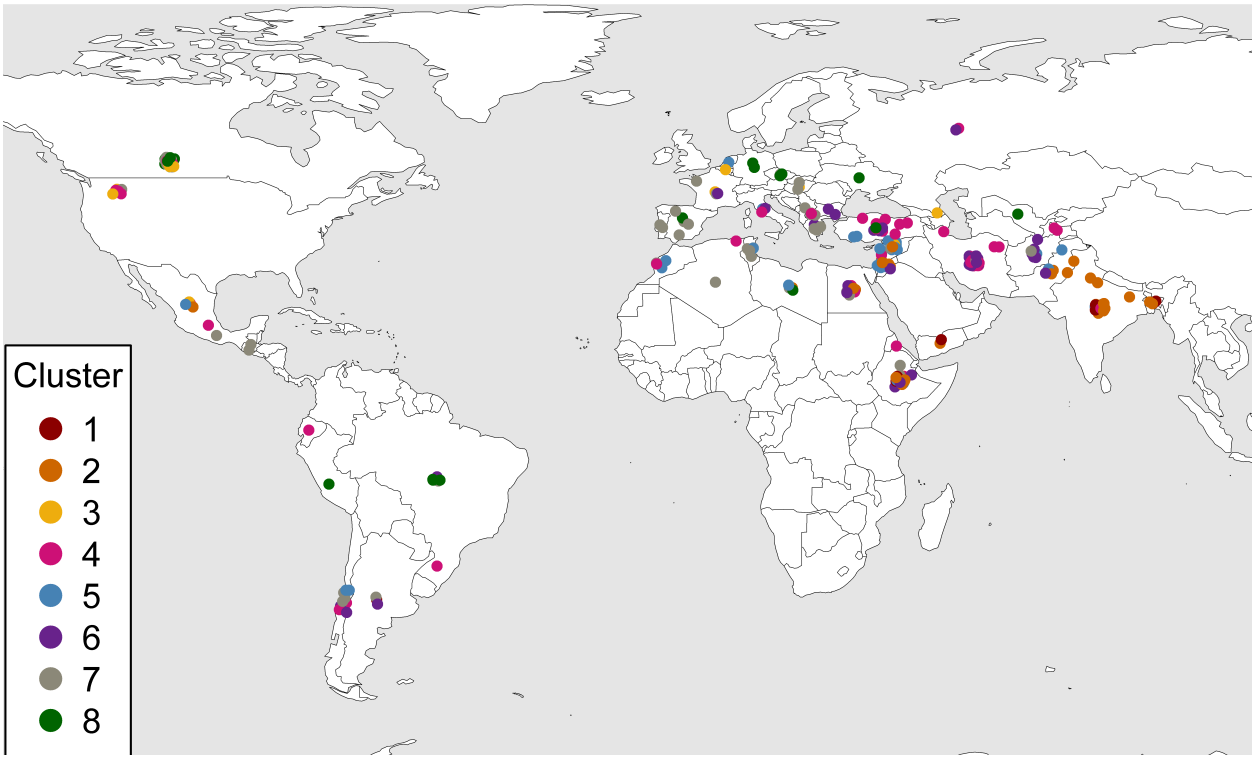
```
  mutate(Origin = factor(Origin, levels = yy))
# Plot
mp <- ggplot(xx, aes(y = DTF2, x = Origin)) +
  geom_quasirandom(aes(color = Cluster)) +
  facet_grid(Location+Year ~ ., scales = "free_y") +
  scale_color_manual(values = colors) +
  theme_AGL +
  theme(legend.position = "top",
        panel.grid.major.x = element_blank(),
        axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5)) +
  guides(colour = guide_legend(nrow = 1, override.aes = list(size = 3))) +
  labs(y = "Days from sowing to flower")
ggsave("Additional/Additional_Figure_07.png", mp, width = 5, height = 7, dpi = 600)
```

Additional Figure 8 Cluster Origins




```
# Prep data
pca <- read.csv("data/data_pca_results.csv") %>% mutate(Cluster = factor(Cluster))
xx <- ldp %>% left_join(select(pca, Entry, Cluster), by = "Entry") %>%
  mutate(test1 = factor(paste(Origin, Cluster)))
x1 <- xx %>% filter(Origin != "ICARDA") %>%
  group_by(Origin, Cluster) %>% summarise(Count = n()) %>%
  spread(Cluster, Count) %>%
  left_join(select(ct, Origin=Country, Lat, Lon), by = "Origin") %>%
  ungroup() %>% as.data.frame()
x1[is.na(x1)] <- 0
# Plot
mp <- ggplot(xx, aes(x = Origin, fill = Cluster)) +
  geom_bar(stat = "count") +
  facet_grid(. ~ Cluster, scales = "free", space = "free") +
  scale_fill_manual(values = colors) +
  theme_AGL +
  theme(legend.position = "none",
        panel.grid.major.x = element_blank(),
        axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5)) +
  labs(x = NULL)
ggsave("Additional/Additional_Figure_08.png", width = 16, height = 4, dpi = 600)
```

Additional Figure 9 LDP Origins By Cluster

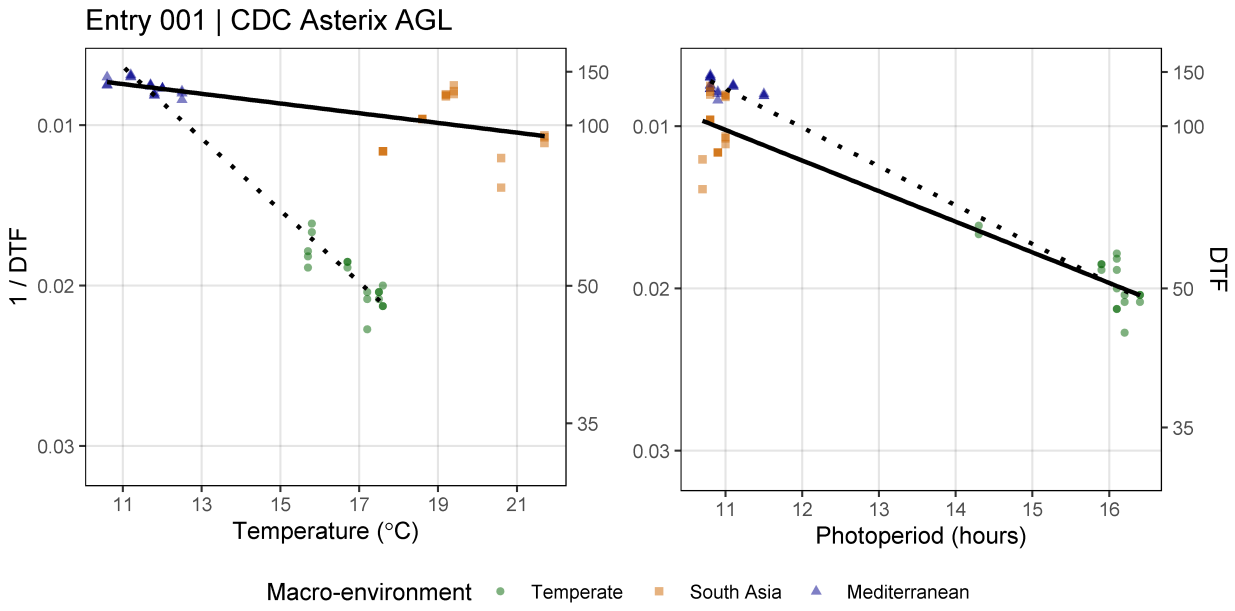



```
# Prep data
x1 <- read.csv("data/data_pca_results.csv") %>% mutate(Cluster = factor(Cluster))
xx <- ldp %>% select(Entry, Name, Lat, Lon) %>% left_join(x1, by = "Entry") %>%
  left_join(select(ct, Origin=Country, cLat=Lat, cLon=Lon), by = "Origin") %>%
  mutate(Lat = ifelse(is.na(Lat), cLat, Lat),
         Lon = ifelse(is.na(Lon), cLon, Lon),
         Lat = ifelse(duplicated(Lat), jitter(Lat, 1, 1), Lat),
         Lon = ifelse(duplicated(Lon), jitter(Lon, 1, 1), Lon), Size = 1)
# Plot
invisible(png("Additional/Additional_Figure_09.png",
              width = 7200, height = 4400, res = 600)) #res = 150
par(mai = c(0,0,0,0), xaxs = "i", yaxs = "i")
mapBubbles(dF = xx, nameX = "Lon", nameY = "Lat", nameZColour = "Cluster",
           nameZSize = "Size", symbolSize = 0.5, pch = 20, addLegend = F,
           colourPalette = colors[1:8], addColourLegend = F,
           xlim = c(-140,110), ylim = c(0,20),
           oceanCol = "grey90", landCol = "white", borderCol = "black")
legend(-139.5, 15.5, title = "Cluster", legend = 1:8, col = colors,
       pch = 16, cex = 2, pt.cex = 3, box.lwd = 2)
invisible(dev.off())
```

Modeling DTF

Additional Figures - Entry Regressions

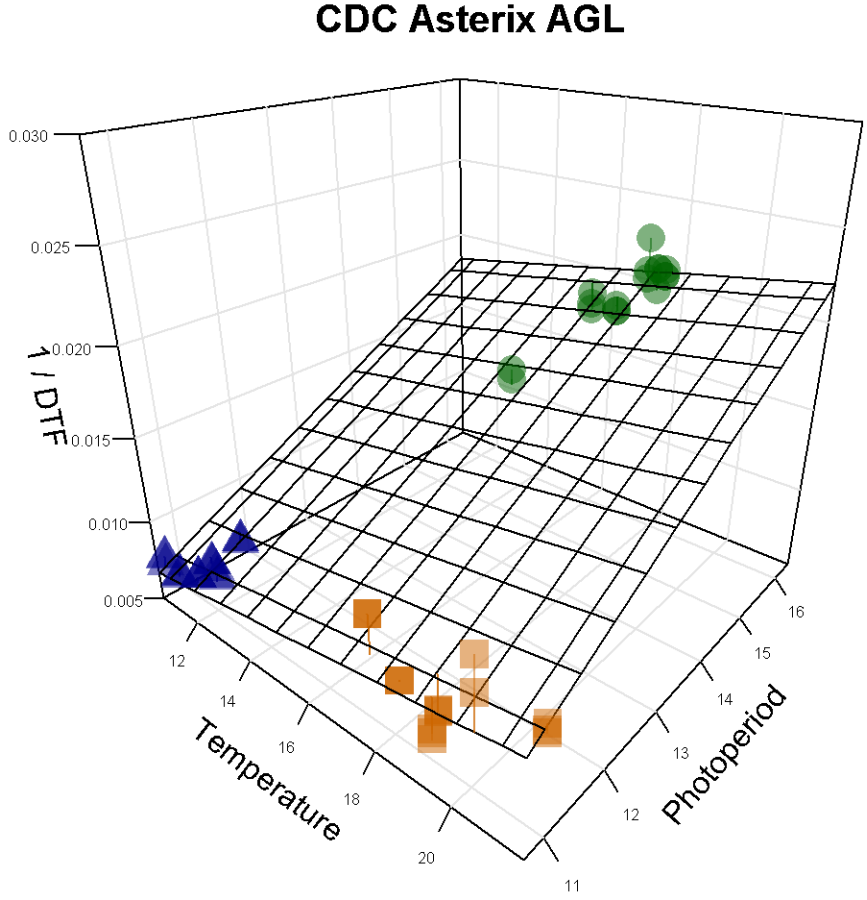
```
myfills <- alpha(c("darkgreen", "darkorange3", "darkblue"), 0.5)
mymin <- min(rr$RDTF, na.rm = T); mymax <- max(rr$RDTF, na.rm = T)
mp <- list()
for(i in 1:324) {
  xx <- rr %>% filter(Entry == i) %>%
    left_join(select(ff, Expt, MacroEnv, T_mean, P_mean), by = "Expt") %>%
    mutate(myfill = MacroEnv)
  x1 <- xx %>% filter(MacroEnv != "South Asia")
  x2 <- xx %>% filter(MacroEnv != "Temperate")
  x3 <- xx %>% filter(MacroEnv != "Mediterranean")
  figlab <- paste("Entry", str_pad(i, 3, "left", "0"), "|", unique(xx$Name))
  # Plot (a) 1/f = a + bT
  mp1 <- ggplot(xx, aes(x = T_mean, y = RDTF)) +
    geom_point(aes(shape = MacroEnv, color = MacroEnv)) +
    geom_smooth(data = x1, method = "lm", se = F, color = "black", lty = 3) +
    geom_smooth(data = x2, method = "lm", se = F, color = "black") +
    scale_y_continuous(sec.axis = dup_axis(~ 1/., name = NULL, breaks = c(35,50,100,150)),
                       trans = "reverse", breaks = c(0.01,0.02,0.03),
                       limits = c(mymax, mymin)) +
    scale_x_continuous(breaks = c(11,13,15,17,19,21)) +
    scale_shape_manual(name = "Macro-environment", values = c(16,15,17)) +
    scale_color_manual(name = "Macro-environment", values = myfills) +
    theme_AGL +
    labs(title = figlab, y = "1 / DTF",
         x = expression(paste("Temperature (", degree, "C)", sep = "")))
  # Plot (b) 1/f = a + cP
  mp2 <- ggplot(xx, aes(x = P_mean, y = RDTF)) +
    geom_point(aes(shape = MacroEnv, color = MacroEnv)) +
    geom_smooth(data = x1, method = "lm", se = F, color = "black", lty = 3) +
    geom_smooth(data = x3, method = "lm", se = F, color = "black") +
    scale_y_continuous(sec.axis = dup_axis(~ 1/., name="DTF", breaks = c(35,50,100,150)),
                       trans = "reverse", breaks = c(0.01,0.02,0.03),
                       limits = c(mymax, mymin)) +
    scale_x_continuous(breaks = c(11,12,13,14,15,16)) +
    scale_shape_manual(name = "Macro-environment", values = c(16,15,17)) +
    scale_color_manual(name = "Macro-environment", values = myfills) +
    theme_AGL +
    labs(title = "", y = NULL,x = "Photoperiod (hours)")
  #
  mp[[i]] <- ggarrange(mp1, mp2, ncol = 2, common.legend = T, legend = "bottom")
  ggsave(paste0("Additional/Entry_TP/TP_Entry_", str_pad(i, 3, pad = "0"), ".png"),
         mp[[i]], width = 8, height = 4, dpi = 600)
}
pdf("Additional/pdf_TP.pdf", width = 8, height = 4)
for(i in 1:324) { print(mp[[i]]) }
dev.off() #dev.set(dev.next())
```



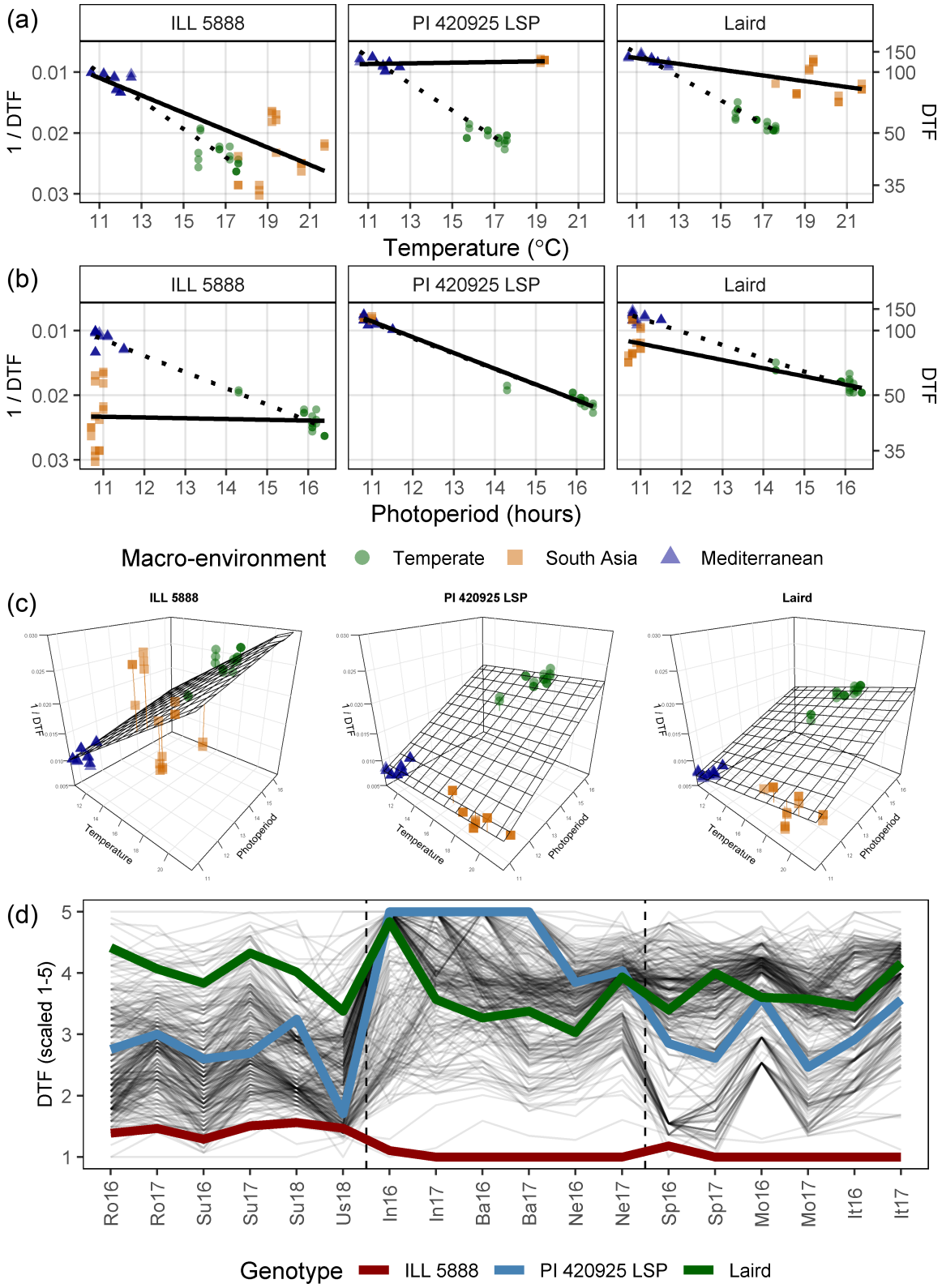
PhotoThermal Plane

```
# Prep data
xx <- rr %>% filter(!is.na(RDTF)) %>%
  left_join(select(ff, Expt, T_mean, P_mean, MacroEnv), by = "Expt")
# Create plotting function
gg_PTplane <- function(x, i) {
  x1 <- x %>% filter(Entry == i)
  x <- x1$T_mean
  y <- x1$P_mean
  z <- x1$RDTF
  fit <- lm(z ~ x + y)
  # Create PhotoThermal plane
  fitp <- predict(fit)
  grid.lines <- 12
  x.p <- seq(min(x), max(x), length.out = grid.lines)
  y.p <- seq(min(y), max(y), length.out = grid.lines)
  xy <- expand.grid(x = x.p, y = y.p)
  z.p <- matrix(predict(fit, newdata = xy), nrow = grid.lines, ncol = grid.lines)
  pchs <- plyr::mapvalues(x1$Expt, names_Expt, c(rep(16,6),rep(15,6),rep(17,6))) %>%
    as.character() %>% as.numeric()
  # Plot with regression plane
  par(mar=c(1.5, 2.5, 1.5, 0.5))
  scatter3D(x, y, z, pch = pchs, cex = 2, main = unique(x1$Name),
    col = alpha(c("darkgreen", "darkorange3", "darkblue"),0.5),
    colvar = as.numeric(x1$MacroEnv), colkey = F, col.grid = "gray90", bty = "u",
    theta = 40, phi = 25, ticktype = "detailed", cex.lab = 1, cex.axis = 0.5,
    xlab = "Temperature", ylab = "Photoperiod", zlab = "1 / DTF", zlim = c(0.005,0.03),
    surf = list(x = x.p, y = y.p, z = z.p, col = "black", facets = NA, fit = fitp) )
}
# Plot each Entry
```

```r
for (i in 1:324) {
  png(paste0("Additional/Entry_3D/3D_Entry_", str_pad(i, 3, pad = "0"), ".png"),
      width = 1000, height = 1000, res = 600) #res = 200
  gg_PTplane(xx, i)
  dev.off()
}
# Create PDF
pdf("Additional/pdf_3D.pdf")
par(mar=c(1.5, 2.5, 1.5, 0.5))
for (i in 1:324) {
  gg_PTplane(xx, i)
}
dev.off() #dev.set(dev.next())
#
# Plot ILL 5888 & ILL 4400 & Laird
xx <- xx %>% mutate(Name = gsub(" AGL", "", Name))
for (i in c(235, 94, 128)) {
  png(paste0("Additional/Temp/3D_Entry_", str_pad(i, 3, pad = "0"), ".png"),
      width = 1000, height = 1000, res = 600) # res = 200
  gg_PTplane(xx, i)
  dev.off()
}
# Create animation
xx <- read.csv("data/model_t+p_coefs.csv") %>% arrange(b, c)
lf <- list.files("Additional/Entry_3D")[xx$Entry]
mp <- image_read(paste0("Additional/Entry_3D/", lf))
animation <- image_animate(mp, fps = 10)
image_write(animation, "Additional/Animation_3D.gif")
```


CDC Asterix AGL
0.030
0.025
0.020
0.015
0.010
0.005
1 / DTF
12
14
16
18
20
Temperature
11
12
13
14
15
16
Photoperiod

