Appendix

1. Flamingo data preparation

Used libraries for the analysis

```
library(lubridate)
library(raster)
library(plyr)
```

Dataset preparation for analysis of individuals ringed in Saline di Comacchio site

```
flamingo <- subset(read.table("data_orig_clean.csv", sep=";", header=T), Ring-
ingSit=="Saline di Comacchio")
flamingo$Month <- month(as.Date(flamingo$ControlDat, format =
"%d.%m.%Y"))
```

Variables X and Y represent the ETRS coordinates of the "ControlSit" values

```
shp <- shapefile("flamingos_ETRS.shp")
flamingo <- join(flamingo, subset(shp@data, select=c("X","Y","ID")))
x_com <- flamingo$X[flamingo$ControlSit=="Saline di Comacchio"][1]
y_com <- flamingo$Y[flamingo$ControlSit=="Saline di Comacchio"][1]
```

"Distance" variable represents distance between Saline di Comacchio (Italy) and the "ControlSit" places.

```
flamingo$distance<-sqrt((flamingo$X-x_com)**2+(flamingo$Y-y_com)**2)
```

Variable "comacchio" shows if individual was exactly in or in a range of interested sites (limited within a radius less than 1000 m). Variables "breeding" and "wintering" represent if the individuals were in the site of interest in April-July (breeding season) and November-January (winter season) periods respectively

```
flamingo$comacchio <- flamingo$distance < 10000
flamingo$breeding <- flamingo$Month %in% c(4,5,6,7)
flamingo$winter<-flamingo$Month %in% c(11,12,1)
```

The proportion of individuals breeding inside Saline di Comacchio was estimated for each year as the number of observations present in the breeding season in the colony divided to the total number of all its observations

```
breed.sum <- ddply(subset(flamingo, Age_inMont > 3 & breeding==TRUE),
.(Year), summarize, isinde = length(unique(PVC[coma
chio==TRUE]))/length(unique(PVC)))

flamingo$Year_art <- flamingo$Year
flamingo$Year_art[flamingo$Month == 1] <- flamingo$Year_art[flamingo$Month
== 1] - 1
winter_sum<-ddply(subset(flamingo, Age_inMont>3 & winter==TRUE), .
(Year_art), summarize, inside = length(unique(PVC[comac-
chio==TRUE]))/length(unique(PVC)))
```

Dataset preparation for analysis of individuals in Parc Ornithologique de Pont de Gau (Camargue)

Variables X and Y represent the ETRS coordinates of the "ControlSit" values

```
flamingo_cam <- join(flamingo, subset(shp@data, select=c("X","Y","ID")))
```

```
flamingo_cam$ControlDat<-as.Date(flamingo_cam$ControlDat, for-
mat="%d.%m.%Y")
x_cam <- flamingo_cam$X[flamingo_cam$ControlSit=="Parc ornithologique de
Pont de Gau"][1]
y_cam <- flamingo_cam$Y[flamingo_cam$ControlSit=="Parc ornithologique de
Pont de Gau"][1]
```

"Distance" variable represents distance between Parc Ornithologique, (Camargue, France) and the "ControlSit" places.

```
flamingo_cam$distance<-sqrt((flamingo_cam$X-x_cam)**2+(flamingo_cam$Y-
y_cam)**2)
```

Variable "camargue" shows if individual was exactly in or in a range of interested sites (limited within a radius less than 1000 m). Variables "breeding" and "wintering" represent if the individuals were in the site of interest in April-July (breeding season) and November-January (winter season) periods respectively

```
flamingo_cam$camargue <- flamingo_cam$distance < 10000
flamingo_cam$breeding <- flamingo_cam$Month %in% c(4,5,6,7)
flamingo_cam$winter<-flamingo_cam$Month %in% c(11,12,1)
```

The proportion of individuals breeding inside Parc Ornithologique de Pont de Gau was estimated for each year as the number of observations present in the breeding season in the colony divided to the total number of all its observations

```
cam_breed_sum<-ddply(subset(flamingo_cam, Age_inMont>3 & breed-
ing==TRUE), .(Year), summarize, inside = length(unique(PVC[ca-
margue==TRUE]))/length(unique(PVC)))
flamingo_cam$Year_art <- flamingo_cam$Year
flamingo_cam$Year_art[flamingo_cam$Month == 1] <- fla-
mingo_cam$Year_art[flamingo_cam$Month == 1] - 1
cam_winter_sum<-ddply(subset(flamingo_cam, Age_inMont>3 & win-
ter==TRUE),. (Year_art), summarize, inside = length(unique(PVC[ca-
margue==TRUE]))/length(unique(PVC)))
```

2. **Weather data preparation**

Used libraries for the analysis

```
library(raster)
library(lubridate)
```

Preparation of the temperature rasters

```
btrasters <-lapply(list.files("Chelsa_big_temp", pattern=".tif"), function(adr) {
  r <- raster(paste("Chelsa_big_temp", adr, sep="/"))
  r
})
times <- sapply(list.files("Chelsa_big_temp", pattern=".tif"), function(adr) {year
<- strsplit(adr, "_", fixed = TRUE)[[1]][3]
mon <- strsplit(adr, "_", fixed = TRUE)[[1]][4]
d <- paste(year, mon, 15, sep="-")
d})
times <- as.Date(times, format = "%Y-%m-%d")
save(btrasters, file = "btrasters.RData")
```