Supplemental Figure 4 Regressions



```
# Prep data
myfills <- alpha(c("darkgreen", "darkorange3", "darkblue"), 0.5)
yy <- c("ILL 5888 AGL", "PI 420925 LSP AGL",  "Laird AGL")
xx <- rr %>% filter(Name %in% yy, !is.na(DTF)) %>%
  left_join(select(ff, Expt, MacroEnv, T_mean, P_mean), by = "Expt") %>%
  mutate(Name = gsub(" AGL", "", Name),
         Name = factor(Name, levels = gsub(" AGL", "", yy)),
         myfill = MacroEnv)
x1 <- xx %>% filter(MacroEnv != "South Asia")
x2 <- xx %>% filter(MacroEnv != "Temperate")
x3 <- xx %>% filter(MacroEnv != "Mediterranean")
# Plot (a) 1/f = a + bT
mp1 <- ggplot(xx, aes(x = T_mean, y = RDTF)) +
  geom_point(aes(shape = MacroEnv, color = MacroEnv)) +
  geom_smooth(data = x1, method = "lm", se = F, color = "black", lty = 3) +
  geom_smooth(data = x2, method = "lm", se = F, color = "black") +
  scale_y_continuous(trans = "reverse", breaks = c(0.01,0.02,0.03),
        sec.axis = dup_axis(~ 1/., name = "DTF", breaks = c(35,50,100,150))) +
  scale_x_continuous(breaks = c(11,13,15,17,19,21)) +
  scale_shape_manual(name = "Macro-environment", values = c(16,15,17)) +
  scale_color_manual(name = "Macro-environment", values = myfills) +
  theme_AGL + facet_grid(. ~ Name) +
  theme(axis.title.y = element_text(size = 9),
        plot.margin = unit(c(0,0,0,0), "cm")) +
  guides(colour = guide_legend(override.aes = list(size = 3))) +
  labs(y = "1 / DTF", x = expression(paste("Temperature (", degree, "C)", sep = "")))
# Plot (b) 1/f = a + cP
mp2 <- ggplot(xx, aes(x = P_mean, y = RDTF)) +
  geom_point(aes(shape = MacroEnv, color = MacroEnv)) +
  geom_smooth(data = x1, method = "lm", se = F, color = "black", lty = 3) +
  geom_smooth(data = x3, method = "lm", se = F, color = "black") +
  scale_y_continuous(trans = "reverse", breaks = c(0.01,0.02,0.03),
        sec.axis = dup_axis(~ 1/., name="DTF", breaks = c(35,50,100,150))) +
  scale_x_continuous(breaks = c(11,12,13,14,15,16)) +
  scale_shape_manual(name = "Macro-environment", values = c(16,15,17)) +
  scale_color_manual(name = "Macro-environment", values = myfills) +
  theme_AGL + facet_grid(. ~ Name) +
  theme(axis.title.y = element_text(size = 9),
        plot.margin = unit(c(0,0,0,0), "cm")) +
  guides(colour = guide_legend(override.aes = list(size = 3))) +
  labs(y = "1 / DTF",x = "Photoperiod (hours)")
# Append (a) and (b)
mp <- ggarrange(mp1, mp2, ncol = 1, common.legend = T, legend = "bottom")
ggsave("Additional/Temp/Temp_SF04_1.png", mp, width = 6, height = 3.75, dpi = 600)
# Append (c)s
im1 <- image_read("Additional/Temp/3D_Entry_094.png")
im2 <- image_read("Additional/Temp/3D_Entry_235.png")
im3 <- image_read("Additional/Temp/3D_Entry_128.png")
im <- image_append(c(im1, im2, im3)) %>% image_scale("3600x")
image_write(im, "Additional/Temp/Temp_SF04_2.png")
# Prep data
xx <- dd %>% filter(Name %in% yy) %>%
  mutate(Name = gsub(" AGL", "", Name),
```

```
        Name = factor(Name, levels = gsub(" AGL", "", yy)))
# Plot D)
mp3 <- ggplot(dd, aes(x = ExptShort, y = DTF2_scaled, group = Name)) +
  geom_line(color = "black", alpha = 0.1) +
  geom_vline(xintercept = 6.5,  lty = 2) +
  geom_vline(xintercept = 12.5, lty = 2) +
  geom_line(data = xx, aes(color = Name), size = 2) +
  scale_color_manual(name = "Genotype", values = colors[c(1,5,8)]) +
  theme_AGL + labs(y = "DTF (scaled 1-5)", x = NULL) +
  theme(legend.position = "bottom",
        legend.margin = unit(c(0,0,0,0), "cm"),
        plot.margin   = unit(c(0,0.2,0,0.5), "cm"),
        panel.grid    = element_blank(),
        axis.title.y = element_text(size = 9),
        axis.text.x  = element_text(angle = 90, vjust = 0.5))
ggsave("Additional/Temp/Temp_SF04_3.png", mp3, width = 6, height = 2.5, dpi = 600)
# Append (a), (b), C) and D)
im1 <- image_read("Additional/Temp/Temp_SF04_1.png") %>%
  image_annotate("(a)", size = 100, location = "+0+0") %>%
  image_annotate("(b)", size = 100, location = "+0+1000")
im2 <- image_read("Additional/Temp/Temp_SF04_2.png") %>%
  image_annotate("(c)", size = 100)
im3 <- image_read("Additional/Temp/Temp_SF04_3.png") %>%
  image_annotate("(d)", size = 100)
im <- image_append(c(im1, im2, im3), stack = T)
image_write(im, "Supplemental_Figure_04.png")
```

Modeling DTF - functions

```
# Create functions
# Plot Observed vs Predicted
gg_model_1 <- function(x, title = NULL, type = 1,
    mymin = min(c(x$DTF,x$Predicted_DTF)) - 2,
    mymax = max(c(x$DTF,x$Predicted_DTF)) + 2 ) {
  x <- x %>% mutate(Flowered = ifelse(is.na(DTF), "Did not Flower", "Flowered"))
  # Prep data
  if(type == 1) {
    myx <- "DTF"; myy <- "Predicted_DTF"
    x <- x %>% filter(!is.na(DTF))
  }
  if(type == 2) {
    myx <- "RDTF"; myy <- "Predicted_RDTF"
    x <- x %>% filter(!is.na(RDTF))
  }
  myPal <- colors_Expt[names_Expt %in% unique(x$Expt)]
  r2 <- round(modelR2(x = x[,myx], y = x[,myy]), 3)
  # Plot
  mp <- ggplot(x) +
    geom_point(aes(x = get(myx), y = get(myy), color = Expt)) +
    geom_abline() +
    geom_label(x = mymin, y = mymax, hjust = 0, vjust = 1, parse = T,
```

```
              label = paste("italic(R)^2 == ", r2)) +
    scale_x_continuous(limits = c(mymin, mymax), expand = c(0, 0)) +
    scale_y_continuous(limits = c(mymin, mymax), expand = c(0, 0)) +
    scale_color_manual(name = NULL, values = myPal) +
    theme_AGL + guides(colour = guide_legend(override.aes = list(size = 2)))
  if(type == 1) {
    mp <- mp + labs(y = "Predicted DTF (days)", x = "Observed DTF (days)")
  }
  if(type == 2) {
    mp <- mp +
      scale_x_reverse(limits = c(mymax, mymin), expand = c(0, 0)) +
      scale_y_reverse(limits = c(mymax, mymin), expand = c(0, 0)) +
      labs(y = "Predicted RDTF (1/days)", x = "Observed RDTF (1/days)")
  }
  if(!is.null(title)) { mp <- mp + labs(title = title) }
  mp
}
# Facets by Expt
gg_model_2 <- function(x, myX = "DTF", myY = "Predicted_DTF", title = NULL,
                       x1 = 30, x2 = 30, y1 = 145, y2 = 120, legend.pos = "bottom") {
  # Prep data
  pca <- read.csv("data/data_pca_results.csv") %>% select(Entry, Cluster) %>%
    mutate(Cluster = factor(Cluster))
  x <- x %>%
    filter(!is.na(get(myX))) %>%
    left_join(pca, by = "Entry")
  xf <- x %>% group_by(Expt) %>%
    summarise(Mean = mean(DTF)) %>% ungroup() %>%
    mutate(r2 = NA, RMSE = NA)
  for(i in 1:nrow(xf)) {
    xi <- x %>% filter(Expt == xf$Expt[i])
    xf[i,"r2"]   <- round(modelR2(x = xi[,myX],   y = xi[,myY]), 2)
    xf[i,"RMSE"] <- round(modelRMSE(x = xi[,myX], y = xi[,myY]), 1)
  }
  # Plot
  mp <- ggplot(x, aes(x = get(myX), y = get(myY))) +
    geom_point(aes(color = Cluster), size = 0.75, alpha = 0.7) + geom_abline() +
    geom_text(x = x1, y = y1, color = "black", hjust = 0, vjust = 0, size = 3,
              aes(label = paste("RMSE = ", RMSE, sep = "")), data = xf) +
    geom_text(x = x2, y = y2, color = "black", hjust = 0, vjust = 0, size = 3,
              aes(label = paste("italic(R)^2 == ", r2)), parse = T, data = xf) +
    facet_wrap(Expt ~ ., ncol = 6, labeller = label_wrap_gen(width = 17)) +
    scale_x_continuous(limits = c(min(x[,myX]), max(x[,myX]))) +
    scale_y_continuous(limits = c(min(x[,myX]), max(x[,myX]))) +
    scale_color_manual(values = colors) +
    theme_AGL +
    theme(legend.position = legend.pos, legend.margin = unit(c(0,0,0,0), "cm"),
          panel.grid = element_blank()) +
    guides(colour = guide_legend(nrow = 1, override.aes = list(size = 3))) +
    labs(y = "Predicted DTF (days)", x = "Observed DTF (days)")
  if(!is.null(title)) { mp <- mp + labs(title = title) }
  mp
}
```

```r
# R^2 function
modelR2 <- function(x, y) {
  1 - ( sum((x - y)^2, na.rm = T) / sum((x - mean(x, na.rm = T))^2, na.rm = T))
}
# RMSE function
modelRMSE <- function(x, y) {
  sqrt(sum((x-y)^2, na.rm = T) / length(x))
}
```

$$R^2 = 1 - \frac{SS_{residuals}}{SS_{total}} = 1 - \frac{\sum(x-y)^2}{\sum(x-\bar{x})}$$

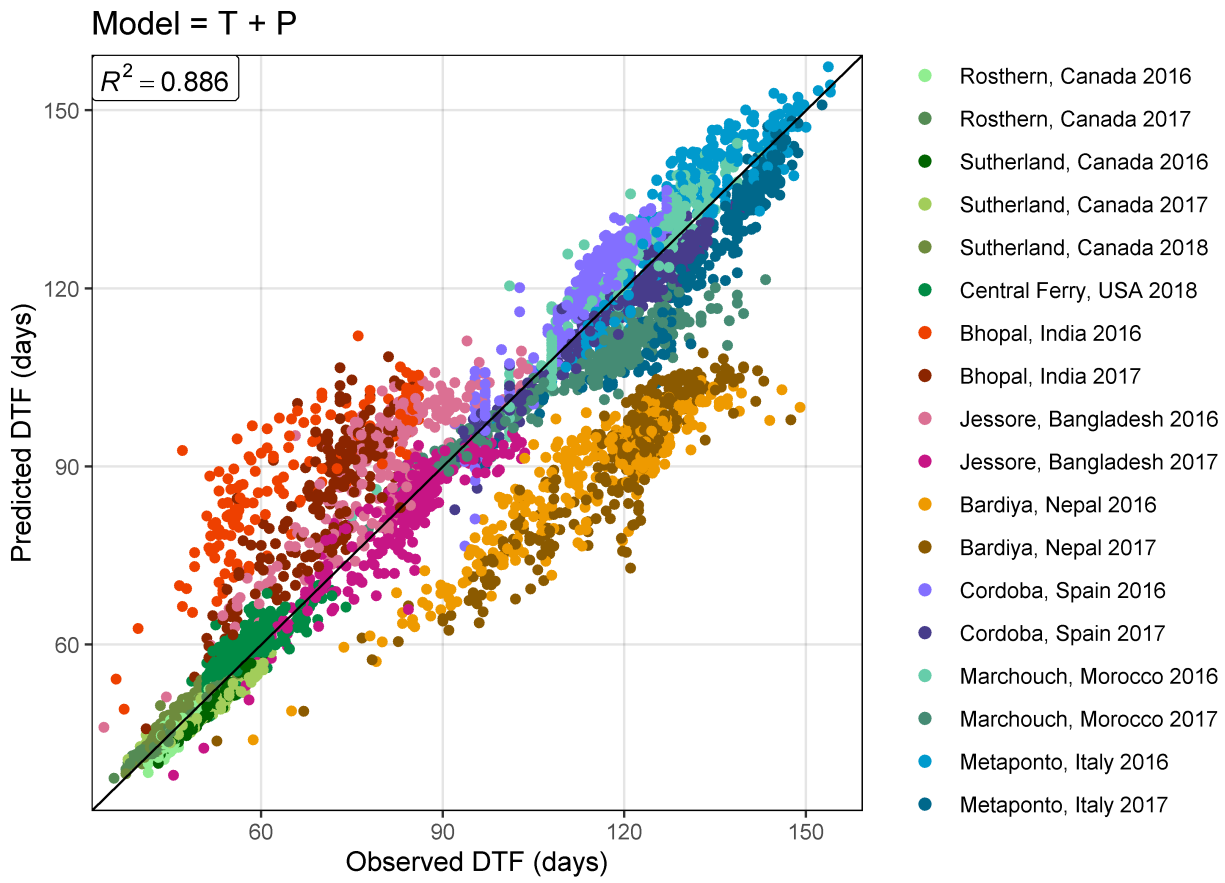
$$RMSE = \frac{\sum(y-x)^2}{n}$$

Modeling DTF (T + P) - All Site-years

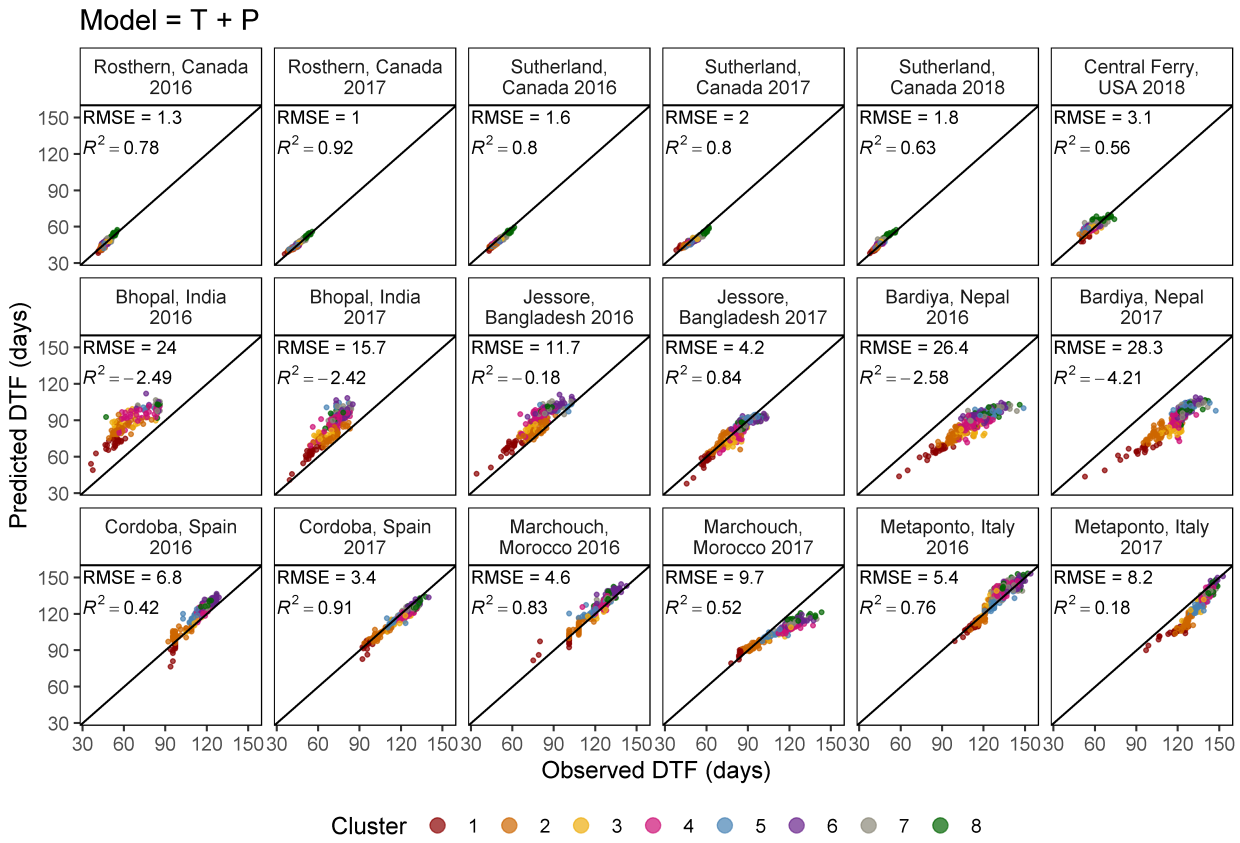
```r
############################
# 1/f = a + bT + cP (All) #
############################
# Prep data
xx <- rr %>% filter(!is.na(RDTF)) %>%
  left_join(select(ff, Expt, T_mean, P_mean), by = "Expt") %>%
  select(Plot, Entry, Name, Rep, Expt, ExptShort, T_mean, P_mean, RDTF, DTF)
mr <- NULL; md <- NULL
mc <- select(ldp, Entry, Name) %>%
  mutate(a = NA, b = NA, c = NA, RR = NA, Environments = NA,
         aP = NA, bP = NA, cP = NA)
# Model
for(i in 1:324) {
  # Prep data
  xri <- xx %>% filter(Entry == i)
  xdi <- xri %>% group_by(Entry, Name, Expt, ExptShort) %>%
    summarise_at(vars(DTF, RDTF, T_mean, P_mean), funs(mean), na.rm = T) %>%
    ungroup()
  # Train Model
  mi <- lm(RDTF ~ T_mean + P_mean, data = xri)
  # Predict DTF
  xri <- xri %>% mutate(Predicted_RDTF = predict(mi),
                        Predicted_DTF = 1 / predict(mi))
  xdi <- xdi %>% mutate(Predicted_RDTF = predict(mi, newdata = xdi),
                        Predicted_DTF = 1 / predict(mi, newdata = xdi))
  # Save to table
  mr <- bind_rows(mr, xri)
  md <- bind_rows(md, xdi)
  # Save coefficients
  mc[i,c("a","b","c")] <- mi$coefficients
  # Calculate rr and # of environments used
  mc[i,"RR"] <- 1 - sum((xri$DTF - xri$Predicted_DTF)^2, na.rm = T) /
    sum((xri$Predicted_DTF - mean(xri$DTF, na.rm = T))^2, na.rm = T)
  mc[i,"Environments"] <- length(unique(xri$Expt[!is.na(xri$DTF)]))
  mc[i,"aP"] <- summary(mi)[[4]][1,4]
  mc[i,"bP"] <- summary(mi)[[4]][2,4]
```

```
  mc[i,"cP"] <- summary(mi)[[4]][3,4]
}
mr <- mr %>% mutate(Expt = factor(Expt, levels = names_Expt))
md <- md %>% mutate(Expt = factor(Expt, levels = names_Expt))
# Save Results
write.csv(mr, "data/model_t+p.csv",       row.names = F)
write.csv(md, "data/model_t+p_d.csv",     row.names = F)
write.csv(mc, "data/model_t+p_coefs.csv", row.names = F)
#
# Plot Each Entry
mp <- list()
for(i in 1:324) {
  mp1 <- gg_model_1(mr %>% filter(Entry == i), paste("Entry", i, "| DTF"),
           mymin = min(c(mr$Predicted_DTF, mr$DTF), na.rm = T),
           mymax = max(c(mr$Predicted_DTF, mr$DTF), na.rm = T))
  mp2 <- gg_model_1(mr %>% filter(Entry == i), paste("Entry", i, "| RDTF"), type = 2,
           mymin = min(c(mr$Predicted_RDTF, mr$RDTF)) - 0.001,
           mymax = max(c(mr$Predicted_RDTF, mr$RDTF)) + 0.001)
  mp[[i]] <- ggarrange(mp1, mp2, ncol = 2, common.legend = T, legend = "right")
  fname <- paste0("Additional/entry_model/model_entry_", str_pad(i, 3, pad = "0"), ".png")
  ggsave(fname, mp[[i]], width = 10, height = 4.5, dpi = 600)
}
pdf("Additional/pdf_model.pdf", width = 10, height = 4.5)
for (i in 1:324) { print(mp[[i]]) }
dev.off() #dev.set(dev.next())
```

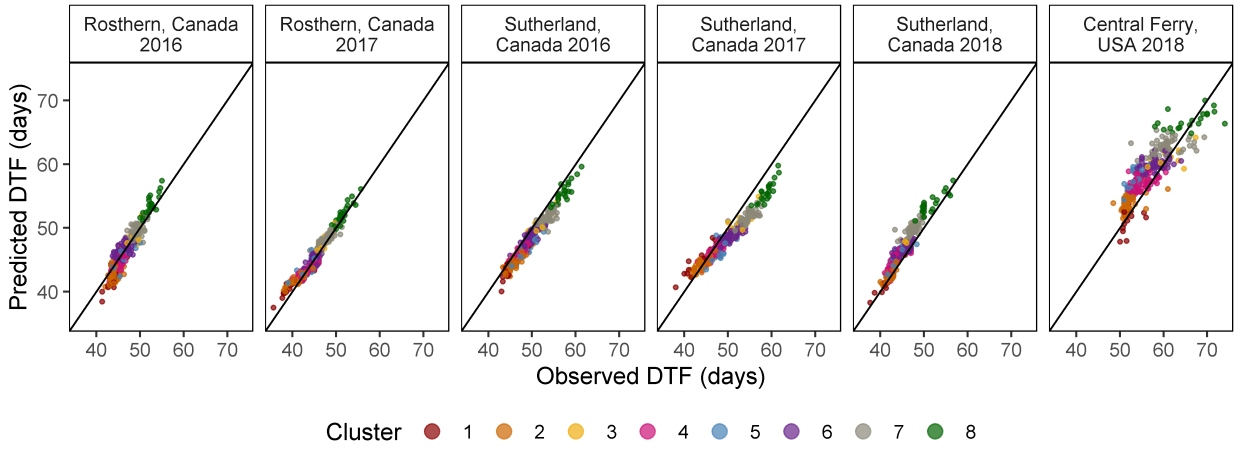
```
# Prep data
xx <- read.csv("data/model_t+p_d.csv") %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
# Plot Observed vs Predicted
mp <- gg_model_1(xx, title = "Model = T + P")
ggsave("Additional/Model/Model_1_1.png", mp, width = 7, height = 5, dpi = 600)
```




```r
# Plot Observed vs Predicted
mp <- gg_model_2(xx, title = "Model = T + P")
ggsave("Additional/Model/Model_2_1.png", mp, width = 8, height = 5.5, dpi = 600)
```



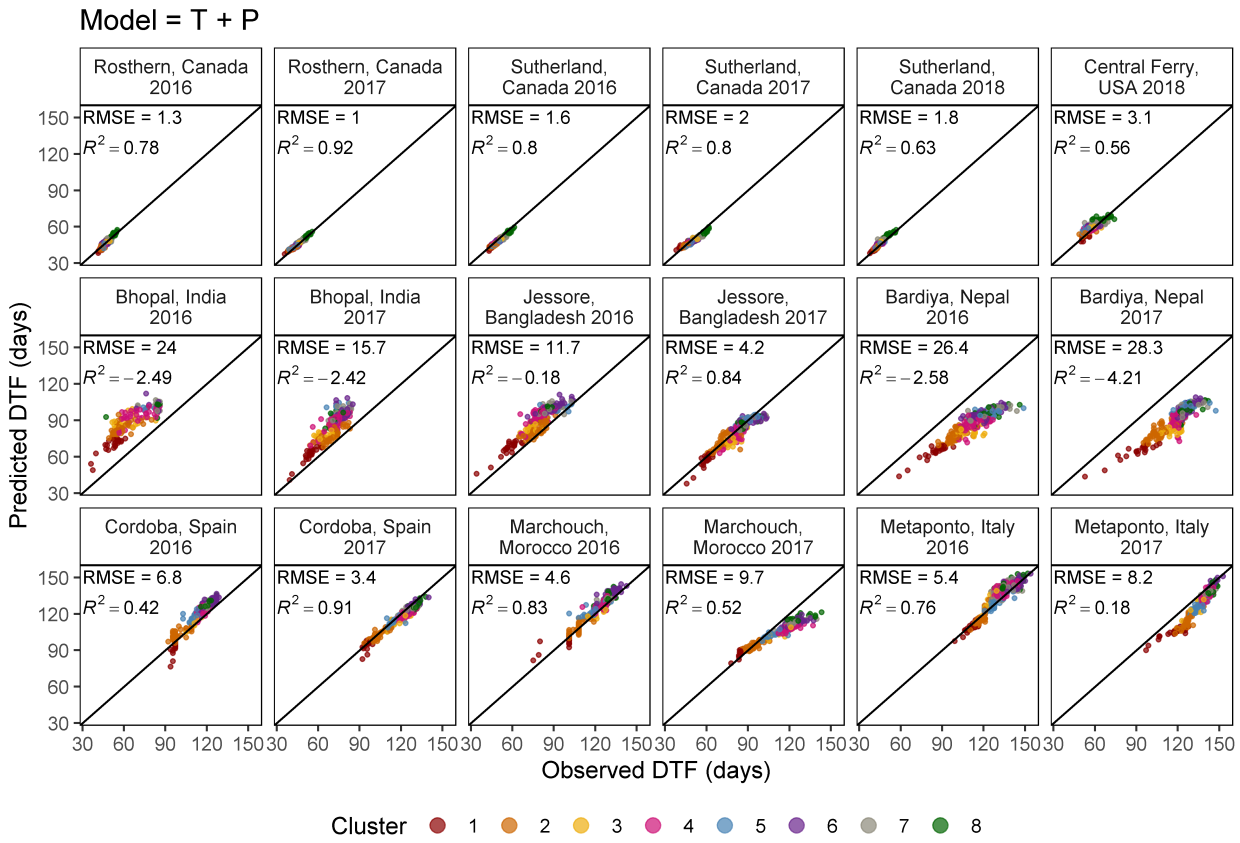

```
# Plot Observed vs Predicted for Temperate Locations
myexpts <- c("Ro16","Ro17","Su16","Su17","Su18","Us18")
mp <- gg_model_2(xx %>% filter(ExptShort %in% myexpts))
ggsave("Additional/Model/Model_3_1.png", mp ,width = 8, height = 3, dpi = 600)
```



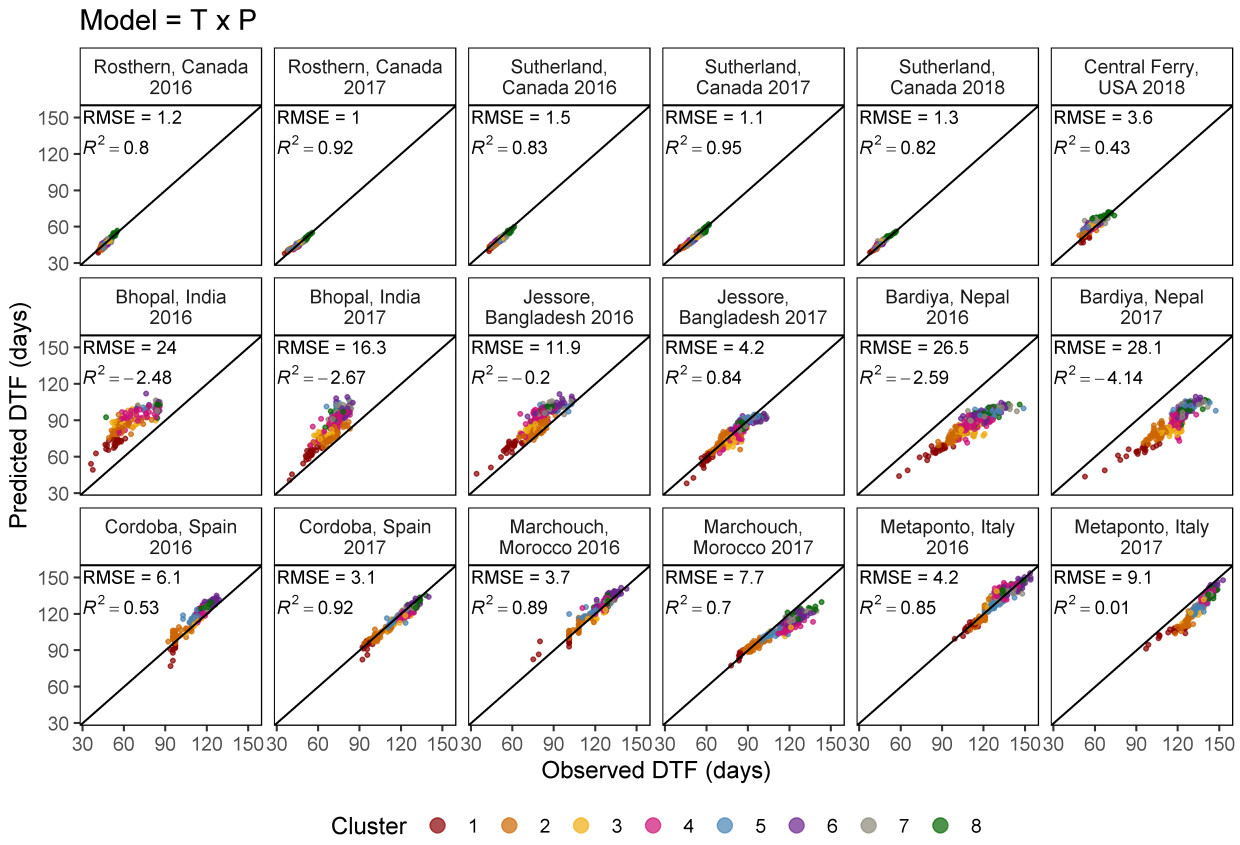
Modeling DTF (T x P) - All Site-years

```
############################
# 1/f = a + bT + cP (All) #
############################
# Prep data
xx <- rr %>% filter(!is.na(RDTF)) %>%
  left_join(select(ff, Expt, T_mean, P_mean), by = "Expt") %>%
  select(Plot, Entry, Name, Rep, Expt, ExptShort, T_mean, P_mean, RDTF, DTF)
mr <- NULL; md <- NULL
mc <- select(ldp, Entry, Name) %>%
  mutate(a = NA, b = NA, c = NA, d = NA, RR = NA, Environments = NA,
         aP = NA, bP = NA, cP= NA, dP = NA)
# Model
for(i in 1:324) {
  # Prep data
  xri <- xx %>% filter(Entry == i)
  xdi <- xri %>% group_by(Entry, Name, Expt, ExptShort) %>%
    summarise_at(vars(DTF, RDTF, T_mean, P_mean), funs(mean), na.rm = T) %>%
    ungroup()
  # Train Model
  mi <- lm(RDTF ~ T_mean * P_mean, data = xri)
  # Predict DTF
  xri <- xri %>% mutate(Predicted_RDTF = predict(mi),
                        Predicted_DTF = 1 / predict(mi))
  xdi <- xdi %>% mutate(Predicted_RDTF = predict(mi, newdata = xdi),
                        Predicted_DTF = 1 / predict(mi, newdata = xdi))
  # Save to table
  mr <- bind_rows(mr, xri)
  md <- bind_rows(md, xdi)
  # Save coefficients
  mc[i,c("a","b","c","d")] <- mi$coefficients
  # Calculate rr and # of environments used
  mc[i,"RR"] <- 1 - sum((xri$DTF - xri$Predicted_DTF)^2, na.rm = T) /
    sum((xri$Predicted_DTF - mean(xri$DTF, na.rm = T))^2, na.rm = T)
  mc[i,"Environments"] <- length(unique(xri$Expt[!is.na(xri$DTF)]))
  mc[i,"aP"] <- summary(mi)[[4]][1,4]
  mc[i,"bP"] <- summary(mi)[[4]][2,4]
  mc[i,"cP"] <- summary(mi)[[4]][3,4]
  mc[i,"dP"] <- summary(mi)[[4]][4,4]
}
mr <- mr %>% mutate(Expt = factor(Expt, levels = names_Expt))
md <- md %>% mutate(Expt = factor(Expt, levels = names_Expt))
# Save Results
write.csv(mr, "data/model_txp.csv",       row.names = F)
write.csv(md, "data/model_txp_d.csv",     row.names = F)
write.csv(mc, "data/model_txp_coefs.csv", row.names = F)
```

```
# Prep data
xx <- read.csv("data/model_txp_d.csv") %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
# Plot Observed vs Predicted
mp <- gg_model_1(xx, title = "Model = T x P")
ggsave("Additional/Model/Model_1_2.png", mp, width = 7, height = 5, dpi = 600)
```




```
# Plot Observed vs Predicted
mp <- gg_model_2(xx, title = "Model = T x P")
ggsave("Additional/Model/Model_2_2.png", mp, width = 8, height = 5.5, dpi = 600)
```

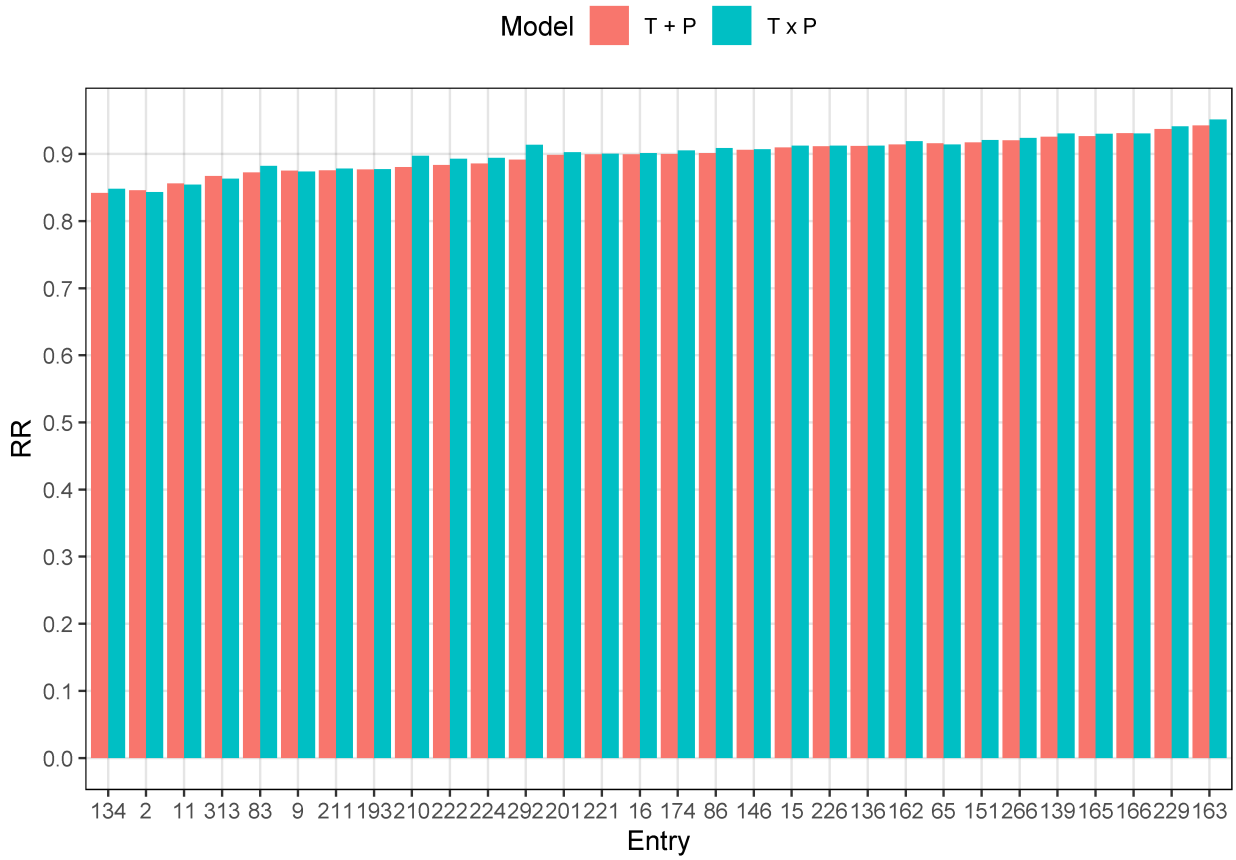


Supplemental Table 3 Model Constants

```
# Prep data
x1 <- read.csv("data/model_t+p_coefs.csv")
x2 <- read.csv("data/model_txp_coefs.csv")
xx <- bind_rows(x1, x2) %>% arrange(Entry) %>%
  select(Entry, Name, a, b, c, d, RR, Environments,
         a_p.value=aP, b_p.value=bP, c_p.value=cP, d_p.value=dP)
# Save
write.csv(xx, "Supplemental_Table_03.csv", na = "", row.names = F)
```

```
'data.frame':   648 obs. of  12 variables:
 $ Entry       : int  1 1 2 2 3 3 4 4 5 5 ...
 $ Name        : Factor w/ 324 levels "3156-11 AGL",..: 2 2 19 19 1 1 6 6 3 3 ...
 $ a           : num  -0.01877 0.00727 -0.01468 0.02093 -0.01388 ...
 $ b           : num  0.000337 -0.001202 0.000352 -0.001752 0.000356 ...
 $ c           : num  0.002046 -0.000317 0.001691 -0.001534 0.001587 ...
 $ d           : num  NA 0.00014 NA 0.000191 NA ...
 $ RR          : num  0.898 0.899 0.846 0.843 0.883 ...
 $ Environments: int  16 16 18 18 16 16 17 17 17 17 ...
 $ a_p.value   : num  2.41e-21 6.20e-01 1.99e-15 1.69e-01 3.05e-18 ...
 $ b_p.value   : num  5.43e-08 1.69e-01 2.76e-07 5.34e-02 3.33e-10 ...
 $ c_p.value   : num  3.68e-31 8.11e-01 1.07e-24 2.63e-01 4.76e-29 ...
 $ d_p.value   : num  NA 0.0794 NA 0.0213 NA ...
```

Additional Figure 10 significant T x P interactions

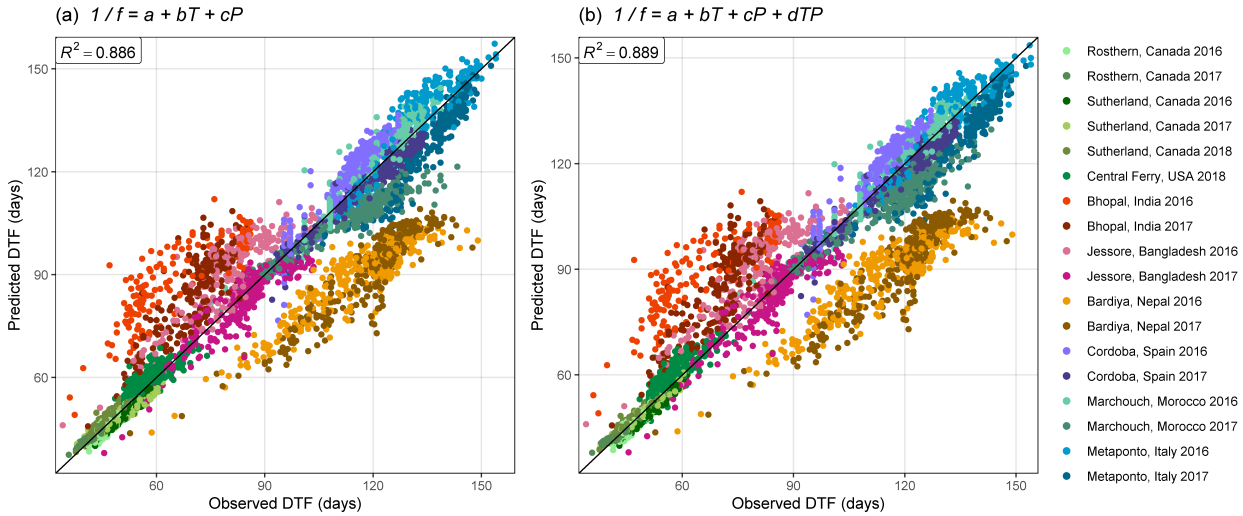



```
# Prep data
ents <- x2 %>% filter(dP < 0.05) %>% pull(Entry)
xx <- xx %>% filter(Entry %in% ents)
xx <- xx %>% arrange(RR) %>%
  mutate(Entry = factor(Entry, levels = unique(Entry)),
         Model = ifelse(is.na(d), "T + P", "T x P"))
length(ents)
```

```
[1] 30
```

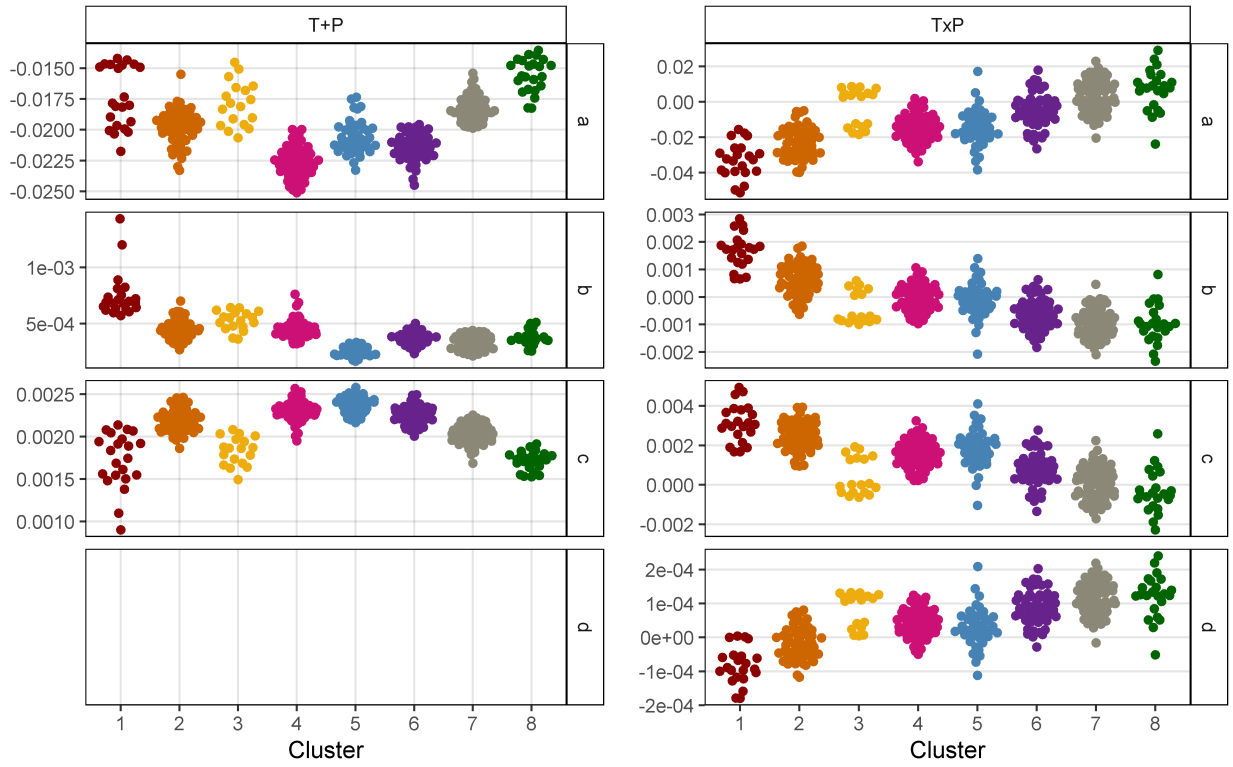
```
# Plot
mp <- ggplot(xx, aes(x = Entry, y = RR, fill = Model)) +
  geom_bar(stat = "identity", position = "dodge") +
  scale_y_continuous(breaks = seq(0,1,0.1), minor_breaks = seq(0,1,0.01)) +
  theme_AGL +
  theme(legend.position = "top")
ggsave("Additional/Additional_Figure_10.png", mp, width = 7, height = 5, dpi = 600)
```