Join temperature values in Saline di Comacchio with dates

```
commaccio<-data.frame(x=12.200000, y=44.65000)
```

```
temperatures <- sapply(btrasters, function(r) extract(r, commaccio))
temp <- data.frame(temp=temperatures, date=times)
```

Join temperature values in Parc Ornithologique de Pont de Gau (Camargue) with dates

```
camargue<-data.frame(x=4.420833, y=43.48611)
cam_temperatures<-sapply(btrasters, function(r) extract(r, camargue))
cam_temp<-data.frame(temp=cam_temperatures, date=times)
```

Preparation of the precipitation rasters

```
prasters <-lapply(list.files("Data_Chelsa_prec", pattern=".tif"), function(adr) {
r <- raster(paste("Data_Chelsa_prec",adr,sep="/"))
times<- sapply(list.files("Data_Chelsa_prec", pattern=".tif"), function(adr) {
year <- strsplit(adr, "_", fixed = TRUE)[[1]][3]
mon <- strsplit(adr, "_", fixed = TRUE)[[1]][4]
d <- paste(year, mon, 15, sep="-")
d})
times <- as.Date(times, format = "%Y-%m-%d")

save(prasters, file = "rasters_precip.RData")
```

Join precipitation values in Saline di Comacchio with dates

```
commaccio<-data.frame(x=12.200000, y=44.65000)

precipitation <- sapply(prasters, function(r) extract(r, commaccio))
prec <- data.frame(prec=precipitation, date=times)
```

Join precipitation values in Parc Ornithologique de Pont de Gau (Camargue) with dates

```
camargue<-data.frame(x=4.420833, y=43.48611)
cam_precipitation<-sapply(prasters, function(r) extract(r, camargue))
cam_prec<-data.frame(prec=cam_precipitation, date=times)
```

3. Flamingo presence in study colonies

Used libraries for the analysis

```
library (plyr)
library (ggplot2)
```

The variable as a ratio of presence was computed. It is defined as proportion of individuals who were in the colony or its vicinity (within radius 1000m) after dispersal divided by the total ringed individuals

Ratio of individuals present in Saline di Comacchio site

```
flam.sum <- ddply(subset(flamingo, Age_inMont > 3), .(Year, Month),

summarize, isinde = length(unique(PVC[comac-
chio==TRUE]))/length(unique(PVC)))

flam.sum$date <- as.Date(paste(flam.sum$Year, flam.sum$Month, 15, sep=":"),
format="%Y:%m:%d")
```

Ratio of individuals present in Parc Ornithologique de Pont de Gont (Camargue)

```
cam_flam.sum<-ddply(subset(flamingo_cam, Age_inMont > 3), .(Year, Month),
summarize, isinde = length(unique(PVC[ca-
margue==TRUE]))/length(unique(PVC)))
```

```
cam_flam.sum$date<-as.Date(paste(cam_flam.sum$Year, cam_flam.sum$Month, 15, sep=":"), format="%Y:%m:%d")
```

Visualisation of the analysis results for the individuals present in Saline di Comacchio

```
ggplot(flam.sum, aes(x=date, y=isinde)) +

geom_line()+

labs(x="Year", y="Ratio of presence (Saline di Comacchio)")+

scale_x_date(date_breaks = "1 year", date_labels = "%Y")+

ggsave("flamingo_com_vs_year.png", dpi=300, width = 16, height = 7)
```

Visualisation of the analysis results for the individuals present in Parc Ornithologique de Pont de Gont (Camargue)

```
ggplot(cam_flam.sum, aes(x=date, y=isinde))+

geom_line()+

labs(x="Year", y="Ratio of presence (Parc Ornitoloique, Camargue")+

scale_x_date(date_breaks = "1 year", date_labels = "%Y")

ggsave("flamingo_cam_vs_year.png", dpi=300, width = 16, height = 7)
```

4. Age effect on dispersal

Used libraries for the analysis

```
library(plyr)
library(ggplot2)
library(fmsb)
load("flam_data.RData")
```

This probability of an individual being observed during breeding season in its natal colony was estimated for each individual and season as the number of its observations made during a particular breading season in Comacchio, divided by the number of all its observations during that period (table "flam.inds"). This proportion was further averaged across the whole population for each age class (table "inds.mean")

```
flam.inds <- ddply(subset(flamingo, Age_inMont > 3), .(Age_inYear, PVC, breeding), summarize, inside = length(PVC[comacchio==TRUE])/length(PVC))
inds.mean <- ddply(subset(flam.inds, breeding==TRUE), (Age_inYear), summarize, in.mean = mean(inside), in.sd = sd(inside))
```

To quantify the possible effect of age on natal philopatry, a binomial generalized linear model (GLM) with logit link function was fitted, with the proportion of an individual's observations made in Saline di Comacchio (during breeding season) as a response and its age as a continuous predictor.

```
m <- glm(inside~Age_inYear, data=subset(flam.inds, breeding=TRUE), family=binomial)
summary(m)
m$deviance/m$df.residual
```

A goodness-of-fit of the model was estimated by the Nagelkerke's pseudo R^2 value

```
NagelkerkeR2(m)
```

The model prediction plot (including Wald 95% confidence bands)

```
df <- data.frame(Age_inYear = 1:9)
df <- cbind(df, predict(m, newdata=df, se=TRUE))
df$in.mean <- exp(df$fit)/(1+exp(df$fit))
df$upr <- exp(df$fit + 1.96*df$se.fit)/(1+exp(df$fit + 1.96*df$se.fit))
df$lwr <- exp(df$fit - 1.96*df$se.fit)/(1+exp(df$fit - 1.96*df$se.fit))
```

Visualization of the result with model prediction plot

```
ggplot(inds.mean, aes(x=Age_inYear, y=in.mean)) +
geom_col(alpha=0.5) +
geom_line(data=df) +
geom_ribbon(data=df, aes(ymin=lwr, ymax=upr), alpha=0.3) +
scale_x_continuous(breaks = 1:9) +
labs(x="Age (years)", y="Natal philopatry") +

ggsave("natal_philo_stats.png", dpi=300, height = 10, width = 14, units = "cm")
```

5. Instant weather effect on flamingo presence

Instant temperature effect on the flamingo presence in Saline di Comacchio

```
flam.sum <- ddply(subset(flamingo, Age_inMont > 3),.(Year, Month), summarize,
isinde = length(unique(PVC[comachio==TRUE]))/length(unique(PVC)))

flam.sum$date <- as.Date(paste(flam.sum$Year, flam.sum$Month, 15, sep=":"),
format="%Y:%m:%d")
```

The temperature values were extracted from the rasters and matched with the appropriate months when flamingos were observed inside Saline di Comacchio

```
df.cor <- join(flam.sum, temp)
```

Dependency between the temperature and proportion of flamingo in the colony during the whole year

```
cor.test(df.cor$isinde, df.cor$temp, method="spearman")
```

Dependency between the temperature and proportion of flamingo in the colony during the whole year

```
fl.breed <- subset(df.cor, Month %in% c(4,5,6,7))

cor.test(subset(df.cor, Month %in% c(4,5,6,7))$isinde, subset(df.cor1, Month
%in%

c(4,5,6,7))$prec, method="spearman")
```

Visualisation of the results:

Proportion of flamingo in the colony during the whole year

```
ggplot(df.cor, aes(x=temp/10-273.15, y=isinde)) +
geom_point() +
geom_smooth(method="lm") +
scale_x_continuous(breaks = c(5,10,15,20,25,30)) +

labs(x="Temperature (C)", y="Ratio of presence (Saline di Comacchio)") +

ggsave("indiv_inside_Com_temp.png", dpi=300, width = 16, height = 10, units =
"cm")
```

Proportion of flamingo in the colony during breeding period

```
ggplot(fl.breed, aes(x=temp/10-273.15, y=isinde)) +
geom_point() +
geom_smooth(method="lm")+
scale_x_continuous(breaks = c(5,10,15,20,25,30))+
labs(x="Temperature (C)", y="Ratio of breeding presence (Saline di Comac-
chio)")+
ggsave("indiv_brinside_Com_temp.png", dpi=300, width = 16, height = 10, units =
"cm")
```

Instant precipitation effect on the flamingo presence in Saline di Comacchio

The precipitation values were extracted from the rasters and matched with the appropriate months when flamingos were observed inside Saline di Comacchio

```
df.cor1 <- join(df.cor, prec, by="date")
```

Dependency between the precipitation and proportion of flamingo in the colony during the whole year

```
cor.test(df.cor1$isinde, df.cor1$prec, method = "spearman")
```

Dependency between the precipitation and proportion of flamingo in the colony during the breeding period

```
fl.breed.prec <- subset(df.cor1, Month %in% c(4,5,6,7))
cor.test(subset(df.cor1, Month %in% c(4,5,6,7))$isinde, subset(df.cor1, Month
   %in%c(4,5,6,7))$prec, method="spearman")
```

Visualisation of the results:

Proportion of flamingo in the colony during the whole year

```
ggplot(df.cor1, aes(x=prec, y=isinde)) +
geom_jitter(alpha=.3) +
geom_smooth(method="lm")+labs(x="Precipitation (mm)", y="Ratio of pre-
sense (Saline di Comacchio)") +
ggsave("indiv_inside_Com_prec.png", dpi=300, width = 16, height = 10, units =
"cm")
```

Proportion of flamingo in the colony during breeding period

```
ggplot(fl.breed.prec, aes(x=prec, y=isinde)) +
geom_point() +
geom_smooth(method="lm")+labs(x="Precipitation (mm)", y="Ratio of
breeding presense (Saline di Comacchio)") +
ggsave("indiv_brinside_Com_prec.png", dpi=300, width = 16, height = 10, units
= "cm")
```