Supplemental Figure 5 Model T + P vs T x P



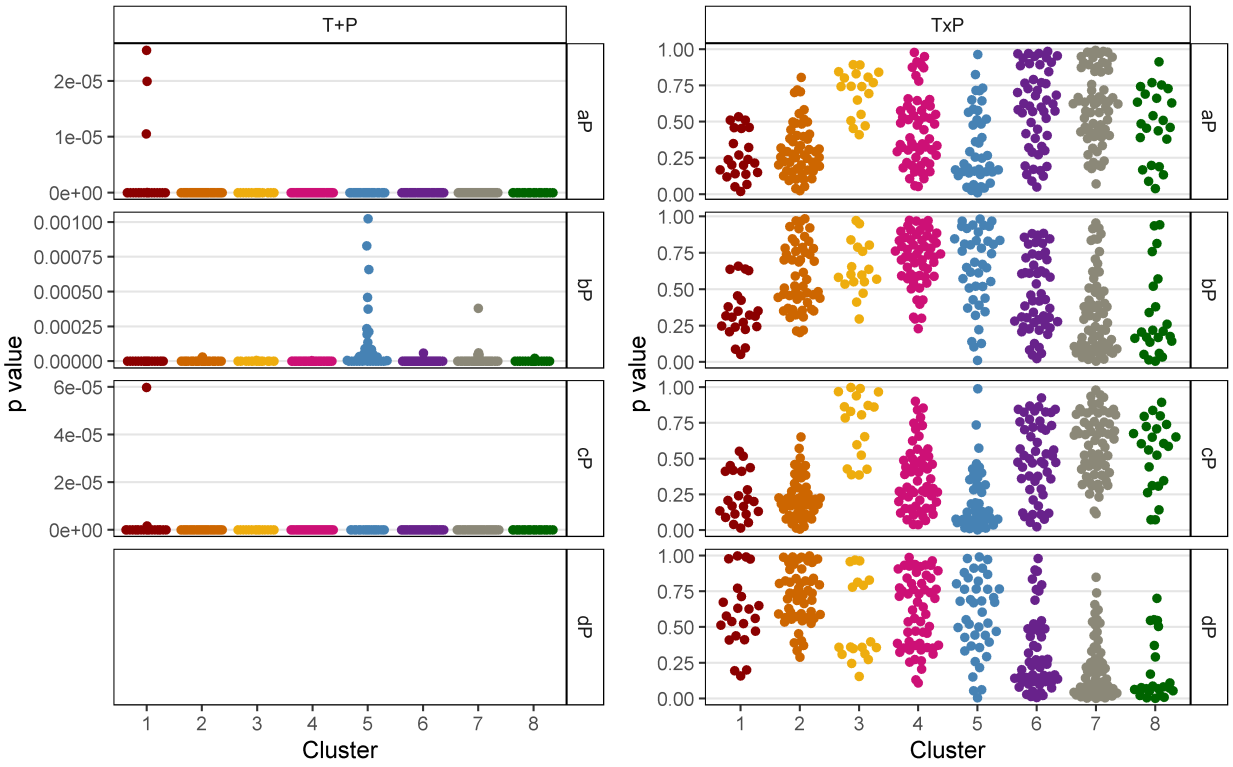

```
# Prep data
xx <- read.csv("data/model_t+p_d.csv") %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
# Plot Observed vs Predicted
mp1 <- gg_model_1(xx,
  title = expression(paste("(a) ", italic(" 1 / f = a + bT + cP"))))
# Prep data
xx <- read.csv("data/model_txp_d.csv") %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
# Plot Observed vs Predicted
mp2 <- gg_model_1(xx,
  title = expression(paste("(b) ", italic(" 1 / f = a + bT + cP + dTP"))))
# Append
mp <- ggarrange(mp1, mp2, ncol = 2, common.legend = T, legend = "right")
ggsave("Supplemental_Figure_05.png", mp, width = 12, height = 5, dpi = 600)
```

Additional Figure 11 Constants



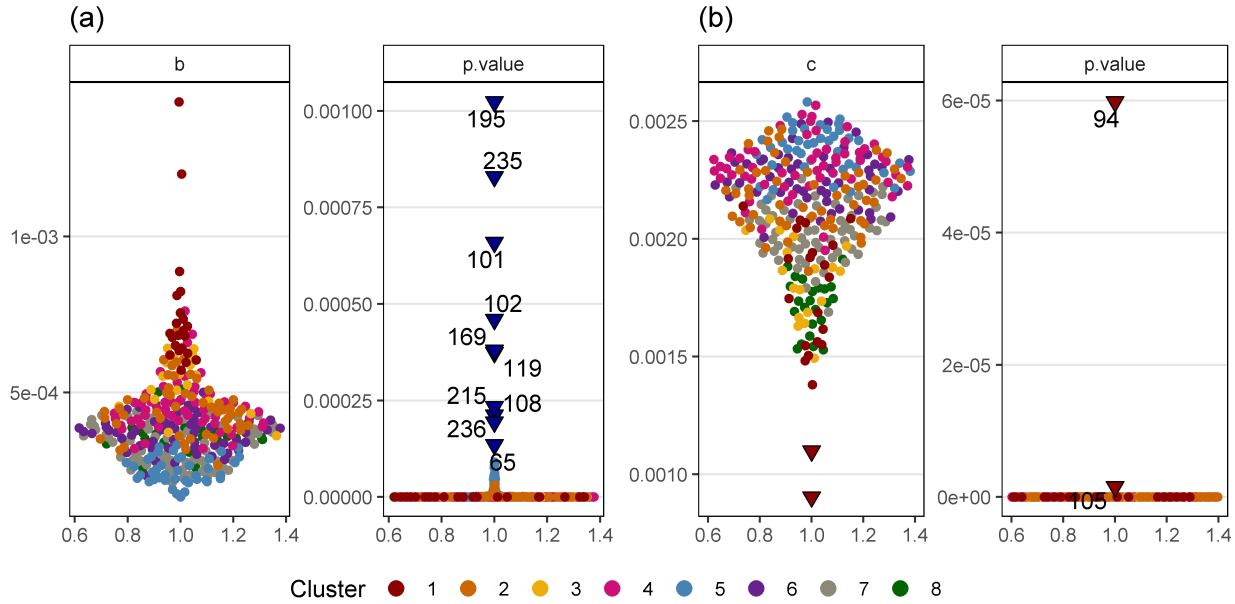

```r
# Prep data
pca <- read.csv("data/data_pca_results.csv") %>% mutate(Cluster = factor(Cluster))
x1 <- read.csv("data/model_t+p_coefs.csv") %>% mutate(Model = "T+P")
x2 <- read.csv("data/model_txp_coefs.csv") %>% mutate(Model = "TxP")
xx <- bind_rows(x1, x2) %>%
  gather(Coef, Value, a,b,c,d) %>%
  left_join(pca, by = "Entry") %>% mutate(Cluster = factor(Cluster))
# Plot
mp1 <- ggplot(xx%>%filter(Model=="T+P"), aes(x = Cluster, y = Value, color = Cluster)) +
  geom_quasirandom() + theme_AGL +
  facet_grid(Coef~Model, scales = "free_y") +
  scale_color_manual(values = colors) + labs(y = NULL)
mp2 <- ggplot(xx%>%filter(Model=="TxP"), aes(x = Cluster, y = Value, color = Cluster)) +
  geom_quasirandom() +
  facet_grid(Coef~Model, scales = "free_y") +
  theme_AGL +
  theme(panel.grid.major.x = element_blank()) +
  scale_color_manual(values = colors) + labs(y = NULL)
mp <- ggarrange(mp1, mp2, ncol = 2, legend = "none")
ggsave("Additional/Additional_Figure_11.png", mp, width = 8, height = 5, dpi = 600)
```

Additional Figure 12 Coefficient p-values




```
# Prep data
pca <- read.csv("data/data_pca_results.csv") %>% mutate(Cluster = factor(Cluster))
x1 <- read.csv("data/model_t+p_coefs.csv") %>% mutate(Model = "T+P")
x2 <- read.csv("data/model_txp_coefs.csv") %>% mutate(Model = "TxP")
xx <- bind_rows(x1, x2) %>% gather(Coef, Value, aP,bP,cP,dP) %>%
  left_join(pca, by = "Entry") %>% mutate(Cluster = factor(Cluster))
# Plot
mp1 <- ggplot(xx%>%filter(Model=="T+P"), aes(x = Cluster, y = Value, color = Cluster)) +
  geom_quasirandom() +
  facet_grid(Coef~Model, scales = "free_y") +
  scale_color_manual(values = colors) +
  theme_AGL +
  theme(panel.grid.major.x = element_blank())  +
  labs(y = "p value")
mp2 <- ggplot(xx%>%filter(Model=="TxP"), aes(x = Cluster, y = Value, color = Cluster)) +
  geom_quasirandom() +
  facet_grid(Coef ~ Model, scales = "free_y") +
  theme_AGL +
  theme(panel.grid.major.x = element_blank()) +
  scale_color_manual(values = colors) +
  labs(y = "p value")
mp <- ggarrange(mp1,mp2,ncol=2, legend = "none")
ggsave("Additional/Additional_Figure_12.png", mp, width = 8, height = 5, dpi = 600)
```

Additional Figure 13 p-values b c




```
# Prep data
pca <- read.csv("data/data_pca_results.csv") %>% mutate(Cluster = factor(Cluster))
xx <- read.csv("data/model_t+p_coefs.csv") %>%
  mutate(Sig = factor(ifelse(bP > 0.0001, "Sig","Less Sig"))) %>%
  select(Entry, Sig, p.value=bP, b) %>%
  gather(Trait, Value, p.value, b) %>%
  left_join(pca, by = "Entry")
x1 <- xx %>% filter(Sig == "Sig", Trait == "p.value")
# Plot (a)
mp1 <- ggplot(xx, aes(x = 1, y = Value)) +
  geom_quasirandom(aes(color = Cluster)) +
    geom_point(data = x1, size = 2.5, pch = 25, color = "black", fill = "darkblue") +
  geom_text_repel(data = x1, aes(label = Entry)) +
  facet_wrap(.~Trait, scales = "free_y") +
  scale_color_manual(values = colors) +
  guides(colour = guide_legend(nrow = 1, override.aes = list(size = 3))) +
  theme_AGL +
  theme(panel.grid.major.x = element_blank()) +
  labs(title = "(a)", x = NULL, y = NULL)
# Prep data
xx <- read.csv("data/model_t+p_coefs.csv") %>%
  mutate(Sig = factor(ifelse(cP > 0.000001, "Sig","Less Sig"))) %>%
  select(Entry, Sig, p.value=cP, c) %>%
  gather(Trait, Value, p.value, c) %>%
  left_join(pca, by = "Entry")
x1 <- xx %>% filter(Sig == "Sig")
# Plot B)
mp2 <- ggplot(xx, aes(x = 1, y = Value)) +
  geom_quasirandom(aes(color = Cluster)) +
  geom_point(data = x1, size = 2.5, pch = 25, color = "black", fill = "darkred") +
  geom_text_repel(data = x1 %>% filter(Trait =="p.value"), aes(label = Entry)) +
```

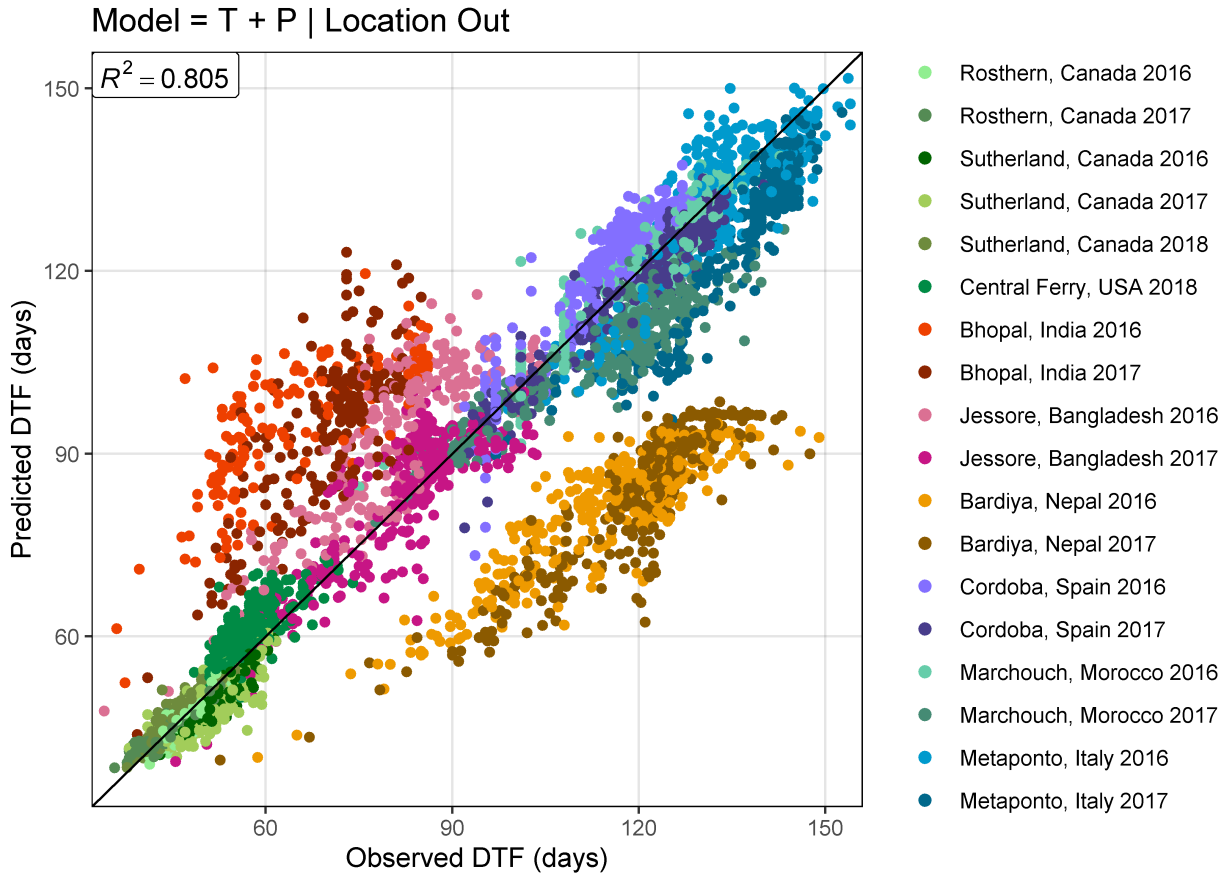
```
  facet_wrap(.~Trait, scales = "free_y") +
  scale_color_manual(values = colors) +
  guides(colour = guide_legend(nrow = 1, override.aes = list(size = 3))) +
  theme_AGL +
  theme(panel.grid.major.x = element_blank()) +
  labs(title = "(b)", x = NULL, y = NULL)
# Append (a) and (b)
mp <- ggarrange(mp1, mp2, ncol = 2, common.legend = T, legend = "bottom")
ggsave("Additional/Additional_Figure_13.png", mp, width = 8, height = 4, dpi = 600)
```

Modeling DTF (T + P) - Location Out

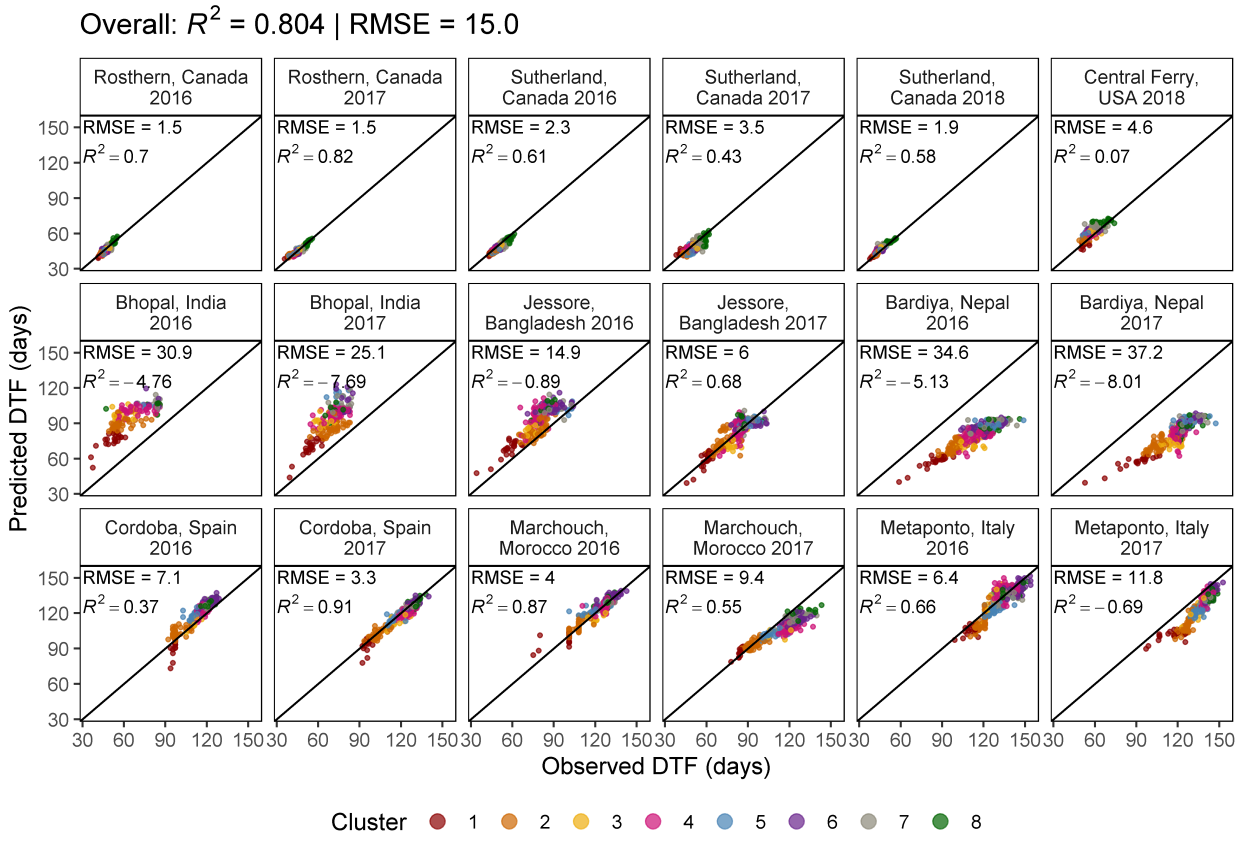
Train the model without the location used for prediction

```
####################################
# 1/f = a + bT + cP (Location Out) #
####################################
# Prep data
xx <- rr %>% filter(!is.na(RDTF)) %>%
  left_join(select(ff, Expt, T_mean, P_mean), by = "Expt")
mr <- NULL; md <- NULL
# Model - For each Location, the model is re-trained without that locations data
for(i in 1:324) {
  for(k in unique(xx$Location)) {
    # Prep data
    xi1 <- xx %>% filter(Entry == i, Location != k)
    xi2 <- xx %>% filter(Entry == i, Location == k)
    xd2 <- xi2 %>% group_by(Entry, Name, Expt, ExptShort) %>%
      summarise_at(vars(DTF, RDTF, T_mean, P_mean), funs(mean), na.rm = T) %>%
      ungroup()
    # Train model
    mi <- lm(RDTF ~ T_mean * P_mean, data = xi1)
    # Predict DTF
    xi2 <- xi2 %>% mutate(Predicted_DTF = 1 / predict(mi, newdata = xi2))
    xd2 <- xd2 %>% mutate(Predicted_DTF = 1 / predict(mi, newdata = xd2))
    # Save to table
    mr <- bind_rows(mr, xi2)
    md <- bind_rows(md, xd2)
  }
}
# Save Results
write.csv(mr, "data/model_test.csv", row.names = F)
write.csv(md, "data/model_test_d.csv", row.names = F)
```

Figure 4 Test Model




```
# Prep data
xx <- read.csv("data/model_test_d.csv") %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
# Plot Observed vs Predicted
mp <- gg_model_1(xx, title = "Model = T + P | Location Out")
ggsave("Additional/Model/Model_1_3.png", mp, width = 7, height = 5, dpi = 600)
```



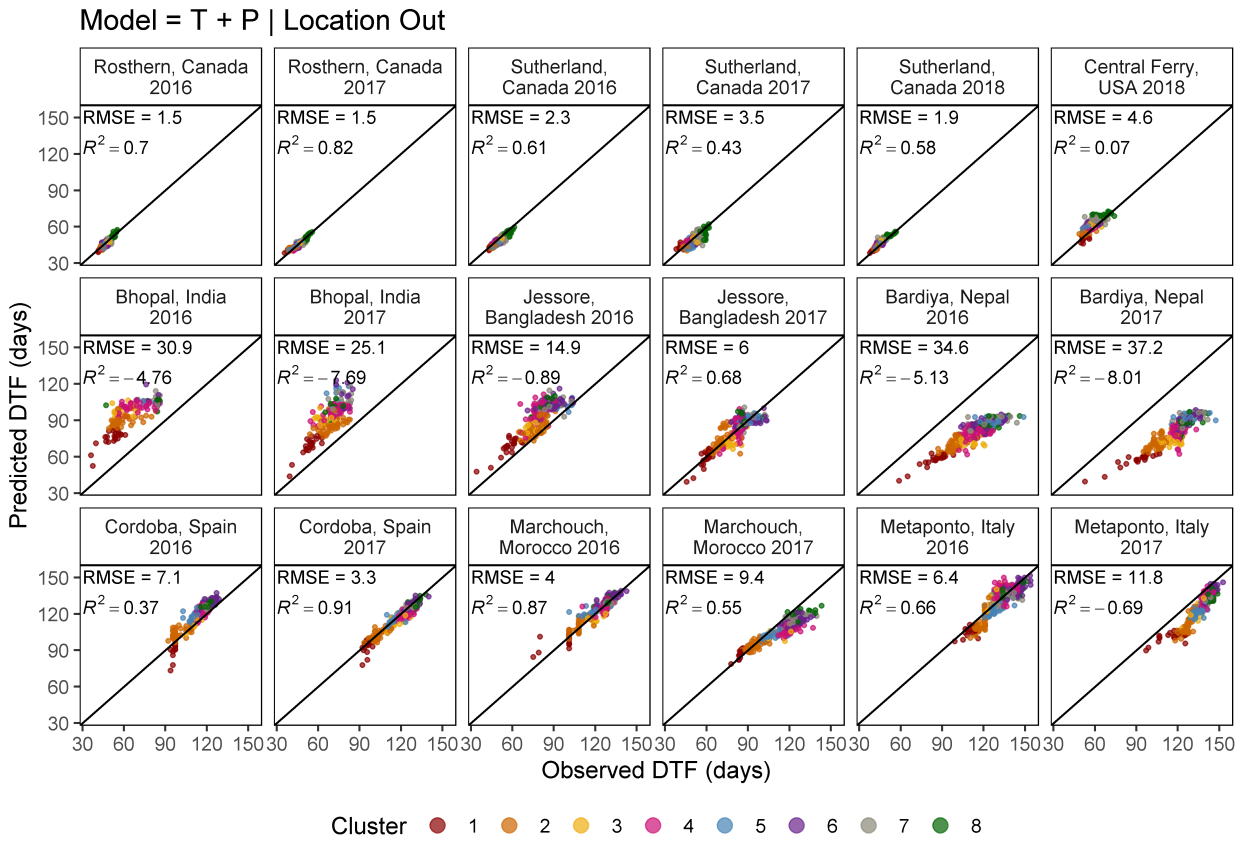

```
modelR2(xx$DTF, xx$Predicted_DTF)
```

```
[1] 0.8045254
```

```
modelRMSE(xx$DTF, xx$Predicted_DTF)
```

```
[1] 15.01078
```

```
# Plot (a)
mp <- gg_model_2(xx, title = expression(paste("Overall: ",
        italic("R")^2, " = 0.804 | RMSE = 15.0")))
ggsave("Figure_04.png", mp, width = 8, height = 5.5, dpi = 600)
mp <- gg_model_2(xx, title = "Model = T + P | Location Out")
ggsave("Additional/Model/Model_2_3.png", mp, width = 8, height = 5.5, dpi = 600)
```