6. Time-lag effect of weather on the flamingo presence

Analysis of time-lag effect on individuals present in Saline di Comacchio

Temperature time-lag effect

Dependency between the proportion of flamingos breeding inside Saline di Comacchio and time-lag of temperature (dataset "temp") fluctuations was evaluated via application of correlation test, method "spearman". Transitional result was represented as a table ("breed.cor" for breeding period) with correlation value (Spearman correlation coefficient) of each time-lag (month) and its significance (p value).

```
breed.cor <- data.frame(
lag=c(3:0,11:4), cor=sapply(1:12, function(i){temp. <- subset(temp, month(date)==i)$temp
if (i > 4) {temp. <- temp.[1:(length(temp.)-1)]} else {temp. <- temp.[2:length(temp.)]}
cor <- cor.test(breed.sum$isinde, temp., method="spearman")
cor$estimate}),
p=sapply(1:12, function(i){temp. <- subset(temp, month(date)==i)$temp
if (i > 4) {temp. <- temp.[1:(length(temp.)-1)]} else {temp. <- temp.[2:length(temp.)]}
cor <- cor.test(breed.sum$isinde, temp., method="spearman")
cor$p.value }))
breed.cor$significance <- breed.cor$p < 0.05
```

Table 1. Representation of the correlation test result for the time-lag effect of temperature on the presence of flamingos in Saline di Comacchio in breeding season

Lag	Corr.value	p-value	Significance
3	0.09244024	0.8130182	FALSE
2	0.33333333	0.385323	FALSE
1	0.34309924	0.3660292	FALSE
0	-0.26666667	0.4933311	FALSE
11	-0.12552411	0.7476182	FALSE
10	-0.33473096	0.378595	FALSE
9	-0.4	0.2911927	FALSE
8	-0.26666667	0.4933311	FALSE
7	0.51262314	0.1582071	FALSE
6	0.49372817	0.1767598	FALSE
5	-0.02510482	0.9488837	FALSE
4	0.21757513	0.5738747	FALSE

Visualisation of the results

```
ggplot(breed.cor, aes(x=lag, y=cor)) +
 geom_line() +
geom_point(aes(shape=significance), size=3) +
scale_shape_manual(values = c(1,2))+
```

```
scale_x_continuous(breaks=0:11)+
labs(x="Time lag (months)", y="Spearman correlation coeffiecient") +
ggsave("breed_com_temp_corrs.png", dpi=300, width = 16, height = 10, units = "cm")
```

Dependency between the proportion of flamingos wintering inside Saline di Comacchio and time-lag of temperature (dataset "temp") fluctuations was evaluated via application of correlation test, method "spearman". Transitional result was represented as a table ("winter.cor" for wintering period) with correlation value (Spearman correlation coefficient) of each time-lag (month) and its significance (p value).

```
winter.cor <- data.frame(lag=c(10:0,11),cor=sapply(1:12, function (i){temp. <- subset(temp, month(date)==i)$temp
if (i > 11) {temp. <- temp.[1:(length(temp.)-1)]} else {temp. <- temp.[2:length(temp.)]}
cor <- cor.test(winter_sum$inside, temp., method="spearman")
cor$estimate}),
p=sapply(1:12, function (i){temp. <- subset(temp, month(date)==i)$temp
if (i > 11) {temp. <- temp.[1:(length(temp.)-1)]} else {temp. <- temp.[2:length(temp.)]}
cor <- cor.test(winter_sum$inside, temp., method="spearman")
cor$p.value}))
winter.cor$significance <- winter.cor$p < 0.05
```

Table 2. Representation of the correlation test result for the time-lag effect of temperature on the presence of flamingos in Saline di Comacchio in winter season

Lag	Corr.value	p-value	Significance
10	0.27732072	0.47001264	FALSE
9	0.63333333	0.07603616	FALSE
8	0.4853599	0.18535382	FALSE
7	0.35	0.35858135	FALSE
6	-0.1	0.80998126	FALSE
5	0.05857792	0.88100675	FALSE
4	-0.3	0.43662368	FALSE
3	0.2	0.61340388	FALSE
2	-0.29288959	0.4443547	FALSE
1	-0.05020964	0.8979284	FALSE
0	0.18410203	0.63538265	FALSE
11	-0.2594165	0.50026826	FALSE

Visualization of the results

```
ggplot(winter.cor, aes(x=lag, y=cor)) +
```

```
geom_line() +
geom_point(aes(shape=significance), size=3) +
scale_shape_manual(values = c(1,2))+
scale_x_continuous(breaks=0:11) +
labs(x="Time lag (months)", y="Spearman correlation coeffiecient") +
ggsave("winter_com_temp_corrs.png", dpi=300, width = 16, height = 10, units = "cm")
```

Precipitation time-lag effect

Dependency between the proportion of flamingos breeding inside Saline di Comacchio and time-lag of precipitation (dataset "prec") fluctuations was evaluated via application of correlation test, method "spearman". Transitional result was represented as a table ("breed.cor.precip" for breeding period) with correlation value (Spearman correlation coefficient) of each time-lag (month) and its significance (p value

```
breed.cor.precip <- data.frame(
lag=c(3:0,11:4),
cor=sapply(1:12, function(i){prec. <- subset(prec, month(date)==i)$prec
if (i > 4) {prec. <- prec.[1:(length(prec.)-1)]} else {prec. <- prec.[2:length(prec.)]}
cor <- cor.test(breed.sum$isinde, prec., method="spearman")
 cor$estimate}),
p=sapply(1:12, function(i){
prec. <- subset(prec, month(date)==i)$prec
if (i > 4) {prec. <- prec.[1:(length(prec.)-1)]} else {prec. <- prec.[2:length(prec.)]}
cor <- cor.test(breed.sum$isinde, prec., method="spearman")
cor$p.value}))
breed.cor.precip$significance <- breed.cor.precip$p < 0.05
```

Table 3. Representation of the correlation test result for the time-lag effect of precipitation on the presence of flamingos in Saline di Comacchio in breeding season

Lag	Corr.value	p-value	Significance
3	-0.3	0.4366237	FALSE
2	-0.4167	0.2695822	FALSE
1	-0.15	0.7080688	FALSE
0	-0.4667	0.212522	FALSE
11	-0.3833	0.3125	FALSE
10	-0.4686	0.2032355	FALSE
9	-0.0586	0.8810068	FALSE
8	0.18333	0.6436398	FALSE
7	-0.1333	0.7435406	FALSE
6	-0.0167	0.9815697	FALSE
5	0.06667	0.8800926	FALSE
4	-0.1333	0.7435406	FALSE

Visualization of the result

```
ggplot(breed.cor.precip, aes(x=lag, y=cor)) +
geom_line() +
geom_point(aes(shape=significance), size=3) +
scale_shape_manual(values = c(1,2))+
scale_x_continuous(breaks=0:11)+
labs(x="Time lag (months)", y="Spearman correlation coeffiecient") +
ggsave("breeding_com_prec_corrs.png", dpi=300, width = 16, height = 10, units = "cm")
```

Dependency between the proportion of flamingos wintering inside Saline di Comacchio and time-lag of precipitation (dataset "prec") fluctuations was evaluated via application of correlation test, method "spearman". Transitional result was represented as a table ("winter.cor.precip" for winter period) with correlation value (Spearman correlation coefficient) of each time-lag (month) and its significance (p value

```
winter.cor.precip <- data.frame(
lag=c(10:0,11),cor=sapply(1:12, function (i){prec. <- subset(prec, month(date)==i)$prec
if (i > 11) {prec. <- prec.[1:(length(prec.)-1)]} else {prec. <- prec.[2:length(prec.)]}
cor <- cor.test(winter_sum$inside, prec., method="spearman")
cor$estimate}),
p=sapply(1:12, function (i){prec. <- subset(prec, month(date)==i)$prec
```

```
if (i > 11) {prec. <- prec.[1:(length(prec.)-1)]} else {prec. <-
prec.[2:length(prec.)]}

cor <- cor.test(winter_sum$inside, prec., method="spearman")

cor$p.value}))

winter.cor.precip$significance <- winter.cor.precip$p < 0.05
```

Table 4. Representation of the correlation test result for the time-lag effect of precipitation on the presence of flamingos in Saline di Comacchio in winter season

Lag	Corr.value	p-value	Significance
10	-0.0833	0.843182319	FALSE
9	0.3	0.436623677	FALSE
8	0.3	0.436623677	FALSE
7	0.18333	0.643639771	FALSE
6	0.68333	0.050319665	FALSE
5	0.89541	0.001098526**	TRUE
4	0.19328	0.618298133	FALSE
3	-0.1833	0.643639771	FALSE
2	-0.2833	0.46299052	FALSE
1	0.13333	0.743540564	FALSE
0	-0.2	0.61340388	FALSE
11	-0.7167	0.036866182*	TRUE

[a] P-value (level of significance): ‘*’ < 0.05, ‘**’ < 0.01, ‘***’ < 0.001

Visualization of the results

```
ggplot(winter.cor.precip, aes(x=lag, y=cor)) +
geom_line() +
geom_point(aes(shape=significance), size=3) +
scale_shape_manual(values = c(1,2))+
scale_x_continuous(breaks=0:11) +
labs(x="Time lag (months)", y="Spearman correlation coeffiecient") +
ggsave("winter_com_prec_corrs.png", dpi=300, width = 16, height = 10, units
= "cm")
```

Analysis of time-lag effect on individuals present in Parc Ornithologique de Pont de Gau (Camargue)

Temperature time-lag effect

Dependency between the proportion of flamingos breeding inside Parc Ornithologique de Pont de Gau and time-lag of temperature (dataset “temp”) fluctuations was evaluated via application of correlation test, method “spearman”. Transitional result was represented as a table (“c_breed.cor” for breeding period) with *correlation value (Spearman correlation coefficient) of each time-lag (month) and its significance (p value).*

```
c_breed.cor <- data.frame(lag=c(3:0,11:4), cor=sapply(1:12, function (i){
cam_temp. <- subset(cam_temp, month(date)==i)$temp
if (i > 4) {cam_temp. <- cam_temp.[1:(length(cam_temp.)-1)]} else {cam_temp.
<- cam_temp.[2:length(cam_temp.)]}
cor <- cor.test(cam_breed_sum$inside, cam_temp., method="spearman")
cor$estimate}),
p=sapply(1:12, function (i){cam_temp. <- subset(cam_temp,
month(date)==i)$temp
if (i > 4) {cam_temp. <- cam_temp.[1:(length(cam_temp.)-1)]} else {cam_temp.
<- cam_temp.[2:length(cam_temp.)]}
cor <- cor.test(cam_breed_sum$inside, cam_temp., method="spearman")
cor$p.value}))
c_breed.cor$significance <- c_breed.cor$p < 0.05
```