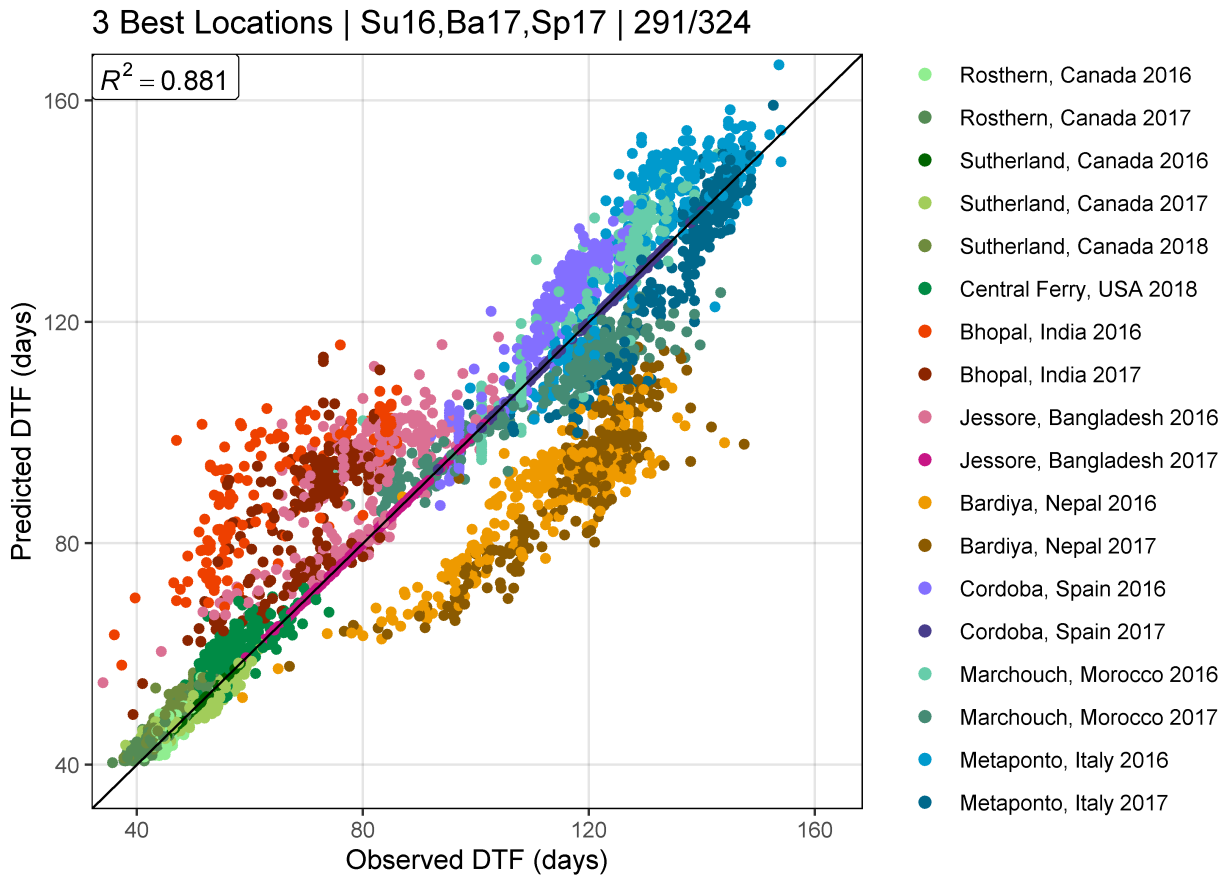
Supplemental Table 4 Test Model

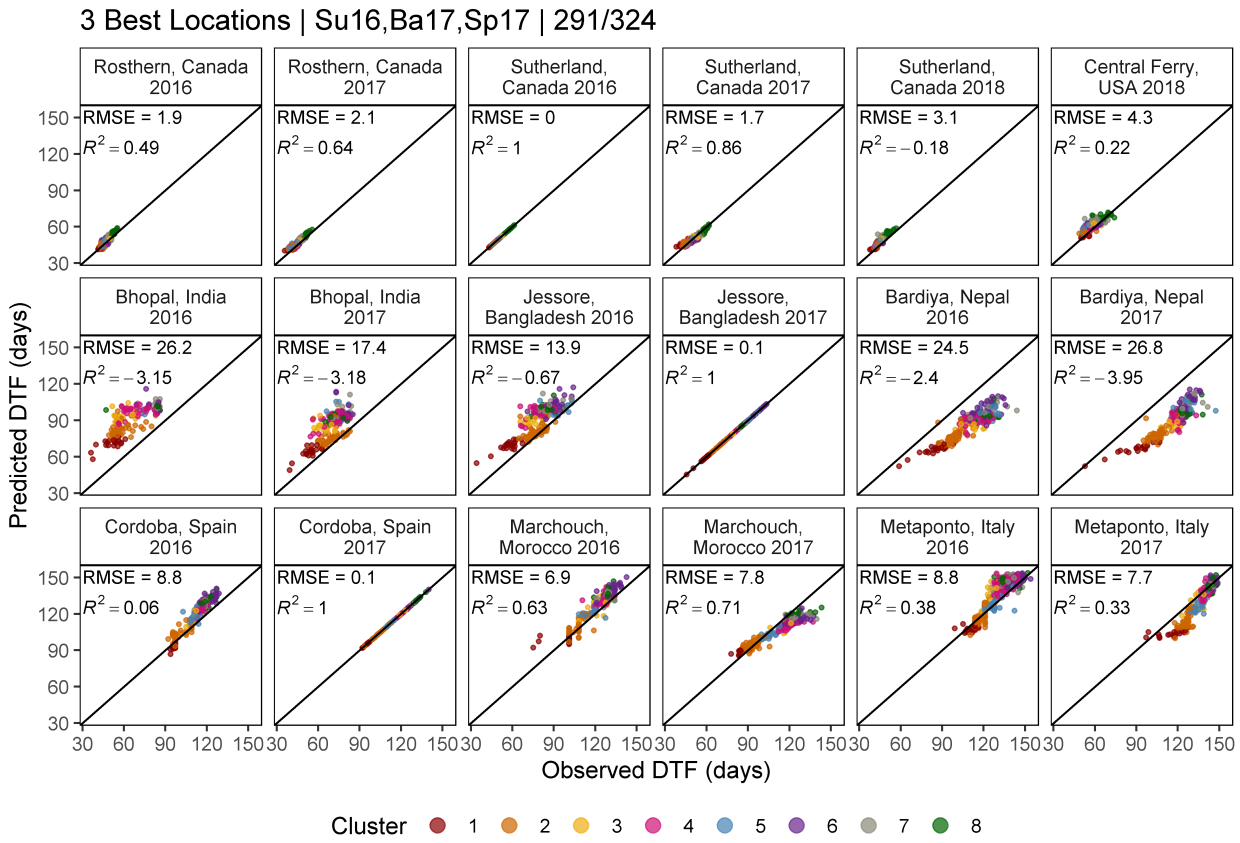
```
####################################
# 1/f = a + bT + cP (3 Locations) #
####################################
# Prep data
xx <- rr %>% #filter(!is.na(DTF)) %>%
  left_join(select(ff, Expt, T_mean, P_mean), by = "Expt")
mt <- data.frame(Temperate_Location     = rep(names_ExptShort[1:6],  each = 36),
                 SouthAsian_Location    = rep(names_ExptShort[7:12], times = 36)) %>%
  arrange(SouthAsian_Location) %>%
  mutate(Mediterranean_Location = rep(names_ExptShort[13:18], 36),
                 RR = NA, Genotypes = NA)
# Run each combination
for(t in names_ExptShort[1:6]) { # Temperate site-years
  for(s in names_ExptShort[7:12]) { # South asian site-years
    for(m in names_ExptShort[13:18]) { # Mediterranean site-years
      mr <- NULL; md <- NULL
      for(i in 1:324) {
        # Prep data
        xi1 <- xx %>% filter(Entry == i, ExptShort %in% c(t, s, m))
        xi2 <- xx %>% filter(Entry == i)
        xd2 <- xi2 %>% group_by(Entry, Name, Expt, ExptShort) %>%
          summarise_at(vars(DTF, RDTF, T_mean, P_mean), funs(mean), na.rm = T) %>%
```

```
          ungroup()
        # Train model
        mi <- lm(RDTF ~ T_mean + P_mean, data = xi1)
        # Predict DTF
        xi2 <- xi2 %>% mutate(Predicted_DTF = 1 / predict(mi, newdata = xi2))
        xd2 <- xd2 %>% mutate(Predicted_DTF = 1 / predict(mi, newdata = xd2))
        # Save to table
        mr <- bind_rows(mr, xi2)
        md <- bind_rows(md, xd2)
      }
      remEntries <- unique(md$Entry[is.na(md$DTF) & md$ExptShort %in% c(t, s, m)])
      md2 <- md %>% filter(!Entry %in% remEntries, !md$ExptShort %in% c(t, s, m))
      myrow <- mt$Temperate_Location     == t &
               mt$SouthAsian_Location    == s &
               mt$Mediterranean_Location == m
      mt[myrow,"RR"] <- round(modelR2(md2$DTF, md2$Predicted_DTF), 6)
      mt[myrow,"Genotypes"] <- length(unique(md2$Entry))
    }
  }
}
# Save
write.csv(mt %>% arrange(RR), "Supplemental_Table_04.csv", row.names = F)
```

	Temperate_Location	SouthAsian_Location	Mediterranean_Location	RR	Genotypes
1	Ro17	In16	Sp16	0.461770	159
2	Su18	In16	Sp16	0.462242	159
3	Ro16	In16	Sp16	0.466809	159
4	Su17	In16	Sp16	0.469932	159
5	Su16	In16	Sp16	0.473691	159
6	Ro17	In16	It17	0.475920	159
211	Ro17	Ba17	Sp17	0.858843	291
212	Su16	Ba17	Mo16	0.858923	291
213	Ro16	Ba17	Sp17	0.859936	291
214	Us18	Ba17	Sp17	0.861168	289
215	Su17	Ba17	Sp17	0.862977	291
216	Su16	Ba17	Sp17	0.863054	291

Modeling DTF (T + P) - 3 Best






```
####################################
# 1/f = a + bT + cP (3 Locations) #
####################################
# Prep data
xx <- rr %>% filter(!is.na(RDTF)) %>%
  left_join(select(ff, Expt, T_mean, P_mean), by = "Expt")
mr <- NULL; md <- NULL
mc <- select(ldp, Entry, Name) %>%
  mutate(a = NA, b = NA, c = NA, RR = NA, Environments = NA )
k <- c("Sutherland, Canada 2016", "Jessore, Bangladesh 2017", "Cordoba, Spain 2017")
# Model - only the ^above^ three site-years are used to train the model
for(i in 1:324) {
  # Prep data
  xi1 <- xx %>% filter(Entry == i, Expt %in% k)
  xi2 <- xx %>% filter(Entry == i)
  xd2 <- xi2 %>% group_by(Entry, Name, Expt, ExptShort) %>%
    summarise_at(vars(DTF, RDTF, T_mean, P_mean), funs(mean), na.rm = T) %>%
    ungroup()
  # Train model
  mi <- lm(RDTF ~ T_mean * P_mean, data = xi1)
  # Predict DTF
  xi2 <- xi2 %>% mutate(Predicted_DTF = 1 / predict(mi, newdata = xi2))
  xd2 <- xd2 %>% mutate(Predicted_DTF = 1 / predict(mi, newdata = xd2))
  # Save to table
  mr <- bind_rows(mr, xi2)
  md <- bind_rows(md, xd2)
```

```
  # Save coefficients
  mc[i,c(3:5)] <- mi$coefficients
  # Calculate rr and # of environments used
  mc[i,6] <- 1 - sum((xi2$DTF - xi2$Predicted_DTF)^2) /
    sum((xi2$Predicted_DTF - mean(xi2$DTF))^2)
  mc[i,7] <- length(unique(xi2$Expt))
}
ents <- xx %>% filter(ExptShort %in% c("Su16", "Ba17", "Sp17"), is.na(DTF)) %>%
  pull(Entry) %>% unique()
mr <- mr %>% filter(!Entry %in% ents)
md <- md %>% filter(!Entry %in% ents)
mc <- mc %>% filter(!Entry %in% ents)
# Save Results
write.csv(mr, "data/model_3best.csv",        row.names = F)
write.csv(md, "data/model_3best_d.csv",      row.names = F)
write.csv(mc, "data/model_3best_coefs.csv",  row.names = F)
```

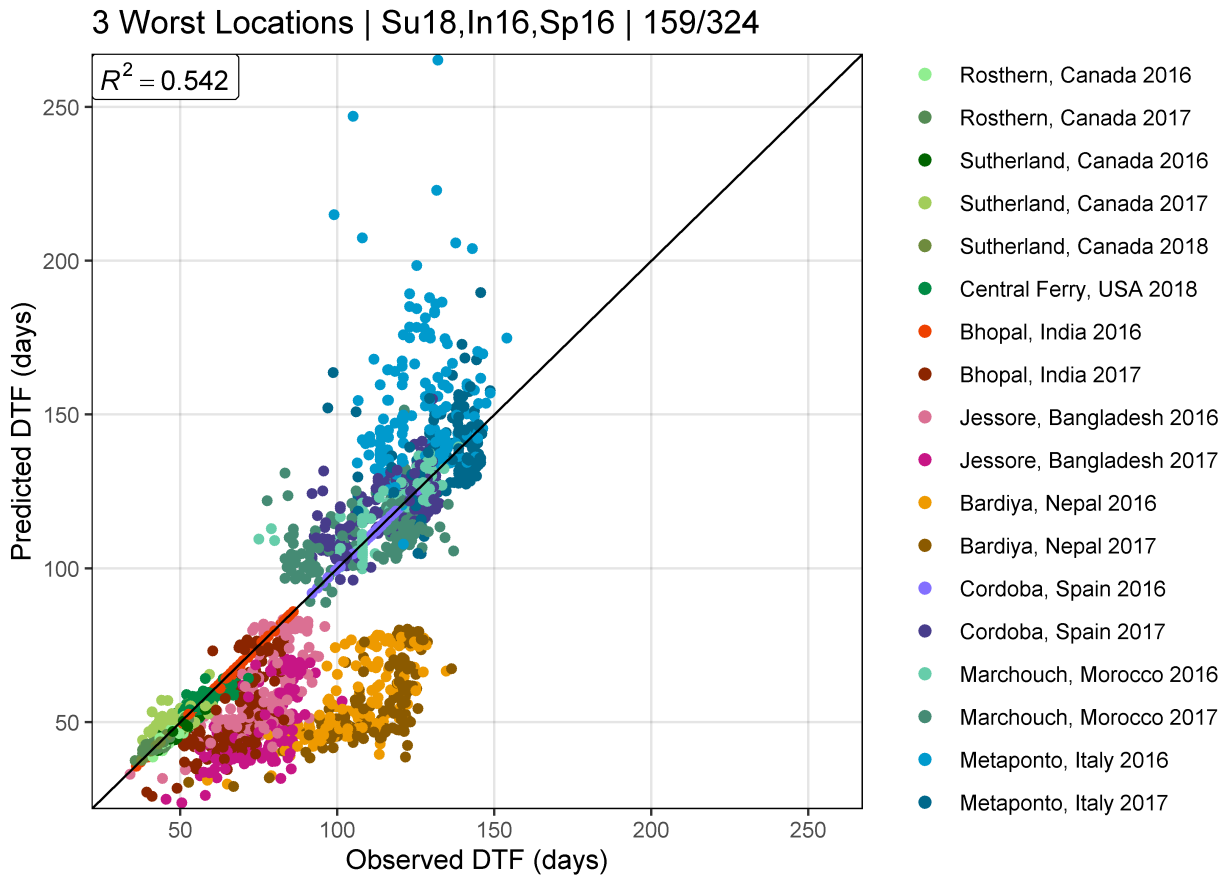
```
# Prep data
xx <- read.csv("data/model_3best_d.csv") %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
length(unique(xx$Entry))
```

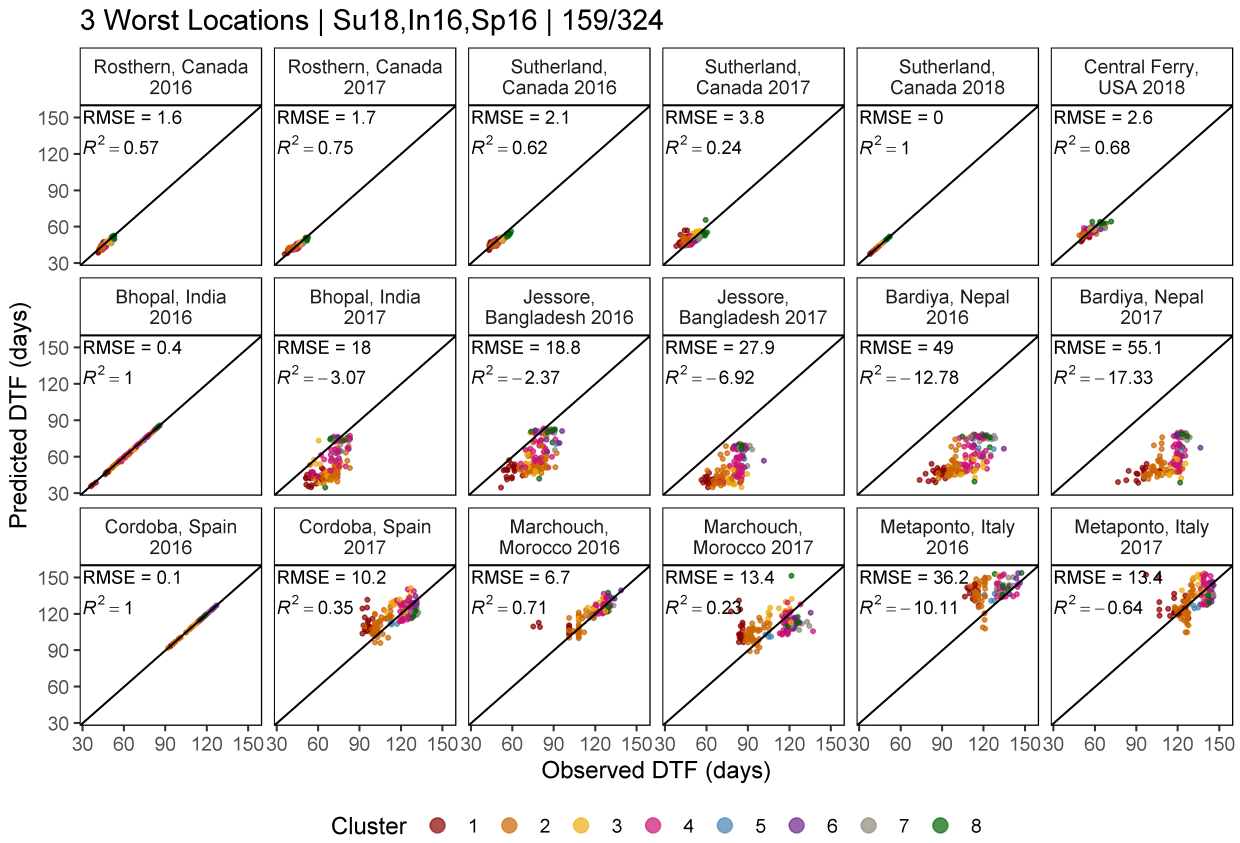
```
[1] 291
```

```
# Plot Observed vs Predicted
mp <- gg_model_1(xx, title = "3 Best Locations | Su16,Ba17,Sp17 | 291/324")
ggsave("Additional/Model/Model_1_4.png", mp, width = 7, height = 5, dpi = 600)
```

```
# Plot B)
mp <- gg_model_2(xx, title = "3 Best Locations | Su16,Ba17,Sp17 | 291/324")
ggsave("Additional/Model/Model_2_4.png", mp, width = 8, height = 5.5, dpi = 600)
```

Modeling DTF (T + P) - 3 Worst






```
####################################
# 1/f = a + bT + cP (3 Locations)  #
####################################
# Prep data
xx <- rr %>% filter(!is.na(RDTF)) %>%
  left_join(select(ff, Expt, T_mean, P_mean), by = "Expt")
mr <- NULL; md <- NULL
mc <- select(ldp, Entry, Name) %>%
  mutate(a = NA, b = NA, c = NA, RR = NA, Environments = NA )
k <- c("Sutherland, Canada 2018", "Bhopal, India 2016", "Cordoba, Spain 2016")
# Model - only the ^above^ three site-years are used to train the model
for(i in 1:324) {
  # Prep data
  xi1 <- xx %>% filter(Entry == i, Expt %in% k)
  xi2 <- xx %>% filter(Entry == i)
  xd2 <- xi2 %>% group_by(Entry, Name, Expt, ExptShort) %>%
    summarise_at(vars(DTF, RDTF, T_mean, P_mean), funs(mean), na.rm = T) %>%
    ungroup()
  # Train model
  mi <- lm(RDTF ~ T_mean * P_mean, data = xi1)
  # Predict DTF
  xi2 <- xi2 %>% mutate(Predicted_DTF = 1 / predict(mi, newdata = xi2))
  xd2 <- xd2 %>% mutate(Predicted_DTF = 1 / predict(mi, newdata = xd2))
  # Save to table
  mr <- bind_rows(mr, xi2)
  md <- bind_rows(md, xd2)
```

```
  # Save coefficients
  mc[i,c(3:5)] <- mi$coefficients
  # Calculate rr and # of environments used
  mc[i,6] <- 1 - sum((xi2$DTF - xi2$Predicted_DTF)^2) /
    sum((xi2$Predicted_DTF - mean(xi2$DTF))^2)
  mc[i,7] <- length(unique(xi2$Expt))
}
ents <- xx %>% filter(ExptShort %in% c("Su18", "In16", "Sp16"), is.na(DTF)) %>%
  pull(Entry) %>% unique()
mr <- mr %>% filter(!Entry %in% ents)
md <- md %>% filter(!Entry %in% ents)
mc <- mc %>% filter(!Entry %in% ents)
# Save Results
write.csv(mr, "data/model_3worst.csv",        row.names = F)
write.csv(md, "data/model_3worst_d.csv",      row.names = F)
write.csv(mc, "data/model_3worst_coefs.csv",  row.names = F)
```

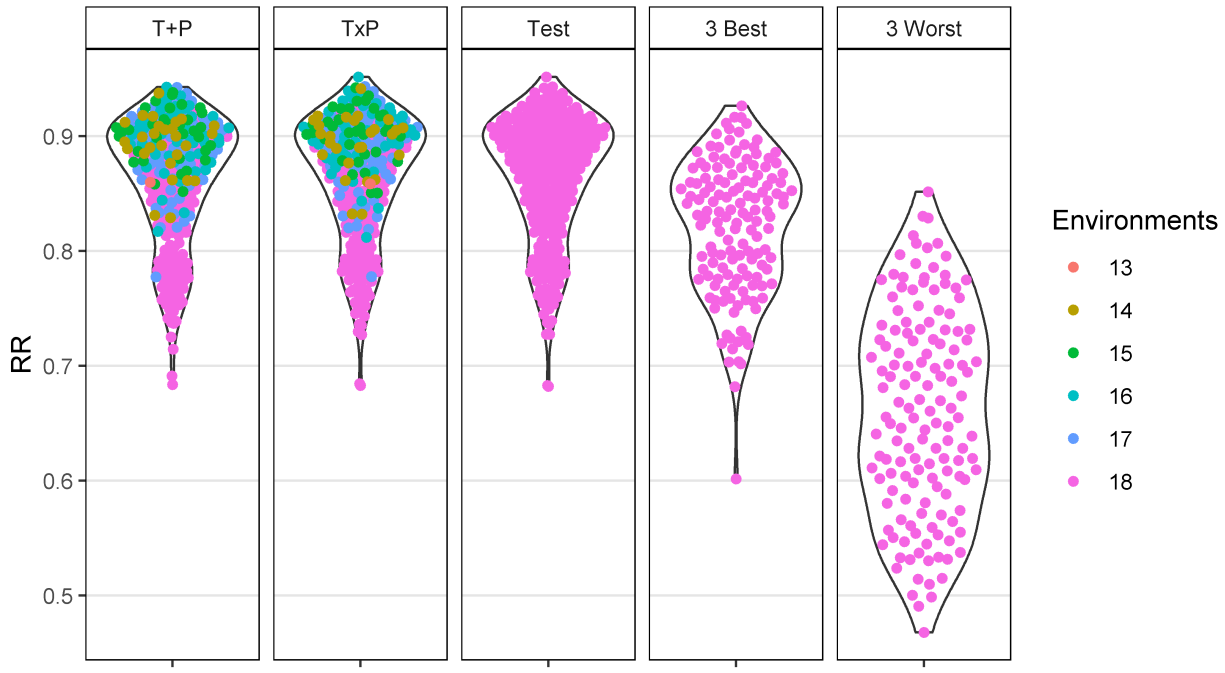
```
# Prep data
xx <- read.csv("data/model_3worst_d.csv") %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
length(unique(xx$Entry))
```

```
[1] 159
```

```
# Plot Observed vs Predicted
mp <- gg_model_1(xx, title = "3 Worst Locations | Su18,In16,Sp16 | 159/324")
ggsave("Additional/Model/Model_1_5.png", mp, width = 7, height = 5, dpi = 600)
```

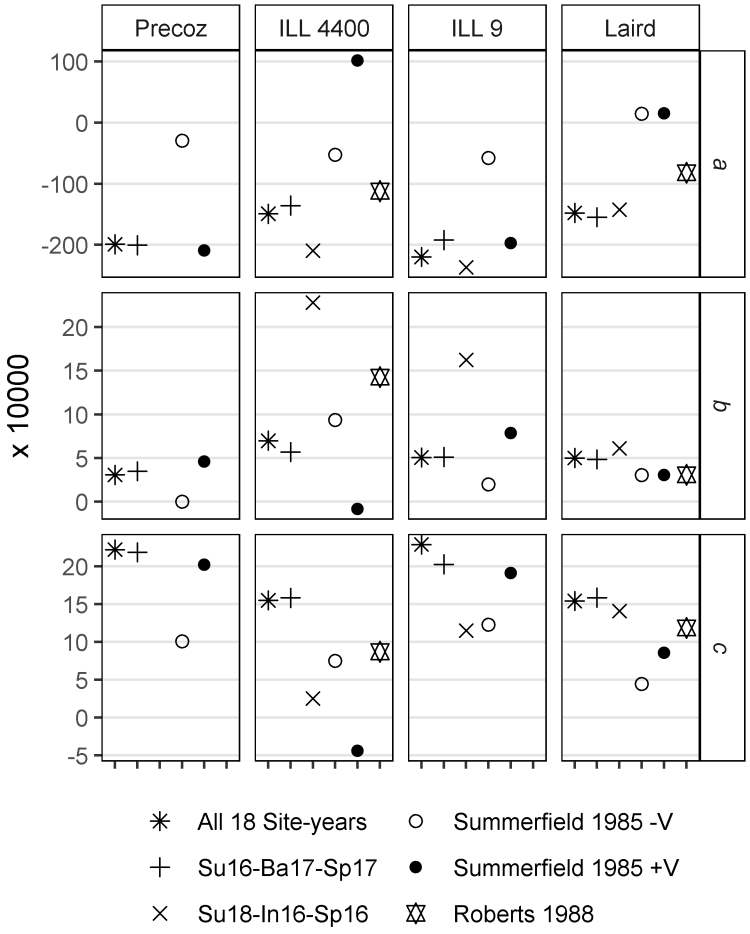
```
# Plot B)
mp <- gg_model_2(xx, title = "3 Worst Locations | Su18,In16,Sp16 | 159/324")
ggsave("Additional/Model/Model_2_5.png", mp, width = 8, height = 5.5, dpi = 600)
```

DTF Model correlation coefficients




```
# Prep data
x1 <- read.csv("data/model_t+p_coefs.csv") %>% mutate(Model = "T+P")
x2 <- read.csv("data/model_txp_coefs.csv") %>% mutate(Model = "TxP")
x3 <- read.csv("data/model_test_coefs.csv") %>% mutate(Model = "Test")
x4 <- read.csv("data/model_3best_coefs.csv")  %>% mutate(Model = "3 Best")
x5 <- read.csv("data/model_3worst_coefs.csv")  %>% mutate(Model = "3 Worst")
xx <- bind_rows(x1, x2, x3, x4, x5) %>%
  mutate(Model = factor(Model, levels = unique(Model)),
         Environments = factor(Environments))
# Plot RR
mp <- ggplot(xx, aes(x = "", y = RR)) +
  geom_violin() + geom_quasirandom(aes(color = Environments)) +
  facet_grid(. ~ Model) +
  theme_AGL +
  theme(panel.grid.major.x = element_blank()) +
  labs(x = NULL)
ggsave("Additional/Model/Model_pvalues.png", mp, width = 7, height = 4, dpi = 600)
```

Supplemental Figure 6 Compare Constants Entry

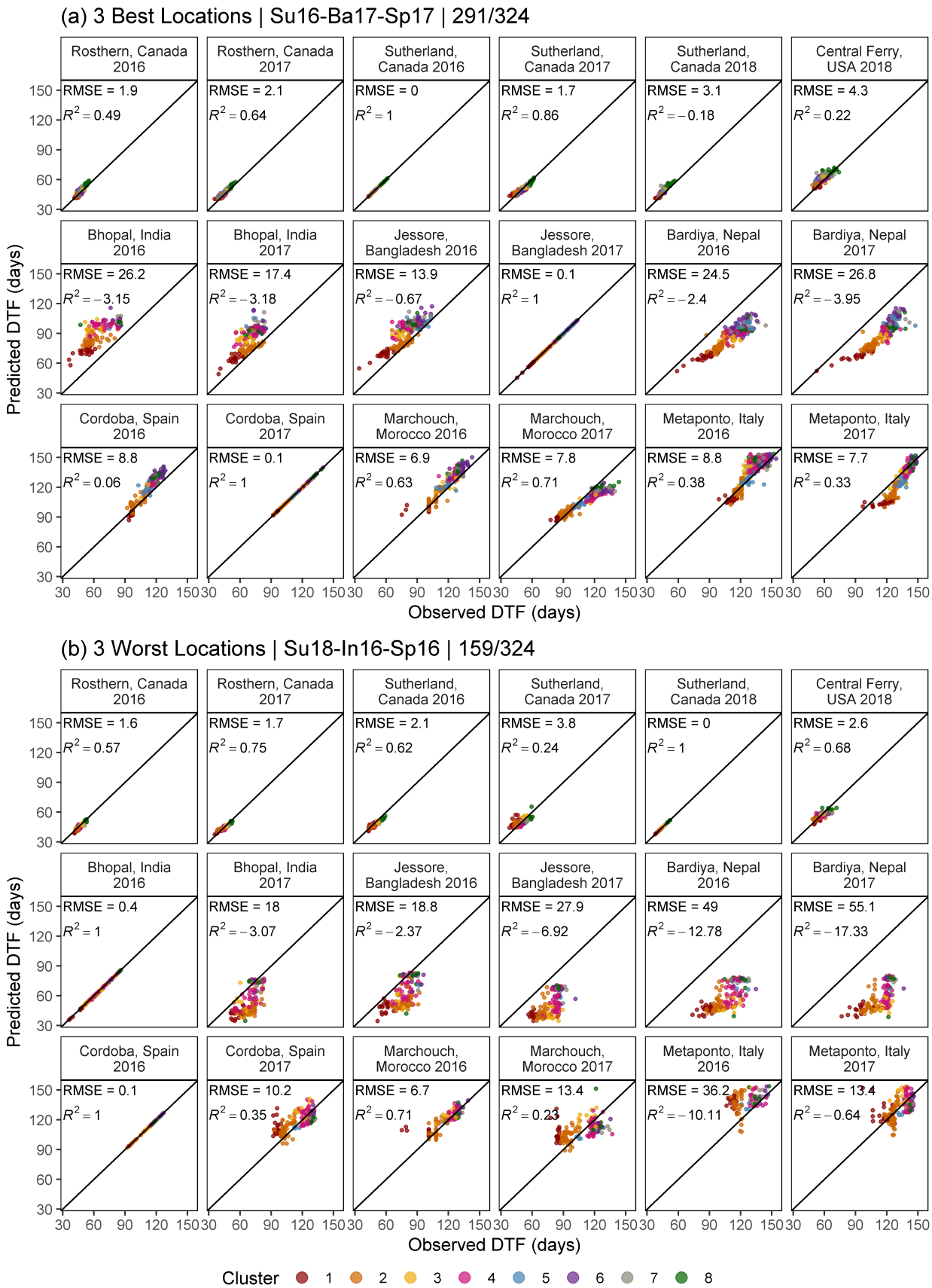


- Entry 76 = ILL 4400 (Syrian Local Large)
- Entry 77 = ILL 4605 (Precoz)
- Entry 118 = ILL 9
- Entry 128 = Laird

```
# Prep data
x1 <- read.csv("data/model_t+p_coefs.csv") %>%
  filter(Entry %in% c(76, 77, 118, 128)) %>%
  mutate(Expt = "All 18 Site-years")
x2.1 <- read.csv("data/model_3best_coefs.csv") %>%
  filter(Entry %in% c(76, 77, 118, 128)) %>%
  mutate(Expt = "Su16-Ba17-Sp17")
x2.2 <- read.csv("data/model_3worst_coefs.csv") %>%
  filter(Entry %in% c(76, 77, 118, 128)) %>%
  mutate(Expt = "Su18-In16-Sp16")
# Summerfield et al., 1985
x3 <- x1 %>% mutate(Expt = "Summerfield 1985 -V")
x3[x3$Entry == 76,  c("a","b","c")] <- c(-0.002918,  0,          0.0010093)
x3[x3$Entry == 77,  c("a","b","c")] <- c(-0.0052226, 0.00093643, 0.00075104)
x3[x3$Entry == 118, c("a","b","c")] <- c(-0.0057408, 0.00020113, 0.0012292)
```

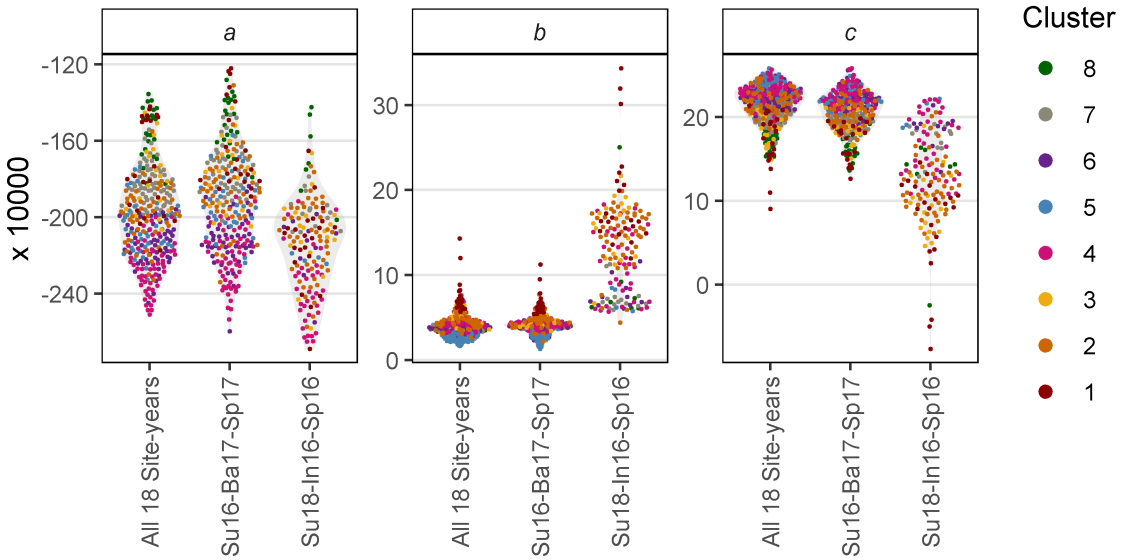
```
x3[x3$Entry == 128, c("a","b","c")] <- c( 0.0014689, 0.00030622, 0.00044640)
x4 <- x1 %>% mutate(Expt = "Summerfield 1985 +V")
x4[x4$Entry == 76,  c("a","b","c")] <- c(-0.020910,   0.00045813,  0.0020210)
x4[x4$Entry == 77,  c("a","b","c")] <- c( 0.0101590, -0.00008401, -0.00044067)
x4[x4$Entry == 118, c("a","b","c")] <- c(-0.0196948,  0.00078441,  0.0019110)
x4[x4$Entry == 128, c("a","b","c")] <- c( 0.0015094,  0.00030622,  0.00085502)
# Roberts et al., 1988
x5 <- x1 %>% filter(Entry %in% c(77, 128)) %>% mutate(Expt = "Roberts 1988")
x5[x5$Entry == 77,  c("a","b","c")] <- c(-0.0112,   0.001427, 0.000871)
x5[x5$Entry == 128, c("a","b","c")] <- c(-0.008172, 0.000309, 0.001187)
#
xx <- bind_rows(x1, x2.1, x2.2, x3, x4, x5) %>%
  gather(Constant, Value, a, b, c) %>%
  mutate(Entry = factor(Entry),
         Name = plyr::mapvalues(Entry, c(76,77,118,128),
                  c("Precoz","ILL 4400","ILL 9","Laird")),
         Expt = factor(Expt, levels = c("All 18 Site-years",
                  "Su16-Ba17-Sp17", "Su18-In16-Sp16",
                  "Summerfield 1985 -V", "Summerfield 1985 +V", "Roberts 1988")))
# Plot
mp <- ggplot(xx, aes(x = Expt, y = Value * 10000, shape = Expt)) +
  geom_quasirandom(size = 2, width = 0.2) +
  facet_grid(Constant ~ Name, scales = "free_y") +
  scale_shape_manual(name = NULL, values = c(8,3,4,1,16,11)) +
  guides(shape=guide_legend(nrow = 3, byrow = F)) +
  theme_AGL +
  theme(legend.position = "bottom", legend.margin = unit(c(0,0,0,0), "cm"),
        strip.text.y = element_text(face = "italic"),
        panel.grid.major.x = element_blank(),
        #panel.grid.minor = element_blank(),
        axis.text.x = element_blank()) +
  labs(x = NULL, y = "x 10000")
ggsave("Supplemental_Figure_06.png", mp, width = 4, height = 5, dpi = 600)
```

Supplemental Figure 7 3 best 3 worst



```
# Plot (a)
xx <- read.csv("data/model_3best_d.csv") %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
mp1 <- gg_model_2(xx, title = "(a) 3 Best Locations | Su16-Ba17-Sp17 | 291/324")
# Plot (b)
xx <- read.csv("data/model_3worst_d.csv") %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
mp2 <- gg_model_2(xx, title = "(b) 3 Worst Locations | Su18-In16-Sp16 | 159/324")
# Append (a) and (b)
mp <- ggarrange(mp1, mp2, ncol = 1, common.legend = T, legend = "bottom")
ggsave("Supplemental_Figure_07.png", mp, width = 8, height = 11, dpi = 600)
```

Supplemental Figure 8 Compare Constants All



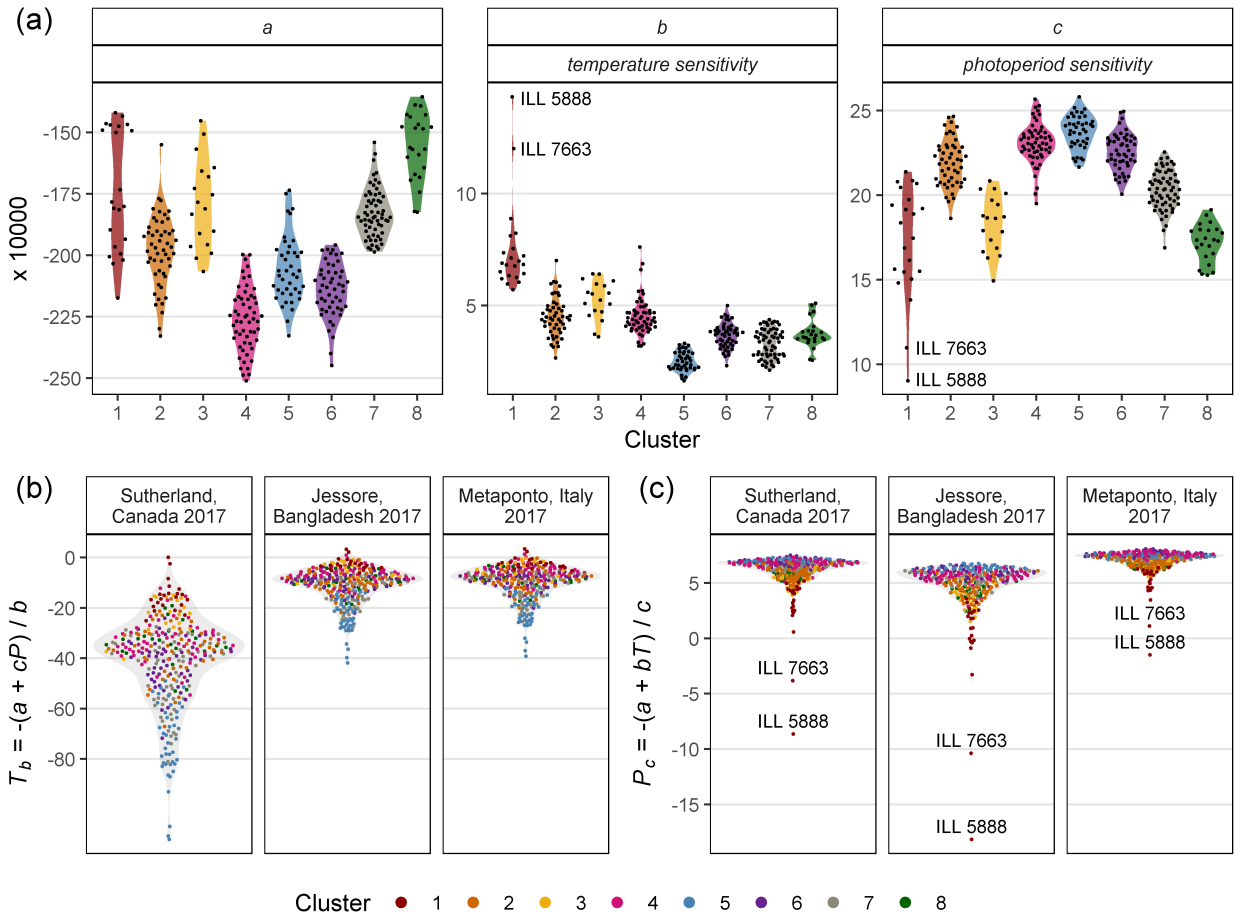

```
# Prep data
levs <- c("All 18 Site-years", "Su16-Ba17-Sp17", "Su18-In16-Sp16")
pca <- read.csv("data/data_pca_results.csv") %>% select(Entry, Cluster) %>%
  mutate(Cluster = factor(Cluster))
x1 <- read.csv("data/model_t+p_coefs.csv") %>%
  mutate(Expt = levs[1]) %>% select(-RR)
x2 <- read.csv("data/model_3best_coefs.csv") %>%
  mutate(Expt = levs[2])
x3 <- read.csv("data/model_3worst_coefs.csv") %>%
  mutate(Expt = levs[3])
xx <- bind_rows(x1, x2,x3) %>%
  left_join(pca, by = "Entry") %>%
  gather(Trait, Value, a, b, c) %>%
  mutate(Expt = factor(Expt,levels = levs))
# Plot
mp <- ggplot(xx, aes(x = Expt, y = Value * 10000 )) +
  geom_violin(alpha = 0.3, color = NA, fill = "grey") +
  geom_quasirandom(aes(color = Cluster), size = 0.3) +
  facet_wrap(Trait ~ ., scales = "free") +
```

```
  scale_color_manual(values = colors, breaks = 8:1) +
  theme_AGL +
  theme(strip.text = element_text(face = "italic"),
        panel.grid.major.x = element_blank(),
        axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1)) +
  guides(colour = guide_legend(override.aes = list(size = 2))) +
  labs(x = NULL, y = "x 10000")
ggsave("Supplemental_Figure_08.png", mp, width = 6, height = 3, dpi = 600)
```