Table 5. Representation of the correlation test result for the time-lag effect of temperature on the presence of flamingos in Parc Ornithologique de Pont de Gau (Camargue) in breeding season

Lag	Corr.value	p-value	Significance
3	-0.5527	0.122714867	FALSE
2	-0.7029	0.034670107*	TRUE
1	-0.4118	0.270823861	FALSE
0	0.2479	0.520136737	FALSE
11	-0.8571	0.003146166**	TRUE
10	0.25739	0.503748008	FALSE
9	0.12605	0.746587951	FALSE
8	-0.4958	0.174669574	FALSE
7	0.38655	0.304100601	FALSE
6	0.25105	0.514673586	FALSE
5	0.38494	0.306298535	FALSE
4	0.05858	0.88100675	FALSE

[a] P-value (level of significance): '*' < 0.05, '**' < 0.01, '***' < 0.001

Visualization of the results

```
ggplot(c_breed.cor, aes(x=lag, y=cor)) +
geom_line() +
geom_point(aes(shape=significance), size=3) +
scale_shape_manual(values = c(1,2))+
scale_x_continuous(breaks=0:11)+
labs(x="Time lag (months)", y="Spearman correlation coeffiecient")+
ggsave("breed_cam_temp_corrs.png", dpi=300, width = 16, height = 10, units =
"cm")
```

Dependency between the proportion of flamingos wintering inside Parc Ornithologique de Pont de Gau and time-lag of temperature (dataset "temp") fluctuations was evaluated via application of correlation test, method "spearman". Transitional result was represented as a table ("c_winter.cor" for wintering period) with correlation value (Spearman correlation coefficient) of each time-lag (month) and its significance (p value).

```
c_winter.cor <- data.frame(lag=c(10:0,11),cor=sapply(1:12, function (i){
cam_temp. <- subset(cam_temp, month(date)==i)$temp
if (i > 11) {cam_temp. <- cam_temp.[1:(length(cam_temp.)-1)]} else
{cam_temp. <- cam_temp.[2:length(cam_temp.)]}
cor <- cor.test(cam_winter_sum$inside, cam_temp., method="spearman")
cor$estimate}),
```

```
p=sapply(1:12, function (i){cam_temp. <- subset(cam_temp,
month(date)==i)$temp
if (i > 11) {cam_temp. <- cam_temp.[1:(length(cam_temp.)-1)]} else
{cam_temp. <- cam_temp.[2:length(cam_temp.)]}
cor <- cor.test(cam_winter_sum$inside, cam_temp., method="spearman")
cor$p.value}))
c_winter.cor$significance <- c_winter.cor$p < 0.05
```

Table 6. Representation of the correlation test result for the time-lag effect of temperature on the presence of flamingos in Parc Ornithologique de Pont de Gau (Camargue) in winter season

Lag	Corr.value	p-value	Significance
10	-0.375530769	0.319272	FALSE
9	-0.585779186	0.097434	FALSE
8	-0.680672269	0.043577*	TRUE
7	-0.415966387	0.265472	FALSE
6	-0.176470588	0.649696	FALSE
5	0.590722558	0.093951	FALSE
4	0.289915966	0.449207	FALSE
3	0.474789916	0.19654	FALSE
2	0.453781513	0.219864	FALSE
1	-0.150628934	0.698884	FALSE
0	-0.004201681	0.991441	FALSE
11	0.142260659	0.715032	FALSE

[a] P-value (level of significance): '*' < 0.05, '**' < 0.01, '***' < 0.001

Visualization of the results

```
ggplot(winter.cor, aes(x=lag, y=cor)) +
geom_line() +
  geom_point(aes(shape=significance), size=3) +
  scale_shape_manual(values = c(1,2))+
  scale_x_continuous(breaks=0:11)+
  labs(x="Time lag (months)", y="Spearman correlation coeffiecient") +
  ggsave("winter_cam_temp_corrs.png", dpi=300, width = 16, height = 10, units
  = "cm")
```