Base Temperature & Critical Photoperiod

```
# Calculate Tf and Pf
xx <- read.csv("data/model_t+p_coefs.csv") %>% select(-Name) %>%
  mutate(predicted_Tf = 1/b, predicted_Pf = 1/c )
xx <- rr %>% left_join(xx, by = "Entry") %>%
  left_join(select(ff, Expt, T_mean, P_mean), by = "Expt") %>%
  mutate(Tb = -(a + c * P_mean) / b,
         Pc = -(a + b * T_mean) / c,
         Tf_0 = NA, Tf_5 = NA, Tf = NA, Pf = NA, PTT = NA)
for(i in 1:nrow(xx)) {
  e1 <- ee %>% filter(Expt == xx$Expt[i])
  for(k in 1:nrow(e1)) {
    e1$Tfsum[k] <- sum(e1$Temp_mean[1:k] - xx$Tb[i])
    e1$Pfsum[k] <- sum(e1$DayLength[1:k] - xx$Pc[i])
  }
  ei <- e1 %>%
    filter(Date <= xx$PlantingDate[i] + xx$DTF2[i], !is.na(Temp_mean))
  if(nrow(ei) > 0) {
    xx$Tf_0[i]  <- round(sum(ei$Temp_mean), 1)
    xx$Tf_5[i]  <- round(sum(ei$Temp_mean - 5), 1)
    xx$Tf[i]    <- round(sum(ei$Temp_mean - xx$Tb[i]), 1)
    xx$Pf_0[i]  <- round(sum(ei$DayLength), 1)
    xx$Pf_7[i]  <- round(sum(ei$DayLength - 7), 1)
    xx$Pf[i]    <- round(sum(ei$DayLength - xx$Pc[i]), 1)
    xx$PTT_0[i] <- round(sum(ei$Temp_mean * ei$DayLength), 1)
    xx$PTT[i]   <- round(sum((ei$Temp_mean - xx$Tb[i]) * (ei$DayLength - xx$Pc[i])), 1)
    eTf <- e1 %>% filter(Tfsum > xx$predicted_Tf[i])
    ePf <- e1 %>% filter(Pfsum > xx$predicted_Pf[i])
    xx$predicted_DTF_Tf[i] <- eTf$DaysAfterPlanting[1]
    xx$predicted_DTF_Pf[i] <- ePf$DaysAfterPlanting[1]
  }
}
xx <- xx %>% left_join(select(ff, Expt, MacroEnv), by = "Expt") %>%
  group_by(Entry, Name, Expt, ExptShort, MacroEnv) %>%
  summarise_at(vars(DTF, Tb, Pc, Tf_0, Tf_5, Tf, Pf_0, Pf_7, Pf, PTT, PTT_0,
                    predicted_DTF_Tf, predicted_DTF_Pf,
                    predicted_Pf, predicted_Tf), funs(mean), na.rm = T) %>%
  ungroup()
# Save
write.csv(xx,"data/data_tb_pc.csv", row.names = F)
```

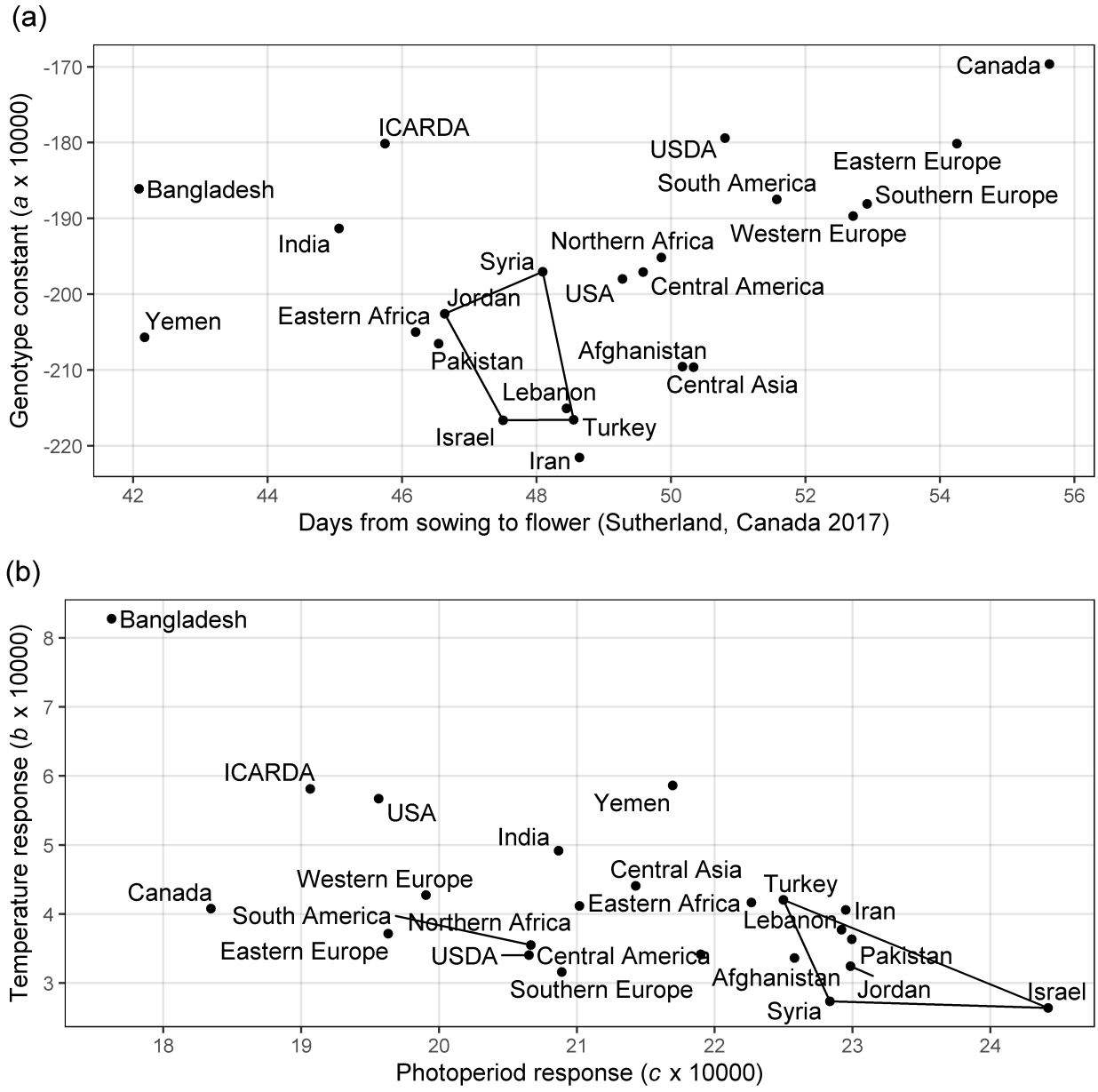
Figure 5 Tb and Pc




```
# Prep data for (a) a, b and c
pca <- read.csv("data/data_pca_results.csv") %>% select(Entry, Cluster) %>%
  mutate(Cluster = factor(Cluster))
xx <- read.csv("data/model_t+p_coefs.csv") %>%
  left_join(pca, by = "Entry") %>%
  select(Entry, Name, Cluster, a, b, c) %>%
  gather(Constant, Value, 4:ncol(.)) %>%
  mutate(Meaning = plyr::mapvalues(Constant, c("a","b","c"),
           c("", "temperature sensitivity", "photoperiod sensitivity")))
x1 <- xx %>% filter(Entry %in% c(94,105), Constant != "a") %>%
  mutate(Name = gsub(" AGL", "", Name))
# Plot (a) a, b and c
mp1 <- ggplot(xx, aes(x = Cluster, y = Value * 10000) ) +
  geom_violin(aes(fill = Cluster), color = NA, alpha = 0.7) +
  geom_quasirandom(size = 0.3) +
  geom_text_repel(data = x1, aes(label = Name), size = 3, nudge_x = 0.5) +
  facet_wrap(Constant+Meaning ~ ., nrow = 1, scales = "free") +
  theme_AGL +
  theme(strip.text = element_text(face = "italic"),
        legend.position = "none", panel.grid.major.x = element_blank()) +
  scale_fill_manual(name = NULL, values = colors) +
```

```
  guides(fill = F) +
  labs(y = "x 10000")
# Prep data
xx <- read.csv("data/data_tb_pc.csv") %>%
  left_join(pca, by = "Entry") %>%
  mutate(Expt = factor(Expt, levels = names_Expt)) %>%
  select(Entry, Name, Expt, ExptShort, Cluster, Tb, Pc, predicted_Tf, predicted_Pf)
x1 <- xx %>%
  filter(ExptShort %in% c("Su17", "Ba17", "It17")) %>%
  group_by(Entry, Name, Expt, ExptShort, Cluster) %>%
  summarise_at(vars(Tb, Pc), funs(mean), na.rm = T)
# Plot (b) Tb
mp2.1 <- ggplot(x1, aes(x = 1, y = Tb)) +
  geom_violin(fill = "grey", alpha = 0.3, color = NA) +
  geom_quasirandom(aes(color = Cluster), size = 0.3) +
  facet_grid(. ~ Expt, labeller = label_wrap_gen(width = 17)) +
  scale_y_continuous(breaks = seq(-80,0,20), minor_breaks = seq(-110,0,10)) +
  scale_color_manual(values = colors) +
  theme_AGL +
  theme(axis.text.x  = element_blank(),
        axis.ticks.x = element_blank(),
        panel.grid.major.x = element_blank()) +
  guides(colour = guide_legend(nrow = 1, override.aes = list(size=2))) +
  labs(y = expression(paste(italic("T")[italic("b")], " = -(", italic("a"), " + ",
              italic("cP"), ") / ", italic("b"))), x = NULL)
# Plot (c) Pc
x2 <- x1 %>% filter(Entry %in% c(94,105)) %>%
  ungroup() %>% mutate(Name = gsub(" AGL", "", Name))
mp2.2 <- ggplot(x1, aes(x = 1, y = Pc)) +
  geom_violin(fill = "grey", alpha = 0.3, color = NA) +
  geom_quasirandom(aes(color = Cluster), size = 0.3) +
  facet_grid(. ~ Expt, labeller = label_wrap_gen(width = 17)) +
  geom_text(data = x2, aes(label = Name), size = 3, nudge_y = 1.2) +
  scale_y_continuous(breaks = c(-20,-15,-10,-5,0,5)) +
  scale_color_manual(values = colors) +
  theme_AGL +
  theme(axis.text.x        = element_blank(),
        axis.ticks.x       = element_blank(),
        panel.grid.major.x = element_blank()) +
  guides(colour = guide_legend(nrow = 1, override.aes = list(size=2))) +
  labs(y = expression(paste(italic("P")[italic("c")], " = -(", italic("a"), " + ",
              italic("bT"), ") / ", italic("c"))), x = NULL)
mp2 <- ggarrange(mp2.1, mp2.2, nrow = 1, ncol = 2, common.legend = T, legend = "bottom",
                 labels = c("(b)","(c)"), font.label = list(face = "plain"))
#
mp <- ggarrange(mp1, mp2, nrow = 2, ncol = 1, align = "hv",
                labels = c("(a)",""), font.label = list(face = "plain")) #heights =
ggsave("Figure_05.png", mp, width = 8, height = 6, dpi = 600)
```

Figure 6 Origin Constants



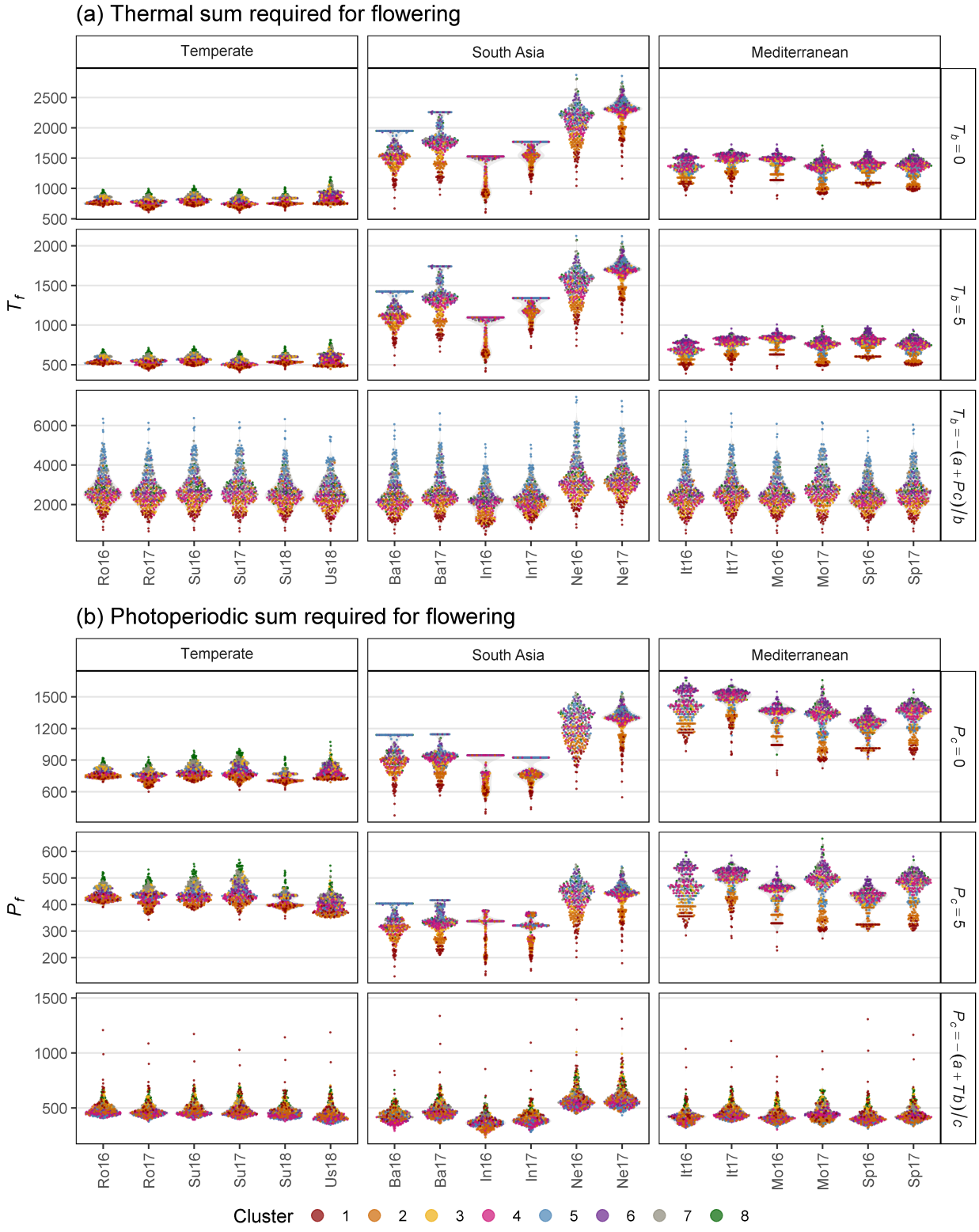

```
# Prep data
mycts <- c("Canada", "USA", "Iran", "Yemen",
           "India", "Pakistan", "Bangladesh", "Afghanistan",
           "Syria", "Jordan", "Turkey", "Lebanon", "Israel")
xx <- read.csv("data/model_t+p_coefs.csv") %>%
  left_join(select(ldp, Entry, Origin), by = "Entry") %>%
  left_join(select(ct, Origin=Country, SubRegion), by = "Origin") %>%
  filter(Origin != "Unknown") %>%
  mutate(SubRegion = as.character(SubRegion), Origin = as.character(Origin),
         SubRegion = ifelse(Origin %in% c("ICARDA", "USDA"),
                            Origin, as.character(SubRegion)),
         Origin = ifelse(Origin %in% mycts, Origin, as.character(SubRegion)))
```

```
x1 <- xx %>%
  left_join(dd %>% filter(ExptShort == "Su17") %>% select(Entry, DTF), by = "Entry") %>%
  group_by(Origin) %>%
  summarise_at(vars(DTF, a, b, c), funs(mean, sd)) %>%
  filter(Origin != "Unknown")
x2 <- x1 %>% mutate(CO = 1) %>%
  filter(Origin %in% c("Syria", "Jordan", "Turkey", "Lebanon", "Israel"))
# Plot (a) a vs DTF
find_hull <- function(df) df[chull(df[,"DTF_mean"], df[,"a_mean"]), ]
polys <- plyr::ddply(x2, "CO", find_hull)
mp1 <- ggplot(x1, aes(x = DTF_mean, y = a_mean * 10000)) +
  geom_polygon(data = polys, fill = NA, color = "black") +
  geom_point() + geom_text_repel(aes(label = Origin)) +
  scale_x_continuous(breaks = seq(42, 56, 2)) +
  theme_AGL +
  theme(plot.title = element_text(hjust = -0.085) ) +
  labs(title = "(a)",
       y = expression(paste("Genotype constant (", italic(a)," x 10000)")),
       x = "Days from sowing to flower (Sutherland, Canada 2017)")
# Plot (b) b vs c
find_hull <- function(df) df[chull(df[,"c_mean"], df[,"b_mean"]), ]
polys <- plyr::ddply(x2, "CO", find_hull)
mp2 <- ggplot(x1, aes(x = c_mean * 10000, y = b_mean * 10000)) +
  geom_polygon(data = polys, fill = NA, color = "black") +
  geom_point() + geom_text_repel(aes(label = Origin)) +
  scale_x_continuous(breaks = seq(18, 24, 1)) +
  scale_y_continuous(breaks = 3:8) +
  theme_AGL +
  theme(plot.title = element_text(hjust = -0.06) ) +
  labs(title = "(b)",
       y = expression(paste("Temperature response (", italic(b), " x 10000)")),
       x = expression(paste("Photoperiod response (", italic(c), " x 10000)")))
# Append (a) and (b)
mp <- ggarrange(mp1, mp2, ncol = 1, nrow = 2)
ggsave("Figure_06.png", mp, width = 7, height = 7, dpi = 600)
ggsave("Additional/Temp/Temp_F06_1.png", mp1, width = 8, height = 4, dpi = 600)
ggsave("Additional/Temp/Temp_F06_2.png", mp2, width = 8, height = 4, dpi = 600)
```

```
# Prep data
mycts <- c("Canada", "USA", "Iran", "Yemen",
           "India", "Pakistan", "Bangladesh", "Afghanistan",
           "Syria", "Jordan", "Turkey", "Lebanon", "Israel")
xx <- read.csv("data/model_t+p_coefs.csv") %>%
  left_join(select(ldp, Entry, Origin), by = "Entry") %>%
  left_join(select(ct, Origin=Country, SubRegion), by = "Origin") %>%
  filter(Origin != "Unknown") %>%
  mutate(SubRegion = as.character(SubRegion), Origin = as.character(Origin),
         SubRegion = ifelse(Origin %in% c("ICARDA", "USDA"),
                            Origin, as.character(SubRegion)),
         Origin = ifelse(Origin %in% mycts, Origin, as.character(SubRegion)))
x1 <- xx %>%
  left_join(dd %>% filter(ExptShort == "Su17") %>% select(Entry, DTF), by = "Entry") %>%
  group_by(Origin) %>%
```

```
  summarise_at(vars(DTF, a, b, c), funs(mean, sd)) %>%
  filter(Origin != "Unknown")
x2 <- x1 %>% mutate(CO = 1) %>%
  filter(Origin %in% c("Syria", "Jordan", "Turkey", "Lebanon", "Israel"))
# Plot (a) a vs DTF
find_hull <- function(df) df[chull(df[,"DTF_mean"], df[,"a_mean"]), ]
polys <- plyr::ddply(x2, "CO", find_hull)
mp1 <- ggplot(x1, aes(x = DTF_mean, y = a_mean * 10000)) +
  geom_polygon(data = polys, fill = NA, color = "black") +
  geom_point() + geom_text_repel(aes(label = Origin)) +
  scale_x_continuous(breaks = seq(42, 56, 2)) +
  theme_AGL +
  theme(plot.title = element_text(hjust = -0.085) ) +
  labs(title = "(a)",
       y = expression(paste("Genotype constant (", italic(a)," x 10000)")),
       x = "Days from sowing to flower (Sutherland, Canada 2017)")
# Plot (b) b vs c
find_hull <- function(df) df[chull(df[,"c_mean"], df[,"b_mean"]), ]
polys <- plyr::ddply(x2, "CO", find_hull)
mp2 <- ggplot(x1, aes(x = c_mean * 10000, y = b_mean * 10000)) +
  geom_polygon(data = polys, fill = NA, color = "black") +
  geom_point() + geom_text_repel(aes(label = Origin)) +
  scale_x_continuous(breaks = seq(18, 24, 1)) +
  scale_y_continuous(breaks = 3:8) +
  theme_AGL +
  theme(plot.title = element_text(hjust = -0.06) ) +
  labs(title = "(b)",
       y = expression(paste("Temperature response (", italic(b), " x 10000)")),
       x = expression(paste("Photoperiod response (", italic(c), " x 10000)")))
# Append (a) and (b)
mp <- ggarrange(mp1, mp2, ncol = 1, nrow = 2)
ggsave("Figure_06.png", mp, width = 7, height = 7, dpi = 600)
ggsave("Additional/Temp/Temp_F06_1.png", mp1, width = 8, height = 4, dpi = 600)
ggsave("Additional/Temp/Temp_F06_2.png", mp2, width = 8, height = 4, dpi = 600)
```

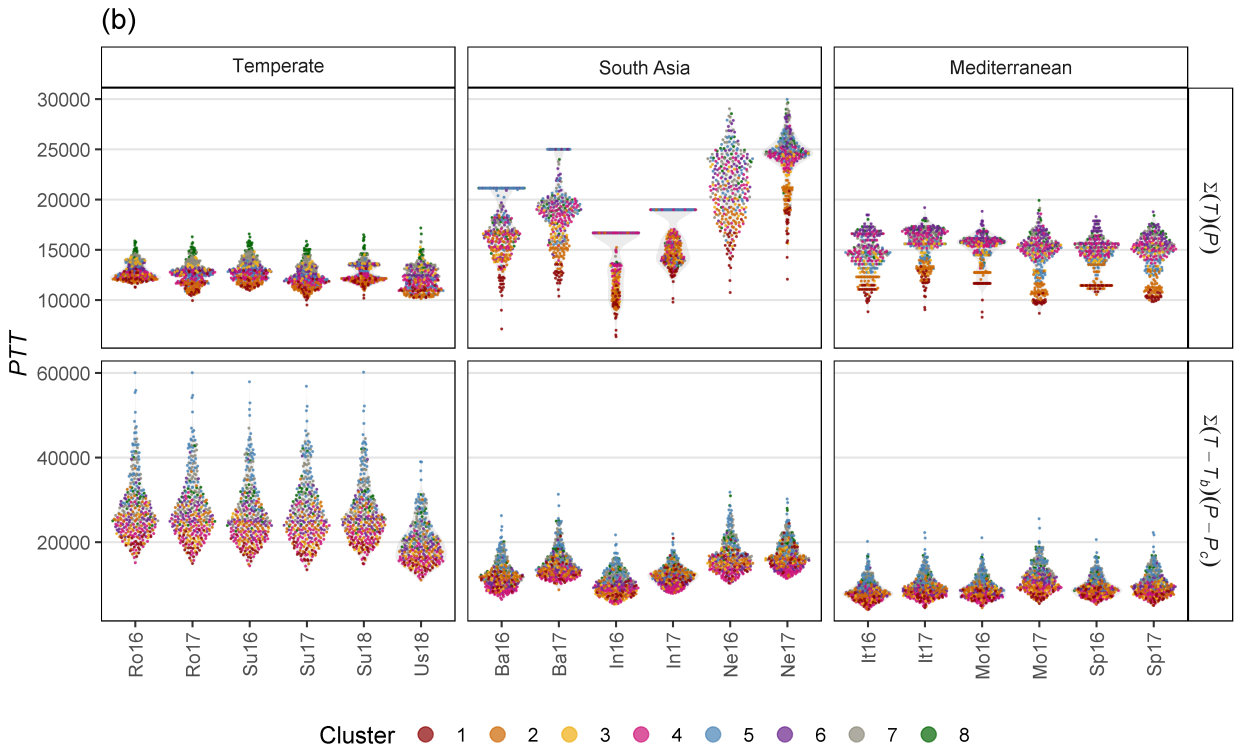
Supplemental Figure 9 Pc Tf PTT



```r
# Prep data for (a) Tf
pca <- read.csv("data/data_pca_results.csv") %>% select(Entry, Cluster) %>%
  mutate(Cluster = factor(Cluster))
xx <- read.csv("data/data_tb_pc.csv") %>%
  left_join(pca, by = "Entry") %>%
  mutate(MacroEnv = factor(MacroEnv, levels = macroEnvs))
x1 <- xx %>%
  select(Entry, Name, Expt, ExptShort, MacroEnv, Cluster, Tf_0, Tf_5, Tf) %>%
  gather(Trait, Value, Tf_0, Tf_5, Tf) %>%
  mutate(Trait = factor(Trait, levels = c("Tf_0", "Tf_5", "Tf")))
new.lab <- as_labeller(c(
  Tf_0 = "italic(T)[italic(b)]==0", Tf_5 = "italic(T)[italic(b)]==5",
  Tf = "italic(T)[italic(b)]==-(italic(a)+italic(Pc))/italic(b)",
  Mediterranean = "Mediterranean", Temperate = "Temperate",
  `South Asia` = "South~Asia"), label_parsed)
# Plot (a) Tf
mp1 <- ggplot(x1, aes(x = ExptShort, y = Value)) +
  geom_violin(fill = "grey", alpha = 0.3, color = NA) +
  geom_quasirandom(aes(color = Cluster), size = 0.1, alpha = 0.7) +
  facet_grid(Trait ~ MacroEnv, scales = "free", labeller = new.lab) +
  scale_color_manual(values = colors) +
  theme_AGL +
  theme(legend.position = "bottom",
        legend.margin = unit(c(0,0,0,0), "cm"),
        panel.grid.major.x = element_blank(),
        axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5)) +
  guides(colour = guide_legend(nrow = 1, override.aes = list(size = 3))) +
  labs(title = "(a) Thermal sum required for flowering",
       y = expression(italic("T")[italic("f")]), x = NULL)
# Prep data for B) Pf
x1 <- xx %>%
  select(Entry, Expt, ExptShort, MacroEnv, Cluster, Pf_0, Pf_7, Pf) %>%
  gather(Trait, Value, Pf_0, Pf_7, Pf) %>%
  mutate(Trait = factor(Trait, levels = c("Pf_0", "Pf_7", "Pf")))
new.lab <- as_labeller(c(
  Pf_0 = "italic(P)[italic(c)]==0", Pf_7 = "italic(P)[italic(c)]==5",
  Pf = "italic(P)[italic(c)]==-(italic(a)+italic(Tb))/italic(c)",
  Mediterranean = "Mediterranean", Temperate = "Temperate",
  `South Asia` = "South~Asia"), label_parsed)
# Plot (b) Pf
mp2 <- ggplot(x1, aes(x = ExptShort, y = Value)) +
  geom_violin(fill = "grey", alpha = 0.3, color = NA) +
  geom_quasirandom( aes(color = Cluster), size = 0.1, alpha = 0.7) +
  facet_grid(Trait ~ MacroEnv, scales = "free", labeller = new.lab) +
  scale_color_manual(values = colors) +
  theme_AGL +
  theme(legend.position = "bottom",
        panel.grid.major.x = element_blank(),
        axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5)) +
  guides(colour = guide_legend(nrow = 1, override.aes = list(size = 3))) +
  labs(title = "(b) Photoperiodic sum required for flowering",
       y = expression(italic("P")[italic("f")]), x = NULL)
```

```
# Append (a), (b) and (c)
mp <- ggarrange(mp1, mp2, ncol = 1, common.legend = T, legend = "bottom")
# Save
ggsave("Additional/Temp/Temp_SF09_1.png", mp1,
       width = 10, height = 13 * 3 / 8.2, dpi = 600)
ggsave("Additional/Temp/Temp_SF09_2.png", mp2,
       width = 10, height = 13 * 3 / 8.2, dpi = 600)
ggsave("Supplemental_Figure_09.png", mp, width = 8, height = 10, dpi = 600)
```

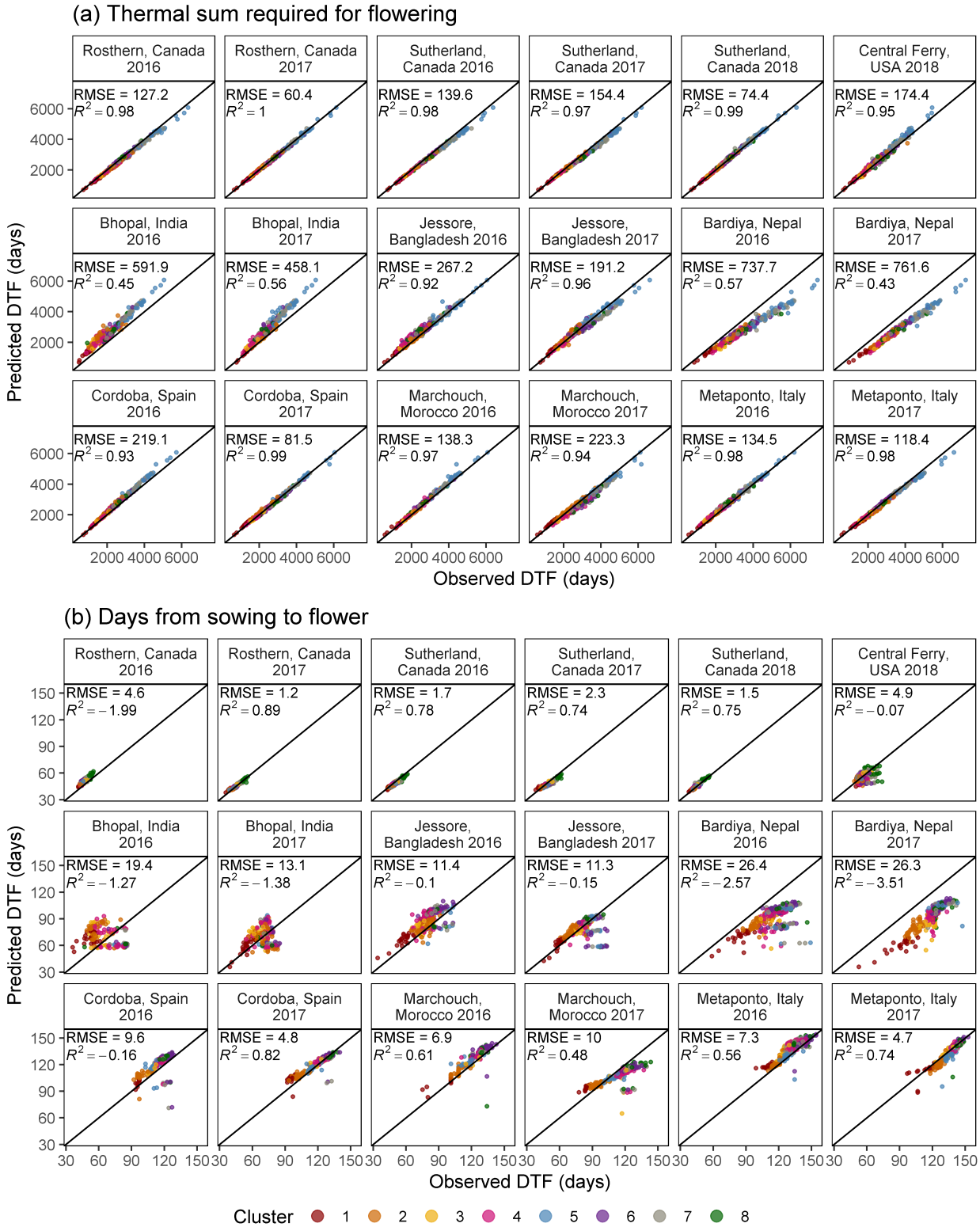
Additional Figure 14 PTT




```
# Prep data
pca <- read.csv("data/data_pca_results.csv") %>% select(Entry, Cluster) %>%
  mutate(Cluster = factor(Cluster))
xx <- read.csv("data/data_tb_pc.csv") %>%
  left_join(pca, by = "Entry") %>%
  mutate(MacroEnv = factor(MacroEnv, levels = macroEnvs)) %>%
  select(Entry, Expt, ExptShort, MacroEnv, Cluster, PTT_0, PTT) %>%
  gather(Trait, Value, PTT_0, PTT) %>%
  mutate(Trait = factor(Trait, levels = c("PTT_0", "PTT")))
new.lab <- as_labeller(c(PTT_0 = "Sigma(italic(T))(italic(P))",
  PTT = "Sigma(italic(T)-italic(T)[italic(b)])(italic(P)-italic(P)[italic(c)])",
  Mediterranean = "Mediterranean", Temperate = "Temperate",
  `South Asia` = "South~Asia"), label_parsed)
# Plot PTT
mp <- ggplot(xx, aes(x = ExptShort, y = Value)) +
  geom_violin(fill = "grey", alpha = 0.3, color = NA) +
```

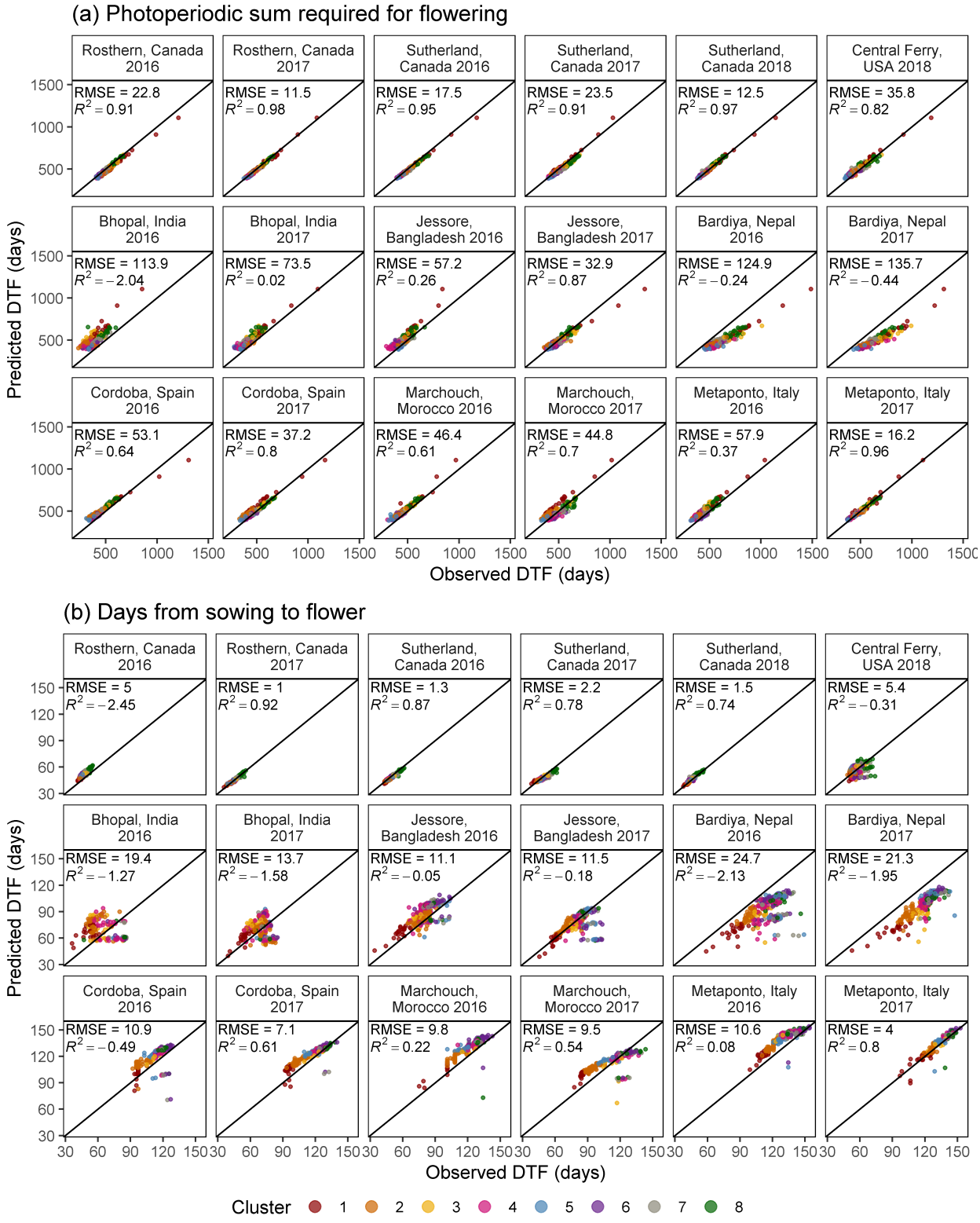
```
  geom_quasirandom(aes(color = Cluster), size = 0.1, alpha = 0.7) +
  facet_grid(Trait ~ MacroEnv, scales = "free", labeller = new.lab) +
  scale_color_manual(values = colors) +
  theme_AGL +
  theme(legend.position = "bottom",
        panel.grid.major.x = element_blank(),
        axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5)) +
  guides(colour = guide_legend(nrow = 1, override.aes = list(size = 3))) +
  labs(title = "(b)", y = expression(italic("PTT")), x = NULL)
ggsave("Additional/Additional_Figure_14.png", mp, width = 8, height = 5, dpi = 600)
```

Supplemental Figure 10 Thermal Sums



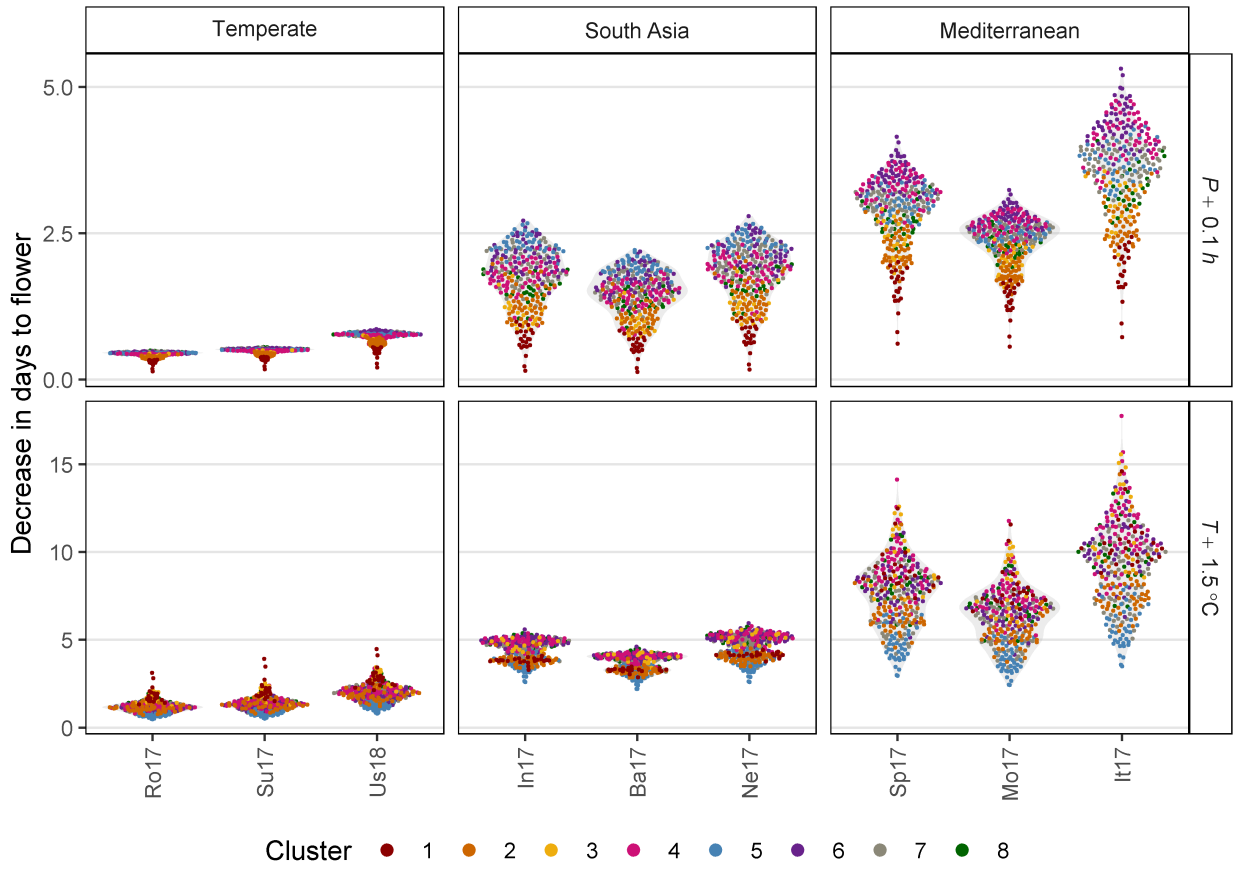
```r
# Prep data
xx <- read.csv("data/data_tb_pc.csv") %>% #select(-MacroEnv) %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
# Plot (a)
mp1 <- gg_model_2(xx, "Tf", "predicted_Tf", "(a) Thermal sum required for flowering",
                  200, 200, 6600, 5500)
# Plot (b)
mp2 <- gg_model_2(xx, "DTF", "predicted_DTF_Tf", "(b) Days from sowing to flower",
                  30, 30, 145, 125)
# Append (a) and (b)
mp <- ggarrange(mp1, mp2, nrow = 2, ncol = 1, common.legend = T, legend = "bottom")
ggsave("Supplemental_Figure_10.png", mp, width = 8, height = 10, dpi = 600)
```

Supplemental Figure 11 Photoperiodic Sums



```
# Prep data
xx <- read.csv("data/data_tb_pc.csv") %>% #select(-MacroEnv) %>%
  mutate(Expt = factor(Expt, levels = names_Expt))
# Plot (a)
mp1 <- gg_model_2(xx, "Pf", "predicted_Pf", "(a) Photoperiodic sum required for flowering",
                  190, 190, 1350, 1150)
# Plot (b)
mp2 <- gg_model_2(xx, "DTF", "predicted_DTF_Pf", "(b) Days from sowing to flower",
                  30, 30, 145, 125)
# Append (a) and (b)
mp <- ggarrange(mp1, mp2, nrow = 2, ncol = 1, common.legend = T, legend = "bottom")
ggsave("Supplemental_Figure_11.png", mp, width = 8, height = 10, dpi = 600)
```

Figure 7 Temperature Increase By MacroEnv




```
# Prep data
yy <- c("Ro17", "Su17", "Us18", "In17", "Ba17", "Ne17", "Sp17", "Mo17", "It17")
coefs <- read.csv("data/model_t+p_coefs.csv")
pca <- read.csv("data/data_pca_results.csv") %>% select(Entry, Cluster) %>%
  mutate(Cluster = factor(Cluster))
xx <- dd %>%
  select(Entry, Expt, ExptShort, DTF) %>%
  left_join(coefs, by = "Entry") %>%
```

```
  left_join(pca, by = "Entry") %>%
  left_join(select(ff, Expt, MacroEnv, T_mean, P_mean), by = "Expt")
# Temp +1
x1 <- xx %>%
  mutate(T_mean_1.5 = T_mean + 1.5,
         DTF_1 = 1 / (a + b * T_mean_1.5 + c * P_mean),
         DTF_0  = 1 / (a + b * T_mean + c * P_mean),
         Difference = DTF_0 - DTF_1) %>%
  filter(ExptShort %in% yy)
x2 <- xx %>%
  mutate(P_mean_0.1 = P_mean + 0.1,
         DTF_1 = 1 / (a + b * T_mean + c * P_mean_0.1),
         DTF_0  = 1 / (a + b * T_mean + c * P_mean),
         Difference = DTF_0 - DTF_1) %>%
  filter(ExptShort %in% yy)
x1 <- x1 %>% mutate(Treatment = "T + 1.5")
x2 <- x2 %>% mutate(Treatment = "P + 0.1")
knitr::kable(x1 %>% group_by(MacroEnv) %>%
  summarise(Min = round(min(Difference), 2), Max = round(max(Difference), 2)) )
```

MacroEnv	Min	Max
Temperate	0.48	4.48
South Asia	2.21	5.96
Mediterranean	2.43	17.76

```
knitr::kable(x2 %>% group_by(MacroEnv) %>%
  summarise(Min = round(min(Difference), 2), Max = round(max(Difference), 2)) )
```

MacroEnv	Min	Max
Temperate	0.14	0.87
South Asia	0.13	2.79
Mediterranean	0.57	5.32

```
xx <- bind_rows(x1, x2) %>%
  select(Expt, ExptShort, MacroEnv, Entry, Name, Cluster,
         DTF_0, DTF_1, Difference, Treatment)
write.csv(xx, "data/data_temp_phtoto_increase.csv", row.names = F)
new.lab <- as_labeller(c(`T + 1.5` = "italic(T)~+~1.5~degree*C",
    `P + 0.1` = "italic(P)~+~0.1~italic(h)", Mediterranean = "Mediterranean",
    Temperate = "Temperate", `South Asia` = "South~Asia"), label_parsed)
my_breaks <- function(x) { if (max(x) < 6) c(0,2.5,5) else seq(0,30,5) }
#my_minor_breaks <- function(x) { if (max(x) < 6) 1:5 else 1:30 }
# Plot
mp <- ggplot(xx, aes(x = ExptShort, y = Difference)) +
  geom_violin(fill = "grey", alpha = 0.3, color = NA) +
  geom_quasirandom(aes(color = Cluster), size = 0.3) +
  facet_grid(Treatment ~ MacroEnv, scales = "free", labeller = new.lab) +
  scale_y_continuous(minor_breaks = 0:30, breaks = my_breaks) +
  scale_color_manual(values = colors) +
```

```
  theme_AGL +
  theme(legend.position = "bottom",
        legend.margin = unit(c(0,0,0,0), "cm"),
        axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5),
        panel.grid.major.x = element_blank()) +
  guides(colour = guide_legend(nrow = 1, override.aes = list(size=2))) +
  labs(y = "Decrease in days to flower", x = NULL)
ggsave("Figure_07.png", mp, width = 7, height = 5, dpi = 600)
```