Precipitation time-lag effect

Dependency between the proportion of flamingos breeding inside Parc Ornithologique de Pont de Gau and time-lag of precipitation (dataset "prec") fluctuations was evaluated via application of correlation test, method "spearman". Transitional result was represented as a table ("prec_breed.cor" for breeding period) with correlation value (Spearman correlation coefficient) of each time-lag (month) and its significance (p value)

```
prec_breed.cor <- data.frame(lag=c(3:0,11:4),cor=sapply(1:12, function(i){
```

```
cam_prec. <- subset(cam_prec, month(date)==i)$prec
if (i > 4) {cam_prec. <- cam_prec.[1:(length(cam_prec.)-1)]} else {cam_prec. <-
cam_prec.[2:length(cam_prec.)]}
cor <- cor.test(cam_breed_sum$inside, cam_prec., method="spearman")
cor$estimate}),
p=sapply(1:12, function(i){cam_prec. <- subset(cam_prec,
month(date)==i)$prec
if (i > 4) {cam_prec. <- cam_prec.[1:(length(cam_prec.)-1)]} else {cam_prec. <-
cam_prec.[2:length(cam_prec.)]}
cor <- cor.test(cam_breed_sum$inside, cam_prec., method="spearman")
cor$p.value}))
prec_breed.cor$significance <- prec_breed.cor$p < 0.05
```

Table 7. Representation of the correlation test result for the time-lag effect of precipitation on the presence of flamingos in Parc Ornithologique de Pont de Gau (Camargue) in breeding season

Lag	Corr.value	p-value	Significance
3	-0.28151	0.463043505	FALSE
2	-0.21097	0.585834443	FALSE
1	-0.92437	0.000363578***	TRUE
0	0.426782	0.25195669	FALSE
11	-0.09283	0.812245385	FALSE
10	0.016807	0.965769684	FALSE
9	-0.56067	0.116326795	FALSE
8	0.585779	0.097433911	FALSE
7	0.331933	0.382841419	FALSE
6	0.635989	0.065594758	FALSE
5	0.075314	0.847294022	FALSE
4	0.066946	0.864126671	FALSE

[a] P-value (level of significance): '*' < 0.05, '**' < 0.01, '***' < 0.001

Visualization of the results:

```
ggplot(prec_breed.cor, aes(x=lag, y=cor)) +
geom_line() +
geom_point(aes(shape=significance), size=3) +
scale_shape_manual(values = c(1,2))+
scale_x_continuous(breaks=0:11)
labs(x="Time lag (months)", y="Spearman correlation coeffiecient") +
ggsave("breed_cam_prec_corrs.png", dpi=300, width = 16, height = 10, units =
"cm")
```

Dependency between the proportion of flamingos wintering inside Parc Ornithologique de Pont de Gau and time-lag of precipitation (dataset "prec") fluctuations was evaluated via application of correlation test, method "spearman". Transitional result was represented as a table ("prec_winter.cor" for winter period) with correlation value (Spearman correlation coefficient) of each time-lag (month) and its significance (p value)

```
prec_winter.cor <- data.frame(lag=c(10:0,11),

cor=sapply(1:12, function (i){cam_prec. <- subset(cam_prec,
month(date)==i)$prec

if (i > 11) {cam_prec. <- cam_prec.[1:(length(cam_prec.)-1)]} else {cam_prec. <-
cam_prec.[2:length(cam_prec.)]}

cor <- cor.test(cam_winter_sum$inside, cam_prec., method="spearman")

cor$estimate}),
```

```
p=sapply(1:12, function (i){cam_prec. <- subset(cam_prec,
month(date)==i)$prec
if (i > 11) {cam_prec. <- cam_prec.[1:(length(cam_prec.)-1)]} else {cam_prec. <-
cam_prec.[2:length(cam_prec.)]}
cor <- cor.test(cam_winter_sum$inside, cam_prec., method="spearman")
cor$p.value}))
prec_winter.cor$significance <- prec_winter.cor$p < 0.05
```

Table 8. Representation of the correlation test result for the time-lag effect of precipitation on the presence of flamingos in Parc Ornithologique de Pont de Gau (Camargue) in winter season

Lag	Corr.value	p-value	Significance
10	-0.3571429	0.345399	FALSE
9	-0.2784835	0.468075	FALSE
8	-0.5714286	0.107986	FALSE
7	0.6778302	0.044809*	TRUE
6	-0.3713113	0.325177	FALSE
5	-0.4557003	0.217674	FALSE
4	-0.8786688	0.001816**	TRUE
3	0.2175751	0.573875	FALSE
2	0.2394958	0.534826	FALSE
1	-0.1554622	0.689604	FALSE
0	0.0334731	0.931873	FALSE
11	0.4853599	0.185354	FALSE

[a] P-value (level of significance): ‘*’ < 0.05, ‘**’ < 0.01, ‘***’ < 0.001

Visualization of the results

```
ggplot(prec_winter.cor, aes(x=lag, y=cor)) +
geom_line() +
geom_point(aes(shape=significance), size=3) +
scale_shape_manual(values = c(1,2))+
scale_x_continuous(breaks=0:11)
ggsave("winter_cam_prec_corrs.png", dpi=300, width = 16, height = 10, units
= "cm")
```

7. Weather effect on regional dispersal of flamingo

Used libraries for the analysis

```
library(raster)
library(lubridate)
library(raster)
library(sp)
```

```
library(plyr)
library(ggplot2)
```

Effect of temperature on regional distribution of flamingo

```
monyear <- expand.grid(mon=1:12, year=2000:2009)
load("btrasters.RData")
```

Extraction of flamingo subset born in Saline di Comacchio. Temperature values were extracted from the rasters and matched with the coordinates where flamingos were observed tables

```
flam <- subset(read.table("data_orig_clean.csv", header=T, sep=";"), RingingSit
== "Saline di Comacchio" & Age_inMont > 3)
flam$mon <- month(as.Date(flam$ControlDat, format="%d.%m.%Y"))
flam <- do.call(rbind, lapply(1:nrow(monyear), function(i){print(paste("Work-
ing on", monyear$mon[i], monyear$year[i]))
flush.console()
df <- subset(flam, Year == monyear$year[i] & mon == monyear$mon[i])
if (nrow(df) > 0){
points <- SpatialPoints(coords=data.frame(x=df$LngControl, y=df$LatCon-
trol))
df$temperature <- extract(btrasters[[i]], points)/10 - 273.15} else {df$temper-
ature <- numeric(0)}
df}))
flam$time <- as.Date(flam$ControlDat, format="%d.%m.%Y")
```

The table with the list of all big colonies in the Mediterranean area was obtained and coordinates to the each of this place were assigned. The following step was extract temperature values from the rasters to the corresponding coordinates of these colonies

```
bsites <- read.table("breeding_sites.txt", header=T, sep="\t")
sites <- SpatialPoints(coords=data.frame(x=bsites$Lon, y=bsites$Lat))
curves <- do.call(rbind, lapply(1:length(btrasters), function(i) {data.frame(
temperature = extract(btrasters[[i]], sites)/10 - 273.15, time =
as.Date(paste(15, monyear$mon[i], monyear$year[i], sep="."), for-
mat="%d.%m.%Y"), site = bsites$Site)}))
```

The average values were computed for each month of the period 2000-2009

```
means <- ddply(flam, .(mon, Year), summarize, temperature=mean(tempera-
ture))
means$time <- as.Date(paste(15, means$mon, means$Year, sep="."), for-
mat="%d.%m.%Y")
```

Visualisation of the results

```
ggplot(flam, aes(y=temperature, x=time)) +
geom_point(alpha=.3) +
geom_line(data=subset(curves, site=="SALINE DI COMACCHIO"),
aes(color=site)) +
geom_line(data=subset(curves, site=="SALIN DE GIRAUD SALTPANS, CA-
MARGUE"), aes(color=site))+
geom_line(data=means, color="blue")+
labs(x="Time", y="Temperature") +
```

```
ggsave("last.first.png", dpi=300, width = 25, height = 10, units = "cm")
```

Effect of precipitation on regional distribution of flamingo

```
monyear <- expand.grid(mon=1:12, year=2000:2009)

load("rasters_precip.RData")
```

Extraction of flamingo subset born in Saline di Comacchio. Precipitation values were extracted from the rasters and matched with the coordinates where flamingos were observed tables

```
flam2<-subset(read.table("data_orig_clean.csv", header=T, sep=";"), RiningSit
== "Saline di Comacchio" & Age_inMont > 3)

flam2$mon <- month(as.Date(flam2$ControlDat, format="%d.%m.%Y"))

flam2 <- do.call(rbind, lapply(1:nrow(monyear), function(i){

df <- subset(flam2, Year == monyear$year[i] & mon == monyear$mon[i])

if (nrow(df) > 0){points <- SpatialPoints(coords=data.frame(x=df$LngCon-
trol, y=df$LatControl))

df$prec <- extract(prasters[[i]], points)} else {df$prec <- numeric(0)}

df}))
```

A few recordings derived from the precipitation raster were extremely high with the value 65535mm, therefore these outliers were excluded from the further analysis with the range of precipitation 28mm-329mm

```
flam3<-subset(flam2, prec<=329)

flam3$time <- as.Date(flam3$ControlDat, format="%d.%m.%Y")
```

The table with the list of all big colonies in the Mediterranean area was obtained and coordinates to the each of this place were assigned. The following step was extract precipitation values from the rasters to the corresponding coordinates of these colonies

```
bsites <- read.table("breeding_sites.txt", header=T, sep="\t")

sites <- SpatialPoints(coords=data.frame(x=bsites$Lon, y=bsites$Lat))

curves2 <- do.call(rbind, lapply(1:length(prasters), function(i) {data.frame(

prec = extract(prasters[[i]], sites),time = as.Date(paste(15, monyear$mon[i],
monyear$year[i], sep="."), format="%d.%m.%Y"), site = bsites$Site)}))

curves3<-subset(curves2, prec<=329)
```

The average values were computed for each month of the period 2000-2009

```
means2 <- ddply(flam3, .(mon, Year), summarize, prec=mean(prec))

means2$time <- as.Date(paste(15, means$mon, means$Year, sep="."),
fomat="%d.%m.%Y")
```

Visualization of the results

```
ggplot(flam3, aes(y=prec, x=time)) +

geom_point(alpha=.3) +

geom_line(data=subset(curves3, site=="SALINE DI COMACCHIO"),
aes(color=site)) +
```

```
geom_line(data=subset(curves3, site=="SALIN DE GIRAUD SALTPANS, CA-
MARGUE"), aes(color=site))+
geom_line(data=means2, color="blue")+labs(x="Years", y="Precipitation
(mm)") +
ggsave("last.second.png", dpi=300, width = 25, height = 10, units = "cm)
```